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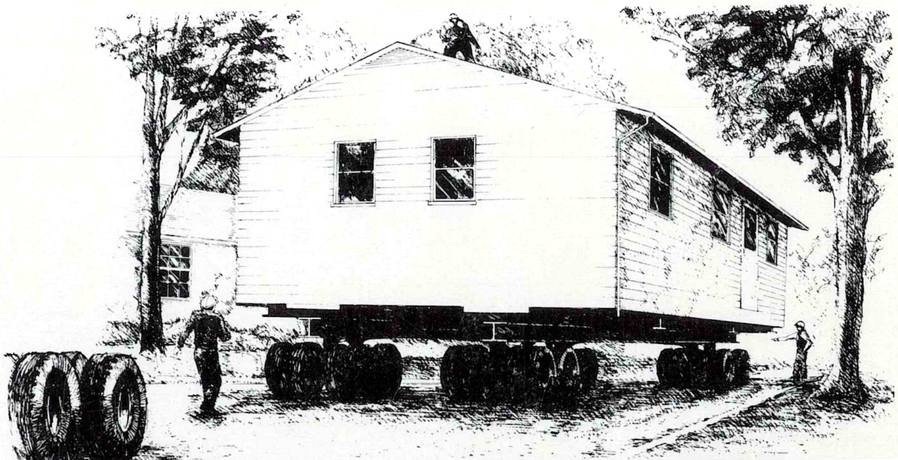
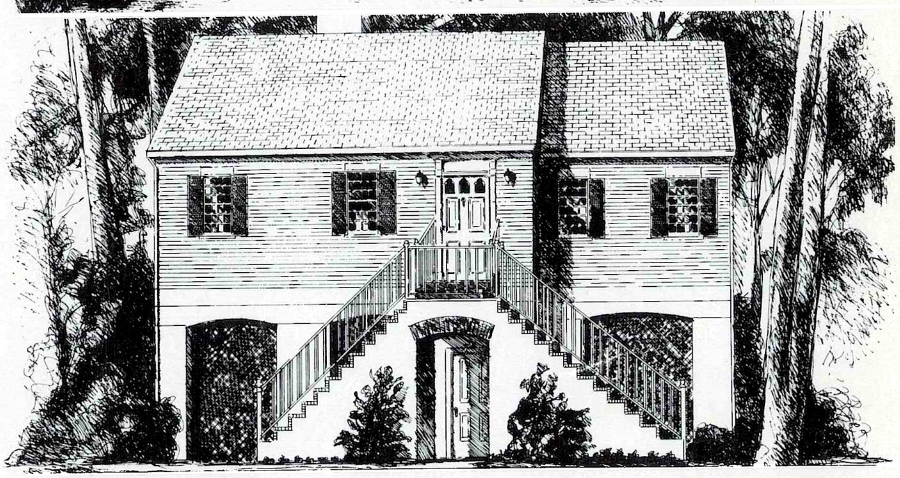
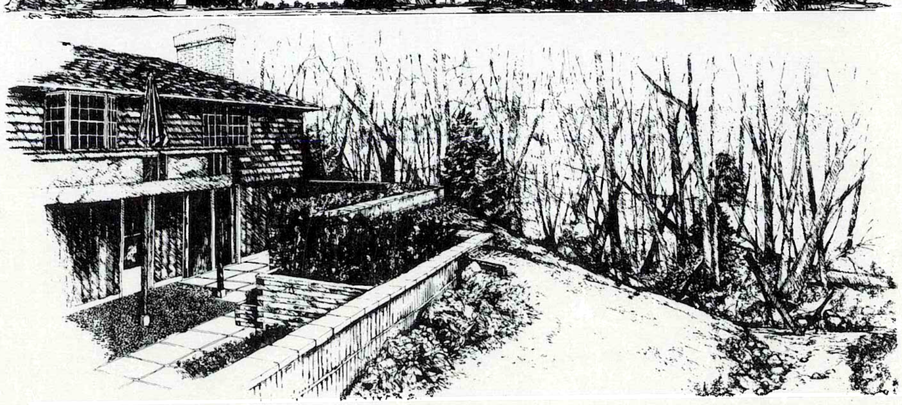
Design Manual for Retrofitting Flood-prone Residential Structures







Federal Emergency Management Agency

Design Manual for

Retrofitting Flood-prone Residential Structures

Federal Insurance Administration
Office of Loss Reduction

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Chapter 1

INTRODUCTION TO RETROFITTING

Every year, flooding causes more property damage in the United States than any other type of natural disaster. In fact, over the last decade, flood-related property damage has averaged well over three billion dollars a year. In 1985 alone, damages were estimated to have topped six billion dollars, and affected more than a quarter of a million structures.

1.1 INTRODUCTION

Bold terms found throughout this manual are defined in Appendix E-Glossary.

Every year, **flooding** causes more property damage in the United States than any other type of natural disaster. In fact, over the last decade, flood-related property damage has averaged well over three billion dollars a year. In 1985 alone, damages were estimated to have topped six billion dollars, and affected more than a quarter of a million structures.

FIGURE 1-1. *Flooding strikes thousands of homes every year.*

While recent improvements in construction practices and regulations have made new homes less prone to flood damage, there are a significant number of existing homes that continue to be susceptible to repetitive flood losses. National insurance loss records show that as many as 34,000 homes have experienced more than one flood during the six-year period beginning in 1978, and have accounted for over one billion dollars in flood damages.

Many of these homeowners feel they are trapped in a never-ending cycle of flooding and repairing. In addition, even though the flood damage can be repaired, the house is rarely the same, and its value usually declines.

However, there are ways that this cycle of repetitive flooding can be broken. Throughout the country, numerous examples can be found that illustrate practical and cost-effective methods for reducing or eliminating the risk of a house being flooded again.

One site involved a large number of residential communities that had been built outside of Atlanta in the mid-1960s. Several of these neighborhoods are located near wooded streams, and the heavy thunderstorms typical of this area resulted in repeated flooding.

After flood waters entered their home for the second time, one family decided to do something about it. They hired a contractor who raised their house onto concrete columns so it would be above flood levels. There was

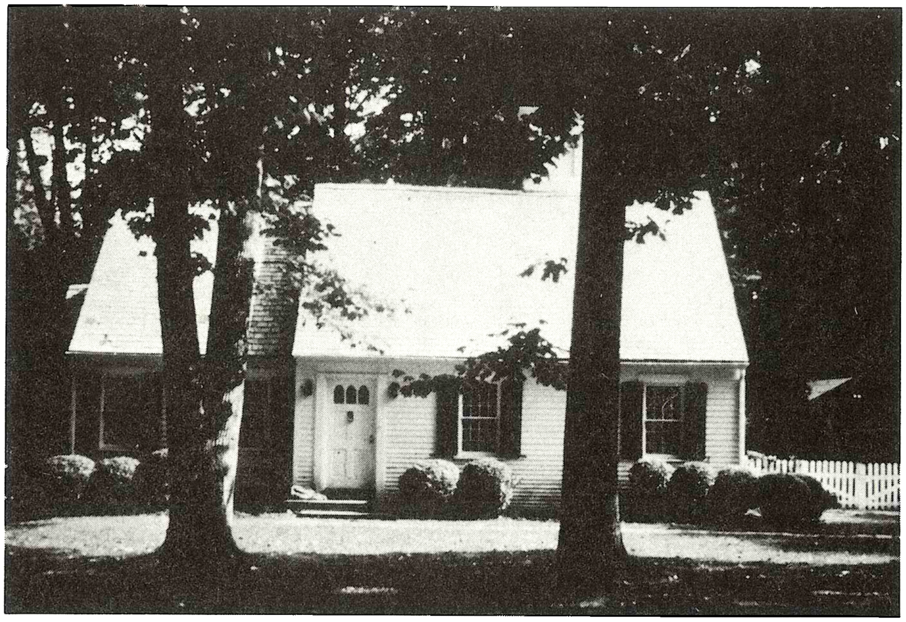


FIGURE 1-2. *This Atlanta house was flooded several times, the worst being almost two feet above the first floor.*

some concern about how the house would look after it was elevated, but those fears were groundless. The space below the raised structure was covered using a traditional latticework between the elevating columns. Building access was provided by a staircase that also provided an architectural focal point.

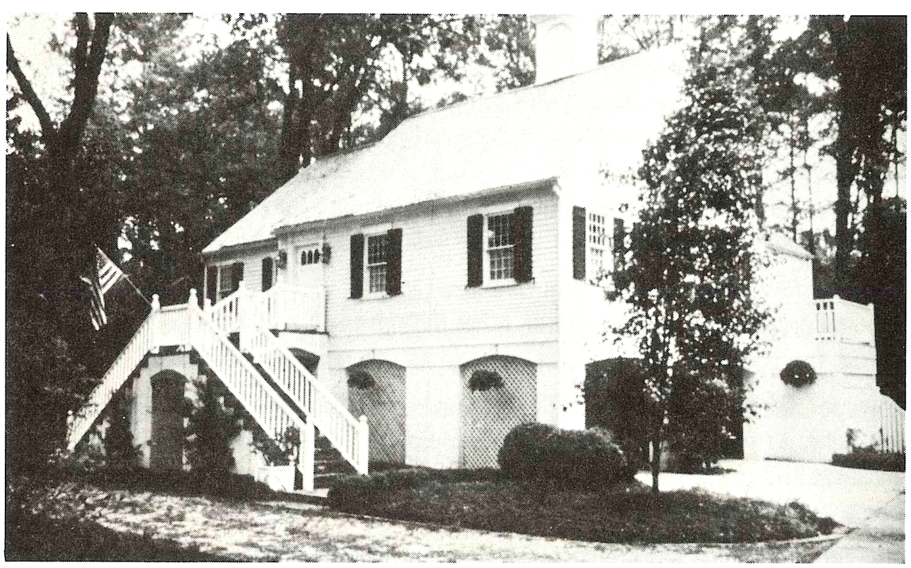


FIGURE 1-3. *The house was elevated in a way that actually added to its value and appearance . . .*

FIGURE 1-4. *. . . and it is now protected against future flooding.*

In the Midwest, the spring rains and snowmelt often combine to result in flooding rivers. Making the situation worse are accompanying chunks of ice that jam up the rivers, raise flood levels, and then break apart to batter the already flooded homes.

This was the situation along the Illinois River when several Peoria homeowners decided to do something about it. Their solution was to physically move their homes beyond the reach of the floods. Hundreds of houses are relocated every year for many reasons; and more and more they are moved out of the floodplain to eliminate the threat of flooding.

FIGURE 1-5. *This attractive Illinois house is similar to homes throughout the country.*

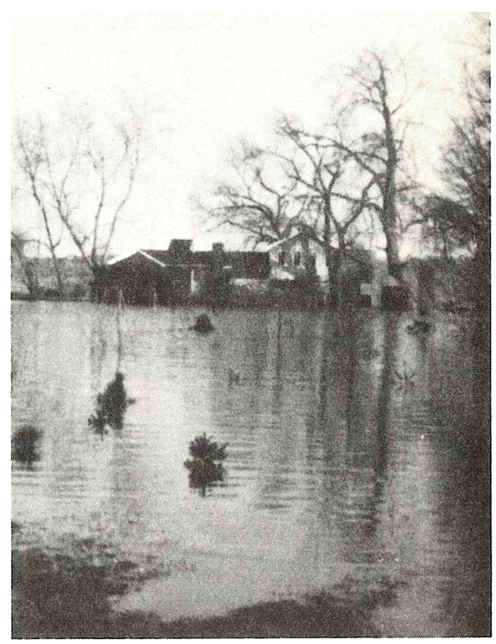


FIGURE 1-6. *Every spring, rising flood waters often cause serious damage.*

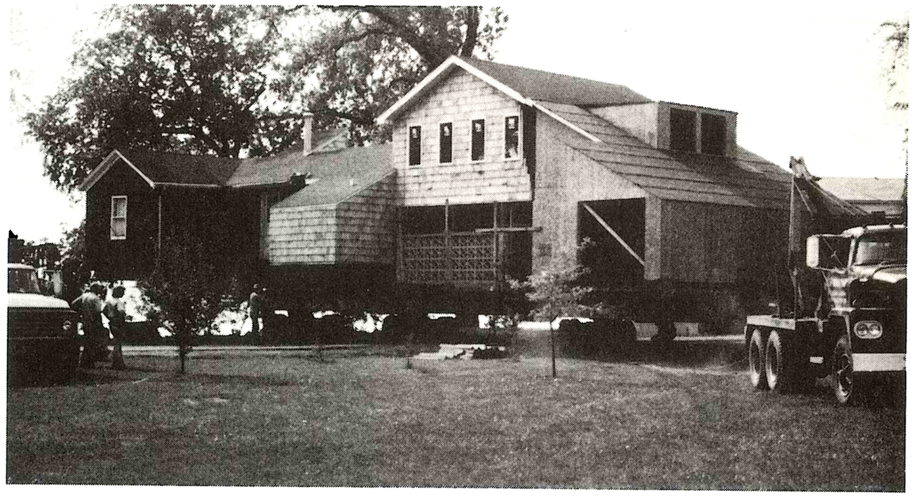


FIGURE 1-6a. *The owners had the house moved to a location out of the floodplain.*

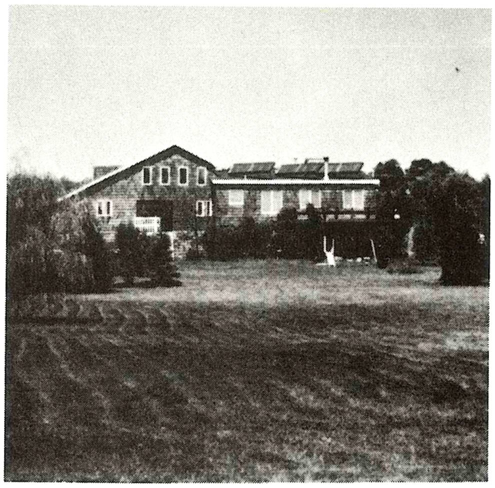


FIGURE 1-7. *At its new site, the house is just as attractive, but it is above all flood levels.*

In Minnesota, as in many other areas, houses were often placed near scenic streams that originally posed little flood threat. However, upstream development eventually increased the runoff, resulting in greater flood levels. Previously unthreatened homes became subject to repeated flooding. One community organized a project to construct floodwalls for several homes that were susceptible to flooding. By working with the homeowners, the contractor created a blend of floodproofing and landscaping that consisted of floodwalls faced with sculptured block that bordered raised patios. The end result was a flood protection system that also increased the beauty and value of these homes.

These examples are all based on actual events—situations where homes have been threatened by flooding, but where homeowners have been able to take actions to reduce or eliminate their problems.

FIGURE 1-8. *Flooding from the creek repeatedly threatened this neighborhood.*

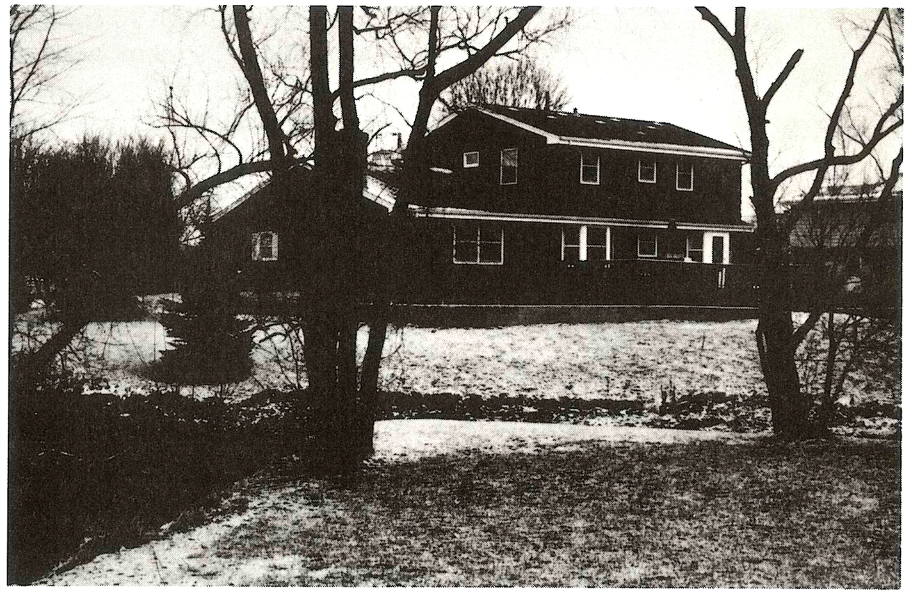


FIGURE 1-9. *The floodwalls are both attractive and effective flood protection.*

There is no way to measure the grief and hardship caused to the individual homeowner who has experienced flooding. However, for any homeowner who has experienced a flood loss, or even for those who know it could happen to them, this manual presents a number of options that can reduce or prevent the chance of being flooded in the future.

Floodproofing is any measure that homeowners might take to minimize flood damage to their homes. There are many ways to accomplish this, though they are normally incorporated into the initial design of the house. However, there are also many things that can be done to an existing house to minimize or eliminate the potential for flood damage. Floodproofing an existing structure is referred to in this manual as **retrofloodproofing** or **retrofitting.**

This manual will describe the application of permanent retrofitting measures that can be implemented on a residential structure to reduce future flood damage. Permanent retrofitting measures are preferable over temporary measures such as sandbagging for a number of reasons. For example, permanent measures are incorporated directly into the structure, which increases its quality and value. In addition, there is less dependence on human involvement, which cannot always be guaranteed during a flood. Finally, permanent measures may qualify the homeowner for a reduction in flood insurance rates.

1.2 USING THIS MANUAL

Retrofitting a structure involves several steps, and this manual is arranged to cover them in a logical order. Before a retrofitting technique can be chosen, the various flood, site and regulatory characteristics must first be understood. These characteristics are discussed in Chapter 2, which also includes a brief description of each technique to point the reader to the methods that will be most applicable.

Chapters 3 through 10 cover the various retrofitting methods. Each chapter is laid out in the same basic pattern, first introducing the method in simple terms and then listing the various considerations that would apply. Next, the chapter provides design criteria and construction information, and finally presents cost guidelines. Where necessary, the chapter includes a final section entitled Technical Design Criteria. These sections are distinguishable by the shading at the top of the page, and are intended to assist engineers, architects and contractors in designing and implementing a retrofitting action.

Chapter 11 outlines the process needed to properly select the most applicable retrofitting method, and how to implement it. This includes how to perform a simple cost/benefit analysis.

The final section of this manual contains several appendices that provide information that can be useful in the retrofitting process. This includes a guide to selecting architectural/engineering services and contractors, a description of the National Flood Insurance Program, a technical discussion of the various flood and wind forces that must be accounted for in the design, sources of assistance and several case studies.

Chapter 2

CONSIDERATIONS FOR RETROFITTING

The ultimate goal of retrofitting a house is to significantly reduce or eliminate the potential of flood damage in a manner that is cost-effective, complies with all applicable floodplain regulations, and most important of all, is acceptable to the homeowner in terms of appearance and livability.

2.1 INTRODUCTION

The ultimate goal of retrofitting a house is to significantly reduce or eliminate the potential of flood damage in a manner that is cost-effective, complies with all applicable floodplain regulations, and most important of all, is acceptable to the homeowner in terms of appearance and livability.

There are many methods of retrofitting that are suitable for most residential structures, although some are more common than others. In order to choose the best method for a specific location, the many factors that play a role in this determination must be understood. These factors include flood, site, and building characteristics, as well as regulatory and cost considerations. The first step in retrofitting a home is to examine these factors, and then use this information to select the most applicable retrofitting method or methods.

2.2 FLOOD CHARACTERISTICS

In general, flooding can be divided into two major categories, riverine and coastal. Riverine flooding is usually the result of heavy or prolonged rainfall or snowmelt occuring in upstream inland **watersheds.** In some cases, especially in and around urban areas, flooding can also be caused by inadequate or improper drainage.

FIGURE 2-1. *Riverine flooding is usually the result of upstream rainfall or snowmelt.*

Coastal flooding is usually the result of large storms such as hurricanes or northeasters. Flood waters are usually driven ashore by high winds, an event known as storm surge. Damage from coastal flooding is often more severe since it involves velocity wave action and accompanying high winds. As a result, the types of retrofitting methods that can be used in coastal areas are limited to those few that are able to withstand these forces.

FIGURE 2-2. *Because of velocity wave action and high winds, flood damage is more severe in coastal areas.*

Beyond these general types of flooding, there are several different flood characteristics that must be examined in order to determine which retrofitting method will be best suited for a specific location. These characteristics not only indicate the precise nature of flooding for a given area, but can also be used to determine how different retrofitting methods will perform. These factors include depth, frequency, velocity, rate of rise, duration and the potential presence of ice and debris.

Depth

Determining the potential depth of flooding is the first and most logical step, since it is often the primary factor in evaluating the potential for flood damage. The depth of flooding is also critical in determining the extent of retrofitting that will be needed, and which method or methods will be most appropriate for a given site.

Every floodplain is unique in terms of the different levels of flooding that can be expected. Very shallow flooding, usually meaning a depth of one foot or less, while not life threatening, can still cause considerable amounts of water damage to a building, yet retrofitting is usually simple and relatively inexpensive. Similarly, shallow flooding, or one to three feet in depth, can result in significant amounts of damage to both a structure and its contents. Retrofitting can still be a cost effective solution, although it may require a greater level of planning and work.

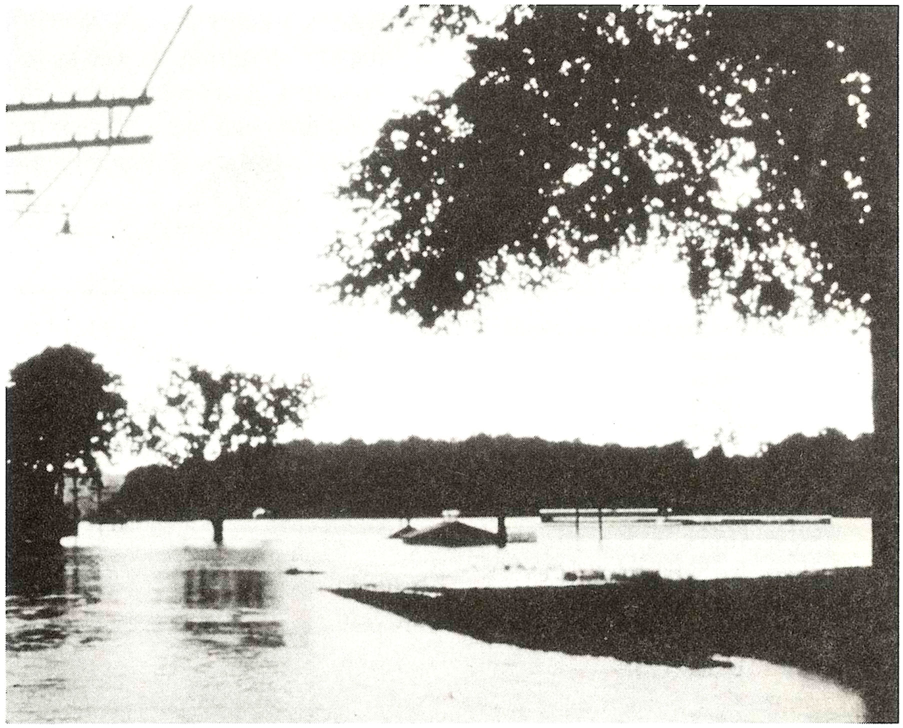


FIGURE 2-3. *Deep flooding can damage or destroy any type of home.*

Moderate flooding, or depths of three to six feet, can easily destroy a building and threaten lives because of the large flood forces involved. It can still be feasible to retrofit a building threatened by moderate flooding, but choosing, planning and implementing a method will be an extensive process and professional help is recommended.

Deep flooding, any depth that may exceed six feet, presents a very difficult problem since the extreme flood forces can easily result in the failure of most floodproofing measures. While retrofitting is still possible, the only feasible methods are usually to relocate the structure or elevate it on certain types of foundations.

Frequency

Any given floodplain location will be subject to floods of differing depths, with lower flood levels occurring more often, or more frequently, than higher levels. Determining what frequency of flooding to protect against goes hand in hand with deciding what flood depths to protect against. While historical flood depths may give some indication of the level of risk, there is no certain method to predict future flood levels.

A method of estimating flood frequencies has been developed to determine the statistical probability of specific flood levels. The frequency normally used as a standard is the flood level that has a one-percent chance of being equaled or exceeded in any given year. This is also referred to as the **100-year flood**. It is important to note that contrary to popular notion, the term 100-year flood does not imply that this flood level will occur only once every 100 years. It is instead a statistical tool that is used to estimate the risk of certain flood levels.

A homeowner can use this information to help decide whether it would be feasible to retrofit, as well as to what elevation. As an example of the statistical uses of this information, given a homeowner that lives at the 100-year flood level and has a 30-year mortgage, there is roughly a one in four chance of the house being flooded during the life of the mortgage.

TABLE 1

FLOOD RISK

The tabled values represent the probabilities, expressed in percentages, of one or more occurrences of a flood of given magnitude or larger within a specified number of years.

Adapted from Coordination During Flood Insurance Studies, Community Assistance Series No. 2 Prepared by the Federal Insurance Administration.

Period (Years)	Flood Frequency (year-event) 10	25	50	100	500
1	10%	4%	2%	1%	0.2%
10	65%	34%	18%	10%	2%
20	88%	56%	33%	18%	5%
25	93%	64%	40%	22%	5%
30	96%	71%	45%	26%	6%
50	99+%	87%	64%	39%	10%
100	99.99+%	98%	87%	63%	18%

Base Flood Elevation

The 100-year flood level is also known as the **base flood elevation** (BFE). The BFE is normally determined by engineers, hydrologists, and hydrographers working under contract for the **Federal Emergency Management Agency** (FEMA). Each BFE is determined based on the history of flooding in the area, along with localized factors such as the size and configuration of the stream channel, the rate of stream rise and fall, obstructions to the stream flow, analysis of soils, vegetation, meteorological patterns, and other information.

The BFE is the elevation above **mean sea level** (MSL). This elevation is normally given referencing NGVD (National Geodetic Vertical Datum). In order to determine the depth of flooding, the ground elevation in feet above MSL is subtracted from the BFE.

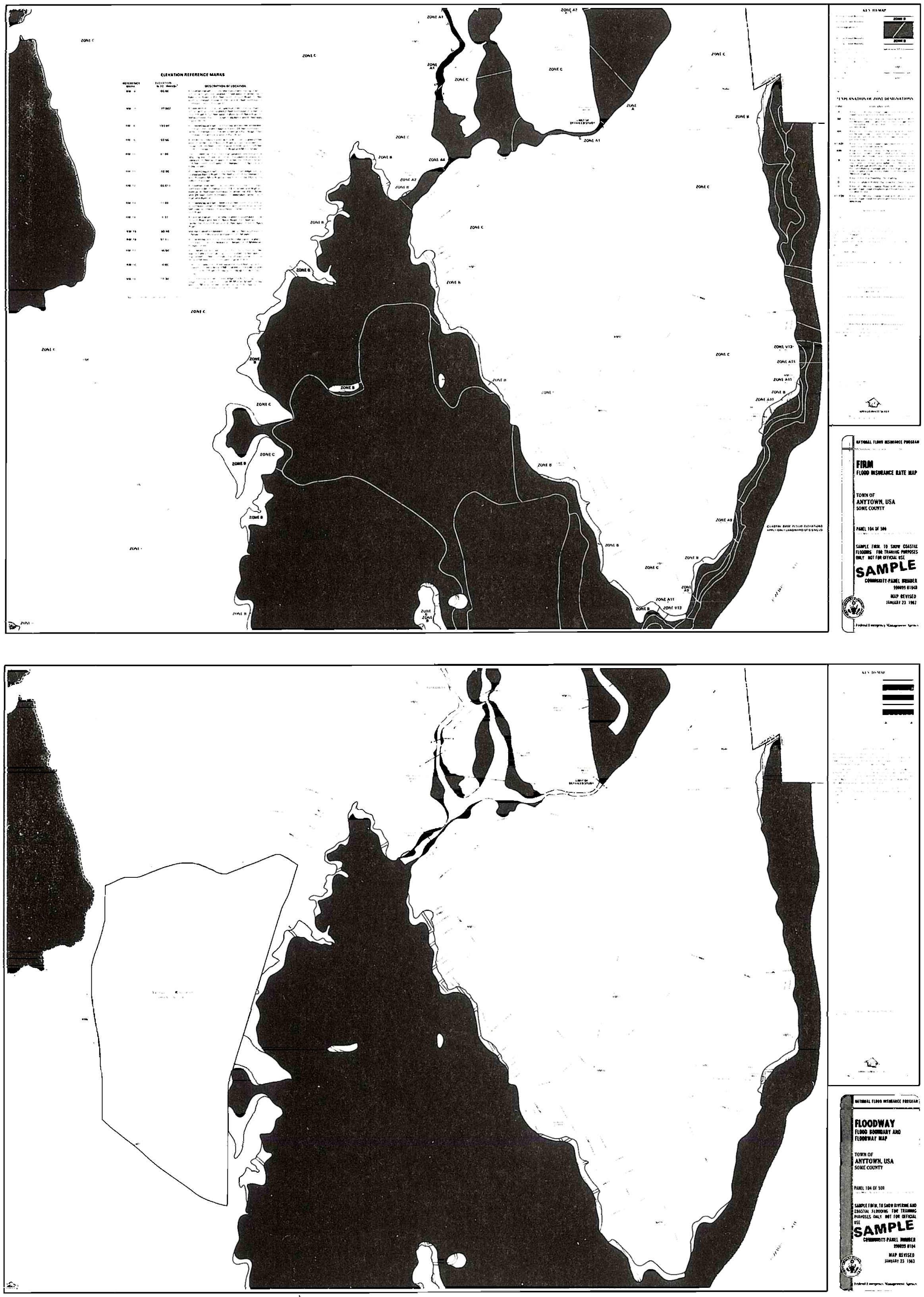


FIGURE 2-4. *The Flood Insurance Rate Map (FIRM) and Flood Boundary and Floodway Map (FBFM) pinpoint flood boundaries, flood zones and base flood elevations for a particular community.*

Once a BFE has been established, it is published on a **Flood Insurance Rate Map**. These maps delineate areas of a specific community that are subject to the base flood. They are printed by FEMA and are available from the National Flood Insurance Program as well as from local floodplain management offices.

There may be some areas where the maps may not provide sufficient detail for homeowners to determine the BFE in relation to their houses. In that case, they should call on a surveyor, engineer, or local floodplain management official for assistance.

Velocity

Another flood characteristic that must be taken into consideration is the speed or velocity at which flood waters move. Slow moving flood waters are generally defined as those having a velocity of less than three feet per second, and they usually do not present any significant additional problems.

As flood waters move faster, the pressure exerted on a stationary object increases tremendously. Faster moving flood waters, such as those moving over five feet per second, can quickly erode or **scour** the soil. When the soil is supporting a building's foundation system, undermining from scour and erosion can result in structural failure. In addition, these forces can also move a house off its foundation.

FIGURE 2-5. *Erosion of the supporting soil resulted in the collapse of this house.*

Unfortunately, there is no easy method of determining potential flood velocities. Although it is possible to hydraulically calculate theoretical velocities, historical information from past flood events is often the best source.

Rate of Rise

The rate or speed at which flood waters rise is the primary factor in determining the amount of warning time that will be available. For example, in mountainous areas, the steep topography can cause flood waters to rise dangerously fast, a condition known as a **flash flood**. This information is very im-

EVACUATING WHEN FLOODING THREATENS

Even though retrofitting a structure will protect it from flood damage, it should never be occupied during a flood. No matter how well protected a building is, or high it is elevated, there is always a chance that the next flood can be severe enough to overtop or exceed the design of the retrofitting technique. While the odds of this may be very small, the potential always exists, and the stakes may well be the lives of the occupants.

One of the most important steps in preparing for a flood is developing an evacuation plan so that all of the residents can safely get to high ground before floodwaters arrive. An adequate evacuation plan should take into account all of the flood characteristics listed in this chapter, especially the rate of rise, which determines how much warning time is available. Some communities have established flood warning procedures, but most have not. In addition, the evacuation route should be carefully chosen to ensure it will not be flooded or backed up before it can be used.

FIGURE 2-6. *Flash flooding is a serious threat to lives and property.*

portant in developing evacuation plans, something that should be done for every flood-prone residence.

The rate of rise can play a major role in choosing a retrofitting option, since many techniques cannot withstand the sudden pressures associated with a rapid increase in the depth of water. In addition, several retrofitting techniques require the presence of a person capable of taking specific action. This **human intervention** includes any action needed to secure against flooding, such as inserting and sealing a closure, and will require time that may not be available.

Ice and Debris

In many cases, ice and/or debris can pose a greater danger than the flood water itself. In colder areas of the country, ice floes, caused by ice breakup, can often strike a building and cause serious damage. Another danger is that ice may form around a flooded house, causing uplift and damaging the structure.

Flood waters, especially fast moving mountain streams, often contain debris such as boulders, trees and portions of other structures. Combined with the water's velocity, the impact forces of such debris can easily overwhelm any floodproofing measure and quickly demolish a building. All flood waters will include some floating debris as well as mud and silt, which will cause additional damage to an already flooded home.

FIGURE 2-7. *Ice floes can completely destroy a building.*

2.3 SITE CHARACTERISTICS

Location Within the Riverine Floodplain

The **floodplain** is usually defined as the area inundated by a flood having a 100-year recurrence interval. The riverine floodplain is often further divided into two sections.

The **floodway** is the central portion of the floodplain that contains the stream and enough of the surrounding land to enable flood waters to pass without increasing flood depths upstream. Because of the high flood depths and velocities in the floodway, this is the most dangerous portion of the floodplain. Also, since the floodway carries most of the flood flow, any obstruction in it may cause flood waters to back up and increase flood levels upstream. For these reasons, new construction or substantial improvement that would increase flood levels is prohibited in these areas. Additional details can be found in the section entitled "Restrictions on Building in The Floodway," located in Section 5.2.

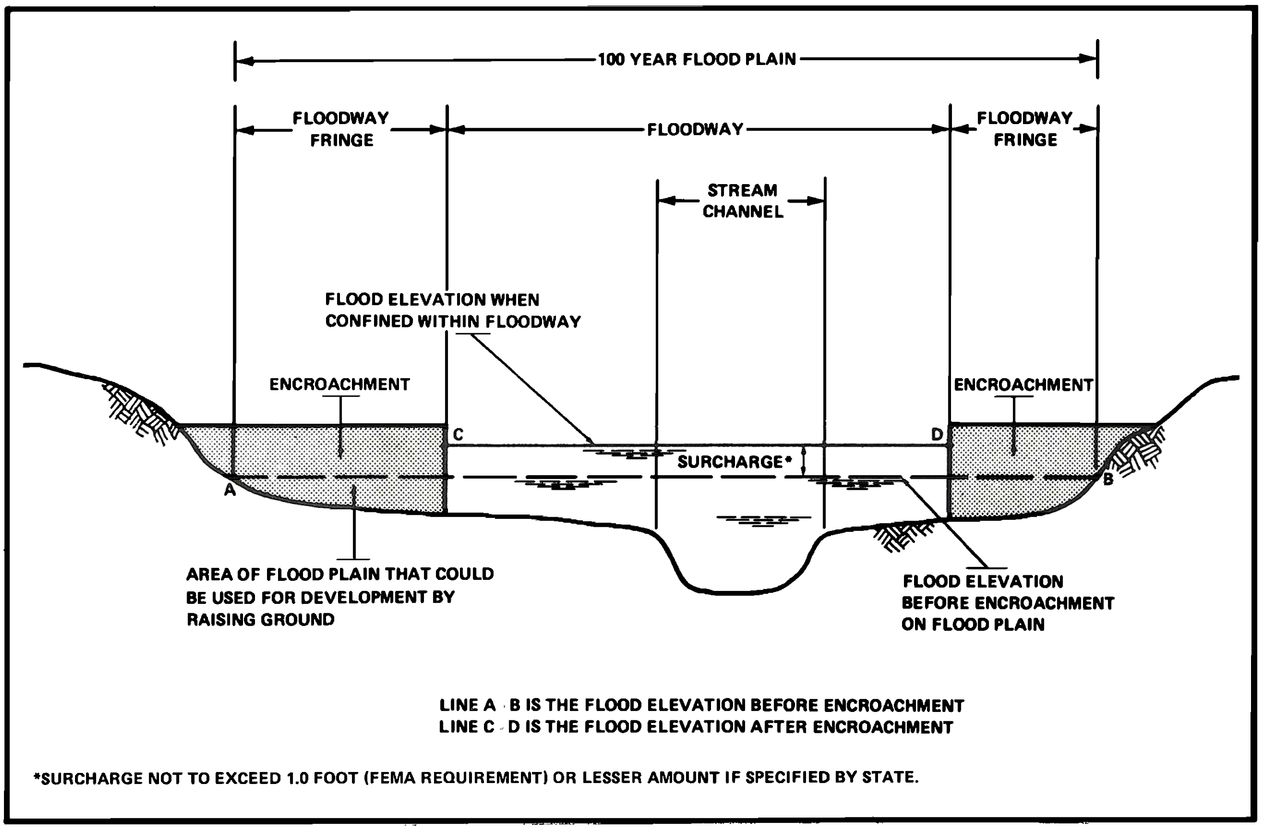


FIGURE 2-8. *The floodplain is made up of the floodway, which handles most of the flood flow, and the flood fringe.*

The remainder of the floodplain outside the floodway is called the **flood fringe**. This area normally experiences more shallow flood depths and lower velocities. With proper precautions, it is possible to build in this area with an acceptable degree of safety.

Location Within the Coastal Floodplain

In coastal regions, the floodplain is also divided into two portions, known as V-Zones and A-Zones. **V-Zones** are those areas adjacent to the beach that are subject to unusually high tides with wind-driven, velocity waves of three feet or more in height. **A-Zones** are areas further inland subject to inundation by flooding with waves of less than three feet in height.

In both of these areas, certain regulations exist that will determine which retrofitting methods can be used. In the V-Zone, because of the increased forces, these construction and land use requirements are more stringent, and the only retrofitting options available are elevation on pilings, posts or columns, or **relocation**.

Soil Condition

Another site consideration that may affect the selection of a retrofitting method is the type of soil at the site. If the soil is too **permeable**, which is its ability to allow water to pass between soil particles, then certain retrofitting methods, such as **levees** and **floodwalls**, will be impractical. Likewise, the bearing capacity of the soil will play a role in deciding what type of foundation can be used to elevate a structure.

Additional information on this characteristic may be available through the local office of the Soil Conservation Service or through local engineering firms.

2.4 BUILDING CHARACTERISTICS

Type of Construction

An equally important consideration in retrofitting is the type of construction involved. Specifically, the type of foundation, foundation materials, wall materials and the method of connection all play a role in deciding which retrofitting method will be most applicable.

Existing, unelevated **foundations** usually consist of either basement, **crawl space**, concrete slab at grade or any combination of the three. The type of foundation will determine which of the various retrofitting methods that directly involve the structure will be feasible.

Foundation materials normally consist of poured concrete, masonry block or wood. The type of material used will determine its resistance to flood forces. For example, poured reinforced concrete walls are capable of withstanding higher flood forces than unreinforced masonry block construction. This is a consideration since some retrofitting methods will expose the structure to various levels of flood forces.

The type of wall and how it is connected to the foundation is of importance if consideration is being given to sealing the structure against flood waters. There are very few types of wall construction that can withstand the forces of even two to three feet of flooding directly against them. Figure 2-9 shows the tremendous pressures that build up against a flooded structure as water levels increase.

HYDROSTATIC PRESSURES BY WATER DEPTH	
HEIGHT (H)	P_H (LBS/SQ. FT.)
1	62.4
2	124.8
3	187.2
4	249.6
5	312.0
6	374.4
7	436.8
8	499.2
9	561.6
10	624.0

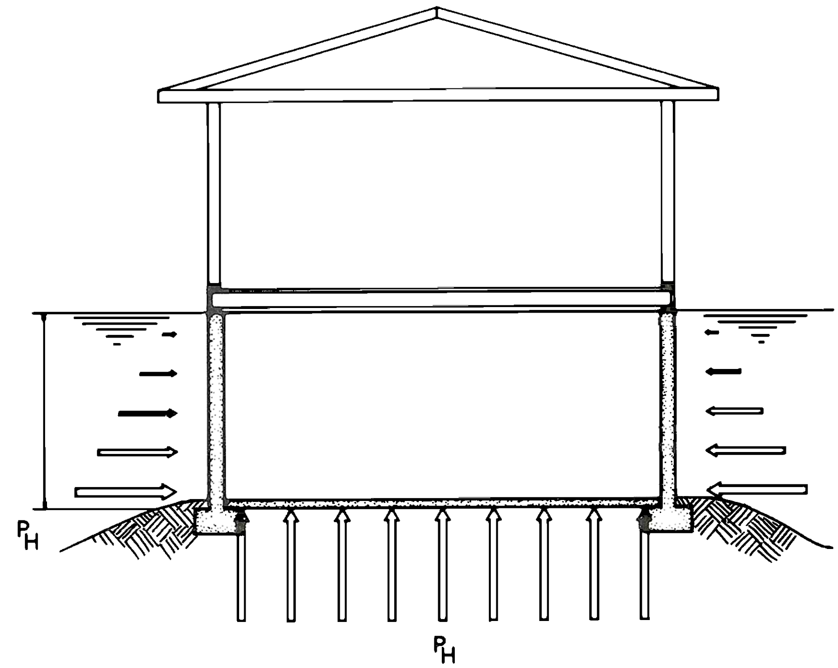


FIGURE 2-9. Hydrostatic Pressures.

Condition of the Structure

The condition of the building is an important consideration in almost any retrofitting plan. The only exceptions are levees and floodwalls, which are independent of the structure. Operations involving a building in poor condition may easily wind up further damaging the building and costing more than its original value.

2.5 REGULATORY LIMITATIONS

The National Flood Insurance Program

Until the late 1960s, it was very difficult to obtain flood insurance at a price that most homeowners could afford. This was because for any insurance program to be financially successful, the risks have to be spread over a wide segment of the population. In other words, many more people have to buy the insurance than will really need it.

Because only a minority of the population lives in flood-prone areas, and since most of those who live on higher ground have no reason to purchase flood insurance, it is difficult for private companies to establish a financially viable flood insurance program.

In 1968, in order to alleviate the heavy financial burdens that floods have traditionally imposed on individuals and local governments, and to control rapidly growing flood disaster relief costs, the Congress established the **National Flood Insurance Program** (NFIP). This program is managed by the **Federal Insurance Administration** (FIA), which is a part of the Federal Emergency Management Agency.

Under the NFIP, federally backed flood insurance is made available to cover buildings and their contents in flood-prone communities that participate in the program. In return for participating in the NFIP, these communities agree to establish methods of reducing flood losses by adopting zoning and building regulations and developing restrictions to control new building and **substantial improvements** to **existing construction** in the floodplain.

Additional information on the NFIP can be found in Appendix B.

Local Restrictions

Local zoning, **building codes**, and housing covenants may all affect what retrofitting techniques can be used. Some communities have even greater restrictions than the NFIP regulations. For example, some require a review of all structural changes to houses in the floodplain, while others, in an effort to encourage residents to move out of the floodplain, will not issue any building permits to homes that are subject to flooding. Consequently, it is essential to review local building codes and zoning restrictions before proceeding with any retrofitting action. This information is usually available at the office of the local building inspector or city engineer at the courthouse or city hall.

2.6 COST CONSIDERATIONS

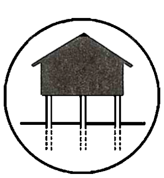
The final consideration in choosing a retrofitting method is deciding if its benefits outweigh its costs. This is often difficult because of the lack of information on the true cost of flooding. While it is possible to estimate the cost of a particular method and the potential loss value for a particular structure and its contents, it is very difficult to place a value on the other costs of flooding. These include the loss of irreplaceable personal items, the time lost in salvaging the contents and rebuilding the structure, and the personal pressure and hardship that occur every time flood waters threaten.

The process of weighing the economic factors involved is known as a <u>cost/benefit analysis.</u> It is possible to perform a simplified cost/benefit analysis with a minimum of research using this manual. The basic steps in developing this analysis to decide on the most effective retrofit technique are found in Chapter 11.

2.7 OVERVIEW OF RETROFITTING METHODS

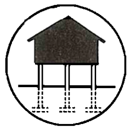
There are many different retrofit options available, varying from a simple and inexpensive method to complex systems. As described in the first chapter, this manual will deal only with permanent measures since they offer the greatest reliability. The following is an overview of these retrofit methods, each of which is covered in a separate chapter.

Elevation (Chapter 3)



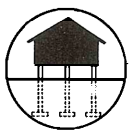
This method consists of raising a house on an elevated support structure to place it above future flood waters. The exact method can include a number of possibilities that depend on local conditions such as expected flood and wind forces, building type and size, and soil bearing capacity. **Elevation** may be considered for all types of homes, including structures built slab-on-grade or over crawlways and basements. Types of elevated foundations consist of:

Elevation on Extended Foundation Walls—The house is elevated and set on walls that have been built up from the original foundation. This method is particularly appropriate where the characteristics of flooding involve up to moderate depths with slow velocities, and is commonly used.



Elevation on Piers—This method is employed for shallow flooding with slow to moderate velocities. The house is elevated and set on low foundations that are constructed of reinforced masonry block or reinforced concrete.

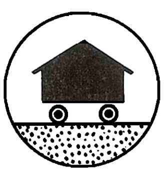
Elevation on Posts or Columns—This method is used for shallow to moderate flood depths with slow to moderate velocities. The house is set on taller structures, generally made of wood, steel, or concrete, set in pre-dug holes and braced together.



Elevation on Pilings—This method is employed where high-velocity water could undermine other structures such as in **coastal high-hazard areas**. It is also suitable for deep flood depths or poor soil conditions. The house is set on tall foundation pilings, usually wood, that have been driven into the ground.

Elevation on Fill—This method is limited to areas of low flood depths and low velocities. The house is elevated on compacted soil. The method has a number of drawbacks as a retrofitting technique and therefore is covered in Chapter 10.

Relocation (Chapter 4)

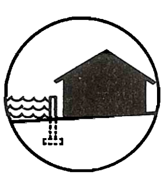


Perhaps the only technique for completely preventing future flood damage, this method involves moving a house out of a flood area to a new location where there is no threat of flooding. The technique for moving most any house in good structural condition is well developed. It is generally more expensive and time consuming than most elevation techniques, but it can be a very feasible method in many cases.

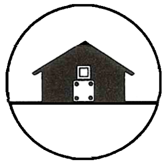
Levees (Chapter 5)

A possible technique in areas of shallow and moderate flooding depths with low velocity, this is a method of creating a barrier of compacted soil to keep the water away from a house. It can be one of the least expensive techniques, and it can be attractively landscaped. Its construction, however, requires great care, and there must be continued attention and maintenance to prevent its failure.

Floodwalls (Chapter 6)



This method is sometimes practical for areas with low to moderate flooding depths and velocities. As with levees, floodwalls are designed to keep the water away from a house, but are constructed of materials such as masonry block and reinforced concrete. They are more expensive than levees, but if properly designed, do not require as much concern with continued inspection and maintenance. However, because some designs have openings for access to the house, they often require closures and human presence to make sure they are in place prior to flooding.



Closures (Chapter 7)

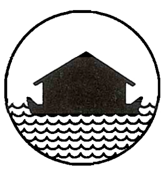
Often used in conjunction with other techniques such as floodwalls and levees, **closures** involve techniques for protecting gaps that have been left open for day-to-day convenience, such as walks, doors, and driveways.

Sealants (Chapter 8)

Sometimes referred to as **dry floodproofing**, this method can be used only in areas of very shallow flooding to completely seal a home against water. Because of the tremendous pressures that water can exert against a structure protected by this method, the technique can only be used on brick veneer or masonry construction in good structural condition, and then only when the flood levels cannot exceed two to three feet and flood velocities are negligible.

Utility Protection (Chapter 9)

Often very costly damage to utilities such as heating, air conditioning, electrical, and plumbing systems occurs during floods. Simple and relatively low-cost measures can usually prevent damage to these systems, which are essential to the habitability of a residence.



Special Techniques (Chapter 10)

These are some special floodproofing techniques used in unusual flooding situations. They include retrofitting in **alluvial fans**, elevation on **fill** and elevation on reinforced mat slabs.

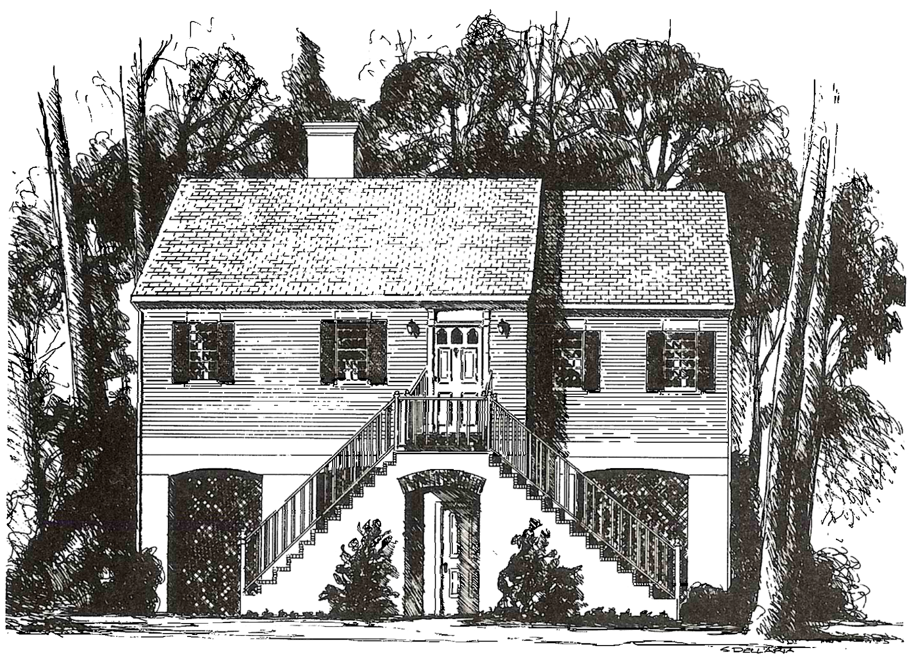
Choosing a Method (Chapter 11)

The final chapter outlines the process of choosing the most applicable and feasible retrofitting method for a specific location.

Chapter 3

ELEVATION

One of the most common of all retrofitting techniques is to raise an entire existing structure above flood hazard. When properly done, the elevation of a house places the living area above all but the most severe floods.



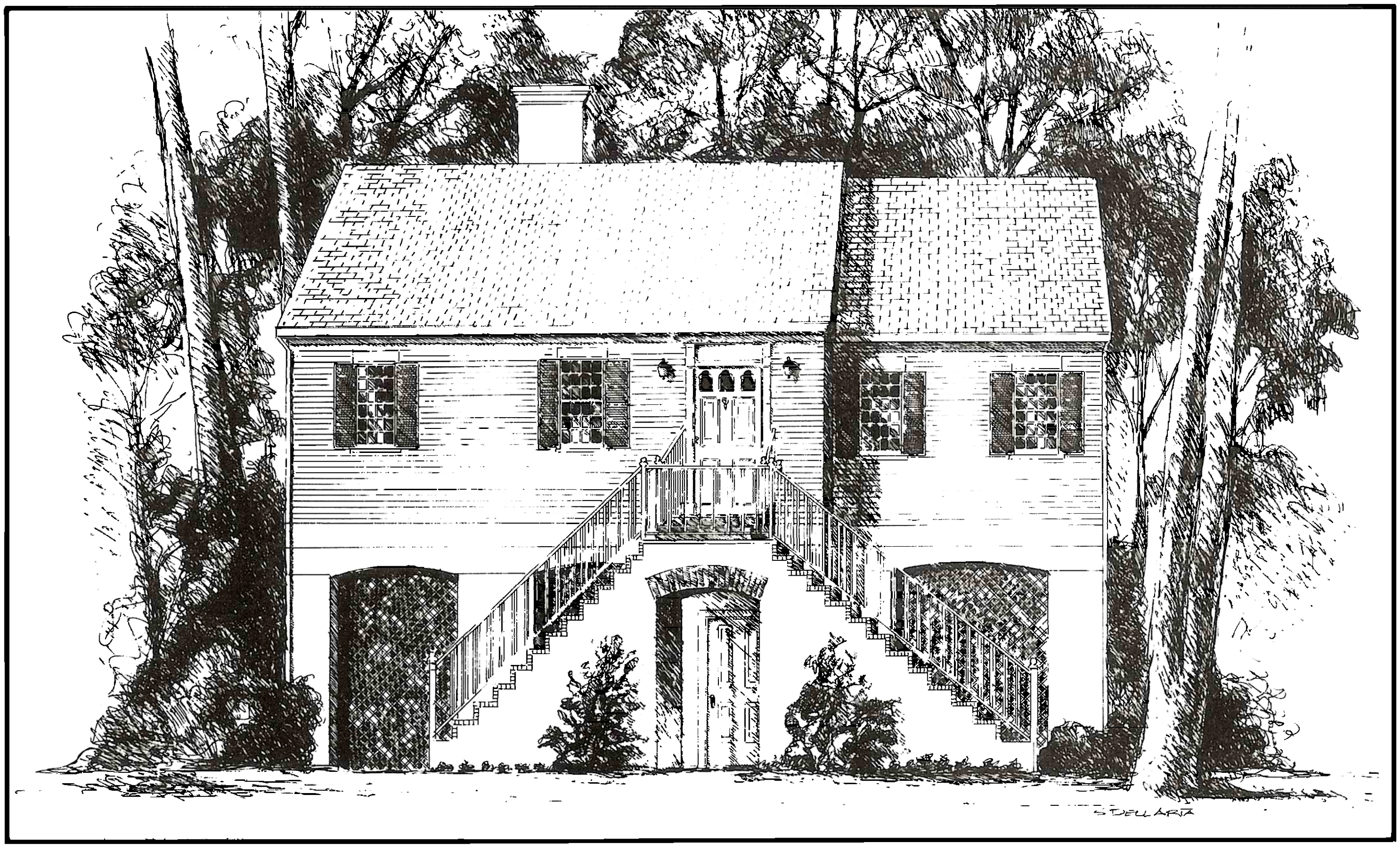


FIGURE 3-1. Detailed Rendering of House Elevated on Posts.

3.1 INTRODUCTION

One of the most common of all retrofitting techniques is to raise an entire existing structure above the flood hazard. When properly done, the elevation of a house places the living area above all but the most severe floods.

In general, the steps required for elevating a building are essentially the same in all cases. A cradle of steel beams is inserted under the structure; jacks are used to raise both the beams and structure to the desired height; a new elevated foundation for the house is constructed; and the structure is then lowered back onto the new foundation and reconnected.

While the same basic elevation techniques are used in all situations, the final siting and appearance of the house will depend on the final elevation and type of foundation used. However, the actual elevation process is only a small part of the whole operation in terms of planning, time, and expense. The most critical steps involve the preparation of the house for elevation and the construction of an adequate elevated foundation.

If properly performed, elevation offers several advantages. When a house is raised, the living area is placed above potential flood levels. This means there is usually little need for human intervention to prepare for flooding, making this one of the most reliable retrofitting methods. In addition, the elevation height is limited only by the type of support foundation used, making this one of the most cost effective methods for higher flood levels.

One other advantage of elevating a building is that since flood insurance is rated according to the elevation of the lowest habitable floor, this method offers the greatest chance to reduce flood insurance premiums.

3.2 CONSIDERATIONS

There are a number of factors that need to be studied when planning to elevate a structure. Considerations such as elevation height, flood characteristics, condition of the building, and type of building being raised all need to be examined to ensure the success of this retrofitting technique.

Elevation Height

The usual practice for inland areas is to elevate the house high enough so that the lowest habitable floor is above the base flood elevation. Some communities and building code groups have dictated that the bottom of the floor system must be elevated above the BFE to reduce the potential of water damage. In coastal areas subject to velocity waves during storms, the house should always be elevated such that the bottom of the structural floor support system is above the BFE. The reason for this is that velocity waves impacting on the floor support system could overload the structure.

In cases where elevation to the BFE may not be economically feasible, elevation to a lower height is an option. While the degree of protection is reduced, this is still better than no protection at all. It should be realized however, that the reduction in flood insurance rates will be significantly less.

Low level elevation will normally have little effect on the appearance of a house and the restoration work that is needed, such as grading, landscaping, etc., will usually be minimal.

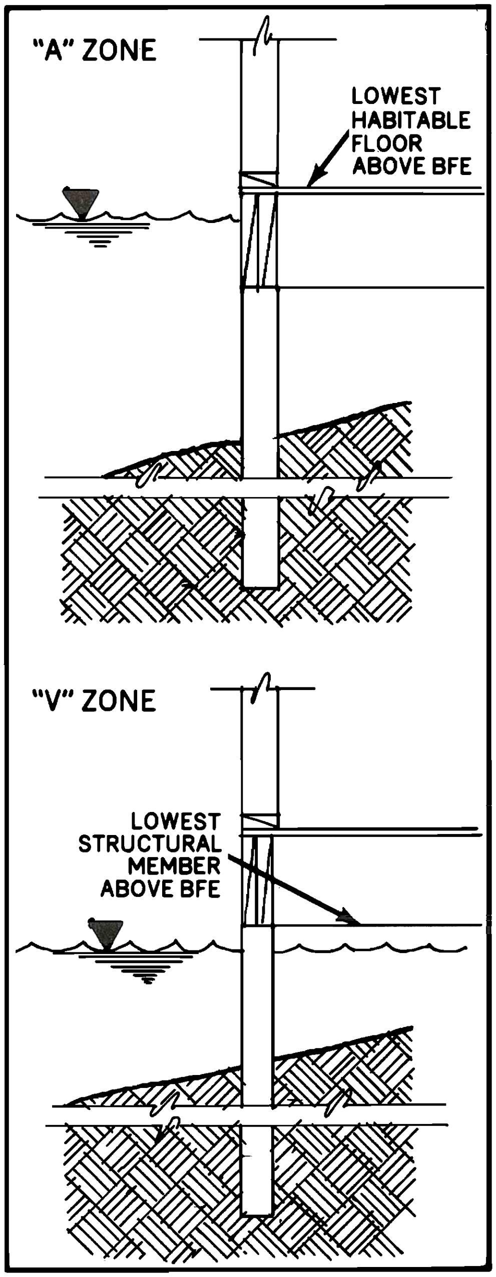


FIGURE 3-2. *Requirements for elevated foundations differ in A-Zones and V-Zones.*

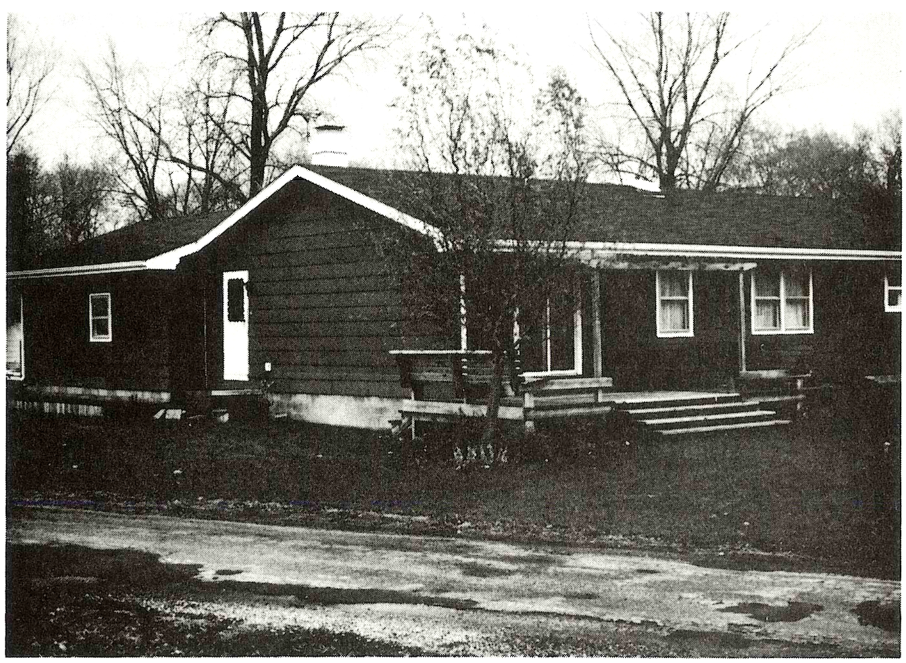


FIGURE 3-3. *The owner of this house in Illinois elevated his house the height of only three masonry blocks, but in this case, it significantly reduced the exposure to flood damage.*

ELEVATION REGULATIONS OF THE NFIP

In those areas that have adopted the National Flood Insurance Program, certain regulations may apply in the elevation of residential structures depending on whether the retrofitting project can be classified as a substantial improvement. In A-Zones (riverine and coastal flood-prone areas subject to storm surges with velocity waves of less than three feet), regulations require that the top of a building's lowest floor (including basement) be elevated to or above the Base Flood Elevation (BFE).

For structures located in the V-Zone (coastal flood-prone areas subject to storm surges with velocity waves of three feet or more), regulations require that the lowest portion of the horizontal structural members supporting the lowest floor be elevated on pilings or columns to or above the BFE.

Other requirements include the following:

- *Building materials including interior walls and floors located below the BFE must be resistant to flood damage;*
- *The walls and floors of any enclosed area below the BFE must be constructed in a manner to prevent flotation, collapse, and lateral movement of the structure;*
- *Construction of basements (enclosures with floor levels completely below ground level) is never permitted below the BFE, unless an exception has been granted to the community;*
- *All machinery and equipment servicing the building (furnaces, heat pumps, hot water heaters, air-conditioners, washers, dryers, refrigerators and similar appliances, elevator lift machinery, and electrical junction and circuit breaker boxes) must be elevated to or above the BFE or designed so as to prevent water from entering or accumulating during flooding;*
- *All space designed for human habitation must be elevated to or above the BFE, including bedrooms, bathrooms, kitchen, and dining, living, family and recreation rooms.*
- *Uses permitted in spaces below the BFE are restricted to vehicular parking, limited storage, and building access (stairs, stairwells and elevator shafts).*

If the BFE is more than four feet above the grade of the existing structure, then it may be desirable to elevate the house one full story and use the space below the elevated floor for parking or storage. In these cases, a number of steps must be taken to keep the house livable and to restore the surrounding site.

Flood Characteristics

Because structures can be elevated on different types of foundations, elevation is practical for almost any type of flooding. However, the various flood characteristics of the site must be examined to determine which type of foundation will be the most suitable.

The velocity of the flood waters for a specific site, along with the type of soil present, will determine the potential for scour or erosion. Since scour can undermine a foundation and result in collapse of the building, this hazard will be a major factor in designing the foundation system.

In some areas, flood waters tend to carry large amounts of debris such as trees, rocks, or ice. The battering of debris against the foundation can often cause more damage than the flood, and the foundation system must be strong enough to withstand these impact forces.

Building Type and Condition

Because one of the most critical phases in the elevation of a house is getting steel beams under it to do the lifting, certain types of buildings are easier to elevate than others. Generally the easiest and least expensive houses to elevate are one-story frame structures built over crawl spaces at least 18 inches high. This process becomes more difficult as other factors are added, such as:

Houses over basements. These are more difficult to elevate than homes with crawl spaces because basements usually contain utilities and equipment which must be disconnected and elevated or floodproofed. Also, after elevation, the basement walls may have been extended to the point where they cannot structurally withstand flood forces (see Figure 3-17). In this case, either part or all of the basement may have to be backfilled and a new basement slab poured.

Houses with no existing crawl space or basement. If there is no crawl space or basement, a trench must be dug around the house to provide working space, followed by other trenches dug under the house to provide space for inserting lifting beams.

Slab-on-grade construction. One of the greatest problems in elevating houses occurs in **slab-on-grade** type structures. In some areas, this is one of the more common methods of construction, with the lowest floor of the house sitting directly on a concrete pad which rests on the ground. When the slab is poured during initial construction, structural reinforcing is rarely included, and it is difficult to raise the slab and the house without damaging both. In most cases, the elevation of a slab-on-grade house involves detaching the house structure from the slab, raising just the structure, and building a new floor system along with an elevated foundation.

FIGURE 3-4. *This house on the Willamette River in Oregon sustained extensive damages when six feet of flood water covered its first floor.*

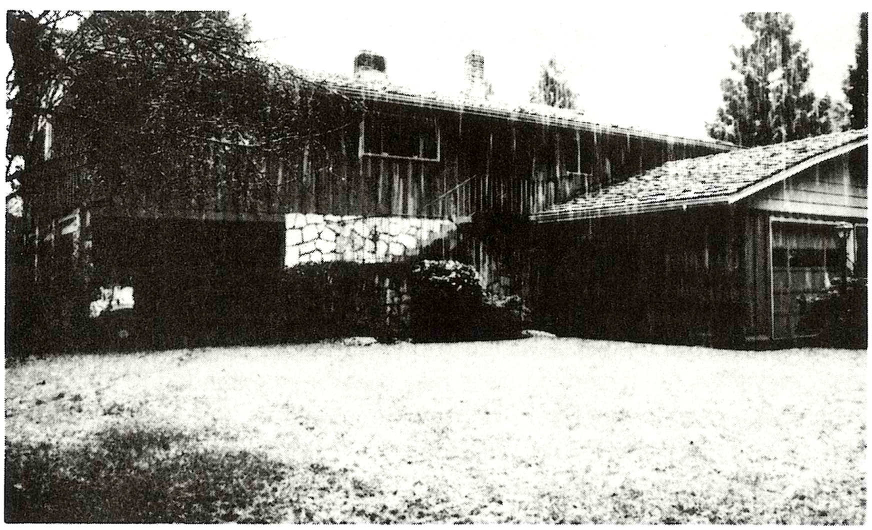


FIGURE 3-5. *The same house was elevated eight feet. The garage was separated from the structure when the house was elevated.*

Heavy building materials/complex design. Although most any building, even one constructed of brick and block, can be raised, the process becomes more complicated and, consequently, more expensive with heavier materials and more complex building designs. Brick veneer and stucco, for example, may have to either be removed before the elevation and later replaced, or extensively braced during the operation. In addition, multi-story buildings are generally more difficult to stabilize for raising.

Building additions. Generally, rectangular-shaped or box-shaped structures are simpler to elevate, while wings of the house, add-ons, and garages often must be separated and elevated independently from the main structure.

FIGURE 3-6. *This Alabama house was originally slab-on-grade and was elevated above flooding.*

Before a house can be raised, it is advisable to have a survey done by a structural engineer to determine its structural soundness. All the structural members, joists, etc., as well as the structural connections must be able to withstand the stresses of elevation. Elevation of an unsound structure may lead to problems, possibly resulting in expenses that could exceed the original value of the home.

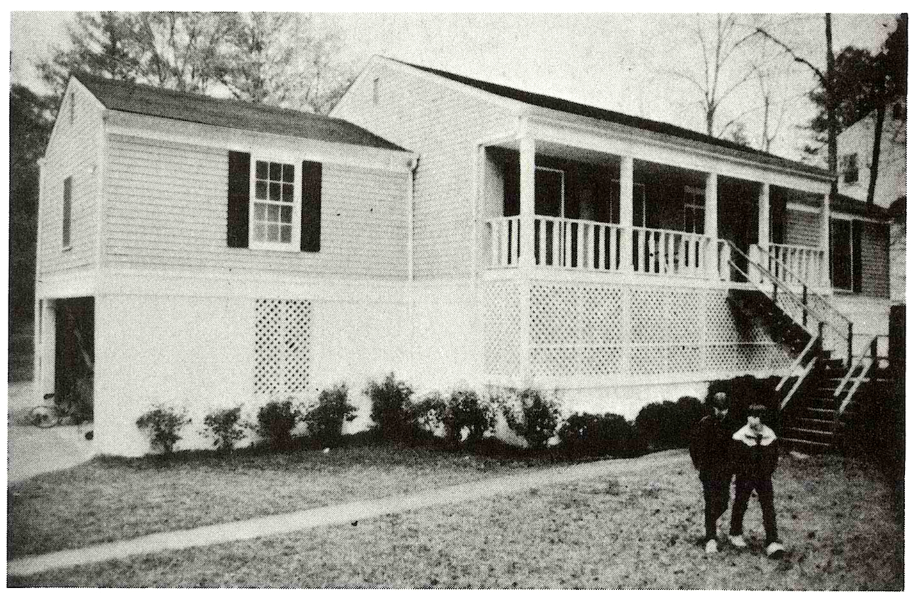


FIGURE 3-7. *This Atlanta, Georgia house was elevated one full story. The garage and storage area sit at the house's original elevation.*

Access

Elevation of a home may require a change in the method of access, normally requiring the construction of exterior and/or interior stairways. This is often the main objection to elevating a house, but the problem can easily be solved in a functional and yet attractive manner, as shown in the photographs that accompany this chapter.

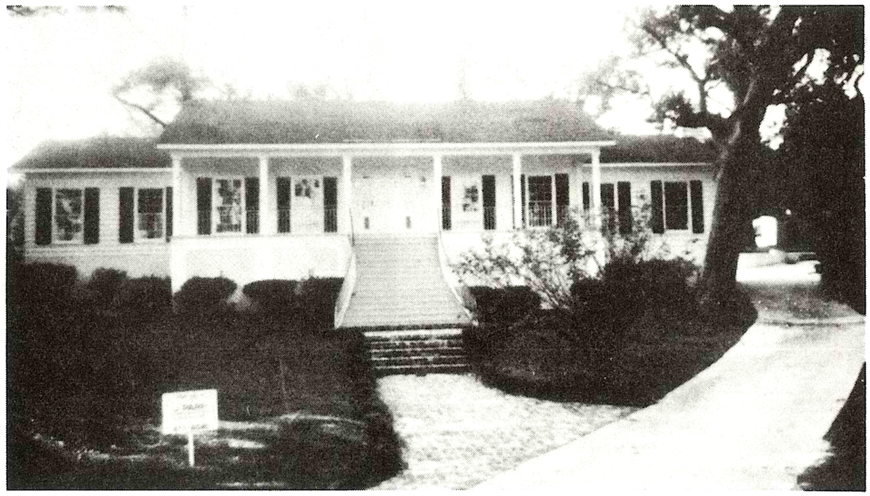


FIGURE 3-8. *With some attention to detail and planning, homeowners have created attractive retrofitted structures.*

For low level elevations, a driveway adjacent to a house can be rebuilt by bringing in fill and grading it to allow parking next to the elevated house or in a newly constructed garage. If the garage is attached to the house, then it may be possible to install a fill pad to the new level and pour a new garage slab.

If the house must be elevated four feet or more, it may be worthwhile to elevate one full story and use the space below the structure for parking.

However, with the driveway at grade level, emergency services may not be able to reach the house during a flood. A possible solution to this problem is to provide access from the structure to higher ground via a raised walk or driveway. This is practical only if the house is near higher ground, such as a road on an embankment, as in Figure 3-9. The escape route should also lead away from the floodplain.

FIGURE 3-9a. *A walkway to an elevated house near Sacramento, California doubles as an escape route. These photos show the house in both a flooded and unflooded condition.*

FIGURE 3-9b.

Other Considerations

If before elevation, the utilities are located in the basement or in a lower part of the house, then they also must be elevated or otherwise floodproofed. Additional details are provided in Chapter 9, "Protection of Utilities." Electrical lines coming in from poles can be raised along with the house. Utility lines that come in from underground, such as water, sanitary sewer, and natural gas lines will have to be protected from the effects of flood forces and debris impact when they are exposed by elevation.

If the house has been elevated off a slab, and if the lowest floor was not insulated before, the newly exposed underside of the floors must be insulated to prevent additional heat loss. Foil backed fiberglass insulation is recommended, although the insulating or "R" value will depend on the location.

Among general aesthetic considerations to study is planning the lower part of the house to be the same style as the upper part. An architect can be very helpful in doing this. Also, with the careful but creative use of landscaping with trees, shrubs, and fences, the gap between the ground and the upper floor can be closed over in an attractive manner.

3.3 ELEVATION OF STRUCTURES ON FOUNDATION WALLS

The procedures used in raising a house on either a basement or crawl space are essentially the same, regardless of the final elevation. The elevation process is outlined in the following drawings.

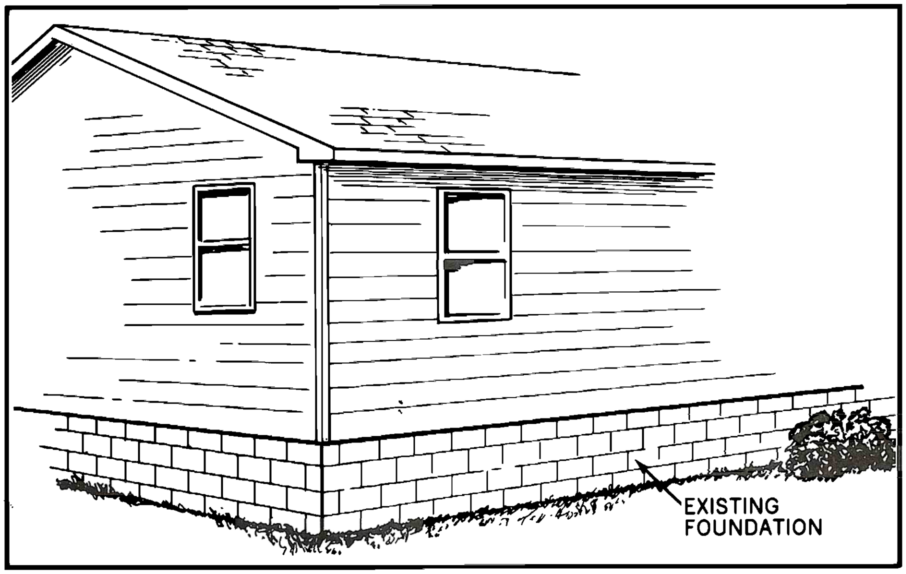


Figure 3-10a. *Elevating a house involves a number of steps. Prior to elevation, all utility hookups, wire, and plumbing are disconnected.*

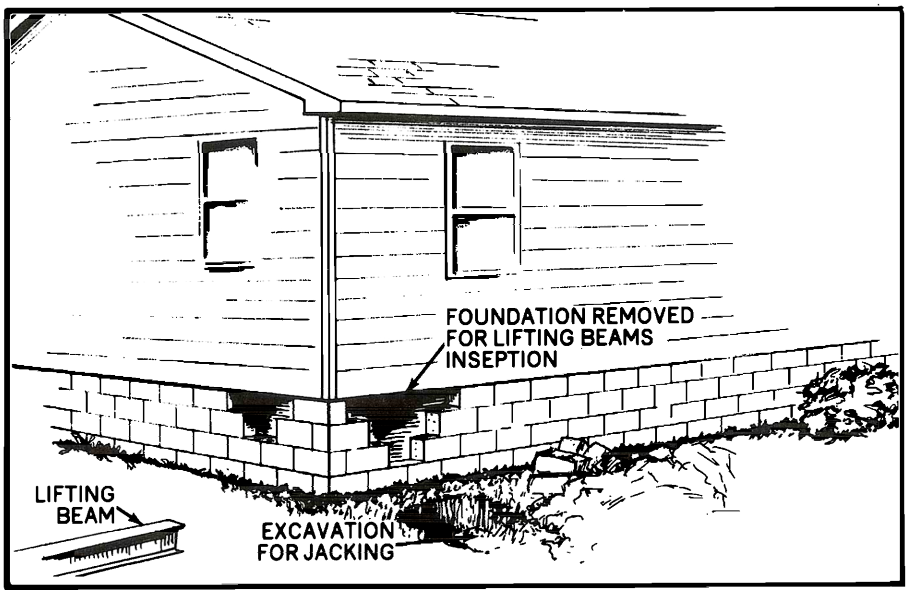


Figure 3-10b. *Blocks must be removed at points where I-beams will be located to support the structure.*

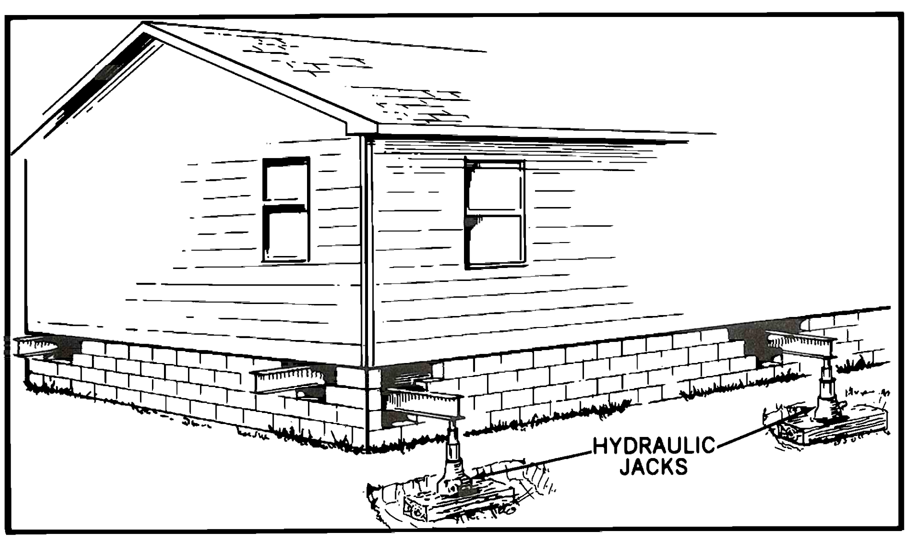


Figure 3-10c. *I-beams are placed under critical lifting points, perpendicular to the floor joists, and a second set of I-beams is placed beneath these to ensure uniform lifting of the structure by jacks.*

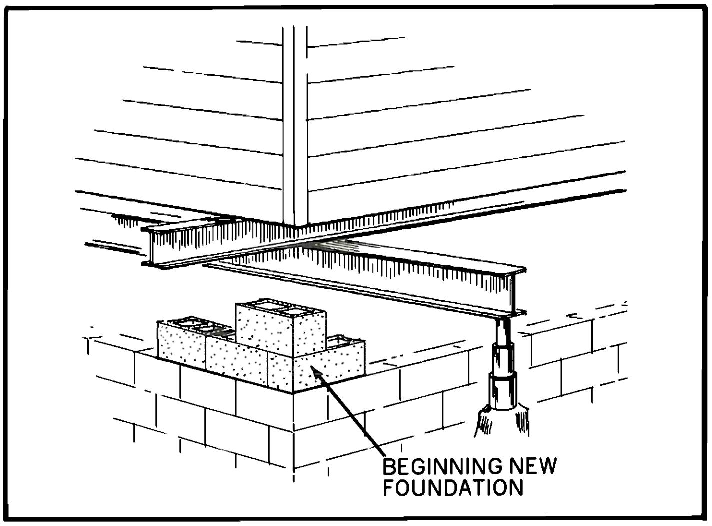


FIGURE 3-10d. *After the structure is detached from the foundation, it is lifted by the jacks. The new foundation wall is then built, either on the old wall if it has been determined to be strong enough, or on a new foundation system.*

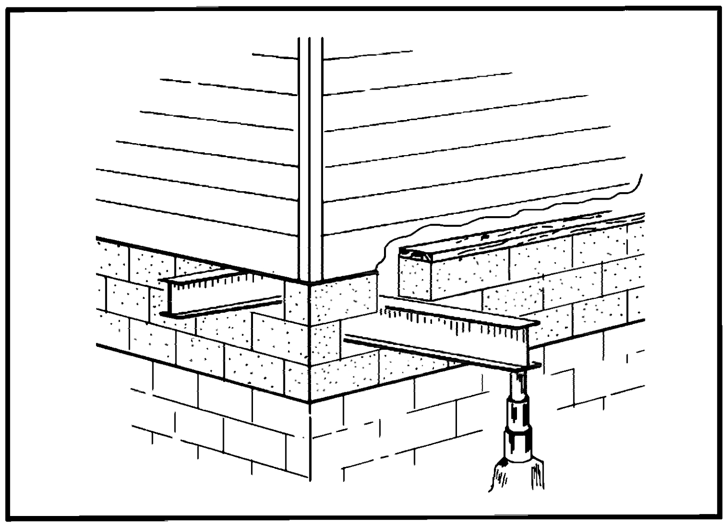


FIGURE 3-10e. *When the new foundation is completed, the house is lowered onto it. The I-beams are then removed and the holes in the new foundation filled.*

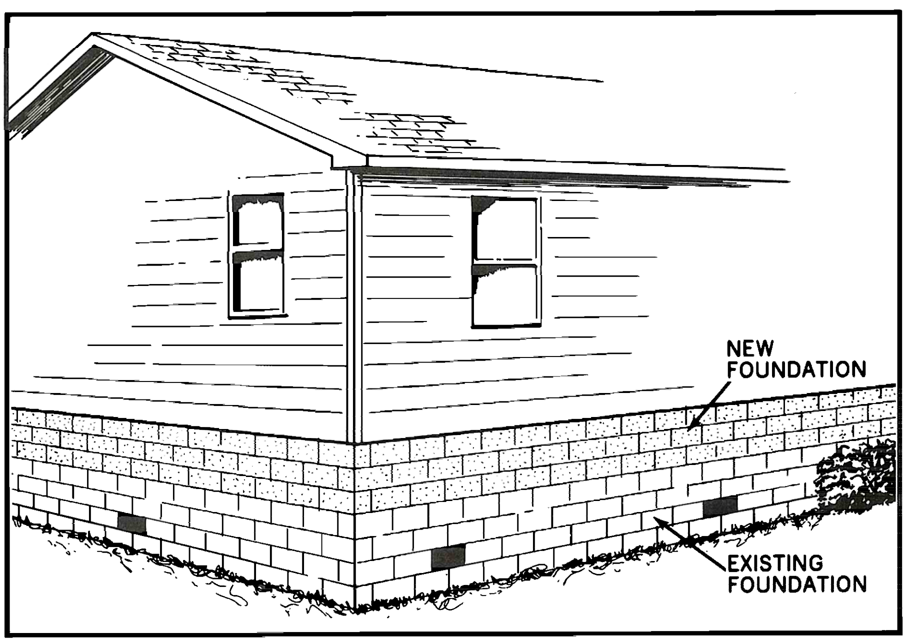
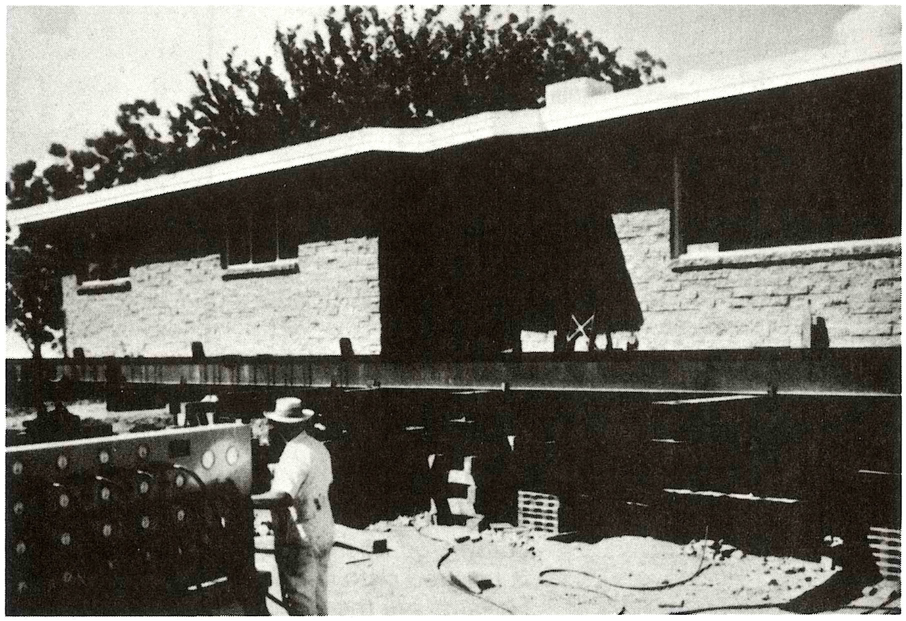


FIGURE 3-10f. *The utilities are reconnected, the site relandscaped and the house is now elevated for flood protection. The openings shown on the foundation wall allow flood waters to enter the unfinished lower area to equalize water pressures.*

The actual process of lifting utilizes either crank-type or hydraulic fluid jacks, each individually and gradually raised by workers. With more modern machinery, all the jacks are controlled from a central hydraulic panel where the house mover can coordinate the operation automatically.

FIGURE 3-11. *Working from a central hydraulic panel, a house mover can coordinate the elevation of a structure.*

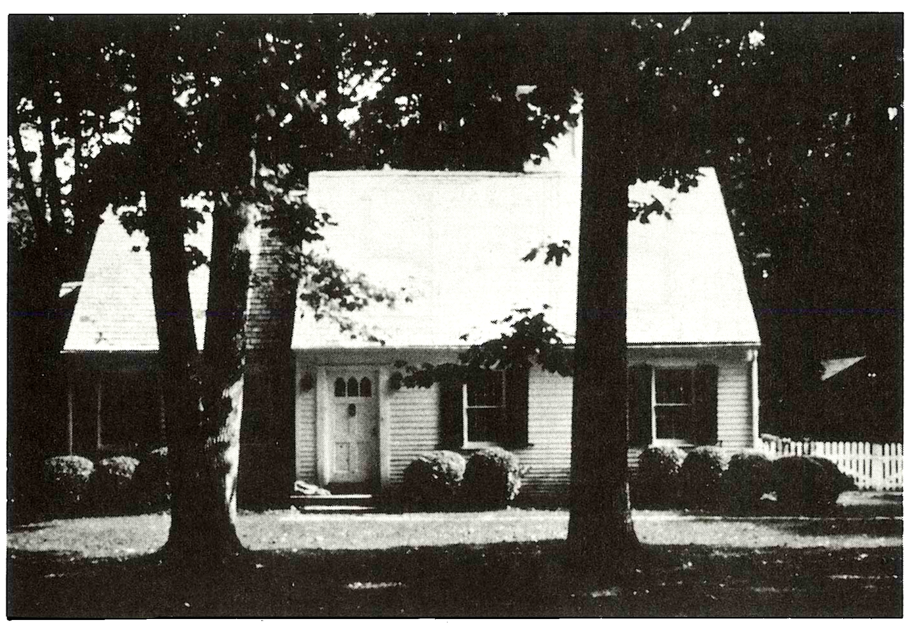


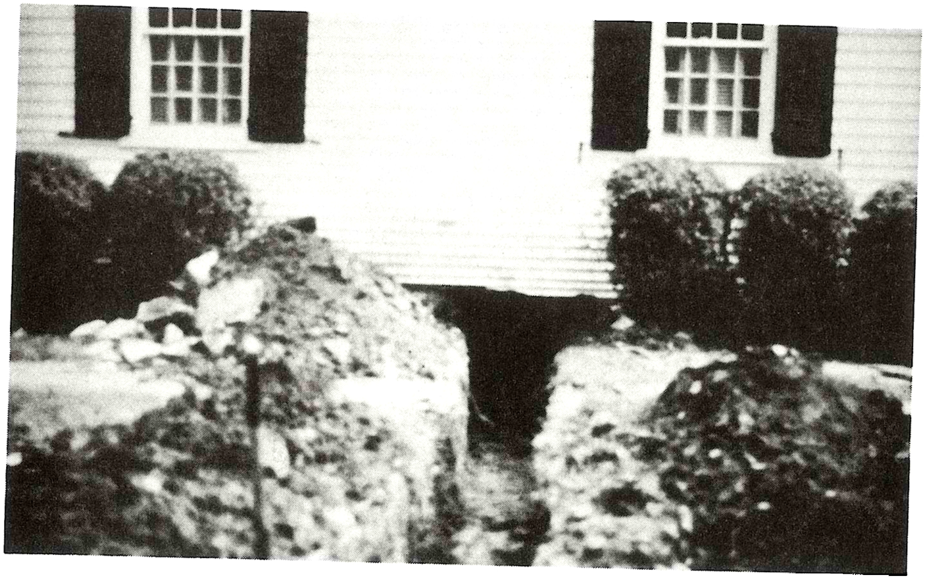
If the desired height is greater than the fully extended length of the jacks, then the operation is done in segments. This is done by raising the jacks as far as they will go and then inserting cribbing, or layers of timbers, under the house. After resetting the jacks, the house is raised again and the process is repeated until the desired height is reached.

The photo sequence in this chapter shows this actual process being performed on a house in Atlanta, Georgia.

FIGURE 3-12. House Elevation Sequence (Atlanta)

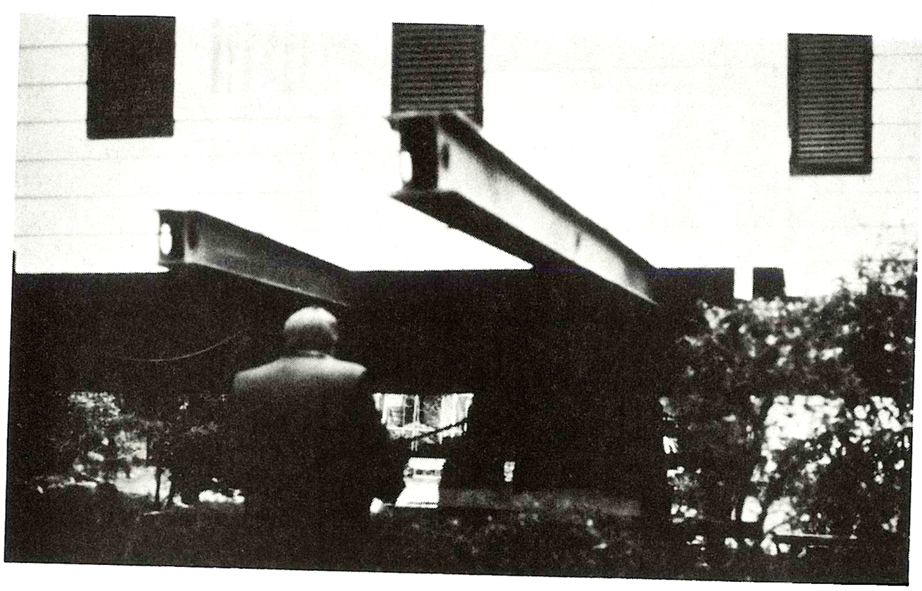
After being flooded several times, the owners of this Atlanta home decided to elevate the structure.





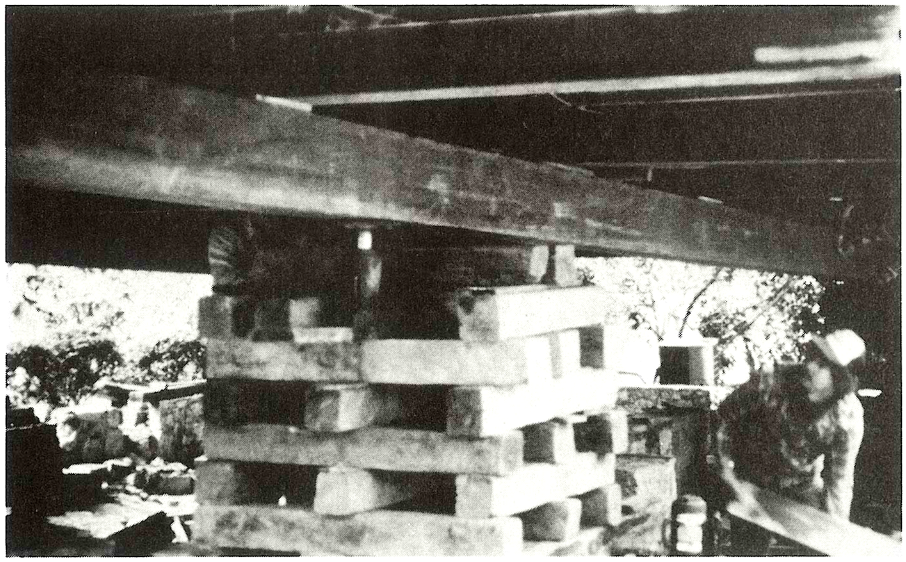
Trenches were dug below the home to allow lifting beams to be placed in position.

Lifting beams were then inserted . . .



. . . and the structure lifted.

Cribbing was used to support the structure . . .

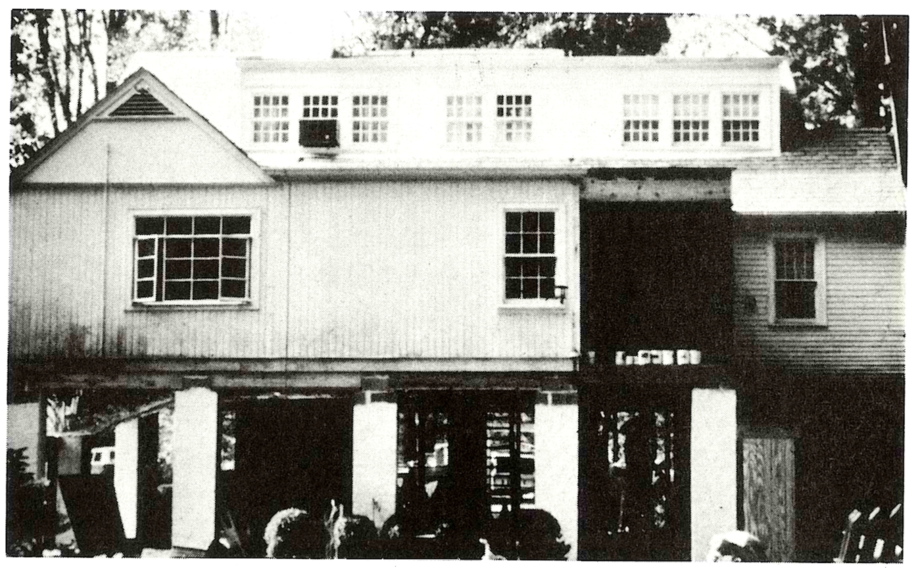


. . . while the jacks were reset to continue the lifting process.

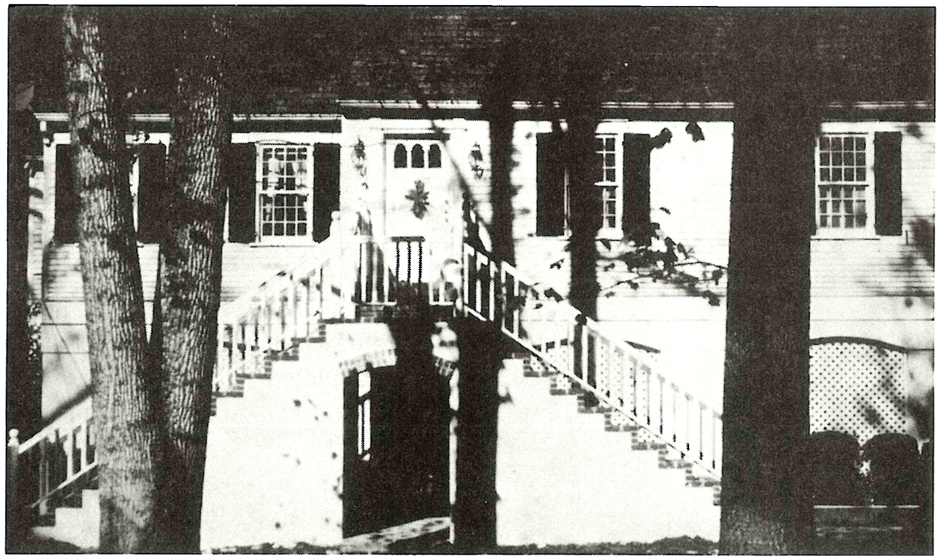
The house at its highest elevation.

Utilities are also elevated.

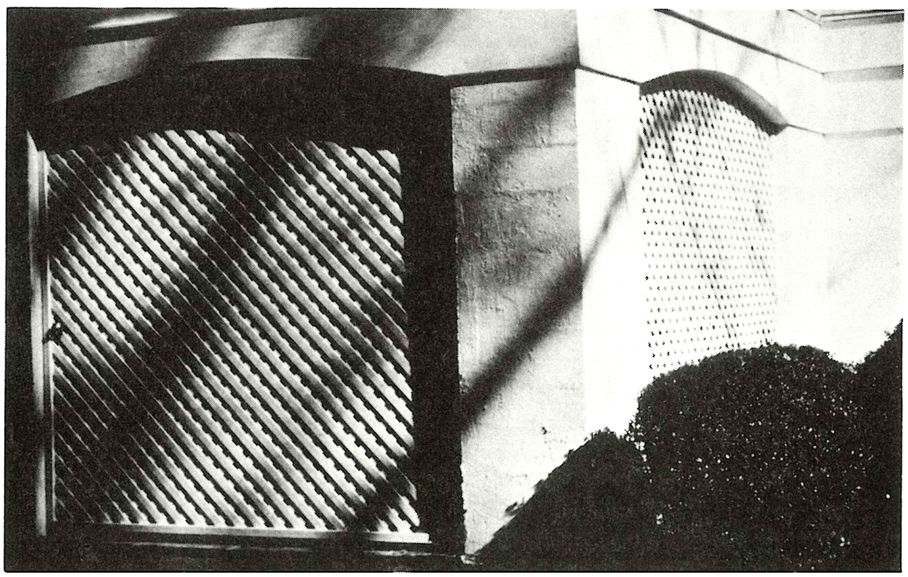
Construction of the foundation.



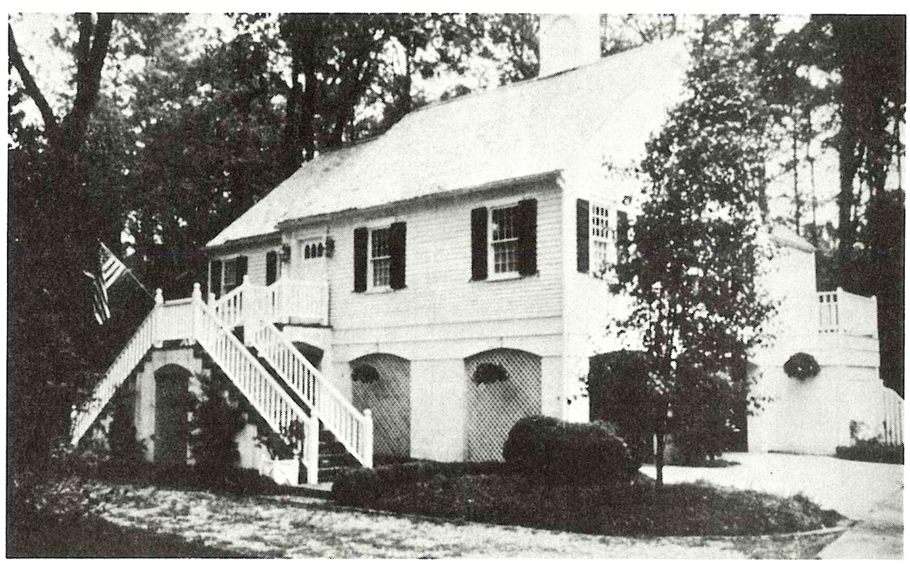
Access stairway under construction.



The house lowered onto its foundation.



Breakaway walls are placed between posts.



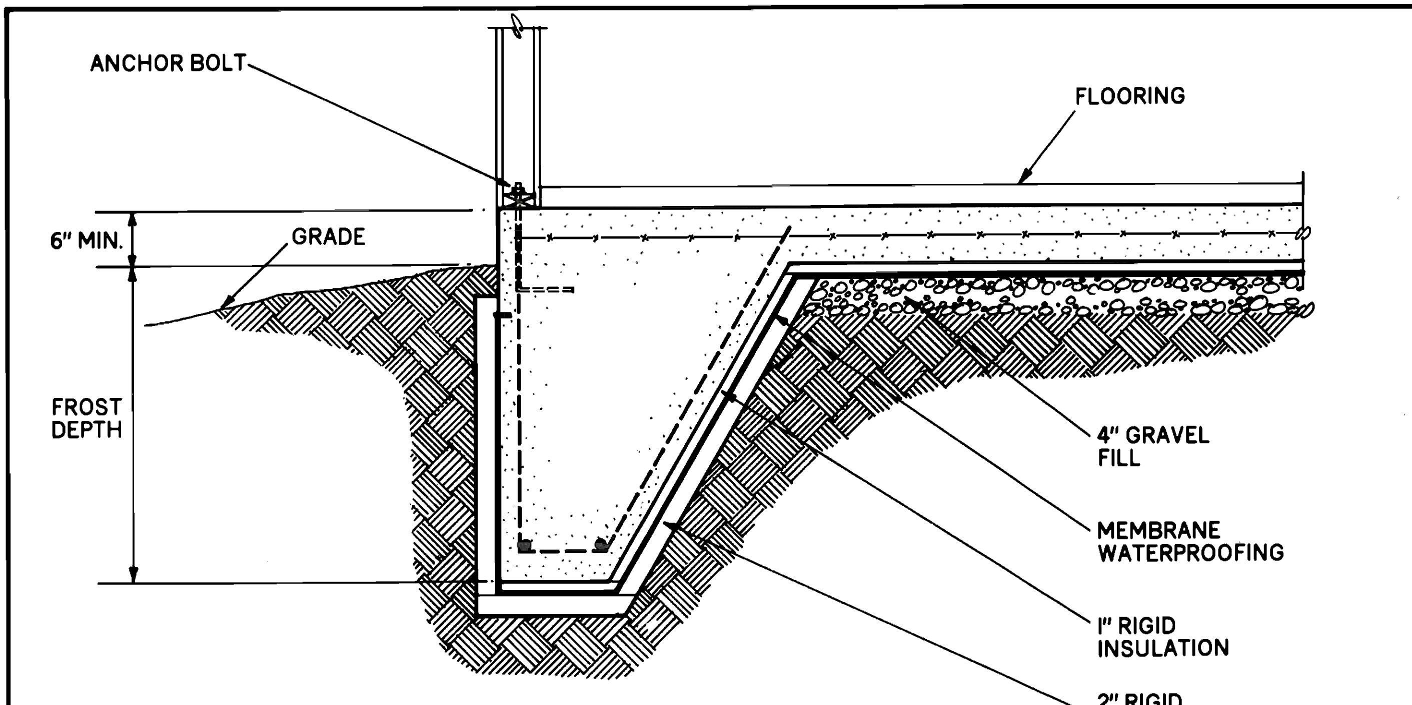
Elevation complete.

As previously described, this type of structure is usually the easiest to elevate. The main item of concern is that the entire project be planned out well in advance. This method of elevation can often be the least expensive retrofitting option available. Cost data on all elevation methods is located in Section 3.10.

3.4 ELEVATION OF A SLAB-ON-GRADE STRUCTURE

In many parts of the country, houses are commonly constructed on a concrete slab that sits directly on the ground. This is known as **slab-on-grade** construction. In almost all cases, there is little, if any, structural reinforcing of the concrete slab. When constructing a new house, contractors will generally pour a four- to six-inch concrete slab within the floor area. Prior to the pour, they lay in a wire mesh or fabric of $\frac{1}{32}''$ to $\frac{1}{16}''$ thickness. This serves mainly to help prevent shrinkage cracking and to hold the wet concrete in place for easier maneuvering and finishing. Once the concrete has set, the wire fabric adds little, if any, structural reinforcement to the slab. In addition, in colder areas of the country, the edges of the slab are sometimes thickened or "turned down" to help protect the slab from frost damage.

FIGURE 3-13. *In northern sections of the country, the edges of the slab are turned down to help protect it from damage by freezing.*



Typical Turned Down Slab

As a result, it is extremely difficult to lift a house and slab of this type without breaking the slab, which would then threaten the structural integrity of the house itself.

In some special cases, houses have been constructed with slabs that have been adequately reinforced and structurally connected to the house. This is called a **structural mat slab**, and is generally found in areas where land subsidence is a problem, such as the Southwest. This type of construction represents a very small percentage of homes built in the United States. Elevation of a house on a structural mat slab can be done by elevating the slab along with the rest of the building. This process is covered in Chapter 10.

There are a number of factors that must be examined in making a decision to elevate any slab-on-grade structure. A structural or foundation engineer should be contacted to assist in determining if this method will be feasible. The original plans for the house would be helpful, since they generally include references to the necessary specifications. The factors to be examined include the following:

> Whether the exterior and interior walls of the house are strong enough structurally to withstand the stresses of elevation;
>
> Whether electrical, gas, or other utility lines are encased in the slab, and how plans should be coordinated to allow for disconnection and eventual reconnection;
>
> Whether the shapes of the slab and structure lend themselves to elevation.

Because it is constructed differently, a slab-on-grade house cannot be lifted in the same manner as a framed floor structure. Since homes with unreinforced slabs lack the structural floor supports, their interior walls would probably fall loose or collapse, and the sides of the home could twist or bend, causing a loss of structural integrity. To avoid this, slab-on-grade houses must be braced for both exterior and interior stability to eliminate twisting or bending at all points where pressures of the lifting operation meet the structure.

In addition to the normal steps involved in any type of elevation, the process involved in elevating a house detached from its slab is outlined on the following drawings:

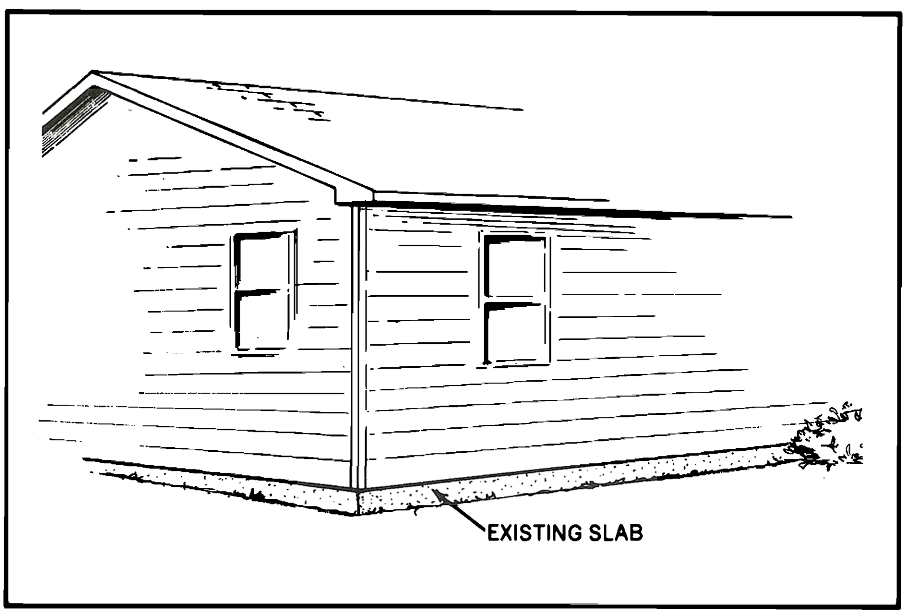


FIGURE 3-14a. *The first step in elevating a slab-on-grade home is to identify the best location for the principal lift beams, lateral support beams and framing lumber, and to evaluate their adequacy. This is generally determined by a structural engineer, based principally on the square footage, layout, and weight of the house.*

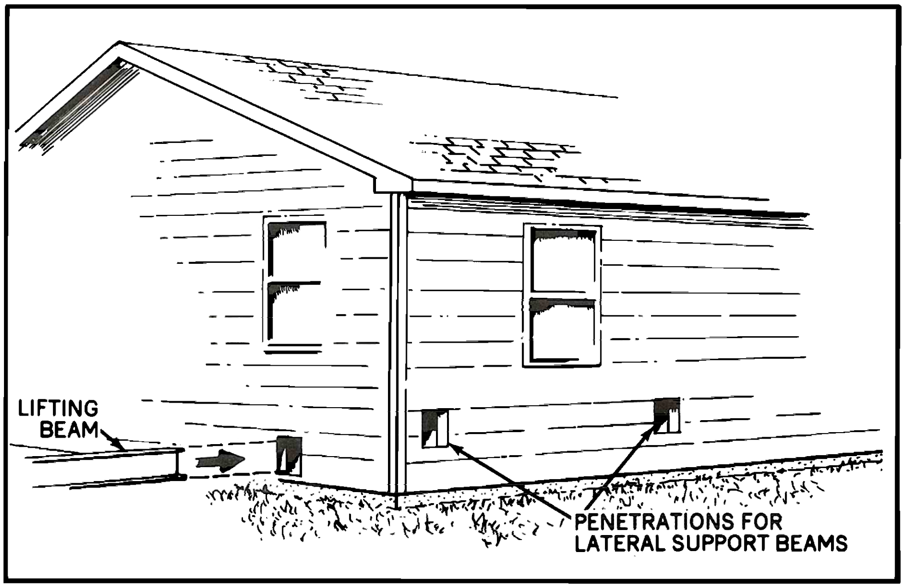


FIGURE 3-14b. *First, holes for I-beam supports are cut in the exterior and interior walls of the house and the main lifting beams are inserted lengthwise through the structure on top of the slab. Similar holes are cut width-wise through the house, and lateral support beams are inserted in these holes and through all of the interior walls of the house to rest directly on top of the main lift beams.*

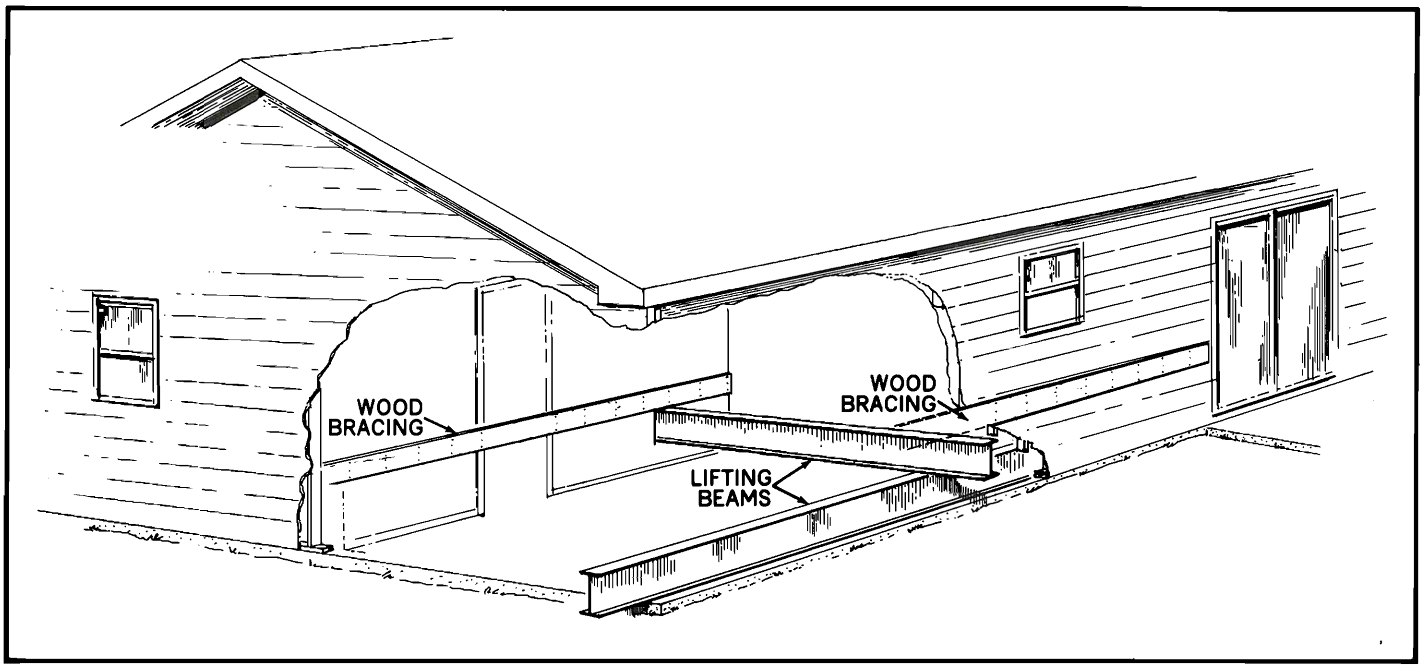
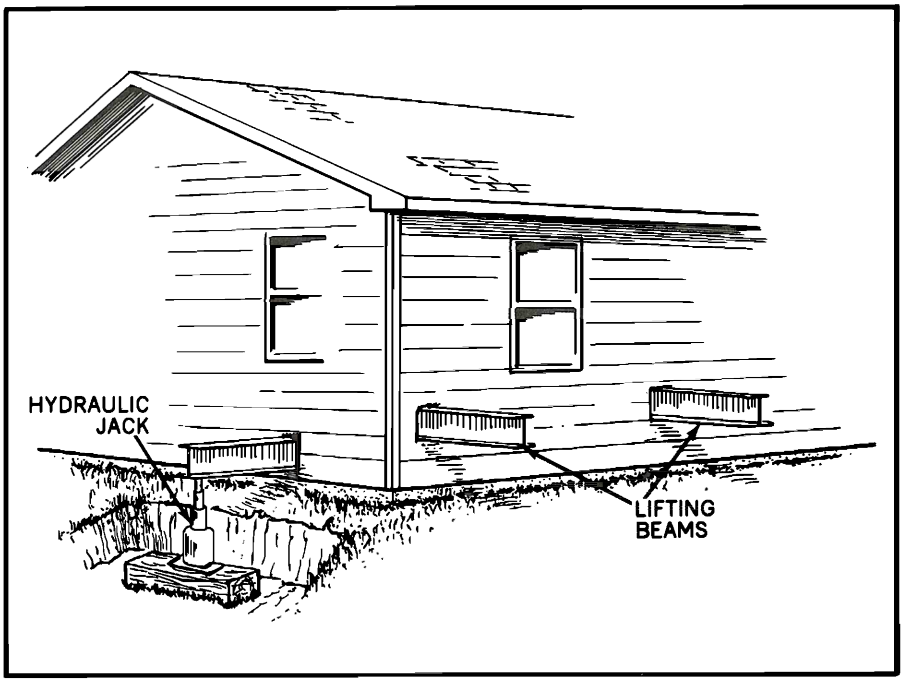


FIGURE 3-14c. *An interior view depicts the need for wood bracing of interior walls atop the I-beam members in order to transfer the lifting force equally across all of the wall of the house. Wood bracing, or headers, usually consists of 2"x12" boards that are set flush on the lateral support beams. Each header should be nailed across at least four studs with heavy nails. The exterior perimeter of the house, depending on its construction, may also require heavy wood framing and cross bracing. Then, temporary supports made of 2"x4" boards are set from the beams to the ceilings and roof to transfer weight across the structure.*

FIGURE 3-14d. *When all interior supporting is complete, jacks are moved into place and the structure is prepared for lifting. All straps or bolts used to secure the house perimeter stud plate to the concrete slab are cut off. The stud plate is generally a 2"x10" board running beneath the exterior walls and fastened to the slab.*



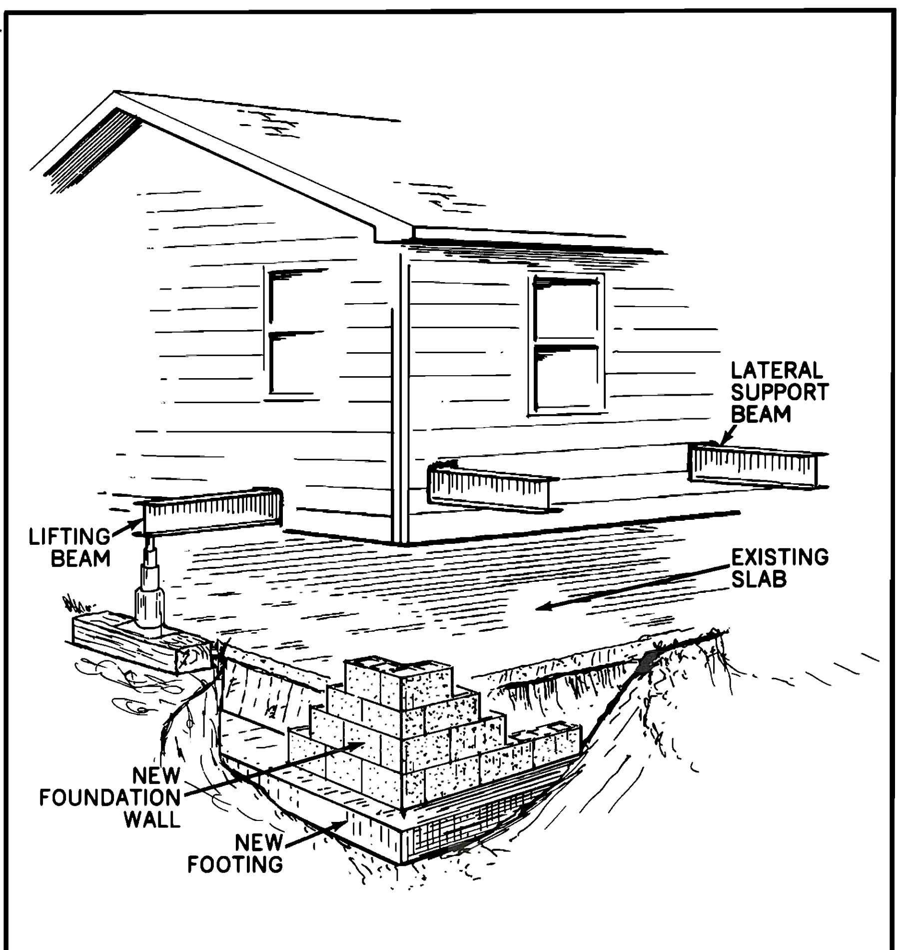


FIGURE 3-14e. *The house is uniformly elevated using jacks. Because most slabs are not designed to carry the weight of the house, the outer edges will usually have to be chopped off to make room for a footing as shown in Figure 3-15. Construction of the new foundation wall is then started on the new footing.*

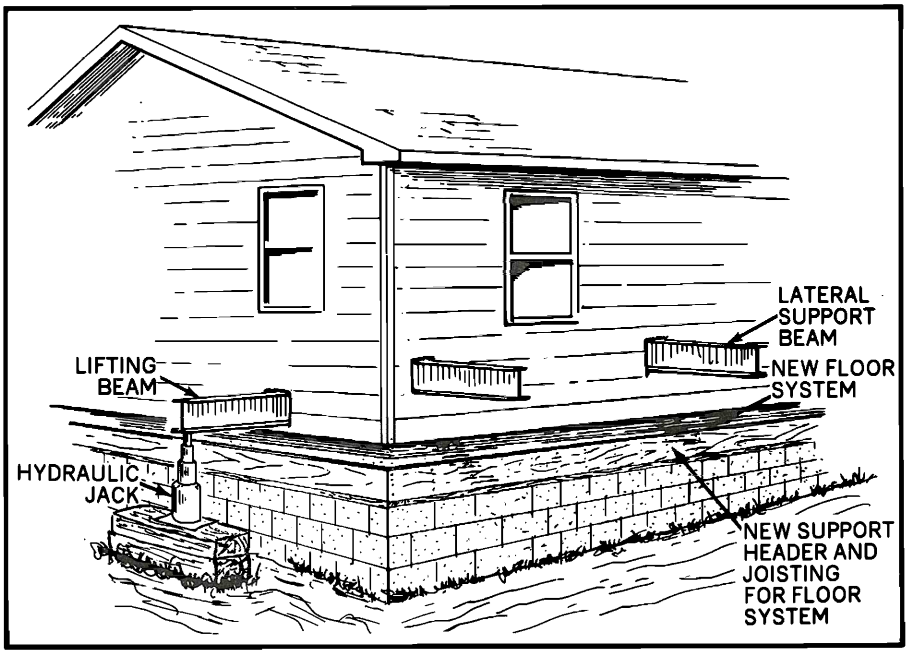


FIGURE 3-14f. *New support headers and floor system are placed on the completed foundation and the house is lowered onto its new support.*

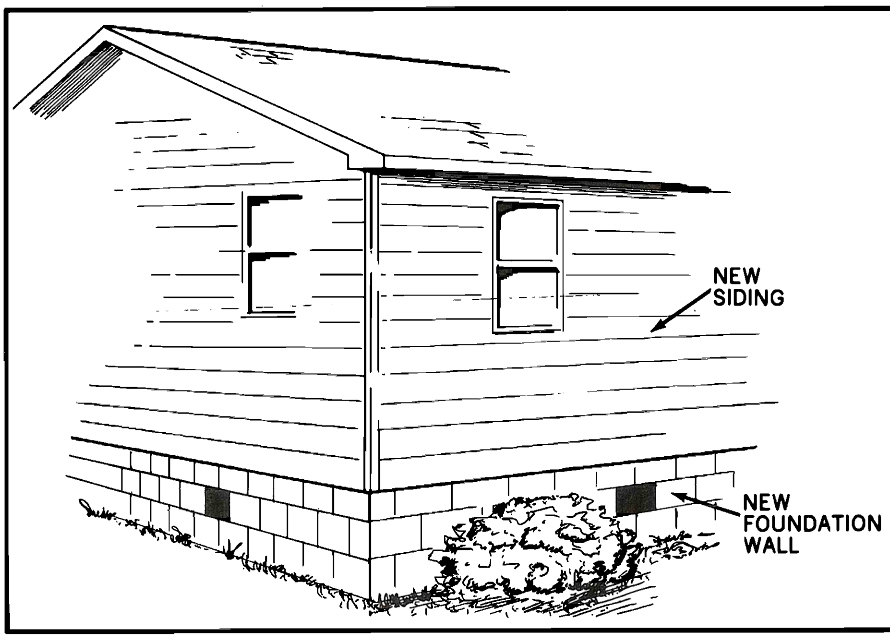


FIGURE 3-14g. *The temporary framing is removed and all holes are patched. New siding is added over the new header and the elevation process is completed. The openings shown in the foundation allow for equal water pressure during flooding.*

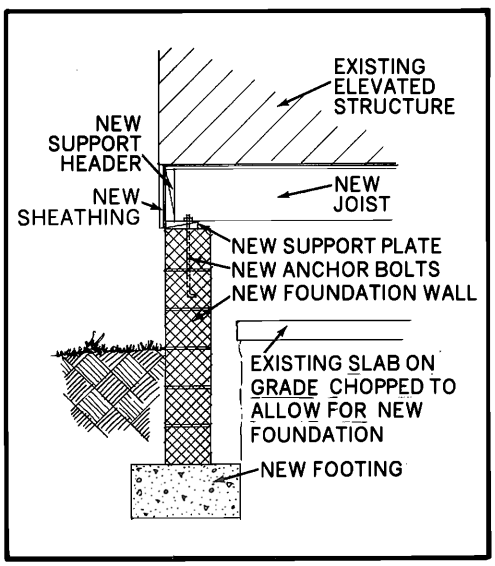


FIGURE 3-15. *When a slab-on-grade house is elevated-detached from its slab, the slab must be chopped off in order for a new foundation to be built.*

Unlike other types of elevations, the elevation of a house detached from its slab involves a great deal of interior patchwork and painting. There may also be a considerable amount of work in reconnecting the utilities.

Other items of concern when considering this retrofitting method include the amount of planning that must be done beforehand and the amount of post construction rehabilitation work that will be needed. However, even with these concerns, elevation of a house detached from its slab is often still one of the most affordable options. Cost data on elevation off the slab is located in Section 3.10.

3.5 ELEVATION ONTO EXTENDED FOUNDATION WALLS

One of the most common foundations used when elevating a structure is the **extended foundation wall**. This foundation can be used for many different types of buildings, such as those with crawl spaces or basements. It is also commonly used along with a new floor system for slab-on-grade structures, as described earlier in this chapter.

This foundation is normally used in areas of low to moderate water depth and velocity. After the house is jacked up, existing foundation walls can be built up using such materials as masonry block or poured concrete. The house is then set down on the extended walls. While elevating on foundation walls is often the easiest solution to the problem of flooding, there are several important considerations.

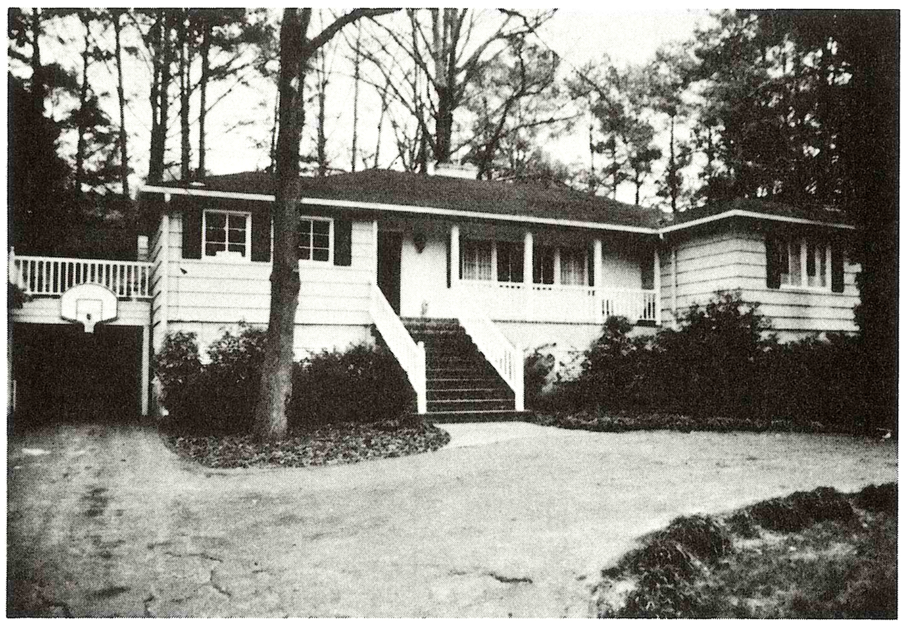


FIGURE 3-16. *This house in Atlanta, Georgia was protected from flooding by elevating it on extended foundation walls.*

Considerations

The most important concern is that the original foundation and **footing** must be able to withstand the extra loading, not only from the additional vertical dead load of the new wall, but also from the additional pressures of flood forces. If the footings are not deep and wide enough, they may not be able to resist the additional loads, which could result in overturning or undermining of the walls and subsequent collapse of the house. In addition, the original foundation walls may not be thick enough to be extended. A structural or foundation engineer should be able to help make these determinations.

Depending on the potential flood loads, if new footings have to be poured, it will usually be necessary to reinforce both the footings and walls using steel reinforcing bar, or rebar. The reinforcing in the foundation and the wall should be tied together to help prevent them from separating under flood loads.

In order to specify the materials and design that should be used for the foundation walls, the exact nature of the expected flood forces must be determined. This is needed in order to calculate the exposure stresses for the walls. If the walls are extended too high with insufficient lateral strength, hydrostatic and hydrodynamic pressures could cause their collapse (see Figure 3-17).

HYDROSTATIC PRESSURES BY WATER DEPTH	
HEIGHT (H)	P_H (LBS/SQ. FT.)
1	62.4
2	124.8
3	187.2
4	249.6
5	312.0
6	374.4
7	436.8
8	499.2
9	561.6
10	624.0

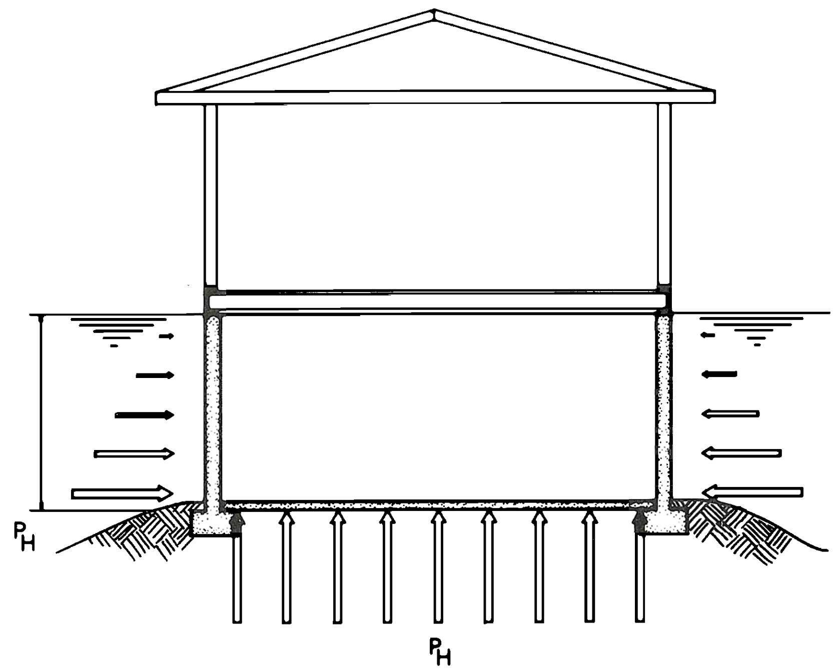


FIGURE 3-17. Hydrostatic Pressure Diagram

In most cases, foundation walls can be constructed using reinforced masonry block. However, when flood forces are too high, stronger walls can be constructed from poured-in-place concrete containing reinforcing steel bars tied into the footings. A structural engineer can help specify the materials and design the wall. Design details are provided in Section 3.12, "Technical Design Criteria—Extended Wall Foundations."

An equally important concern regarding the new foundation wall construction is how it is connected to the existing superstructure of the house. This connection must be sufficiently strong to withstand the wind loads present at the higher elevation. It must also be capable of transferring the loading forces that occur between the foundation and the superstructure without failing. Design details are provided in Section 3.13, "Technical Design Criteria—Anchorage of Superstructure to Foundation."

Regardless of what type of wall construction is used, hydrostatic forces are still a serious problem that can result in collapse of the building. In order to eliminate this danger, foundation walls should be constructed with openings, or **vents**, to allow flood waters to enter the enclosure and equalize the hydrostatic pressure. There are many ways to accomplish this. If the wall is of masonry block construction, blocks can be turned on end at regular intervals. If the wall is constructed of poured concrete, a pipe can be set in the concrete at regular intervals.

National Flood Insurance Program guidelines for venting a foundation call for one square inch of opening for every square foot of floor area of the enclosure, with the bottom of the openings no more than one foot above the interior grade. If flood waters are expected within two feet of the house floor, then venting should also be provided to release trapped air.

All openings should be equipped with a rodent barrier, such as mesh screen. These barriers should be arranged to break off under flood forces to prevent their becoming clogged with debris.

Another possibility, one that often results in what appears to be a house set on a low hill, is to elevate the structure on fully extended foundation walls, then backfill around them as shown on Figure 3-18. Caution should be used in employing this technique, and it is recommended that an engineer be involved in this operation. Not only can careless backfilling and compacting of soil cause the collapse of foundation walls, but soil saturated from flooding can create additional pressure, causing the foundations to collapse. One way to avoid this is to carefully fill and compact material inside as well as outside of the walls to help equalize pressures.

WET FLOODPROOFING

In order for a building elevated on foundation walls to be considered elevated as defined by local floodplain management ordinances, the lower enclosed area must be allowed to fill with water during flooding, and only certain uses of this lower area; primarily parking, limited storage, and access to the elevated section, are permitted.

Taking these ordinances one step further, it is also possible to remodel an existing multi-story structure so that the first floor fits the above criteria and all living area is restricted to the second story and above.

Whichever the case, any of the permitted uses of the lower area must always be arranged so that flood damages are minimized. Measures such as the use of water resistant building materials and contents in an area where floodwaters are intentionally admitted are known as wet floodproofing. Additional details on wet floodproofing can be found in the Federal Emergency Management Agency Technical Standards Bulletin No. 85-1, Wet Floodproofing.

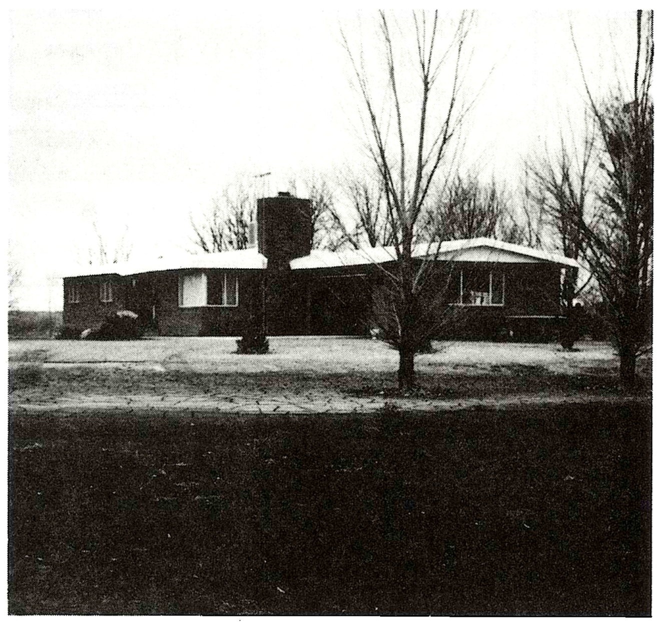


FIGURE 3-18. *Using a backfilling technique, this elevation on foundation walls resulted in the 'look' of an elevation of fill. Close examination also shows success of the technique, since mud from a recent flood appears in the photo.*

If fill is used in an area susceptible to scour or erosion, it may be advisable to cover the slope with vegetation that has extensive root systems. For serious cases, it may be necessary to **armor** the surface by covering it with large rock, known as **riprap**. Either method will help stabilize the slope.

Partial Foundation Walls

A potential solution to the problem of excessive flood forces on foundation walls is to elevate the house on only two walls, spanning the house between them and leaving the two ends open. By orienting the walls parallel to the flow of water, the amount of wall area resisting the forces from velocity flood waters is less and loading is significantly reduced.

For example, consider a house facing a creek that floods periodically with significant velocity flow. With the walls aligned parallel to the creek, the enclosure would appear to be solid from the front of the house. However, both ends would be open to allow the passage of water without exposing the foundation to dangerous flood forces.

In many cases, the ends are not left totally open. For aesthetic or security reasons, it may be desirable to enclose the area, yet allow for the free flow of water during a flood. The solution to this problem is to use walls that are designed to break off under flood forces. These **breakaway walls** are described in detail in the next section.

Although elevation on two foundation walls is a feasible option for many homes, it is usually not done alone, but in combination with other structural supports. The reason for this is that most conventional residential construction is not designed with the heavy floor support beams that would be required to carry a large span completely between the foundation walls.

The exact limit of this maximum allowable span will vary according to the types of materials and construction, such as the dimension of the floor joists, but it generally does not exceed twelve feet.

3.6 USE OF OPEN FOUNDATIONS

In areas where flood forces may include high velocities, significant depths, or the potential for erosion, and in coastal areas where wave action is a threat, elevation of a house on one of several open-type foundations is recommended.

There are a variety of methods to choose from, depending on the exact nature of flooding. The various techniques all allow for an unimpeded flow of water below the building to reduce the potential of damage from these severe flood forces. There is some overlap in what these foundations are called in formal engineering or architectural terms. For purposes in this manual, they are divided into **piers**, **posts**, and **piles**.

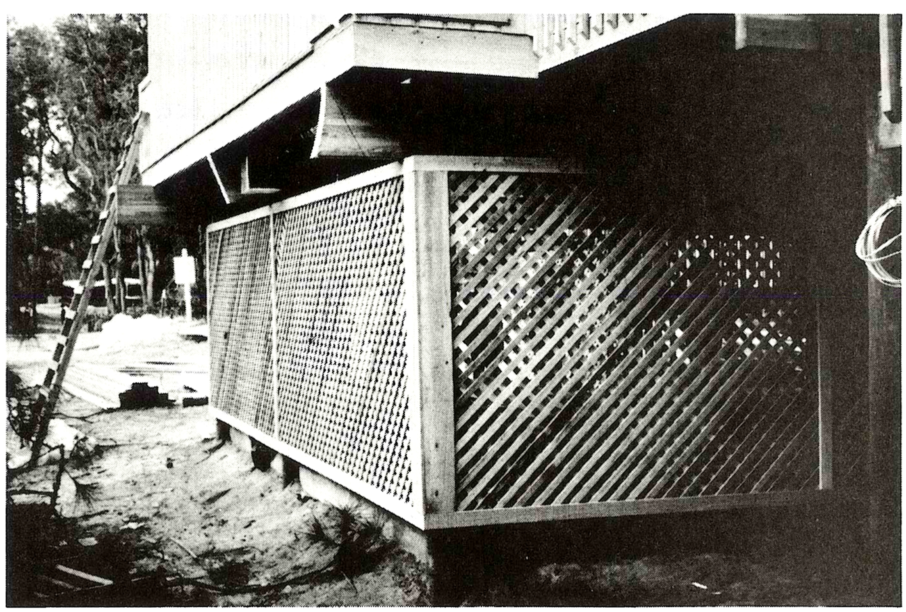


FIGURE 3-19. *Wood latticework makes an attractive breakaway wall on this elevated house.*

The use of these open foundations can result in a large amount of open space under the house which can often be used for limited storage or parking. These lower areas can be enclosed using breakaway walls, which are designed to release under flood conditions and not transmit flood forces to the structure.

There are several ways of constructing breakaway walls, depending on the flood conditions, architectural style of the home, and desired level of security. The main concern, however, is that breakaway walls be designed so that they do not transfer damaging flood forces to the building structure or foundation. Breakaway walls should be capable of withstanding normal loads, such as wind forces, as dictated by local code, but also be designed to release or break away before flood forces can damage the structure. They must also be constructed so that they do not endanger the house as they break away.

Common types of breakaway walls include lightweight, open wood latticework, which goes well with many architectural styles, and aluminum or fiberglass screening. Latticework and screens will both break away long before flood forces can affect the foundation. Another technique of enclosing a lower area is to use freestanding plywood panels that are held in place using a small number of lightweight anchors attached to the structure. Solid breakaway walls require a greater pressure to release, and the danger of damaging the foundation is consequently greater. For this reason, the design should follow FEMA's Coastal Construction Manual as revised in 1986. The breakaway wall specifications outlined in this manual are required in coastal high-hazard areas, but are also useful for designing all breakaway walls.

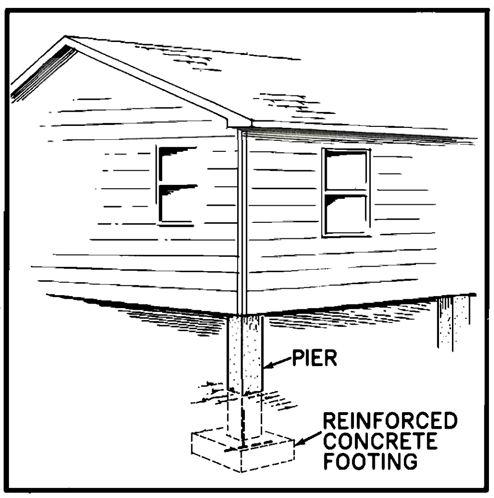


FIGURE 3-20. *The sole method of support for piers is a reinforced concrete footing.*

3.7 ELEVATION ONTO PIERS

The most common example of an open elevation support structure is the pier. Piers are vertical structural members that are supported entirely by reinforced concrete footings. While they may be the most representative type of foundation, they are the least suited for withstanding flood forces.

Considerations

In conventional use, piers are designed primarily for vertical loading. When exposed to flooding however, they will also experience horizontal loads due to hydrodynamic or impact forces. For this reason, piers used in retrofitting to support an elevated residence must not only be substantial enough to support the structure, but must also be sufficiently reinforced to resist a range of flood forces.

Piers are generally used in low depth flooding conditions with little velocity flow, and are normally constructed of either masonry block or poured-in-place concrete. In either case, they should have steel reinforcing both in the pier itself and in the footing on which they sit, and this reinforcing should be tied together to prevent separation.

There are commonly accepted minimum design dimensions for both piers and footings. The minimum standard for masonry block piers is 12″ × 12″, while for their footings, the minimum is 24″ × 24″ square and 8″ deep.

There are also cautions regarding pier footings, including the need to place their bases below the frost line, ensure that they are substantial enough to resist overturning, and situate them deep enough so that they will not be undermined by scour or erosion. Design details are provided in Section 3.14, "Technical Design Criteria—Open Foundations."

3.8 ELEVATION ONTO POSTS OR COLUMNS

For flooding that is characterized by moderate depths and velocities, elevation on posts (also referred to as **columns**) is a frequently used retrofitting method.

Considerations

Posts are generally square, since this shape is easier to attach to the house structure, although round posts are also used. Posts are made of wood, steel, or even precast reinforced concrete. They are set with their ends into predug holes, and material such as earth, gravel or crushed stone is backfilled around them. Since substantial loading is usually expected, posts are normally anchored into a concrete pad at the bottom of the hole.

FIGURE 3-21. *Posts are placed into pre-dug holes and may be anchored into a concrete pad at the bottom of the hole.*

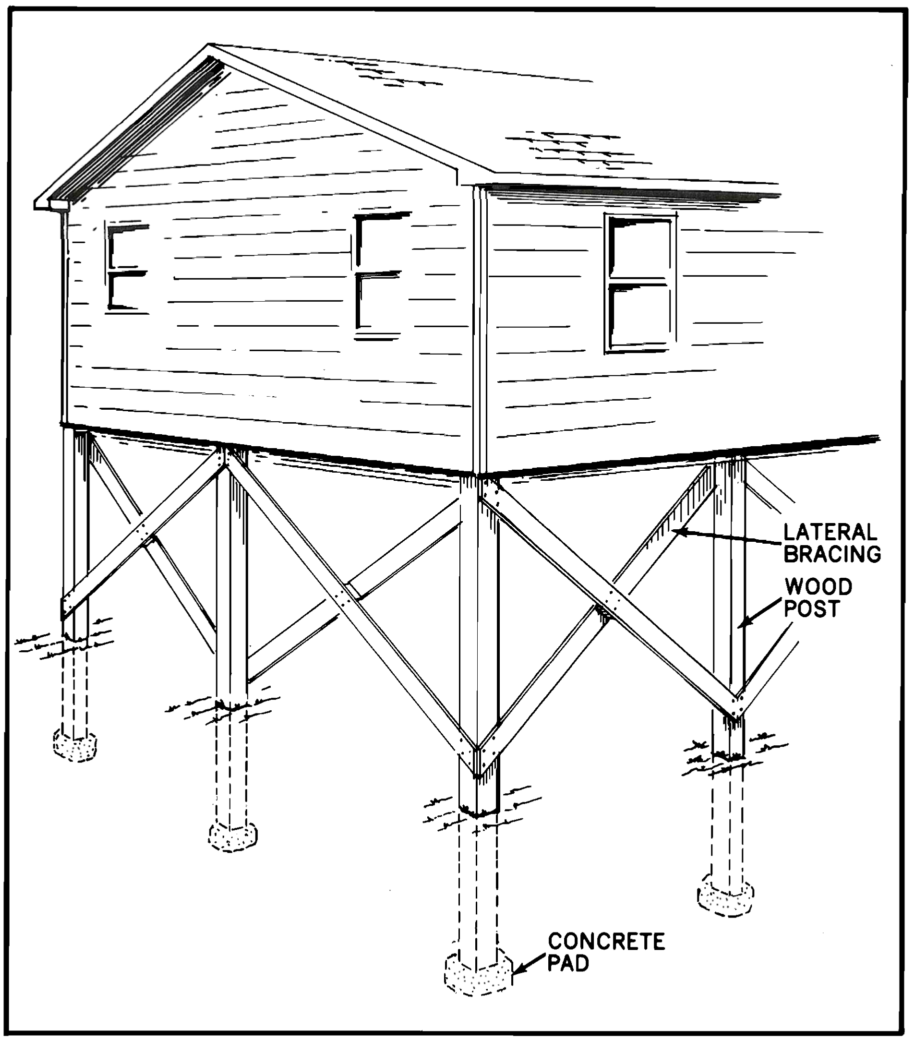
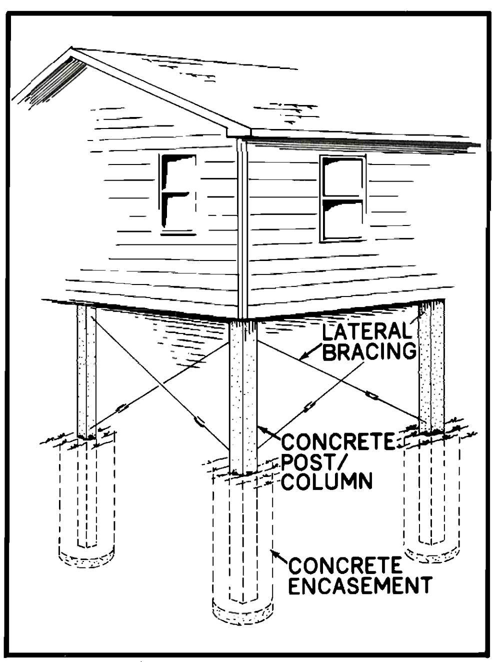


FIGURE 3-21a. *Posts can also be anchored in concrete encasements.*



While piers are designed to act as individual support units, posts normally must be braced. There are a variety of bracing techniques, using several different materials. The type to be specifically employed on an elevated residence in a particular area would depend on local flood conditions and loads. Some of the more commonly used bracing techniques include wood knee and cross bracing, steel rods and guy wires (see Figure 3–21). Additional information on bracing also can be obtained from structural engineers, architects, and such publications as Elevated Residential Structures and the Coastal Construction Manual. Design details are provided in Section 3.14, "Technical Design Criteria—Open Foundations."

3.9 ELEVATION ONTO PILES

For areas where high-velocity flooding can result in scouring, piles are the best type of foundation, although they may have a limited use in retrofitting. Piles differ from posts in that they generally are more slender and are mechanically driven deeper into the ground. Because of this, they are less susceptible to the effects of velocity flood waters and scouring.

Considerations

Piles must either rest on a support layer such as bedrock or be driven deep enough so that there is enough friction between the pile and the surrounding soil to carry the load. Piles are generally made of wood, although steel and

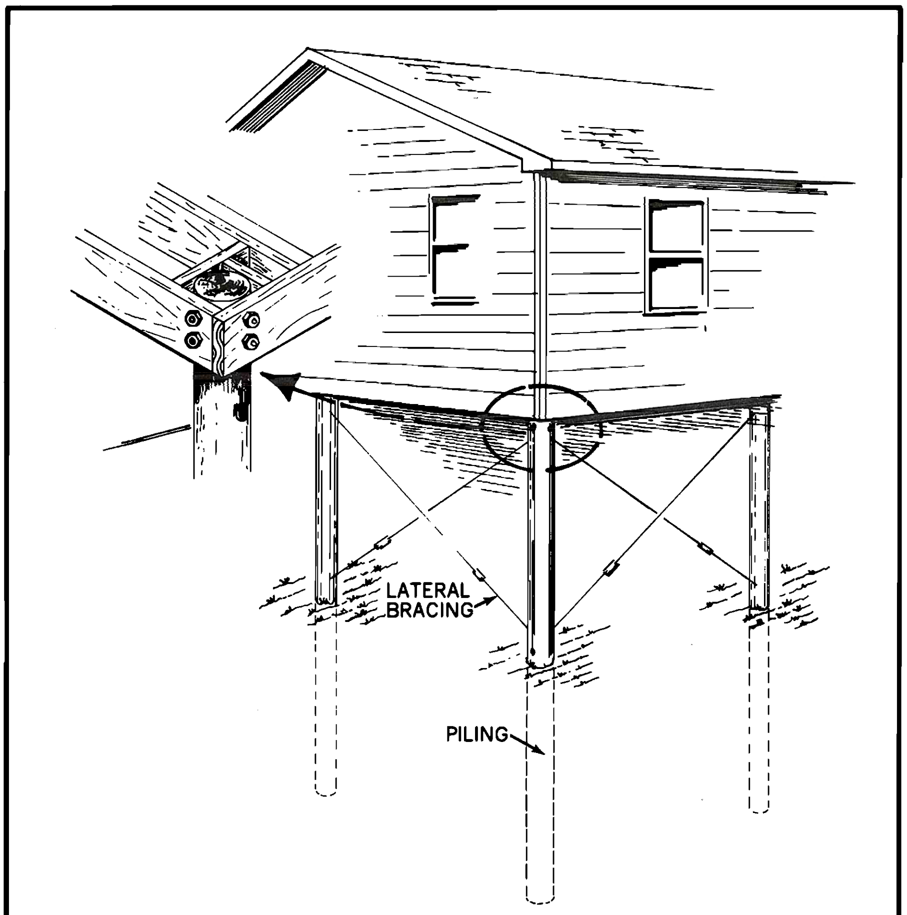


FIGURE 3-22. *Pilings are mechanically driven deeper into the ground, making them less susceptible to velocity flooding and scour.*

reinforced precast concrete are also used. They will often require bracing similar to the methods described for posts. Design details are provided in Section 3.14, "Technical Design Criteria—Open Foundations."

Because driving piles generally requires bulky machinery, an existing house that is being retrofitted would have to be temporarily moved aside and set on cribbing until the driving of piles is complete. This additional cost will need to be considered when choosing the most feasible retrofit method.

There is one situation, however, where retrofitting on a pile foundation is a common practice. This is in coastal areas, including the Great Lakes, where building sites are often subject to erosion. In these cases, the main problem is not the structure's elevation, it is the fact that the beach has eroded to the point that the building is threatened by normal water levels.

FIGURE 3-22a. *This elevated structure was moved from its former piling foundation (on the left) to its present piling foundation because of coastal erosion.*

What is done in these cases is to drive a new pile foundation at a point further inland, either on the same lot or at a new location. The structure is then elevated off the old foundation, which is abandoned, and moved onto the new foundation, where it is better protected against flooding.

3.10 COST GUIDELINES

The costs associated with retrofitting a house using elevated foundations such as foundation walls, piers, posts, or piles can vary widely according to such factors as size, shape, type of construction and condition of the house, choice of elevated foundation, elevation height, and local labor conditions.

Unit Costs

It is possible to estimate the cost of elevation once procedures have been developed and "construction unit quantities" have been defined. The cost of most construction work is calculated on a "unit price" basis. For example, to determine the cost of excavation, the first step is to quantify the amount, which would be the number of cubic yards of material to be removed. Using volume equations, the quantity in cubic yards is determined and a price is applied to each unit to develop a total price. As stated previously, the particular cost of elevation or any other retrofit technique will vary with type of flooding, soil conditions, contractor availability, etc. Unit price ranges for elevation projects are presented in Table 2.

TABLE 2

UNIT COST ESTIMATING FOR ELEVATION PROJECTS

	ITEM	UNIT	UNIT COST 1985 DOLLARS	NO. UNITS NECESSARY	ITEM COST
1.	Excavation	Cubic Yard (Cu. Yd.)	$3.00 - $8.00	________	_____
2.	Boring for Lift Beams (Under Slab)	Linear Foot (Lin. Ft.)	$125 - $175	________	_____
3.	Jacking - Hydraulic	Ft.	$300 - $500	________	_____
4.	Cribbing Timber	Thousand Board - Ft.	$800 - $1,000	________	_____
5.	Concrete (Reinforced, in place)	Cu. Yd.	$225 - $300	________	_____
6.	8" Concrete Masonry Units (CMU) reinforced, in place	Thousand (880 sq. ft.)	$2,000 - $2,500	________	_____
7.	8" CMU - Unreinforced, in place	Thousand (880 sq. ft.)	$1,800 - $2,200	________	_____
8.	Driving Pile (Timber)	Ft.	$15 - $20	________	_____
9.	Driving Pile (Concrete)	Ft.	$20 - $30	________	_____
10.	Steel Beams - Material Only	lb.	$.50 - $1.00	________	_____
11.	Sanitary Sewer Line 4"-6" in place, buried or strapped to foundation	Lin. Ft.	$4.00 - $8.00	________	_____
12.	Service Water Line 3/4" - 1", Copper or PVC, in place, buried or strapped	Lin. Ft.	$3.00 - $6.00	________	_____
13.	Backfill	Cu. Yd.	$3.00 - $8.00	________	_____
14.	Seeding	Square Yard	$1.25 - $1.50	________	_____

Typical Examples

The following are some representative cases:

- Midwestern State, low level flooding with little velocity:

  This house is a 1,600-square-foot structure with a garage. The main living space is constructed of wood joist design and the garage was added later as a slab-on-grade. The floor supports, walls, and framing of the main living space were raised three block courses, elevating the residence out of the 100-year floodplain. The garage was raised separately by filling with compacted earth and pouring a new, supported and reinforced concrete slab. The earth fill was graded around the house and landscaping was completed.

  Total costs (approx) $35,000.00

- Midwestern State, deep flooding:

  The owner in this case filled in his basement, poured a new basement slab and had the house raised ten block courses, or over six feet. Simple joist flooring construction and no adjoining garage resulted in elevation costs of only $5,000, even though the house was raised higher than in the previous example. However, costs for trucking in fill, window openings on the new floor level, and elevation of outdoor heat pump and wiring were necessary in this case.

  Total costs $16,000.00

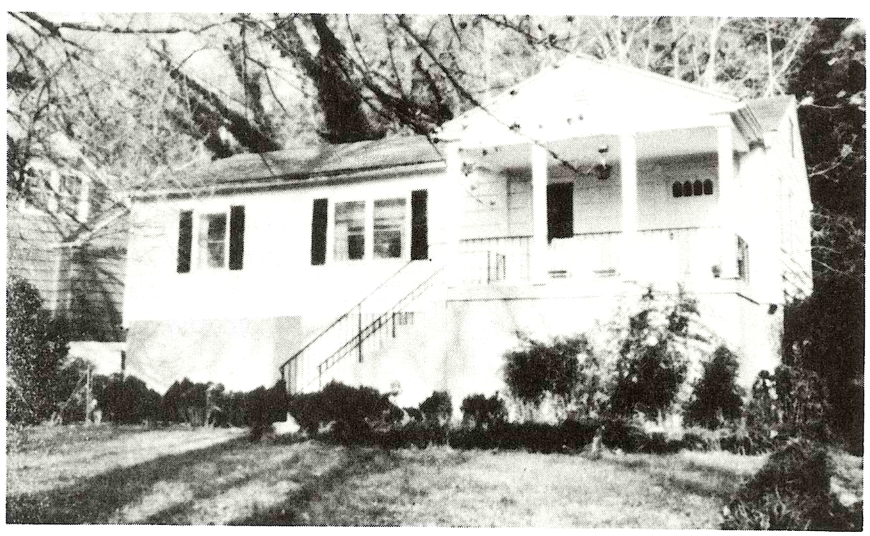


FIGURE 3-23. *The owner of this house in Illinois elevated the structure ten block courses.*

- Gulf Coast City, low level flooding:

  In a city-sponsored program supported by local and federal funding, sixteen houses were elevated from slab-on-grade to heights of up to 40 inches above grade and set on masonry block walls. The costs varied according to size and other factors.

One house involved in this project was a 1,585-square-foot frame house which required no special changes or preparations to the exterior beside the normal tasks involved in accomplishing the elevation. It was raised approximately 36 inches above grade and supported on masonry block extended foundation walls. Costs for the project totaled $22,800.00.

A second house in this area, somewhat larger than the previous example (1,711 square feet), was also more complex in that it was constructed with a brick veneer exterior which had to be removed for the elevation. The house was elevated 38 inches above grade using extended block foundation walls, which later were covered with brick facing veneer. Because of these extra steps, costs for this elevation were $41,750. The average cost for all of the projects in this city's program was $18.73 per square foot or $25,000 per household.

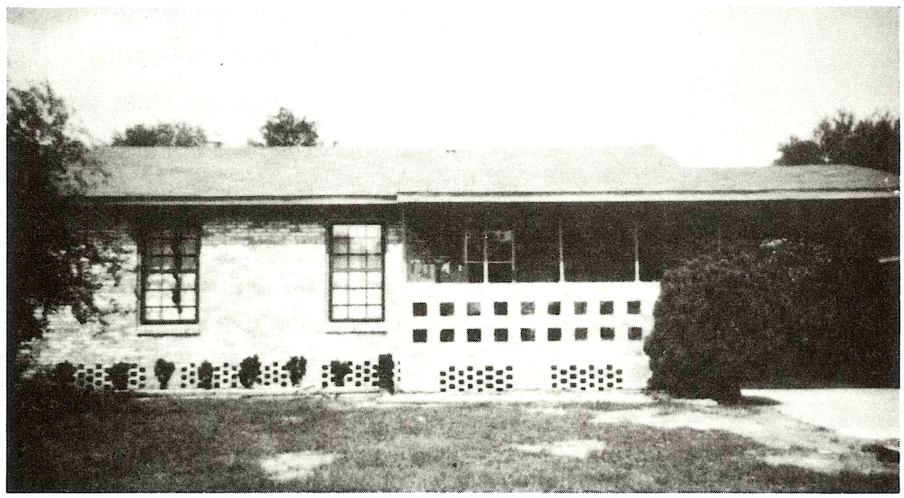


FIGURE 3-24. *One of sixteen houses elevated in a joint state-federal project on the Gulf Coast.*

- **Southeastern City, deep flooding:**
  In this case, a 1,800-square-foot house was elevated above deep flooding levels. New footings were poured; the house was elevated on two extended foundation walls and masonry block piers to support the center of the span; the chimney and fireplace were elevated on the new structure; furnace and utilities were elevated; and a new front porch was constructed of masonry block and a poured concrete slab. The costs were as follows:

EXPRESSED AS 1985 COSTS[1]

Raising House	
Including removal of old plumbing, furnace duct work and gas line, etc.	$ 5,312.00
Foundation and front porch	$22,642.00
Consulting Engineer	400.00
	23,042.00
Removing rubble, new surface under house and floor insulation	2,500.00
Yard fill and rough landscape	1,260.00
Seed, etc..	188.00
Permits, etc.	160.00
TOTAL	$32,462.00

[1]R.S. Means, 1981–1985.

3.11 TECHNICAL DESIGN CRITERIA—LIFTING BEAMS FOR RAISING STRUCTURES

The elevation of a building, whether it encompasses placing the house on extended foundation walls, piers, posts, or piles, or for relocation, requires careful planning to assure proper and safe execution. Factors affecting the placement of lifting beams include the size and shape of the house, existing framing and structural parameters, deflection limitations, and distribution of the structure's weight. Each of these factors must be taken into account to ensure the integrity of the structure during the elevation process.

The major consideration for the location of lifting beams is to limit cracking due to excessive deflection during elevation. The lifting beams, in tandem with cross beams, must provide sufficient support for the structure so that when the house is elevated, the lifting beams and cross beams provide as stable a support as the original foundation. Deflection of any portion of the structure is normally a result of the manner in which the weight of the house is distributed, the location of the jacks under the lifting beams, and the rigidity of the lifting beam. Proper placement of lifting beams, jacks, and cross beams will assure the protection from cracking of the interior and exterior finishes as well as the integrity of the entire house. In slab-on-grade elevation, wood members, called headers, (generally 2 × 12s) are fastened flush to the interior and exterior walls to provide a temporary means of transferring the dead loads of the structure to the lifting beams.

A second consideration concerning the installation of lifting beams is whether the house will be relocated or whether it will be elevated and a new or extended foundation system constructed to support the structure. Relocation of the structure entails elevating the house off its foundation, then actually moving the house. In this situation, the location of the lifting beams must be such that the house can be lowered onto a trailer. The specific route to be taken during the relocation of the house dictates the physical size and weight limitations of the structure due to the horizontal and vertical clearances from obstructions. The house might have to be cut into sections and moved separately to negotiate the available route. Lifting beams, therefore, would have to be located for each section to be moved. The entire elevation framing must also be rigid enough to take the forces associated with movement. For elevation without relocation, the lifting beams can be located as required to handle the dead load of the structure.

Since it would cause additional deflection, the weight of heavier construction materials on portions of the structure such as brick veneer, chimneys, and fireplaces warrants special attention when determining the location of the lifting beam system. Even with minimal deflection, brick construction is subject to cracking. Therefore, extra precautions will be needed in the form of additional beam support, or removal of the brick and later replacement. The physical size and shape of the house also affects the placement and number of lifting beams. A simple rectangular floor plan allows for the easiest and most straightforward type of elevation. Generally placement of the longitudinal beams, with cross beams located as required, is the system utilized for the elevation process. Larger or more complex shapes, such as L-shaped homes or multi-level homes, necessitate additional lifting beams and jacks to provide a stable lifting support system. Every consideration of the load based upon the size and shape of the structure should be incorporated into the design and layout of the lifting beam system.

Tables 3 and 4 present a partial listing of building material weights for use in determining the dead load of the residential structure. For each home, the materials used in the construction of the roof, wall, and floor sections must be determined before the actual weight can be calculated. Generally the weights for building materials are given in terms of pounds per square foot or pounds per linear foot. The weight of each building system, such as the roof, wall, and floor, can then be determined by adding the weights of the system components to yield a square foot dead load.

TABLE 3

WEIGHTS OF BUILDING MATERIALS

Materials	Weight Lb. per Sq. Ft.	Materials	Weight Lb. per Sq. Ft.
CEILINGS		**PARTITIONS**	
Channel suspended system	1	Clay Tile	
Lathing and plastering	See Partitions	3 in.	17
Acoustical fiber tile	1	4 in.	18
		6 in.	28
		8 in.	34
FLOORS		10 in.	40
Concrete-Reinforced (1 inch)			
Stone	12-1/2	Gypsum Block	
Slag	11-1/2	2 in.	9-1/2
Lightweight	6 to 10	3 in.	10-1/2
		4 in.	12-1/2
Concrete-Plain (1 inch)		5 in.	14
Stone	12	6 in.	18-1/2
Slag	11		
Lightweight	3 to 9	Wood Studs 2 X 4	
		12-16 in. o.c.	2
Fills (1 inch)			
Gypsum	6	Steel partitions	4
Sand	8		
Cinders	4	Lathing	
		Metal	1/2
Finishes		Gypsum Board 1/2 in.	2
Terrazzo 1 in.	13		
Ceramic Tile 3/4 in.	10	Plaster 1 in.	
Linoleum 1/4 in.	1	Cement	10
Mastic 3/4 in.	9	Gypsum	5
Hardwood 7/8 in.	4		
Softwood 3/4 in.	2-1/2		
ROOFS		**WALLS**	
Copper or tin	1	Brick	
		4 in.	40
Corrugated steel		8 in.	80
3-ply ready roofing	1	12 in.	120
3-ply felt and gravel	5-1/2		
5-ply felt and gravel	6	Hollow Concrete Block	
		(Heavy Aggregate)	
Shingles		4 in.	30
Wood	2	6 in.	43
Asphalt	3	8 in.	55
Clay tile	9 to 14	12-1/2 in.	80
Slate 1/4	10		

TABLE 3
(CONT.)

WEIGHTS OF BUILDING MATERIALS

Materials	Weight Lb. per Sq. Ft.	Materials	Weight Lb. per Sq. Ft.
		Hollow Concrete Block (Light Aggregate)	
Sheathing		4 in.	21
Wood 3/4 in.	3	6 in.	30
Gypsum 1 in.	4	8 in.	38
Insulation (1 in.)		12 in.	55
Loose	1/2		
Poured in place	2	Clay tile (Load Bearing)	
Rigid	1-1/2	4 in.	25
		6 in.	30
		8 in.	33
		12 in.	45
		Stone 4 in.	55
		Glass Block 4 in.	18
		Windows, Glass, Frame & Sash	8
		Structural Glass 1 in.	15
		Corrugated Cement Asbestos 1/4 in.	3

TABLE 4A

WEIGHT OF STRUCTURAL LUMBER

TIMBER, U.S. SEASONED	WEIGHT LB. PER CU. FT.
Ash, white, red	40
Cedar, white, red	22
Chestnut	41
Cypress	30
Fir, Douglas spruce	32
Fir, eastern	25
Elm, white	45
Hemlock	29
Hickory	49
Locust	46
Maple, hard	43
Maple, white	33
Oak, chestnut	54
Oak, live	59
Oak, red, black	41
Oak, white	46
Pine, Oregon	32
Pine, red	30
Pine, white	26
Pine, yellow, long-leaf	44
Pine, yellow, short-leaf	38
Poplar	30
Redwood, California	26
Spruce, white, black	27
Walnut, black	38
Walnut, white	26

Moisture Content by Weight: Seasoned timber 15 to 20%
Green timber up to 50%

TABLE 4B

CONVERSION TABLE FOR 4A

Nominal size b(inches)d	Standard dressed size b(inches)d	Weight in pounds per linear foot of piece when weight of wood per cubic foot equals:					
		25 lb.	30 lb.	35 lb.	40 lb.	45 lb.	50 lb.
1 x 3	3/4 x 2-1/2	0.326	0.391	0.456	0.521	0.586	0.651
1 x 4	3/4 x 3-1/2	0.456	0.547	0.638	0.729	0.820	0.911
1 x 6	3/4 x 5-1/2	0.716	0.859	1.003	1.146	1.289	1.432
1 x 8	3/4 x 7-1/4	0.944	1.133	1.322	1.510	1.699	1.888
1 x 10	3/4 x 9-1/4	1.204	1.445	1.686	1.927	2.168	2.409
1 x 12	3/4 x 11-1/4	1.465	1.758	2.051	2.344	2.637	2.930
2 x 3	1-1/2 x 2-1/2	0.651	0.781	0.911	1.042	1.172	1.302
2 x 4	1-1/2 x 3-1/2	0.911	1.094	1.276	1.458	1.641	1.823
2 x 5	1-1/2 x 4-1/2	1.172	1.406	1.641	1.875	2.109	2.344
2 x 6	1-1/2 x 5-1/2	1.432	1.719	2.005	2.292	2.578	2.865
2 x 8	1-1/2 x 7-1/4	1.888	2.266	2.643	3.021	3.398	3.776
2 x 10	1-1/2 x 9-1/4	2.409	2.891	3.372	3.854	4.336	4.818
2 x 12	1-1/2 x 11-1/4	2.930	3.516	4.102	4.688	5.273	5.859
2 x 14	1-1/2 x 13-1/4	3.451	4.141	4.831	5.521	6.211	6.901

The total dead load acting along a foundation wall is determined by taking the tributary length for both the floor and roof systems and multiplying these by the calculated system weight. This figure should then be added to the product of the wall system weight and the wall height. This yields a dead load in pounds per linear foot for the foundation. To find the dead load on a pier following the same procedure, one could take the dead load acting on the wall from all the framing systems and multiply by the tributary length.

Once the load per linear foot on the foundation is established, specific I-beams can be sized and selected. While manufacturers publish load tables for various I-beam sizes, the consumer should be aware that the load capacities cited are developed for specific building framing applications where the spans are simple spans and rotational restraint is provided by standard connections. *This is not the case when the I-beams are used for lifting purposes.*

Beams used to lift a structure are subject to a greater variety of forces which can reduce the manufacturer's cited capacity. In addition to load calculations, very careful attention must be paid to connections, deflections, unbraced beam lengths, rotational restraint, shear and bearing stresses, torsional effects, lateral torsional buckling, wind loads, and jacking forces. Selection of appropriate sizes of steel beams and development of details of the lifting system are therefore best referred to a qualified structural engineer.

Due to the varying nature of framing for each residence, the location of the lifting beams and jacking points must be determined on a case-by-case basis. After the load determination for each lifting beam location has been calculated, the location of jacking points in relation to the loading must be carefully determined, based on the deflection criteria for the particular steel beam used. This process is complex and usually requires the services of a structural engineer.

3.12 TECHNICAL DESIGN CRITERIA—EXTENDED WALL FOUNDATIONS

Several factors must be taken into account when the technique of extended wall foundation support for an elevated house is used. Primarily, the foundation system must be adequate, both in strength and the underlying soil bearing capacity, to take the additional loads imposed by the extended foundation walls. Factors affecting the overall wall capacities include: existing foundation wall construction materials and method of construction; extended wall portion strength and materials; proper strength at the interface of the existing and extended portions of the foundation walls; and the height of the wall extension as it relates to the structural stability of the total wall design.

Construction Materials

The integration of the extended walls of the elevated foundation system to the existing foundation walls is a major factor in the selection of materials for the new construction. The existing wall and the new wall materials must be compatible and offer a continuity in the structural integrity of the entire wall. Concrete masonry construction includes both unreinforced and reinforced construction for foundation walls. Unreinforced concrete block is generally limited to use in constructing crawl space walls. Where basement construction exists, with its significant lateral loads, either thicker unreinforced masonry or reinforced masonry construction is warranted. Reinforced concrete masonry offers greater flexibility due to the increased strength in flexure and in shear, resulting from the use of reinforcing to take the tensile forces acting on the structure.

For concrete masonry construction, either reinforced or unreinforced, it is imperative to provide an adequate structural continuity to the entire foundation wall system. For unreinforced concrete masonry, this continuity is primarily influenced by the proper bonding of the newly laid mortar onto the top of the existing wall. In reinforced concrete masonry, the structural integrity of the interface between existing and new construction into the existing wall is provided by doweling into both walls. The depth of the doweling into the old and new wall sections will be determined by the potential forces involved. To ensure proper bonding, the existing wall surface must be clean and free from all dirt, debris, and loose particles. The existing wall should be wetted to prevent the absorption of too much water from the mortar. Bonding agents applied to the existing wall before new construction can also help bonding at the interface. The grout core in the existing wall is drilled and cleaned, then the reinforcing bar is placed using grout or epoxy. The reinforcing bar extends into the core of the new construction and is grouted in place after the courses of block are laid.

Other factors affecting the integrity of the extended wall are proper placement and construction of control and expansion joints. Details concerning these items are presented in the Concrete Masonry Structures Commentary, ACI-531R-79, SECTION 6.7.

Concrete masonry construction is subject to the allowable stresses outlined in Building Code Requirements for Concrete Masonry Structures, American Concrete Institute Standard 531-79. For technical notes outlining design procedures, refer also to the NCMA-TEK series by the National Concrete Masonry Association. Both of these publications outline the allowable design stresses, the accepted engineering practices, and the materials and construction specifications for concrete masonry structures.

Concrete construction, even more than masonry, requires proper bonding and load transfer at the interface of the existing wall and the extended portion. The transfer of loads, both shear and moment, should be made by doweling into the existing portion of the wall. The depth of the doweling will be determined by the potential forces involved. Shear can be transferred by shear friction across the construction interface, while the moment is transferred by the tensile capacity of the reinforcing. Doweling should be utilized in both unreinforced and reinforced concrete wall extensions. Surface bonding between the old concrete and the new concrete is not reliable enough for proper transfer of forces across the construction interface, even with the use of bonding agents.

All concrete construction must conform to the Building Code Requirements for Reinforced Concrete, American Concrete Institute Standard 318-83. The allowable design criteria for concrete construction, including all aspects of design stresses, reinforcing standards, and construction requirements, are presented in this publication.

Existing Foundations and Walls

In considering whether extension of a foundation wall can be undertaken, the overall capacity of the existing foundations must be determined. The additional weight added to the foundation will vary according to the planned height of the extended portion of the wall. Determination of an allowable soil bearing capacity for the foundation and the structural integrity of the foundation are the overriding guidelines for calculating the allowable amount of height extension. The allowable bearing capacity should be determined by a soils engineer or from information used in the original design.

The existing construction of the foundation walls is the second factor for determining the feasibility of extending these walls. The stresses on the existing portion of the wall due to the height extension of the walls must still fall within the allowable limits for the type of wall construction. It is possible that the wall extension could create overstresses in the existing portion of the foundation walls such that it would structurally overload the existing wall system. Factors affecting the existing walls are construction materials, loadings, and total height of the wall. Special care must be focused on the extension of foundation walls when dealing with basement walls. The increased height of the wall and the possible presence of significant lateral loads increase the chances of overloading the existing walls. When this situation occurs, the overstresses can be negated with methods such as filling the basement with compacted soil and pouring a new slab which effectively reduces the overall height of the foundation wall.

Loads

Appendix C describes the types of possible loading forces which can affect the stability of extended walls. These loads can be a combination of **hydrostatic**, equivalent fluid pressure, **hydrodynamic**, and impact loadings as well as the dead loads from the superstructure and the wall itself. The majority of flood forces involve a buildup of hydrostatic pressures that can quickly cause collapse. For this reason, the interior of the wall foundation should be allowed to fill with water. This allows the pressure on the foundation wall system to equalize, which will effectively eliminate hydrostatic pressures on the wall system. In the case of lower walls, a suitable alternative would be to backfill the interior to offset hydrostatic forces. This may be preferable depending on the type of soil present and the configuration of the foundation. In any event, the remainder of the above mentioned loads must also be incorporated into the overall design of the total wall system.

Construction Guidelines

The discussion of construction materials focuses on the proper application of materials in order to extend the foundation walls. As noted earlier, the most important aspect for the extension is that the structural integrity of the wall must be maintained in the existing section, the interface between the old and new portions, and the new wall section. The completed wall must also be properly attached to the structure to allow the proper transfer of loads through the wall to the supports at the top and bottom. Details such as the design of the reinforcement, the location and construction of control and expansion joints, and the connection of the existing and new construction must all be adequate to ensure the total integrity of the constructed foundation wall.

3.13 TECHNICAL DESIGN CRITERIA— ANCHORAGE OF SUPERSTRUCTURE TO FOUNDATION

General Criteria

The **anchorage** of the superstructure of a house to the foundation system serves a dual purpose in the structural integrity of the entire building. First, it provides a means to anchor the superstructure so that it will not separate from the foundation when uplift forces due to wind loads occur. Secondly, the superstructure, especially the floor framing system, provides structural support by resisting any lateral loads that might occur against the foundation wall. This anchorage provides the means for the transfer of the wall reaction force throughout the entire structure.

The typical sill assembly used in frame construction will not survive significant uplift forces or lateral forces. Often in this type of construction, there is inadequate anchorage between the sill plate and the foundation wall.

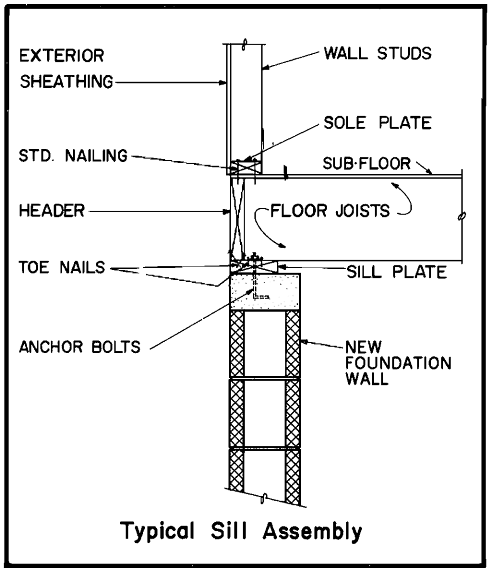


FIGURE 3-25. *This typical sill assembly affords little support against flood forces.*

When uplift forces occur, the entire floor assembly can simply separate from the foundation. When lateral loads occur on the foundation wall, the superstructure offers little lateral resistance, resulting in movement of the foundation wall. Even if the sill is anchored to the foundation wall, separation or movement can occur between the sill plate and the floor joists.

As a result of uplift forces, failure is also possible between the sole plate and the wall stud. A discussion of the lateral forces that can act against a structure can be found in Appendix C.

The details discussed below are most easily implemented for retrofitting situations that involve some new construction, such as the building of extended foundation walls for elevation. When the elevated house is placed on the newly extended foundations, final attachments can be made that ensure proper and adequate anchorage. Proper connections to the elevated wall provide the structural integrity necessary to resist the lateral loads against the house.

The anchoring details discussed below could be useful in the sealing of foundations, although implementing this measure could be difficult due to lack of working room or access to the area where the connection is to be made. As in retrofitting cases involving wall construction, the additional lateral forces acting on sealed foundation walls due to water-related loads need to be properly transferred into the floor framing system.

Design Details

Connection details covered in this section offer several examples of proper construction practice, but this by no means excludes the use of other types of fastening techniques that provide strength capacities.

ANCHOR BOLTS

Anchor bolts should be a minimum of one half inch in diameter and placed in the foundation wall at a maximum interval of four feet. The anchor bolts should extend into the foundation wall a minimum of 18 inches, terminating in the wall with a standard hook, as specified by American Concrete Institute Standard 318-83, or with a washer and nut tack welded to the anchor bolt, forming an embedded head. The anchor bolts should project above the top of the foundation wall to permit attachment of the sill plate to the foundation wall using a minimum of ½″ diameter anchor bolts. While it is impractical to retrofit anchor bolts to an existing structure, it is possible for expansion anchors to be drilled into the top of the wall through the sill plate to provide some anchorage between the wall and sill plate. After the actual load and the wall reaction have been determined, the spacing of the anchor bolt or expansion anchors to provide adequate resisting capability can be calculated based on the allowable capacity of the anchor.

Where lateral forces due to hydrostatic, hydrodynamic, and/or impact loads are of a significant magnitude, closer spacing for the anchor bolts for the wall system is warranted. The total reaction force from lateral reaction must be transferred through the anchor bolt into the anchorage system.

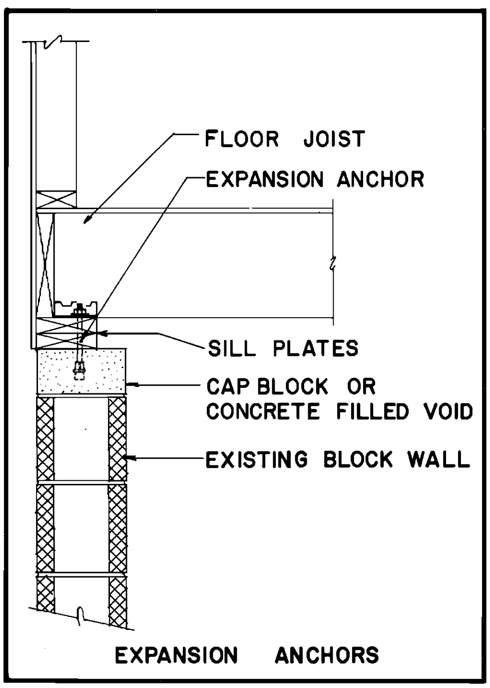


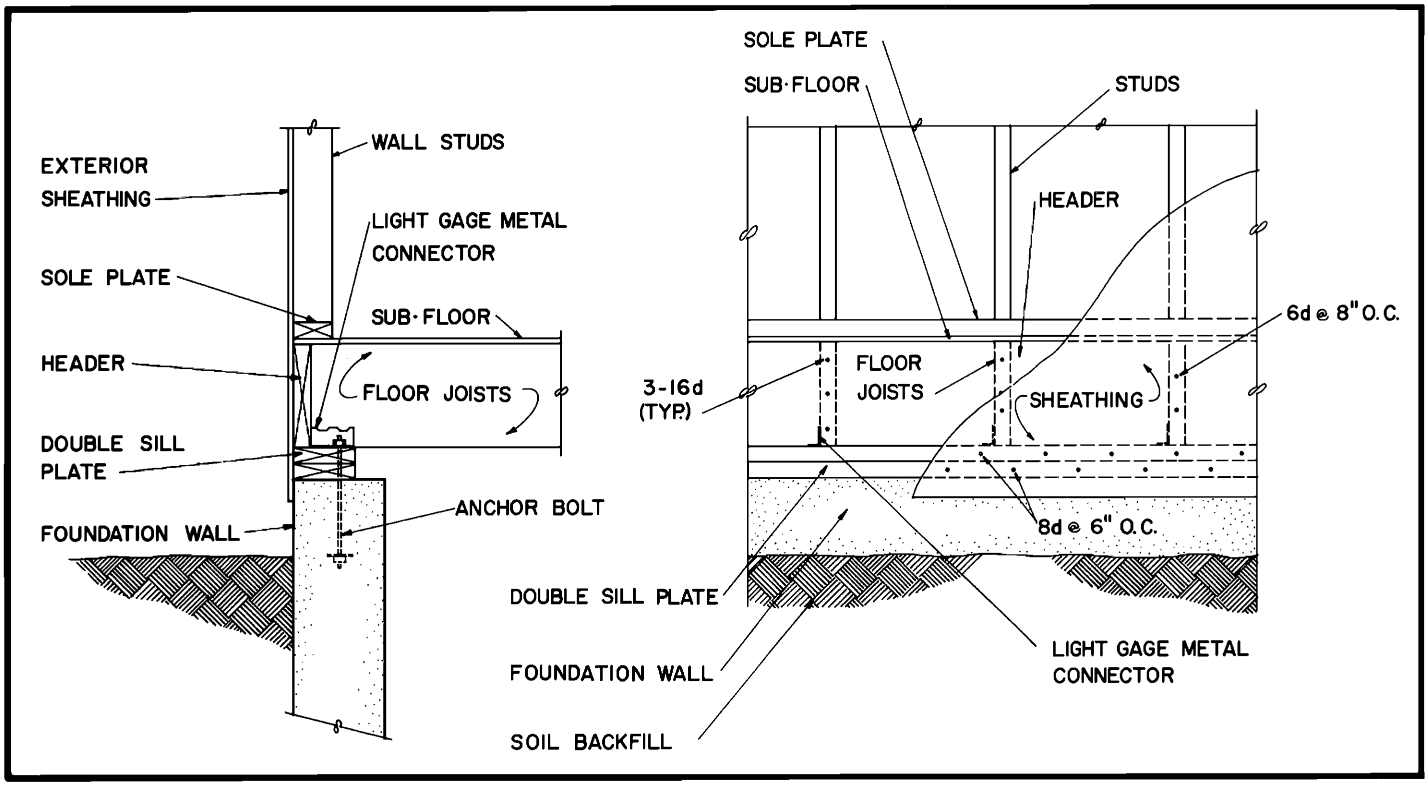
FIGURE 3-26. Drawing of Expansion Anchor

Expansion anchors provide an excellent means for transfer of lateral forces to the framing system, but are not as effective as anchor bolts in resisting uplift forces. Expansion anchors can therefore be substituted for anchor bolts on the doubled sill system, the angle connector system, and the end wall system. It is recommended, however, that expansion anchors be used only in retrofitting existing structures and not for techniques involving new construction such as extension of foundation walls.

DOUBLE SILL SYSTEM

The wall sill plate consists of two 2 × 6 wood members, bolted to the foundation wall by anchor bolts with 2-inch diameter washers, as shown in Figure 3-26. Floor joists and headers rest on top of sill plate with the subfloor attached atop this assembly. The sole plate bears on the subfloor with the wall studs attached to the sole plate. One half inch exterior plywood sheathing is then installed overlapping the header and the double sills. The uplift forces are transferred from the anchor bolt to the sole plate into the sheathing. Where moderate to high lateral loads are possible, a light gauge metal connector between the joist and the sill is recommended to transfer lateral reaction force determined by load analysis of the foundation wall.

FIGURE 3-26a. Double Sill System



ANGLE CONNECTOR SYSTEM

The angle connector system is similar to the double sill system, having only a few modifications. There is only one sill plate on the foundation wall and the anchor bolt fastens the sill plate and an angle connector, which in turn is connected to the header, as shown in Figure 3-27. This arrangement allows uplift forces to be transferred from the anchor bolt to the header and sill plate. The loads are then carried by the sheathing to the sole plate and wall studs. Lateral reaction loads can be resisted by the same system described in the double sill system.

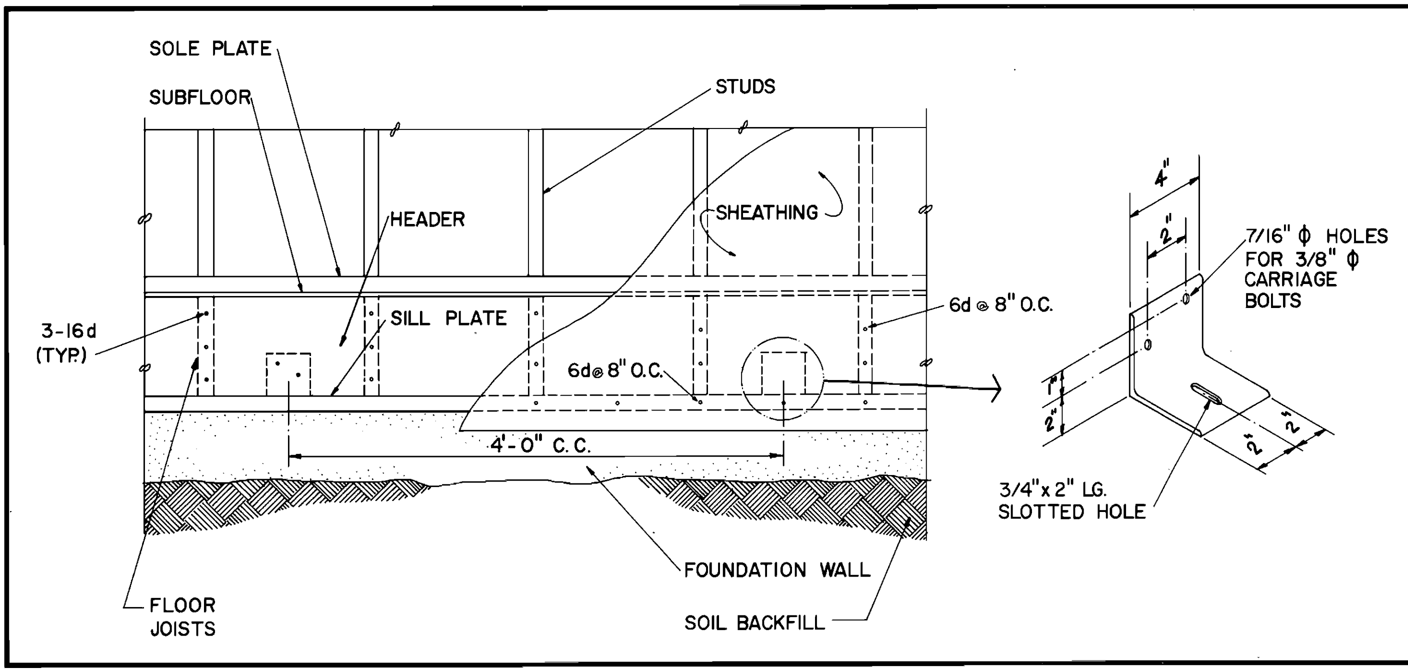


FIGURE 3-27. Angle Connector System

SOLE PLATE ANCHOR SYSTEM

The sole plate anchor system utilizes the same construction as the angle connector system, with a process modification to the anchoring system. Instead of using an angle connector, this system extends the anchor bolt through the sill plate, floor joists, subfloor, and sole plate to clamp the entire system in place (refer to Figure 3-28). Lateral reactions are handled in the same manner as in the previous system.

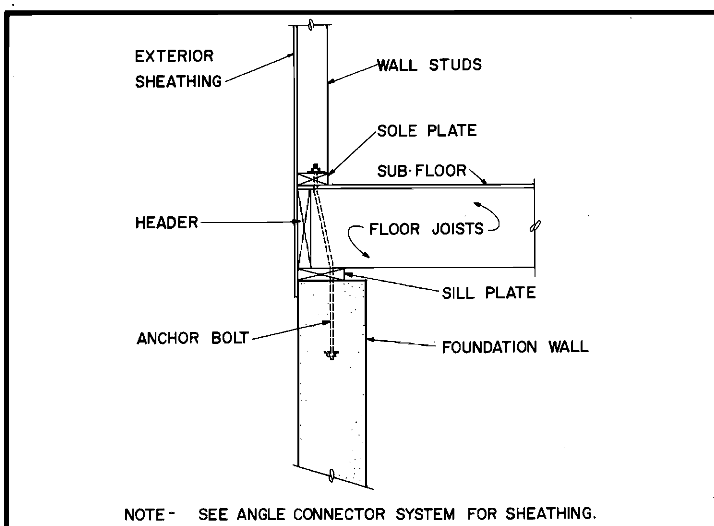


FIGURE 3-28a. Sole Plate Anchor System

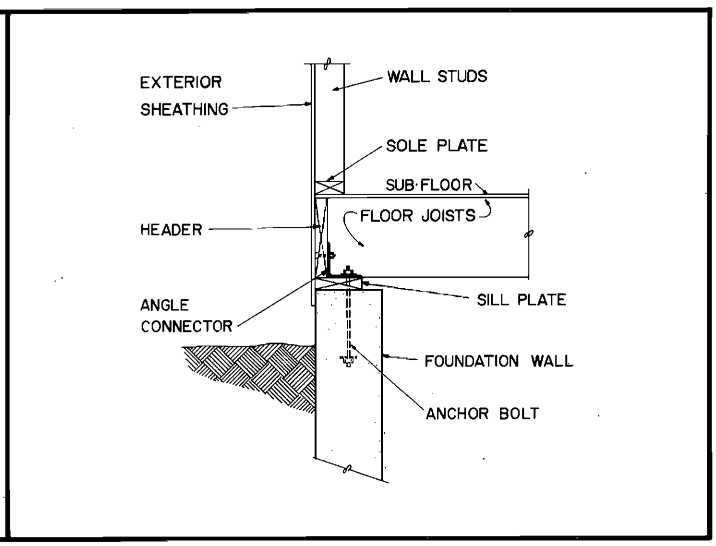


FIGURE 3-28b. Improved Connector System

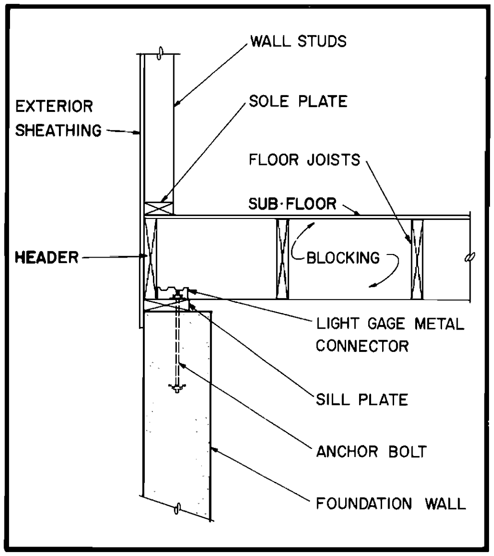


FIGURE 3-29. End Wall System Anchor

END WALL SYSTEM

The foundation wall system running parallel to the floor joist can utilize the anchorage system as prescribed in the double sill, angle connector, and sole plate anchor systems. The lateral loads, however, have no effective path to transmit reaction forces to the floor system. Figure 3-29 shows the angle connector system applied to an end wall of a foundation system. To effectively transfer the lateral reaction, blocking should be added between the floor joists for at least three spaces.

Summary

Each of the anchorage systems discussed in this section represents several means for providing the structural connection between the superstructure and foundation wall system. Other systems can be utilized as long as the lateral reaction forces from the foundation wall and any uplift forces on the superstructure can be resisted, which requires the proper transfer of design forces throughout every structural element.

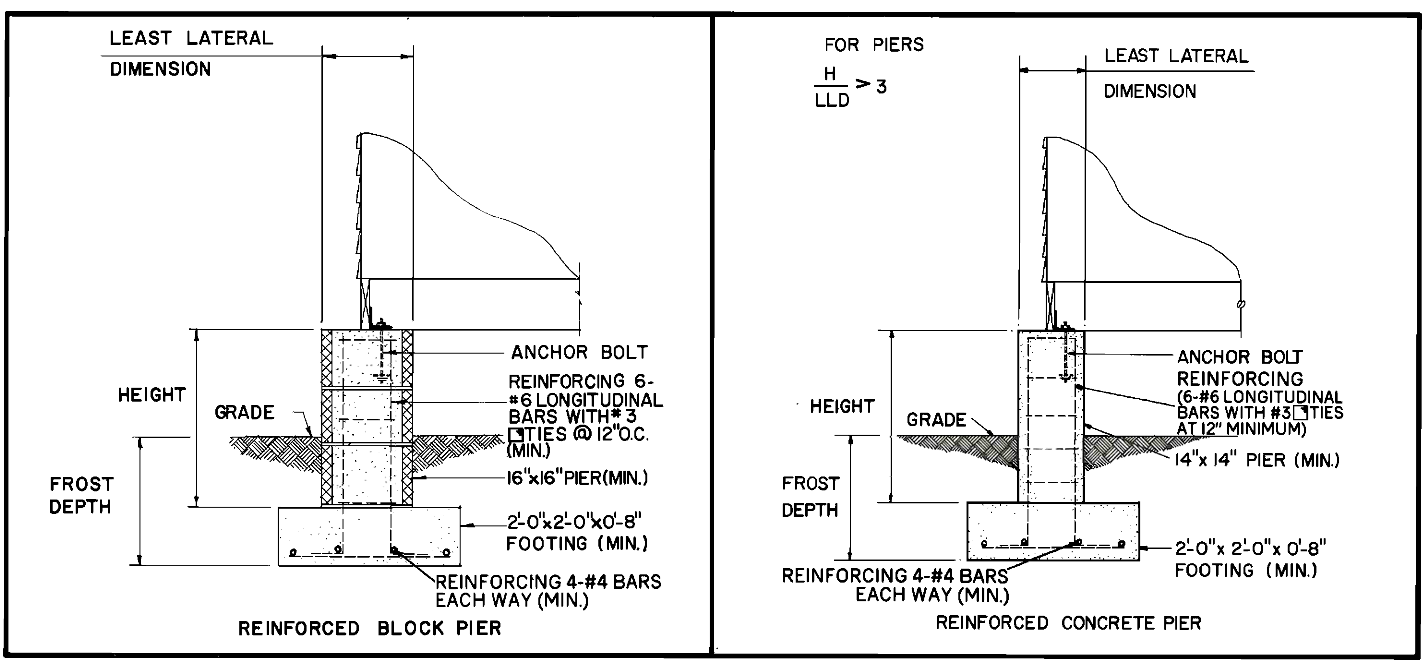
3.14 TECHNICAL DESIGN CRITERIA—OPEN FOUNDATIONS

General Criteria

One technique used in the elevation of a residential structure is to place the structure on open foundations, such as piers, columns, or piles. These three types of support are similar in appearance, but there are distinguishing characteristics both physically and structurally.

A pier is defined as a vertical structural member with a height-to-least-lateral dimension of less than three, and is primarily used to support axial compression loads, as shown in Figure 3-30. Piers can be constructed of a variety of materials, but either concrete block or poured-in-place concrete are normally used. A reinforced concrete footing is used to transfer the axial loads to the earth and to provide lateral stability for the foundation.

FIGURE 3-30. *A pier is a vertical structural member primarily used to support axial compression loads. Piers may be constructed of block or poured-in-place concrete, as shown here.*



A post or column is defined as a vertical member with a height-to-least-lateral dimension of three or more, and is also used primarily to support axial compression loads. Columns are usually larger members constructed of concrete block or poured, reinforced concrete. Because of their greater heights, a greater amount of reinforcing is usually required to provide greater strength characteristics. Posts are usually smaller members constructed of treated lumber. In either case, posts or columns are tied into footings which spread the axial loads so that the allowable soil bearing pressure is not exceeded.

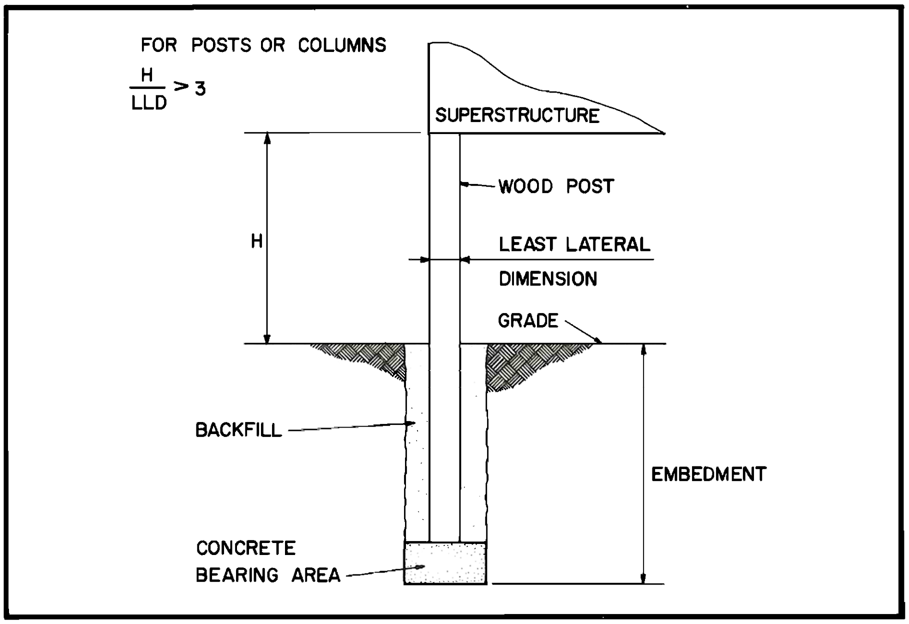


FIGURE 3-31. *A post, or column, is a vertical member with a height-to-least-lateral dimension of three or more, and is primarily used to support axial compression loads.*

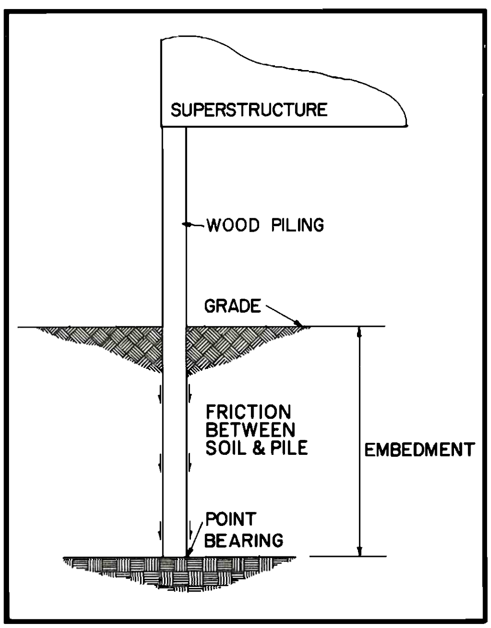


FIGURE 3-32. *The depth of pile embedment provides stability to resist lateral loads through passive earth pressures.*

Piles are long, slender structural members made of wood, steel, or concrete that are embedded into loose soil to support loadings. The depth of embedment provides the stability to resist lateral loads through passive earth pressures. Piles are usually mechanically driven into the ground. Vertical loads are resisted by friction between the pile and the surrounding soil and by end bearing of the pile on soil or rock strata.

For all three types of foundations, the loads acting on the foundation vary not only due to the weight of the structure they support, but also according to the physical characteristics of flooding, including hydrodynamic and impact loads. Hydrostatic loads are generally negligible since they are equally applied around the elevating member. Other loads that should be considered are the actual loads from the superstructure, which are vertical, and any wind loads acting on the superstructure, which are horizontal. The complete design must incorporate all facets of loading, including water loads, wind loads, structural dead loads and design live loads.

Design Details for Piers and Posts

The location and number of both piers and posts (or columns) depends upon several considerations. First, the allowable bearing pressure needs to be determined by a qualified soils engineer. Soil suitability and capacity will determine the size of footings and hence the total load capacity.

A second consideration is the ability of the foundation to adequately withstand the vertical loads from the superstructure. The location of the members must be such that the floor system is structurally adequate. This involves checking the framing system, and particularly, the girder members, to see if they are adequate for the new span distances. The National Concrete Masonry Association recommends that spacing not exceed 8 feet in the direction perpendicular to joists and 12 feet in the direction parallel to joists.

Another important factor of foundation design is whether the member can be free standing or will require lateral bracing. As with any elevated structure, lateral forces such as hydrodynamic and wind loads must be transferred to the foundation. Free standing members take the lateral load in addition to the vertical loads from above, and transfer these forces to the footing through shear, bending, and axial stresses. The presence of lateral forces at the top increases the required size of footing due to the potential for overturning.

Laterally braced members use structural mechanisms such as cross bracing, knee bracing, shear walls, etc., to help transmit the horizontal forces to the footing, which significantly reduces the shear and bending forces.

The overall system in relation to the structure must be considered to determine how the design forces are actually transferred to the foundation system. How the lateral loads are transferred to the ground determines the total lateral load acting on each member. A qualified structural engineer can determine the loads and base the design on proven structural techniques to handle loadings according to magnitude, direction, and type.

Considerations in choosing the depth of the pier or post footing include soil bearing capacity, frost zone location and potential scour depth. Additionally, certain types of soil are unsuitable for these foundations due to poor bearing capacity or high potential for scouring.

The potential for scouring on foundations is a complex problem. All granular soils in which the individual particles are not cemented to one another are subject to scour, erosion, and transportation by the force of moving water. Those grains larger than clay size (approximately $1/256$ of a millimeter) are the most susceptible to scour. Grains composed of clay minerals become bonded together electrically in aggregate and are therefore less susceptible to scour. Also, soils containing clay mixed with larger grain sizes may be scour-resistant to various degrees depending upon the relative proportions of the clay and larger grains. Soils which contain sufficient proportions of clay to be described as <u>compact</u> are more resistant to scour than the same grain sizes without clay as an intergranular bond.

The scourability of any loose, granular soil is related to both grain size and water velocity passing over or through it. Larger grain sizes require higher velocities for erosion to occur. For any specific case, the textural properties of the soil will determine what the threshold velocity for scour would be. Assessment of expected flow velocity also can be complicated somewhat by the effects of turbulence. Examples of localized scour due to turbulence can be seen on the downcurrent side of pilings or under breaking waves.

In consideration of the above, soils generally most susceptible to scouring are granular types containing little or no clay. Resistance to scouring increases with clay content. Clean sand and gravel are most susceptible to scouring. Soils with sand or gravel that also contain a clay-rich matrix are less susceptible to scouring. While these general rules of thumb will assist in determination of foundation conditions, caution is urged in accepting or applying these general guidelines to a site-specific design. The mechanical properties of soils are complex and, for any given project, a professional soils engineer should be consulted.

In designing a pier foundation, all possible forces must be accounted for, as well as mechanisms within the pier to adequately distribute these forces. Loads possible on the pier include lateral, axial compression or axial tension, and bending forces. Either anchor bolts or anchor straps should be embedded in the pier for proper transfer of design forces from the floor system to the pier. The pier is then designed for the applied loads according to the design capacities of the materials used. Proper transfer of forces must be considered at the interface of the pier and the footing to provide a stable foundation system. This transfer of forces from the pier to the footing is generally taken by dowels embedded in the footing and extended vertically into the pier.

The materials for construction are chosen according to the magnitude of design loads to be resisted by the pier. Smaller loads can be resisted using concrete block masonry construction without reinforcing. Moderate to heavy loading systems require substantially greater structural capacities that are offered by reinforced masonry block or reinforced concrete. The allowable design stresses for each type of construction material are outlined in the building codes in force at the particular site.

The relatively greater heights of post or column construction generally warrant a bracing system to transfer any lateral forces from the superstructure to the ground. Without a bracing system, free standing posts generally will require larger and more expensive footings to resist the lateral forces. Use of a bracing system transfers the lateral forces, generally reducing any bending forces. Lateral bracing also can reduce the effective length, which translates directly into the allowable axial forces for the material used in post construction.

Construction materials for posts or columns require greater strength to handle the stability factors and loads. Acceptable construction for columns includes rolled steel, reinforced masonry block, and reinforced concrete masonry. Posts for elevation of homes are generally made of treated wood. The design for each material is governed by the applicable local building codes in force. As with pier design, the complexities of most designs should be investigated by a structural engineer to verify the integrity of the column foundation system.

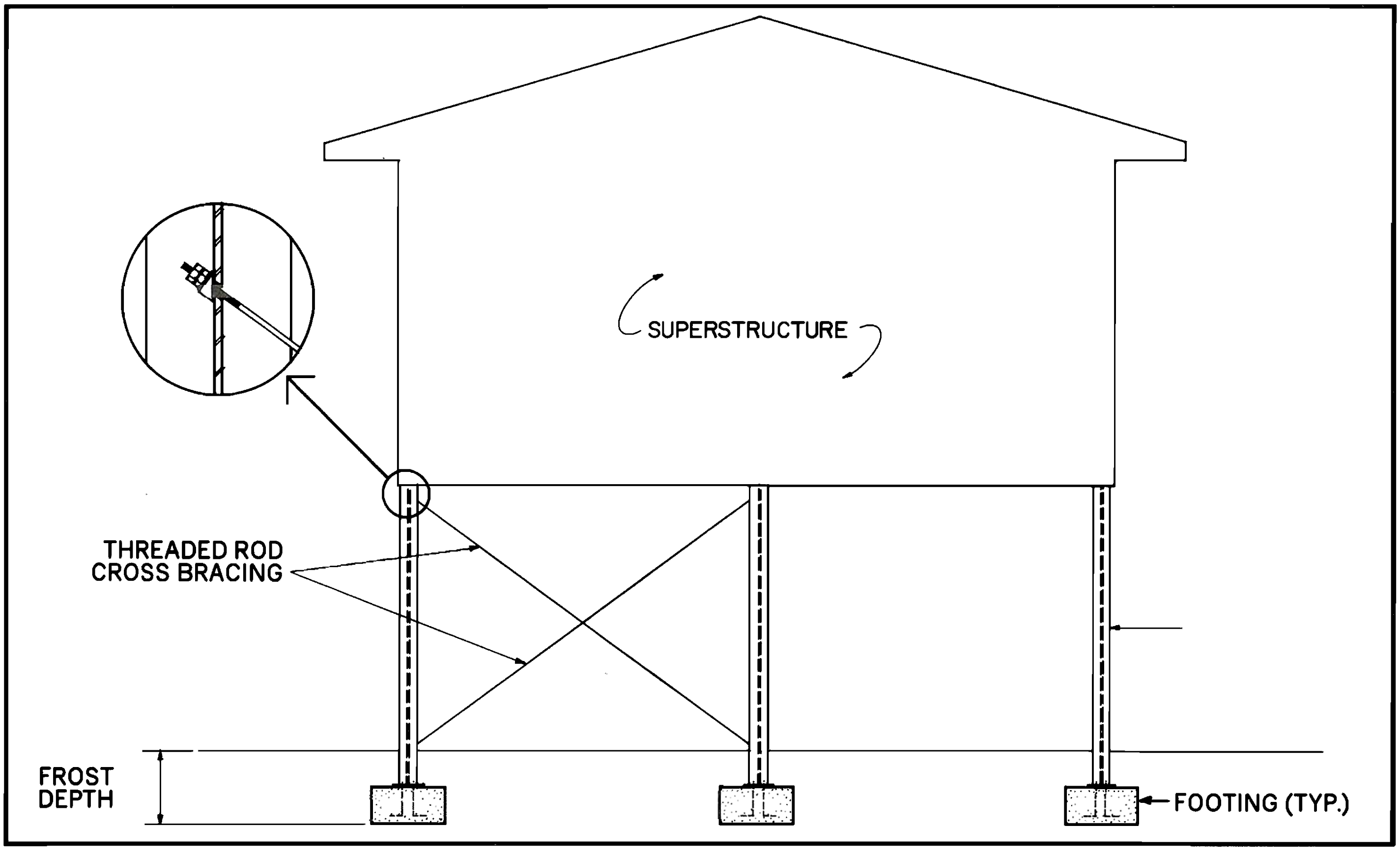


FIGURE 3-33. *Use of a bracing system on posts transfers the lateral forces and can reduce the effective length.*

Design Details for Piles

Piles offer greater flexibility than either a pier or a post foundation system for higher velocity flooding areas. The embedment depth is based on soil parameters and scouring depths caused by the velocity of water. The material utilized for residential pile construction is usually treated wood, although steel and concrete are also used. Each of these materials exhibits strength properties necessary for the driving forces experienced during installation of piles.

The depth of embedment for piles is determined by soil conditions. Bearing forces and passive earth pressures are dependent on several soil characteristics which can be determined using standard soil engineering procedures. The specific factors affecting depth include friction forces between the pile and the soil, and the end bearing capacity for the pile.

Unlike piers and posts which derive their stability from the spread footing to which they are attached, the pile derives structural stability by its embedment into the ground. The depth of embedment is dependent on the passive bearing capacity which provides the soil resistance to the pile loads acting against the ground. The backfill and compaction around a pile determine its ability to resist lateral loads. Possible backfill materials include sand, gravel, soil-cement, concrete, and earth. Additionally, a lateral bracing system may be utilized to assist in transferring lateral forces to the ground. The bracing system can reduce bending loads on the above ground section and can also increase the allowable axial stresses in the members. Because of the potential problems involved in pile construction, including embedment factors and soil parameters, the services of a qualified design professional or builder experienced in this type of construction should be obtained.

After the design loads are determined for the pile system, the actual design must incorporate several factors, including the lateral support from embedment, the effective length of post or pile above the ground, and the strength of the material used. All loads must be applied to the member, which should adequately resist these forces. Proper connection to the superstructure is also needed to ensure the proper transfer of design loads to the foundation. Details of pile design are contained in FEMA's Coastal Construction Manual.

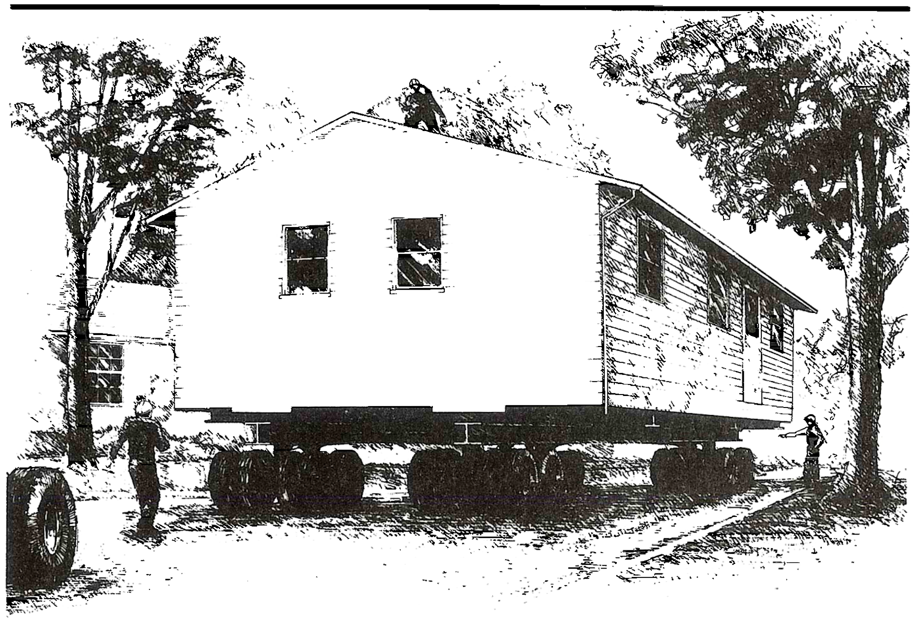
Summary

Each design parameter must be carefully analyzed with respect to the physical and structural capabilities of the member. Piers and posts are more suitable for lower flow velocities while piles generally offer greater resistance to higher velocity floods. Refer to Colorado Department of Natural Resources, Water Conservation Board, Colorado Flood Proofing Manual (October 1983) and to Federal Emergency Management Agency, Elevated Residential Structures (1984), for further discussion on piers, posts, columns, and piles.

Chapter 4

RELOCATION

Relocation is a retrofitting technique that can offer the greatest security from future flooding, but it may also be the most expensive alternative. Since relocation involves moving the entire home out of the floodplain, it is the most reliable of all retrofitting techniques.



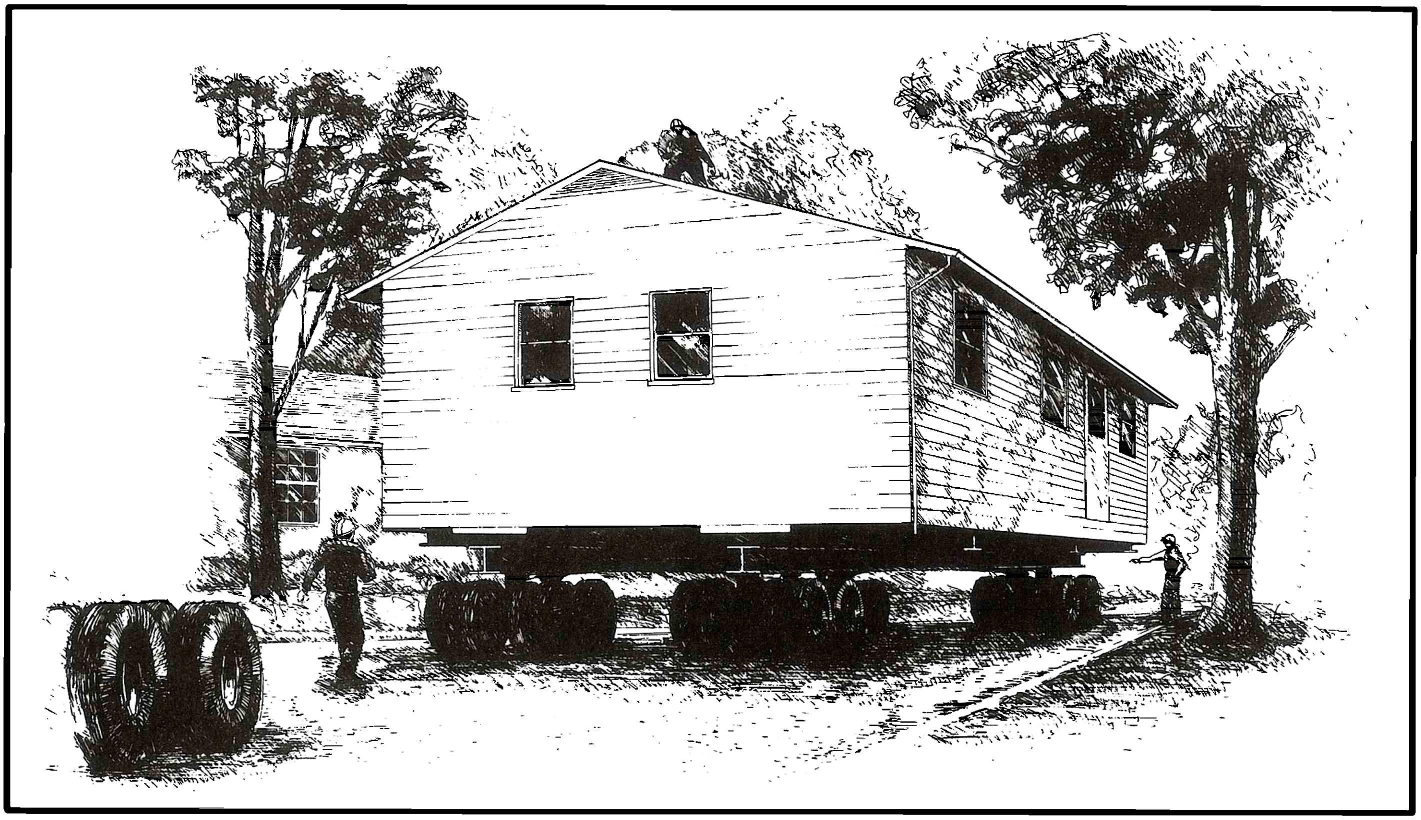


FIGURE 4-1. Detailed Rendering of House Relocation

4.1 INTRODUCTION

Relocation is a retrofitting technique that can offer the greatest security from future flooding, but it may also be the most expensive alternative. Since relocation involves moving the entire home out of the floodplain, it is the most reliable of all retrofitting techniques. In addition to relieving the homeowner from future anxiety about flooding, this method can offer the opportunity to significantly reduce or even eliminate flood insurance premiums.

In practice, the first stages of relocation are similar to those used for elevation, covered in Chapter 3. The difference is that once the house is elevated, instead of putting it back down on a raised foundation, it is placed on a heavy duty truck bed, transported to a new site out of the floodplain, and set on a conventional foundation. While this sounds simple, there are a number of considerations that must be carefully planned for the operation to be successful.

4.2 CONSIDERATIONS

A house must be in sound structural condition in order to be moved. A house in poor condition, especially one which is flood damaged, will need so much bracing that this procedure may become impractical.

In general, those structures that are easiest and least expensive to elevate are also the easiest to relocate. Single-story frame houses over a crawlway or basement are the easiest to relocate, while homes that are slab-on-grade or multi-story are more difficult.

It is feasible to move even the heaviest houses, such as those of brick or block, or very large ones, though this will usually be more expensive. However, the exact method used, or even the ability to do it at all, depends greatly on the nature of the route the move will take. Such things as load capacity of roads and bridges, or road restrictions on height and width, must be considered for every relocation plan.

As structures become larger, moving them becomes more complicated and more expensive. The main problem normally involves clearances of bridges, road cuts, etc., along the route. If a large house will not clear these obstacles, then it will have to be cut, moved in sections, and reassembled at the new site. Though not an everyday operation for most contractors, experienced house movers can make the cuts and reassemble a house so that it would be impossible to tell that it had ever been apart.

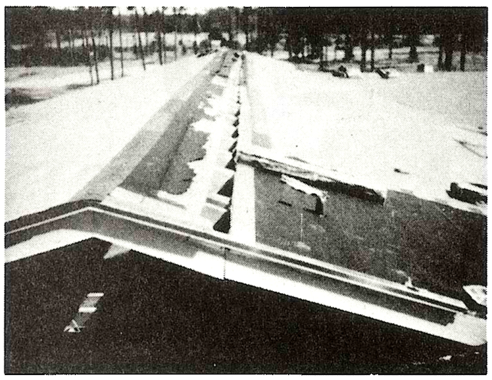


FIGURE 4-2. *When a house is too large to be relocated in one piece, careful planning is necessary in order to cut the structure in pieces and move them separately.*

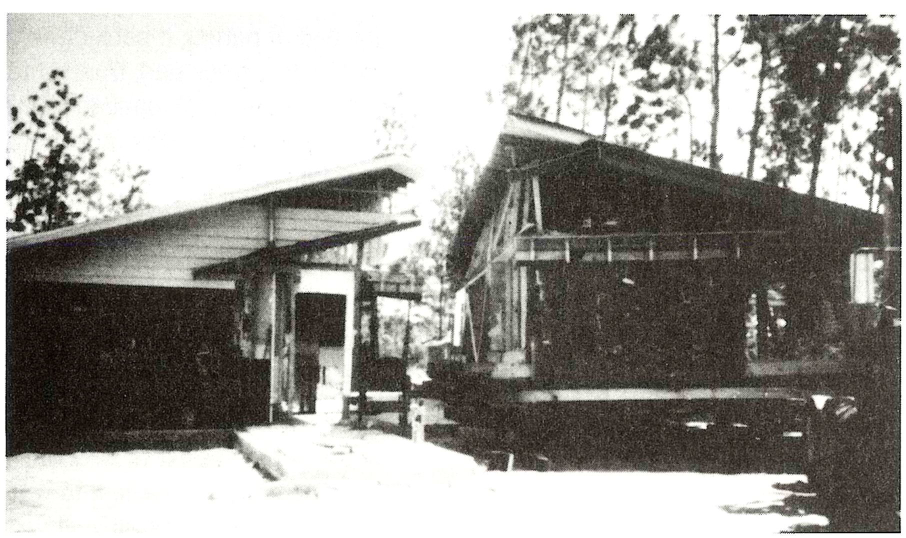
The relocation process becomes more complicated with houses having brick or stone veneer. Because veneer tends to crack or peel off when disturbed, it may be cheaper and more prudent to remove it before relocating and then replace it once the house is on its foundation at the new site. For the same reason, chimneys should either be removed and rebuilt afterwards, or extensively braced before the house is moved.

Technical details on relocation are addressed in Section 3.11, "Technical Design Criteria—Lifting Beams for Raising Structures."

Ultimately, expense may be the deciding factor in evaluating the feasibility of relocating a house. Every house moving operation is different, so a homeowner should thoroughly check out the costs involved and the alternatives to decide if it will be worthwhile. Among the major expenses will be the price of the new lot outside the floodplain, the cost of preparing the land, and building a new foundation.

There are often various forms of assistance for those who desire to relocate out of the floodplain. These range from local, state or federal government loans to programs that may pay for most of the move.

FIGURE 4-2a.



Relocation tends to be more disruptive to the occupants of a house than other retrofitting options. During the time that the house is being jacked up and moved, the occupants will likely have to live in temporary lodging, possibly for a matter of weeks. In addition, it may be necessary for furniture and belongings to be moved out and placed in temporary storage, particularly in those cases where the house must be cut into sections.

Obviously, the moving of a house is a complex operation and will have to be done by a professional. Unless there is a hidden structural defect, most homes can be moved with no more damage other than occasional slight cracks in the plaster or wallboard joints.

There are reputable and able house movers in most parts of the country, but homeowners should thoroughly examine all prospective companies. If there have been other relocation projects in the area, an attempt should be made to contact the owners involved for recommendations. Also, a list of references should be requested from area house movers.

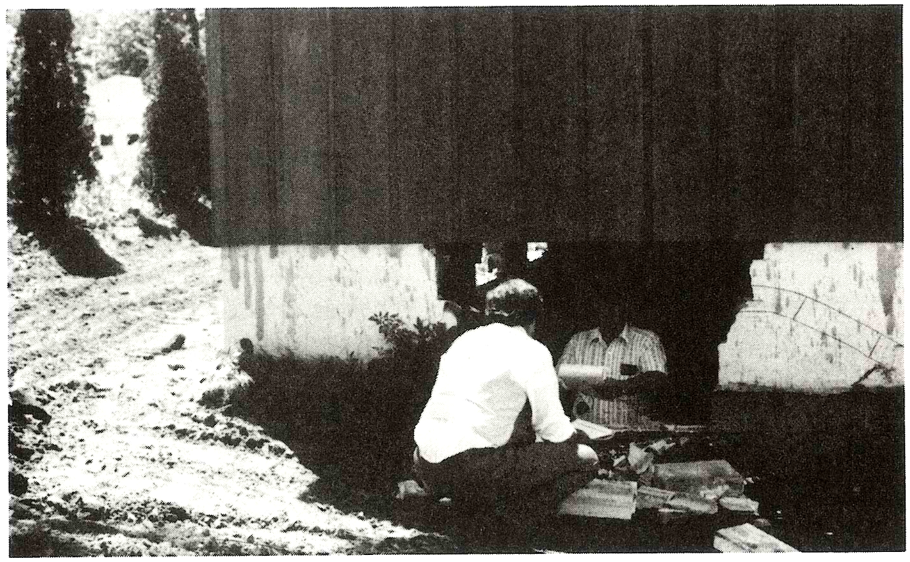
A homeowner should obtain bids from several house movers and contractors. This will help to decide whether relocation is the best option. Before simply choosing the lowest bid, a homeowner should be certain that the particular mover or contractor has the experience and resources to complete the project near the quoted price. Keep in mind that these are only estimates, since many unexpected things can occur in house moving that may change the price.

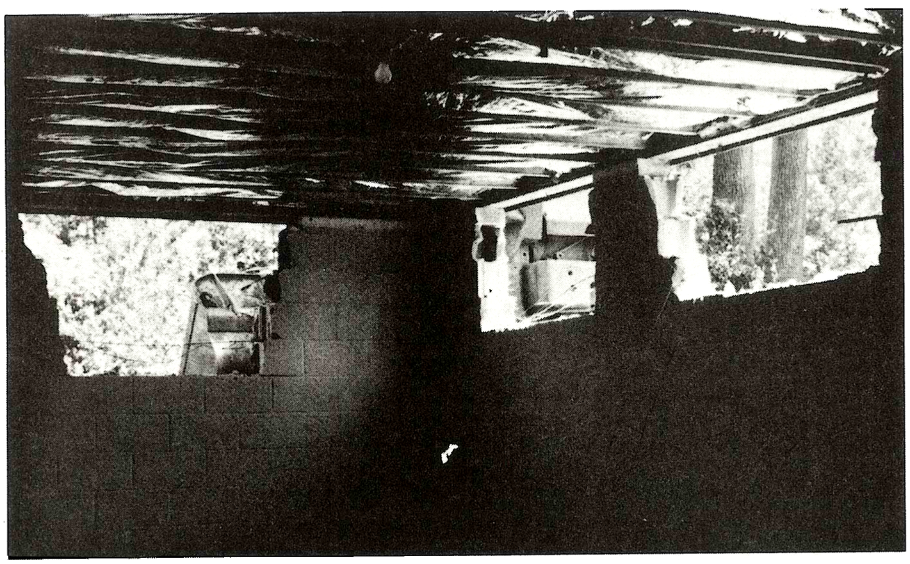
4.3 THE RELOCATION PROCESS

FIGURE 4-3. Photo Sequence of the Relocation Process

The first step in relocating a house is clearing paths beneath the structure for lifting supports.

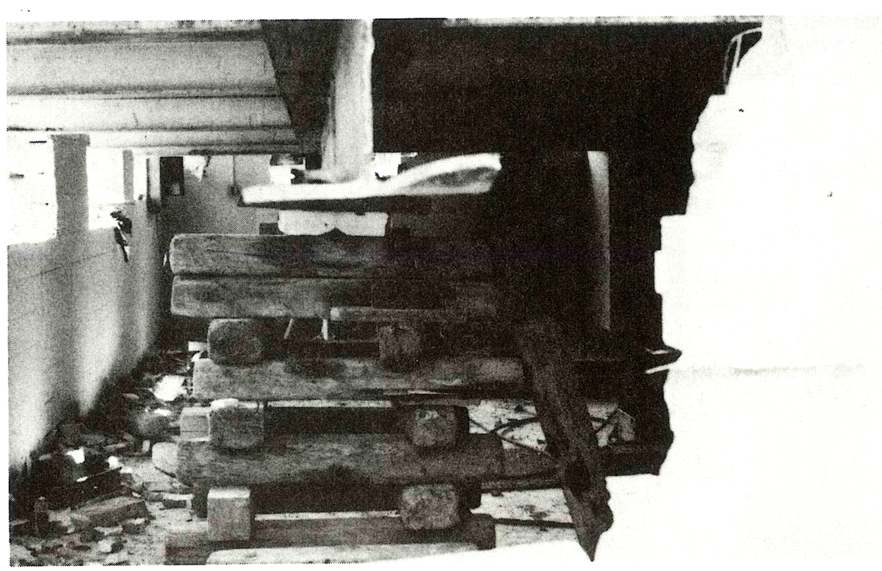
Cleared pathways should be deep enough to allow for movement of people and machinery.

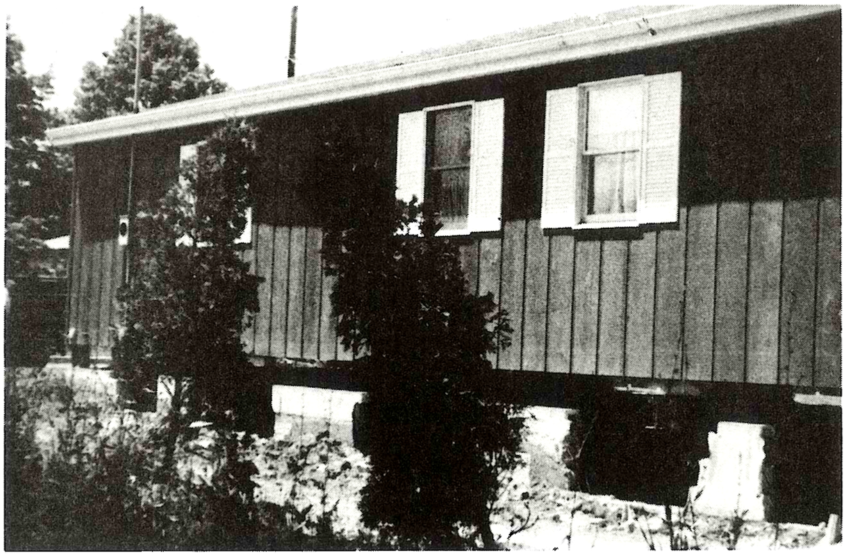




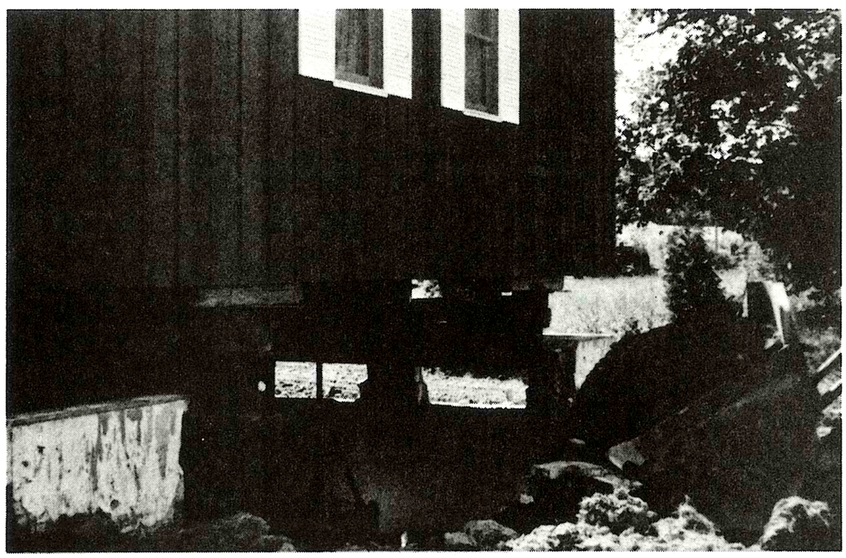
From beneath the structure, the pathways for lifting beams are easily recognized.

Beams are placed beneath the house structure at all critical lift points and support cribbing is added as the structure is elevated from its old foundation.

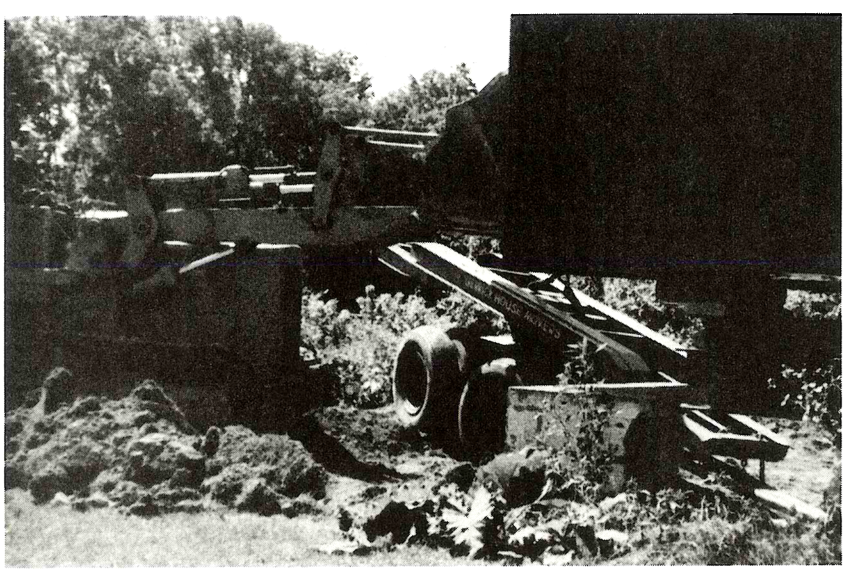




From outside, the structure now stands free from its former foundation.

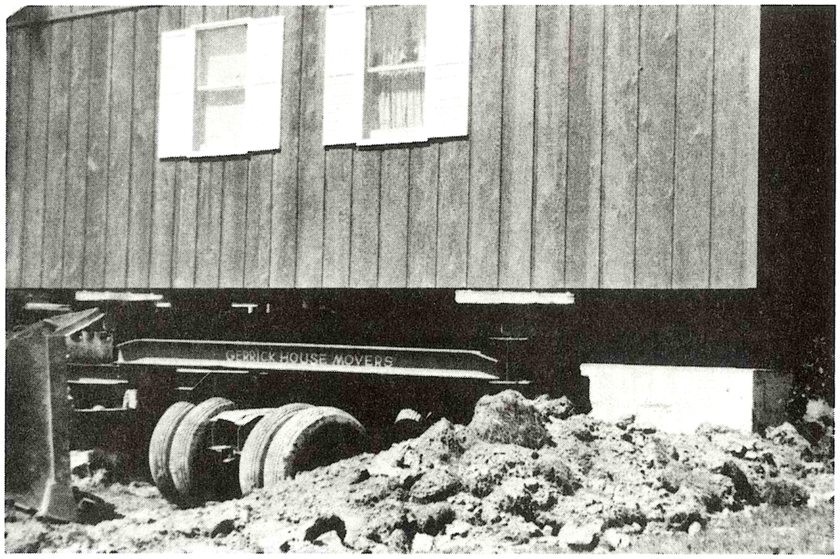


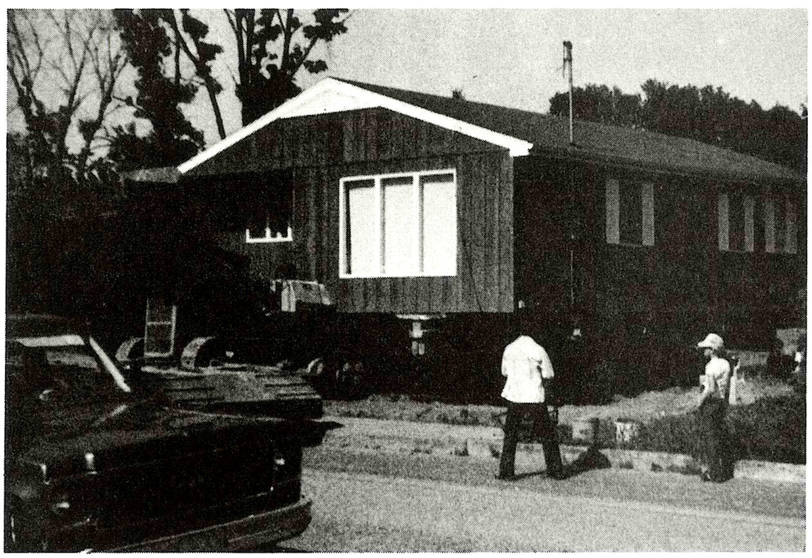
Excavation of a temporary roadway is then done at one end of the structure.



The trailer that will be used to move the house is brought to the site and placed beneath the cross member I-beams.

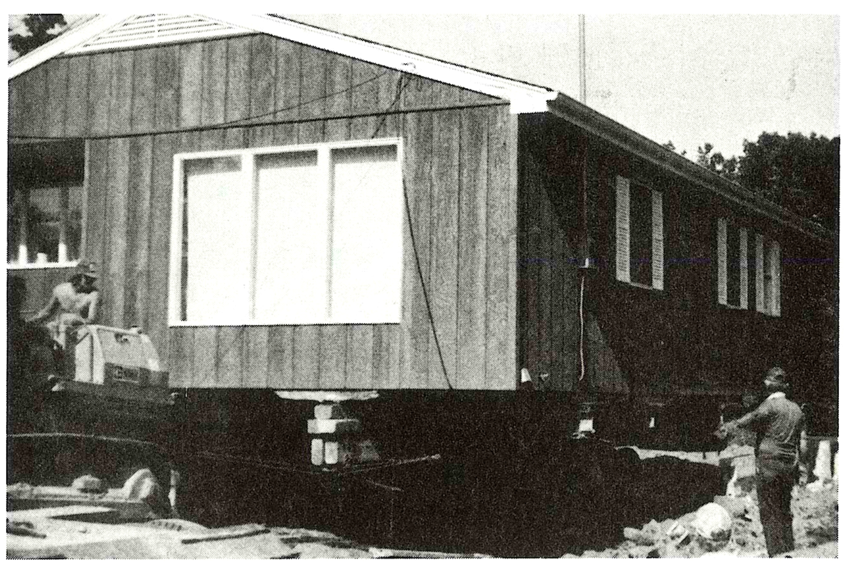
The house is then lowered onto the trailer unit.

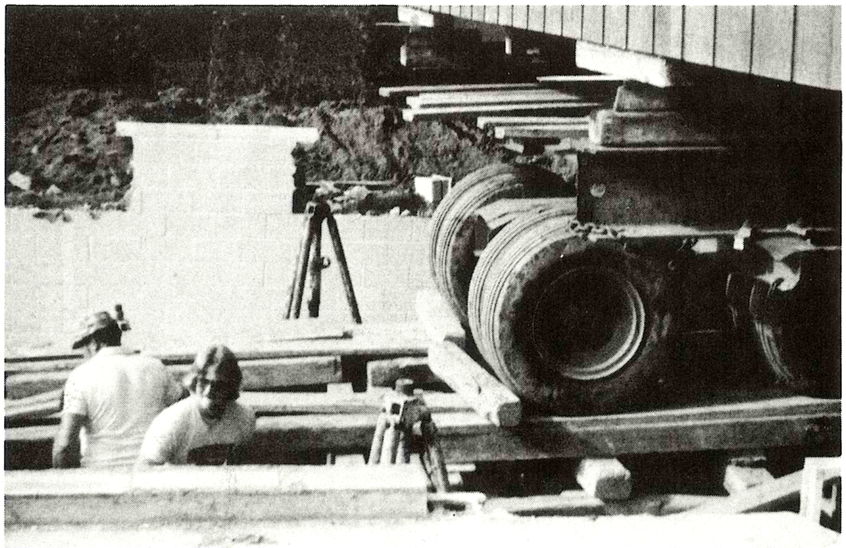




The trailer unit and tractor/dozer are attached in preparation for moving the house from its original site.

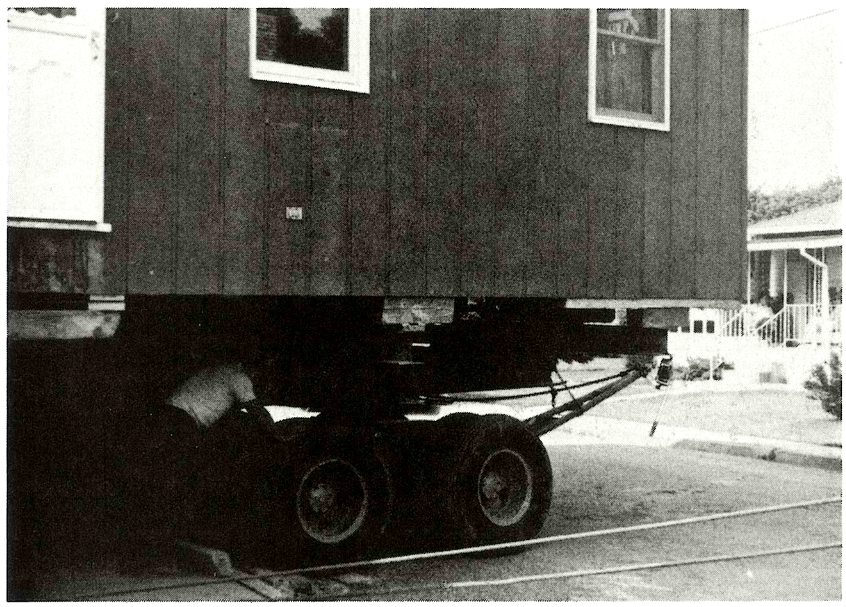
The tractor/dozer is used to pull the house to street level.



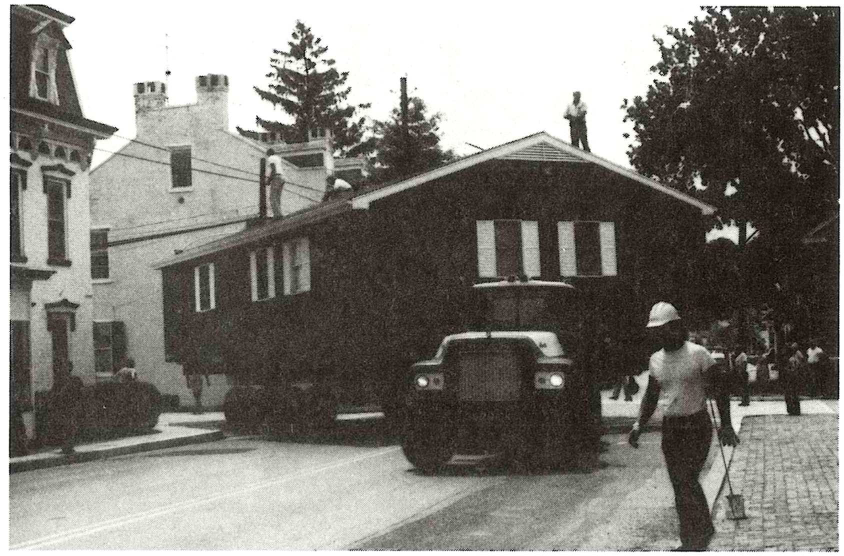


While carefully pulling the house off the original site, workmen continually block the wheels to prevent sudden movement.

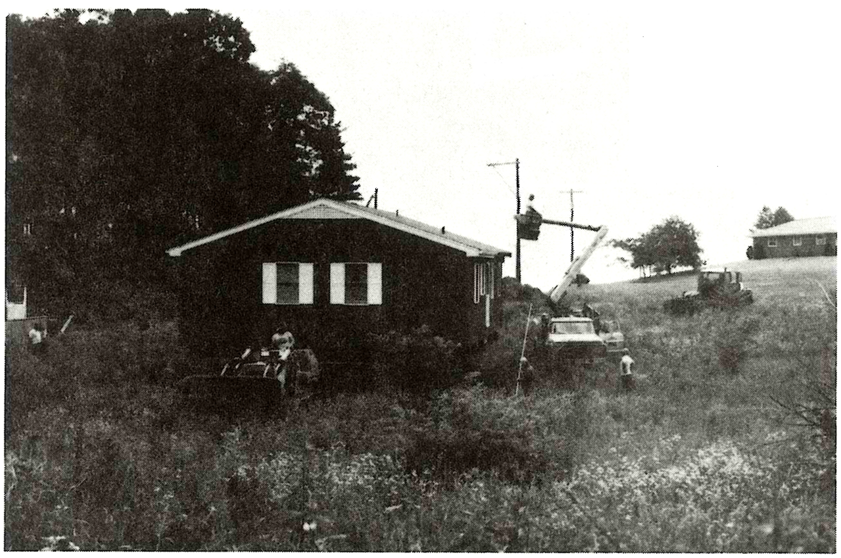
At street level, the house is stabilized and a truck is connected to the trailer.



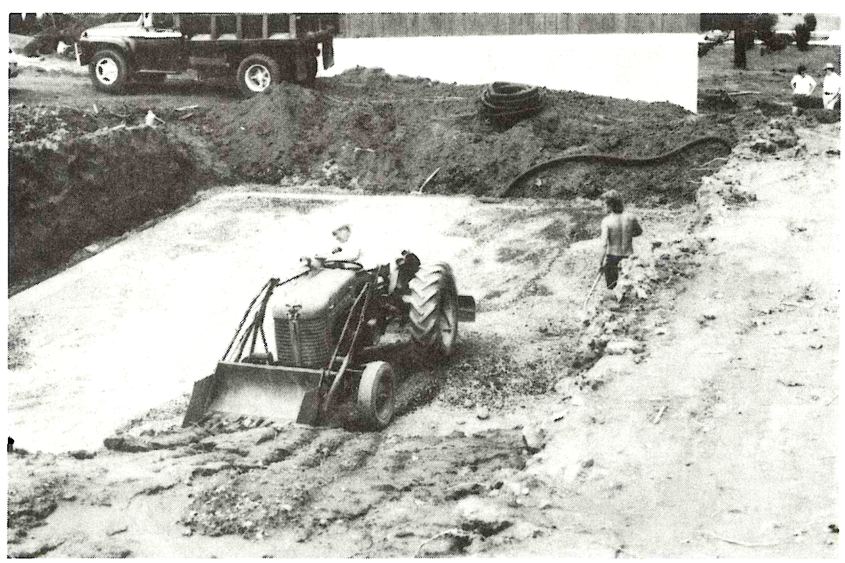
With connections to the truck completed, the journey to the new site begins.



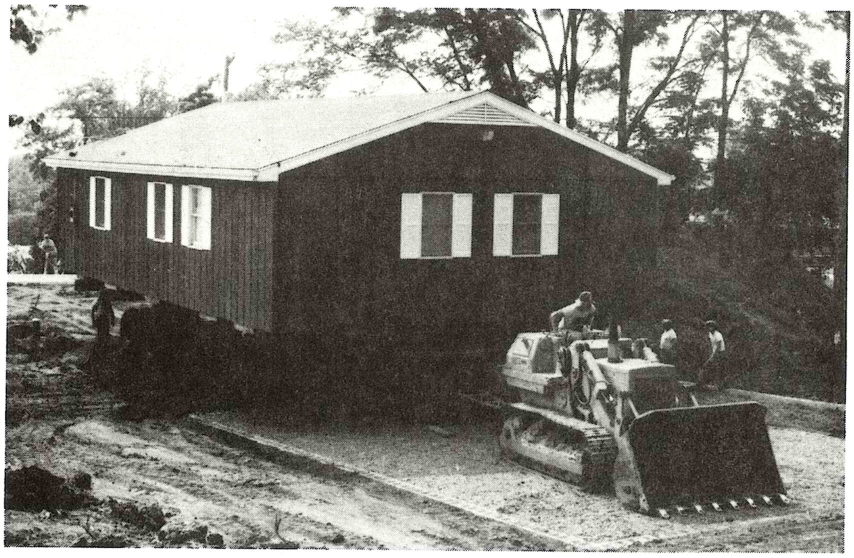
Adequate clearance during the journey must be assured.



The path of least resistance — in this case a flat, open field — is the best transportation route.

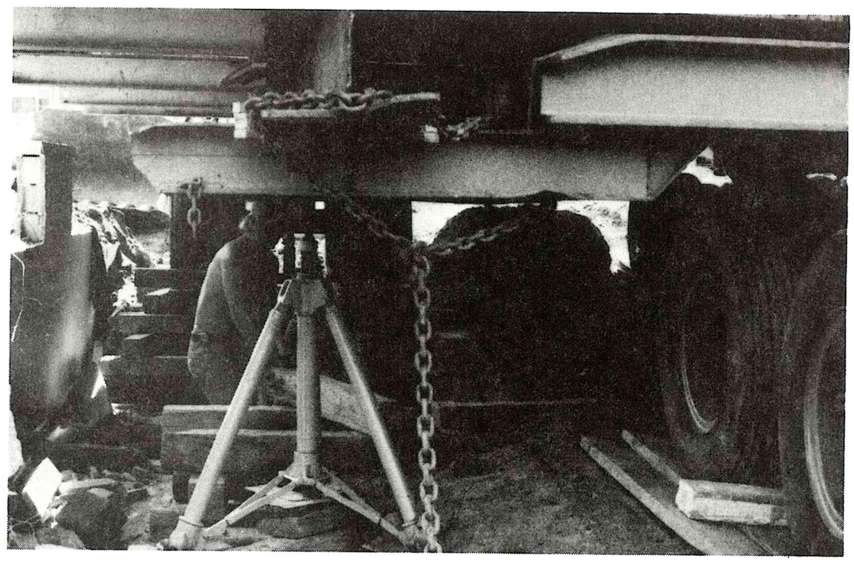


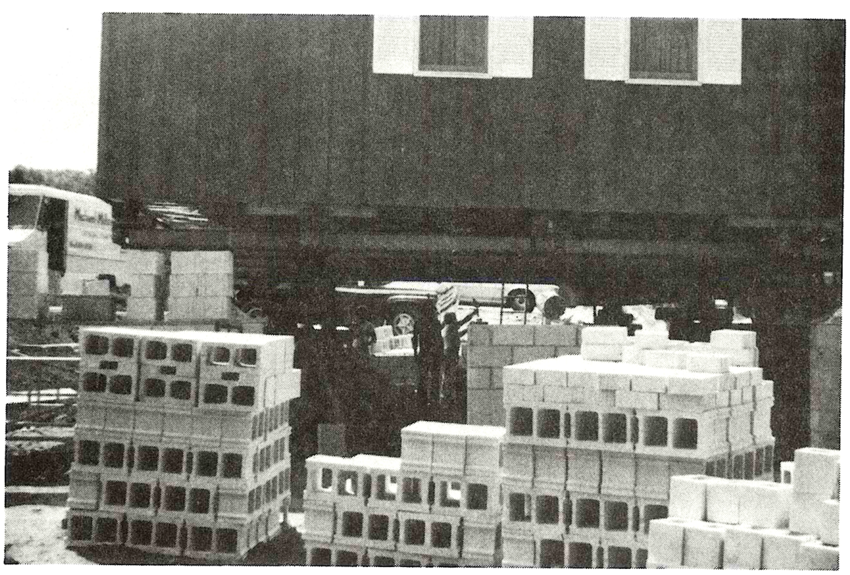
At the new site, excavation and preparation of the foundation are underway.



The house is moved to its new site.

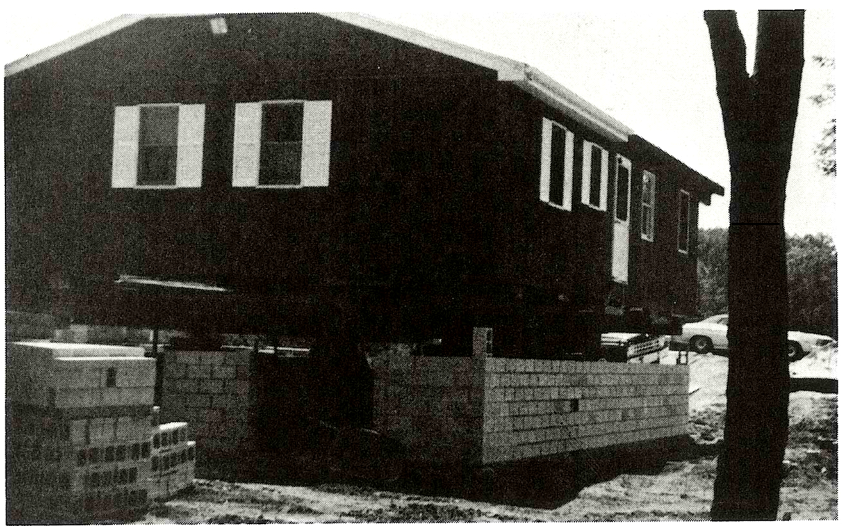
Support cribbing is put in place to allow the structure to be jacked up off the trailer bed, which is then removed.





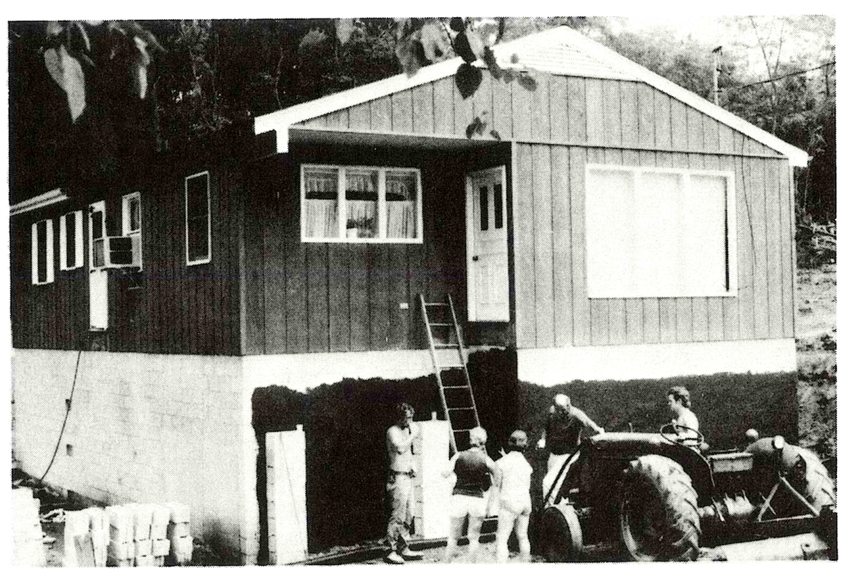
With support cribbing in place, materials for completion of the foundation are readied.

The foundation wall construction begins.



Once the desired height of the new wall is reached, the house is lowered onto its new foundation, cribbing is removed, and foundation walls are completed.

Finishing touches, like preparing the foundation for backfilling, are done to blend the house in with its new environment.



4.4 THE HOMEOWNER'S ROLE

There are many things that can be done to help the contractor successfully complete the job. For example, homeowners should carefully plan out their needs, know what they can afford to do, and have a complete set of house plans to help the mover or contractor determine the loading points and potential structural problems.

Numerous small details of the moving operation will require attention before and during the move of the house. They are time consuming and occasionally expensive, but they will help the move go smoothly and more quickly and, possibly, reduce the overall cost. These details include the following:

1. Obtain all the necessary moving permits not only in the area from where the house is being moved, but in all jurisdictions through which the move is passing.
2. Make certain that the house as it is being moved will clear all narrow passages such as road cuts, light poles, tight turns around buildings, bridges and overpasses.
3. Make certain it will clear all overhead utility lines; many of these can be lifted during the move, but utility companies sometimes require the presence of their employees and will charge for this service.
4. To remove a hazard, the old basement may have to be backfilled. Check local regulations to see if old foundation and utility connections have to be removed.
5. Make certain that when the house is moved to its new lot, it will conform to all the new setback lines and to the building codes and zoning regulations in the new area.
6. Make sure that all utilities are available at the new site and that they can be brought directly into the house.

There also might be other laws, requirements, or restrictions that could present unexpected problems. House movers, contractors, and other people who have moved their houses should be able to help spot such potential problems.

4.5 COST GUIDELINES

Unit Cost

The homeowner should be able to estimate the cost of relocation by determining the various quantities of construction material or tasks, and the unit costs for these materials and/or labor tasks. The following units and unit prices may be utilized to make a rough estimate for each individual case. Upper limits of cost ranges should be used for homes with over 2,000 sq. ft. of living space. Table 5 details a process for unit cost estimating for relocation projects.

TABLE 5

UNIT COST ESTIMATING FOR RELOCATION PROJECTS

	ITEM	UNIT	UNIT COST 1985 DOLLARS	NO. UNITS NECESSARY	ITEM COST
1.	Excavation	Cu. Yd.	\$3.00 - \$8.00	________	_____
2.	Boring for lift beams (under slab)	Lin. Ft.	\$125 - \$175	________	_____
3.	Jacking	Ft.	\$300 - \$500	________	_____
4.	Steel Beam - Material only transportation	lb.	\$.50 - \$1.00	________	_____
5.	Moving Operation	Lump Sum	Apx. \$5,000 - \$7,000 flat fee, plus an apx. fee of \$500 - \$1500 for each mile over the first	________	_____
6.	Concrete, reinforced, in-place	Cu. Yd.	\$150 - \$250	________	_____
7.	Concrete masonry units (CMU), reinforced, in-place	Thousand	\$2,000 - \$2,500	________	_____
8.	CMU, unreinforced, in-place	Thousand	\$1,800 - \$2,200	________	_____
9.	Brick, in-place	Thousand	\$120 - \$180	________	_____
10.	New lot (.2-6.0 acres)	Lump Sum	\$2,000 - \$22,000 depending upon local real estate market conditions, lot location and lot size	________	_____
11.	Water Supply (high range for individual well)	Lump Sum	\$500 - \$5,000	________	_____
12.	Sewer Hook-up (high range for septic tank)	Lump Sum	\$500 - \$5,000	________	_____
13.	Sanitary Sewer Line 4"-6" in-place	Lin. Ft.	\$4.00 - \$8.00	________	_____
14.	Water Service Line 3/4"-1" in-place	Lin. Ft.	\$3.00 - \$6.00	________	_____

TABLE 5
(CONT.)

UNIT COST ESTIMATING FOR RELOCATION PROJECTS

	ITEM	UNIT	UNIT COST 1985 DOLLARS	NO. UNITS NECESSARY	ITEM COST
15.	Internal/ External repair flooring, painting, etc. houses to 1,000 sq. ft.	Lump Sum	\$3,000 - \$5,000	________	____
16.	Internal/ External repair flooring, painting, etc. houses from 1,000 - 2,500 sq. ft.	Lump Sum	\$5,000 - \$15,000	________	____
17.	Grading	Sq. Yd.	\$150 - \$250	________	____
18.	Seeding	Sq. Yd.	\$1.25 - \$1.50	________	____

Typical Examples

Following are details of several cost summaries of relocation cases.

- Midwestern, U.S., frame house relocated from floodplain:

  This 1,350-square-foot house, located near Chillicothe, Illinois, faced an annual flooding threat from the nearby Illinois River. Floods had left many houses in the neighborhood with as much as three feet of water over the finished first floor. The house was moved approximately five miles out of the 100-year floodplain. Relocation costs, adjusted to 1986 dollars, are as follows:

New lot	\$14,000
Bracing new foundation, utilities and basement construction	12,500
Moving contractor	11,500
TOTAL	\$38,000

- Midwestern U.S., large, rambling house, that had rooms added on over a period of time:

  This house faced not only moderate wave action, but also battering from ice floes in its former floodplain location. Relocating the 1,857-square-foot, multi-level structure was a complex undertaking. The house was larger than the first example, yet the overall expense was comparable primarily due to the fact that the homeowner was an architect. Since he was knowledgeable about contracting work, he was able to keep a tight rein on costs and perform much of the design, bracing, and contracting work himself. Costs are expressed in 1986 dollars.

FIGURE 4-4. *Even extremely large and complex structures can be successfully relocated.*

House Moving	$13,000
New Lot	7,800
New Foundation & Site Preparation	12,320
New well, septic tank, and plumbing	5,675
Electric, gas, and telephone connections	1,095
Utility company permits to move wires	1,035
TOTAL	$40,925

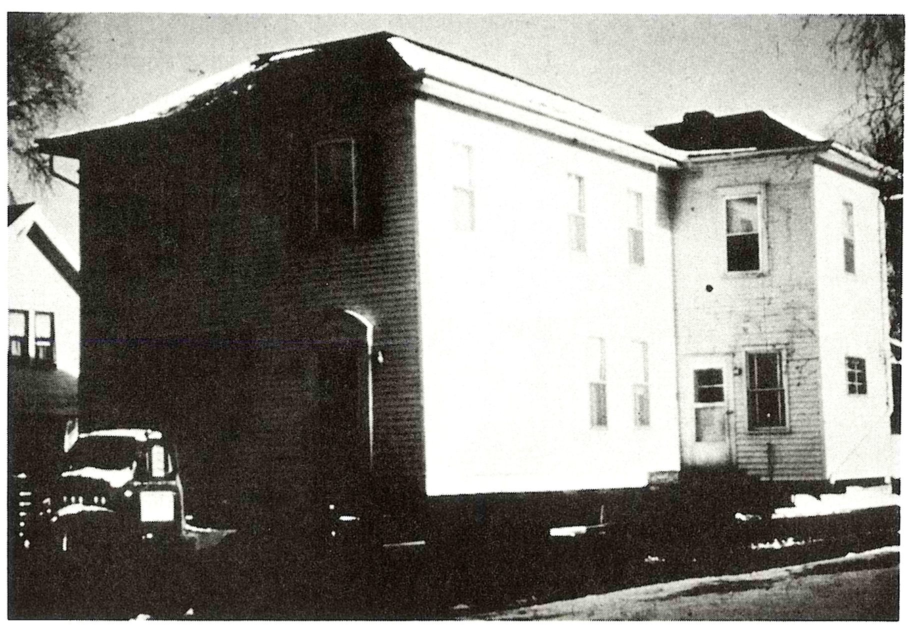


FIGURE 4-5. *Two story wood structures can be relocated with proper planning.*

- Southwestern U.S., large, slab-on-grade house, with field stone veneer, (market value listed as $100,000.00):

  This 3,200-square-foot house in Tulsa County, Oklahoma was twice threatened by major floods, and was included in a flood protection project funded by the U.S. Army Corps of Engineers in 1981. Because of the complexity of the structure, it had to be cut in four sections to be relocated. The house was moved 15 miles to a flood-free site.

Cost of Moving and Rebuilding Home

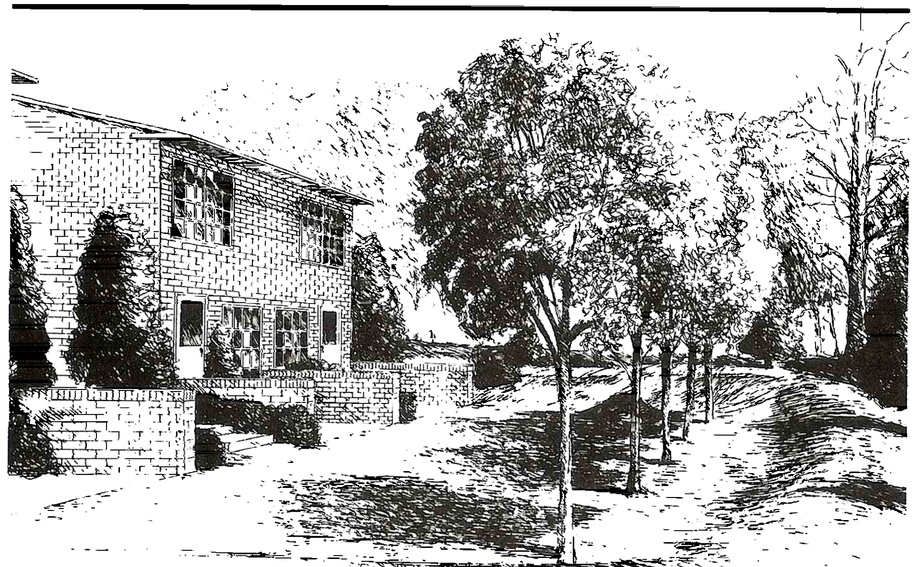
Item	Cost
House Mover	$18,750
Carpentry and materials	24,700
Air conditioning and heating	6,650
Foundation and slab	5,600
Masonry	5,490
Plumbing	4,360
Floor coverings	3,895
Electrical work	1,740
Septic system	2,080
Painting	1,470
Sheetrocking	1,230
Insulation	1,230
Driveway (gravel) and sidewalk (concrete)	575
Miscellaneous	1,035
Total Cost	$78,795

NOTE: The above data does not include costs for land, moving and storing furniture, or general contracting and other work completed by the owner.

Chapter 5

LEVEES

Levees are embankments of compacted soil that for shallow to moderate flooding can keep water from reaching a structure. Depending upon the availability of suitable local soil, they may be one of the least expensive of all retrofitting techniques.



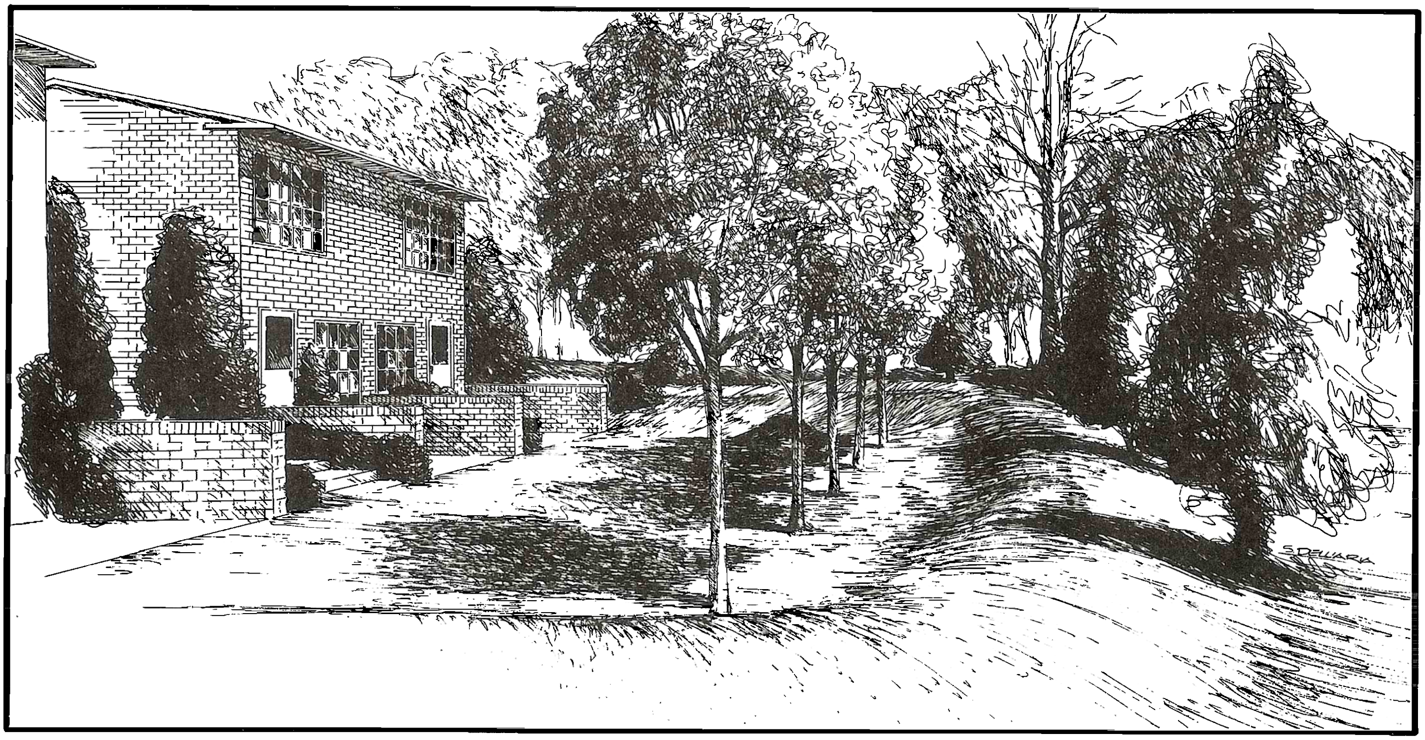


FIGURE 5-1. Detailed Rendering of House Protected by Levee

5.1 INTRODUCTION

Levees are embankments of compacted soil that can keep shallow to moderate flood waters from reaching a structure. Depending upon the availability of suitable local soil, they may be one of the least expensive of all retrofitting techniques.

Unlike other retrofitting techniques, a well designed and constructed levee results in no water pressure on the house itself. Consequently, as long as the levee holds or is not overtopped, the structure should not be exposed to damaging hydrostatic or hydrodynamic forces.

One distinct advantage of levees is that they are made of earth and often have rounded outlines that can blend in nicely with the surrounding landscape. As a result, they are often easier to landscape than most other retrofitting methods. Another advantage with this technique is that since it is constructed on land surrounding the house, there is no need to alter the structure in any manner.

5.2 CONSIDERATIONS

Although levees may be attractive in terms of economics and appearance, they have a number of distinct drawbacks that may make them impractical for many homeowners. One potential problem is that levees can impede the natural flow of water in a floodplain, possibly resulting in increased flooding of adjacent property. Similarly, they can also block the natural drainage from surrounding property. For these reasons, local zoning laws may prohibit or restrict their use. In most cases, a homeowner will have to obtain permits before beginning the construction of a levee.

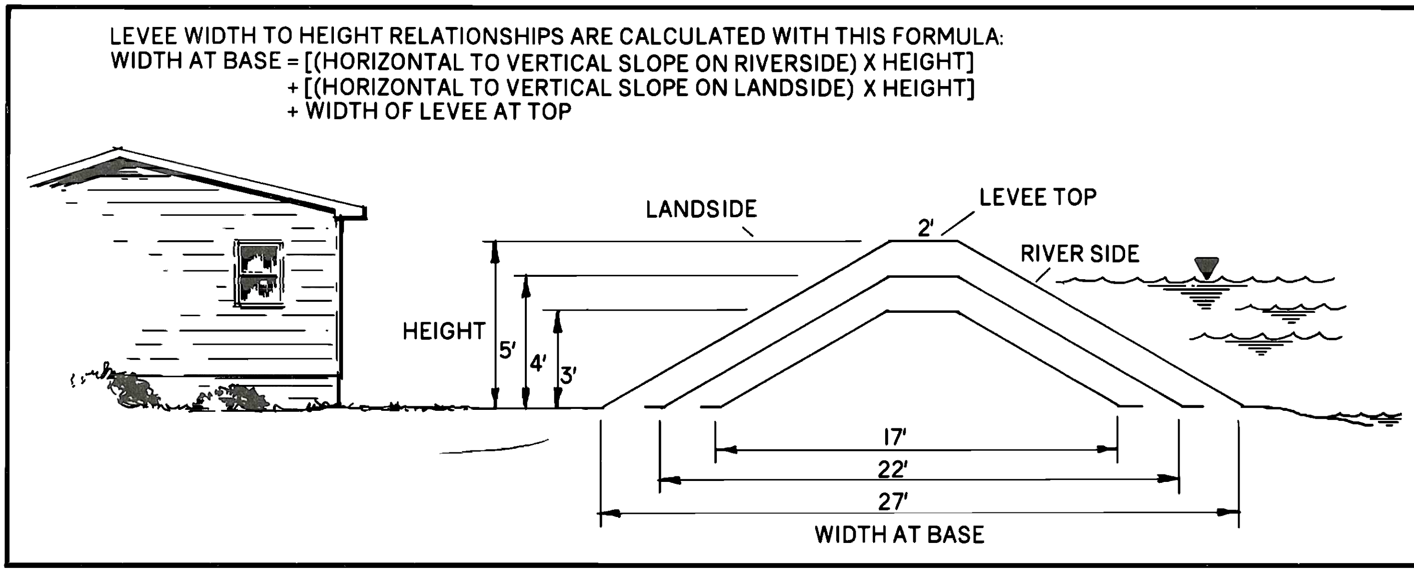


FIGURE 5-2. Levee Width to Height Relationships

Another major drawback to constructing levees is that they take up a great deal of property space. To minimize scour and erosion and to provide adequate stability, their embankment slopes have to be fairly gentle, usually a ratio of one vertical to two or three horizontal. Because of this, their width will be several times their height.

For example, a levee three feet high and two feet wide at the top with a horizontal to vertical slope of three on the riverside and two on the landside would have a base width of 17 feet. A levee that was four feet high, with two feet at the top, would be 22 feet wide at the bottom.

FIGURE 5-3. *By using a levee as a retrofitting technique, a homeowner may not have to alter the structure in any way.*

An important factor in determining the feasibility of a levee involves the availability of suitable fill material for the levee, as well as the adequacy of the underlying soil which must support the levee. Most types of soils are suitable

RESTRICTIONS ON BUILDING IN THE FLOODWAY

The floodway is the central portion of the floodplain that carries the greatest amount of the waterflow during a flood. Many communities have adopted statutes defining a regulatory floodway. This is the portion of the floodplain necessary to discharge a 100-year flood without increasing water levels elsewhere on the floodplain by more than a designated height, usually one foot. The primary purpose of a floodway is to allow for the discharge of flood waters without any increase in flood levels upstream.

The relevant section of the general provisions of the National Flood Insurance Program reads: "Communities in the program shall prohibit encroachments, including fill, new construction, substantial improvements and other development within the adopted regulatory floodway that would result in any increase in flood levels within the community during the occurrence of the base flood discharge."

for constructing most residential levees. The exceptions are very wet, fine grained or highly organic soils. The best soils are those which have a high clay content, and are therefore highly impervious. Impervious soils minimize seepage problems either through or under the levee system.

FIGURE 5-3a.

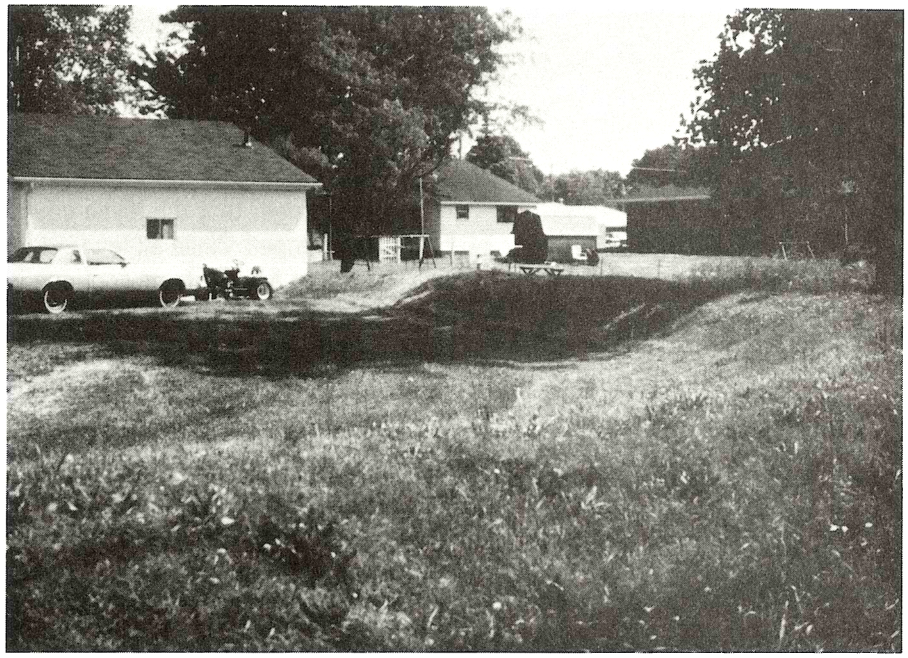
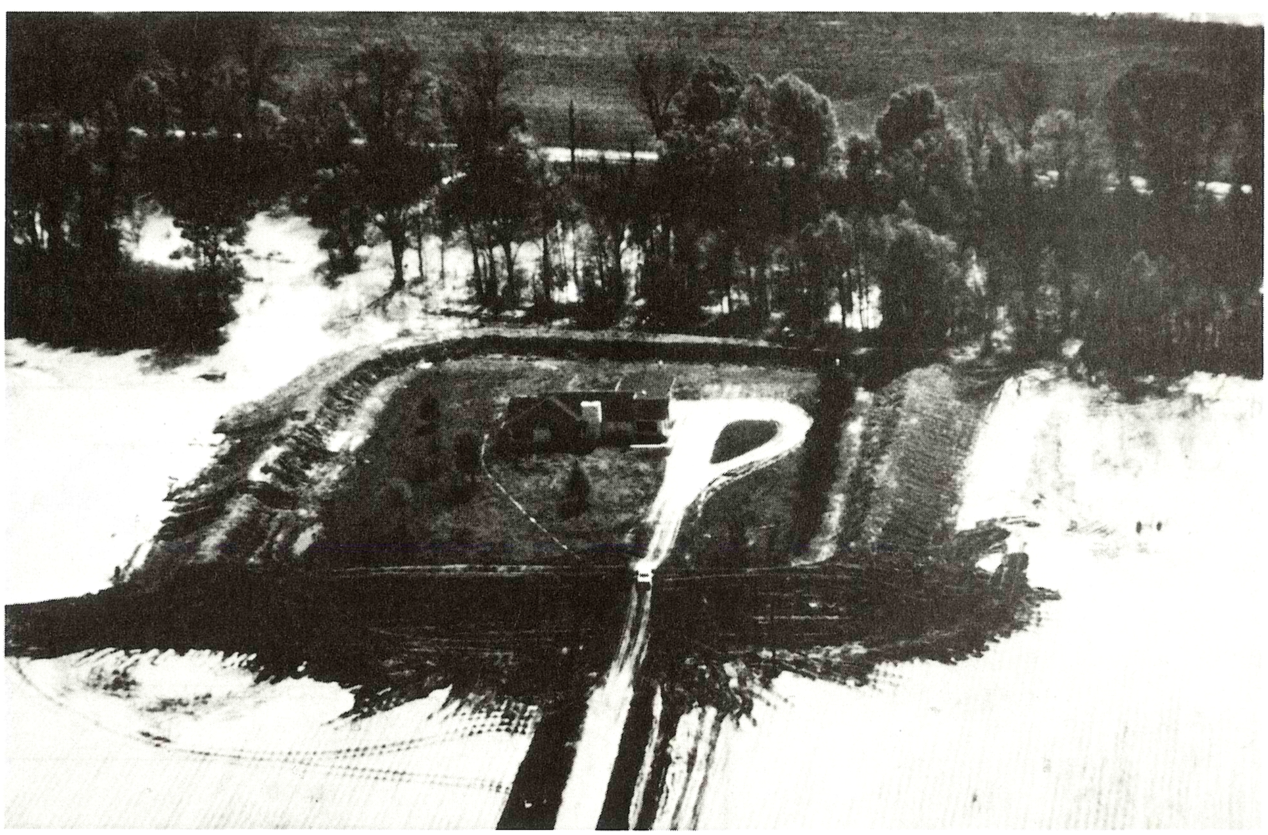


FIGURE 5-3b.



Because of the importance of these soil factors, such as soil bearing capacity, permeability, and depth to impervious soil layers, the services of a soils or foundation engineer should be utilized. In cases where the soil is known to be impervious, and the height of the levee does not exceed two feet, such consultation may not be required.

In those cases where suitable fill material is not locally available, the expense of transporting proper material to the site can be significant. This additional cost could be a major factor in determining the feasibility of this option.

Levees are most effective against floods that rise slowly, have little velocity, and do not last more than 3 to 4 days. If a flood has a high velocity, there is the danger that the levee could collapse due to scouring or erosion of the side slopes. While all levee slopes should have vegetation, one way to further protect a levee from scouring is to armor the vulnerable areas with resistant material. Effective armoring techniques include securely anchoring railroad ties to the slope, the placing of riprap (large broken rock), the use of gabions (groups of rock bundled together with wire), or the laying of concrete mats.

The proper alignment and configuration of a levee can also help minimize the potential of failure. If the levee is oriented so that it is parallel to the water flow, then resistance to scour and erosion is lessened. Similarly, reducing the angle of the slope will reduce the potential of scouring.

Constructing a levee around a house will not only keep water out, but it could also keep water in. One method of draining water that collects naturally from rain and from seepage through and under a levee is to install drain tiles that extend through the levee. While this will allow for drainage by gravity, the drains must be equipped with **check valves**, designed to close automatically

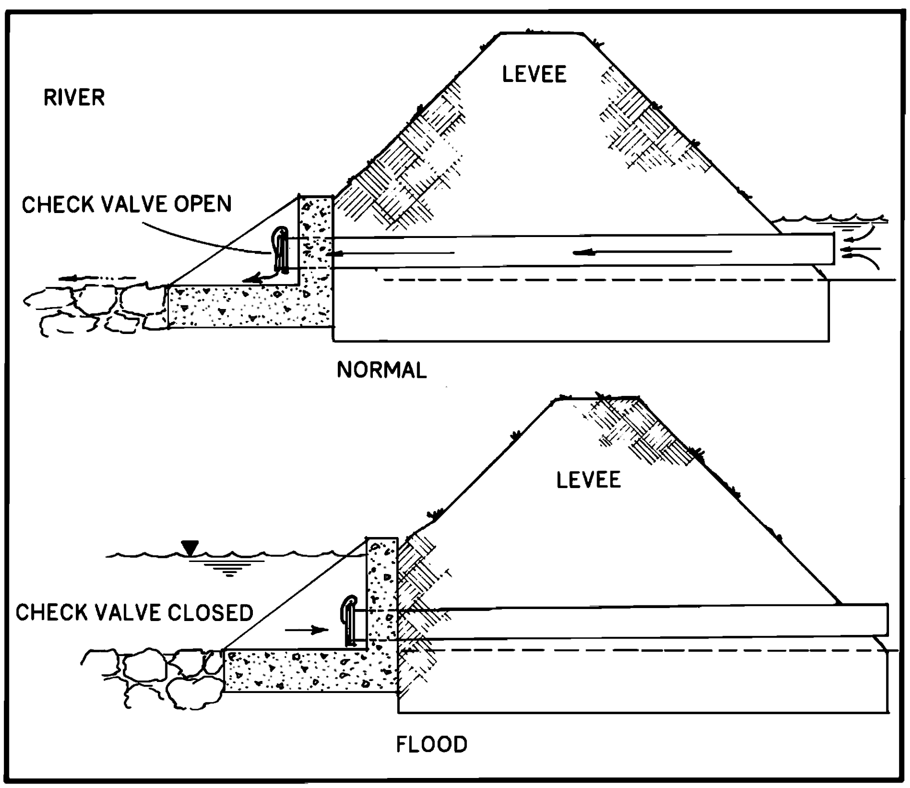


FIGURE 5-4. *Check valves drain water from within a protected area but prevent backflow of flood waters. They are placed at drainage points inside the levee.*

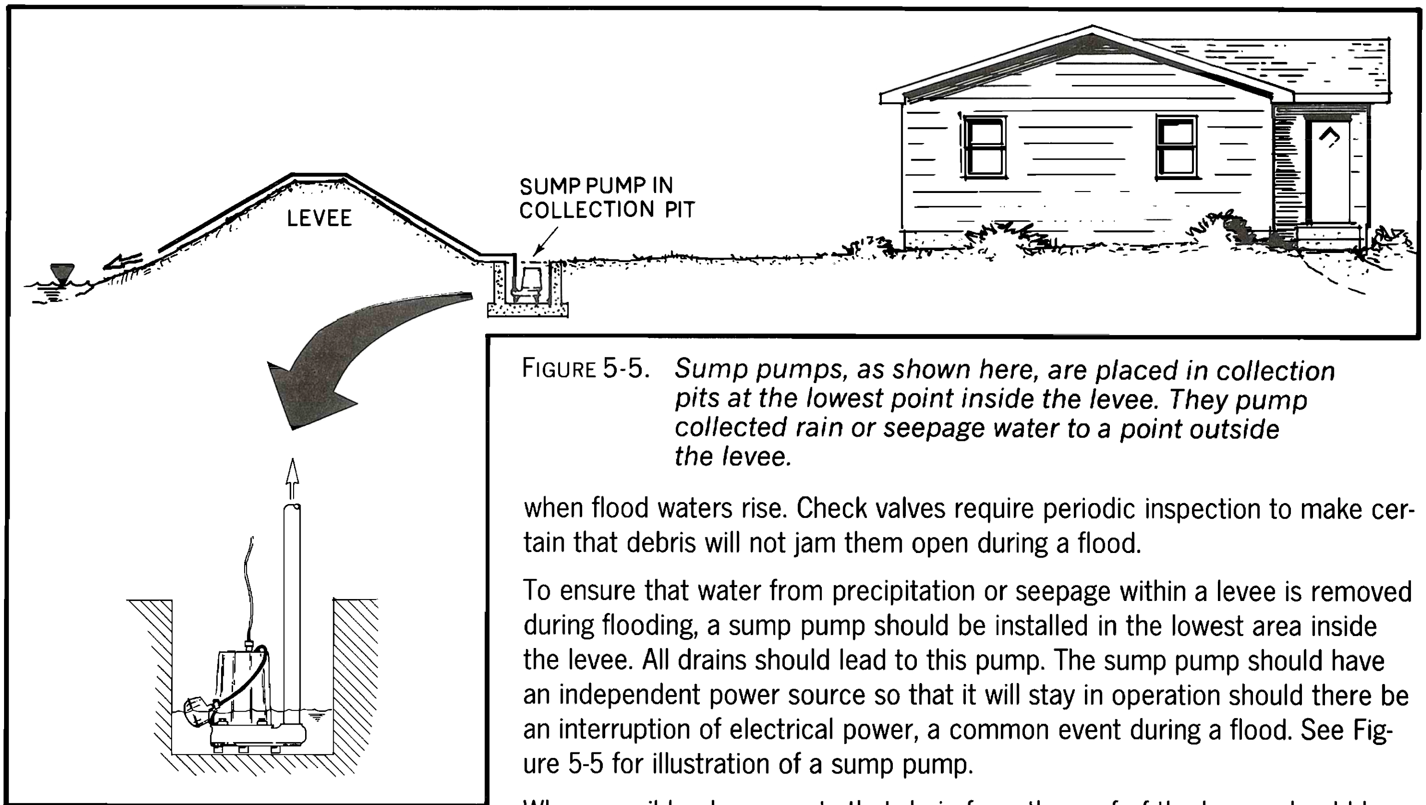


FIGURE 5-5. *Sump pumps, as shown here, are placed in collection pits at the lowest point inside the levee. They pump collected rain or seepage water to a point outside the levee.*

when flood waters rise. Check valves require periodic inspection to make certain that debris will not jam them open during a flood.

To ensure that water from precipitation or seepage within a levee is removed during flooding, a sump pump should be installed in the lowest area inside the levee. All drains should lead to this pump. The sump pump should have an independent power source so that it will stay in operation should there be an interruption of electrical power, a common event during a flood. See Figure 5-5 for illustration of a sump pump.

When possible, downspouts that drain from the roof of the house should be directed over the levee so that they do not contribute to the collection of water.

A backwater valve should also be installed in the building's sanitary plumbing system as shown in Figure 5-6. This will prevent flood waters from flowing back through the sewer system and entering the house.

Once the levee is completed, it is important that there be a continuous inspection and maintenance program. Otherwise, small problems, such as erosion, settlement, cracking, or loss of vegetation could quickly become a major problem in the course of a flood. At a minimum, these inspections should be performed in the spring and the fall, as well as immediately after a flood.

Levees offer substantial protection from flooding in many cases, but the homeowner should not be lulled into a false sense of security. There are many precautions that still need to be taken.

A levee can fail due to overtopping by a larger flood than that for which it was designed. If that occurs, damage to the structure will be just as great, and it may take longer to remove the water from inside of the levee than it takes for flood levels to subside.

In an emergency, where flood waters are threatening to overtop a levee, it may be possible to raise the height temporarily with sandbags. But higher

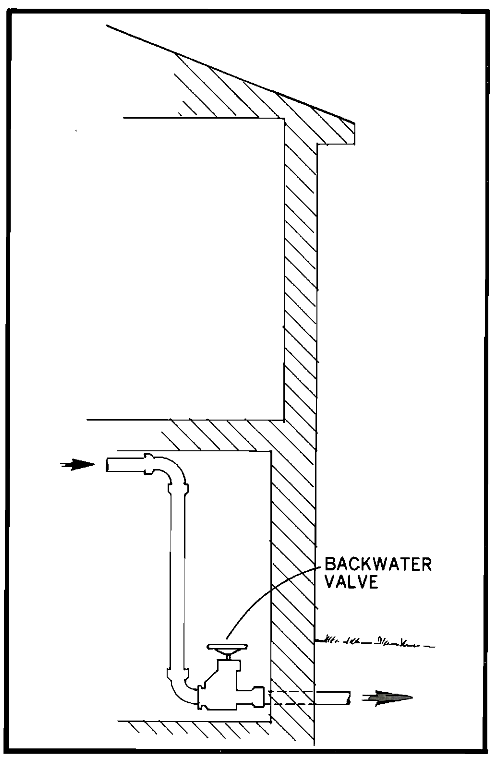


FIGURE 5-6. *Backwater valves prevent backflow of sewage water into residences during flooding. A variety of manual and automatic backwater valves are available.*

flood waters exert more pressure on the entire levee. If the levee does fail, the onrush of water and damage to the house may well be greater than if there had been no levee originally.

Levees can also fail when water pressures weaken the system. This will most likely occur when the levee becomes saturated, either because improper soil was used, or because of prolonged exposure to flood waters. In addition, failure can occur if the levee is subjected to fast currents that can cause scour or erosion. This condition can also be worsened by water-borne debris impacting on the levee.

The most important consideration of all is that the homeowner who has constructed a levee not have a false sense of security about the property's protection. Every flood is different, and the one that exceeds levee design height and floods the house can happen at any time. For this reason the flood areas should always be evacuated.

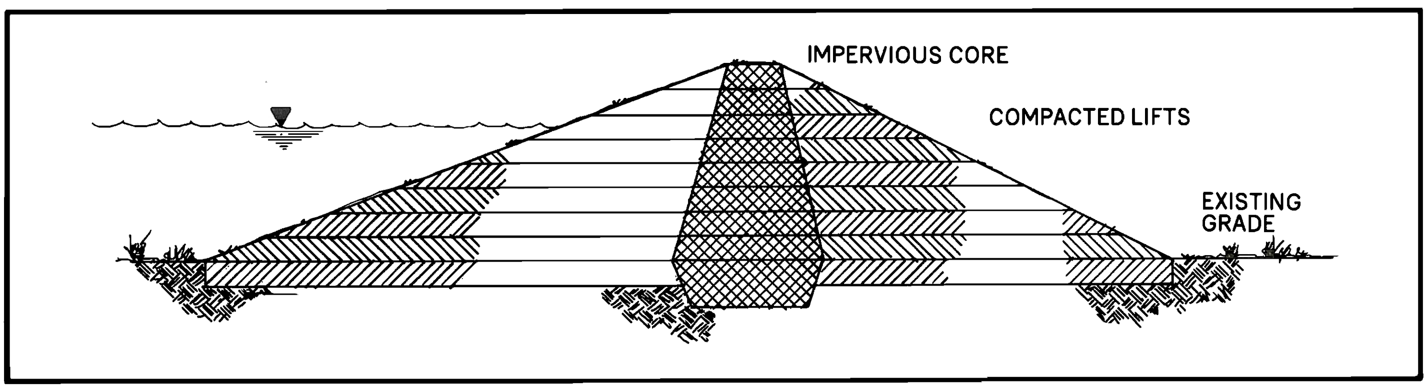
5.3 CONSTRUCTION TECHNIQUES

A homeowner deciding to construct a levee should try to take advantage of the natural terrain around the home. Depending on the ground elevations, it may not have to completely encircle the residence, but could be built on lower terrain and then tapered out or tied into the higher slopes. This technique has the added advantage of blending with the natural topography of the lot.

To prepare for the construction of a levee, all ground vegetation and topsoil should be removed at the levee site. The sod should be set aside and saved for surfacing the levee when it is finished.

As the levee is constructed, it should be built up in layers, each of which must be individually compacted. Each layer, or **lift**, should be no more than six inches deep. (See Figure 5-7.)

FIGURE 5-7. *Levees are constructed by building up compacted layers of soil called lifts. A core of impervious soil can help prevent seepage.*



If there is a shortage of impervious soils in the area, then the core of the levee can be made a barrier to water by a variety of measures. By constructing the core of the levee with impervious soils or another type of barrier and using permeable soils on the outside, seepage through the levee can be minimized. However, the use of permeable soils means that the angle of the slopes will have to be reduced to control scour and the base of the levee will increase proportionately.

If the soil under the levee is particularly permeable, then underseepage may be prevented by using a sheet pile core or other impervious barriers. Further information on these devices is provided later in this chapter.

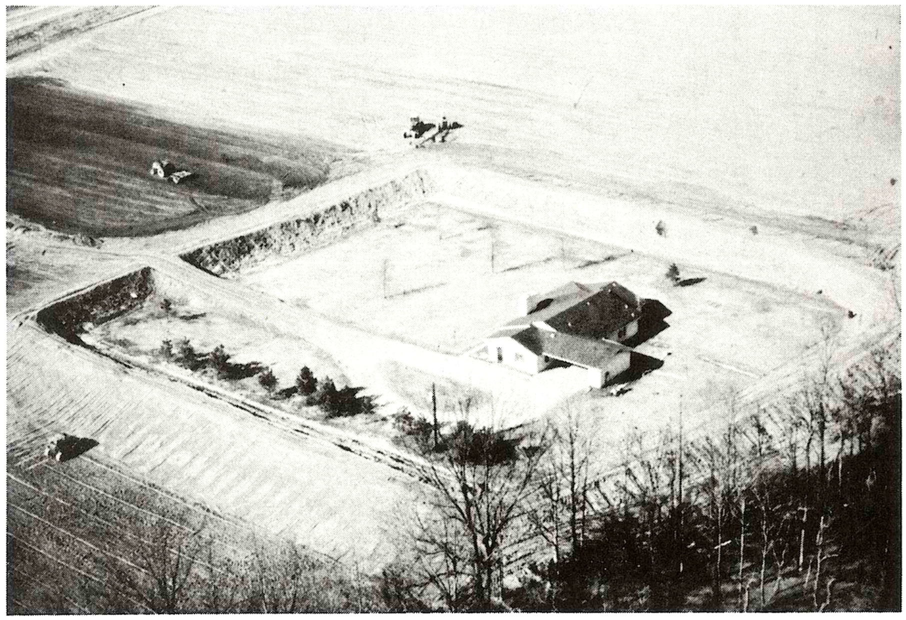


FIGURE 5-7a. *Pictured here is a levee in the process of construction.*

Another way to help stabilize a levee that might be threatened by internal seepage is to install some type of interior drain system to carry groundwater away from the levee. The shape and size of these drains will depend on such factors as the size of the levee, the nature of the underlying soil and the amount of seepage. Additional details, including illustrations, are also provided later in this chapter.

The design height of a levee is generally determined using base flood elevations. To provide a margin of safety, an additional height, known as **freeboard** is recommended. This freeboard allowance helps protect against wave action, scouring, overtopping, and other uncertainties involved in flood predictions. A minimum of one additional foot of height is recommended for levees less than three feet in height. For larger levees, freeboard of three feet is recommended.

In addition, the levee should be constructed at least five percent higher than the elevation desired to allow for soil settlement.

Because of problems with available space, material costs, and other drawbacks, there is a practical height limit to which a residential levee can be built. In practice, this limit is usually six feet. If flood threats could reach this height, it might be better to consider another retrofitting technique, such as elevation or relocation of the house.

Proper maintenance of a completed levee is extremely important. As a part of a regular inspection/maintenance program the area should be examined to locate any potential failure points, such as eroded portions or low spots. Immediate corrective action should be taken to repair these problems.

Any levee design should include a good ground cover on the top and slopes of the levee. Levee maintenance should include keeping the vegetation in good condition and preventing the intrusion of any large roots from trees or bushes, or animal burrows, since they can create openings in the levee through which water can follow, enlarging the openings.

The complete encirclement of a house with a levee can create access problems not only for the homeowner but for emergency vehicles. There are several ways of solving these problems. If the levee is low enough, additional fill material can be added to lower the angle in one area for a vehicle access ramp running over the levee. If it is necessary to have a gap in the levee, then this can be closed in case of flooding through the use of a gate or closure. Additional details are provided in Chapter 7, entitled "Closures."

5.4 COST GUIDELINES

Unit Cost

Construction unit prices in Table 6 may be used to estimate the cost of levee construction. The homeowner should also budget five percent of the total construction capital outlay annually for maintenance of the levee.

TABLE 6

UNIT COST ESTIMATING FOR LEVEES

ITEM	UNIT	UNIT COST 1985 DOLLARS	NO. UNITS NECESSARY	ITEM COST
1. Clearing & Grubbing	Acre	$250 - $300	________	________
2. Removal of topsoil	Sq. Yd.	$2.00 - $3.00	________	________
3. Compacted Backfill	Cu. Yd.	$3.00 - $8.00	________	________
4. Graded stone, in-place	Ton	$8.00 - $10.00	________	________
5. Drain tile 4" - 6", PVC in-place	Ft.	$6.00 - $10.00	________	________
6. Drain tile 8" - 10", PVC/RCP in-place	Ft.	$8.00 - $15.00	________	________
7. Sump pumps, gasoline powered to 3 Hp	Each	$800 - $1,100	________	________
8. Sump pumps, gasoline powered 3 to 8 Hp	Each	$1,500 - $2,000	________	________

TABLE 6
(CONT.)

UNIT COST ESTIMATING FOR LEVEES

ITEM	UNIT	UNIT COST 1985 DOLLARS	NO. UNITS NECESSARY	ITEM COST
9. Discharge piping, sump pump 1"-2"	Ft.	\$3.00 - \$6.00	________	________
10. Seeding	Sq. Yd.	\$1.00 - \$1.50	________	________
11. Borrow Material 1-5 mi. haul	Cu. Yd.	\$1.50 - \$4.00	________	________
12. Borrow Material 5-15 mi. haul	Cu. Yd.	\$2.50 - \$6.00	________	________
13. Cut-off sheet pilings, driven, in-place	Sq. Ft.	\$10 - \$15	________	________
14. Riprap (150 lb.), in-place	Sq. Yd.	\$40 - \$50	________	________

Typical Example

- Cost Estimate—Levee 3 ft. high, 216 feet long, to protect a 1,600 sq. ft. house[1], Montgomery County, Maryland.

ESTIMATED COST (Expressed in 1985 Dollars)[2]

ITEM	
1. Import and compact levee fill	\$ 2,233.00
2. Relandscape	1,990.00
3. Remove and replace concrete driveway and walk	5,712.00
4. Modify interior drainage, install sump pump	2,373.00
5. Sewer gate valve	585.00
Total First Cost	\$12,893.00

5.5 TECHNICAL DESIGN CRITERIA

There are several elements to properly designing and constructing a functional and reliable levee system. These include using a proper soil with sufficient impermeability, adequate site preparation and compaction techniques, and suitable seepage and drainage controls.

[1]Montgomery County, Maryland, Dept. of Environmental Protection, Manual for Nonstructural Flood Damage Reduction
[2]Robert Snow Means Company, Inc., Building & Construction Cost Data, 1976–1985

Soils and Compaction

A principal concern for the construction of the levee is the availability of suitable fill. In order to be feasible, the **borrow area** should be located near the site, and the soil should be tested by a soils engineer to determine its suitability. This may not be necessary if soil is known to be impervious and levee height is two feet or less. Because many soils are suitable for levee construction (except wet fine-grained, highly organic, or highly permeable soils), the location of the borrow site is usually the controlling factor. Compaction should be performed at or near optimum moisture content with pneumatic tires, sheepfoot rollers, or other acceptable compaction equipment. Fill should be placed in layers not exceeding 6 inches and compacted to the Standard Proctor density (ASTM D698) prescribed by the soils engineer.

Seepage

The properties of both levee fill material and underlying soils will determine the need for seepage and drainage control measures on levees. Various soil types and their permeabilities are provided in Tables 7 and 8.

TABLE 7

SOIL TYPES

Material	Clay, %	Silt, %	Sand, %	Approximate permeability, gpd/sq. ft.
Clay	30-100	0-50	0-50	10^{-4}
Silty clay	30-50	50-70	0-20	10^{-3}
Sandy clay	30-50	0-20	50-70	10^{-3}
Silty clay loam	20-30	50-80	0-30	10^{-2}
Clay loam	20-30	20-50	20-50	10^{-2}
Sandy clay loam	20-30	0-30	50-80	10^{-2}
Silt loam	0-20	50-100	0-50	10^{-1}
Loam	0-20	30-50	30-50	10^{-1}
Sandy loam	0-20	0-50	50-80	1
Sand	0-20	0-20	80-100	Over 10

Where foundation soils are highly permeable (consisting primarily of sandy loam soils), impervious cutoffs should be used to reduce seepage. These cutoffs can include sheet pile metal curtains, cementitious grout curtains, or compacted impervious fill in the levee foundation design. However, such measures are generally very expensive and beyond the financial capabilities of most homeowners. These methods are usually incorporated in large levee design projects undertaken for protection of industrial sites or larger land areas such as development sites. With these types of pervious soils, a professional soils engineer should always be consulted.

TABLE 8

APPROXIMATE PARTICLE SIZE AND PERMEABILITY OF VARIOUS SOILS

Material	Particle Size,* mm	Approximate permeability gpd/sq. ft.
Clay	0.0001 - 0.005	10^{-5} to 10^{-2}
Silt	0.005 - 0.05	10^{-2} to 10
Very fine sand	0.05-0.10	10 to 50
Fine sand	0.10-0.25	50 to 250
Medium sand	0.25-0.50	250 to 1,000
Coarse sand	0.50-2.00	1,000 to 15,000

*1 mm = 0.03937 in.

Source: Water Resources Engineering
Linsley and Franzini, 1964

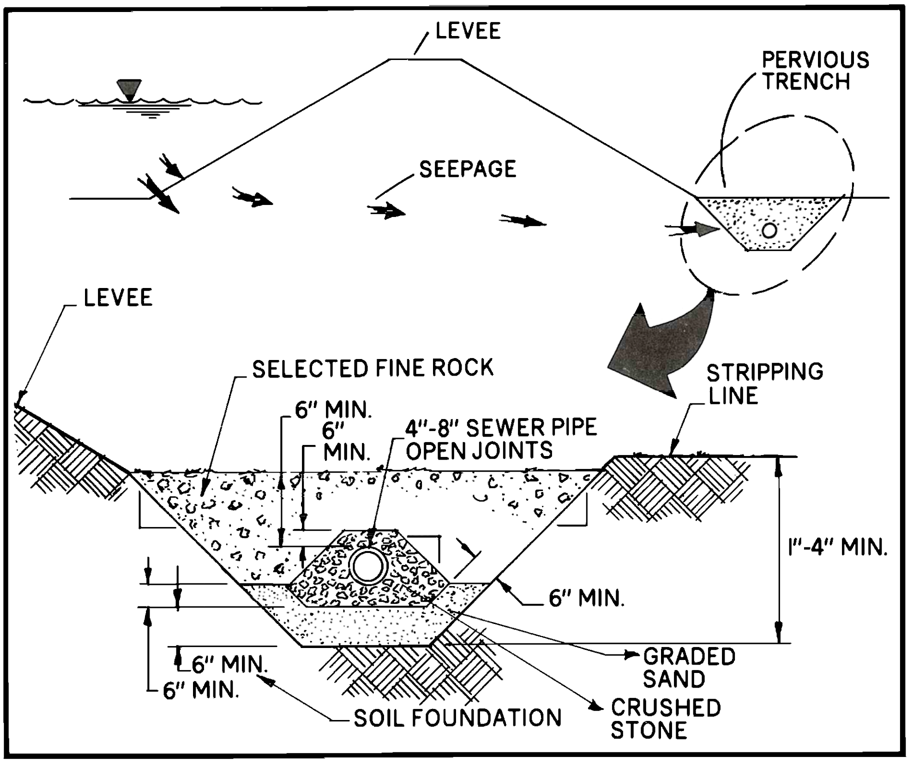
In cases where seepage must be controlled through layers of pervious and impervious foundation and levee embankment soils, controls such as pervious trenches, pressure relief wells, drainage blankets, and drainage toes are more suitable and should be employed.

Two types of seepage must be considered in the design of a residential levee system: foundation seepage and embankment seepage. The amount of seepage will be directly related to the type and compaction of soils in both the foundation and the levee. The pervious trench and pressure relief well controls are meant to address foundation seepage, while the drainage blanket and drainage toe solutions are meant to address embankment problems.

In each of these cases, the measure is designed to relieve the pressure of flood waters on the river side of the levee so that piping may be avoided. Piping is the creation of a flowpath for water through a soil structure such as a levee, dam, or other embankment, resulting in a pipe carrying water through the structure. Piping becomes a more serious problem as the permeability of the foundation soil increases.

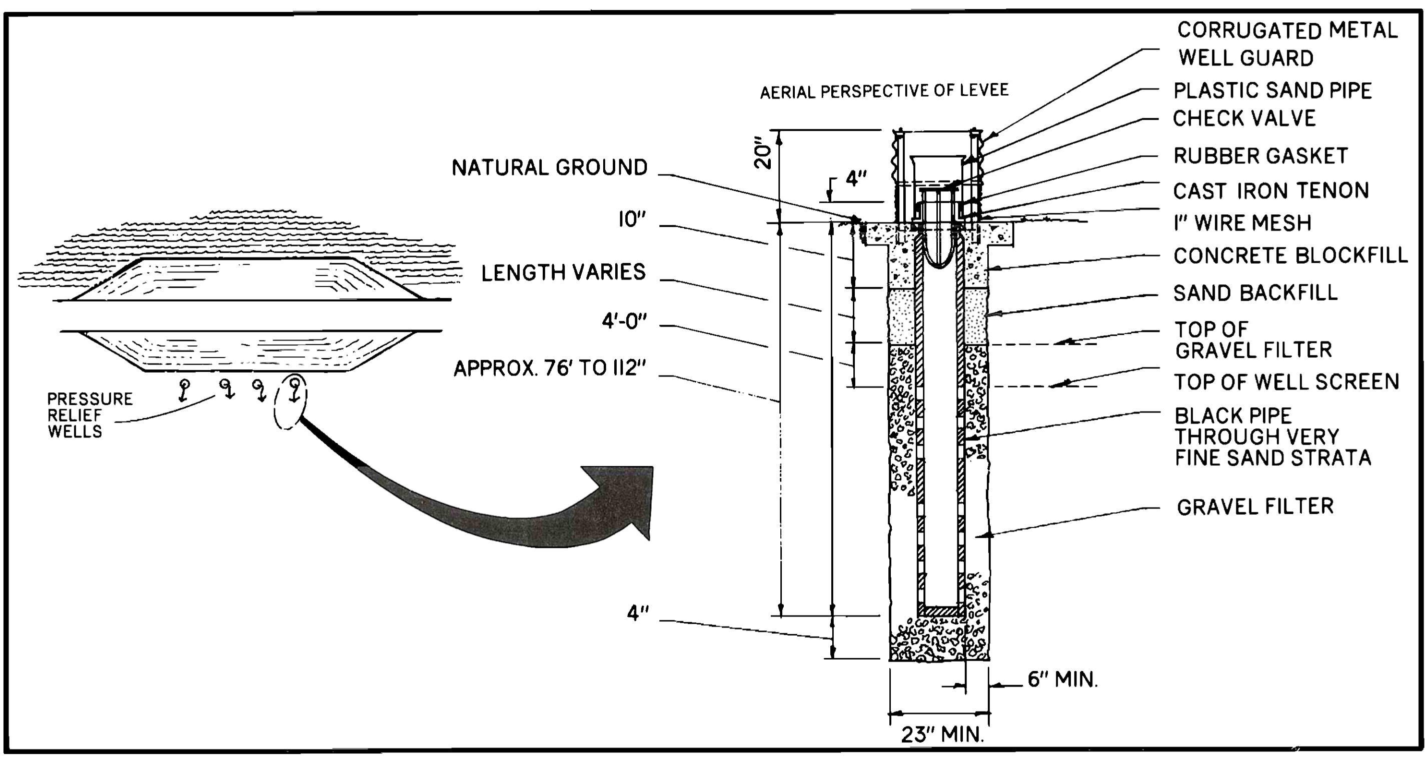
Foundation seepage can be controlled through the use of a pervious trench (see Figure 5-8), which incorporates a trench at the foot of the levee's interior slope. The drainage trench consists of a drain pipe surrounded by a soil/ gravel filter. Normally, the filter consists of two layers and the material is graded in such a way that neither the foundation nor the levee structure particles can penetrate and clog the filter. Generally, filter layers are placed from finer particle layers to more coarse particle layers from the periphery of the drain to the center of the drain. A drainage pipe then carries the seepage water to a collection pool where it can be pumped out.

FIGURE 5-8. Pervious Trench



A second method of controlling foundation seepage is a pressure relief well. This well is a drainage pipe augered into the ground at the foot of the levee interior. Typical construction of the pressure relief well is shown in Figure 5-9. Water seeping through the levee foundation may be pumped from these pipes to a holding location or outside the levee.

FIGURE 5-9. Pressure Relief Wells

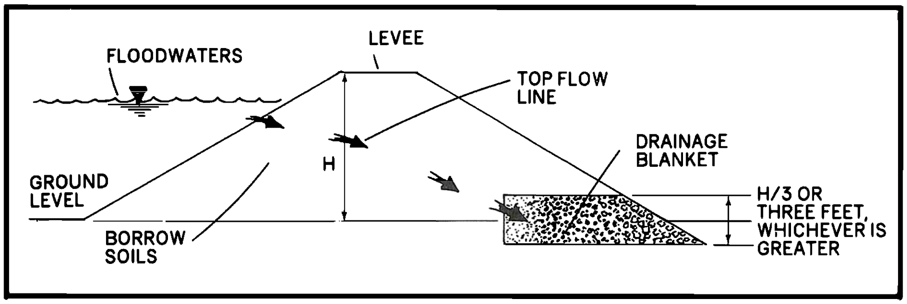


Both the pervious trench and pressure relief well solutions also lend themselves to situations where an existing levee is experiencing seepage problems. Either solution can be accomplished without disturbing the levee structure itself.

When the soil used in constructing the levee is pervious, controls to reduce embankment seepage may be required. The two most common measures are drainage blankets and drainage toes.

The drainage blanket (see Figure 5-10) is a horizontal filter laid on the levee foundation at the landward side of the levee and under the levee body. In some cases, it can be incorporated into the levee body as the extension of its interior slope. The filter material is graded from relatively fine near the center of the levee to coarse near the landward edge of the drainage blanket. This prevents the movement of fine particles from the levee body into the filter.

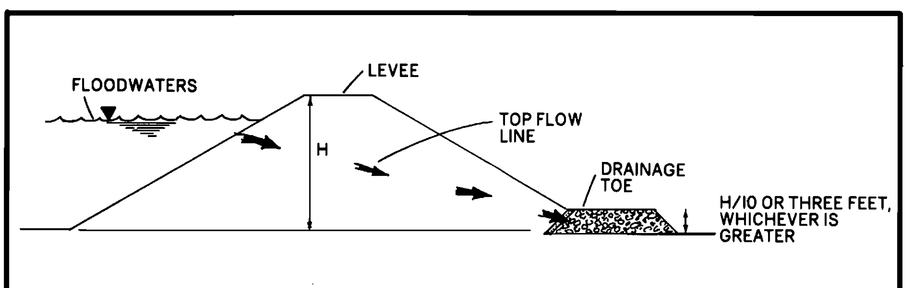
FIGURE 5-10. Drainage Blanket



The drainage blanket controls the top flow line of seepage through the levee. The top flow line is that point at which seepage water exits the levee's interior embankment surface. Placing the drainage blanket closer to the headwater will lower the position of the top flow line. In some cases, incorporating a drainage blanket will allow the building of a levee with steeper interior slopes.

The drainage toe solution to seepage problems (see Figure 5-11) is similar in design to the drainage blanket except that it incorporates the filter material in a step on the landward side of the levee at its base. Again, the filter material is graded from relatively fine at the levee side to coarse at the most landward side of the step. As with the drainage blanket design, this prevents the movement of fine particles from the levee body into the filter step. The drainage toe likewise controls the top flow line of seepage, thus providing protection of the levee itself from damage due to seepage.

FIGURE 5-11. Drainage Toe



The drainage blanket and drainage toe solutions can be expensive options, requiring a detailed engineering analysis to determine top flow conditions and local availability of suitable filter material. In fact, properly constructed drainage blankets and toes may be more costly than the levee itself. Depending on the nature of flooding and value of the protected property, though, they may be options worth serious consideration.

The decision of which controls should be used is largely a measure of which type of seepage is occuring (foundation vs. embankment) in combination with an on-site analysis of the soils. If foundation soils are permeable, the pervious trench or pressure relief well solutions should be considered. If the borrow soil for the levee includes permeable soils, a drainage blanket or toe should be considered. The size of the controls will be dependent on the depth, duration, and frequency of flooding, as well as the types of soils existing in the foundation and the levee structure itself. In all cases where pervious soils are used in the construction, a professional soils engineer should be consulted on seepage control measure designs.

Embankment Stability

Slope stability of levee embankment is related to the resistance of a given embankment to soil slippage, or the tendency of soil to move to a more stable angle. Two modes of shear failure for a levee embankment are the rotational slide, approximated by a circular arc; and the translatory slide, occuring along a definite plane of weakness near the base of the embankment. When moderate side slopes are used, such as 3:1 on the water side and 2:1 on the protected side, then detailed stope stability studies are generally not required. For a more detailed discussion of slope stability, refer to U.S. Army Corps of Engineers, Design and Construction of Levees [EM 1110-2-1913].

Scouring

The waterside of the levee embankment requires protection from excessive velocities or erosion may result. For potential flow rates up to three feet per second, sodded embankment will generally provide adequate erosion protection. Some vegetative covers, such as Salix species, Ligustrum vulgare and Red Twig Dogwood offer erosion protection up to five feet per second. Generally, if flow rates can reach five feet per second, the embankment should be protected using a riprap layer of a minimum one foot thick with a minimum stone size of 150 pounds. Velocities above five fps will require a greater thickness of riprap. However, if velocities can exceed eight feet per second, the scour potential becomes so great that a different retrofitting method should be considered.

Interior Drainage

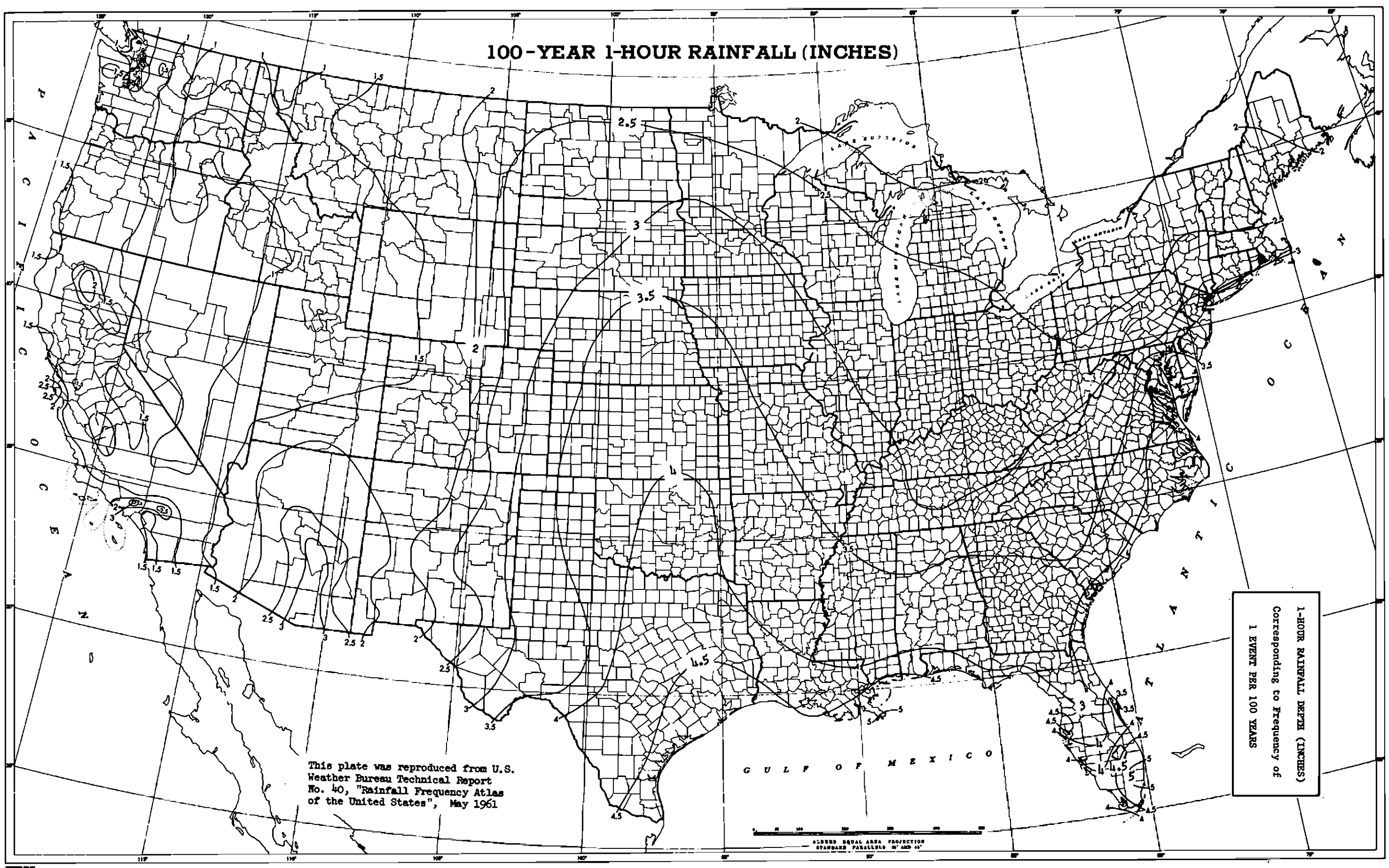
The drainage system for the interior area enclosed by a levee must accommodate the precipitation runoff from this interior area and the anticipated seepage from the levee during flooding conditions. The design of the drainage system for a levee can also be applied where floodwalls are used, as described in Chapter 6.

A means of positive drainage for the interior of the floodwall or levee area is needed to discharge the accumulated water to the outside of the enclosed area. First, a collection system composed of pervious trenches or underground tiles must be designed to transport the accumulating water to a sump area. In the levee application, these drains should be incorporated into the collection system. The anticipated seepage from under and through levees and floodwalls must also be taken into consideration.

To determine the amount of precipitation that can collect in the enclosure, P(a), the rainfall intensity, i, must be determined for a particular location. This is shown in Figure 5-12, and is given in inches per hour. This value should be multiplied by both the area enclosed by the levee in square feet and a conversion factor of 0.01. The answer will be given in gallons per minute.

$$P(a) = i\,(A_L)\,0.01$$

FIGURE 5-12. Rainfall Intensity for 100-year, 1-hour Duration for United States



In some cases, a levee or floodwall may only extend partially around the property and tie into higher ground. For these cases, the amount of precipitation that can flow downhill as runoff into the enclosure, P(f), must be included. To calculate this value, the area of land, A, in acres, that can discharge water into the enclosure should be estimated. This value is then multiplied by the previously determined rainfall intensity, i, and by the most suitable terrain coefficient provided in Table 9. The product of these three values is the rate of flow in gallons per minute into the enclosure.

$$P(f) = 450CiA$$

TABLE 9
TERRAIN COEFFICIENTS

Roof	.85
Street, parking lot	.85
Urban area, paved areas	.80
Industrial area	.70
Residential area (homes or apartments)	.60
Unimproved vegetated areas	.20
Grass area	
grade is 7 percent or more	.25
grade is 2 percent to 7 percent	.15
grade is flat to 2 percent	.10

Seepage flow rates from the levee, P(s), must also be estimated. In general, unless this seepage rate is calculated by a qualified soils engineer, a value of one gallon per minute for every 100 square feet of levee interior slope should be assumed.

$$P(s) = \frac{\text{levee ht.} \times \text{levee length}}{100}$$

The values for precipitation within the enclosed area, runoff from uphill areas draining into the enclosure, and seepage through the levee should be added together, and the sum multiplied by a safety factor of 1.5. The result is the minimum discharge size in gpm of the sump pump.

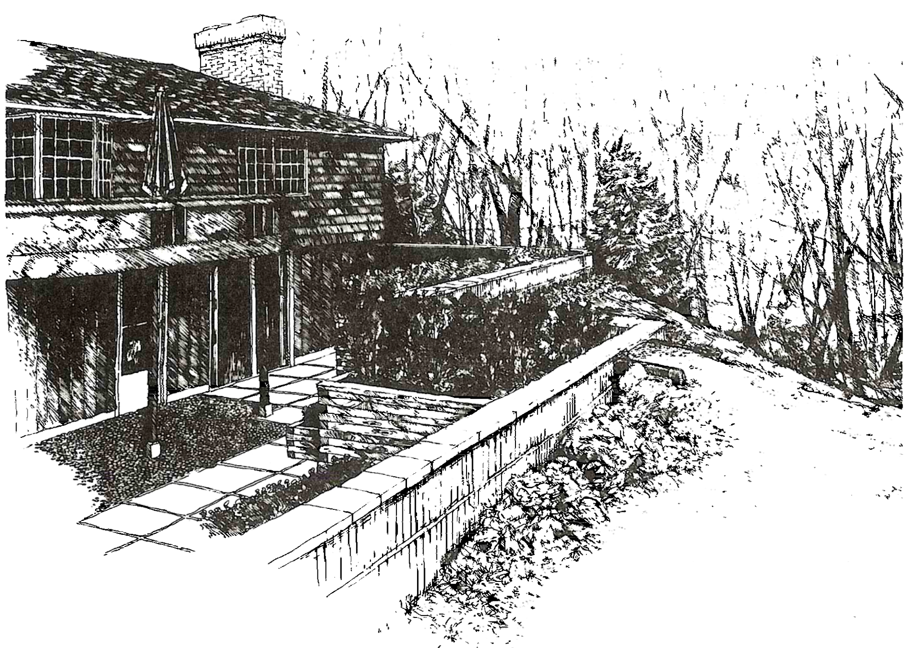
The sump pump used to discharge the collected water from the levee interior should be a submersible-type model mounted in the sump basin with a backup electrical generator. The backup electrical generator should be available during power outages, which often happen during flooding conditions. Under normal circumstances, the electrical service from the house can operate the pump. The pump controls should consist of three float-type mercury tube switches to activate the pump, turn it off, and to signal high water levels. The pump motor should be able to operate, without damage, when the sump is dry. The pump motor should be fully submerged in an oil-filled chamber providing efficient heat dissipation, permanent lubrication, and sealing for complete protection from the environment. The pump should have a semi-open, non-clog type impeller capable of passing a 2-inch solid sphere without damage. The housing should be cast iron with corrosion resistant fasteners and a mechanical seal between the pump and motor. A check and gate valve should be installed on the discharge piping.

An alternative might be a suction-type pump powered by a gasoline engine. A control system should consist of water level switches automatically operating an electric starter for the gasoline engine. The pump performance should match that of the submersible pump described above. The major disadvantanges of this system are the need for constant monitoring of fuel levels, and the additional cost of control and starter implementation.

Chapter 6

FLOODWALLS

Floodwalls are barriers of man-made materials that can be used to protect a structure from flooding. A floodwall can be constructed using a variety of designs and materials and can be used to protect practically any type of structure. Designed to not only protect a house, floodwalls can also enhance its appearance.



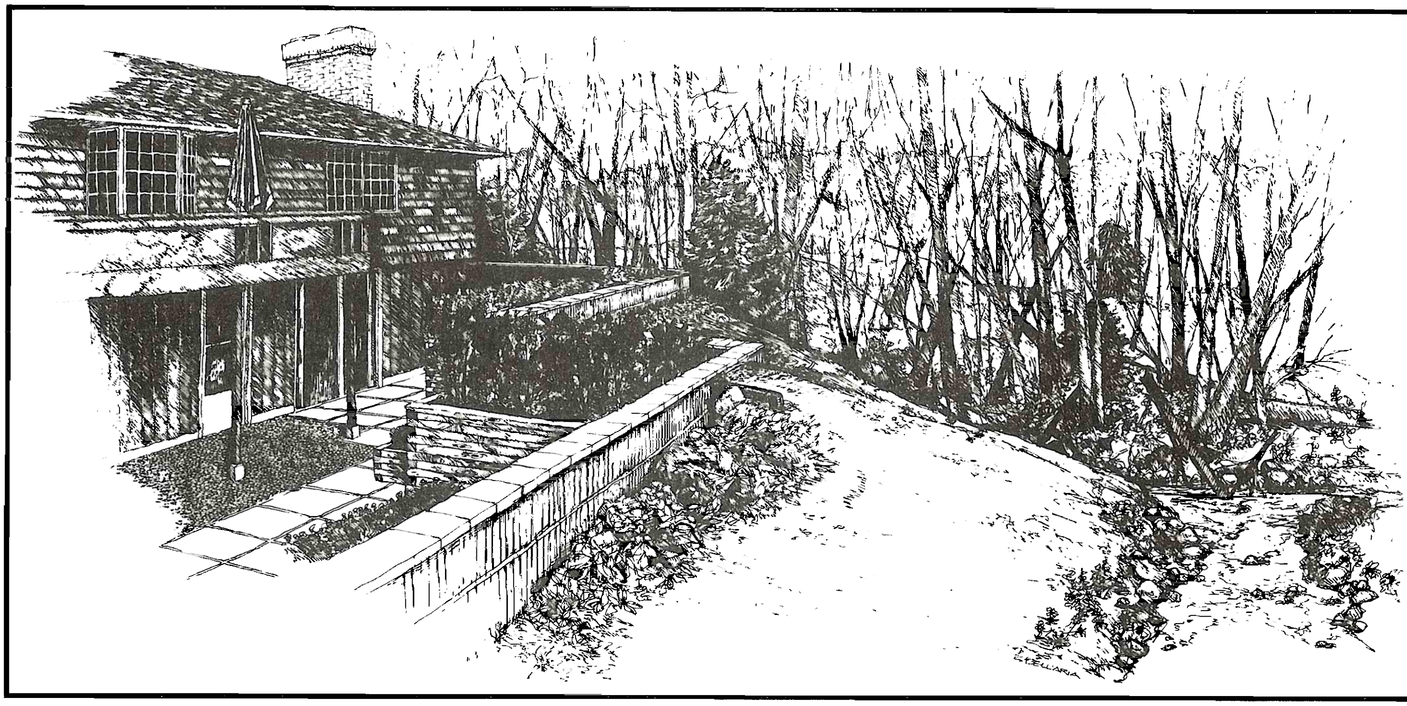


FIGURE 6-1. Detailed Rendering of House Protected by Floodwall

6.1 INTRODUCTION

Floodwalls are barriers of man-made materials that can be used to protect a structure from flooding. Floodwalls can provide greater flexibility by keeping water away from the house, just as levees do. However, floodwalls are constructed of stronger materials, so they are thinner, take less space, and generally require less maintenance than levees.

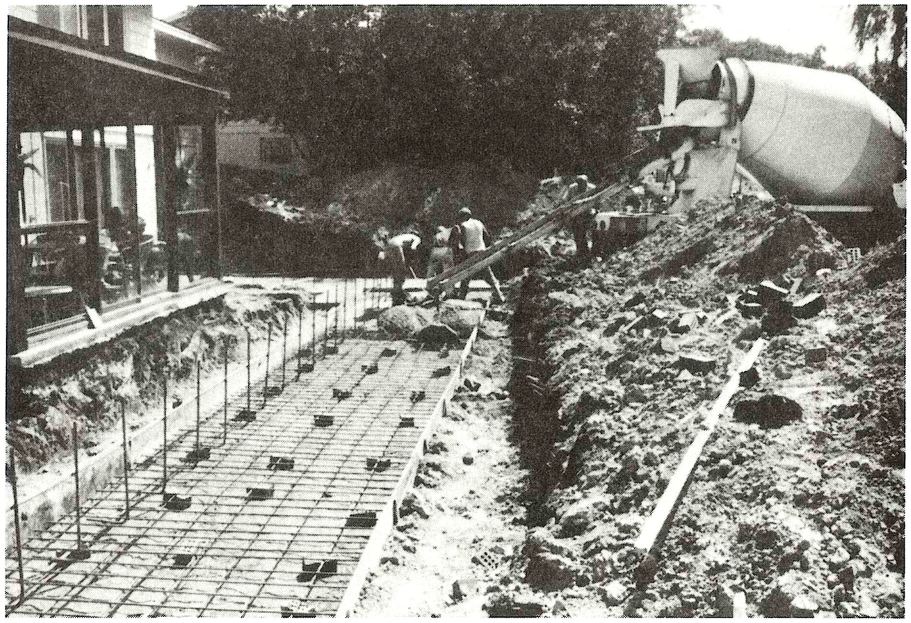
Floodwalls can be constructed using a variety of designs and materials. By taking into account the individual house design, siting and topography, and with some imagination, a floodwall can be constructed that not only protects a house, but also enhances its appearance. While some retrofitting techniques are limited to certain types of buildings, floodwalls can be used to protect practically any type of structure.

As with levees, floodwalls can protect several structures at once if they are clustered together. The floodwall can encircle an entire house or, depending on flood levels and topography, can be used to protect only the low side of the residence. If there is only a very low water threat, low floodwalls can be built around only the threatened openings, such as doors, window wells or basement entrances. In all cases, there are a number of elements that must be examined before constructing a floodwall.

6.2 CONSIDERATIONS

Selection of a floodwall design is primarily dependent on the type of flooding expected at the building site. Tremendous pressures can be created by high water levels and velocities. While it is possible to design for most flood forces, residential floodwalls are only practical up to a height of six feet. Fast moving water can also be a danger since erosion might undermine the floodwall or its footing and cause failure.

FIGURE 6-2. Floodwall Under Construction



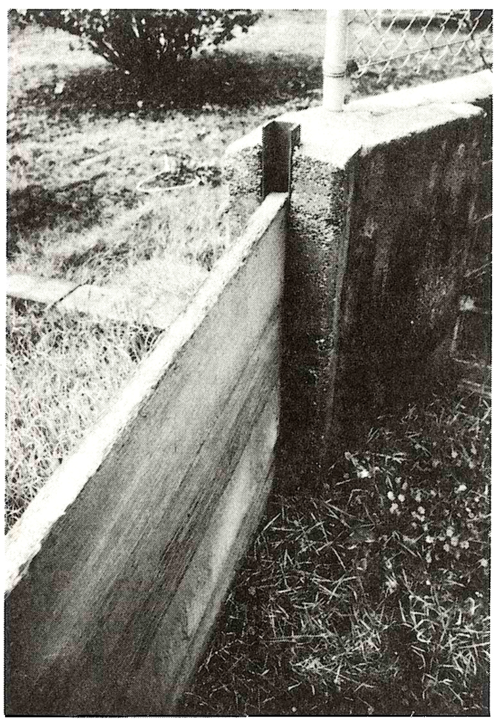


FIGURE 6-3. *This slide-in closure in California allows access through the floodwall, but can be secured when the Sacramento River floods.*

When designing a floodwall system, it must be verified that it will not obstruct the floodway or cause flooding of adjacent property by blocking normal drainage. Floodway considerations are outlined in the special section in Chapter 5. Additional information on drainage and floodway requirements can be obtained from a local zoning commission, building inspector, or local water control board. Before deciding on a design, a check should also be made of local building codes, zoning ordinances, or property covenants that might prohibit or restrict the type of wall planned.

Materials for floodwalls are generally more expensive than levees, and floodwall construction may require skilled labor. However, depending upon other considerations, this may still be a less expensive option than other retrofitting methods.

Driveways, sidewalks, and other entrances for the residence will require that gaps be provided in the floodwall. There are a variety of means of closing off these gaps at the time of flooding. The preferred types of closures include permanent ones, either hinged to the wall or designed to slide into a slot constructed in the wall and stored when not in use. Prefabricated closure panels that can be stored in a separate location are also acceptable alternatives.

Whatever style is used, closures must be secured tightly in place and incorporate a gasket to prevent leaking. In addition, the use of closures requires that someone be available when the flood warning is received to make sure that the closure is set in place. Chapter 7, "Closures," provides more information on protecting openings in a floodwall.

If a floodwall is low enough, access for a walkway may be provided by the construction of a low stairway, or **stile**, which extends over the floodwall.

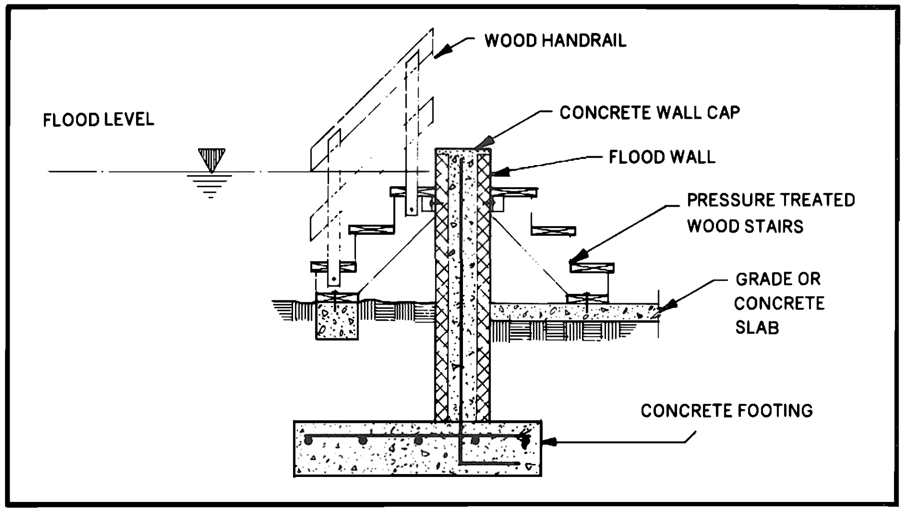


FIGURE 6-4. *Where a floodwall is low enough, access may be provided by a low stairway, or stile.*

A homeowner may find the floodwall a challenge to landscape or to blend into the terrain. By using the natural topography and employing waterproof decorative bricks or blocks, the floodwall can not only blend in with the house and landscape, but even make an area more attractive by creating a privacy fence, or by outlining patio and garden areas.

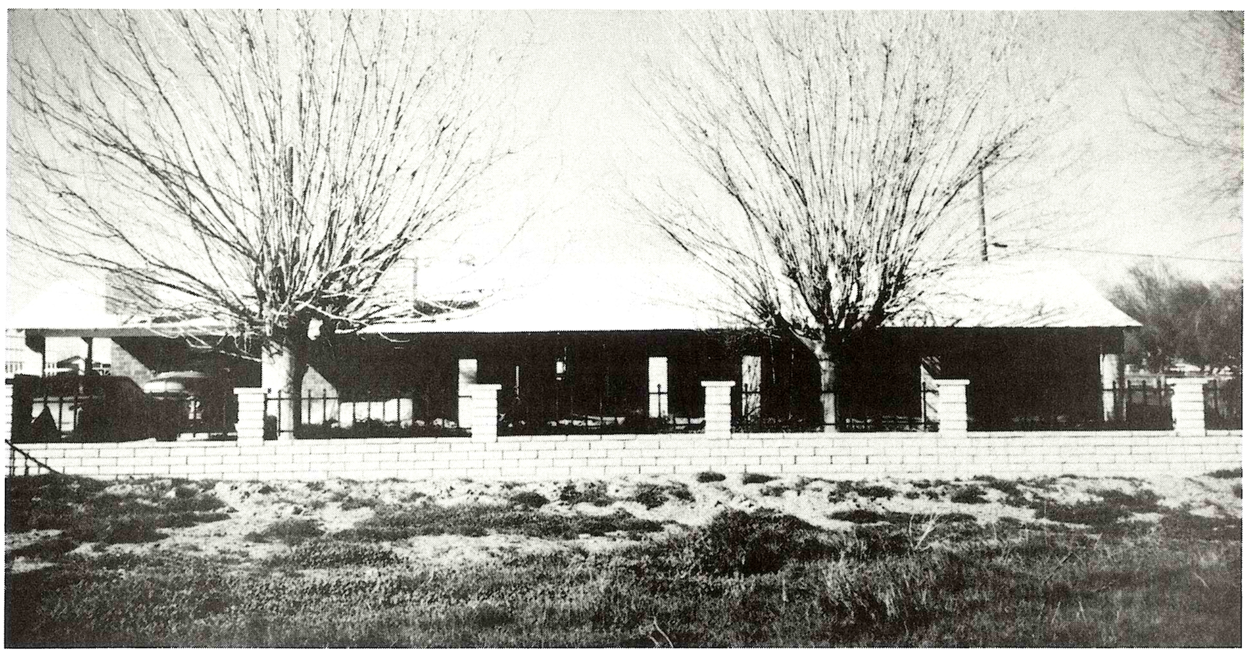


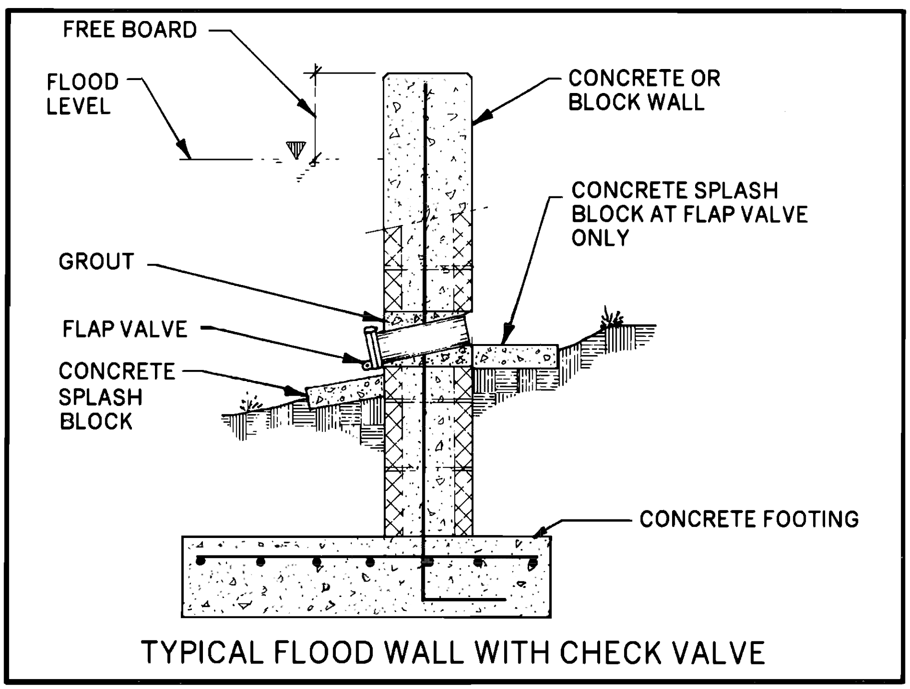
FIGURE 6-5. *A floodwall can make an area more attractive by creating a privacy fence.*

As with levees, it is necessary that some provision be made for draining the water that collects behind the wall from seepage or rainwater. It is possible to install drain tiles for interior drainage, but these must be equipped with a check valve, which is designed to allow water to flow in only one direction. However, the check valve has to be kept clear of debris, or it may jam open as the water rises. In addition, a check valve will only drain when the water level is lower outside. The only way to remove water accumulated during flooding is by using a sump pump that operates from an independent power source.

FIGURE 6-5a. *In times of flooding, floodwalls act to keep water completely away from the structure.*

As with certain other types of retrofitting, provisions should be made to prevent sewer backup by installing a backflow valve or pinch valve, as shown in Figure 5-6.

FIGURE 6-6. *A check valve allows water to flow only in one direction.*



Once completed, the floodwall will generally require fewer inspections than levees, but there should be a regular inspection program to identify defects such as cracks, tree roots, or animal burrows that could allow water to leak inside. This should be done at least annually.

The most important consideration of all is that the homeowners who have constructed a floodwall should not have a false sense of security about their property protection. Every flood is different, and the one that exceeds the design height and overtops the floodwall can happen at any time. For this reason, the flood area should always be evacuated.

6.3 CONSTRUCTION TECHNIQUES AND MATERIALS

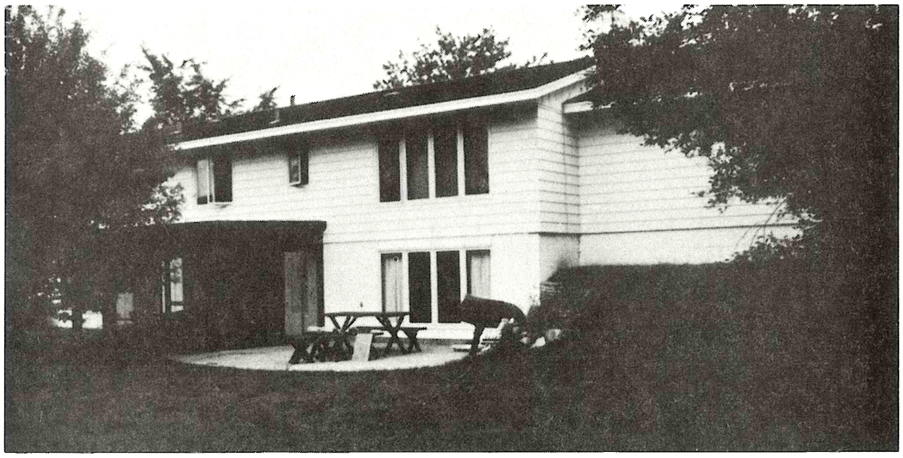
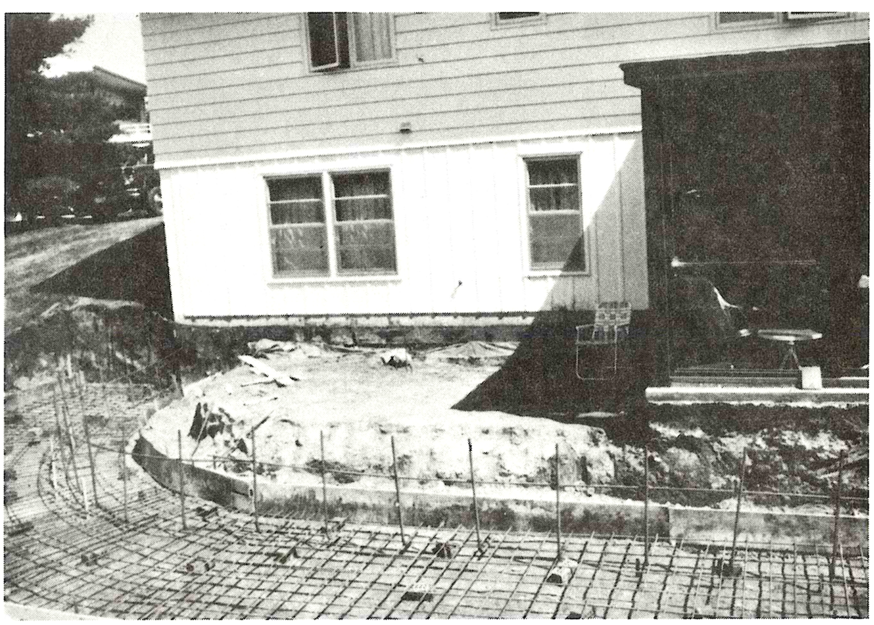


FIGURE 6-7. Floodwall Construction Photo Sequence

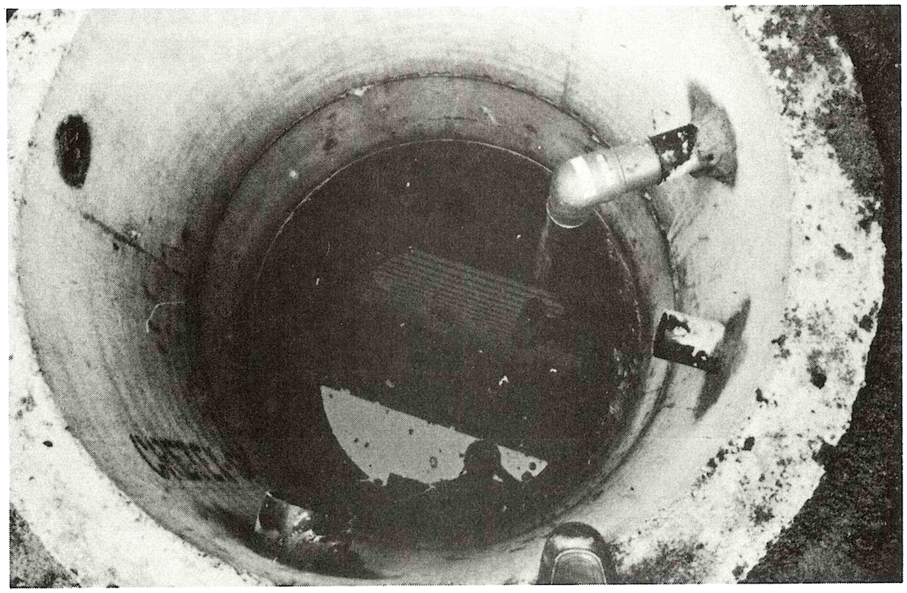
The floodwall construction process followed on this Minnesota residence is typical of what would be required for most floodwall retrofitting projects.

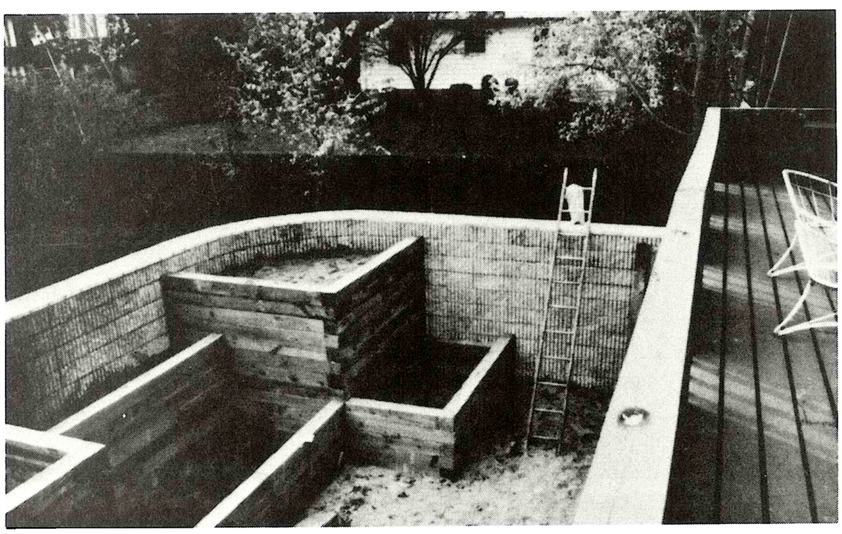
After soils and flood history have been studied, site preparations begin. In this case relandscaping was necessary.



Proper foundation design and wall reinforcing are necessary steps.

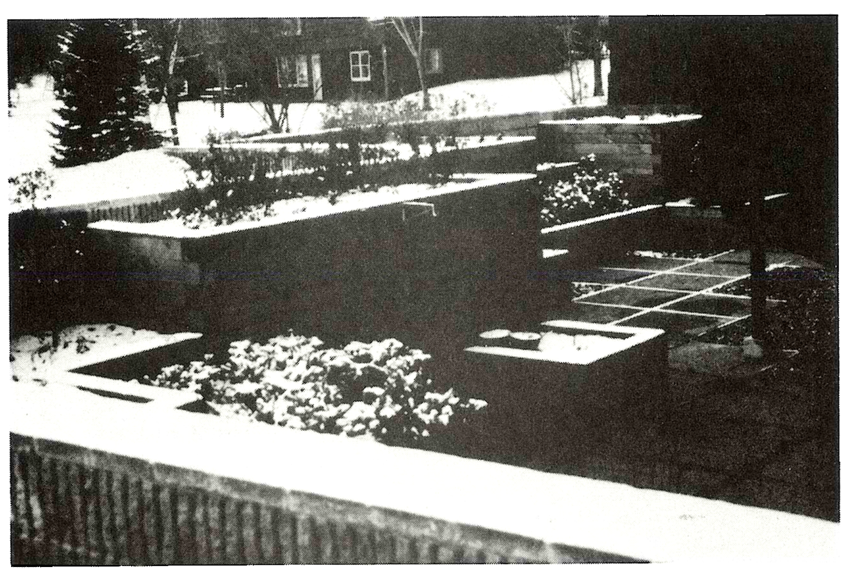
Floodwalls should always incorporate a water collection area or pit and a sump pump to remove rain and seepage water.

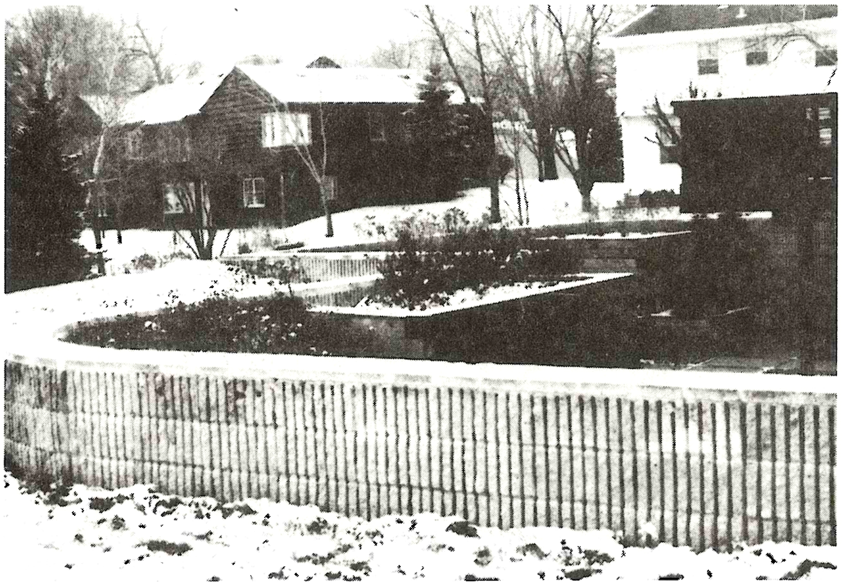




Planters and landscaping inside the floodwall can dress up the protected interior area.

The end result of careful planning is a well protected and funtionally attractive addition to the home.





The exterior of the floodwall itself can be faced with brick to blend in with the site characteristics.

The initial design should begin with a study of the soil on which the wall will sit and the type of flooding that is anticipated. Both of these factors will ultimately decide the design and construction techniques.

Floodwalls most often fail through overturning, which is caused by failure of either the base or the soil underneath the wall. A design sometimes used in low level flooding is the gravity wall, shown in Figure 6-8, which relies on the weight and mass of the material, particularly at the base, to resist flood forces. Because of this, a greater amount of material is needed than for other floodwall designs of the same height.

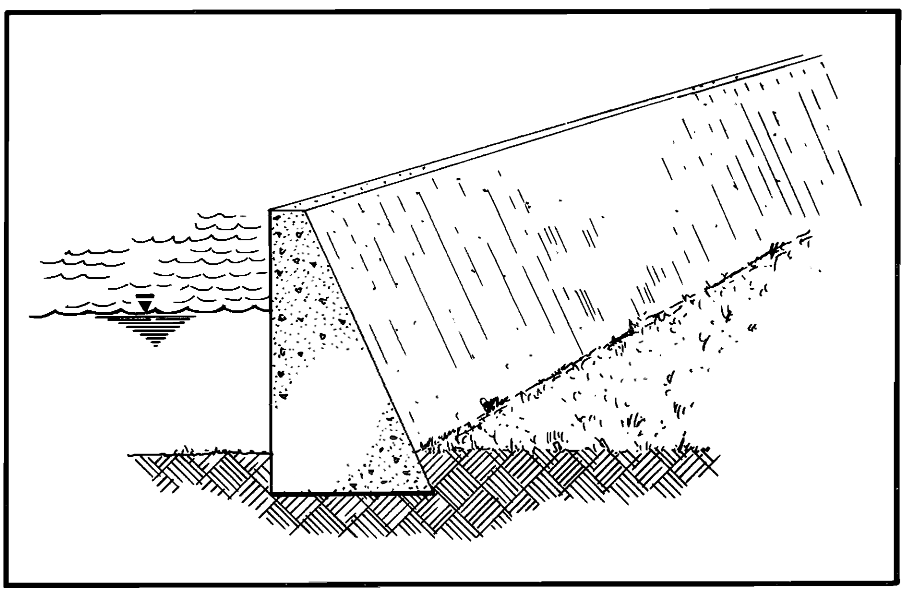


FIGURE 6-8. *The gravity wall, used in low level flooding, depends on weight and mass of material to resist flood forces.*

The cantilever wall, shown in Figure 6-9, is designed to use the weight of soil and water over a portion of its footing to hold it in place against flood forces. It is more slender than the gravity wall, and thus often more cost effective, but it requires greater care in design and in construction details such as reinforcement.

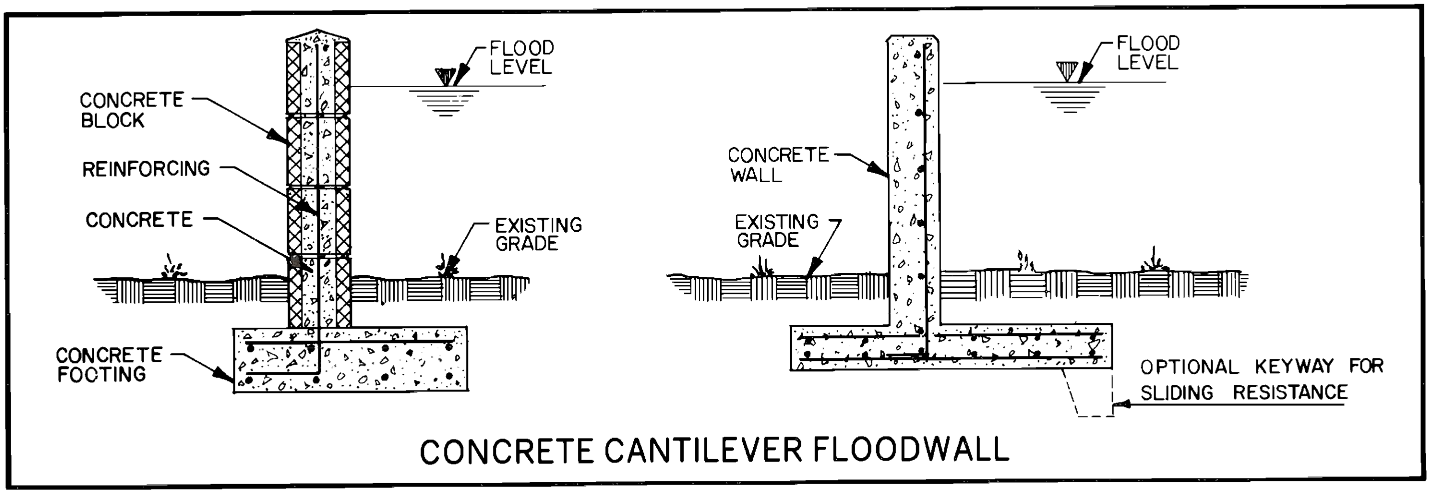
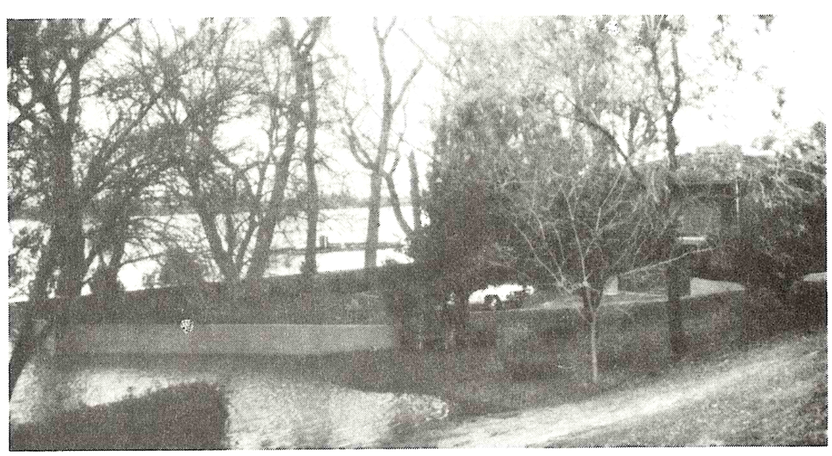


FIGURE 6-9. *The cantilever wall uses the weight of soil and water over a portion of its footing to hold it in place.*

Certain types of soil, such as those with a high percentage of sand, are prone to seepage while some others, such as certain types of clays, tend to be less stable when saturated, which would provide less support for the floodwall. As with levee systems, these permeable soils dictate special treatment, such as extending the floodwall several feet below ground level. Alternatives to this technique of preventing seepage include the use of a sheet pile, which is a barrier of sheet metal driven into the ground, or a concrete curtain placed in the ground before the wall is constructed.

For determining information on local soil type, assistance can often be obtained from the local district office of the Soil Conservation Service. Also, other professional engineering assistance could provide recommendations on the strength and design of the wall that would be needed for particular flood characteristics and for the precise kinds of materials and reinforcing that are required.

FIGURE 6-10. *One homeowner in Sacramento, California, constructed a wall four feet above finished grade, but because he was concerned about the permeability of the alluvial type soil, in some places he extended the wall five feet below finished grade.*



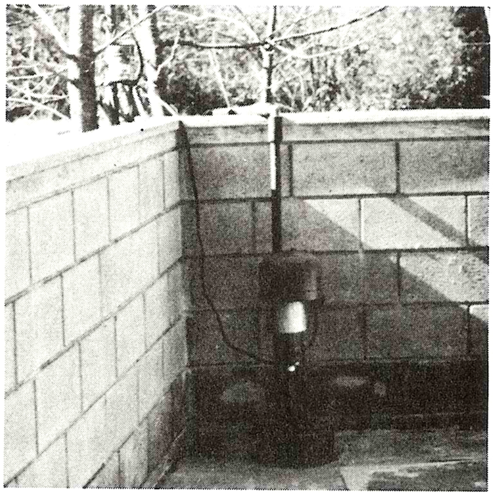


FIGURE 6-10a. *Sump pumps are used to discharge water which collects inside the wall.*

There are a variety of materials available for constructing floodwalls, but all materials must have two essential qualities: strength and impermeability. Specifications for floodwall reinforcing, thickness, materials, and footings are covered in the Technical Design Criteria section of this chapter.

The most common construction materials for floodwalls are masonry block and poured concrete. If masonry blocks are used, then the mortar joints should be waterproofed to prevent seepage. To make floodwalls more attractive, they can be faced with decorative blocks or brick. Such cosmetic facing materials also should be made resistant to water damage.

As the level of water rises, the water pressure acting on the wall increases tremendously (see Figure 3-17). The wall must not only have a substantial footing to resist overturning, but must have its own integral strength to resist failure. The strongest type of wall is made of reinforced concrete, but even it must have sufficient mass and reinforcing to withstand flood forces. The typical standards for normal retaining walls may not be strong enough to withstand the tremendous forces of high water. A qualified professional engineer can assist in determining the likely water forces against a designed floodwall.

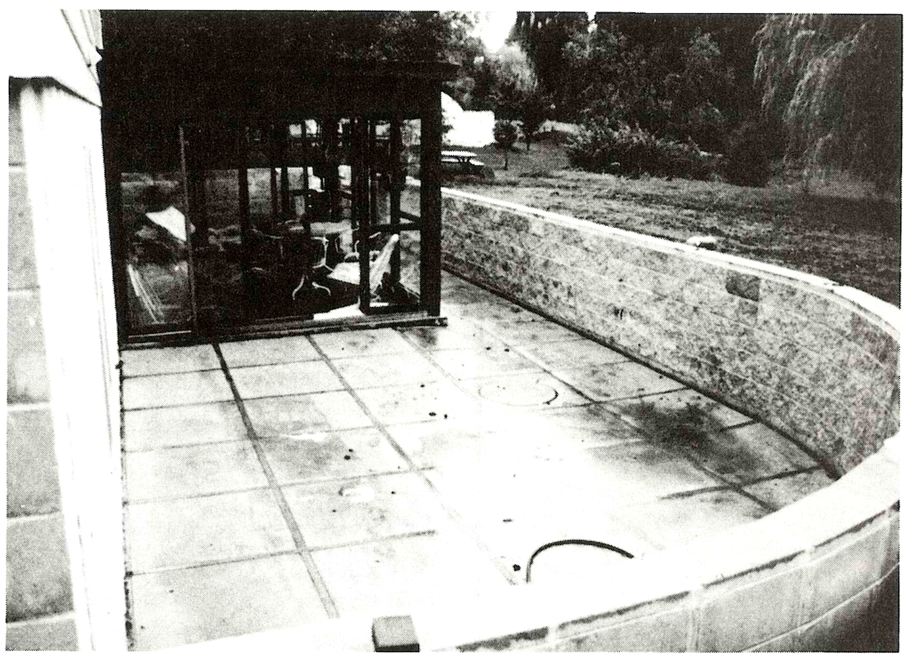


FIGURE 6-11. *To make them more attractive, floodwalls can be faced with decorative blocks or brick.*

6.4 COST GUIDELINES

Unit Cost

The costs for building a floodwall will vary greatly depending on such factors as the materials used, how long and how high the wall is, how much reinforcing is needed, how much landscaping is required, and how much of the work is performed by professional labor. Unit price cost ranges noted in Table 10 may be used for general estimating purposes once the volume of needed materials has been determined.

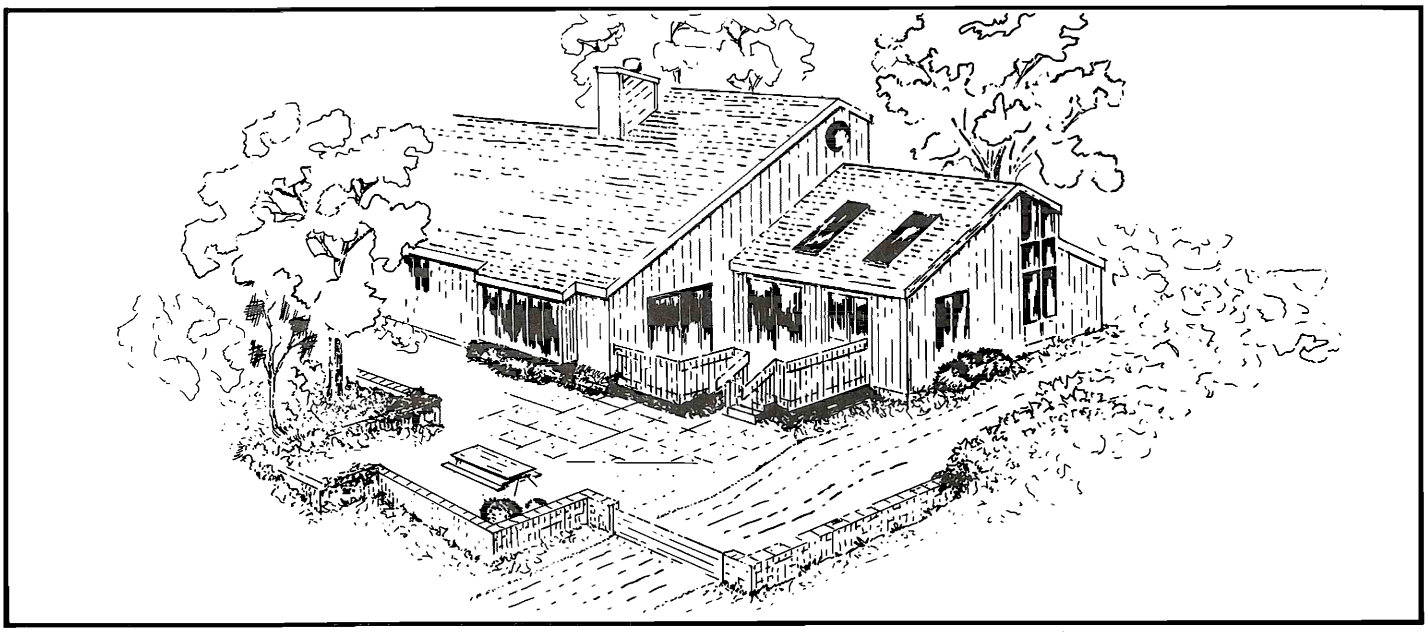


FIGURE 6-12. *There are numerous ways to impove the appearance of floodwalls and have them contribute to the beauty of a site.*

TABLE 10
UNIT COST ESTIMATING FOR FLOODWALLS

	ITEM	UNIT	UNIT COST (1985 DOLLARS)*	NO. UNITS NECESSARY	ITEM COST
1.	Excavation for footings (soil)	Cubic Yard (cu. yd.)	\$3.00 - \$8.00	________	________
2.	Excavation for footings (rock)	Cu. Yd.	\$12.00 - \$20.00	________	________
3.	Reinforcing steel	lb.	\$1.00 - \$1.50	________	________
4.	Concrete (formed & poured, in place)	Cu. Yd.	\$150 - \$200	________	________
5.	Facing brick	Thousand	\$120 - \$180	________	________
6.	8" concrete masonry units (unreinforced) in place	Thousand	\$1800 - \$2200	________	________
7.	8" concrete masonry units (reinforced & grout filled)	Thousand	\$2000 - \$2500	________	________
8.	Seeding	Sq. Yd.	\$1.25 - \$1.50	________	________
9.	Backfill material	Cu. Yd.	\$3.00 - \$8.00	________	________
10.	Rough grading	Sq. Yd.	\$150 - \$250	________	________
11.	Clearing & grubbing	Acre	\$250 - \$300	________	________

* Repair & Remodeling Cost Data Commercial/Residential 1985 R. S. Means Co., Inc.

Typical Examples

There are many variables that can greatly affect individual project costs, including materials used, height, length, type of soil, and degree of landscaping. As an example, the following are costs of a typical project:

140 Foot Wall in Montgomery County, Maryland[1] (expressed in 1985 dollars)[2]

	3 ft. wall	5 ft. wall
• Trench, place reinforcing and concrete for footing, place masonry wall	$4,697	$7,812
• Brick veneer, one side only	2,521	3,599
• Relandscape	1,036	1,036
• Regrade lot for drainage and add sump pump	2,258	2,258
• Sewer and anti-backflow valve	585	585
• Seepage Control (underdrain)	1,783	1,783
TOTAL	$12,880	$17,073

6.5 TECHNICAL DESIGN CRITERIA

Final floodwall design depends upon characteristics of the design flood, site and soil conditions, as well as cost consideration. It is unlikely that a specific design will be applicable for any two situations. The assistance of a qualified engineering consultant will usually be required to develop a satisfactory design. The data presented in this section is intended for planning purposes and to develop preliminary design concepts. For a more detailed discussion of floodwall design, refer to numerous texts on structural foundation analysis and design, in particular, Chapter 1 (Floodwalls) of the U.S. Army Corps of Engineers' Engineering Manual 1110-2-2501.

Materials

The cost and availability of materials for the construction of a floodwall will vary in different sections of the country. The stem (or wall) portion of the floodwall can be constructed utilizing one of several different materials. However, the footing for the floodwall will always be composed of reinforced concrete. This section will deal only with construction materials that are usually available throughout the country, those that are generally accepted as material for this application, and those that attain adequate strength needed to resist the substantial design loads. For that reason, only unreinforced block, reinforced **concrete masonry units**, and reinforced concrete are covered. Each construction material has various strengths and limitations for the application of floodwalls.

Unreinforced masonry block construction has limited application for floodwalls due to the strength constraints of the constructed wall. The block material, whether solid or hollow, is only as good as the mortar bed joints of the

[1]Montgomery County, Maryland, Department of Environmental Protection, Manual for Nonstructural Flood Damage Reduction (November 1981)

[2]Robert Snow Means Company, Inc., Building Construction Cost Data, 1976–1985

wall. The limiting factor is generally the tension normal to the bed joints. This is caused by the bending due to lateral loads on the wall.

Several publications for designs utilizing block construction materials are available. For concrete masonry construction, refer to the NCMA-TEK series by the National Concrete Masonry Association. The NCMA-TEK series consists of technical aids for the design of masonry block construction including accepted engineering practices and materials, and construction specifications. The definitive guide for concrete masonry construction is set forth in Building Code Requirements for Concrete Masonry Structures, American Concrete Institute Standard 531-79. ACI 531-79 is a code publication outlining the allowable design stresses and construction practices.

An example of the height limitations for an unreinforced concrete masonry floodwall can be shown by determining the maximum water height allowable for an 8" hollow core masonry wall with type S mortar. Assuming cantilever construction, the allowable bending moment M is given by

$$M = F_t S$$

Where F_t is the allowable tensile stress normal to bed joints in pounds per square inch and S is the section modulus of the block wall in inches^3 per foot of wall length. M is therefore expressed as a unit of pound-inches per foot of wall length. S for eight inch hollow concrete masonry block is 81 in ^{3}/ft and F_t equals $.5\sqrt{M_o}$, M_o being the 28 day compressive strength of mortar. For type S mortar, M_o is 1800 psi. F_t then equals $.5\sqrt{1800} = 21.2$ lb/in^2. Maximum allowable moment is therefore

$$M = F_t S = (21.2 \text{ psi})(81 \text{ in}^3) = 1717 \text{ lb-in}$$

The moment at the base of the wall caused by hydrostatic load is

$$M = F_H (h/3)$$

where $F_H = \frac{1}{2} \gamma_w h^2$ (See Appendix C),

therefore, $M = \frac{1}{6} \gamma_w h^3$

Equating the allowable moment to hydrostatic moment and solving for h

$$h = \left(\frac{6M}{\gamma_w}\right)^{1/3} = \left(\frac{6 F_t S}{12 \gamma_w}\right)^{1/3}$$

$$h = \left[\frac{6(21.2)(81)}{12(62.4)}\right]^{1/3}$$

$$h = 2.40 \text{ feet}$$

Thus, for this particular example, the allowable stress the wall can withstand is equivalent to the hydrostatic pressures resulting from only 2.40 feet of water. This method does not take into account hydrodynamic loads which may significantly reduce this figure if the floodwall is exposed to velocity flow. Table 11 lists the allowable tension, F_t, normal to bed joints for hollow masonry for various types of mortar. Table 12 presents the section modulus for various nominal thicknesses of hollow block.

The earlier section on Design Criteria established the overall procedures necessary for the proper design of floodwall structures for flood protection.

TABLE 11

ALLOWABLE TENSION NORMAL TO BED JOINTS FOR HOLLOW MASONRY

TYPE MORTAR	COMPRESSIVE STRENGTH* @ 28 DAYS (M_o)	ALLOWABLE TENSION (F_t)
M	2500	25
S	1800	21.2
N	750	13.7
0	350	9.4

TABLE 12

SECTION PROPERTIES OF HOLLOW BLOCK

NOMINAL BLOCK THICKNESS, INCHES	SECTION MODULUS S (IN^3/FT) FACE SHELL BEDDED	WHERE MORTAR IS: FULLY BEDDED
4	21	25
6	46	50
8	81	88
10	118	132
12	160	183

Reinforced concrete masonry uses steel reinforcing to take the bending tensile stresses generated by lateral pressures due to hydrostatic loads. Since steel is far superior to mortar in taking tensile stresses, the severe limitations present in unreinforced construction no longer apply. In reinforced masonry design, the limiting factor is likely to be in the allowable compressive stress due to bending or possibly even allowable shear for the wall section.

The same references previously listed apply for reinforced masonry construction with respect to allowable loads, design procedures and engineering practice. The allowable stresses are based on several physical properties of the constructed materials. The most important physical attribute of reinforced concrete masonry is the specified compressive strength, f'_m, for net area of masonry. Most of the allowable stresses for concrete masonry construction are based on this specified compressive strength. The values for f'_m for masonry are a function of the compressive strength of the masonry units themselves, and the type of mortar (M, S or N) used during the construction of the structure.

As with any type of flood resistant construction, reinforced and unreinforced masonry must be properly constructed to form an effective barrier to prevent intrusion of water into the residence. Proper location of control and expansion joints is necessary to provide a wall free from unsightly, problematic cracks. These locations must be sealed properly with water-resistant caulking at control joints and by waterstops at expansion joints. ACI 531R-79, Concrete Masonry Structures Commentary, Section 6.7, outlines some general recommendations for unreinforced and reinforced masonry control and expansion joints. To prevent failure of the walls, the masonry must not be overstressed and the construction of the wall on the footing must be accomplished in a manner that allows proper transfer of lateral forces from the wall to the footing. Figure 6-13 shows typical details of reinforced masonry at the base section.

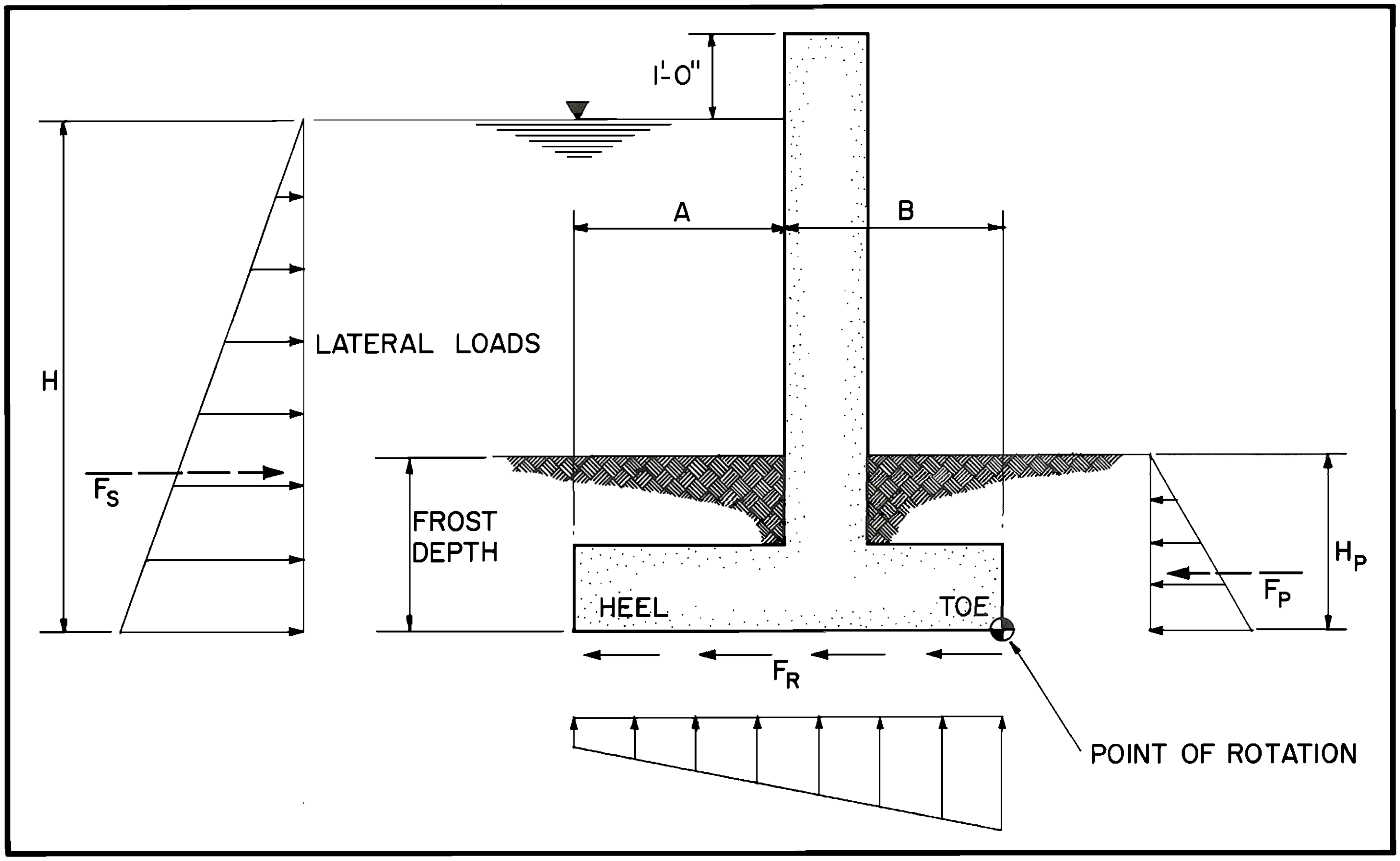


FIGURE 6-13. Soil Bearing Pressure

Reinforced concrete is one of the most widely accepted construction materials for floodwalls. Reinforced concrete offers high strength to withstand the substantial forces generated by water and/or soil loadings. This high structural capability, in turn, creates a more flexible design medium to handle design loads from hydrostatic and hydrodynamic pressures.

All concrete construction should conform with the Building Code Requirements for Reinforced Concrete, American Concrete Institute Standard 318-83. ACI 318-83 presents the design criteria for concrete construction including all aspects of allowable design stresses, reinforcing standards, and construction requirements. Almost all allowable design stresses for reinforced concrete construction are based on, in some form or another, the specified compressive strength of concrete, f'_c and the yield stress of the reinforcing steel.

Proper guidelines must be followed during construction to assure that the concrete floodwall will function under loading as it was assumed to behave in design. Details such as development of vertical reinforcement, shrinkage reinforcement, and location and construction of control and expansion joints, will all determine the total integrity of the constructed floodwall. Proper development of reinforcing is presented in ACI 318-83, Chapter 12. Recommendations concerning shrinkage reinforcement, control joints, and expansion joints are detailed in Control of Cracking in Concrete Structures, ACI 224R-80. Figure 6-13 shows typical details of reinforced concrete at the base section.

Soils

The soil properties of any particular site are the basis for the determination of loads, the allowable bearing capacity, and ultimately, the suitability of the floodwall as a retrofitting method. For these reasons, it is important to consult a soils engineer to determine the physical properties and hence, the design properties of the soil for any given site.

As discussed more extensively in Appendix C, the type of soil at the construction location, if backfilled against the floodwall, will determine the lateral pressures which act on the floodwall under normal conditions. The coefficient of active pressure, K_a, is usually around .33 for cohesionless soils to .5 to 1.0 for cohesive soils. The actual lateral pressure, or the equivalent fluid pressure, can vary significantly from one soil type to another.

Another important consideration is the allowable bearing capacity of the soil. As with all cantilever design, the weight of the wall along with the weight of backfilled soil (if present) create a vertical pressure under the footing which must be resisted by the soil. The soil type determines the overall capacity of the soil to resist this vertical force. Once the allowable bearing capacity is determined by a soils engineer, the designer can vary the width of the footing so that the actual bearing pressure is less than the allowable bearing pressure. Also, certain types of soil exhibit very poor bearing capacities when saturated; therefore, floodwall applications in those particular conditions would not be feasible.

The ability of soils to bear loads, usually expressed as shearing resistance, is a function of many complex factors, including some that are site-specific. A very significant factor affecting shearing resistance is the presence and movement of water within the soil. Under conditions of saturation, shear strengths may decrease due to the buoyancy effect of the interstitial water or, in the case of cohesive soils, to physical or chemical changes brought about in clay minerals. While there are many possible site-specific effects of saturation on soil types, some classes of soil can be identified which have generally low shearing resistances under most conditions of saturation. These include:

(1) Fine silty sand which, in some localities, may have a metastable internal structure. As a result, it may suddenly compact when loaded or shaken, resulting in a phenomenon known as liquefaction.

(2) Sand or fine gravel in which the hydraulic gradient of upward-moving water within the soil equals the compressive pressure of the soil. In this case, the soil loses its shear strength, becoming quicksand, which will not support loads at the surface.

(3) Extrasensitive and quick clays. When loaded under saturated conditions, these soils may undergo internal rearrangement as a result of compaction of the aggregate or loss of crystal components by ion exchange or solution. When this occurs, bearing capacity of the soil will fail.

(4) Clays in general may have low shear strengths under saturated conditions due to the effects of pore water on intergranular contacts.

Other types of saturated soil may also have low shearing resistances under loads, depending on numerous site-specific factors such as slope, hydraulic head, stratigraphic relationships, internal structures, and bulk properties.

Generally, the soils noted above should not be considered for floodwall construction design, and when they are known to be present, a soils engineer must be consulted for site-specific solutions. Mechanical properties of all soils are complex. Attempts to construct water-retaining structures without a thorough understanding of soil mechanics and analysis of on-site soils can result in expensive mistakes and project failure.

Loads

The design of the floodwall must incorporate all possible loads that occur at the floodwall location. These loads can be a combination of hydrostatic, equivalent fluid pressure, hydrodynamic and impact loadings as well as the dead loads from the wall structure. The reader is referred to Appendix C for the determination of the actual loads.

Overturning Resistance

The lateral forces acting on a floodwall create an overturning force which must be counteracted to maintain the stability of the floodwall. The overturning force is usually taken at the toe of the footing (refer to Figure 6-13). The overturning moment, M_O, consists of the moment about the toe of the footing from the lateral forces acting on the entire floodwall structure. The resisting moment, M_R, includes the moment about the toe of the footing due to the weight of the footing, the weight of the wall portion, and the effective weight of any backfilled soil on top of the footing.

The factor of safety (FS) for overturning is determined by

$$FS = M_R/M_O$$

M_R and M_O are the resisting and overturning moment, respectively. The factors of safety, FS, must be equal to or greater than the recommended factors of safety against overturning given below.

Loading Condition	Factor of Safety
D + S + F	1.75
D + S + F + FI	1.50
D + S + F + FI	1.50
D + F*	1.00
D + S + EQ	1.50
D + W	1.30
D + S	2.00

*Assumes water to top of floodwall.

Key:

D = dead load

S = soil load (may be included in equivalent fluid pressure)

F = flood water load (may be hydrostatic or included in equivalent fluid pressure)

FI = impact load

W = wind load (as required by applicable building code)

EQ = earthquake load (as required by applicable building code)

Source: Floodproofing Non-Residential Structures, Federal Emergency Management Agency

Sliding Resistance

Sliding resistance is a design factor which is as important as overturning resistance. However, it is sometimes overlooked in the design process. Sliding forces are a result of lateral loads applied to the floodwall structure which tend to displace the entire structure away from the lateral loads. The sliding force, F_S, is the summation of all lateral loads acting on the floodwall, as shown in Figure 6–13. The sliding resisting force, F_{SR}, is the summation of all forces which resist the movement of the wall. Resisting forces include the friction between the footing and the soil, the passive soil pressure created when the structure is pushed against the soil, any cohesive properties of the soil to the footing, and possibly any artificial means of preventing movement such as abutting ground slabs, etc.

The resisting force, F_R, against sliding due to friction and cohesion of the soil can be summarized by the equation

$$F_R = R \tan \phi' + c'B$$

where R includes all vertical forces and B is the width of the footing. Tan ϕ' represents the friction, f, which may be taken as the range of values between tan ϕ to .67 tan ϕ, where ϕ is the angle of internal friction determined by soils testing. The base cohesion, c', is taken as .5c to .75c where c is the cohesion of the soil determined by soils testing. For a cohesionless soil, the second term (c'B) of the formula above is taken as zero.

Another resisting force present is the passive resistance of the soil where the floodwall pushes against the soil on the inside of the floodwall. As in active pressure, the passive pressure of the soil is caused when the displacement of the wall occurs, but the displacement is of a larger magnitude. The coefficient of passive pressure, K_p, which can be determined from soils testing, usually varies from 3 to 14 for cohesionless soil and from 1 to 2 for cohesive soils. For any given height from the bottom of the footing to the top of the soil on the land side of the floodwall, H_p, the passive resistance force, F_p, can be expressed as

$$F_p = \tfrac{1}{2} K_p \, \gamma_{soil} \, (H_p)^2$$

When the sliding is determined to be a problem for a particular floodwall, resistance to sliding can be increased by adding a keyway to the bottom of the footing which increases the passive resistance depth, H_p, and hence the resisting force against sliding.

The total sliding resistance, therefore, can be expressed as

$$F_{SR} = R \tan \phi' + c'B + F_p \qquad \text{or} \qquad F_{SR} = F_R + F_p$$

Artificial or constructed means of sliding resistance can be designed for floodwalls. To resist lateral loads on the floodwall, a ground slab abutting the floodwall utilizes the friction and cohesion forces due to the weight and length of the slab. These artificial resistance methods are quite effective in resisting sliding forces.

The factor of safety (FS) recommended for sliding resistance is determined by

$$FS = F_{SR}/F_S$$

Here, F_{SR}, and F_S, are the sliding resistance and sliding force respectively. The calculated factor of safety for sliding, FS, for each floodwall must be equal to or greater than the recommended values below

Loading Condition	Factor of Safety
D + S + F	1.3
D + S + F + FI	1.1
D + S + F + FI + W	1.1
D + F*	1.1
D + S + EQ	1.1
D + W	1.1
D + S	1.5

*Assumes water to top of floodwall.

Design

The references listed earlier in the chapter present some of the accepted engineering practices and allowable stresses to be used in the design of the floodwall. The previous criteria discussed in this section deal with the determination of loads, bearing capacities and stability of structure needed to successfully design a floodwall. The reference and criteria presented herein are intended to be used only as a guideline to assist the engineer in all aspects of floodwall design.

Table 13 presents some minimum dimensions for floodwall foundations for various heights of flood water. The footings are based on several factors.

TABLE 13
MINIMUM FLOODWALL FOOTING DIMENSIONS

(Refer to Figure 6-13)

Height of Water (H) Above Bottom of Ftg.	Height of Water (h) Above Soil	Minimum Footing Dimension* A (Heel)	B (Toe)
3.5	1	1'-0"	1'-8"
4.5	2	2'-0"	1'-8"
5.5	3	3'-10"	1'-8"
6.5	4	4'-0"	2'-6"
7.5	5	4'-0"	4'-0"
8.5	6	5'-0"	4'-6"

* Based on following criteria

- Frost depth of 2' 6"
- Saturated soil condition, soil dry unit weight 100 PCF
- Factor of safety against overturning = 1.75 (See Overturning Resistance Section)
- Minimum allowable soil bearing pressure = 1.5 KSF (in saturated condition)
- Sliding resistance must be verified for soil conditions present

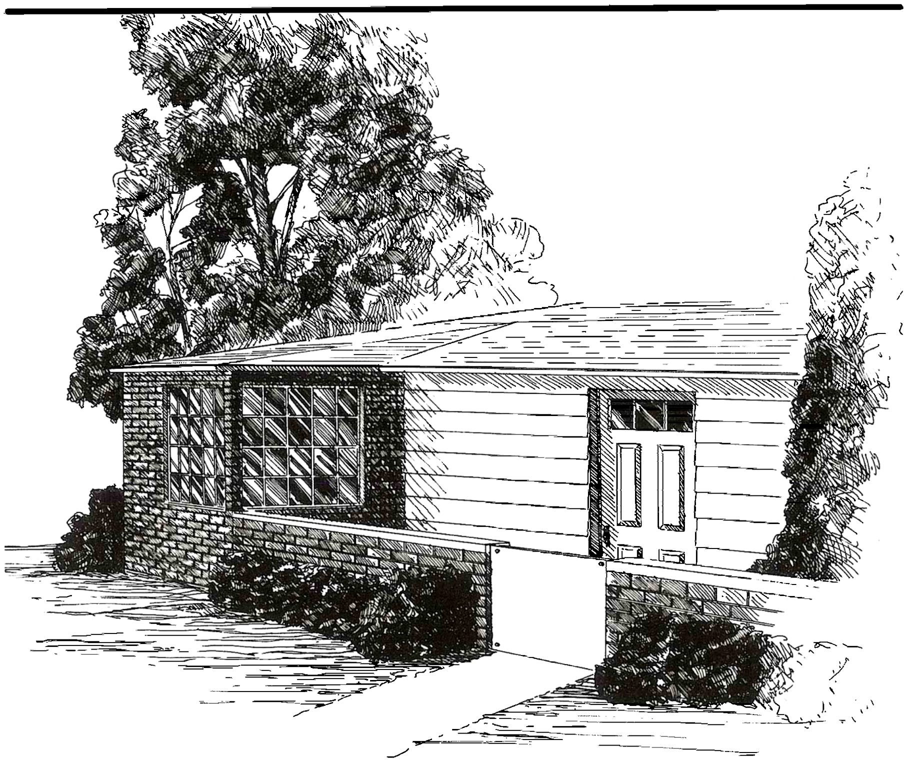
As a final precaution, the factor of safety against sliding must be checked by a structural engineer familiar with the soil conditions present at the site. A footing key may be required to prevent sliding. Dimensions shown are for estimating purposes only. Final design of the floodwall should be completed or checked by a structural engineer.

First, the allowable soil bearing pressure must be at least 1500 psf when saturated. The factor of safety for overturning is taken as 1.75 (see "Overturning Resistance" section) for the dead, soil and water loads. No hydrodynamic loads have been included in the calculations for the footing size. A frost depth of 2'6" was assumed for the floodwall design and the dry unit weight of the soil is 100 pcf. The soil is assumed to be saturated under the entire footing. The controlling factor on footing size is the overturning resistance. The sliding resistant forces, however, must be checked for each case in accordance with the soil parameter present at the site to determine if the lateral resistance for the floodwall is adequate.

Chapter 7

CLOSURES

Many of the floodproofing techniques that keep water away from a residence, such as floodwalls, levees, and structural sealing, may require special treatment for openings such as doors, windows, driveways, etc. These closures act as shields to cover the gap and prevent water from entering, and can be of a variety of shapes, sizes, and materials.



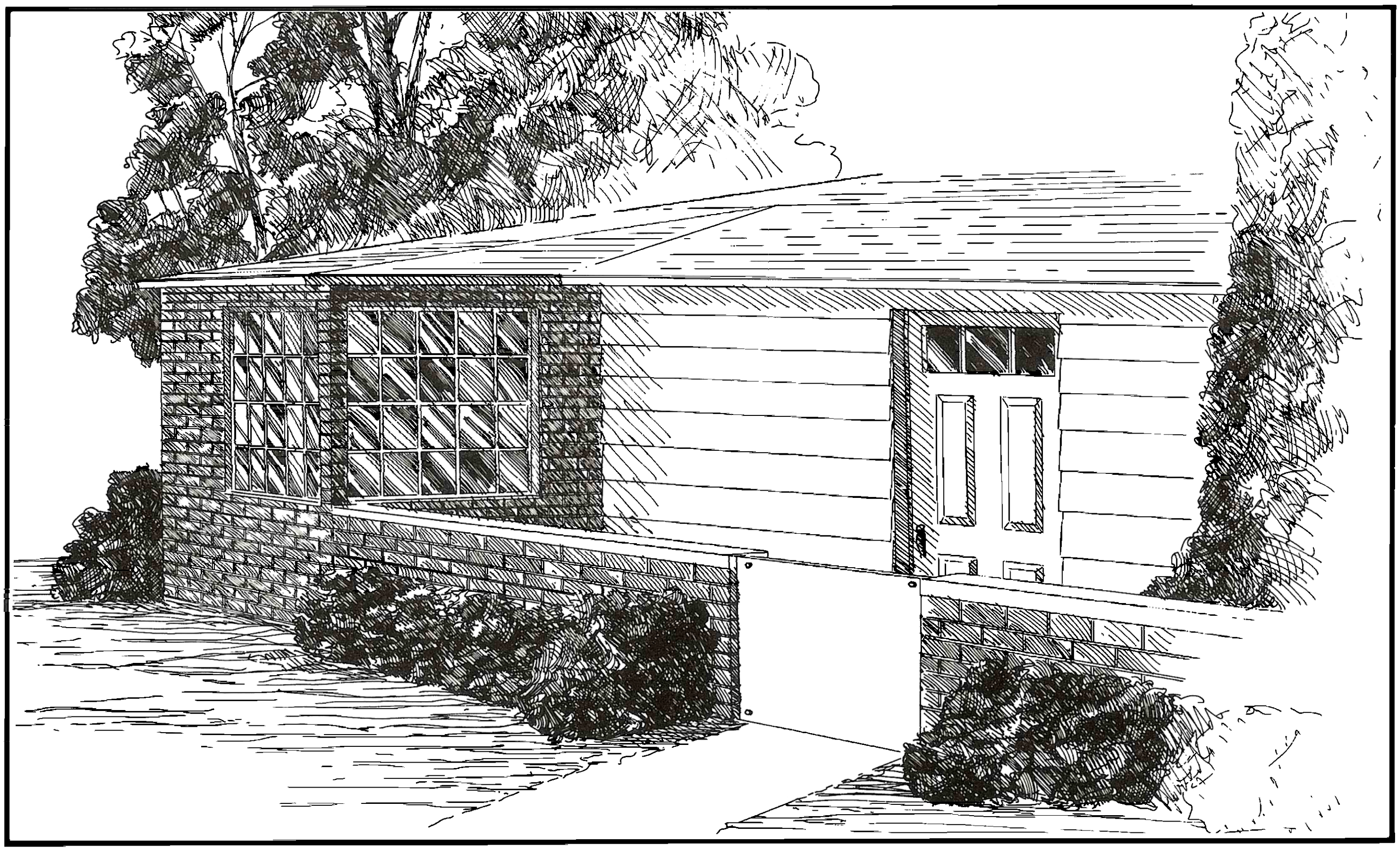


FIGURE 7-1. Detailed Rendering of Floodwall with Closures

7.1 INTRODUCTION

Many of the floodproofing techniques that keep water away from a residence, such as floodwalls, levees, and structural sealing, may require special treatment for openings such as doors, windows, driveways, etc. These closures act as shields to cover the gap and prevent water from entering, and can be of a variety of shapes, sizes, and materials.

In some cases closures are permanently attached using hinges so that they can remain open when there is no flood threat. They may also be portable, normally stored in a convenient location and slipped into place when a flood threatens. In certain situations, when flooding is of a very low level, usually less than one foot, some method of enclosing low entrances such as basement doors or window wells might be a satisfactory option. In any case, there are a number of elements involved in designing and using a closure system.

7.2 CONSIDERATIONS

Closures may be separated into two basic categories: permanent, such as a low wall or bricking in of an existing non-essential door or window; or temporary, such as an aluminum panel over a door or in a floodwall opening which is installed when flooding is expected. Combinations of permanent and temporary closures are also feasible.

In areas of shallow, low velocity flooding, closures can be used on doors, windows, vents, and other building openings. However, the first step with the use of closures placed directly on buildings is to be certain that both the closure and the wall systems are strong enough and sufficiently watertight to withstand flood pressures. The use of closures directly on a structure is considered to be a part of the sealing process. There are many important limitations involved in sealing, and this method is covered in Chapter 8, "Sealants."

Closures can be considered as an option only if a flooding situation provides sufficient warning time to properly install the closures. The need for both sufficient warning time and "human intervention" is critical, since all closure systems require personnel to install them and make certain they are properly sealed.

Closures that are stored between floods must be readily accessible. The effectiveness of an entire closure system will be compromised if the closures are stored such that flooding renders them inaccessible, or if even one closure is improperly installed.

Closure systems are most effective where there are a limited number of openings. If there are too many, leakage could overwhelm and defeat the system. No matter how many closures are involved, however, a sump pump system having a reliable power source should be installed to provide for seepage removal.

For most flooding situations, a homeowner should consult with a professional engineer to be certain that the closure system being planned can withstand the hydrostatic and hydrodynamic pressures that will be involved.

7.3 LOW PROFILE PERMANENT CLOSURES

For cases involving flood levels of up to two feet, a type of "mini"-floodwall can be used to permanently protect various types of openings. Possible materials for this use include brick, concrete block and poured concrete.

Additional details are provided in Chapter 6, "Floodwalls." Figure 7-2 shows such a wall around a window well. For flooding involving a basement door, a low wall around the entrance may be the solution, as shown in Figure 7-4. If the wall is too difficult to step over, a low set of stairs, or stile, can be installed. Figure 6-4 shows an example of a stile used over a floodwall.

Though these "mini"-walls may not require the degree of reinforcing of larger floodwalls, they should be supported by and securely tied into a footing so that they will not be undercut by scouring. It should be verified that the soil under these walls is fairly impervious to control underseepage.

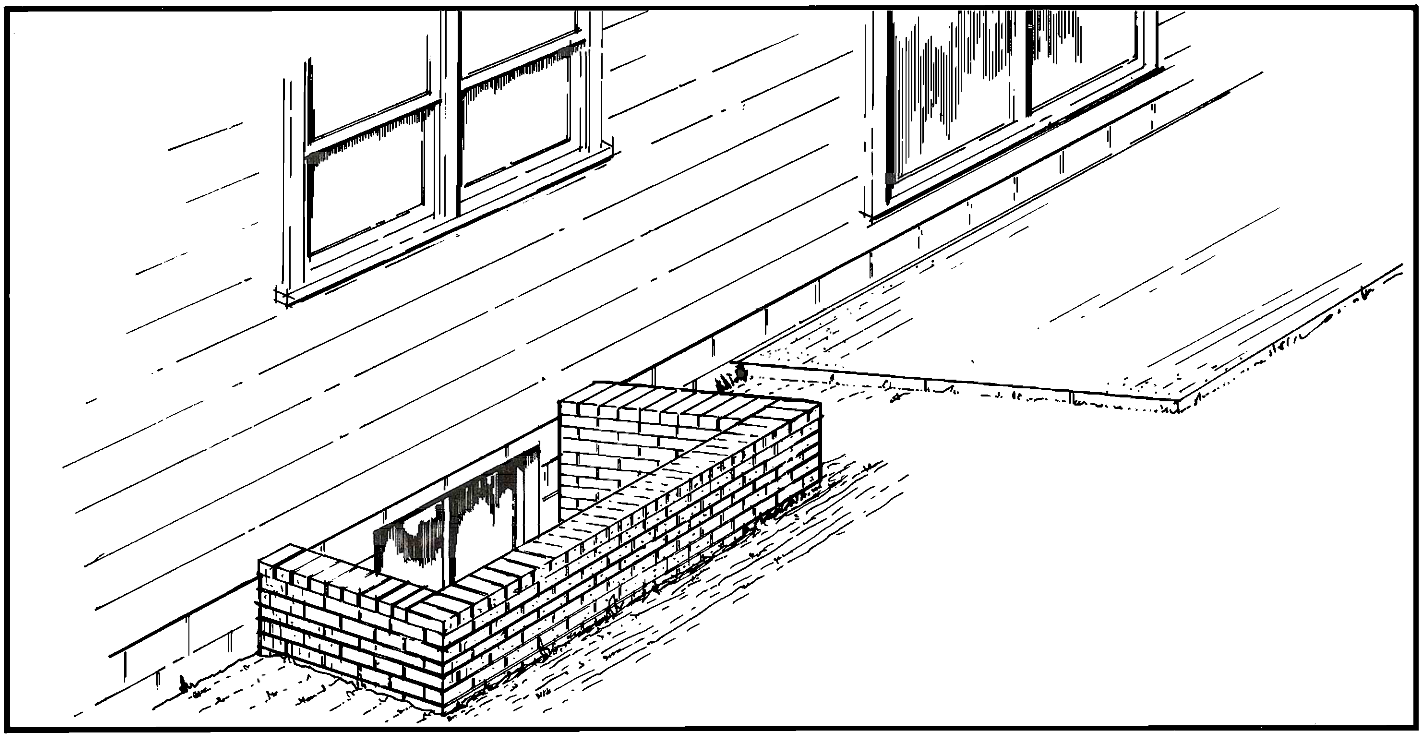


FIGURE 7-2. *A 'mini'-floodwall can protect a window well against low level flooding.*

Depending on the duration of the flooding, some form of sealant may be needed on the outside to control seepage.

Similarly, low level flooding of up to two feet around a basement window or entrance can also be controlled by constructing a small **berm**. As with larger levees, however, they should be constructed of impervious soil, carefully layered and compacted, protected with vegetation, and inspected regularly for erosion.

One simple solution to the problem of low level flooding of a garage or driveway is to install an asphalt mound in the driveway, as shown in Figure 7-5.

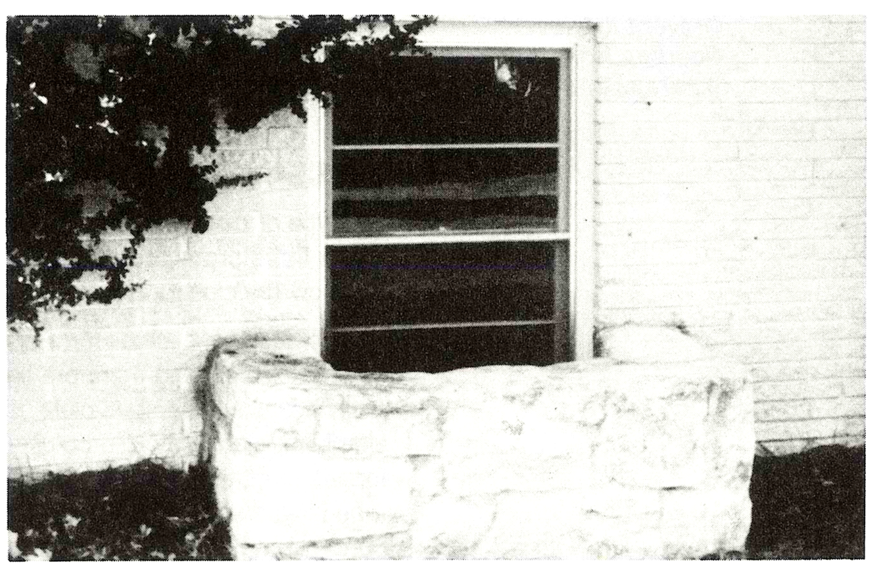


FIGURE 7-3. Mini-Floodwall on a Window

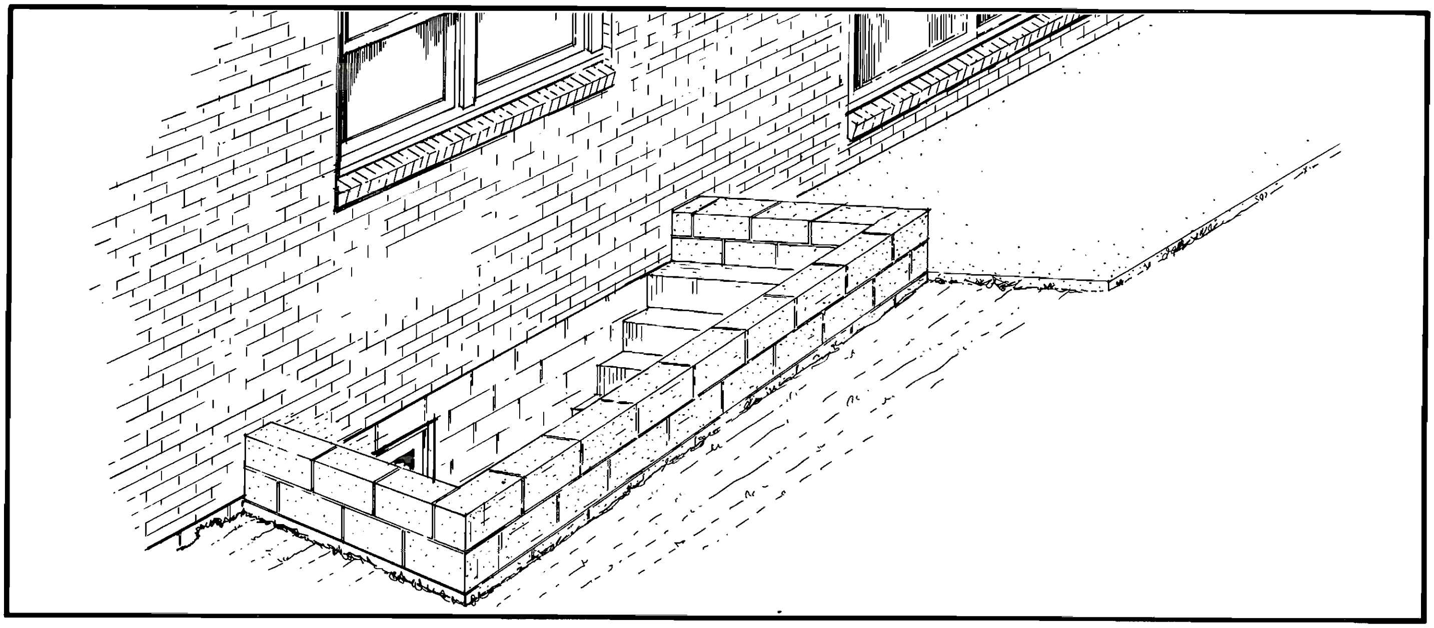


FIGURE 7-4. *A low wall around a basement entrance can prevent low levels of water from entering.*

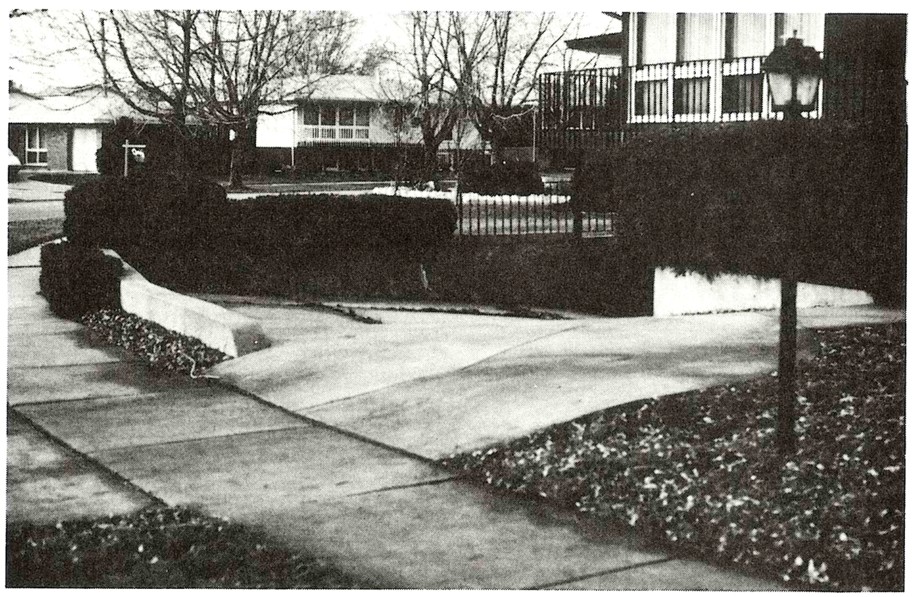


FIGURE 7-5. *A mound in the driveway could prevent low level flooding from entering a garage or driveway.*

7.4 CLOSURE MATERIALS AND CONSTRUCTION

The type of closure used depends primarily on the size of the opening that needs to be protected. This will determine the type of material to be used and how the closure is to be constructed and operated.

Larger closures, such as for a driveway, must be able to withstand significant flood pressures, and therefore should be made of a substantial material. Normally this would be steel plate, protected against rust and corrosion. Heavy aluminum plate may also be used, although it will likely need to be reinforced. In either case, due to the weight of the closure, it is usually best that it be hinged so that it can swing into place. Hinging can be located along the bottom, so the closure lies flat when not in use (Figure 7-6), or it can be

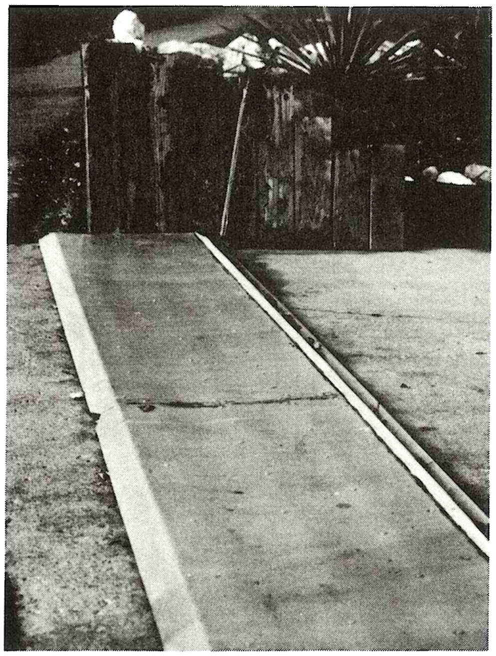


FIGURE 7-6. Closure hinged at its bottom

placed along one side, so the closure can fold back out of the way (Figure 7-7).

For normal passage openings, aluminum is probably the most common material used. It is a lightweight material, allowing for easy fabrication and transport, and it is resistant to corrosion. Aluminum can buckle under heavy water pressure, so it may need some additional reinforcement.

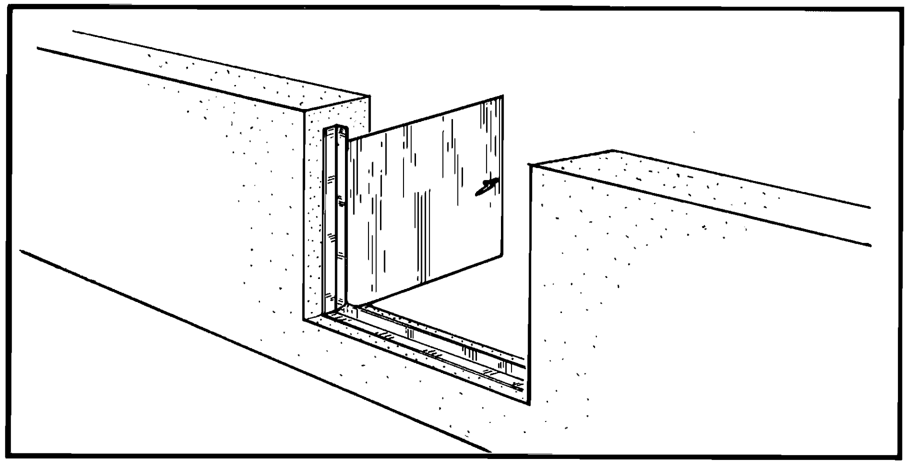


FIGURE 7-7. Side-Hinged Closure on a Floodwall

For smaller openings, exterior grade plywood is also commonly used. It is relatively inexpensive and is easily fabricated. However, plywood is subject to warping if not properly stored. In addition, it will collapse under relatively low flood forces, and will usually require significant reinforcement, usually some type of wood frame.

Aluminum and plywood closures are both light enough to be used for temporary closures that can normally be stored in a safe location and only installed when flood waters threaten. There are many different arrangements that can be used to install these movable closures. The more common methods include the "drop-in" shield that fits into a special slot arrangement as shown in Figure 7-8, and the "bolt-on" shield that is affixed over an opening as shown

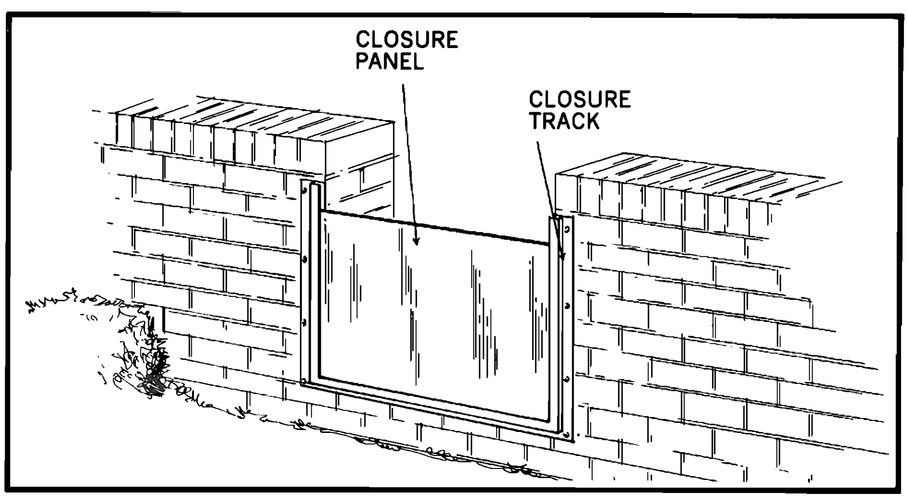


FIGURE 7-8. Detail of a Drop-In Closure

in Figure 7-9. There are several different types of hardware that can be used to secure a closure in place, such as T-bolts, wing nuts on anchored bolts, or latching dogs.

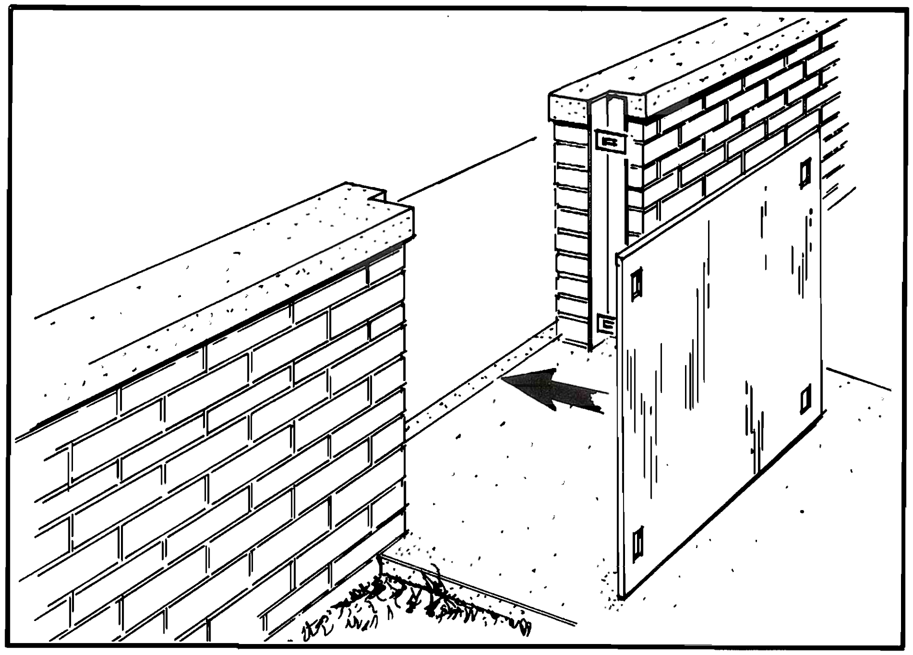


FIGURE 7-9. *Openings in floodwalls may be closed using a variety of materials for shields.*

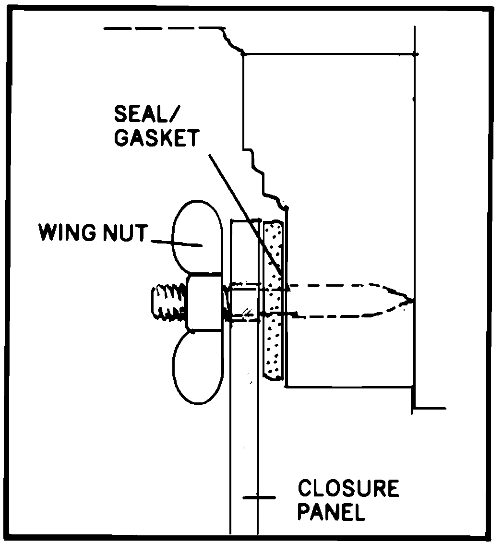


FIGURE 7-10. *Wing nut on an anchor bolt can be used to hold a closure panel in place.*

It is absolutely essential that closures be made watertight. This is normally accomplished through the use of some type of gasket. Neoprene and rubber are materials commonly used, but there are a number of other materials readily available that perform equally as well.

The successful performance of a closure system also requires that it be held firmly against the opening being protected. Although the hydrostatic pressure of the water may help to hold the closure in place, flood water surges can result in negative pressure that can pull off an improperly installed closure.

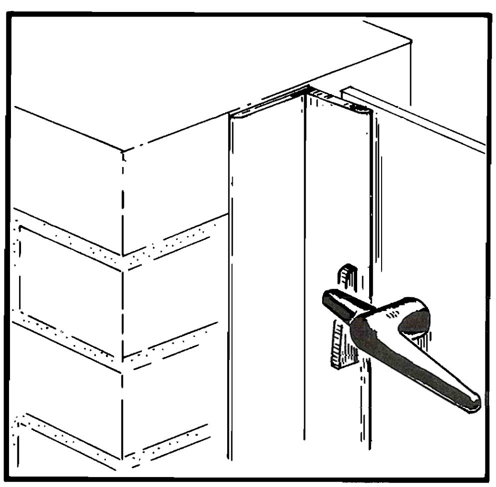


FIGURE 7-11. Latching Dog

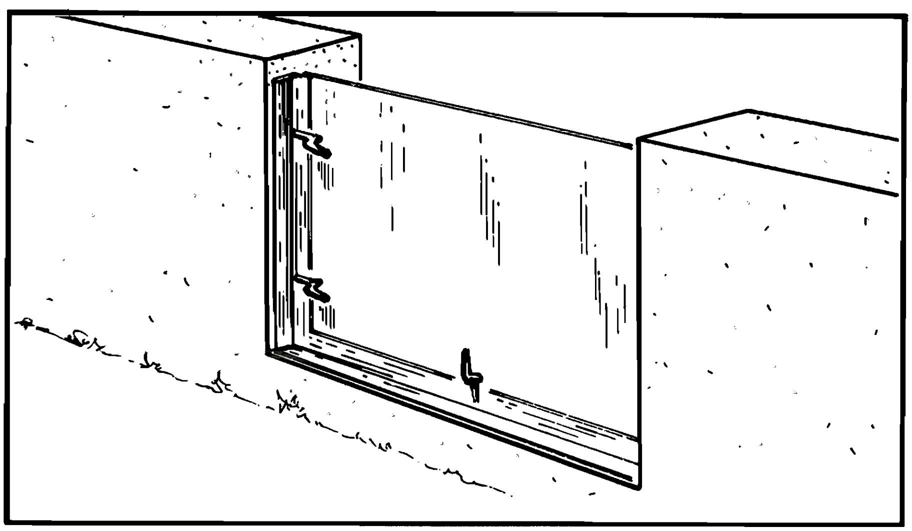


FIGURE 7-12. *Latching dogs are commonly used to secure a closure panel.*

7.5 COST GUIDELINES

Unit Cost

Closures vary greatly in their material and construction costs depending on the type and size gap to be closed, depth of flood waters, and various site characteristics. The price ranges for various materials listed in Table 14 may be used to develop approximate costs for preliminary comparison purposes.

TABLE 14

UNIT COST ESTIMATING FOR CLOSURES

ITEM	UNIT	COST RANGE	NO. UNITS NECESSARY	ITEM COST
1. Plate Steel	Sq. Ft. (1/4" Thick)	$1.00 - $2.00	________	________
2. Plate Aluminum	Sq. Ft. (1/4" Thick)	$1.50 - $3.00	________	________
3. Exterior Grade Plywood	Sq. Ft.	$.40 - $1.00	________	________
4. Sump Pump	Per Unit	$500 - $1,000	________	________

Typical Example

Costs of Commercial Closures—Custom Fitted (1984)

Description	Unit Price
Approx. 3′0″ wide × 1′0″ high, complete with inflatable gasket, portable air tank, and angle adaptors to facilitate surface mounting of conversion frame	$ 1,620.00
Approx. 7′6″ wide × 2′11″ high, complete with inflatable gasket, portable air tank, and angle adaptors to facilitate surface mounting of conversion frame	$ 2,900.00
Approx. 3′0″ wide × 4′6″ high, complete with inflatable gasket, portable air tank, and angle adaptors to facilitate surface mounting of conversion frame	$ 3,410.00

7.6 TECHNICAL DESIGN CRITERIA

In order for a closure to be properly designed, it must be able to resist all potential flood forces, including hydrostatic, hydrodynamic and impact loading. These are detailed in Appendix C.

Whatever material is used, it must be of sufficient strength and thickness to resist bending and deflection failures. The ability of a specific material to withstand bending stresses may be substantially different from its ability to withstand deflection stresses. Therefore, to provide for an adequate factor of safety, the required plate thickness should be calculated twice: first taking into account bending stresses, and second taking into account deflection stresses. The resulting thicknesses should be compared and the larger value specified in the final plate design.

One method of determining the thickness of the closure for steel and aluminum is presented in Formulas for Stress and Strain by Roark and Young. For a flat plate supported on three sides, the plate thickness required due to bending stresses may be determined by the formula

$$t = \sqrt{\frac{qb^2 \beta}{\text{Max } \sigma}}$$

where t = plate thickness
q = water pressure in psi
b = width of plate in inches
a = height of plate in inches
Max σ = allowable stress for the plate material (from material handbooks)
β = moment coefficient from Table 15

Similarly, for a steel or aluminum flat plate supported on three sides, the plate thickness required due to deflection stresses may be determined by the formula

$$t = \sqrt[3]{\frac{360 \alpha qb^3}{E}}$$

where α = deflection coefficient from Table 15
E = modulus of elasticity for the plate material (from material handbooks)

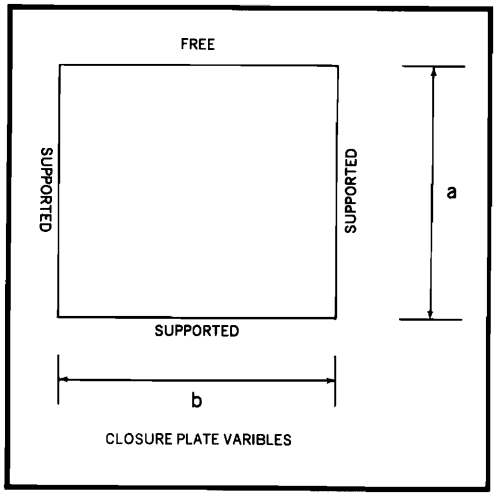


FIGURE 7-13. Diagram: Plywood Closure Formula Variables.

The variables used in the above equations for plate thickness are illustrated in Figure 7-13. Table 15 details the moment and deflection coefficients as a function of the ratio of plate height to width.

TABLE 15

MOMENT COEFFICIENTS

a/b	.050	0.667	1.0	1.5	2.0	2.5	3.0	3.5	4.0
α	0.11	0.16	0.20	0.28	0.32	0.35	0.36	0.37	0.37
β	0.026	0.033	0.040	0.050	0.058	0.064	0.067	0.069	0.070

Allowable values for σ and E may be found for steel plates in Manual of Steel Construction, American Institute of Steel Construction, and for aluminum plates in Aluminum Construction Manual, the Aluminum Association.

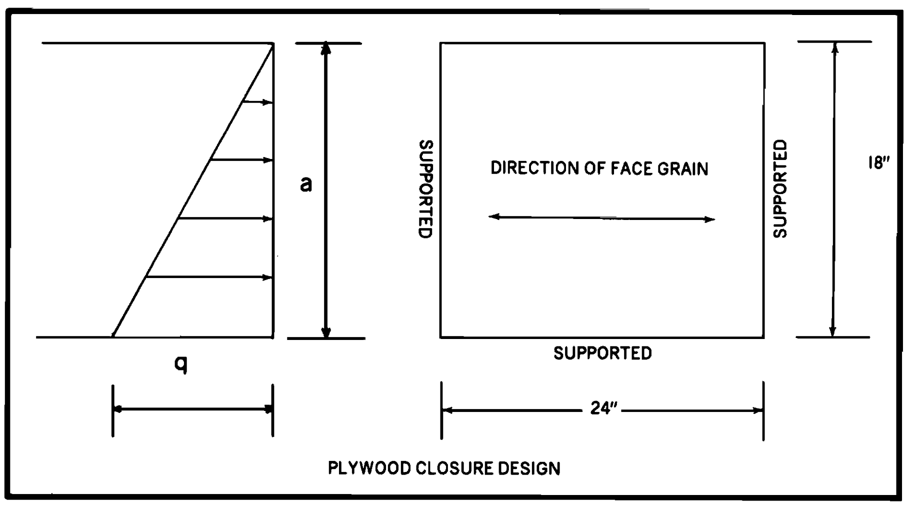
The method of designing plywood closure plates is similar to that of steel and aluminum closure plates except that the varying structural properties of plywood make using a single formula inappropriate. Because these structural properties are dependent upon the grade of plywood sheet, the type of glue used, and the direction of stress in relation to the grain, determination of the thickness and grade required for a plywood closure is best achieved by assuming a thickness and grade of plywood and calculating its ability to withstand bending, shear and deflection stresses. This involves calculating the actual bending, shear and deflection stresses in the plywood closure plate for the thickness and grade specified. These actual stress values are then compared with the maximum allowable bending, shear and deflection stresses (taken from Plywood Design Specifications).

If the actual stresses computed are less than the maximum allowable stresses for bending, shear and deflection, the thickness and grade specified are acceptable for that specific application. However, if either of the actual bending or shear stresses or deflection exceeds the maximum allowable values, the closure plate is not acceptable and a new thickness and/or grade of plywood closure plate should be specified and the calculations repeated until all actual stresses are less than the maximum allowed. The designer is referred to Plywood Design Specifications, American Plywood Association, for a detailed discussion of design guidelines. The following example has been prepared to illustrate one method of designing plywood closure plates. Note that a one-way horizontal span is assumed because the variability of plywood properties is dependent upon grain and stress direction.

Design Example: Plywood Closure Plate

Problem: A plywood closure plate is required for a floodwall situation. As shown in Figure 7-14, the closure plate will be supported on three sides and measures 18 inches in height by 24 inches in width. Assume that the closure will be subject to water pressure over its entire surface. Determine the thickness and grade of plywood to be used as the closure plate.

FIGURE 7-14. Diagram: Plywood Closure Plate Design Example



Solution: Assume a plywood closure with the following characteristics:
Grade: Structural I Underlayment EXT-APA
Thickness: ¾ inch

The following values will be used in the calculations and vary according to the thickness and grade of plywood specified. These values are taken from Plywood Design Specifications:

KS (Effective Section Modulus) = 0.503 in^3/ft = 0.0419 in^3/in

F_b (Allowable Bending Stress, Wet Application) = 1430 psi

F_s (Allowable Rolling Shear Stress, One Direction in the plane of plies) = 63 psi

Ib/Q (Rolling Shear Constant) = 7.379

E (Adjusted Modulus of Elasticity) = 1,500,000 psi
I (Effective Moment of Inertia) = 0.226 in^4/ft

Compute water pressure acting on closure

$$q = (a)(62.4) = (1.5)(62.4) = 93.6 \text{ psf} = 0.65 \text{ psi}$$

Compute bending moment on horizontal one-way span

$$M = \frac{q1^2}{8} = \frac{(0.65)(24)^2}{8} = 4.68\frac{\text{in-lbs}}{\text{in}}$$

Check bending stress

$$f_b = \frac{M}{KS} = \frac{46.8}{0.0419} = 1117 \text{ psi}$$

Since the calculated bending stress for the specified plate (f_b = 1117 psi) is less than the maximum bending stress allowed (F_b = 1430 psi) the closure plate is adequately designed for bending applications.

Compute shear force

$$V = \frac{q1}{2} = \frac{(0.65)(24)}{2} = 7.8 \text{ lbs/in} = 93.6 \text{ lbs/ft}$$

Check shear stress

$$f_s = \frac{VQ}{Ib} = 93.6\left(\frac{1}{7.379}\right) = 12.7 \text{ psi}$$

Since the calculated shear stress for the specified plate (f_s = 12.7 psi) is less than the maximum shear stress allowed (F_s = 63 psi), the closure plate is adequately designed for shear applications.

Compute deflection for a single one-way span

$$\triangle_b = \frac{w(1_3)^4}{921.6EI} = \frac{(93.6)(24+.25)^4}{921.6(1{,}500{,}000)(.226)} = 0.1036 \text{ in.}$$

where w = uniform load in psf = q
1_3 = length in inches of clear span plus a support width factor. Support width factor equals .25 inches for 2-inch nominal frame.

Check Deflection: A customary and acceptable level of deflection may be expressed as

$$\triangle_b \text{(allowable)} = 1/240 = 24/240 = 0.1$$

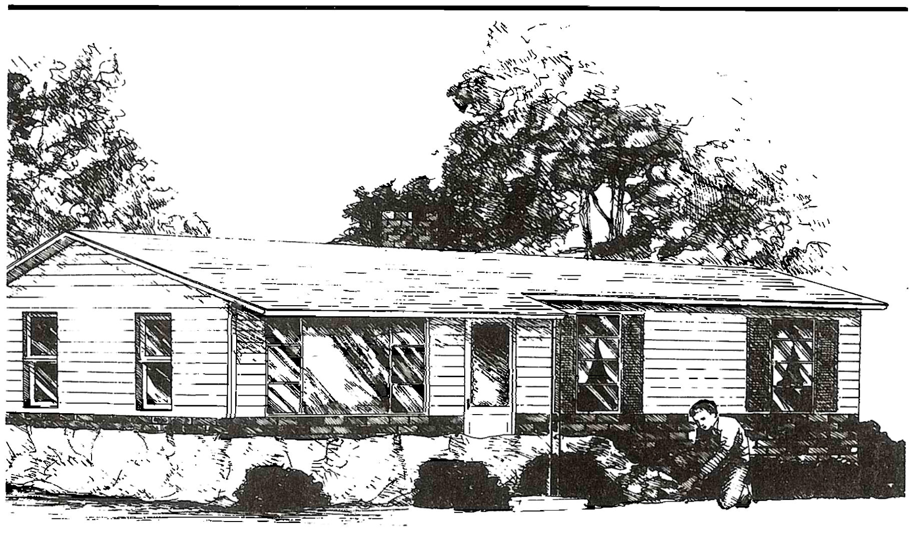
While the calculated deflection ($\triangle_b$ = 0.1036) is greater than the allowable deflection ($\triangle_b$ = 0.1), the values are close enough to assume that the closure plate is adequately designed for deflection situations if the plate is not expected to be subject to long duration flooding events. If long duration flooding events were expected, the plate should be redesigned and the calculations redone.

As shown by the example, closure plates of plywood are limited to short spans and low water heights. It should also be noted that most plywood will deteriorate when exposed to high moisture and therefore plywood closure plates should be examined periodically and replaced as necessary.

Chapter 8

SEALANTS

Some buildings can be protected against low level flooding by completely sealing the structure against the entry of water. Sometimes referred to as watertight, or dry floodproofing, this method can only be employed for buildings that are in good structural condition, constructed of concrete block or brick veneer on wood frame, and are subject to flooding of no more than three feet in height. Perhaps more than any other technique, the successful use of sealants requires greater attention to detail and consultation with a structural engineer.



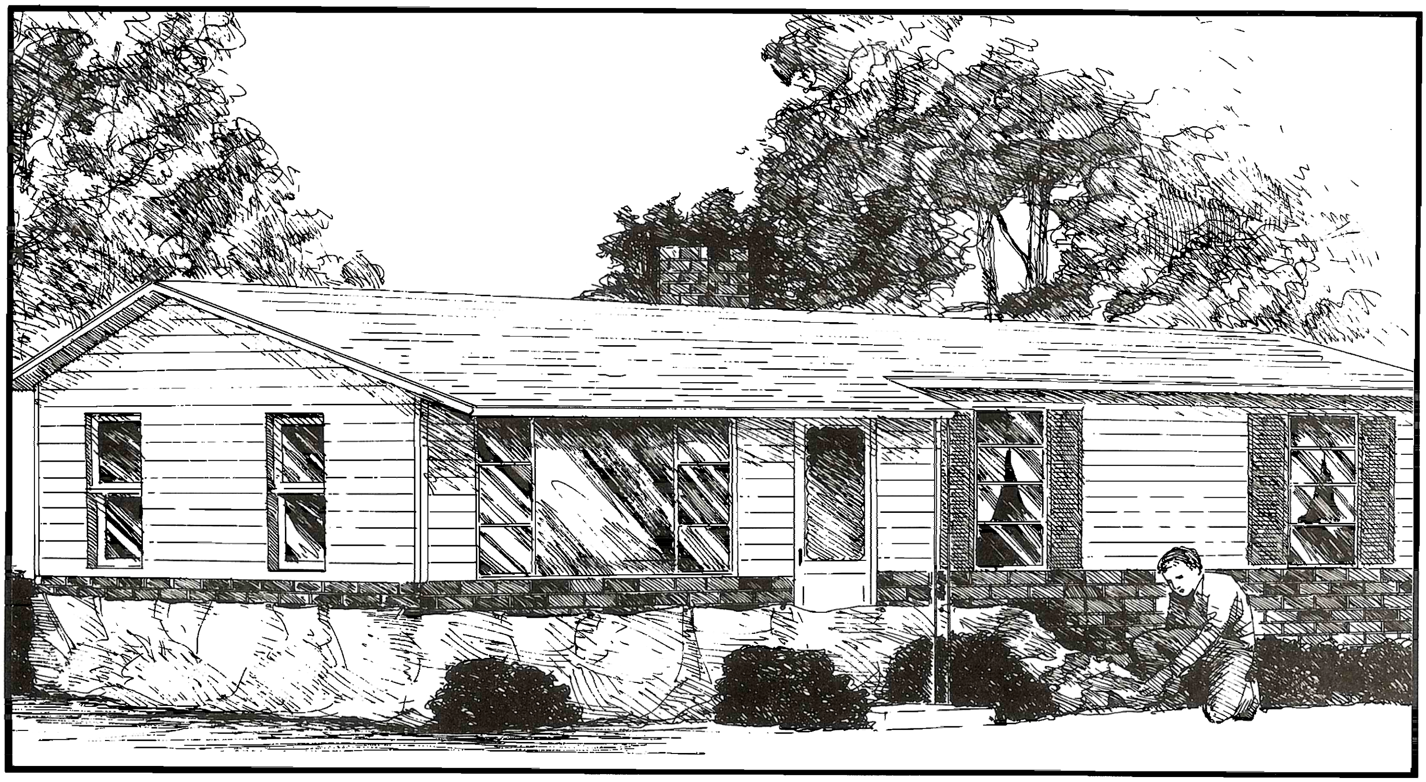


FIGURE 8-1. Detailed Rendering of Sealed House

8.1 INTRODUCTION

Some buildings can be protected against low level flooding by completely sealing the structure against the entry of water. Sometimes referred to as watertight, or dry floodproofing, this method can only be employed for buildings that are in good structural condition, constructed of concrete block or brick veneer on wood frame, and are subject to flooding of no more than two to three feet in height. Perhaps more than any other technique, the successful use of sealants requires greater attention to detail and consultation with a structural engineer.

The principle involved in sealing a building may first appear to be very simple: completely seal the exterior of the house to make it impervious to water, close off all entrances, and pump out all seepage. Though this may seem simple, this is actually a very complicated technique, requiring a full understanding of the potential dangers that could result from inadequate planning.

8.2 CONSIDERATIONS

The first problem relates to the hydrostatic pressure forces which can act on a structure during flooding. Water weighs 62½ pounds per cubic foot, and pushes laterally with the same force as it does downward. The greater the depth of water against the wall of a structure, the greater this force becomes, as shown in Figure 8-2. For example, if the water depth against a wall is four feet, then there is a lateral, or hydrostatic pressure of 250 pounds per square foot pressure at the bottom.

HYDROSTATIC PRESSURES BY WATER DEPTH	
HEIGHT (H)	P_H (LBS/SQ. FT.)
1	62.4
2	124.8
3	187.2
4	249.6
5	312.0
6	374.4
7	436.8
8	499.2
9	561.6
10	624.0

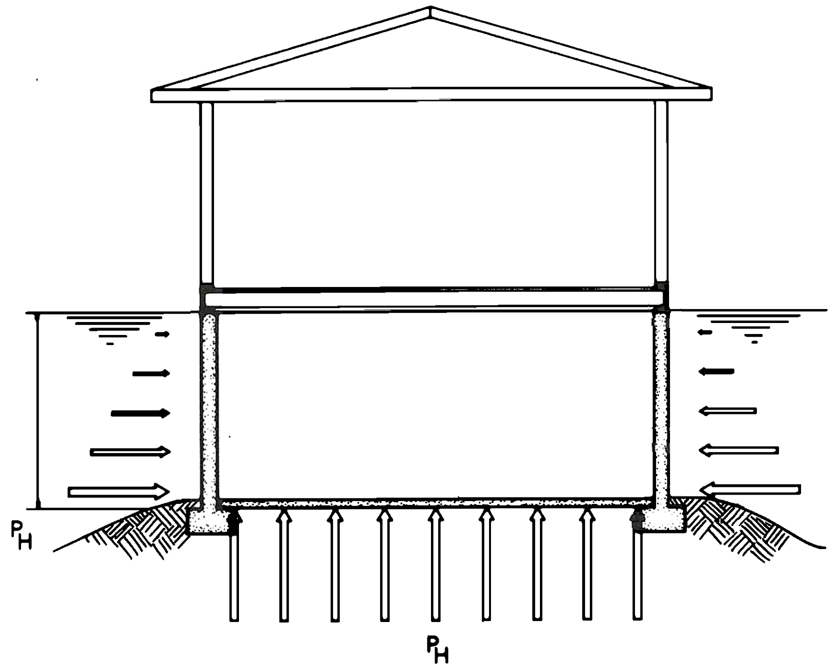


FIGURE 8-2. Diagram: Hydrostatic/ Uplift Pressure

The U.S. Army Corps of Engineers has investigated the effect of various depths of water on brick veneer and masonry walls. The results of their work show that, as a general rule, *no more than two feet of water should be allowed on a brick veneer wall and no more than three feet on a masonry wall.* This research found that while in some cases these depths were exceeded without resulting in complete collapse, most walls did suffer irreversible structural damage.

Because there are so many different designs and construction materials, no definitive research on floodproofing wood frame walls has been undertaken. It is generally accepted that not only is it extremely difficult to completely seal frame houses, but that because of their weaker construction materials, they would fail at a much lower water depth than those constructed of brick or block.

Most authorities believe that the flood depth limits provided above must not be exceeded when attempting to retrofit a house by sealing. *Application of this method requires a professional to determine the structural soundness of a building before undertaking any sealing project.*

In many flooding situations, there may be additional pressure from flowing water, referred to as hydrodynamic forces or from debris battering against the building, known as **impact loads**. Very few residential structures are designed or constructed to withstand these tremendous pressures.

Another potentially destructive flooding force at work on buildings in a flood is buoyancy or uplift, which can cause a building to float off its foundation. It may be difficult to imagine, but it is not unusual for homes to be damaged by flotation in large floods. The U.S. Army Corps of Engineers has also researched the potential of uplift for various structures[1], and has determined the following:

- Single and two story residential structures with basements, framed with wood with a brick or masonry facing, may float at water depths of less than three feet above the first floor;
- Single and two story residential structures without basements, constructed of brick or masonry with slab-on-grade foundations, may fail by buckling of the floor slab at water depths of about three feet; and
- Basements in single story brick or masonry structures may fail by flotation or buckling of the floor slab at depths of four feet above the basement floor if the soil becomes saturated.

The degree of danger depends on such elements as the type of soil, level of saturation, duration of the flood, and the structure's drainage system. Uplift forces can also cause separation of the house from the basement wall, slab, or foundation footings. The potential for separation will depend not only on the depth of flooding, but also on how well the house is anchored to its foundation system.

Every building has different strength characteristics that will limit the height to which the structure can safely be sealed against flooding. Flood waters that exceed this height must be allowed to automatically enter the building to reduce the risk of structural damage or collapse of the walls. While inundation damages will result, they will normally be less expensive to repair than that caused by structural wall or floor failure.

8.3 SEALING TECHNIQUES

Most wall materials, except for some types of high-quality concrete, will leak water unless special construction techniques are used. These techniques require a high level of workmanship if they are to be effective.

The most effective method of sealing a brick faced wall would be to install a watertight seal behind the brick when the house is being constructed. For retrofitting, the best way is to add an additional layer of brick with a seal "sandwiched" between the two layers as shown in Figure 8-3.

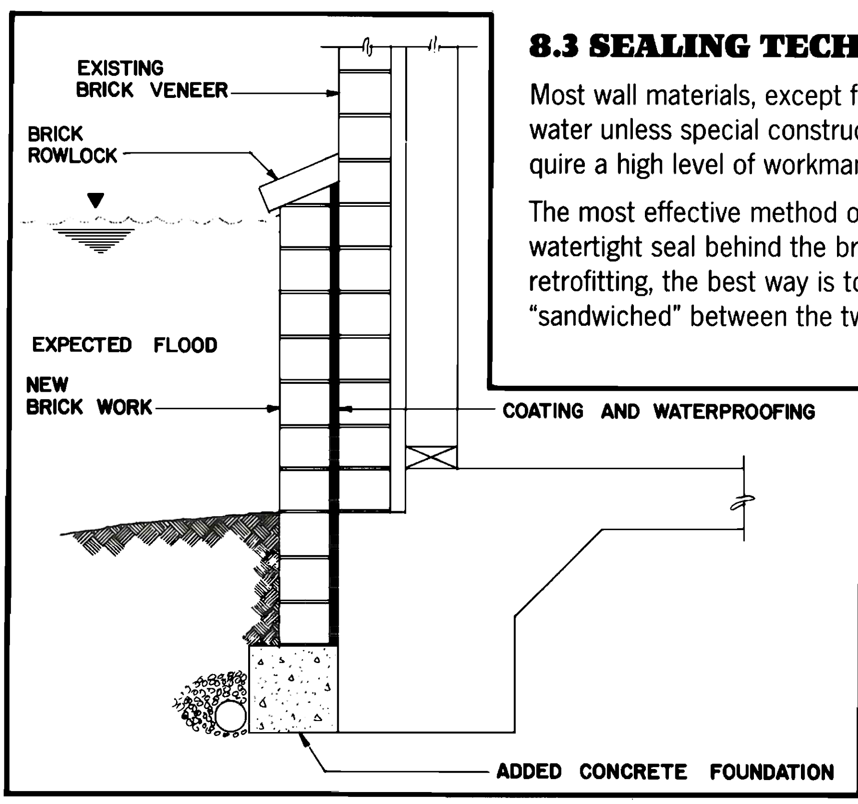


FIGURE 8-3. *The best way to seal an existing brick-faced wall is to add an additional layer of brick with a seal in between.*

[1] U.S. Army Corps of Engineers, Physical and Economic Feasibility of Non-Structural Flood Plain Management Measures

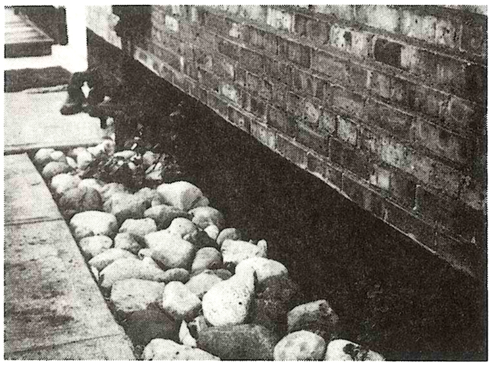


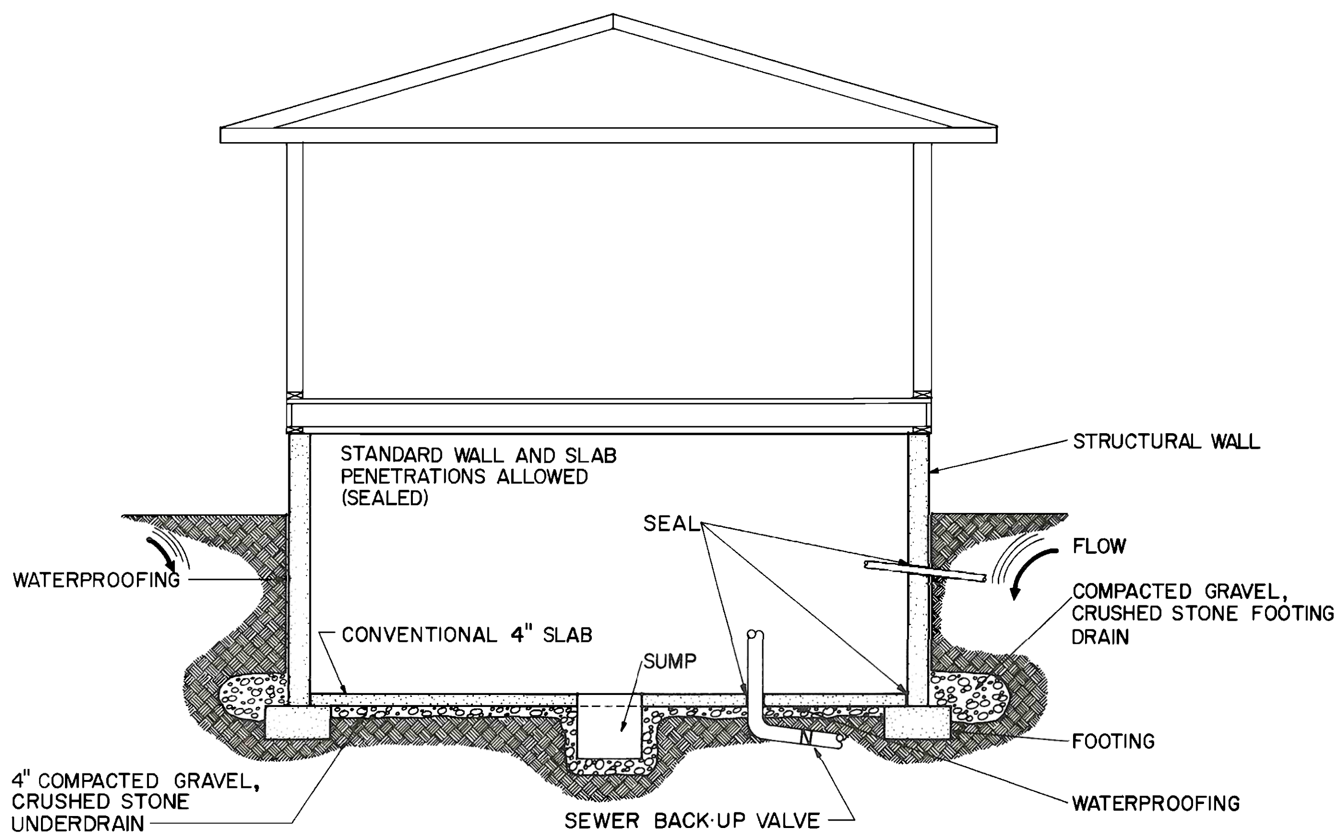
FIGURE 8-4. *This house is sealed to about 12 inches with a bituminous coating. During flooding, a closure is placed over the door.*

FIGURE 8-5. *Any sealed house must have an effective drain system around footings and slabs to reduce water pressure on foundation walls and basements.*

It is possible to apply a sealant to the outside of a brick or block wall, but any coating must be applied carefully. Initial research indicates that the most effective sealants will change the appearance of the brick exterior. Cement or asphalt based coatings are the most effective materials for sealing a brick wall, while clear coatings such as epoxies and polyurethanes tend to be less effective. As a result, the aesthetic advantages of a brick wall are lost with the use of better sealant coatings.

The difficulty and complexity of sealing a structure will depend not only on the type of exterior construction involved, but also on the type of foundation, since all structural joints, such as those where the walls meet foundations or slabs, also require treatment. For example, a slab-on-grade structure is usually the easiest type of construction to seal. This is because the first floor sits directly on the slab and there are fewer joints for the water to enter, as there are with a house constructed over a crawlway or basement.

To be effective, the use of sealants requires that the house have a well-developed drain system to collect the inevitable leaks and underseepage that will develop. This means establishing drains around all footings and slabs by installing perforated pipe surrounded by crushed stone backfill to drain water that seeps through the ground, as shown in Figure 8-5. The seepage drains should run to a central collection point, where there is a sump pump having a continuous power source. Also, as with other retrofitting systems, a sealed house will usually need a sewer backflow protection device.



DRAIN SYSTEM AROUND A HOUSE

One sealing system that has been designed to protect a house against low level flooding is the so-called wrapped house. With this system, the entire lower part of the house is completely wrapped with polyethylene film that is eight feet wide and has a thickness of 6 mil.

When using this technique, however, there are two main considerations: that the plastic be installed directly against the walls so that the pressure acts against the wall and not on the membrane alone, and that there be a drainage system for any leaks that develop.

One successful drainage system involves digging a shallow trench, about eight inches deep, around the base of the building's exterior walls. As shown in Figure 8-6, a four-inch perforated PVC pipe is then installed around the perimeter of the house and is drained to a sump pump. This arrangement allows any water that might leak through the plastic to be drained away from the foundation, reducing the possibility of leakage into the building.

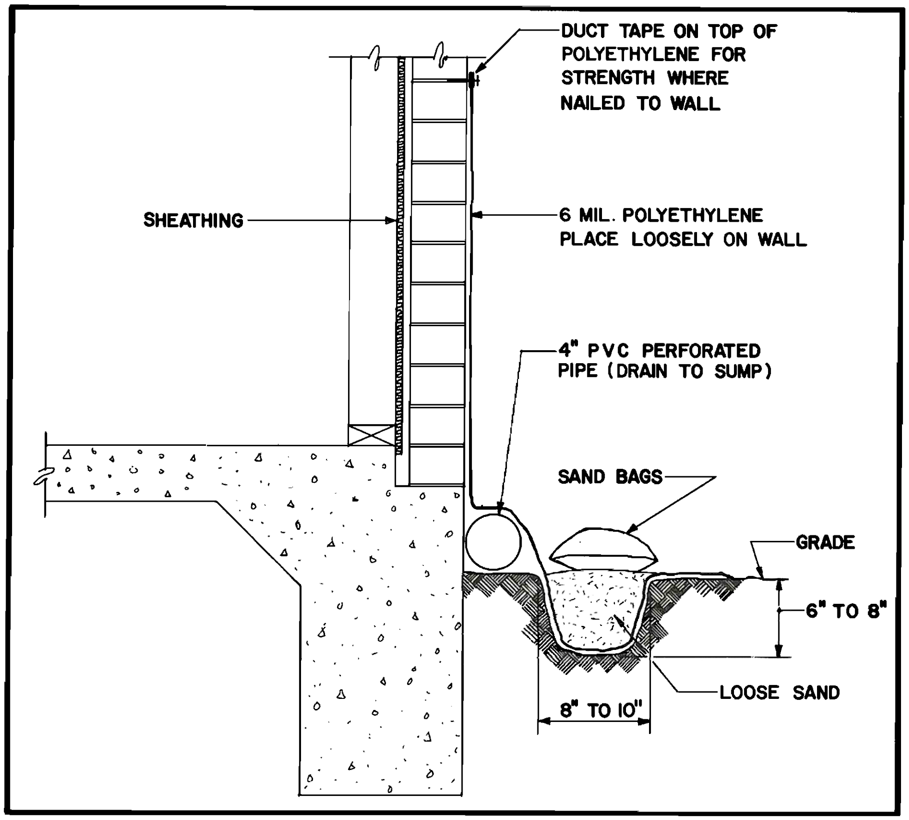


FIGURE 8-6. *One sealing system that has been designed to protect a house against low level flooding is the 'wrapped' house.*

The plastic is then draped on the ground, down through the trench and up the wall for three or four feet where it is hooked to clips on the wall. It should be loose enough so that as the water rises, the plastic can fill gaps without tearing. Sand is then placed into the trench over the plastic to hold it in place. Additionally, sandbags should be placed on top of the sand to further assure that the plastic stays in place.

Because the plastic has little inherent strength, it must be backed and fastened to sections of framed plywood that have been braced wherever it covers access openings such as doorways. The plywood will need to be substantial enough to withstand the same flood forces.

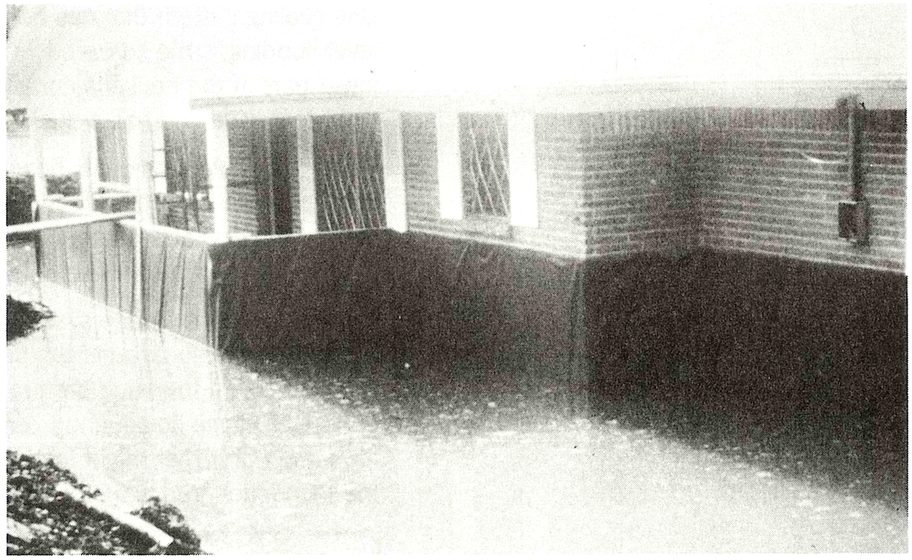
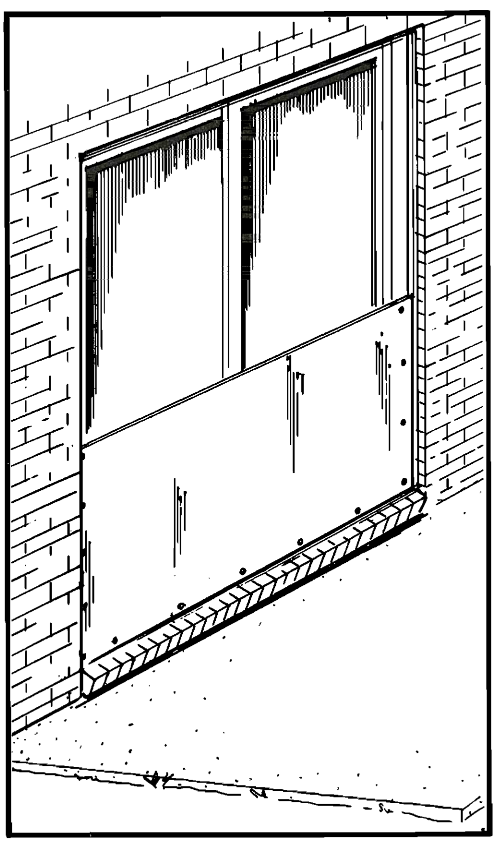


FIGURE 8-6a. *Pictured here is the testing of a commercial sealant system.*

FIGURE 8-7. *This aluminum shield can help prevent low level flooding from entering through a doorway.*



While this system has been effective under certain types of flooding, caution is urged for anyone considering it. All the materials must be ready for use, and it will normally take four to six people several hours of work to put it in place. Many parts of the country do not have sufficient flood warning times to allow for the use of this method. Not only is it a labor-intensive process, but it must be done carefully. Even a small hole made in the plastic will be under pressure during flooding and will leak. Enough holes in the membrane will eventually overwhelm the drainage system and result in flooding of the building.

Several commercial versions of the wrapped house are available with the system preinstalled so that it can be set up in a shorter time. These systems normally involve a vinyl-coated nylon wrapping, set on a roller contained in a box that is installed flush with the ground. To set it up, the top of the box is opened, and the material is pulled up and hooked to clips that are set in the wall. However, the same cautions about water pressure on the walls, adequate drainage, and a sump pump still apply.

8.4 CLOSURES

The use of sealing techniques for retrofitting a structure will require the use of closures on building openings. Since they are the lowest openings on a house, a doorway is the most common point of entry for low level flooding. Most doors are not designed to withstand flood forces, and will quickly fail. For very low flood levels, such as a few inches of water, a door can be retrofitted by installing a waterproof gasket and reinforcing the door jamb, hinge points, and latch or lockset and coating it with a waterproof paint or sealant.

If there is a chance of higher flood levels, then some type of shield will be needed, as shown in Figure 8-7. If the expanse across the door is three feet or greater, then the shield will have to be constructed of heavy materials, such as heavy aluminum or steel plate. Because of the resulting weight, this might have to be a permanent installation, either hinged or of slide-in design. The frame for such an installation must be securely anchored into the structure.

If the flood levels on the closure are less than two feet, then lighter weight materials such as light aluminum or plywood might be used to make a portable closure. The connectors for the bolts must be securely anchored to prevent the shield from being pulled off during flood surges.

Commercial versions of flood closures exist that can be custom fitted for residential openings. They are constructed of heavy duty materials and some feature an inflatable gasket that can be inflated using an air compressor.

For structures being sealed where a window may be exposed to flooding, some form of protection is needed since standard plate glass cannot withstand flood forces. One solution is to brick up all or part of the window. The new bricking must be integrated into the old structure so it will not fail under flood pressure as shown in Figure 8-8. It may also be possible to use glass block instead of brick, to admit light.

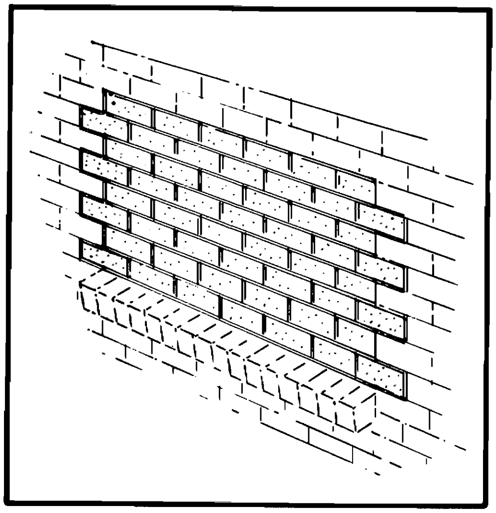


FIGURE 8-8. *Where a window is exposed to a flood, bricking up the opening could eliminate the hazard.*

For normal-sized windows, shields can also be used. They should be made of materials such as heavy plexiglas, aluminum, or framed exterior plywood. These can be screwed in place, or slid into pre-designed frame slots. Another alternative would be to replace the glass with heavy plexiglas, but the window must be sealed shut and waterproofed using water resistant caulking.

Additional information on various closure systems can be found in Chapter 7.

8.5 DESIGN DETAILS

Unlike most of the other retrofitting techniques presented in this manual, use of this method assumes that water will be in direct contact with the building walls and structural components. Because of this, the house will be subject to hydrostatic, hydrodynamic, and/or impact loads. A detailed discussion of these loads is presented in Appendix C. The particular loadings for the site must be determined before a structural analysis can be performed.

The most important factor governing the structural integrity of the house is the type and size of materials that were used for construction. Among the wall systems common to residential-type construction are stud wall with sheathing, stud wall with brick veneer, concrete masonry, and concrete masonry with brick veneer.

Some engineering studies have been conducted to determine the ability of a particular wall system to withstand hydrostatic pressure. The publication, Block and Brick Wall Integrity Against Water Heights and Systems and Materials to Prevent Floodwaters from Entering Buildings, U.S. Army Corps of Engineers, Waterways Experiment Station (December 1984) presents case studies and tests to evaluate the performance of block walls under hydrostatic loads. The findings indicate that concrete block wall construction can resist hydrostatic pressures up to three feet in depth without structural damage. A second report, Structural Integrity of Brick Veneer Buildings [Technical Report C-78-16], U.S. Army Corps of Engineers, Lower Mississippi Valley Division (May 1978), recommends that for brick veneer on stud wall construction, water height should not exceed two feet.

Each of the above studies deals only with hydrostatic loadings. The recommendations for allowable water height given in the studies do not contain any provisions for hydrodynamic or impact loads. For this reason, this retrofitting method should generally not be considered if the structure may be exposed to velocity flood waters or those containing significant amounts of debris.

Regardless of the type of wall construction involved, it must be evaluated by a qualified structural engineer to determine the actual capabilities to withstand water loads. The variation in types of building materials, the physical condition of the structure, and the actual support system all warrant this analysis on a case-by-case basis to determine the integrity of the wall. The structural analysis includes evaluation of load capacity dependent upon size and spacing of structural members, the type of material from which the wall is constructed, and the support conditions which determine structural behavior. This analysis, which should include any possible hydrodynamic and impact loads, will indicate the maximum allowable elevation the water can reach before structural failure can occur. Provisions to flood the interior of the house when the water level exceeds this maximum allowable elevation are mandatory to equalize the hydrostatic loads and preserve the structural integrity of the building. Design criteria for these openings can be found in the elevated foundation wall section of Chapter 3.

The structural integrity of the foundation system must also be considered when the sealing method is employed to protect a residence. Water loads acting on the foundation, whether uplift loads on a slab in slab-on-grade construction, or hydrostatic, hydrodynamic, and impact lateral loads on foundation walls, or uplift and lateral loads on a basement, must be accounted for in the evaluation of the entire structure.

Special precautions must be taken when a building with a basement is to be sealed. Because a basement will usually be completely surrounded by water, it must be capable of withstanding the increased flood forces which result when the surrounding soil becomes saturated. Although dry soil may weigh only about 30 pounds per square foot, once it becomes saturated it can create much greater pressures against the basement walls, sometimes as much as 90 pounds per square foot.

The threat of structural failure arises as a result of conventional home construction practice, which generally is not designed to deal with flood forces. Most basement walls and floor slabs do not have significant reinforcing, and often depend on the weight of the house to help keep them in place. Even a professional engineer may have difficulty determining the quality of concrete and the amount and placement of reinforcing in an existing basement.

With the additional loading during a flood, hydrostatic pressures on the walls can cause them to fail and can also cause uplift forces resulting in buckling of the floor slabs. For new construction, these forces can be withstood by using adequately connected steel reinforcing when building the walls and floor slabs. For an existing basement without such reinforcement, there are two retrofitting methods that can be used to reduce the risk of failure. The first involves keeping the basement watertight and providing adequate structural reinforcement such as shoring or buttresses. Because of the forces that can be involved, this method should only be used when the surrounding soil is relatively impervious and should always be designed by a qualified structural engineer. (See illustrations in FEMA's Flood Emergency and Residential Repair Handbook.)

The second, and more common, method is to allow water to enter the existing basement to prevent hydrostatic pressures from building up. This can be done by installing a "blow-out" plug, designed to relieve pressures well below that which would cause structural damage. The water that enters the basement can be drained to a collection pit equipped with a sump pump.

Additional details on retrofitting basements are located in the Technical Design Criteria section.

8.6 COST GUIDELINES

Regarding costs of sealants, commercial system pricing is available from the manufacturers of such systems. Cost ranges are suggested in Table 16 as rules of thumb for estimating costs of sealant projects.

TABLE 16

UNIT COST ESTIMATING FOR SEALANTS

	ITEM	UNIT	UNIT COST 1985 DOLLARS	NO. UNITS NECESSARY	ITEM COST
1.	Drain Tile 4" - 6", PVC, In Place	Foot	\$6.00 - \$10.00	________	________
2.	Blow-out Plugs	Each	\$100 - \$200	________	________
3.	Polyethylene Membrane Heavy Gauge	Sq. Ft.	\$0.35 - \$0.50	________	________
4.	Excavation	Cu. Yd.	\$3.00 - \$8.00	________	________

8.7 TECHNICAL DESIGN CRITERIA

The use of sealing as a retrofitting technique may increase the soil and water loadings against a basement or foundation. In these instances, the increased loading forces as well as the strength of the existing basement must be calculated to determine the structural adequacy of the system. Additional retrofitting measures may be warranted to ensure the safety of the structure for the increased loading conditions.

There are several factors that must be taken into account in the analysis of a foundation system. These considerations, which are often interdependent, must be examined to determine the capability of the foundation system to resist flood loads.

Loadings

The loading forces on basement walls are the most significant factors in determining whether the construction methods and materials used are adequate. For example, basements subject to soil and water loads caused by soil backfill that has been saturated will require stronger walls to resist those loads. Even when the water level inside the basement is allowed to equalize with the water level outside the structure, there is a lateral load equal to the difference between the equivalent fluid pressure and the specific weight of the water that must be taken into account. For a more detailed discussion of these loads, refer to Appendix C.

Materials

The adequacy of materials for foundations and foundation walls depends on the anticipated loadings for the structure. Unreinforced concrete masonry, typically with thickness of 8 or 12 inches, cannot resist large lateral pressures. Due to its strength limitations, this type of construction is not normally a candidate for watertight sealing. Reinforced concrete masonry construction of the same thickness generally uses mild steel reinforcing grouted into the block cells or cavities developing significant moment capacity to resist lateral pressure. Unreinforced and reinforced concrete masonry construction are governed by the allowable design stresses and construction practices outlined in Building Code Requirements for Concrete Masonry Structures, American Concrete Institute Standard 531-79.

Another material commonly utilized for basement construction is structural plain concrete. This type of wall is typically poured in place without temperature or shrinkage reinforcing. The resisting capacity of the plain concrete is limited by its tensile strength, prohibiting its use for large lateral loads. However, the plain concrete wall, depending on the particular loading conditions, might serve as an efficient load-designed wall. The strength of the concrete varies from 2,000 to 3,000 psi, with 2,500 concrete psi the norm. Structural plain concrete construction is governed by Building Code Requirements for Structural Plain Concrete, American Concrete Institute Standard 318.1-83.

Reinforced concrete offers the greatest lateral resisting capacity of all the construction types presented. The wall is reinforced with vertical mild steel bars, increasing the load resisting capability of the wall significantly over structural plain concrete. Reinforced concrete construction is subject to the allowable design stresses, construction practices and design procedures detailed in the Building Code Requirements for Reinforced Concrete, American Concrete Institute Standard 318-83.

Analysis

Most basement walls act as a single span, where the supports are taken by the foundation or slab system at the bottom and by the floor framing system at the top. Development of a proper support at the bottom of the basement wall generally presents no problem. The connection at the top of the wall, however, is often overlooked or inadequately designed for proper transfer of lateral loads to the floor system. For a more detailed discussion refer to Section 3.13, "Technical Design Criteria—Anchorage of Superstructure to Foundations." Adequate supports, both at the top and at the bottom, assure that the foundation system performs in the manner in which it was designed, thereby reducing the possibility of failure.

After the structural conditions have been established, the next step is to determine what materials should be used. To ensure that all possible loading forces at the site are taken into account, this analysis should be performed by a qualified structural engineer. The analysis will also yield the forces that will be transferred to the top and bottom of the basement wall. These forces must be incorporated into the connection design to ensure that components of the foundation system will be capable of withstanding the increased flood forces associated with this retrofitting method.

Most normal foundation systems are not structurally capable of handling the magnitude of loads introduced by the various aspects of flooding, but several possible retrofitting actions are available to improve their structural integrity. One such possible action is the construction of pilasters to increase the resistance capabilites of the walls. Another solution is the placement of fill and installation of a new slab higher inside the basement to counteract flood pressures on the structure. A simple solution during flooding would be to allow water to flow into the foundation system to help equalize loading forces. The analysis for whatever solution is used must include adequate design for parameters such as loadings, construction, materials, and connection details.

Buoyancy Requirements

Buoyancy forces on a submerged basement must be considered in the design of the structure. Buoyancy forces result from the hydrostatic loads acting on the structure, primarily the floor slab of the basement. The forces acting on the basement slab are dependent upon the level of the water causing flexure load on the slab and the possible floating of the structure. This upward buoyancy force is resisted primarily by the weight of the superstructure and foundations. When the bùoyancy force exceeds the dead load of the entire structure, flotation will occur. It is therefore important that the water level not be allowed to exceed the height at which flotation will begin. If flotation is possible, the most common method to prevent it is to allow the basement to fill with water, thereby equalizing the hydrostatic pressure. Possible methods for accomplishing this include blow-out valves or flapgates which permit this inflow at predetermined elevations. Until this flooding is allowed to occur, the walls and the floor slab must resist the hydrostatic forces acting on the submerged portions of the basement.

The slab of a basement must be able to withstand the uniform uplift load due to hydrostatic pressure. This requires the structural integrity provided by reinforcing, or thickness in plain concrete, to span between the load bearing walls. The analysis of support locations and flexural capabilities should be performed by a structural engineer. In addition to the flexural loads on the slab, the slab must be positively anchored to the foundation or to the basement wall to prevent flotation of the slab and intrusion of water between the slab and foundation. Doweling at the time of construction of the slab and footings allow for a positive control of flotation and seepage. Retrofitting a basement slab which is not adequate for hydrostatic loads may require construction of an additional slab directly on top of the existing slab and doweling into the existing foundation or basement walls.

Drainage System

A properly designed drainage system for a basement can usually help to reduce hydrostatic pressures by removing water from around the structure. A key consideration in the design of a drainage system is its ability to positively discharge water with an adequate outlet to the surface. Granular materials placed adjacent to the basement wall and footing with or without a drain tile under the slab and around the sump area provide a path for drainage to take to the sump area. Figure 8-5 shows a drain system typically used in residential basement construction. Retrofitting a residential structure with a sump and pump is limited to a system which has a means for the water to flow to the sump. When impervious soil is present, the only retrofitting alternative for drainage may be to excavate adjacent to the foundation walls and install a layer of granular material.

The type of soil material at the site determines the flow rate of water to the underdrain system. If the soil is too pervious, a sump and pump may not be able to keep up with the inflow, since most installations can only handle low to moderate seepage rates.

The pump and motor combination should be of the submersible type located in the sump itself, with a watertight electrical supply. Automatic switches which sense the water level and start the pump into operation, along with a high temperature cutoff switch and automatic reset, should also be specified. The power receptacle outlet for the 3 wire heavy duty U.L. listed wire and plug should be located above possible flood water levels. Heavy wall cast iron construction with corrosion resistant fasteners offers a long service life, while a stainless steel strainer at the pump suction prevents impeller damage from pumping foreign objects. The submersible type pump requires no priming and therefore needs little or no human intervention. In case of a power outage, a portable generator should be available to run the pump.

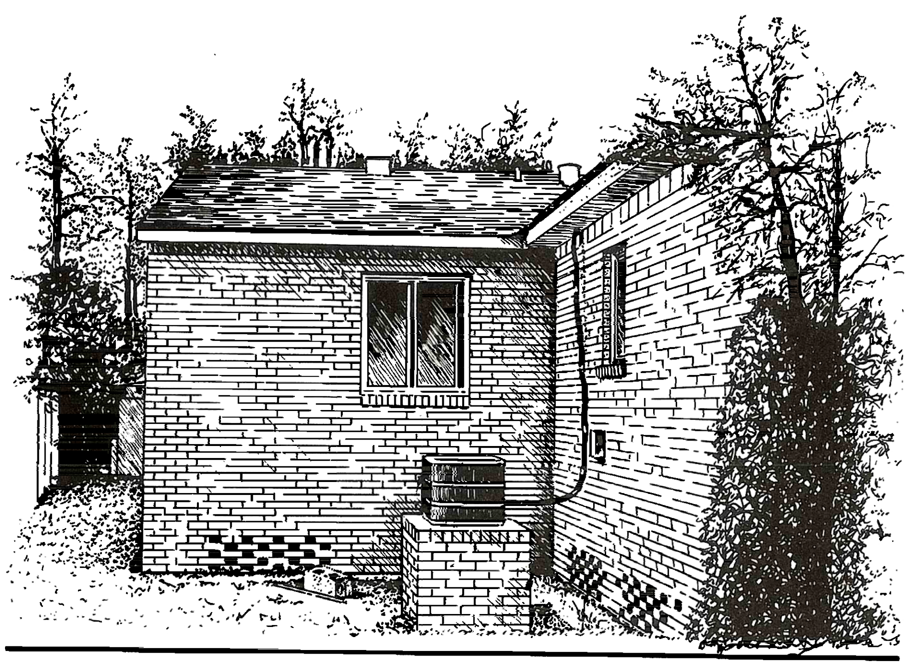
Another possible pump arrangement for a basement sump is a centrifugal, self-priming suction pump powered by a gasoline engine. The drawbacks for this arrangement include provision for exhausting the gasoline engine outside the basement enclosure and the requirement of a control system and electric starter, both of which may be costly alternatives. The reader is referred to the Technical Design Criteria section in Chapter 5, "Levees," for further details regarding sump pumps.

The above design considerations are presented as a guideline for the retrofitting of foundations or basements to increase their ability to withstand flood forces. As with all retrofitting construction, quality of materials and workmanship play a major role in determining the effectiveness of any design application. For a more detailed discussion on construction technique and design criteria, refer to Federal Insurance Administration, Manual for the Construction of Residential Basements in Non-Coastal Environs (March 1977).

Chapter 9

PROTECTION OF UTILITIES

Damage to utility systems is one of the most common losses suffered by homeowners during flooding. Fortunately, the protection of utility systems is also one of the easiest and least expensive retrofitting methods to accomplish.



9.1 INTRODUCTION

Damage to utility systems is one of the most common losses suffered by homeowners during flooding. Fortunately, the protection of utility systems is also one of the easiest and least expensive steps in retrofitting.

Use of this method alone is only adequate for the small percentage of cases where flood waters cannot exceed a depth of one foot with any velocity. Normally, utility systems should be protected along with the entire residence through elevation, relocation, or another retrofitting technique. Even when another retrofitting method is used, however, the location of a building's utilities can still affect flood insurance premiums, as described in the special section, "Elevation Regulations of the NFIP," in Chapter 3.

9.2 CONSIDERATIONS

For those cases where the flood threat has been determined to only involve flooding of outside utilities, there are several cost-effective options that protect only the utilities. The important thing is to first understand what type of flooding threatens the property and where the base flood elevation exists in relation to the utility systems.

There are a number of good reasons to protect utility systems when considering steps to reduce flood damages:

> Even though the house structure itself may survive the flood waters, damage to utility systems could result in a structurally sound house that is uninhabitable because it lacks heat, electrical, gas, water, or sewer services;
>
> In some cases, utility services are required to safeguard the structure during the flood, and therefore must be prepared to withstand flooding; and
>
> Protection of utility systems is one of the few areas where the technology involved is well developed, easy to design and implement, and usually inexpensive.

Damages to utility systems vary greatly depending on two factors: the nature of the flooding threat and the physical placement of the equipment.

The homeowner should be aware that a residential structure is not normally designed with the flooding threat in mind. In fact, the placement of the utility systems in the home is usually based on more typical construction and economic concerns of the builder. For example, the current placement of electrical and heat duct systems in the home was likely based on reducing the length of electrical cable or duct runs, or to hide electrical boxes and allow for simple floor-to-floor connections, rather than to protect them against flood waters.

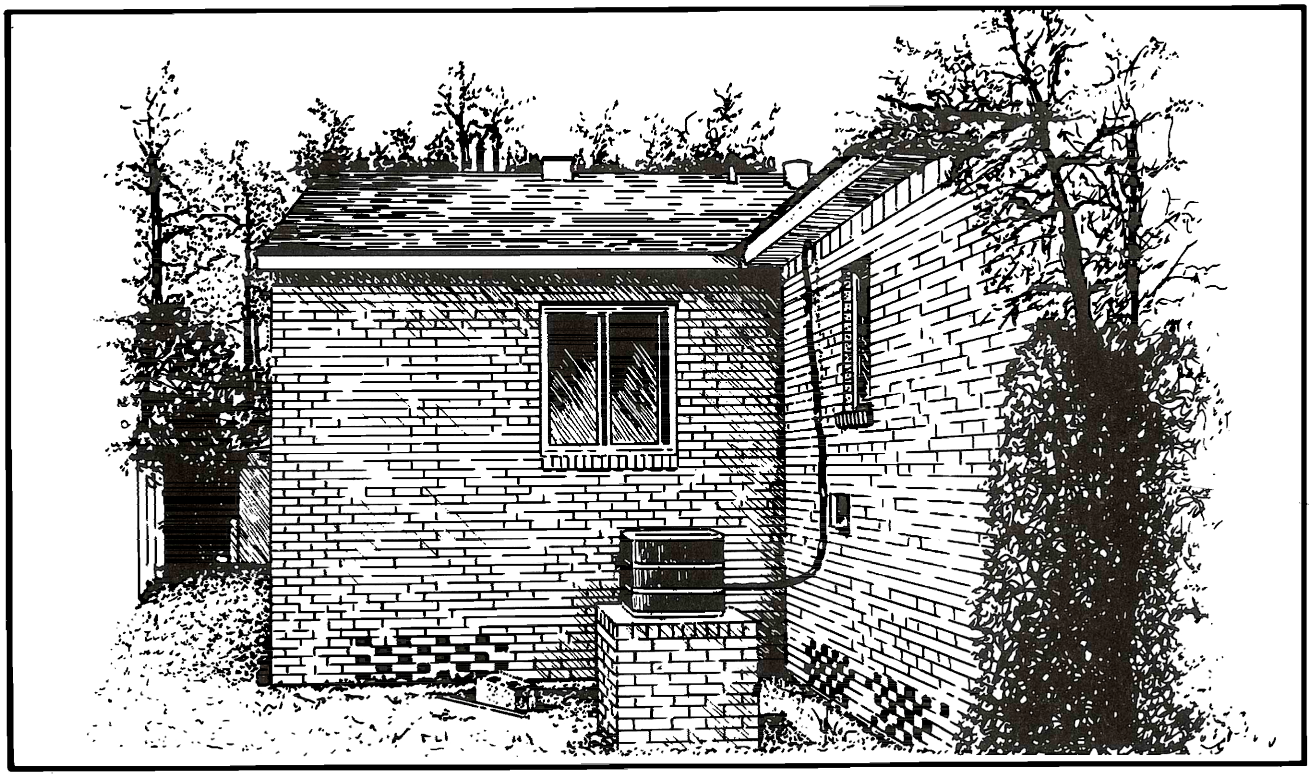


FIGURE 9-1 Detailed Rendering of Protected Utilities.

9.3 EMERGENCY PROTECTIVE MEASURES

No matter what other retrofitting methods are used, there are a number of emergency measures that, if taken prior to flooding, can reduce the utility damages that are likely to occur.

Electrical Service—Electrical power coming into the home is controlled at a main switchbox which is generally located in the basement or on a side or back wall of the first floor living area, and uses either plug fuses or circuit breakers. When flooding is imminent, the homeowner should shut off the main power switch and completely remove plug fuses (simply loosening them will not suffice), or switch off every circuit breaker. After the flood water has gone down, all electrical equipment should be cleaned and dried before restoring power.

Gas Service—In imminent flood situations, close the main gas valve, normally by using a crescent wrench. The valve is usually located outside on the gas piping just before it enters the gas meter.

9.4 PERMANENT PROTECTIVE MEASURES

While emergency measures provide limited protection, there are a number of easy-to-implement retrofitting steps that will provide permanent protection of a structure's utility system.

Utility Connections

The entry points of all utility services are generally found on the side or back exterior walls of a structure. The homeowner should determine if these entry points are above the base flood level. If not, a qualified serviceman should be contacted to reconnect and anchor service lines above the flood level. Where this is impossible due to structural or other concerns, the lines should be encased in a waterproofed conduit or otherwise protected and anchored to withstand flood forces. Examples of entry point relocations include moving the main electrical switch boxes and main gas/water connections above the base flood level.

Shielding

In cases of seepage or shallow flood waters, adequate protection can sometimes be provided through the diversion of water away from basement furnaces and other utilities or appliances. Such diversion could be accomplished using a mini-floodwall structure surrounding the furnace, air handler and washer/dryer appliances.

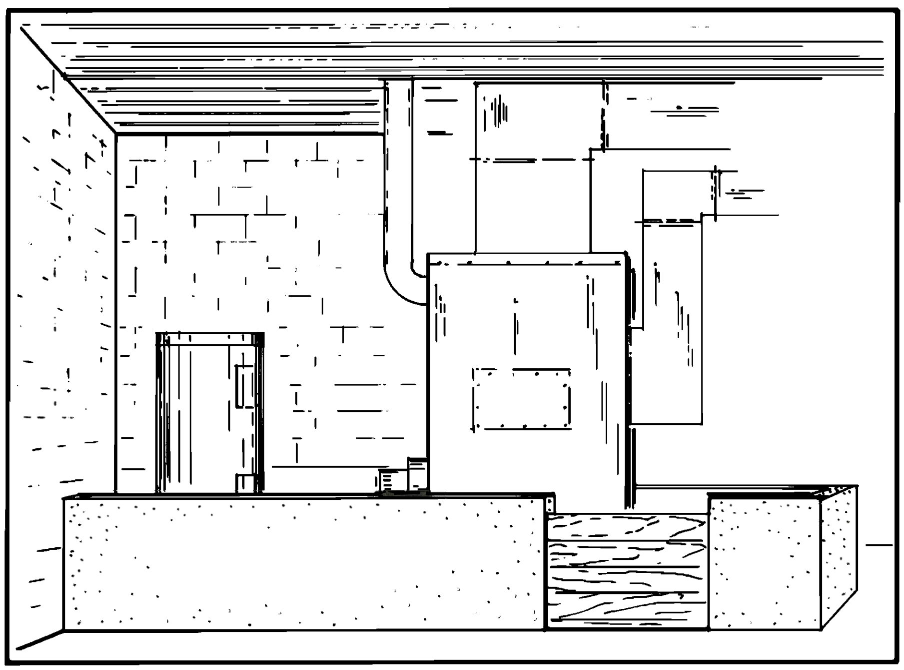


FIGURE 9-2. *A mini floodwall can protect basement utilities from low level flooding.*

If the flood threat is less than 8 inches, then the floodwall could be low enough that it would still be easy to step over the enclosure. For walls that are higher, a removable shield could be installed at the front of the utility enclosure for easier entrance, as shown in Figure 9-2, or a low set of stairs could be constructed over the enclosure. A sump pump should be installed inside the enclosure to handle any buildup of seepage water.

In cases where water depths are greater, more complex shielding arrangements are possible by constructing a utility cell of reinforced concrete to allow protection for furnace and air handling systems. Access to the equipment may be provided through a watertight door. However, this solution is less practical for washers and dryers or other appliances because the construction of the enclosure shield can cost more than the items being protected, and even if the cell could be constructed inexpensively, it could represent an access problem for appliances that involve frequent use and maintenance.

Determining the cost of a shield system for utility protection depends largely on individual site considerations such as size of the enclosure, makeup of the utilities being enclosed or shielded, and type of materials to be employed. A typical cost for a 6′ × 8′ shielded enclosure constructed of four brick layers and mortar and a sump pump would be $250. This cost may vary depending on local availability and market cost of materials, but this investment will usually be feasible since it will protect over $3,000 worth of utilities.

With regard to constructing a utility cell, unless a homeowner had ready access to free or very inexpensive materials, or faced the prospect of serious flooding three or four times over the life of the home, the use of this method will usually not be feasible, and other options discussed in this chapter should be considered.

Low Elevation

In-place protection of utility systems and applicances can be provided by elevating the utility or appliance in its present space. Relatively simple elevations can be made by placing the systems on low platforms constructed from brick, concrete or wood. For basement seepage or low flood waters, the flood problem might be solved inexpensively for little more than the cost of bricks and mortar, which averages about $2.50/square foot of wall.

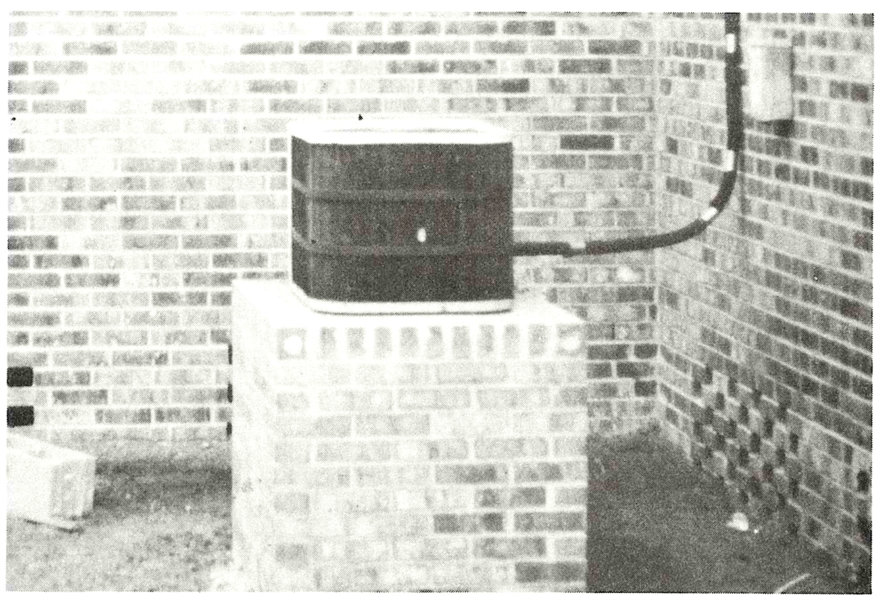


FIGURE 9-3. *This air conditioning unit in Alabama is protected from low level flooding by being elevated on a brick pad.*

Ceiling Suspension

In-place protection or protection within the same space for utility systems is also possible by suspending the utility system from existing overhead floor joists. For furnaces, this option would involve units that are designed to operate horizontally, such as in a crawl space. A variety of possible options exists for suspension systems, including the construction of a suspended wood platform or the use of durable, properly reinforced steel hangers, as in Figure 9-4. Caution must be taken to ensure that the floor joists are of sufficient strength to handle the increased weight load and that adequate connection of the hanger or platform to the floor joists is provided.

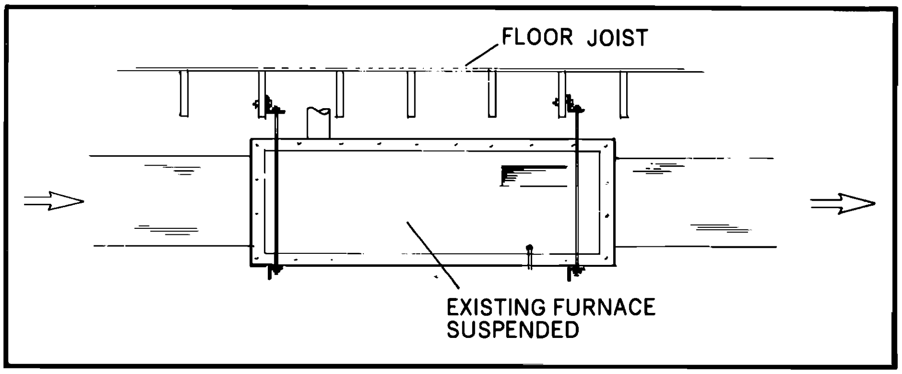


FIGURE 9-4. *Some utilities can be protected from flooding by suspending them from floor joists.*

Costs for such suspended systems will vary depending on material chosen for the support system and applicability of the measure itself to the furnace/air handler in the residence. Generally, the design and construction of a suspended wood platform of 4′w x 4′l x 4′d would range from $700 to $1,000, if completed by the homeowner.

Anchoring Techniques

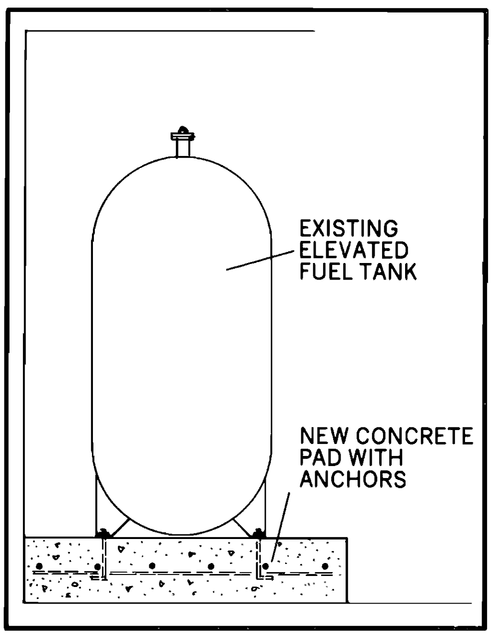


FIGURE 9-5. *To prevent flotation, a basement fuel tank should be properly anchored, preferably in a newly poured concrete slab, and kept topped off.*

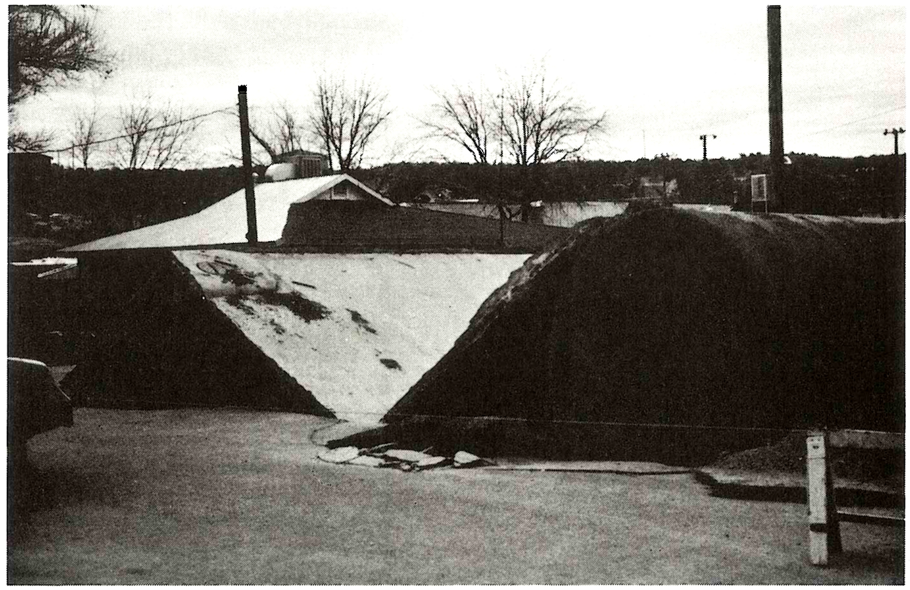
Because the measures outlined above are actually based on the base flood elevation for the specific location, it is possible that floods above the base flood elevation can result in damage to the utilities. For this reason, one protective measure which should be incorporated into all of the utility protection options covered above (shielding, low elevations, and suspended elevations) is the application of protective anchoring. Because each of the covered methods involves some type of construction, the homeowner should consider the addition of solid steel hooks and/or eyelets into the design. These hooks or eyelets, cemented or otherwise securely attached to the elevation or shielding structure, can be used as tie-down points in securing the utility equipment.

Many local codes now require that for new home construction, the fuel oil tank be buried. However, even if covered by earth, the tank can easily float up through saturated earth, as demonstrated in Figure 9-6. It is good practice to keep a fuel tank topped off with oil, since it helps to reduce corrosion and the collection of moisture in the tank. This is even more important during flooding, though, since the additional weight will help reduce uplift forces on the tank. To help provide complete protection, the homeowner can retrofit the tank by excavating down around the tank, placing steel beams across it, and then connecting these beams to earth anchors that have been augered into the ground. This is covered in more detail in Section 9.8.

9.5 UTILITY RELOCATIONS TO EXISTING SPACE

When the flooding threat can exceed the 6–8 inch level or is of significant frequency, the options presented by in-place protection of utilities become less attractive. Besides the obvious cost disadvantages of designing complex

FIGURE 9-6. Fuel Tanks Floating



protective structures in such conditions, the homeowner is faced with constantly cleaning and refurbishing the space following the flood.

Another alternative in these cases is the relocation of utilities to existing space elsewhere in the affected home where flood waters do not represent a danger. This option is most applicable to structures having an exposed basement where utilities could be relocated to a first-floor location, though the technique has been applied to second-story and even attic space. When utility equipment is relocated from a basement to a first floor, space can often be made available from rarely used powder rooms or storage closets, or sectioned off from larger living areas.

The process of relocating the equipment is quite simple as long as space is available. Ductwork for furnaces and air conditioning systems often requires no major re-routing since the main lines generally run vertically throughout a structure, with feeders servicing areas to the side. As a result, relocation to an upper floor means simply sealing off lower area ductwork and re-positioning the main furnace or air conditioning unit and connecting into the nearest duct. Likewise, other retrofitting actions such as relocating water, electric and gas lines to the upper floor usually involve no major technical difficulties.

The cost for completing such a relocation primarily involves the expert assistance required in the physical relocation and hookup of furnace and air conditioning systems; the placement of 220-volt electric lines for the furnace blower and dryer; and the new water and gas plumbing work that would be needed. An actual case study in Massachusetts involving these exact specifications cost the owner approximately $2,000.

9.6 UTILITY RELOCATIONS TO NEW SPACE

When space is not available to relocate the utilities to a higher part of the structure, relocation to a new space is an alternative to be considered. Often, the option to build a utility room addition is very attractive since windows or blank wall space in kitchens can easily be used as access doors to the new utility room.

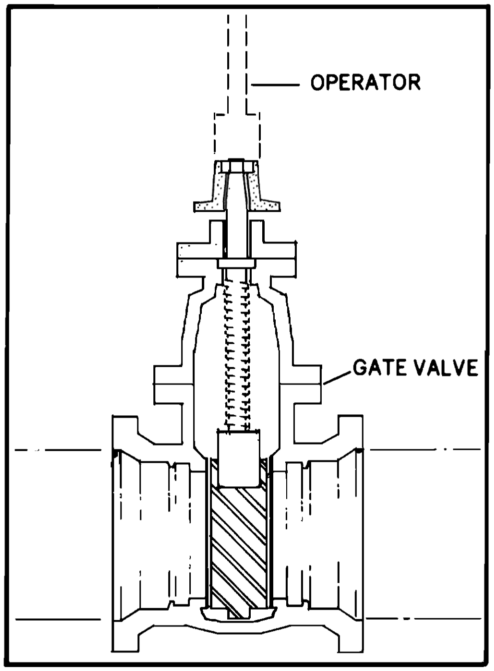


FIGURE 9-7. *A gate valve prevents sewage from flowing back into the house during a flood, and is unlikely to be blocked open.*

Generally, this alternative involves an elevated room supported by piers, columns or pilings. For information on the proper use of elevation techniques, refer to Chapter 3, "Elevation."

If the house at grade is above the base flood elevation, then this may be accomplished even more simply by designing an addition to the structure on a poured concrete slab.

The costs associated with construction of a utility room addition are the same as those involved in relocation of utilities to an existing space, plus the cost of constructing the addition, which will vary with site characteristics. In most cases, the costs will include excavation and backfill work, foundation, structural framing, roofing and siding, doors, gutters and finish work such as caulking and painting. For an average sized room, the project could range in cost from $5,000–8,500, or $25–30 per square foot.

9.7 PLUMBING SYSTEM PROTECTION

Protection of the plumbing system must also be considered by all homeowners facing flooding situations. This protection should include both sewer and water systems.

Often during floods there is increased water pressure or inadequate or overloaded sewer systems, forcing water to flow backward through sewer lines and out through toilets or drains into the basement or lower living areas. Usually, the best solution involves the retrofitting of the sewer line by installing a check valve or a gate valve.

The check valve permits normal sewer flow from the house to the main sewer line, but during flooding prevents sewer water from flowing back into the house by means of a check or restrictive mechanism in the valve. Check valves are also sometimes referred to as backwater valves.

Unfortunately, debris will sometimes block the check valve in an open position, resulting in no protection. To prevent this, regular cleaning and maintenance of a check valve is required.

The gate valve, as shown in Figure 9-7, performs the same function as the check valve but is manually operated and designed so that it is unlikely to be blocked open. However, flood protection using a gate valve is dependent on someone being present to close the valve.

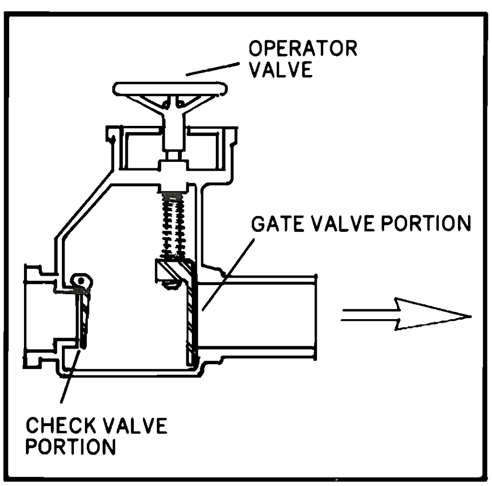


FIGURE 9-8. *A dual backflow valve combines the convenience of a check valve with the positive assurance of a gate valve.*

A third alternative combining both methods is the use of a dual **backflow valve**, as shown in Figure 9-8. It combines the convenience of a check valve with the positive assurance of a gate valve, but it is an expensive option and should be considered primarily in instances of repeated backflow flooding.

Equipment and installation costs of the check valve would normally be $500–$700; $700–$1,000 for the gate valve; and $1,000–$1,500 for the dual backflow system.

Regarding fresh water system protections, owners having well systems should consider capping the well when flooding is predicted. For larger, open wells of the non-conduit variety, the installation of an anchored screen mesh over the well will allow it to naturally fill with flood water and will protect it

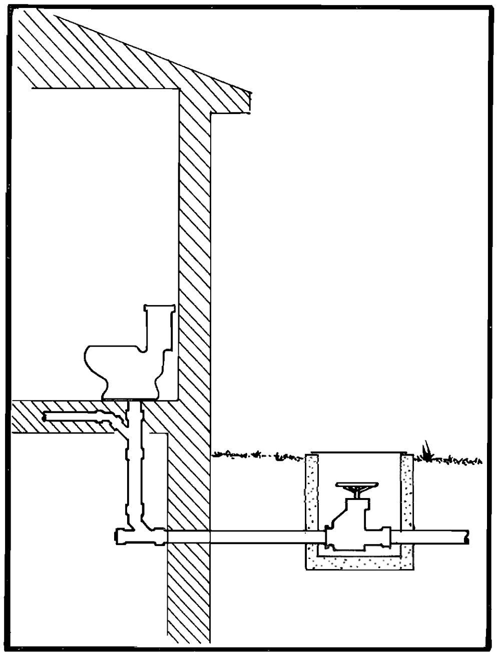


FIGURE 9-9. *The backflow valve prevents sewage from flowing back into the house during a flood by means of a restrictive mechanism.*

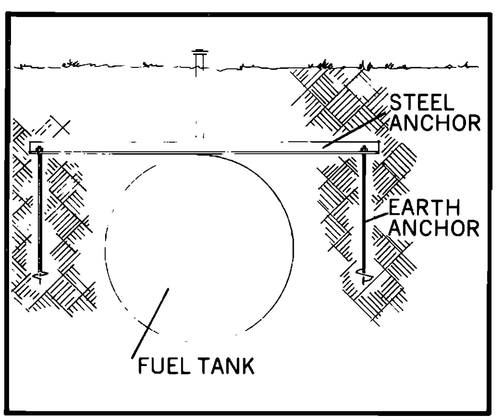


FIGURE 9-10. *Securing a fuel tank with earth anchors can help prevent it from floating out of saturated ground.*

from collapse which might occur if it were capped. Also, the mesh will catch most of the debris atop the well during the flood, allowing for quicker water service clean up after the flood. The main water systems inside the house can be protected simply by shutting the main water valve.

9.8 STORAGE TANK ANCHORAGE

When flooding inundates a storage tank, proper anchorage is needed to prevent the movement of the tank. If it moves, it can rupture connecting piping and present a hazardous condition. The location of the tanks can vary from underground to on the ground, or to elevated installations. The worst design conditions for anchorage occur when the tank is empty and is covered by flood waters or high ground water. Unless proper anchorage is utilized, the buoyancy forces acting on the tank will cause the tank to float off its support.

The anchorage of any tank system consists of attaching the tank to a resisting body with enough weight to hold the tank in place. The attachment, or anchors, must be able to resist the total buoyant force acting on the tank. In addition, hydrodynamic loads may also be present on the above ground installation of tanks and must be accounted for in the total design of the anchorage system. The buoyant force on an empty tank is the volume of the tank multiplied by the specific weight of water (62.4 lb/ft^3). If the volume of the tank is measured in gallons, this can be converted to cubic feet by multiplying the volume by 0.134. To resist this buoyant force, a slab of concrete is usually strapped to the tank in an underground installation, or the tank is attached to a concrete foundation or slab when the tank is above ground or elevated on a frame.

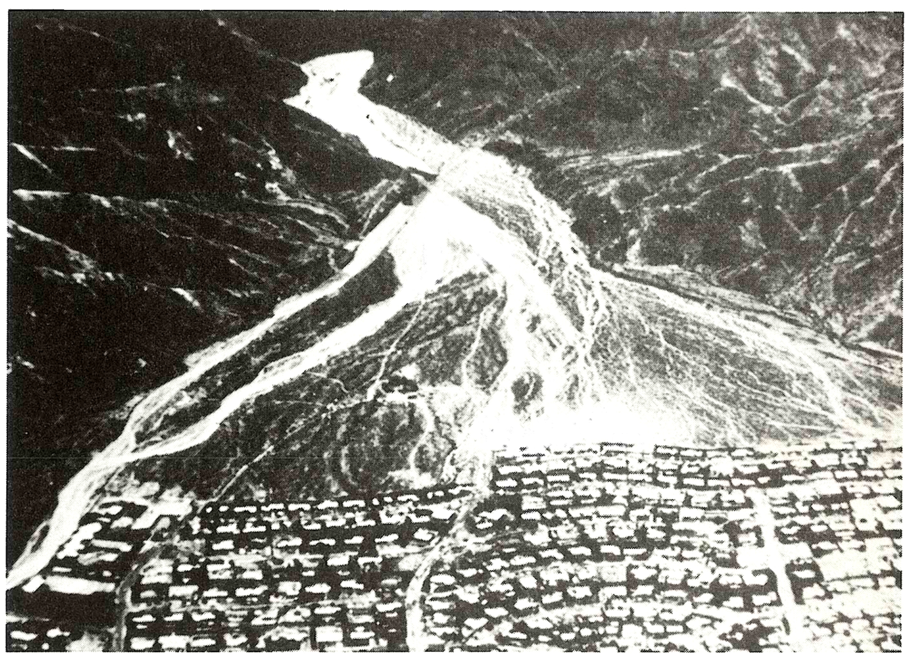
The effective weight of the concrete is the specific weight of concrete (generally from 145 to 150 lbs/ft^3) minus the buoyant weight of water (62.4 lbs/ft^3). A factor of safety of 1.3 for the buoyant force to effective weight ratio is normally applied. The volume of concrete required is therefore the buoyant force times the factor of safety divided by the effective weight of concrete.

After the volume of concrete has been determined, the anchors attaching the tank to the concrete mass must be sized for the buoyant load. The attachments for the elevated tank must be able to transfer the buoyant force from the tank to the frame, or through the frame to the anchors at the foundation acting as the anchoring mass. Metal straps placed over the tank and attached to the concrete slab or foundation with anchor bolts is one type of anchoring system for underground or on ground installation. Another variation is a rod embedded in the foundation with a turnbuckle. Portable tanks can be secured to a concrete pad by running a length of case hardened chain through a hole or handle on the tank and attaching it to an eyebolt of sufficient strength properly embedded in the concrete. For an elevated frame, anchor bolts attaching the legs of the frame to the foundation are required in addition to the anchorage of the tank to the frame as described above. The mass of the concrete foundation is then designed for the applied load from the anchors. It is suggested that an engineer review the anchorage details and masses to determine the effectiveness of the entire anchorage system.

Chapter 10

SPECIAL SITUATIONS

The previous chapters have focused on methods of retrofitting which are prevalent throughout the United States. Several methods of retrofitting which are applicable to selected locations or situations are introduced in this chapter. These situations are alluvial fans, elevation on fill, elevation of a house attached to a mat slab, and floating structures.



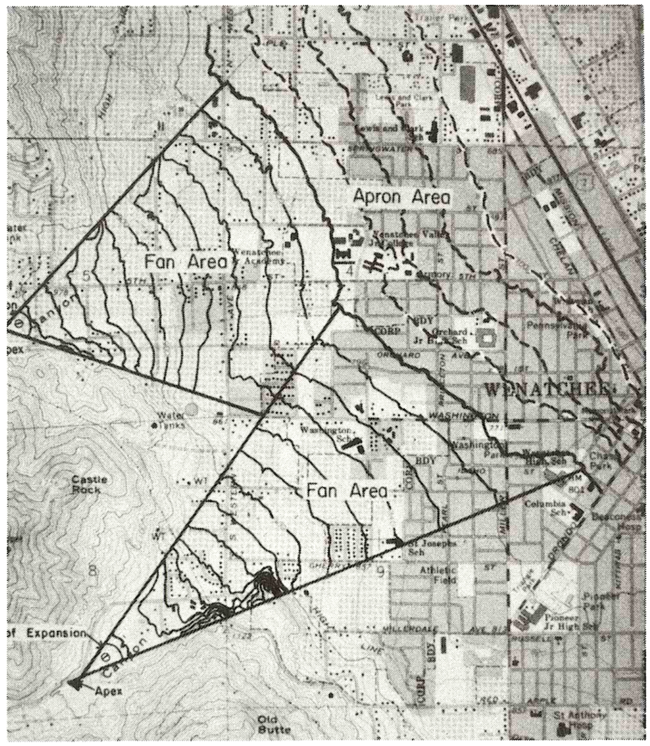


FIGURE 10-1. Alluvial Fan

10.1 ALLUVIAL FANS

Most of the studies of floodplain management and much of the terminology that relates to floodproofing and retrofitting have been developed in riverine and coastal regions where flooding is well documented. However, there is one type of flooding that is increasingly becoming a problem to people of the Western United States because of increased development. Flooding in this area not only tends to behave differently from the river or coastal regions, but also is usually much more unpredictable and dangerous.

This type of flooding occurs in areas known as "alluvial fans." These areas are found in desert and semi-arid regions where sudden rainfalls flow down steep mountain drainages to empty into the valley floor. Floods can be very dangerous because of their unpredictability, high velocities, and the fact that they can carry dangerous debris.

The name "alluvial fan" is taken from the characteristic shape of the area. The upper part tends to be cone shaped, while lower down it becomes more fan-shaped with a lower angle dimension, as shown in Figure 10-1.

While the typical river has fairly predictable areas for the floodplain, such as the floodway, channels, etc., streams on the upper part of the alluvial fans can change their course suddenly and unpredictably. In addition, because of the angle of an alluvial fan's slope and the sparse vegetation in these regions, flood waters can move at a very high velocity. Consequently, they often carry large amounts of silt and debris, such as boulders, and can be very dangerous.

Partly because of the increased settlement of alluvial fan areas and some disastrous flood incidents, there has been a recent increase in the study of these areas. The type of detailed information available for other flood-prone areas is not yet available for alluvial fan situations, but there is beginning to emerge a profile of flooding in alluvial fans and some general recommendations for those who live there. From these investigations, researchers have outlined three basic areas of flooding and some general recommendations for retrofitting in each one.

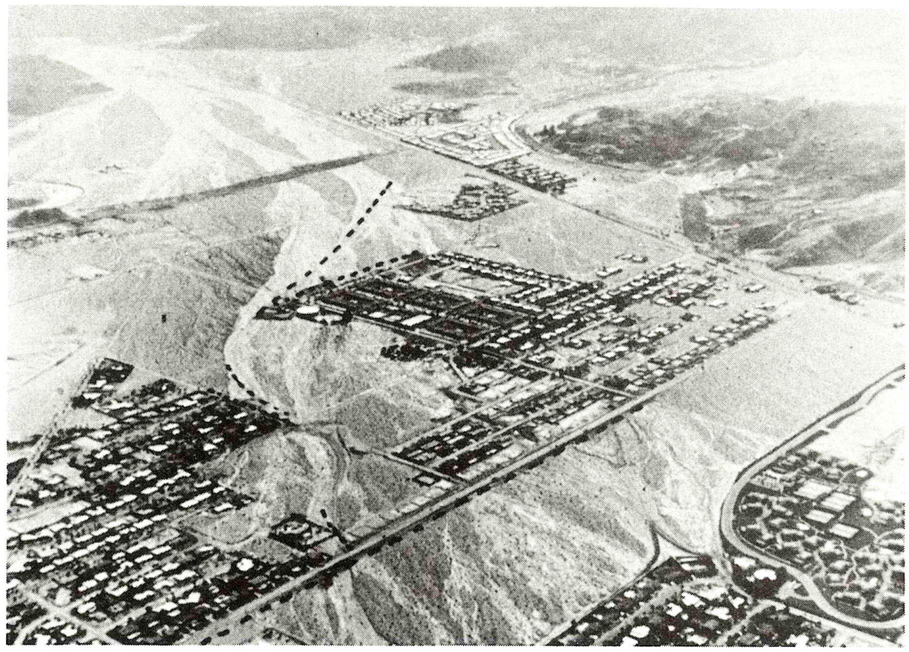


FIGURE 10-2. *This photo shows the alluvial fan area in relationship to a nearby town.*

At the top of the fan, near the apex, the streams characteristically have the highest velocity, usually over 10 feet per second with deep entrenchment, sometimes of fifteen feet and more. Here, the channels may wander, with deep downcuttings and later backfilling of the same area. This is the most dangerous area of the fan, where heavy scouring and the transport of heavy mud and large boulders can quickly destroy any structure. The only acceptable recommendation for retrofitting in these areas is relocation.

FIGURE 10-3. *Due to high velocities and accompanying debris, alluvial fan flooding can demolish a structure.*

Farther down the fan is an area, known as the "braided zone," where the water channel begins to break up into multiple paths. The velocity is usually between 5 and 10 fps with less movement of debris. The general recommendation for retrofitting here is for the elevation of homes on open foundations such as piles or columns, but professional consultation is strongly recommended. Basements should not be built in this area.

FIGURE 10-3a. *Alluvial fan flooding can involve large amounts of sediment.*

At the bottom of the alluvial fan is an area where the water fans out into a more shallow flow. Retrofitting measures recommended are the same as those for the braided area. In addition, armored levees and reinforced floodwalls may also be feasible. Liberal freeboard levels should be considered in all cases.

Because of the uncertain nature of alluvial fan threats, only generalized recommendations can be made. If homeowners believe they live in an alluvial fan zone, the first action should be to consult with local officials and with engineering/geological professionals before designing and undertaking any retrofitting measures.

10.2 ELEVATION ON FILL

Elevation on fill, which is a raised pad of compacted soil, is limited to areas of shallow flood depths with very low velocities. The use of fill to elevate a house is common for new construction, but has several drawbacks for retrofitting. Most important is the need to move the building away from the site while the fill pad is being prepared.

It is possible to use this method to elevate a portion of a structure, such as a garage or other secondary building, while the main residence is retrofitted using a different elevation technique. A second possibility is to prepare a fill pad at a different location, either on the same lot or a different location farther away from the source of flooding, and then relocate the house onto the fill pad.

To prepare a site for elevation on fill, the vegetation, topsoil, and any organic soil must be removed. Soil that is acceptable for compaction of the fill is then brought in, often from off site. This soil is carefully compacted, usually in layers, or lifts that are no more than 12 inches thick, before more is added.

The fill usually has to be allowed to settle for some time before any kind of structure can be set on it. Despite the compaction, and however long the fill has been given to settle, there may be a problem for years with some slight additional settling. Thinner compacted layers can reduce the time and extent of settlement.

The floor of a building elevated on fill will usually be slab-on-grade. Because of the possibility of settlement of the fill, it may be prudent to set the house on a structural mat slab to avoid cracking of the walls and slab. This type of slab is described in the next section.

Generally, an elevation on fill follows these steps:

1. Disconnect utilities;
2. Install support beams for moving and jack up the structure;
3. Relocate the structure to an acceptable temporary site;
4. Overexcavate existing soil as directed by a soils engineer to provide a firm base for the fill material;
5. Place and compact a suitable fill material (which should be recommended by a professional geotechnical soils engineer). Generally, clays and other soil materials with excessive organic material, with shrink/swell potential, should be avoided;
6. Place soil to design elevation in acceptable lifts or layers;
7. Excavate the placed fill for footings and slab;
8. Place underground utilities;
9. Pour concrete footings and slab;
10. Relocate structure over footings;
11. Build foundation walls;
12. Lower building onto foundation walls;
13. Reconnect utilities.

Because this type of elevation impedes the water flow, and can affect flood height and velocity, elevation on fill cannot be used in some areas, particularly floodways. (See "Restrictions on Building in the Floodway" in Section 5.2.) Such construction is also restricted in wetlands.

Another potential problem relates to space. Because large amounts of fill must be used to provide sloping of the material down to the surrounding grade, much of the property space is wasted.

Since certain soils cannot be used for the fill, appropriate fill material may not be available in some locations and will have to be trucked in from some distance. The services of a professional, such as a geotechnical engineer, should be used to determine the correct soil for compaction.

Although in most cases the soil can help insulate the floors of a house set on fill, there is the danger that in freezing weather the fill saturated from flooding can freeze, resulting in uplift of the soil and structural damage.

Because of the potential scouring action and erosion of the slopes of the fill, it may be necessary to protect them. The most common way of doing this is to plant vegetation having extensive root systems to help stabilize the slope. For areas with greater flood velocities and scour potential, it is possible to armor the slopes with large rock, known as riprap.

The greatest drawback of elevation on fill is the expense. Among the things that will drive the costs up are:

- The need to truck in large amounts of soil from a distance;
- The need to carefully compact the soil in layers;
- The need for both test borings of the site and soil analysis of the fill material;
- Consultation with additional professionals, such as geotechnical engineers; and
- The additional topsoil that will have to be brought in for the lawn and landscaping.

10.3 ELEVATION OF A HOUSE ATTACHED TO A MAT SLAB

Before proceeding with this section, it is recommended that Chapter 3, particularly Section 3.4, first be reviewed. If serious consideration is being given to elevating a structure attached to a mat slab, it is strongly recommended that the services of a structural or foundation engineer be utilized.

The first step is to verify that the slab is sufficiently reinforced to ensure its structural stability. The original plans for the house would be helpful, since they generally include the foundation and slab specifications. However, it should not be assumed that specifications calling for steel reinforcing automatically mean that the slab is capable of being elevated. In addition, if the specifications called for **interior grade beams**, which are thicker sections of concrete that act as footings below load-bearing walls, these obstructions will need to be taken into account and the elevation process will be much more difficult.

If a structural or foundation engineer can establish that a house has been built on a structural mat slab, and determines that it is sufficiently reinforced to provide structural integrity for lifting, then elevation of the slab may be a viable option.

A homeowner should be aware that the engineer's examination of the house to determine its fitness for slab elevation is likely to be quite involved. For example, he or she will want to verify the extent of slab reinforcement, which will involve lifting up such coverings as carpets, pads, flooring, or tiles. The homeowner may incur some cost for this type of exploratory work, but this is a far better gamble than assuming that the slab is adequately reinforced, which could endanger the house when it is elevated. If there is doubt about any portion of the slab, another method of retrofitting may be warranted.

Once a determination of the capability of a structural mat slab to withstand lifting forces has been made, the elevation process is very similar to the methods described in Chapter 3 with the following exception—location of lifting beams and jacking points and anchoring the mat slab to the new foundation.

The location of lifting beams and jacking points is dependent on the configuration of the bottom of the mat slab. Slabs generally have irregular bottom surfaces which create high stress areas between the slab and lifting beam contact points, introducing the potential for severe cracking in the mat slab.

Since mat slabs have irregular bottom surfaces, they are not readily attached to a new foundation. Placement of the irregular mat slab surface on a rigid foundation wall can cause severe cracking in the mat slab. One method of minimizing this effect is to place the mat slab on a bed of mortar placed on the top of the foundation wall. Another option would be to integrate the lifting beam into the foundation wall and/or mortar bed. While these methods can minimize the potential for slab cracking, they can not totally remove it.

The size and weight of a mat slab can make anchoring of the slab and house to the new foundation difficult. However, the weight of the slab is usually sufficient to withstand any lateral forces which might act on the new structure. One method of providing a structural connection is to connect the lifting beams to the foundation with anchor bolts.

Figure 10-4 illustrates the process involved in elevating a slab along with the house.

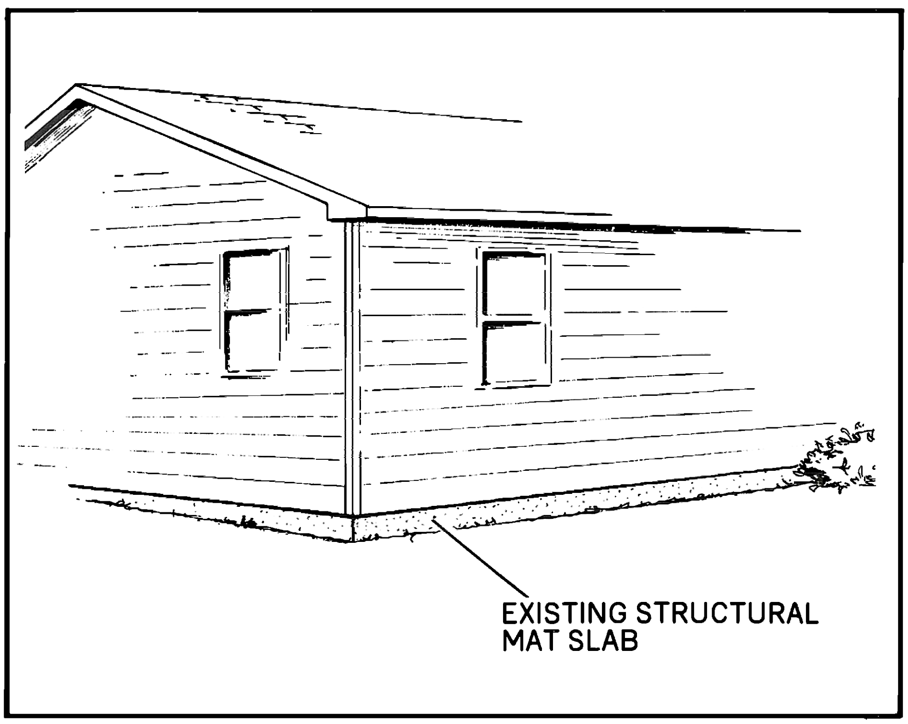


FIGURE 10-4a. *This slab-on-grade home will be elevated along with its structural slab.*

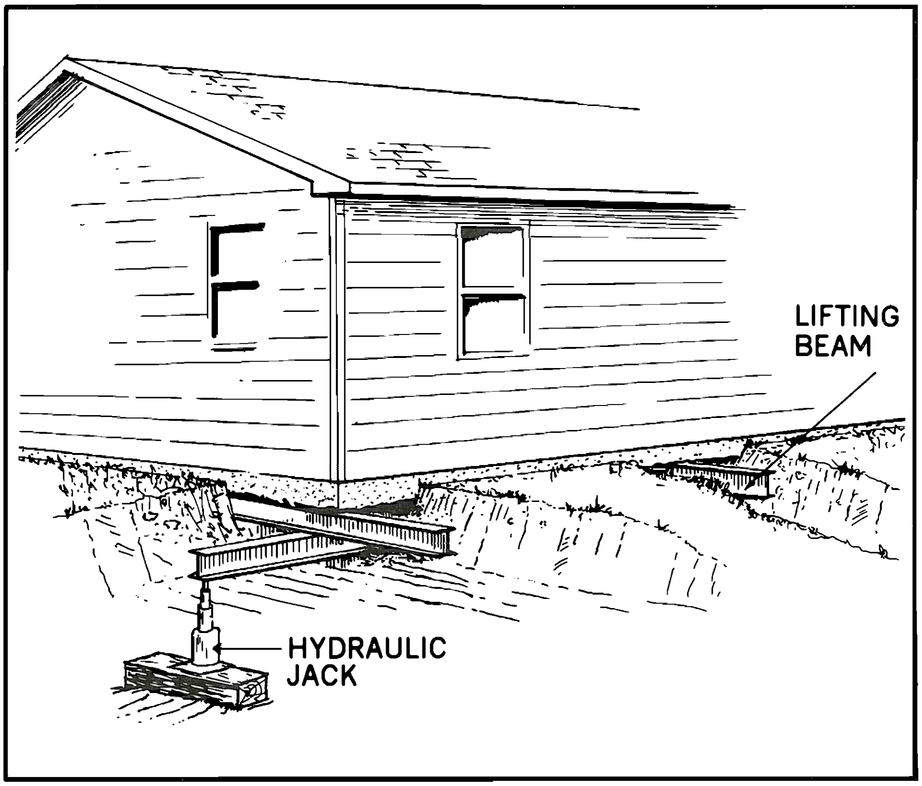


FIGURE 10-4b. *Trenches are excavated to allow for placement of a horizontal boring machine to drill holes through the earth below the slab. I-beams are then placed under the existing slab-on-grade foundation. Jacks are placed beneath the supporting I-beams to allow for elevation of the house and slab.*

FIGURE 10-4c. *With the house and slab now elevated, construction of the new foundation begins.*

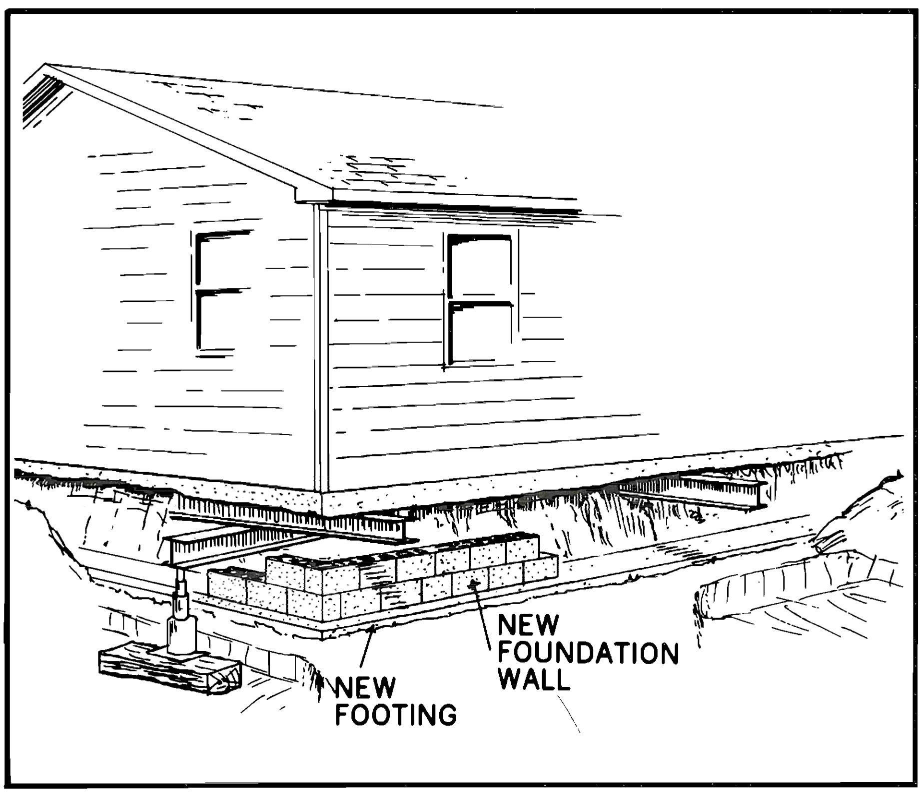
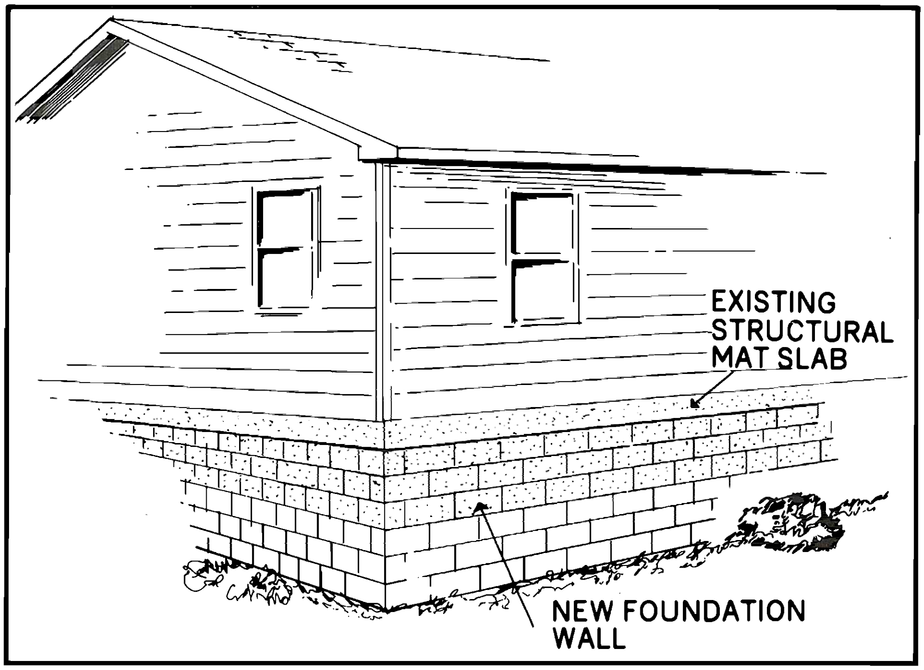


FIGURE 10-4d. *When the foundation is completed, the house is then lowered on it.*



While the elevation of the slab with the house may appear easier than elevation of a home detached from the slab, the costs are often substantially higher. A homeowner should carefully weigh any decision to elevate a slab-on-grade house against costs likely to be encountered in other types of retrofitting. Depending on the value of the home, the degree of flood risk, and the homeowner's ability to finance the project, the elevation project may be well worth the investment.

In summary, elevation of a structure with slab can be one of the more effective retrofitting methods for reducing flood damages, but it should not be undertaken without consideration of three essential elements:

- The direct and continual involvement of a registered professional structural or foundation engineer throughout the project;
- An understanding of the work that a homeowner will need to perform in both planning and implementing the elevation, and in restoring the structure afterwards; and
- A close examination of the financial outlay that will be required as outlined.

10.4 FLOATING STRUCTURES

One of the most unusual approaches to floodproofing has its origins as a technique used locally in areas of Louisiana and southern Arkansas. Designed particularly for areas of deep flooding of long duration, but with low velocities, it involves placing small houses on flotation systems, or barges.

To prevent the structure from floating away, and to guide it as it rises up and down during the flood, metal collars attached to the structure ride on four pylons anchored in the ground at each corner, as shown in Figure 10-6.

Water, sewer and utility lines are connected to the house through flexible piping when flood waters are not present.

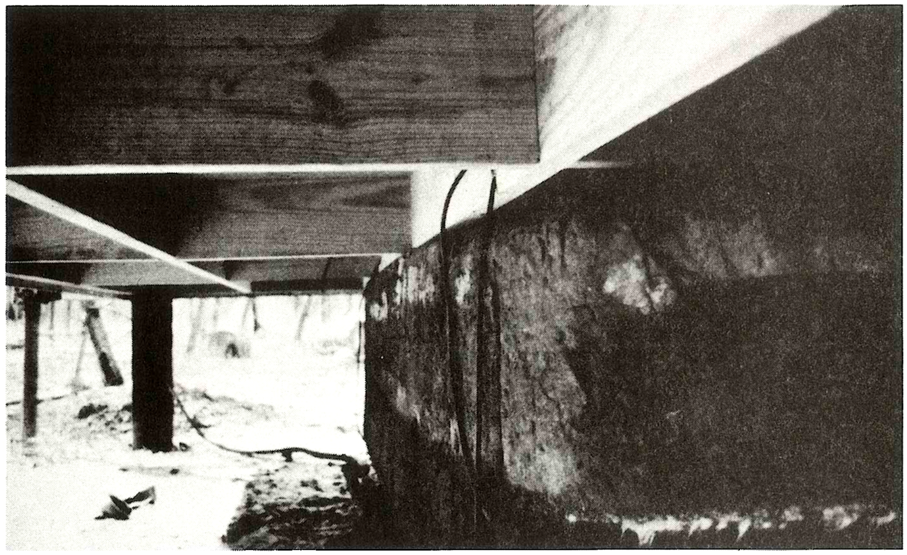


FIGURE 10-5. *The flotation system used on 'floating houses' can be made of large styrofoam floats.*

The house rests on either on a concrete foundation or piers constructed of treated wood.

Most houses employing this system were built this way when they were new. Retrofitting a house involves jacking it up only far enough to perform the work of securely attaching large styrofoam floats to its underframe or placing it on a barge. The house must also be equipped with collars as noted in Figure 10-6.

This technique is most applicable to small houses. Since it is only possible to reach the house by boat during flooding, it is also a technique best suited for vacation or second homes.

Estimated costs of completing the measure for houses up to 1,000 sq. ft. are approximately $6,000.

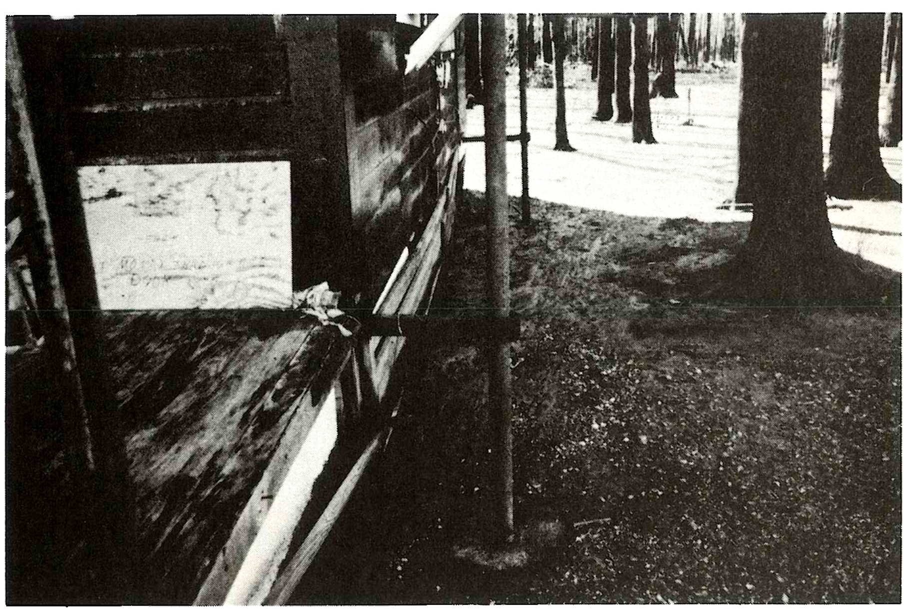
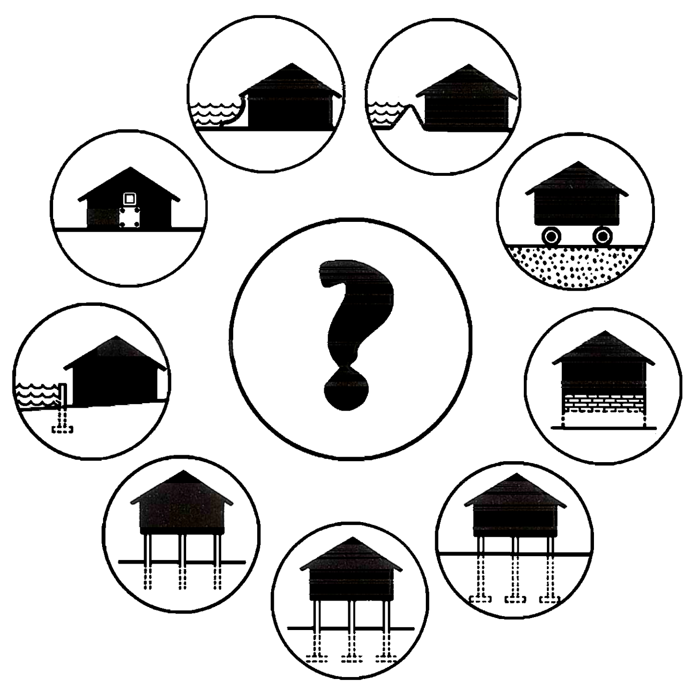


FIGURE 10-6. *'Floating houses' rise and fall with floodwaters, but the structure itself is stabilized in place by a collar system.*

Chapter 11

CHOOSING A METHOD

Armed with a general understanding of the factors involved in selecting a retrofitting method, the homeowner is ready to make a decision on the best method for his particular situation. This chapter is designed to walk the homeowner through the "decision paths" necessary for choosing a retrofitting method.



11.1 SELECTION PROCESS

Armed with a general understanding of the factors involved in selecting a retrofitting method, the homeowner is ready to make a decision on the method best suited for his or her particular situation. This chapter is designed to walk the homeowner through the decision paths necessary for choosing a retrofitting method.

Each prospective retrofitting site is unique and has specific characteristics which set it apart from other locations and make various retrofitting techniques feasible or not feasible. As described in Chapter 2, these characteristics can be divided into three groups—flooding characteristics, site characteristics, and building characteristics.

The flooding characteristics important to the retrofitting process include the flood depth (shallow, moderate, and deep); flood velocity (slow, moderate, and fast); and the potential for flash floods, long duration flooding and debris or ice floes. This information can be obtained from the **Flood Insurance Study** for your community, historical flood records, and local emergency preparedness officials.

Two site-specific characteristics affect choosing a retrofitting technique. These are whether or not the property is located in a regulatory floodway, coastal V-Zone or floodplain, and the nature of the soil (permeable or impermeable) at the site. Much of this information can be obtained from the local government office, the community Flood Insurance Study, or the local office of the United States Geological Survey or Soil Conservation Service.

The characteristics of the structure to be retrofitted are a major consideration when determining the types of retrofitting methods that will be feasible. Building foundation type, building construction type and building condition are the most important characteristics. Homeowners should know whether their houses were built slab-on-grade; with a crawl space or basement; with masonry, concrete, or wood; and the general condition of the building. If the homeowner does not know this information, a building inspector can be of assistance.

Once the characteristics affecting the feasibility of retrofitting methods have been determined, homeowners can select the method or methods most applicable to their specific cases. The decision matrix shown in Figure 11-1 is one way of choosing a retrofitting method.

This decision matrix is designed to walk the homeowner through the process of determining which methods are most applicable for each of the factors or characteristics affecting retrofitting. The first column of the decision matrix lists in 10 rows the characteristics (flooding, site, and building) relevant to selecting a method, and the top row of the chart depicts (graphically and verbally) in 10 columns those retrofitting methods covered in this manual. For each of the specific flooding, site, and building characteristics listed in column one, the homeowner can read across (by row) and determine the feasibility or non-feasibility of each retrofitting method. The homeowner should determine the methods applicable to each characteristic and tabulate the results in the bottom row on the matrix. The method or methods which were selected most often should be examined in detail and a determination of all advantages and disadvantages performed before a method is chosen and the final design is completed. Several case studies are included in Appendix G that illustrate the use of this decision matrix.

FIGURE 11-1. Decision Matrix

RETROFITTING FACTORS		RETROFITTING METHODS: ELEVATION ON FOUNDATION WALL (CHAPTER 3.5)	ELEVATION ON PIERS (CHAPTER 3.7)	ELEVATION ON POSTS OR COLUMNS (CHAPTER 3.8)	ELEVATION ON PILES (CHAPTER 3.9)	RELOCATION (CHAPTER 4)	LEVEES (CHAPTER 4)	FLOODWALLS (CHAPTER 6)	FLOODWALLS WITH CLOSURES (CHAPTER 7)	SEALANTS AND	CLOSURES (CHAPTER 8)
FLOODING CHARACTERISTICS	**1. Flood Depth**										
	Shallow (less than 3 feet)	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
	Moderate (3 to 6 feet)	YES	YES	YES	YES	YES	YES	YES	YES	NO	NO
	Deep (greater than 6 feet)	YES	YES	YES	YES	YES	NO	NO	NO	NO	NO
	2. Flood Velocity										
	Slow (less than 3 fps)	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
	Moderate (3 to 5 fps)	YES	YES	YES	YES	YES	YES	YES	YES	NO	NO
	Fast (greater than 5 fps)	NO	NO	YES	YES	YES	NO	NO	NO	NO	NO
	3. Flash Flood Potential										
	Yes	NO	YES	YES	YES	YES	YES	YES	NO	NO	NO
	No	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
	4. Long Duration Flooding										
	Yes	YES	YES	YES	YES	YES	NO	NO	NO	NO	NO
	No	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
	5. Debris/Ice Floe Potential										
	Yes	NO	YES	YES	YES	YES	YES	YES	NO	NO	NO
	No	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
SITE CHARACTERISTICS	**6. Site Location**										
	Floodway or Coastal V-Zone	NO	YES	YES	YES	YES	NO	NO	NO	NO	NO
	Riverine Floodplain	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
	7. Soil Type										
	Permeable	NO	YES	YES	YES	YES	NO	NO	NO	NO	NO
	Impermeable	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
BUILDING CHARACTERISTICS	**8. Building Foundation**										
	Slab on Grade	YES	YES	YES	NO	NO	YES	YES	YES	YES	YES
	Crawl Space or Basement	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
	9. Building Construction Type										
	Concrete or Masonry	YES	YES	YES	NO	YES	YES	YES	YES	YES	YES
	Wood	YES	YES	YES	YES	YES	YES	YES	YES	NO	NO
	10. Building Condition										
	Excellent to Good	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
	Fair to Poor	NO	NO	NO	NO	NO	YES	YES	YES	NO	NO
TOTAL TIMES FEASIBLE		___	___	___	___	___	___	___	___	___	___

KEY: USING THE RETROFITTING FACTORS, THE METHODS THAT COLLECT THE MOST FEASIBLE VOTES SHOULD BE EXAMINED IN DETAIL FOR RETROFITTING YOUR RESIDENTIAL STRUCTURE.

11.2 LEVEL OF PROTECTION

Since flood levels can vary widely for any given location, a flood depth having a standard recurrence interval, or frequency, is normally determined for all floodplains. This standard depth is the base flood elevation (BFE) minus the ground elevation. BFEs can usually be found on a community's flood maps. The BFE is also used by insurance companies to rate the level of flood risk to a structure.

While there is no requirement dictating that retrofitting should be done to the BFE, it should normally be considered for several reasons. Among them are the fact that retrofitting to a lower elevation will increase the chances of damage from a flood that exceeds the protection height, that using the BFE reduces the risk of flood over the life of the structure to a statistically more acceptable level, and that it will result in the greatest reduction in insurance premiums.

All other factors being equal, it is always most advantageous for the home-owner to retrofit or protect a home to the BFE. However, some factors will sometimes make this infeasible. In that case, the level of protection should always be reduced to the point where protection becomes cost effective. Some level or type of retrofitting will always be feasible for a flood-prone structure, especially since the alternative is no protection at all.

11.3 DETERMINING COST/BENEFIT OF RETROFITTING

The cost/benefit analysis presented in this chapter will enable the home-owner to determine if the benefits of a retrofitting method outweigh its costs. Performing this analysis will involve obtaining data from the FEMA-published Flood Insurance Study for your community. Flood Insurance Study data as well as Flood Insurance Rate Maps should be available from community officials. Once the Flood Insurance Study becomes effective, property owners can also obtain a free flood map by calling FEMA's Flood Map Distribution Center toll-free at 1-800-638-6620.

Cost/Benefit Analysis

1. Obtain the flood profile from the Flood Insurance Study which contains the portion of the stream that causes flooding to the house. Locate the house site on the profile.
2. Determine the elevation of the lowest level of the house. If needed, an accurate determination of the elevation can be made by a land surveyor.
3. Estimate the damages that would be caused by several different flood levels. The following steps will be necessary to determine these damage estimates:
   a. Obtain an estimate of the house's fair market value. This is often available from property tax records or an appraiser.
   b. Determine the value of the contents of the house. This may be available from insurance records. A rough estimate of the contents' value is 30 percent of the fair market value of the house.

c. Determine the flood elevations from the flood profile for different floods above the elevation of the lowest level of the house. Normally, there are four flood elevations shown on the profile, the 10-year, 50-year, 100-year, and 500-year recurrence intervals. For the purposes of this manual, the 500-year recurrence interval is not considered.
d. Calculate the stage for each flood, which is the depth of water above the lowest level of the house. The stage can be determined by subtracting the elevation of the lowest level of the house from each flood elevation.
e. Determine the cost of damage for each flood stage: An estimate of the damage as a percentage of the value of the structure and the contents for different stages and for different types of buildings can be obtained from Table 17 The product of the percentages and the estimated value of both the house and the contents will be the estimated cost of damage. The sum of the cost of damage to the house and to the contents is the total cost.

TABLE 17
DAMAGES, AS A PERCENTAGE OF VALUE

	One-Story House without Basement		Split-Level House without Basement		Two-Story House without Basement		Mobile Home	
Stage, in feet	Structure	Contents	Structure	Contents	Structure	Contents	Structure	Contents
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.1	8.0	5.0	3.0	2.0	4.0	5.0	8.0	3.0
1.0	22.0	35.0	11.0	18.0	10.0	16.0	50.0	30.0
2.0	30.0	50.0	20.0	32.0	16.0	28.0	71.0	56.0
3.0	35.0	60.0	25.0	41.0	20.0	37.0	82.0	72.0
4.0	39.0	68.0	29.0	47.0	24.0	43.0	87.0	79.0
5.0	41.0	74.0	31.0	51.0	27.0	47.0	89.0	84.0
6.0	44.0	78.0	33.0	53.0	29.0	59.0	91.0	87.0
7.0	46.0	81.0	34.0	55.0	32.0	50.0	91.0	88.0
8.0	48.0	83.0	41.0	56.0	34.0	51.0	--	90.0
9.0	50.0	85.0	46.0	62.0	39.0	55.0	--	90.0
10.0	--	--	50.0	69.0	42.0	58.0	--	--
11.0	--	--	53.0	75.0	45.0	65.0	--	--
12.0	--	--	55.0	78.0	47.0	72.0	--	--
13.0	--	--	58.0	80.0	49.0	78.0	--	--
14.0	--	--	59.0	81.0	50.0	79.0	--	--
15.0	--	--	60.0	--	--	--	--	--

Information Provided by The Federal Insurance Administration

If flooding has occurred before, then the loss amount for that stage of flood, after adjusting for inflation, can be used as a guide for estimating the cost of damages for different stages.

f. Table 18 should be compiled to determine the cost of damage.

TABLE 18

COST OF DAMAGE

Estimated value of the house = ______________________________

Estimated value of the contents = ___________________________

Elevation of the lowest level of the house = _______________

FLOOD				DAMAGE AS %		COST OF DAMAGE $		
Recurrence Interval	Probability	Elevation	Stage	Structure	Contents	Structure	Contents	Total
Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7	Col. 8	Col. 9
10-Yr	.1	______	______	______	______	______	______	______
50-Yr	.02	______	______	______	______	______	______	______
100-Yr	.01	______	______	______	______	______	______	______

Explanation:

Column 1: Recurrence interval of flood above the lowest level of the house.

Column 2: Probability of the flood = reciprocal of the recurrence interval.

Column 3: Elevation of each flood from flood profile.

Column 4: Column (2) minus elevation of the lowest level of the house.

Columns 5 & 6: From Table 17.

Column 7: [(Column 5) times (estimated value of the house)] divided by 100.

Column 8: [(Column 6) times (estimated value of the contents)] divided by 100.

Column 9: Column 6 plus Column 7.

4. Determine the expected annual damage by floods. Expected annual damage is the average value of the annual damages over the life of the structure. It is computed by weighting the damage due to any flood by the probability of that flood and summing the products over the range of floods. The following procedure can be used to determine the expected annual damage:

a. Determine the probability of the flood level at the elevation of the lowest level of the house. The probability is the reciprocal of the recurrence interval. The recurrence intervals of 10-year, 50-year, 100-year, and 500-year have a probability value of 0.1, 0.02, 0.01, and 0.002, respectively. The flood elevations corresponding to these probabilities can be determined from the flood profile. Columns 2 and 3 of Table 18 list these probabilities and the corresponding flood elevations. After plotting these two values on the probability paper (see Figure 11-2), the probability of the flood level at the elevation of the lowest level of the house can be determined.

b. Determine the expected annual damage by floods throughout a range of probabilities. Theoretically, there will be no damage by a flood at the elevation of the lowest level of the house. Determine the damage resulting from the flood of the next lowest probability (or higher frequency) than the flood at the lowest level of the house. Find the average cost of damage between these two floods. Multiply this average by the probability interval (the difference of probabilities) between these two floods to determine the average annual damage caused by these two floods. Use the same procedure to determine the average annual damage of other flood's probabilities listed on Table 18, up to the 100-year recurrence interval. The expected annual damage is equal to the summation of all these average annual damages.

c. Table 19 should be compiled to determine the expected annual damage.

TABLE 19
EXPECTED ANNUAL DAMAGES

Probability Col. 1	Damage Col. 2	Average Damage Col. 3	Probability Interval Col. 4	Average Annual Damage Col. 5
(Lowest level of house)	0			
	____	____	____	____
	____	____	____	____

Column 1: The probability of floods at the lowest level of the house and above.

Column 2: Corresponding damages obtained from Column 9 of Table 18.

Column 3: Average cost of damage of two floods.

Column 4: Probability difference between two floods.

Column 5: Column 3 times Column 4.

Expected annual damage = summation of Column 5.

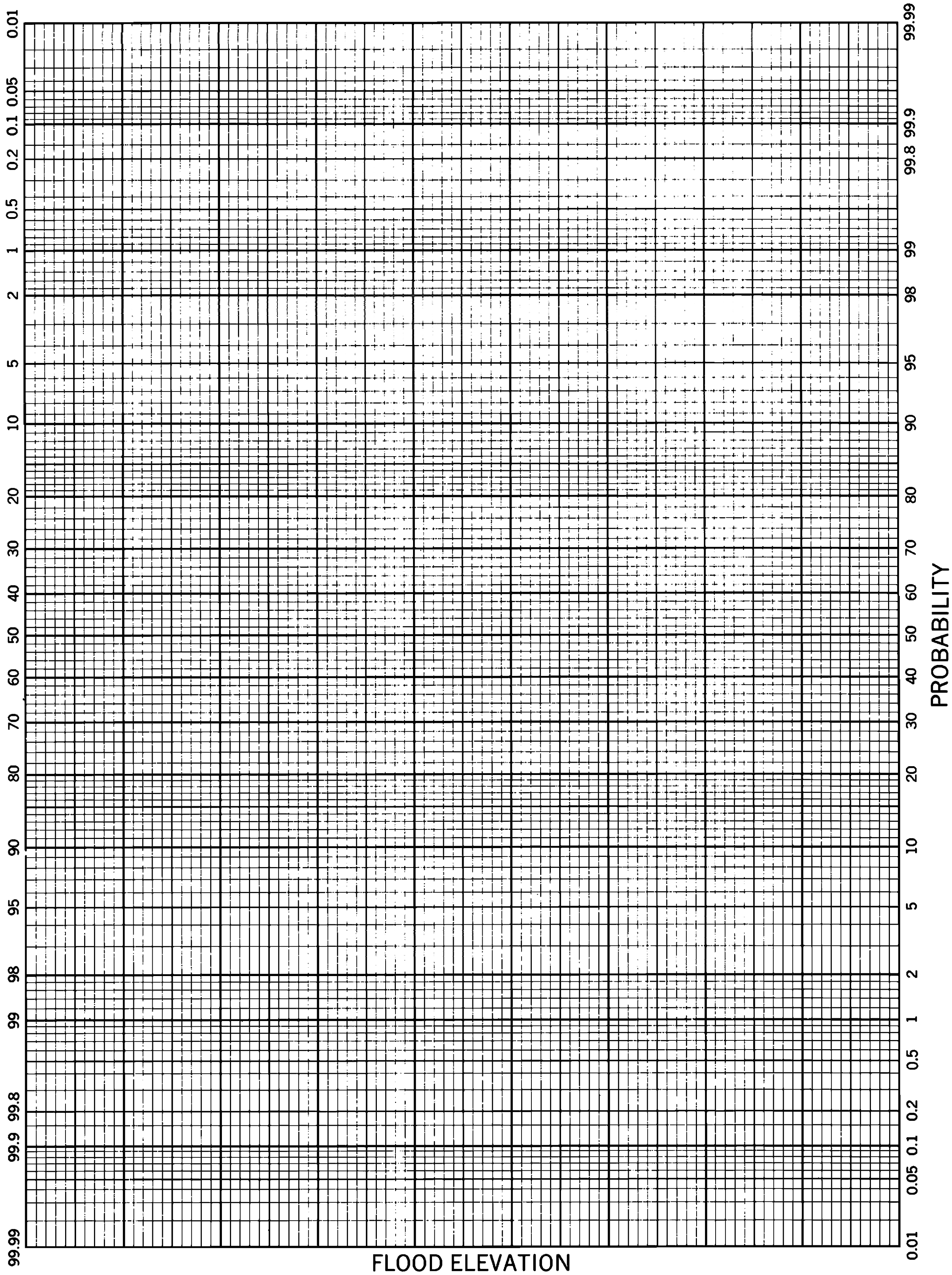


FIGURE 11-2. Probability Paper

5. Determine the payback period. Although the payback period is not a sophisticated method of economic analysis, it will serve the homeowner as a general guide to get an idea of whether or not retrofitting is economically feasible. The payback period is the number of years during which the cost will be offset by the benefits and can be determined by dividing the retrofitting cost by the expected annual damage as obtained from Table 19. Retrofitting cost information is provided in each chapter of this manual. If the payback period is less than the time the homeowner intends to occupy the home, it is feasible to retrofit the house. If the payback period is greater, retrofitting may still be worthwhile, since there are several other factors that may also be considered. These include reduced insurance rates and possible loans and grants that are designed to encourage retrofitting. In addition, there are the intangible advantages of not being continually threatened by flooding that cannot be measured in monetary value.

6. The example presented in Tables 20 and 21 will illustrate how to conduct an economic analysis of retrofitting a house.

TABLE 20
COST OF DAMAGE
EXAMPLE

Estimated value of the house = $85,000.

Estimated value of the contents = 30% of the value = $25,500.

Elevation of the lowest level of the house = 201.0 feet.

FLOOD				DAMAGE AS %[2]		COST OF DAMAGE $		
Recurrence Interval	Probability	Elevation[1]	Stage	Structure	Contents	Structure	Contents	Total
Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7	Col. 8	Col. 9
10-Yr	.1	203.0	2	30	50	25,500	12,750	38,250
50-Yr	.02	205.0	4	39	68	33,150	17,340	50,490
100-Yr	.01	206.0	5	41	74	34,850	18,870	53,720

[1]From flood profile.
[2]From Table 17 for one-story house without basement.

TABLE 21
EXPECTED ANNUAL DAMAGES
EXAMPLE

Probability	Damage	Average Damage	Probability Interval	Average Annual Damage
Col. 1	Col. 2	Col. 3	Col. 4	Col. 5
.3[1]	0	19,125	.2	3,825
.1	38,250	44,370	.08	3,550
.02	50,490	52,105	.01	521
.01	53,720			
		Expected Annual Damage =		7,896

[1]Probability for elevation of the lowest level obtained from flood elevation versus probability graph.

If the retrofitting cost is $25,000, then the payback period = 25,000/7896 = 3.2 years, and retrofitting would definitely be feasible.

Appendix A

A GUIDE TO SELECTING ARCHITECTURAL/ENGINEERING SERVICES AND CONTRACTORS

A.1 INTRODUCTION

The coordination of construction work on a residence can be a difficult, time-consuming, and even frustrating process for the homeowner. It requires considerable knowledge of local building codes and permits, and may also involve hiring a variety of professionals, such as masons, concrete specialists, plumbers, engineers, or architects. Most projects will also involve the legal processes of dealing with contracts. Without proper planning, the inexperienced person attempting this coordination for the first time could face a difficult, financially risky undertaking. There are two general processes a homeowner may follow to simplify this process: obtaining architectural/engineering assistance or hiring a general contractor.

A.2 ARCHITECTURAL/ENGINEERING SERVICES

As pointed out in various sections of this manual, the more complex retrofitting techniques will often require a professional architect or engineer, or some other type of specialized professional service. For example, the construction of a floodwall could require input from a soils engineer to assist in determining bearing capacity; a structural engineer to provide assistance in the structural design of the wall; a civil engineer to provide assistance in sizing drainage structures and sump pumps; and an architect to provide guidance in the placement of the wall to reduce flood forces and improve the aesthetics of the finished project.

Some firms employ professionals having expertise in only one particular area and this could require subcontracting of certain parts of the work. For a more complex retrofitting project requiring a variety of services, the homeowner may wish to consider using a "full-service" Architecture/Engineering (A/E) firm, which would be able to either provide all services in-house or coordinate the various expertise involved. Such a firm would be able to provide one point of contact between the homeowner and the design professionals involved in the project, which would not only provide better coordination of the project and a simpler line of communication, but would also serve to place liability for any problems which may occur with one firm or individual.

In reviewing credentials of A/E firms, the homeowner should examine the following:

A listing of projects similar to the one contemplated by the homeowner including former clients and phone number, the dates of performance, and a brief scope of the work performed;

Familiarity with the project area including knowledge of contractors available to do the work, and knowledge of costs of various parts of the work;

Proximity of the firm to the project site and its ability to respond for consultations on the project;

Qualifications and background of the firm and specific individuals that would be handling the work including a description of which phases of the work could be provided in-house and any proposed subcontracts which might be included; and

A proposed time schedule for the completion date, realistic deadlines for each phase of the project, and the acquisition of necessary building permits, etc.

Once a firm has been chosen, the question of a contract must be addressed. Both the American Institute of Architects and the National Society of Professional Engineers have standard contracts which may be used, or a simple letter of agreement may be sufficient. Homeowners should ensure that the contract includes a detailed scope of work in accordance with their wishes. Professionals suggest that a firm be selected on the basis of capabilities, and then a fee for the work be negotiated with the selected firm. A proposed labor hour breakdown on large projects will assist the homeowner in determining if the fee is in line with the work to be performed.

Some local building officials and some codes require that plans and specifications for a retrofitting project be prepared by or under the direction of a licensed professional engineer or architect. The homeowner should check with the local building official to determine if this is a requirement before procuring a firm to carry out the project.

A.3 GENERAL CONTRACTORS

Contractors are normally also licensed in the state where they do business, and there may be local codes that have additional requirements for certain specialized contractors, such as electricians. Along with price, the criteria for selecting a contractor should be the same as those used for A/E firms. A general contractor will often use subcontractors in the project. This should be specified in advance. Normally, the general contractor's fee will include all payments to subcontractors as well as management of the entire project.

When shopping for a contractor, the homeowner should obtain estimates from two or more contractors on the same project and ask for explanations from each about the differences in price. Since each contractor may operate with different kinds of equipment, different standards of workmanship and different degrees of experience, the final choice should not be based solely on the lowest bid, but also on the quality of work and the ability to deliver.

Homeowners should obtain photos of the contractors' previous projects or details of sites that can be visited to examine their work. They should ask previous customers in particular about the contractor's quality of work, timeliness, and whether the proposed budget was met. A call to the local Better Business Bureau can determine if any complaints have been registered against a particular contractor with the local agency.

Among the questions that should be answered about the contractor are:

Has the contractor previously done any similar work?

Does the contractor regularly work on residential structures? Does the contractor thoroughly understand the work, and will it be completed as specified?

Does the contractor intend to employ subcontractors, and are they qualified to do the work?

Do the contractor and any subcontractors carry liability insurance?

There are various forms of construction contracts used today, but the important items to check for are:

Detailed Scope of Work
Basis of Payment
Period of Performance
Warranties and Bonding
Adequate Insurance Coverage

The homeowner should accept work as final only when all provisions of the contract are satisfied. Never sign "completion papers" before the work is completed or make final payment if work is not completed. Before making final payment to the general contractor, the homeowner should insist that the contractor submit a statement that all subcontractors and material suppliers have been paid. If large sums of money are involved, the homeowner should insist that this statement be signed by the major subcontractors involved. If a subcontractor goes unpaid, in most states, that subcontractor has the legal right to place a lien on the house for the amount of payment. This generally means that the subcontractor would have to be paid and the lien removed before the homeowner would be able to sell the house.

Following these general selection and contracting guidelines, the homeowner should be able to enter into a clear client/ contractor relationship on any retrofitting project.

Appendix B

THE NATIONAL FLOOD INSURANCE PROGRAM

B.1 INTRODUCTION

The U.S. Congress initiated the the National Flood Insurance Program (NFIP) in 1968 as a result of the enormous losses homeowners were suffering from floods and to control the rapidly increasing costs to federal, state, and local governments for flood disaster relief.

The NFIP insurance coverage is available only in communities that agree to implement comprehensive **floodplain management** regulations to reduce the likelihood of future flood damage in their areas. This is usually done through zoning laws, building codes, and development regulations that place restrictions on new construction or substantial improvements to existing flood-prone structures. In addition, there are communities that have adopted codes and zoning ordinances that are even more restrictive than those required by the NFIP.

Before the advent of the NFIP, most homeowners were unable to obtain flood insurance coverage. This is essentially because insurance programs have to spread risks over large segments of the population to allow for both affordable premiums and financially successful ventures. However, because only a small minority live in flood hazard areas, and most people who live away from flood areas do not purchase flood insurance, most private companies were not able to provide coverage.

Currently, the NFIP is administered by the Federal Insurance Administration (FIA), which is a part of the Federal Emergency Management Agency (FEMA). The individual policies are handled by the local insurance agents.

In 1973, the Congress further strengthened the NFIP by requiring that funds related to federal programs that involve any structure in the 100-year floodplain can only be granted if the structure is covered under a flood insurance policy, and if the community participates in the NFIP. Such programs include loans from the Small Business Administration, the Veterans Administration and federally-regulated banks, credit unions, and savings and loan institutions. Also, flood disaster funds are not available to communities that do not participate in the NFIP.

The NFIP is administered in two phases: the Emergency Program and the Regular Program. The function of the Emergency Program is to make flood insurance readily available to property owners throughout flood-prone communities. The operation of the program is simple and direct. The FIA notifies a community that it has been identified as flood prone by providing the community with a **Flood Hazard Boundary Map** (FHBM). This map is a preliminary delineation of **special flood hazard areas** within the community with a definite likelihood of inundation. No elevations are shown. A community receiving such a map may participate in the program by completing an application to FIA. Upon approval of the application, limited amounts of flood insurance become available in that community. The community is required to apply minimal floodplain management regulations based on the FHBM and is encouraged to reasonably use any additional data that may be available from other sources to establish the flood elevations.

A community generally enters the Regular Program after the completion of a detailed technical study of flood hazards. The study includes a determination of elevations of floods of varying intensity, including the base flood, areas inundated by the various magnitudes of flooding, and floodway boundaries. This information is presented on a Flood Insurance Rate Map (FIRM) and Flood Boundary and Floodway Map (FBFM). FIRMs generally show flood-prone areas as either A-Zones or V-Zones. Riverine flood-prone areas and coastal flood-prone areas subject to storm surges with velocity waves of less than three feet during the 100-year flood are generally classified as A-Zones. Coastal high hazard areas are shown on FIRMs as V-Zones. The V-Zone is the portion of the floodplain subject to storm surges with velocity waves of three feet or more during the 100-year flood. Based on this information, regulatory standards that are more detailed than Emergency Program requirements are adopted and enforced by the community.

B.2 BASE FLOOD ELEVATIONS AND THE HAZARD ZONES

Under the NFIP, the chance that a certain area will be flooded is determined on the basis of the 100-year flood elevation. This flood level statistically has a one-percent chance of being equaled or exceeded in any given year.

This is a statistical means of estimating the probability of flooding for insurance and land use planning. What this means for the homeowner, for example, is that over the life of a 30-year mortgage, there is approximately a 25-percent chance that this flood or one of greater magnitude will occur.

To determine the 100-year flood elevation, also known as the base flood elevation (BFE), hydrologists and other specialists use historical records of floods and hydrologic and hydraulic data to establish the BFE on Flood Insurance Rate Maps.

The flood-prone areas on the Flood Insurance Rate Maps are generally divided into two general hazard zones:

- A-Zones: Riverine flood-prone areas and coastal flood-prone areas subject to storm surges with velocity waves of less than three feet.

  New construction or substantial improvements to structures are generally required to have the top of their lowest floor elevated to or above the BFE.

- V-Zones: Coastal high hazard area, which is the portion of the coastal floodplain subject to storm surges with velocity waves of three feet or more during the 100-year flood.

  Standards for the V-Zones require that the lowest portion of the horizontal structural members supporting the lowest floor be elevated on pilings or columns to or above the BFE. The space below the lowest floor in a V-Zone may not be used for human habitation and must be free of obstructions or constructed with non-supporting breakaway walls, open wood latticework, or insect screening.

For more information regarding similar restrictions, see "Elevation Restrictions of the NFIP" in Chapter 3.

B.3 NFIP COVERAGE

NFIP flood insurance policies define a flood as a "general and temporary condition of partial or complete inundation of normally dry land areas" from:

- The overland flood of a lake, river, stream, ditch, etc;
- The unusual and rapid accumulation or runoff of surface waters; and
- Mudflows, or the sudden collapse of shoreline land.

A homeowner can purchase structural coverage for any walled and roofed building, including a mobile home. Provided that the community participates in the NFIP, any building can be insured, regardless of whether or not it is in a floodplain. It should be noted that there is a five-day waiting period before coverage goes into effect. The policy will not cover damages from a flood in progress.

Depending upon the type of policy purchased, insurance will cover the following:

- Damages to walls, floors, insulation, and other items permanently attached to the structure.
- The contents of a building with certain exceptions, such as vehicles, boats, animals, crops in the field, money, valuable papers, fences, docks, trees, and driveways.
- Damages caused by sewer backup if the cause of the backup was a general condition of flooding.
- The cost of moving contents to high ground in advance of a flood.

Insurance rates are set on the basis of designated hazard zones and the elevation of the building or structure in relation to the BFE in that particular zone. The effect of this differential rate structure is to provide an incentive to increase the safety of buildings beyond the minimum standards by giving significant financial benefits to buildings at higher elevations and in less hazardous zones. Table B-1 provides a representative view of actual insurance rate information. Since insurance rates are subject to change, please contact your local insurance agent for the latest rate information.

TABLE B-1

BUILDING COVERAGE RATES
REGULAR PROGRAM POST-FIRM CONSTRUCTION
SINGLE FAMILY ZONES A1-A30
($ PER $100 COVERAGE)

ELEVATION OF LOWEST FLOOR ABOVE OR BELOW BFE	ONE FLOOR, NO BASEMENT		TWO OR MORE FLOORS AND SPLIT LEVEL, NO BASEMENT		TWO OR MORE FLOORS AND SPLIT LEVEL, INCLUDING FINISHED BASEMENT		TWO OR MORE FLOORS AND SPLIT LEVEL, INCLUDING UNFINISHED BASEMENT	
	BASIC LIMITS	ADDITIONAL LIMITS	BASIC LIMITS	ADDITIONAL LIMITS	BASIC LIMITS	ADDITIONAL LIMITS	BASIC LIMITS	ADDITIONAL LIMITS
+3	.12	.07	.12	.07	.12	.07	.12	.07
+2	.14	.07	.12	.07	.12	.07	.12	.07
+1	.17	.07	.13	.07	.12	.07	.12	.07
0	.30	.07	.25	.07	.20	.07	.20	.07
-1	.75	.55	.70	.55	.45	.45	.45	.45
-2	*	*	*	*	*	*	*	*

*SUBMIT TO NFIP FOR RATING.

NOTE: RATE MUST BE DETERMINED BASED ON THE LOWEST FLOOR ELEVATION OF A POST-FIRM BUILDING. THE INSURED MUST PROVIDE AN ELEVATION CERTIFICATION FOR THE AGENT TO DETERMINE THE PROPER RATE. ELEVATION DATA ON POST-FIRM BUILDINGS ARE AVAILABLE FROM THE LOCAL COMMUNITY OFFICIAL RESPONSIBLE FOR ADMINISTERING THE COMMUNITY'S FLOOD PLAIN MANAGEMENT ORDINANCE.

TABLE B-1
(CONT.)

1981 POST-FIRM V1-V30 ZONE RATE TABLE
SECTION I
ANNUAL RATE PER $100 OF INSURANCE
ELEVATED BUILDINGS FREE OF OBSTRUCTIONS BELOW THE BEAM SUPPORTING THE BUILDING'S LOWEST FLOOR (SEE NOTE)

ELEVATION OF THE BOTTOM OF THE FLOOR BEAM OF THE LOWEST FLOOR ABOVE OR BELOW BFE, ADJUSTED FOR WAVE HEIGHT AT BUILDING SITE	BASIC AND ADDITIONAL LIMITS									
	STANDARD DEDUCTIBLE					$3,000 DEDUCTIBLE				
	CONTENTS RATE		BUILDING RATES BASED ON INSURANCE TO REPLACEMENT COST RATIO			CONTENTS RATE		BUILDING RATES BASED ON INSURANCE TO REPLACEMENT COST RATIO		
	RES	NON-RES	.75 OR MORE	.50 TO .74	UNDER .50	RES	NON-RES	.75 OR MORE	.50 TO .74	UNDER .50
+4 OR MORE	.19	.19	.34	.41	.66	.09	.15	.23	.31	.44
+3	.19	.19	.40	.54	.78	.09	.15	.27	.36	.52
+2	.27	.28	.51	.68	1.00	.12	.22	.34	.45	.66
+1	.49	.52	.68	.88	1.30	.22	.42	.45	.60	.85
0	.74	.78	.90	1.20	1.61	.33	.62	.58	.78	1.05
-1	1.07	1.12	1.16	1.55	2.04	.48	.90	.77	1.03	1.33
-2	1.51	1.59	1.51	2.01	2.62	.68	1.27	1.01	1.34	1.71
-3	2.09	2.19	1.97	2.61	3.42	.94	1.75	1.35	1.77	2.24
-4 OR LOWER	*	*	*	*	*	*	*	*	*	*

*SUBMIT TO NFIP FOR RATING.

NOTE: FREE OF OBSTRUCTIONS -- THE SPACE BELOW THE LOWEST FLOOR MUST BE COMPLETELY FREE OF OBSTRUCTIONS OR ANY ATTACHMENT TO THE BUILDING OR MAY HAVE:

- INSECT SCREENING (PROVIDED THAT NO ADDITIONAL SUPPORTS ARE REQUIRED FOR THE SCREENING), OR
- OPEN WOOD CONSTRUCTED LATTICE "BREAKAWAY WALLS" (AT LEAST 50 PERCENT OF THE LATTICE CONSTRUCTION MUST BE OPEN). THESE WALLS MUST BE DESIGNED AND INSTALLED TO COLLAPSE UNDER STRESS WITHOUT JEOPARDIZING THE STRUCTURAL SUPPORT OF THE BUILDING TO MINIMIZE THE IMPACT OF ABNORMALLY HIGH TIDES OR WIND-DRIVEN WATER.

1981 POST-FIRM V1-V30 ZONE RATE TABLE
SECTION II
ANNUAL RATE PER $100 OF INSURANCE
ELEVATED BUILDINGS WITH OBSTRUCTIONS BELOW THE BEAM SUPPORTING THE BUILDING'S LOWEST FLOOR (SEE NOTE)

ELEVATION OF THE BOTTOM OF THE FLOOR BEAM OF THE LOWEST FLOOR ABOVE OR BELOW BFE, ADJUSTED FOR WAVE HEIGHT AT BUILDING SITE	BASIC AND ADDITIONAL LIMITS									
	STANDARD DEDUCTIBLE					$3,000 DEDUCTIBLE				
	CONTENTS RATE		BUILDING RATES BASED ON INSURANCE TO REPLACEMENT COST RATIO			CONTENTS RATE		BUILDING RATES BASED ON INSURANCE TO REPLACEMENT COST RATIO		
	RES	NON-RES	.75 OR MORE	.50 TO .74	UNDER .50	RES	NON-RES	.75 OR MORE	.50 TO .74	UNDER .50
+4 OR MORE	.21	.21	.70	.93	1.38	.09	.17	.48	.63	.95
+3	.21	.21	.82	1.09	1.63	.09	.17	.56	.74	1.11
+2	.29	.29	.89	1.19	1.77	.13	.23	.61	.81	1.21
+1	.51	.53	1.04	1.39	1.99	.23	.43	.71	.95	1.35
0	.76	.79	1.22	1.62	2.21	.34	.63	.83	1.10	1.50
-1	1.09	1.13	1.45	1.93	2.56	.49	.91	.99	1.31	1.74
-2	1.53	1.60	1.81	2.37	3.09	.69	1.28	1.23	1.61	2.10
-3	2.11	2.20	2.32	3.02	3.89	.95	1.76	1.58	2.05	2.65
-4 OR LOWER	*	*	*	*	*	*	*	*	*	*

*SUBMIT TO NFIP FOR RATING.

NOTE: WITH OBSTRUCTIONS -- THE SPACE BELOW CONTAINS EQUIPMENT OR BREAKAWAY SOLID WALL CONSTRUCTION LESS THAN 300 SQUARE FEET. IF ANY PORTION OF THE SPACE BELOW THE ELEVATED FLOOR IS ENCLOSED WITH NON-BREAKAWAY WALL, SUBMIT FOR RATING.

Appendix C

FORCES

C.1 HYDROSTATIC LOADS

Definition

Water at rest exerts pressure on any submerged object, including a structure.

The resulting force is known as hydrostatic pressure. This force is equal to the unit weight of water (normally 62.4 lb/ft^3) times the height of the water level or the height unconfined water would rise, above the point under consideration. Hydrostatic pressures occur at any point above or below ground, are equal in all directions and always act normal (perpendicular) to the surface on which they are applied. The normal application of hydrostatic forces classifies them into vertical and lateral forces.

Types of Forces

Vertical forces are loads acting in an upward or downward direction on a horizontal surface due to the weight of the water above and below the surface. Forces acting in an upward direction on the underside of objects are also known as uplift forces. The net result of vertical forces is called buoyant force and it usually acts in an upward direction.

Lateral forces are loads acting in a horizontal direction on a vertical surface. Lateral forces can cause the collapse of a submerged enclosure.

Application

Certain types of structures may be greatly affected by one type of hydrostatic load but negligibly affected by another type. For instance, a floodwall will primarily be affected by lateral hydrostatic loads. A structure elevated on an open foundation above the maximum water level will experience negligible hydrostatic effect. By contrast, a relatively watertight structure such as a basement, when submerged, will have all three types of hydrostatic forces exerting significant pressures on the structure. An empty storage tank, if submerged by flooding, can experience buoyant forces that will require the use of anchoring to keep the tank in place. These examples illustrate that it is possible to anticipate the type of hydrostatic loadings that will occur, and once this is determined, these loads can be accommodated in the design stage.

Methodology

The basic equations for analyzing hydrostatic forces are provided, since they can be used for several different applications in the respective chapters dealing with each retrofitting method.

The hydrostatic pressure, P_H, at any given point, acting on a building due to a buildup of water, is

$$P_H = \gamma_w H$$

where P_H is in lbs per square foot, γ_w is the specific weight of water (62.4 lb/ft^3) and H is the distance in feet from the surface of the water to the point of action, as shown in Figure C-1. The resulting horizontal hydrostatic force, F_H, acting per linear foot, is the total area of pressure distribution given by

$$F_H = \tfrac{1}{2} (P_H) H = \tfrac{1}{2} \gamma_w H^2$$

where H is distance from surface of water to given point and F_H is in pounds per linear foot, acting at a distance H/3 from the point under consideration.

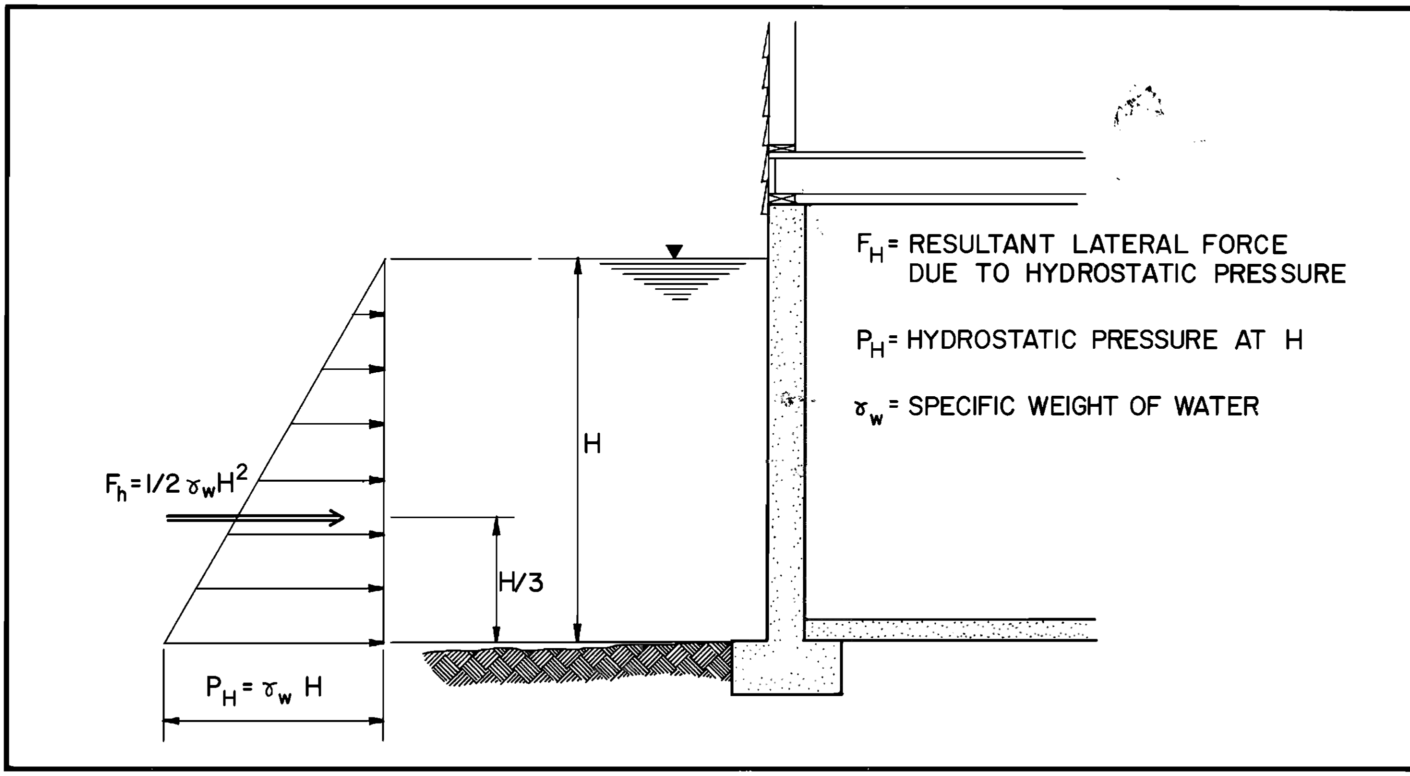


FIGURE C-1. Hydrostatic Force Diagram

The above analysis assumes that the structure or wall is completely above the ground level. When part of the structure is below ground level, soil pressure must also be considered. A discussion on lateral soil pressures is presented later in this section. The result of the vertical forces and the uplift forces is called the buoyant load, F_B, which acts at the center of the horizontal area. This buoyant force is calculated by determining the volume of water displaced in the submerged or partially submerged object, and multiplying it by the specific weight of water. Figure C-2 depicts a house with a basement subject to a water level surcharge equal to H and a saturated soil condition. In the saturated condition, the soil particles are not capable of transmitting vertical forces. Therefore, the total vertical height in contact with soil and water is considered to be submerged. The buoyant force, F_B, is then

$$F_B = \gamma_w A H$$

where γ_w is specific weight of water, A is the area of the horizontal surface where the loads are acting, and H is the depth of the building below the flood level.

The case of water combined with soil loading requires a separate analysis. This situation occurs when either the flood is of a long enough duration to allow the saturation of the soil, or groundwater and seepage are above the ground level of the structure. This condition is most commonly found in structures with basements. The following methodologies used to

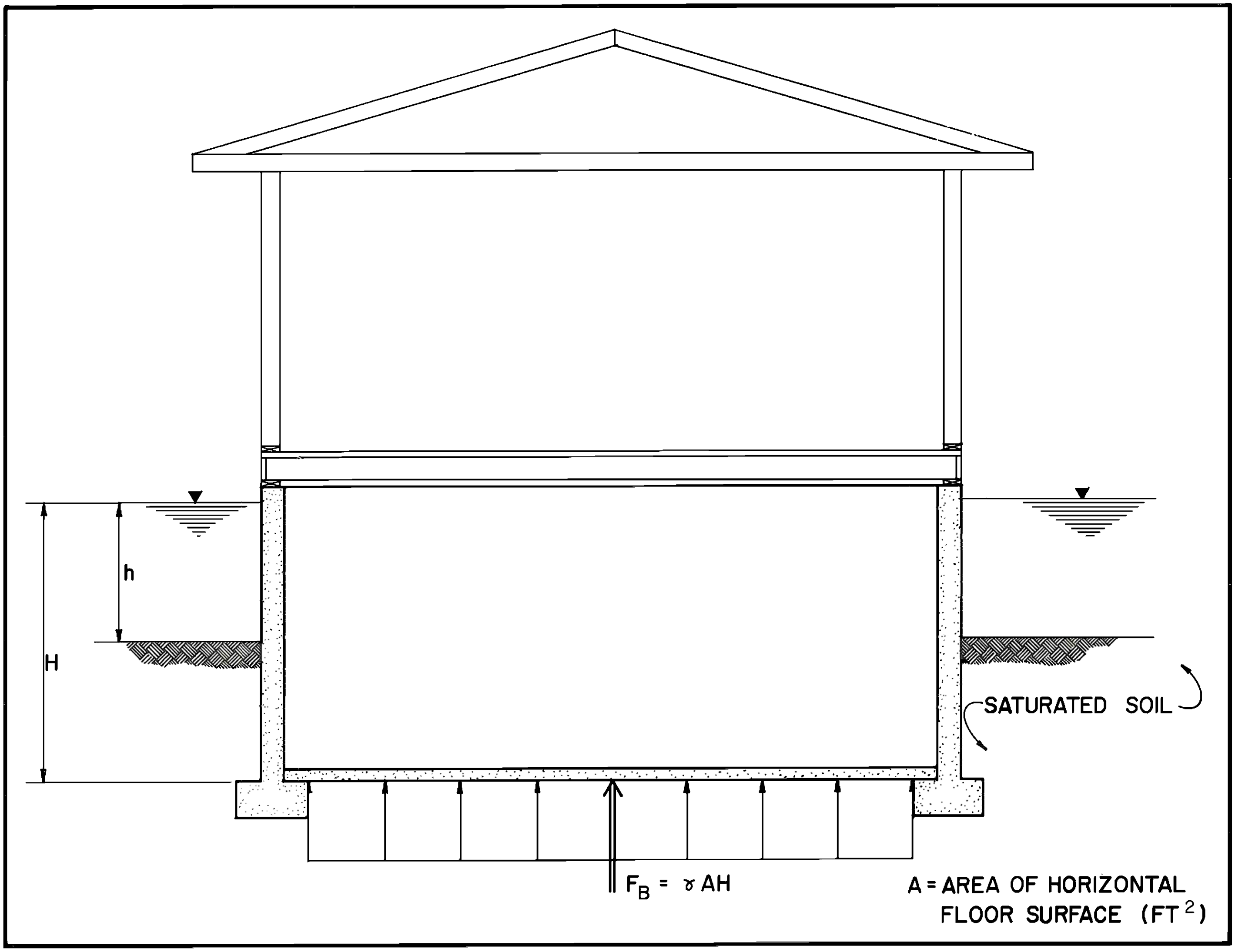


FIGURE C-2. Buoyancy Force Diagram

calculate hydrostatic forces assume saturation of the soil around the structure. The Rankine Theory for active soil pressure is used to determine combined soil and hydrostatic pressure. Active pressure is used in lieu of at rest pressure since most structures will deflect a sufficient magnitude to allow for soil expansion and hence, develop an active stress state.

Under normal conditions without flooding, the soil around a structure creates a lateral soil distribution similar to the hydrostatic pressure distribution due to water. During flooding, and assuming a saturated soil condition, the effective weight of soil is reduced by the buoyant forces on the soil particles, thereby reducing the effective soil pressure. The resultant horizontal force, F_H, is due to the pressure distribution caused by the specific weight of water and the effective saturated weight of soil. The combination of the specific weight of water and the effective saturated weight of soil is called the equivalent fluid weight. This value varies based on the water surface elevation with respect to the ground surface elevation.

Consider the hypothetical condition in Figure C-3, where the water level coincides with the ground level. By the Rankine analysis for a granular soil, such as sand

$$
\begin{aligned}
P_H &= K_a(\gamma_{sat} - \gamma_w)\,a + \gamma_w a \\
&= [K_a(\gamma_{sat} - \gamma_w) + \gamma_w]\,a \\
&= \gamma_{eq}\,a
\end{aligned}
$$

assuming

$$
\begin{aligned}
K_a &= 1/3, \\
\gamma_{sat} &= 120 \text{ pcf, and} \\
\gamma_w &= 62.4 \text{ pcf;}
\end{aligned}
$$

then

$$
\begin{aligned}
P_H &= [1/3\,(120\text{-}62.4) + 62.4]\,a \\
&= 81.6\ a
\end{aligned}
$$

thus

$$
\gamma_{eq} = 81.6 \text{ lbs/ft}
$$

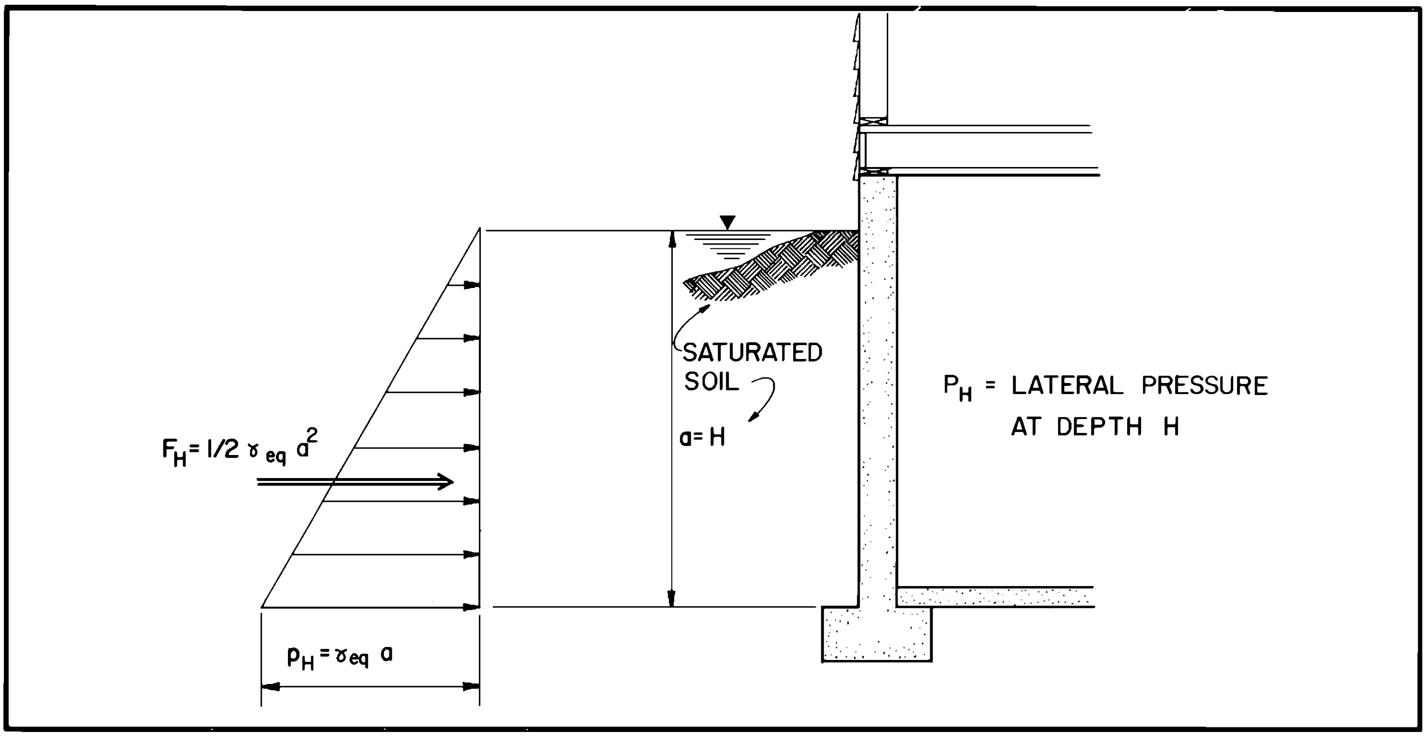


FIGURE C.3. Equivalent Fluid Pressure Force Diagram

For cohesive nonexpansive soils the Rankine analysis becomes

$$
\begin{aligned}
P_H &= K_a(\gamma_{sat} - \gamma_w)\,a - \sqrt{K_a}\,2c + (\gamma_w)\,a \\
&= [K_a(\gamma_{sat} - \gamma_w) + \gamma_w]\,a - \sqrt{K_a}\,2c \\
&= 1/3\,[(120 - 62.4) + 62.4]\,a - \sqrt{K_a}\,2c \\
&= 81.6 - \sqrt{K_a}\,2c
\end{aligned}
$$

where

K_a = Rankine active lateral pressure coefficient
a = Depth from saturated ground surface to point of pressure (H)
P_H = Lateral pressure (psf)
γ_{sat} = Unit weight of saturated soil (pcf)

γ_{eq} = Equivalent fluid weight (pcf)
c = Unit cohesion (psf) (determined by laboratory test on field samples)
γ_w = Unit weight of water (pcf)

Thus for cohesive soils, the net pressure is slightly less. Expansive soils, on the other hand, can produce large loads when saturated. It is therefore recommended that one consult a soils engineer when dealing with all types of clay soils. Table C-1 gives effective saturated soil weights and equivalent fluid weights for various types of soils which are classified in Table C-2.

TABLE C-1
EFFECTIVE EQUIVALENT FLUID WEIGHTS

Soil Type*	Effective Weight of Saturated Soil	eq, Equivalent Fluid Weight
Clean sand and gravel: GW, GP, SW SP	30 pcf	92
Dirty sand and gravel of restricted permeability: GM, GM-GP, SM, SM-SP	35	97
Stiff residual silts and clays, silty fine sands, clayey sands and gravels: CL, ML, CH, MH, SM, SC, GC	45	107
Very soft to soft clay, silty clay, organic silt and clay: CL, ML, OL, CH, MH, OH	100	162
Medium to stiff clay deposited in chunks and protected from infiltration: CL, CH	120	182

* See Table C-2 for soil type definitions.

TABLE C-2
UNIFIED SOIL CLASSIFICATION SYSTEM
(ASTM - D 2487)*

Soil Type	Group Symbol	Description
GRAVELS	GW	Well-graded gravels and gravel sand mixtures, little or no fines.
	GP	Poorly graded gravels and gravel sand mixtures, little or no fines.
	GM	Silty gravels, gravel-sand-silt mixtures.
	GC	Clayey gravels, gravel-sand-clay mixtures.
SANDS	SW	Well-graded sands and gravelly sands, little or no fines.
	SP	Poorly graded sands and gravelly sands, little or no fines.
	SM	Silty sands, sand-silt mixtures.
	SC	Clayey sands, sand-clay mixtures.
	ML	Inorganic silts, very fine sands, rock flour, silty or clayey fine sands.
	CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.
FINE GRAINED SILTS AND CLAYS	OL	Organic silts and organic silty clays of low plasticity.
	MH	Inorganic silts, micaceous or diatomaceous fine sands, or silts, elastic silts.
	CH	Inorganic clays of high plasticity, fat clays.
	OH	Organic clays of medium to high plasticity.

* Several standardized tests are required to positively identify a specific soil class.

There are situations where the water level of the flood exceeds the elevation of the existing ground. In this situation, the hydrostatic loads must be handled in a different manner.

Consider the condition in Figure C-4 where the water level is a distance H above the ground level.

To find the lateral force diagram, one must first find the hydrostatic loads at point 1. From the discussion on hydrostatic loads

$$P_1 = \gamma_w h = 62.4\ h$$

Next find the lateral pressure at point 2, the bottom, assuming granular (noncohesive) soil

$$P_2 = [K_a(\gamma_{sat} - \gamma_w) + \gamma_w]\ a + P_1$$

assuming

$$\begin{aligned} K_a &= 1/3, \\ \gamma_{sat} &= 120\ \text{pcf}, \\ \gamma_w &= 62.4\ \text{pcf} \end{aligned}$$

then

$$\begin{aligned} P_2 &= 1/3\,(120 - 62.4)\ a + 62.4\ h \\ &= 81.6\ a + 62.4\ h \end{aligned}$$

Since the forces transmitted against a structure in a combination soil/water loading are dependent on soil parameters, the reader should consult a qualified soils engineer to determine the exact soil properties for a given site. The reader is also referred to Bowles, Joseph E., Foundation Analysis and Design [Second Edition] (New York: McGraw-Hill Book Co.), or any other foundation or soils mechanics book, for a more detailed discussion of the Rankine Theory for active soil pressure.

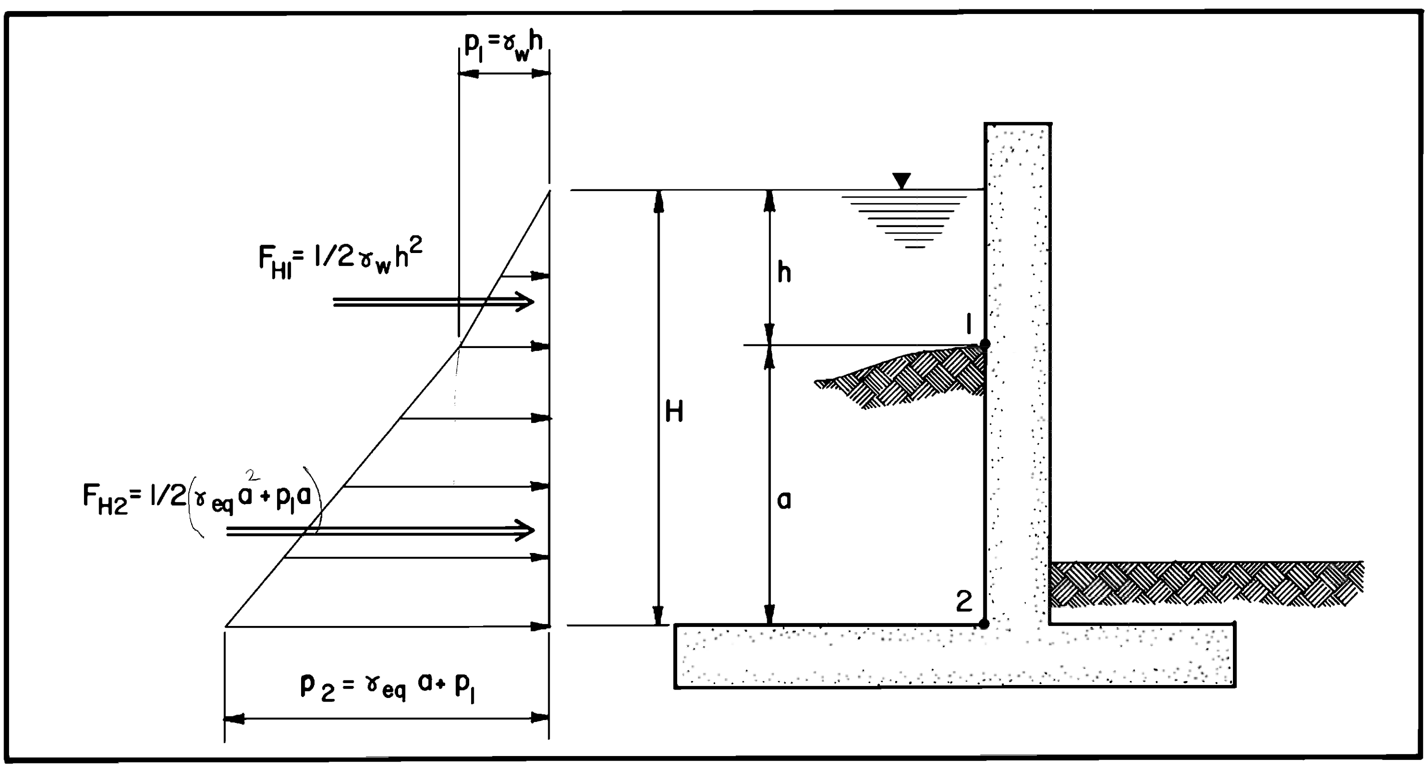


FIGURE C-4. Combination Soil/Water Force Diagram

C.2 HYDRODYNAMIC LOADS

Definition

As water moves around a structure, forces are created on the structure called hydrodynamic forces. Since the force transmitted is due to flowing water acting on the structure, it is dependent primarily on the flow velocity.

Application

Hydrodynamic loads occur above the ground levels where the velocity flow can impact on a structure, and velocity is the important consideration for determining hydrodynamic loads. For lower velocities, especially below 5 feet per second, the hydrodynamic effects are relatively insignificant. Also, since water velocities usually decrease in relation to the distance from the main channel of the stream or river, the location of the structure in the floodplain can help determine whether or not to design the structure for hydrodynamic loads.

Methodology

The equation for hydrodynamic pressure is

$$P_d = C_d \rho \frac{V^2}{2}$$

where P_d is in pounds per sq. ft.
ρ is the mass density = 1.94 slug/ft^3 of water
V is velocity in feet per second
C_d is the drag coefficient

The drag coefficient, C_d, depends on the shape of the object around which the water flows. The value of C_d, unless otherwise evaluated, shall not be less than 1.25. From research related to wind resistance, the value of C_d can be determined from the width to height ratio, b/h, where the width is the side perpendicular to the flow and the height is the distance from the bottom of the structure to the water level. Table C-3 gives C_d values for different width to height ratios. After determination of the hydrodynamic pressure, the total force against the structure can be computed as the pressure times the area over which the water is impacting.

TABLE C-3

DRAG COEFFICIENTS

ONE EDGE ON GROUND — ABOVE GROUND $h' \geq 0.25h$

WATER NORMAL TO FACE

Width to Height Ratio b/h: Wall Above Ground	Width to Height Ratio b/h: Wall On Ground	Drag Coefficient C_d
From 0.5 to 6	From 1 to 12	1.25
10	20	1.3
16	32	1.4
20	40	1.5
40	80	1.75
60	120	1.8
80 or more	160 or more	2.0

For example, three feet of water is impacting on a 6 foot high by 60 foot wide floodwall perpendicular to the surface at a velocity of 8 fps. In order to find the hydrodynamic force on the wall, the width to height ratio must first be determined. For this case, it is $60/3 = 20$, and from Table C-3, the $C_d = 1.3$.

$$
\begin{aligned}
P_d &= C_d \rho \frac{v^2}{2} \\
&= 1.3\ (1.94) \frac{8^2}{2} \\
&= 80.7\ \text{lb/ft}^2 \\
F_d &= P_d\ (\text{wall area}) \\
&= 80.7\ (3)\ 60 \\
&= 14{,}526\ \text{lbs}
\end{aligned}
$$

The resultant force is assumed to act at the center of the applied area; therefore, in this example, the force acts at 1.5 feet from the surface of the water.

For cases where velocities do not exceed 10 feet per second, the hydrodynamic effects of moving water can be converted to an equivalent hydrostatic load by increasing the depth of the water above the flood level by an amount dh, which is

$$dh = \frac{C_d v^2}{2g}$$

where C_d is the drag coefficient, V is the velocity in ft/sec, and g is the acceleration of gravity equal to 32.2 ft/sec.

For the previous example, the equivalent hydrostatic depth would be

$$
\begin{aligned}
dh &= \frac{C_d v^2}{2g} \\
&= \frac{1.3\ (8)^2}{2\ (32.2)} \\
&= 1.3\ \text{ft}
\end{aligned}
$$

The effective depth would therefore be $3 + 1.3 = 4.3$ feet.

This additional load is applied to the upstream side of the structure and above the ground level.

C.3 IMPACT LOADS

Definition

Impact loads are forces that act on a structure when it is struck by a solid object or material being carried by flood waters. Although the exact effect of a material striking a structure is difficult to determine, an estimation must be made for these loads when designing a structure in the floodplain. Impact loads are classified as either normal impact, special impact, or extreme impact.

Application

Normal impact loads are those which relate to isolated occurrences of typically sized ice blocks, logs, or floating objects striking the structure. For design purposes, this can be considered as a concentrated load acting horizontally at the maximum water elevation, or any point below it, equal to the impact force created by a 1000-pound mass traveling at the velocity of the flood water acting on a one-square-foot surface of the structure.

Special impact loads are those which relate to large conglomerates of floating objects, such as ice floes or accumulations of floating debris, either striking or resting against a structure or its parts. In an area where special impact loads may occur, the load considered for design purposes is the impact created by a 100-pound load times the width of building, acting horizontally over a one-foot-wide horizontal strip at the maximum water elevation or at any level below it. Where natural or artificial barriers exist which would effectively prevent these special impact loads from occurring, these loads may be ignored in the design.

Extreme impact loads are those which relate to large floatable objects and masses, such as runaway barges or collapsed buildings and structures, striking the structure or component of the structure under consideration. It is considered impractical to design residential buildings to have adequate strength to resist extreme impact loads. Accordingly, no allowances for these loads are usually made in the design.

Methodology

The methods for determining impact loads have been established in the Application section. Once the object or mass to be designed for has been determined, the impact due to the mass is calculated by multiplying the mass times velocity divided by the duration of impact. The duration of impact is usually assumed to be one second. A safety factor of 1.5 can be used depending on the particular floodplain characteristics in relation to the amount and the type of debris present. Calculation for impact loading is given in the following examples.

Assume the velocity of the water is 6 feet per second and calculate the impact load for normal and special impact conditions.

Normal impact load — 1000 pound mass traveling at velocity of flow

$$F_I = \frac{MV}{t} \qquad M = \frac{W}{g}$$

$$F_I = \frac{WV}{gt}$$

$$= \frac{1000(6.0)}{32.2(1)}$$

= 186 lbs acting on any one square foot of surface of the submerged area normal (perpendicular) to the flow.

where F_I is the normal impact load in pounds
W is weight of object (1000 lbs for normal impact loads)
g is acceleration of gravity (32.2 ft/sec^2)
t is time of impact (generally 1 sec)
V is velocity of flow (fps)

Special impact load: 100 pounds per foot of length normal to the flow, assume the structure is 40 feet wide

$$F_I = \frac{MV}{t} \qquad M = \frac{W}{g}$$

$$F_I = \frac{WV}{gt} \qquad W = (100\ \text{lb/ft})\ 40\ \text{ft} = 4000\ \text{lbs}$$

$$F_I = \frac{4000(6)}{32.2(1)}$$

= 745 lbs acting on any one foot strip of the submerged area for the length of the structure

where F_I is the impact load in pounds
M is the mass (lbs-sec^2/ft)
W is weight (lbs)
g is acceleration of gravity (32.2 ft/sec^2)
t is time of impact (generally 1 sec)
V is velocity of flow (fps)

C.4 WIND LOADS

As discussed earlier in this chapter, when flooding around a house occurs, significant loads can be present on the structure from hydrostatic pressures, hydrodynamic forces and impact loads. In addition to these specific loads, high winds may be present and must be accounted for in the lateral bracing system such as shear walls, diaphragm action, cross bracing, knee bracing, etc. These wind loads acting on the structure must be considered at the same time as the water loads, dead loads and live loads.

The concept of wind producing significant forces on a structure is based on the velocity difference of a medium (air) striking an obstruction (the structure). Wind speeds vary depending on the location within the United States and the frequency with which these loads occur. Most building codes include isolines showing the wind velocity for the mean recurrence interval, usually 50 or 100 year recurrence, from which the design velocity for the particular site can be determined.

Building Codes

Each state is governed by a building code adopted or written for the purpose of setting standards for design and construction of buildings. Some model building codes are adopted by several states. Included among these model building codes are the Building Officials and Code Administrators (BOCA) Code, Standard Building Code (Southern Building Code Congress), and the Uniform Building Code (International Council of Building Officials). Other states choose to write their own codes to govern all building construction. Whatever the governing code in force, the section on wind loads presents the design forces due to wind that must be included in the total design of the structure.

Most building code wind load sections accept the American National Standards Institute (ANSI) provisions. Because of its detailed discussion on wind loads for all types of building and structures, the ANSI wind load treatment is an accepted standard throughout the country.

Application

No matter which building code is used as the wind load standard, the application of the wind loads is primarily the same. These application parameters are: a) the base wind speed, b) the related design pressure, c) the shape coefficients for primary resisting frame, and d) wind load coefficients for secondary framing members.

The base wind speed, as previously discussed, is determined by reading the wind speed from the isoline chart included in the code. Two isoline charts used in the Standard Building Code and the Building Officials and Code Administrators code are provided in Figure C-5 as an example. When measured wind speeds are known to exceed those shown in the code, the design must reflect the known higher base wind speed.

After the wind speed is determined, the wind load is found using the charts given in the codes which translate the wind speed into a wind pressure, usually given in pounds per square foot. The wind design pressure is then applied to the structure for the height range indicated for the particular elevation above the ground. Most building codes have a single table charting the wind pressures for the given wind speeds and the given height above grade. The ANSI standard also introduces the concept of exposure for the three wind speed charts presented.

With the wind pressure now determined, the designer must consider how that wind pressure acts on the structure. The primary members in a wind load resisting system are those which take the loads to the ground during bracing: rigid frames, sheathing, etc. Shape factors are given which depend on the general geometric shape of the structure to which wind loads are applied. For instance, a building should be designed for the wind loads normal to the direction and side from which the wind strikes (windward pressure), uplift factors normal to the roof slopes, suction pressure on the opposite side of the structure (leeward pressure), and along the sides of the structure (blowout pressure). Refer to the ANSI standard or the specific building codes for a more detailed description of the shape factors.

In addition to the design of the primary system, design for members of the secondary system must also be independently considered. The secondary wind framing is the collection system by which wind loads are transmitted to the primary system. Coefficients for secondary framing members are multiplied by the basic wind pressure to yield the design pressure for the design of the member. Secondary members should be designed for both inward pressure loads and outward pressure loads, whichever yield the greater design load.

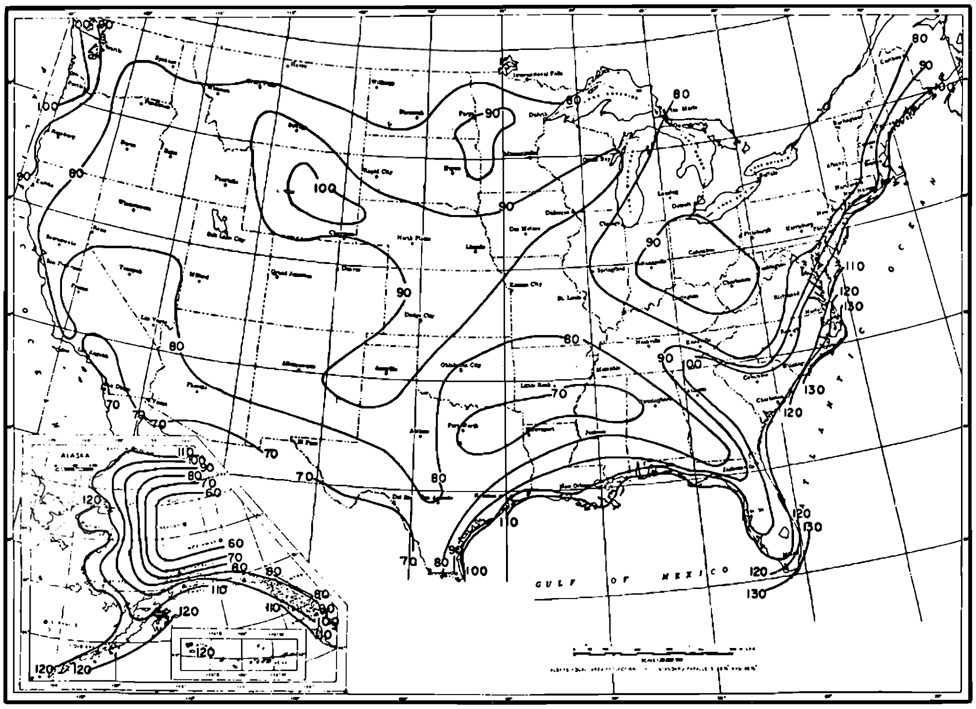


FIGURE C-5a. Basic Wind Speed in Miles Per Hour—100-Year Mean Recurrence Interval

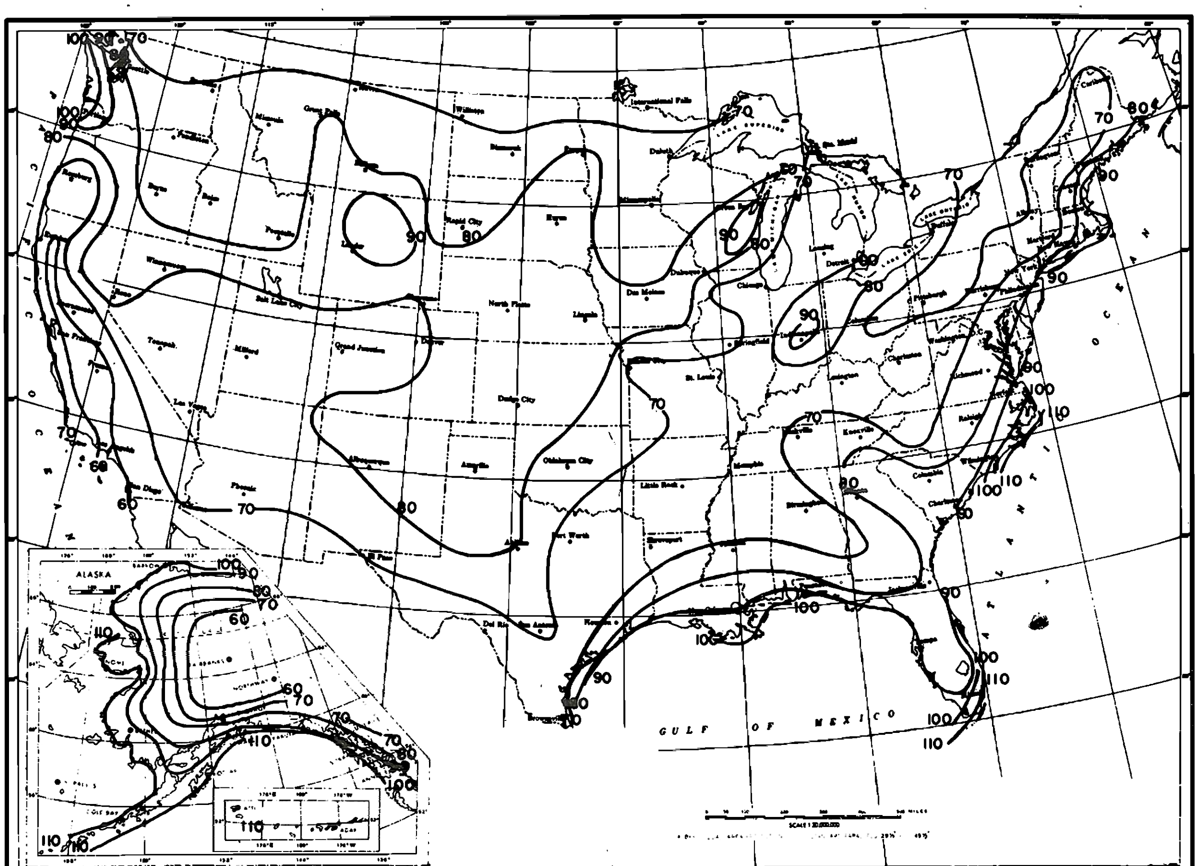


FIGURE C-5b. Basic Wind Speed in Miles Per Hour—50-Year Mean Recurrence Interval

Appendix D

FEDERAL AND STATE CONTACTS

Federal Emergency Management Agency
Regional National Flood Insurance Program Contacts

Region I
J. W. McCormack
POCH, Room 442
Boston, Massachusetts 02109
(617) 223-9561
Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont

Region II
26 Federal Plaza
Room 1349
New York, New York 10278
(212) 264-4734
New Jersey, New York, Puerto Rico, and Virgin Islands

Region III
Liberty Square Building
Second Floor
105 South Seventh Street
Philadelphia, Pennsylvania 19106
(215) 597-7791
Delaware, District of Columbia, Maryland, Pennsylvania, Virginia, and West Virginia

Region IV
1375 Peachtree Street, N. E.
Atlanta, Georgia 30309
(404) 257-2391
Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, and Tennessee

Region V
300 South Wacker Drive
24th Floor
Chicago, Illinois 60606
(312) 372-6098
Illinois, Indiana, Michigan, Minnesota, Ohio, and Wisconsin

Region VI
Federal Regional Center
Room 206
800 North Loop 288
Denton, Texas 76201
(817) 749-9127
Arkansas, Louisiana, New Mexico, Oklahoma, and Texas

Region VII
911 Walnut Street, Room 300
Kansas City, Missouri 64106
(816) 758-2161
Iowa, Kansas, Missouri, and Nebraska

Region VIII
Denver Regional Center, Building 710
P. O. Box 25267
Denver, Colorado 80225-0267
(303) 322-4380
Colorado, Montana, North Dakota, South Dakota, Utah, and Wyoming

Region IX
Building 105
Presidio of San Francisco, California 94129
(415) 556-9840
Arizona, California, Hawaii, and Nevada

Region X
Federal Regional Center
130 228th Street, S. W.
Bothel, Washington 98021-9796
(206) 396-0282
Alaska, Idaho, Oregon, and Washington

State Coordinating Agencies for Flood Insurance

Alabama Department of Economics and Community Affairs
State Planning Division
P. O. Box 2939
3465 Norman Bridge Road
Montgomery, Alabama 36105-0939
(205) 284-8735

Alaska Department of Community and Regional Affairs
Division of Municipal and Regional Affairs
949 East 36 Avenue
Suite 400
Anchorage, Alaska 99508
(907) 561-8586

Arizona Department of Water Resources
Flood Control Branch
99 East Virginia, Second Floor
Phoenix, Arizona 85004
(602) 255-1566

Arkansas Soil and Water Conservation Commission
#l Capitol Mall, Suite 2D
Little Rock, Arkansas 72201
(501) 371-1611

California Department of Water Resources
P. O. Box 388
Sacramento, California 95802
(916) 445-6249

Colorado Water Conservation Board
State Centennial Building
1313 Sherman Street, Room 823
Denver, Colorado 80203
(303) 866-3441

Connecticut Department of Environmental Protection
Water Resources Unit
165 Capitol Avenue
Hartford, Connecticut 06106
(203) 566-7245

Delaware Department of Natural and Environmental Control
Division of Soil and Water Conservation
Richardson and Robbins Building
89 Kings Highway
P. O. Box 1401
Dover, Delaware 19903
(302) 736-4411

District of Columbia Department of Consumer Regulatory Affairs
614 H Street, N. W.
Washington, D. C. 20001
(202) 727-7577

Florida Department of Community Affairs
Division of Resource Planning and Management
2571 Executive Center Circle East
Tallahassee, Florida 32301
(904) 488-9210

Georgia Department of Natural Resources
19 Martin Luther King, Jr. Drive, S. W.
Room 400
Atlanta, Georgia 30334
(404) 656-3214

Guam Office of Civil Defense
P. O. Box 2877
Agana, Guam 96910
(011-671) 477-9841

Hawaii Board of Land and Natural Resources
Department of Land and Natural Resources
P. O. Box 373
Honolulu, Hawaii 96809
(808) 548-7539

Idaho Department of Water Resources
State House
Boise, Idaho 83720
(208) 334-4470

Illinois Department of Transportation
Division of Water Resources
Local Flood Plain Programs
300 North State Street, Room 1010
Chicago, Illinois 60610
(312) 793-3864

Indiana Department of Natural Resources
608 State Office Building
Indianapolis, Indiana 46204
(317) 232-4160

Iowa Department of Water, Air and Waste Management
Wallace State Office Building
Des Moines, Iowa 50319
(515) 281-5029

Kansas State Board of Agriculture
Division of Water Resources
109 Southwest Ninth Street
Topeka, Kansas 66612
(913) 296-3717

Kentucky Department of Natural Resources
Division of Water
18 Reilly Road
Fort Boone Plaza
Frankfort, Kentucky 40601
(502) 564-3410

Louisiana Department of Urban and Community Affairs
P. O. Box 44455, Capitol Station
Baton Rouge, Louisiana 70804
(504) 925-3730

Maine Bureau of Civil Emergency Preparedness
State House
187 State Street
Augusta, Maine 04333
(207) 289-3154

Maryland Department of Natural Resources
Water Resources Administration
Tawes State Office Building D-2
Annapolis, Maryland 21401
(301) 269-3826

Massachusetts Water Resources Commission
Division of Water Resources
State Office Building
100 Cambridge Street
Boston, Massachusetts 02202
(617) 727-3267

Michigan Department of Natural Resources
Water Management Division
P. O. Box 30028
Lansing, Michigan 48909
(517) 373-3930

Minnesota Department of Natural Resources
Division of Waters
444 LaFayette Road
St. Paul, Minnesota 55101
(612) 296-9226

Mississippi Research and Development Center
3825 Ridgewood Road
Jackson, Mississippi 39211
(601) 982-6376

Missouri Department of Natural Resources
1101 R. Southwest Boulevard
P. O. Box 1368
Jefferson City, Missouri 65102
(314) 751-4932

Montana Department of Natural Resources and Conservation
32 South Ewing Street
Helena, Montana 59601
(406) 444-6646

Nebraska Natural Resources Commission
P. O. Box 94876
Lincoln, Nebraska 68509
(402) 471-2081

Nevada Division of Emergency Management
Capitol Complex
Carson City, Nevada 89710
(702) 885-4240

New Hampshire Civil Defense Agency
State Office Park South
107 Pleasant Street
Concord, New Hampshire 03301
(603) 271-2231

New Jersey Department of Environmental Protection
Division of Water Resources
P. O. Box CN 029
Trenton, New Jersey 08625
(609) 292-2296

New Mexico State Engineer's Office
Bataan Memorial Building
Santa Fe, New Mexico 97501
(505) 827-6140

New York Department of Environmental Conservation
Flood Protection Bureau
50 Wolf Road, Room 422
Albany, New York 12233
(518) 457-3157

North Carolina Department of Natural Resources and Community Development
Division of Community Assistance
P. O. Box 27687
Raleigh, North Carolina 27611
(919) 733-2850

North Dakota State Water Commission
State Office Building
900 East Boulevard
Bismarck, North Dakota 58505
(701) 224-2750

Ohio Department of Natural Resources
Flood Plain Planning Unit
Fountain Square
Columbus, Ohio 43224
(614) 265-6755

Oklahoma Water Resources Board
10th and Stonewall, l2th Floor
Oklahoma City, Oklahoma 73105
(405) 271-2533

Oregon Department of Land Conservation and Development
1175 Court Street, N. E.
Salem, Oregon 97310
(503) 378-2332

Pennsylvania Department of Community Affairs
551 Forum Building, Room 317
Harrisburg, Pennsylvania 17120
(717) 787-7400

Puerto Rico Planning Board
P. O. Box 41119, Minillas Station
Santurce, Puerto Rico 09940
(809) 726-7110

Rhode Island Office of State Planning
Statewide Planning Program
265 Melrose Street
Providence, Rhode Island 02907
(401) 277-2656

South Carolina Water Resources Commission
3830 Forest Drive
P. O. Box 4440
Columbia, South Carolina 29240
(803) 758-2514

South Dakota Department of Military and Veterans Affairs
Division of Emergency and Disaster
State Capitol
Pierre, South Dakota 57501
(605) 773-3231

Tennessee Department of Economic and Community Development
Division of Local Planning
1800 James K. Polk Office Building
505 Deaderick Street
Nashville, Tennessee 37219
(615) 741-2211

Texas Department of Water Resources
P. O. Box 13087, Capitol Station
1700 North Congress Avenue
Austin, Texas 78711
(512) 475-2171

Utah Office of Comprehensive Emergency Management
1543 Sunnyside Avenue
Salt Lake City, Utah 84108
(801) 533-5271

Vermont Environmental Conservation Agency
Division of Water Resources
State Office Building
Montpelier, Vermont 05602
(802) 828-2761

Virginia State Water Control Board
P. O. Box 11143
Richmond, Virginia 23230
(804) 257-0075

Virgin Islands Disaster Preparedness Office
Box 1208
St. Thomas, Virgin Islands 00801
(809) 774-6555

Washington Department of Ecology
Mail Stop PV11
Olympia, Washington 98504
(206) 459-6288

West Virginia Office of Emergency Services
Capitol Building, Room EB-80
Charleston, West Virginia 25305
(304) 348-3831

Department of Natural Resources
Flood Plain-Shoreland Management Section
P. O. Box 7921
Madison, Wisconsin 53707
(608) 266-1926

Wyoming Disaster and Civil Defense Agency
P. O. Box 1709
Cheyenne, Wyoming 82003
(307) 777-7566

FLOOD PLAIN MANAGEMENT SERVICES

FLOOD PLAIN AGENCIES / DATA TYPE	Floodwater Control	Floodproofing Information	Preserve Channel Capacity	Development Regulations	Land Use Controls	Public Information	Flood Fighting	Post-Flood Relief	Flood Warning Systems
• Federal Emergency Management Agency		•		•		•	•	•	
• U.S. Army Corps of Engineers	•	•	•	•		•	•	•	•
• U.S. Soil Conservation Service	•	•	•			•		•	
• Department of Housing and Urban Development				•				•	
• National Oceanic and Atmospheric Adminstration						•			•
• U.S. Geological Survey						•			
• Federal Highway Administration	•		•				•		
• State Floodplain Management Coordinating Agency	•	•	•	•	•	•			
• Regional Authorities	•	•	•	•		•	•	•	
• Local Government Planning Agencies				•	•	•			

SUMMARY OF HYDROLOGIC DATA SOURCES

AGENCIES / DATA TYPE	Coastal Surveys and Reports	Flood Control Measure	Flood Boundary Maps	Flood Insurance Rate Maps	Floodplain Information Reports and Technological Studies	Flood Records & Probabilities	Hydrologic Atlases	National Flood Ins. Program Regulations	State Floodplain Regulations	Technical Assistance	Topographic Maps	Zoning Ordinances and Maps
• Local government planning agency or municipal engineer	•	•	•	•	•	•		•	•	•	•	•
• State floodplain management coordinating agency	•	•	•	•		•		•	•	•		
• Federal Emergency Management Agency	•	•	•	•				•		•		
• National Oceanic and Atmospheric Administration (Department of Commerce)	•				•	•						
• Soil Conservation Service (U.S. Dept of Agriculture)		•			•	•						
• U.S. Army Corps of Engineers (Department of Defense)	•	•	•	•	•	•				•	•	•
• U.S. Geological Survey (Department of the Interior)					•	•	•				•	
• Regional authorities (e.g. T.V.A.)		•			•	•				•	•	

Appendix E

GLOSSARY OF TERMS

A-Zone— See **Special Flood Hazard Area**.

Alluvial Fan— Area of deposition where steep mountain drainages empty into valley floors, usually in arid regions. Flooding in these areas often includes characteristics that differ from those in riverine or coastal areas.

Anchor— A series of methods used to secure a structure to its footings or foundation wall so that it will not be displaced by flood or wind forces.

Armor— To protect fill slopes from erosion or scouring by flood waters. Techniques of armoring include the use of riprap, gabions, or concrete mats.

Backflow Valve—See Check Valve.

Base Flood Elevation (BFE)— The elevation for which there is a one-percent chance in any given year that flood levels will equal or exceed it. The BFE is determined by statistical analysis for each local area and designated on the Flood Insurance Rate Maps. It is also known as the **100-Year Flood**.

Berm— A bank or mound of earth, usually placed against a foundation wall.

Borrow Area— An area where material has been excavated for use as fill at another location.

Breakaway Walls— Walls enclosing the area below an elevated structure that are designed to break away before transmitting damaging forces to the structure and its foundation. Breakaway walls are required by NFIP regulations in coastal high-hazard areas (V-Zones) and are recommended in areas where flood waters could flow at significant velocities (usually greater than four feet per second) or could contain ice or other debris.

Building Code— Regulations adopted by local governments that establish standards for construction, modification, and repair of buildings and other structures.

Caulking— Material used to fill joints in a structure, such as around windows or doors.

Check Valve— A type of valve that allows water to flow one way, but automatically closes when water attempts to flow the opposite direction.

Closure— A shield made of strong material, such as steel, aluminum or plywood, used to temporarily fill in gaps in floodwalls, levees, or sealed structures that have been left open for day-to-day convenience at entrances such as doors and driveways.

Coastal High-Hazard Area— Designated as V-Zone on Flood Insurance Rate Maps, this is that portion of the coastal floodplain subject to storm driven velocity waves of three feet or more in height.

Column— Upright support units for a building, set in predug holes and backfilled with compacted material. Columns will often require bracing in order to provide adequate support. They are also known as **posts**, although they are usually of concrete or masonry construction.

Concrete Masonry Unit (CMU)— Blocks of concrete used in construction.

Crawl Space— Low space below the first floor of a house, where there has not been excavation deep enough for a basement, but where there is often access for pipes, ducts, and utilities.

Debris Impact Loads— Sudden loads induced on a structure by debris carried by flood water. Though difficult to predict, allowances for impact loads must be made when floodproofing a structure.

Dry Floodproofing— A floodproofing method used in areas of low level flooding to completely seal a home against water. Referred to as sealing in this manual.

Elevation— The raising of a structure to place it above flood waters on an extended support structure.

Existing Construction— The structures already existing or under construction prior to the effective date of a community's floodplain management regulations.

Extended Foundation— The construction of additional wall above existing foundation walls in order to elevate a structure above flood levels.

Federal Emergency Management Agency (FEMA)— This agency was created in 1978 to provide a single point of accountability for all federal activities related to disaster mitigation and emergency preparedness and response.

Federal Insurance Administration (FIA)— The governmental unit, a part of the Federal Emergency Management Agency, that administers the National Flood Insurance Program.

Fill— Material such as earth, clay, or crushed stone which is dumped in an area and compacted to increase ground elevation.

Flash Flood— A flood that crests in a short length of time and is often characterized by high velocity flow. It is often the result of heavy rainfall in a localized area.

Flood— (For NFIP flood insurance policies) A partial or complete inundation of normally dry land areas from 1) the overland flood of a lake, river, stream, ditch, etc; 2) the unusual and rapid accumulation or runoff of surface waters; and 3) mudflows or the sudden collapse of shoreline land.

Flood Fringe— That portion of the floodplain that lies beyond the floodway and serves as a temporary storage area for flood waters during a flood. This section receives waters that are shallower and of lower velocities than those of the floodway.

Flood Hazard Boundary Map (FHBM)— The official map of a community that shows the boundaries of the floodplain and special flood hazard areas that have been designated. It is prepared by FEMA using the best flood data available at the time a community enters the emergency phase of the NFIP. It is superseded by the FIRM after a more detailed study has been completed.

Flood Insurance Rate Map (FIRM)— The official map of a community prepared by FEMA that shows the Base Flood Elevation, along with the special hazard areas and the risk premium zones for flood insurance purposes. Once it has been accepted, the community is part of the regular phase of the NFIP.

Flood Insurance Study (FIS)— A study performed by any of a variety of agencies and consultants to delineate the special flood hazard areas, base flood elevations and risk premium zones. The study is funded by FEMA and is based on detailed site surveys and analysis of the site-specific hydrologic characteristics.

Floodplain— Normally dry land adjacent to a body of water, such as a river, stream, lake, or ocean, which is susceptible to inundation by floodwaters.

Floodplain Management— A program of corrective and preventive measures for reducing flood damage, including but not limited to flood control projects, floodplain land use regulations, floodproofing or retrofitting of buildings, and emergency preparedness plans.

Floodproofing— Any combination of measures taken on a new or existing structure for reducing or eliminating flood damages.

Floodwall— A constructed barrier of resistant material, such as concrete or masonry block, designed to keep water away from a structure.

Floodway— The central portion of the floodplain that carries the greatest portion of the waterflow in a flood. Obstructions in the floodway will result in increased flood levels upstream.

Footing— The enlarged base of a foundation wall, pier, or column, designed to spread the load of the structure so that it does not exceed the soil bearing capacity.

Foundation— The underlying structure of a building, usually constructed of concrete, that supports the foundation walls, piers, or columns.

Foundation Walls— A support structure that connects the foundation to the main portion of the building, or superstructure.

Freeboard— An additional amount of height used as a factor of safety in determining the design height of a floodproofing or retrofitting method to compensate for unknown factors such as wave action. Certain guidelines and restrictions apply for establishing freeboard on levees and floodwalls in NFIP areas.

Human Intervention— The required presence and active involvement of people to enact any type of floodproofing or retrofitting measure prior to flooding.

Hydrodynamic Loads— Forces imposed on an object, such as a structure, by water moving around it. Among these loads are positive frontal pressure, against the structure; drag effect, along the sides; and negative pressure on the downstream side.

Hydrostatic Loads— Forces imposed on a surface, such as a wall or floor slab, by a standing mass of water. The water pressure increases with the square of the water depth.

Interior Grade Beam— A section of a floor slab that has a thicker section of concrete to act as a footing to provide stability under load-bearing or critical structural walls.

Levee— A barrier of compacted soil designed to keep flood water away from a structure.

Lift— A layer of soil that is compacted before the next layer is added in the construction of a fill pad or levee.

Mean Sea Level— The average height of the sea for all stages of the tide, usually determined from hourly height observations over a 19-year period on an open coast or in adjacent waters having free access to the sea.

National Flood Insurance Program (NFIP)— The federal program, created by an act of Congress in 1968, that makes flood insurance available in communities that enact satisfactory floodplain management regulations.

One Hundred (100) Year Flood— The flood elevation that has a one-percent chance of being equaled or exceeded in any given year. It is also known as the base flood elevation.

Permeability— The property of soil or rock that allows water to pass through it.

Pier— An upright support member of a building, with a height limited to a maximum of three times its least lateral dimension. It is designed and constructed to function as an independent structural element in supporting and transmitting building and environmental loads to the ground.

Pile— An upright support member of a building, usually long and slender in shape, driven into the ground by mechanical means and primarily supported by friction between the pile and the surrounding earth. Piles often cannot act as individual support units, and require bracing to other pilings.

Post— Long upright support units for a building, set in predug holes and backfilled with compacted material. Each post usually requires bracing to other units. They are also known as **columns**, although they are usually made of wood.

Regulatory Floodway— As referenced in a floodplain management ordinance, this is the portion of the floodplain needed to discharge the 100-year flood without increasing the flood elevation by more than a designated height, usually one foot.

Relocation— The moving of a structure from a flood area to a new location, normally to one where there is no threat of flooding.

Retrofitting— Floodproofing measures taken on an existing structure.

Retrofloodproofing— See **Retrofitting**.

Riprap— Broken stone, cut stone blocks, or rubble that is placed on slopes to protect them from erosion or scouring caused by flood waters or wave action.

Scouring— The erosion, or washing away, of slopes or soil by velocity waters.

Slab on Grade— A structural design where the first floor sits directly on a poured concrete slab which sits directly on the ground.

Special Flood Hazard Area— Portion of the floodplain subject to the 100-year flood, also known as the A-Zone. In coastal regions, this area is subject to velocity wave action of less than three feet.

Stile— A set of stairs to allow access over an obstruction, such as a floodwall.

Structural Mat Slab— The concrete slab of a building which includes structural reinforcement to help support the building's structure.

Substantial Improvement— Any repair, reconstruction, or improvement of a structure, the cost of which equals or exceeds 50 percent of the market value of the structure either: a) before the improvement is started, or b) if the structure has been damaged and is being restored, before the damage occurred.

Venting— A system designed to allow flood waters to enter an enclosure, usually the interior of foundation walls, so that the rising water does not create a dangerous differential in hydrostatic pressure. This is usually achieved through small openings in the wall, such as a missing or rotated brick or concrete block, or small pipe.

V-Zone— See **Coastal High Hazard Area**.

Watershed— An area which drains to a single point. In a natural basin, this is the area contributing flow to a given place or stream.

Appendix F

APPENDIX F—BIBLIOGRAPHY

F.1 ANNOTATED BIBLIOGRAPHY

Massachusetts
Office of the Lieutenant Governor
State House
Boston, Massachusetts 02133

A COASTAL HOMEOWNER'S GUIDE TO FLOODPROOFING 22 pages

The Guide is designed to give coastal homeowners information about floodproofing by evaluating the flood risks to their homes and outlining the key steps they should follow if they should decide to floodproof. To assist the homeowner with the evaluation process, the publication includes three checklists to be used depending on the level of flood threat. Included at the back of the Guide is a section, "How to Hire A Contractor," and a sample Home Improvement Contract to be used when hiring professionals for floodproofing work.

Coastal Environments, Inc.
Baton Rouge, Louisiana

BEFORE THE FLOOD! PRACTICAL IDEAS FOR REDUCING DAMAGE (1983) 16 pages

This manual illustrates and briefly describes retrofitting techniques including levees, floodwalls, elevation, sealing of residences and commercial buildings, and interior modifications. It also includes hints for site planning, landscaping, and financing.

Tulsa District
U.S. Army Corps of Engineers

CASE STUDY: RELOCATION OF A LARGE, SLAB-ON-GRADE HOUSE FROM A FLOOD PLAIN TO A FLOOD-FREE SITE (1984) 20 pages

This report, intended for agencies, organizations, and individuals, describes the process of moving a 3,200-square foot house from a Tulsa County, Oklahoma floodplain to a flood-free site. For the homeowner contemplating a house relocation, this publication provides valuable first-hand experience from a person who has actually gone through the experience.

Department of Environmental Protection
Natural Resources Center
Flood Preparedness Project
155 Capitol Avenue, Room 553
Hartford, CT 06106

COASTAL HOMEOWNERS' FLOOD PREPAREDNESS MANUAL (August 1984) 71 pages

Though primarily written for the coastal homeowner, much of the information in this manual is also of use to homeowners in inland areas. Among the subjects covered are a background on the nature of flooding and floodplains; how floods damage structures; the various options and techniques for reducing flood damages; emergency actions; clean up and repair after a flood; tips on restoring flood damaged property; planning against future floods, and a section on floodproofing cost benefit analysis.

Colorado Water Conservation Board
Department of Natural Resources
Denver, Colorado

COLORADO FLOODPROOFING MANUAL (October 1983) 139 pages

Primarily written for engineers and architects, this manual contains extensive, valuable technical information, including numerous drawings, graphs, charts, and equations. Among the subjects covered are Physiographic Considerations, Examples of Floodproofing, Natural and Inherent Methods, Water Loadings, Design Criteria, Closure of Openings, Internal Flooding, Building Materials, Basement Construction, Electrical, Mechanical, Mobile Homes and Parks, and Economic Feasibility.

Baltimore District
U.S. Army Corps of Engineers

COST REPORT ON NON-STRUCTURAL FLOOD DAMAGE REDUCTION MEASURES FOR RESIDENTIAL BUILDINGS WITHIN THE BALTIMORE DISTRICT (July 1977) 120 pages

The publication is intended for planners, homeowners, local officials, and other segments of the public for the purpose of reduction and elimination of flood damages to residential structures. Using a cross section of residential structures within the Susquehanna River Basin and the Baltimore Metropolitan Area, it provides information on design and costs for five "non-structural" measures, including acquisition and demolition of houses, relocation of houses to alternative sites, relocation of household mechanical and electrical equipment, elevation, and basement floodproofing.

Federal Emergency Management Agency
Federal Insurance Administration
Washington, D.C.

COASTAL CONSTRUCTION MANUAL (Feb. 1986) FEMA-55 [GPO 1986 620-214/40618]

The Manual covers in detail the design and construction of new elevated residential structures and how to provide for their resistance to coastal flood, wind, and erosion hazards. Although primarily a technical manual, the publication can provide for the layperson some grounding in techniques of design and construction that protect structures from flood forces in coastal areas.

Federal Emergency Management Agency
Washington, D.C.

DESIGN GUIDELINES FOR FLOOD DAMAGE REDUCTION (1981) 101 pages FEMA-15 [GPO: 1984-436-770]

Prepared as a study for FEMA by the AIA Research Corporation, and with numerous illustrations and photographs, this publication focuses on the need for improved building and site design in flood-prone areas and its relationship to effective floodplain management. The first section of the manual provides background information on flooding, discusses the natural characteristics of floods and the interrelationships between floods and the built environment, and deals with government flood-related progams and outlines general strategies for reducing flood losses. The second section details the range of information needed for pre-design analysis of projects in flood-prone areas and outlines techniques to mitigate flood damage potentials. A final section provides additional sources of information.

Federal Emergency Management Agency
Washington, D.C.

<u>ELEVATED RESIDENTIAL STRUCTURES (1984) 137 pages FEMA-54 [GPO 1984 0-438-116]</u>

This manual provides detailed design and construction standards for new elevated buildings in both coastal and riverine flood hazard areas. A discussion on site analysis and several design examples are also included.

Illinois Department of Transportation
Division of Water Resources
300 N. State, Room 1010
Chicago, Illinois 60610

<u>ELEVATING OR RELOCATING A HOUSE TO REDUCE FLOOD DAMAGE (October 1983) 22 pages</u>

This handbook provides planning guidance for homeowners considering elevating or relocating their houses against flood damage. It provides information on flood hazards; floodplain regulations; financing and the basic construction steps, including dealing with a contractor, building plans and permits.

<u>PROTECT YOUR HOME FROM FLOOD DAMAGE (January 1985) 34 pages</u>

This publication reviews some retrofitting techniques and other measures, including emergency and temporary ones, that could be of value to a homeowner living in a flood-prone area. The manual briefly describes such retrofitting techniques as sealants, levees, floodwalls, elevation, relocation, and wet floodproofing (the deliberate, controlled entry of water into a structure). It also has tips on such things as sewer backup, emergency measures such as sandbagging, flood watches and warnings, evacuation plans, safety and health precautions, cleanup after a flood, and financial assistance.

<u>ELEVATING FLOOD-PRONE BUILDINGS: A CONTRACTOR'S GUIDE (1986) 24 pages</u>

This guide presents specific design and construction standards for contractors relating to the elevation of both new and existing structures on foundation walls in low to moderate velocity flood conditions.

Department of Community Affairs
Commonwealth of Pennsylvania
908 State Office Building
Broad and Spring Garden Streets
Philadelphia, Pennsylvania 19130

<u>FLOOD DAMAGE PREVENTION HANDBOOK (September 1983) 28 pages</u>

This handbook is intended to introduce owners of flood-prone properties to various measures that can be taken to reduce or minimize future flood damages to new or existing houses and other light-frame buildings. After a review of the National Flood Insurance Program is the chapter "Understanding Your Flooding Problem," which helps the homeowner comprehend the nature of the flood threat and how to decide what economic benefits might come from floodproofing. The remainder of the handbook is concerned with the various floodproofing options, including dry and wet floodproofing, levees and floodwalls, elevations, and measures to be taken for mobile homes.

Flood Plain Management Unit
Division of Water
Ohio Department of Natural Resources

FLOOD PLAIN MANAGEMENT IN OHIO, A NONSTRUCTURAL APPROACH (June 1984) 16 pages

After a review of the historical, structural approach (dams, channelization, large levees, etc.) to floodproofing in Ohio, the publication considers the more recent trend towards the non-structural approach: elevation of structures, floodproofing of structures, elevation and anchoring of mobile homes, floodproofing of utilities, and the anchoring of tanks and other miscellaneous items.

Nevada Division of Emergency Management
2525 S. Carson Street
Carson City, Nevada

FLOOD PLAIN MANAGEMENT TECHNIQUES FOR ALLUVIAL FANS, ARID AND SEMI-ARID ENVIRONMENTS (November 1984) 104 pages

This publication covers a subject that thus far has rarely been described in material for the public: the phenomena associated with flooding on alluvial fans and in desert areas of the United States. This type of flooding seems to increasingly cause damage, possibly because of the increased settlement of arid areas. Much of the publication deals with a review of the nature of flooding in arid environments, but one section deals with floodproofing measures that homeowners may take.

Flood Plain Management Section
Nebraska Natural Resources Commission

FLOOD PREPAREDNESS AND RESPONSE HANDBOOK (March 1984) 59 pages

The purpose of this handbook is "to provide property owners, developers and public officials with a source of specific information and procedures for dealing with flood hazards and the property damage which can result from a flood." It achieves this not only though text but with numerous drawings and diagrams. One major section is concerned with actions for homeowners to take after the residence has been flooded, other sections review the major damaging effects of flooding; planning for the flood, including a review of some retrofitting techniques; and emergency actions to be taken just before a flood occurs.

South Atlantic Division
U.S. Army Corps of Engineers
Atlanta, Georgia

FLOOD PROOFING, EXAMPLE OF RAISING A PRIVATE RESIDENCE (March 1977) 19 pages

For the homeowner contemplating an elevation of a residence, this report contains valuable information on the steps involved and the occasional problems encountered. The report is particularly relevant in that it follows an actual elevation project, the raising of a house in the Peachtree Creek area of Atlanta, one of the most publicized retrofit projects in the country.

Water Management Branch
Ministry of Environment
Province of British Columbia
Victoria, British Columbia V8V 1X5
Canada

FLOOD PROOFING NEW RESIDENTIAL BUILDINGS IN BRITISH COLUMBIA (1981) 39 pages

Although devoted exclusively to floodproofing new construction, this attractively illustrated manual provides backgound material that could also be used by those considering retrofitting. In addition to general material concerning Elevation on Fill and Elevation by Structural Means, the manual presents helpful information on such topics as site layout, planning an entry into a floodproofed home, organizing interior and exterior space, landscaping a floodproofed home, and planning accessory structures.

Federal Emergency Management Agency
Washington, D.C.

FLOODPROOFING NON-RESIDENTIAL STRUCTURES (1986) 199 pages FEMA-102 [GPO 1986 6214–393/00128]

While this manual is intended for non-residential construction, it offers valuable technical information on floodproofing that is often applicable to retrofitting residential structures.

Office, Chief of Engineers
U.S. Army Corps of Engineers
Washington, D.C. 20314-1000

FLOOD-PROOFING SYSTEMS & TECHNIQUES (December 1984) 104 pages [GPO: 1985 546-031]

Primarily intended to illustrate the types of floodproofing techniques being used throughout the United States today, this is not a "how to" publication but instead provides a representative cross section of floodproofed structures in the country. Filled with many photographs of structures floodproofed by a wide range of techniques, the report is a result of a national survey by the Corps of Engineers conducted to document the effectiveness of floodproofing techniques used in the United States by various occupants of flood hazard areas.

Department for Economic Development
Office of Community Development
Frankfort, Kentucky

KENTUCKY FLOOD PROTECTION MANUAL (December 1981) 199 pages

Primarily written for local officials, planning agencies, community leaders, and designers, and primarily concerned with the types of flooding that occur in Kentucky, the manual may contain information for the more advanced homeowner. Among the topics discussed are the general effects of flood forces on various types of structures, alternative flood protection techniques, and procedures that should be followed for each flood-prone structure. One large section of the manual contains charts, graphs, and worksheets for determining what type of floodproofing technique is needed and how to implement it.

U.S. Army Corps of Engineers

LOW COST SHORE PROTECTION . . . A PROPERTY OWNER'S GUIDE (1981) 159 pages

Intended for use by property owners whose land is located on sheltered waters protected from direct action of open ocean waves, the report is primarily a guide on basic techniques for preventing or reducing shoreline erosion. The authors define "low cost protection" as "those methods within the financial means of most landowners and commensurate with the value of their property." The report has four main objectives: to acquaint the property owner with the actual shoreline processes at work; to explain available alternatives; to review the entire decision process leading to an appropriate choice from among available options; and to identify sources of additional information.

Federal Emergency Management Agency
Washington, D.C.

MANUFACTURED HOME INSTALLATION IN FLOOD HAZARD AREAS (September 1985) 110 pages FEMA-85 [GPO: 1985–529–684/31054]

The manual provides technical guidance to homeowners, technical persons and local officials on how to reduce the risk of flood damages to manufactured homes. (As used in the context of this publication, the term "manufactured home" also includes those homes previously defined as "mobile homes.") Sections of the publication include an

Overview (background on manufactured homes, typical siting practices, effects of flooding on manufactured homes, and regulatory and building code requirements); Flood and Wind Hazards; Elevation and Anchoring Techniques; Design of Elevated Foundations; and Cost Analysis.

Division of Water
Indiana Department of Natural Resources
Room 605—State Office Building
Indianapolis, Indiana 46204

PROTECTION FOR A FLOODED BASEMENT (September 1984) 12 pages

The publication provides the reader with an understanding of the terms associated with basement flooding, some common causes of the problem and some methods of preventing future damages.

Pacific Ocean Division
U.S. Army Corps of Engineers

RESIDENTIAL CONSTRUCTION PRACTICES HANDBOOK FOR FLOOD PRONE AREAS IN THE STATE OF HAWAII (March 7, 1983) 212 pages

The Handbook describes its intention as "not to encourage development in flood-prone areas, but to provide design features that minimize the potential loss of life and property." It does this by providing a set of guidlines for residential construction in areas susceptible to flooding in the State of Hawaii in an effort to assist contractors, developers, homeowners, and local government officials. Primarily concerned with Pacific coastal flooding, the publication contains numerous photographs and drawings of floodproofed residences along with information for both the layperson and the technical person.

NOTE:

Most Federal Government reports and manuals can be ordered using either the NTIS or GPO accession numbers that appear on the publication. Use the NTIS number to order documents from:

National Technical Information Service (NTIS)
ATTN: Operations Division
5285 Port Royal Road
Springfield, Virginia 22161
703/557-4650

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202/783-3238

Local and state government reports and manuals should be ordered from the agency responsible for their publication.

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Appendix G

CASE STUDY NARRATIVES

This appendix presents three case studies involving actual residential structures that have been subjected to flooding. Each case study describes the specific flood history and characteristics, outlines potential retrofitting options, and presents design details for the chosen retrofitting methods. The information presented in this manual was used in determining the most feasible retrofitting options in terms of both protection and cost, and specific sections are referenced where appropriate. The description of the selected options contains design details and drawings that are typical of what might be prepared for retrofitting projects throughout the country. The cases presented here are based on actual retrofitting projects presently being planned.

For the homeowner considering a retrofitting project, these case studies demonstrate how to determine the necessary data, how to decide on a specific option, and how that option should be designed. Following the processes outlined in these case studies will help the homeowner to complete a successful retrofitting project.

CASE STUDY REPORT #1

Description of the Residence and Flood Characteristics

Case Study #1 is an older brick frame structure similar to those found in flood hazard areas nationwide. This structure is located in a rural Southern town.

The area surrounding the house is relatively flat farm land with wooded hills surrounding planted valley areas. A moderately sized stream is located one block to the north of the residence.

This location has experienced a number of minor floods over the years. The worst flood occurred in 1977 and reached the bottom of the home's floor framing, causing minor water damage. The recorded flood level was roughly four inches below the structure's first-floor elevation. According to the community's Flood Insurance Rate Map, the base flood elevation is one foot above the first-floor level.

Flood velocity at the site is in the slow to moderate range, having rarely exceeded three feet per second. Erosion from flood waters has not been a problem. The duration of flooding has always been less than one day. Flood debris also has been insignificant. According to local soil history obtained from the Soil Conservation Service and local county records, soil at the site of the structure is basically impermeable, allows for adequate drainage, and has good to very good load bearing capacity.

Regarding the building construction type, the structure is a brick veneer on wood frame building, having a wood frame floor system over a crawl space. The foundation consists of concrete spread footings with 8″ concrete block foundation walls. The floor system is made up of 2″ × 10″ framing joists spaced 16 inches on center, supported by girders made up of three 2″ × 10″ members. The building's wall system consists of 2″ × 4″ framing spaced 16 inches on center with a brick veneer exterior. Interior walls are wood frame with drywall finish. Flooring includes carpet and vinyl tile on both plywood and hardwood subflooring. The roof system consists of 2″ × 6″ rafters spaced 6 inches on center with asphalt shingles.

Selection of Retrofitting Options

Utilizing the decision matrix found in Section 11.1 of this manual as a tool, analysis of a number of retrofitting options can be performed as shown on Decision Matrix A in this section. By counting the number of "yes" choices selected for each option, the range of feasible retrofitting methods can be determined.

From the decision matrix, it can be determined that with one exception, all retrofitting methods are feasible. At this point, the decision rests on economical and aesthetic concerns and owner preference. For this study, the choice was narrowed to two of the most economic alternatives. Alternative No. 1 is elevation on foundation walls, and Alternative No. 2 is installation of a levee and floodwall system for the residence.

Description of the Chosen Retrofitting Methods

Alternative No. 1: Elevation on Foundation Walls. This structure is to be elevated approximately 24" on extended foundation walls. All plumbing, oil lines, and electrical service must be disconnected prior to lifting the structure. Some trenching and wall penetrations will be required for inserting the lifting beams. Removal of concrete porch floors will be necessary, and complete removal of brick veneer will be required. The three metal roof awnings should also be taken down and stored for reinstallation.

The elevation sequence described in Chapter 3 would be followed to accomplish the elevation. Excavation would be required for jacking pits and jacking beams due to a limited crawl space of approximately 12 inches. The house would then be jacked up above 24", the desired elevation level. Exterior foundation walls would be extended three block courses except for the openings required around the steel lifting beams. Anchor bolts and wood sill plates would be installed. The house will then be lowered onto the extended foundation. With this complete, lifting beams and jacks will be removed, all utilities reconnected, and the remainder of the foundation walls completed.

Elevation of the front porch, side porch, and stoop will be accomplished as shown on the accompanying drawings, followed by the replacement of the brick veneer and the reinstallation of metal canopies and the oil tank. An earthen berm may be used as shown in the drawings to eliminate the elevated look of the structure.

Estimated Cost of Elevation (Includes Estimated Labor Costs)

Block	250 S.F. @ $3/S.F. (in place)	$ 750.00
Concrete/Labor	7 yds. @ $175/yd. (in place)	1,225.00
Brick Veneer	1,968 S.F. @ $4.55/S.F.	8,954.00
Elevation	Beams/Jacking, etc.	2,500.00
Berm	29 C.Y. @ $8/C.Y.	237.00
Utility Reconnection		400.00
Canopy Reassembly		300.00
Concrete Walk Addition Over Berm		75.00
Porch Labor and Miscellaneous Materials		2,000.00
Miscellaneous Labor and Materials (Including Trenching)		1,000.00
	TOTAL	$17,441.00

Alternative No. 2: Earthen Levee and Masonry Floodwall System. Construction of a three foot high earthen levee is planned for those areas of the site where adequate clearance is available. In areas where clearance will not allow earthen berm construction, masonry floodwalls with closures are proposed. The first construction step will involve clearing a pathway for the levee. Six inches of topsoil would be removed and stored for reestablishing the top of the new levee. A borrow site must be found for obtaining clay or other highly impermeable soil materials. This borrow soil will be placed in six layers (lifts) and compacted at the levee site. A soils engineer should be consulted to analyze the existing site soil as well as the borrow site soil for permeability to determine if any additional protective measures might be required. The soils engineer should also test the levee while the lifts are being constructed.

Care must be exercised in obtaining the levee material to guard against the use of large stones, roots, etc. Upon completion of rough grading, the levee's outer surface will be finished with hand tools and seeded. Any equipment tracks in the yard must also be filled and reseeded. Refer to Section 5.5 for additional information on the precautions that would be taken with regard to the levee construction process.

Excavation for the necessary masonry floodwall sections must be performed carefully due to space restrictions. A portion of the footing excavation may have to be done by hand. The footing ditch should be approximately four feet wide, and it should be inspected for soft places or rock areas. If rock is found, it will be undercut a minimum of 6 inches and padded with sand or crushed gravel. Reinforcement steel for the footing is to be Grade 60 and placed using "high chairs" for steel support. Concrete having a capacity of three thousand pounds per square foot must be used. When the footing is poured, steel dowels will be left protruding upward to tie into the vertical block reinforcing. The masonry floodwall would then be constructed, and a course of 4" brick rowlock added to seal the top of the block wall against water intrusion. All joints would be tooled for aesthetic purposes. Following this design process, the floodwall will blend into the earthen levee to form a monolithic flood barrier.

Two 3′ wide by 3′ tall closures will be installed at front sidewalks and one 8′ wide by 3′ tall closure will be installed at the rear drive. All three aluminum closures will be similar with the exception of horizontal bar or plate stiffeners added to the driveway closure. The ⅜" thick plates will be hinged and will lock against a gasket, using a locking dog and cam latch device. The angle frame will be secured to the masonry floodwall with a toggle bolt or masonry inserts. A concrete sill under the hinged closure poured from the bottom of the closure to the top of the footing will be required for anchorage of the bottom sealing angle as described in Chapter 7.

A 4" gravity pipe installed at the lowest elevation within the floodwall enclosure will be equipped with a check valve on the outfall end to discharge normal rainwater accumulation. Since flood waters may cover the gravity drain pipe, a sump pump system will be required to remove rainwater from inside the floodwall enclosure. A concrete sump pump pit will be constructed at the lowest elevation of the enclosed site. A sump pump equipped with automatic mercury float controls will then be installed. The top of the sump pit would be slightly higher than the gravity drain so that the sump pump will not operate until the check valve is closed by flood waters. The sump pump will discharge through a pipe running over the top of the floodwall. With this pipe installed over the wall, a check valve is not needed. A fused NEMA-rated rain tight disconnect will be installed near the pump according to local code requirements. The pump will be energized from the house circuit breaker panel.

Roof downspouts will be piped directly to the outside of the floodwall enclosure. Therefore, the sump pump or gravity drain will only need to discharge rainwater falling between the house and floodwall or levee, as well as a calculated amount of seepage through the levee and leakage around the closures.

The sump pump control may also be equipped with a high water alarm device. The pump would be sized for a 100-year, 60-minute duration rainfall according to specifications noted in Section 5.5. An emergency generator will be kept on site in the event that electricity service for the pump is interrupted by the flooding.

Cost Estimate for Earthen Levee and Masonry Floodwall System (Includes Estimated Labor Costs)

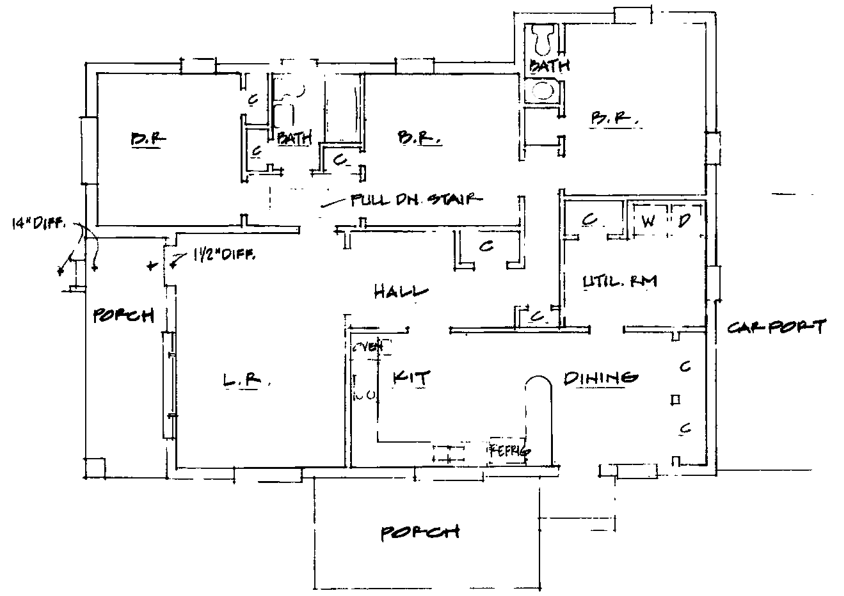
Levee		
Removal of Topsoil	117 sq. yd. @ $3/S.Y.	$ 351.00
Compacted Backfill	80 C.Y. @ $7/C.Y.	560.00
Borrow Material	80 C.Y. @ $5/C.Y.	400.00
Seeding	555 S.Y. @ $1.50/S.Y.	833.00
Extend 8" Drain Pipe		87.00
	Total Cost for Levee	$2,231.00

Floodwall		
Excavation for Footings	81 yds. @ $5/yd.	$ 405.00
Concrete Reinforced Footing	27 C.Y. @ $175/C.Y.	4,725.00
Masonry Wall		
Reinforced/Grouted	500 block @ $2200/thousand	1,100.00
Brick Rowlock	925 brick @ $300/thousand	280.00
Extend Downspouts		160.00
Concrete for Sump Pit	.4 C.Y. @ $175/C.Y.	78.00
Seeding	183 S.Y. @ $150/S.Y.	274.00
Backfill (compacted)	61 C.Y. @ $7/C.Y.	427.00
Cut Existing Sidewall		350.00
Concrete End Wall		200.00
	Total Cost for Floodwall	$7,999.00
Sump Pump		
Pump		$1,840.00
Piping/Installation		250.00
Gravity Drain Pipe and Check Valve		135.00
Wiring/Conduit/Breaker for Pump		278.00
	Total Cost for Pump and Pipe	$2,503.00
Closures		
3" Steel Plate	42 S.F. @ $3.50/S.F.	$ 147.00
$3\frac{1}{2} \times 3\frac{1}{2} \times \frac{3}{8}$ Steel Angle	$4.25 L.F./32 L.F.	136.00
Labor		450.00
Gasket		10.00
Hinges		36.00
Locking Dog	@ $27 ea. × 3	81.00
Anchor Bolts		25.00
Painting		18.00
Stiffeners @ 8'-0" Closure		54.00
	Total Cost For Closure	$ 957.00
	TOTAL	$13,690.00

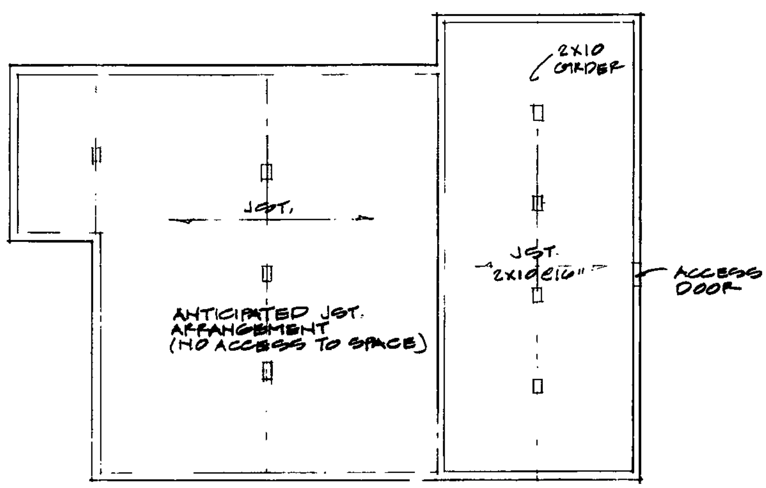
DECISION MATRIX A

RETROFITTING FACTORS		RETROFITTING METHODS: ELEVATION ON FOUNDATION WALL (CHAPTER 3.5)	ELEVATION ON PIERS (CHAPTER 3.7)	ELEVATION ON POSTS OR COLUMNS (CHAPTER 3.8)	ELEVATION ON PILES (CHAPTER 3.9)	RELOCATION (CHAPTER 4)	LEVEES (CHAPTER 4)	FLOODWALLS (CHAPTER 6)	FLOODWALLS WITH CLOSURES (CHAPTER 7)	SEALANTS AND	CLOSURES (CHAPTER 8)
FLOODING CHARACTERISTICS	**1 Flood Depth** Shallow (less than 3 feet) Moderate (3 to 6 feet) Deep (greater than 6 feet)	YES YES YES	YES YES YES	YES YES YES	YES YES YES	YES YES YES	YES YES NO	YES YES NO	YES YES NO	YES NO NO	YES NO NO
	2. Flood Velocity Slow (less than 3 fps) Moderate (3 to 5 fps) Fast (greater than 5 fps)	YES YES NO	YES YES NO	YES YES YES	YES YES YES	YES YES YES	YES YES NO	YES YES NO	YES YES NO	YES NO NO	YES NO NO
	3. Flash Flood Potential Yes No	NO YES	YES YES	YES YES	YES YES	YES YES	YES YES	YES YES	NO YES	NO YES	NO YES
	4. Long Duration Flooding Yes No	YES YES	YES YES	YES YES	YES YES	YES YES	NO YES	NO YES	NO YES	NO YES	NO YES
	5. Debris/Ice Floe Potential Yes No	NO YES	YES YES	YES YES	YES YES	YES YES	YES YES	YES YES	NO YES	NO YES	NO YES
SITE CHARACTERISTICS	**6. Site Location** Floodway or Coastal V-Zone Riverine Floodplain	NO YES	YES YES	YES YES	YES YES	YES YES	NO YES	NO YES	NO YES	NO YES	NO YES
	7 Soil Type Permeable Impermeable	NO YES	YES YES	YES YES	YES YES	YES YES	NO YES	NO YES	NO YES	NO YES	NO YES
BUILDING CHARACTERISTICS	**8. Building Foundation** Slab on Grade Crawl Space or Basement	YES YES	YES YES	YES YES	NO YES	NO YES	YES YES	YES YES	YES YES	YES YES	YES YES
	9. Building Construction Type Concrete or Masonry Wood	YES YES	YES YES	YES YES	NO YES	YES YES	YES YES	YES YES	YES YES	YES NO	YES NO
	10. Building Condition Excellent to Good Fair to Poor	YES NO	YES NO	YES NO	YES NO	YES NO	YES YES	YES YES	YES YES	YES NO	YES NO
TOTAL TIMES FEASIBLE		10	10	10	10	10	10	10	10	9	9

KEY USING THE RETROFITTING FACTORS, THE METHODS THAT COLLECT THE MOST FEASIBLE VOTES SHOULD BE EXAMINED IN DETAIL FOR RETROFITTING YOUR RESIDENTIAL STRUCTURE.



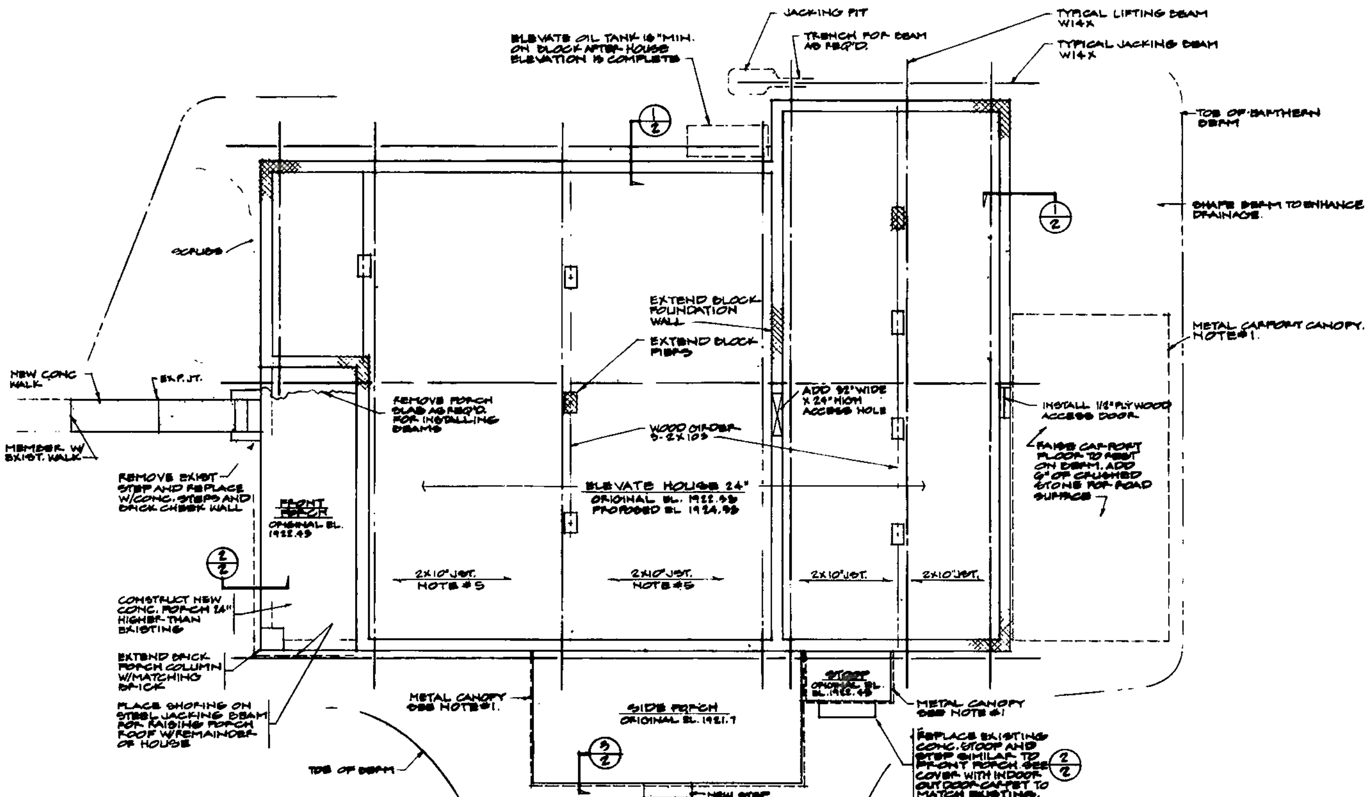
FLOOR PLAN
1/8" — — 1'-0"



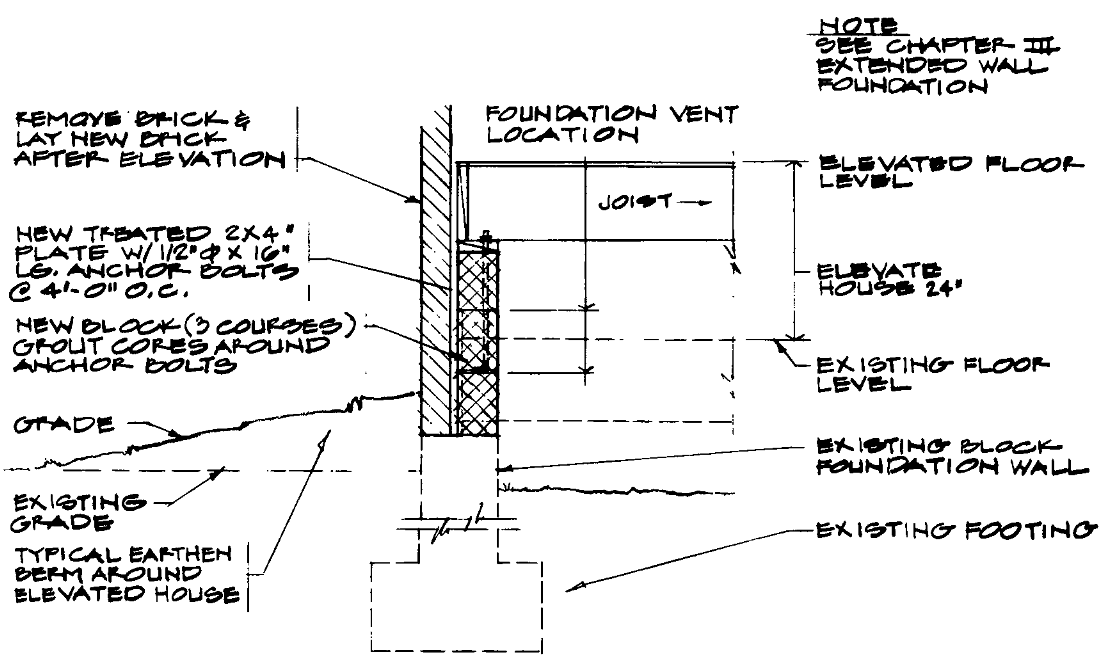
CRAWL SPACE PLAN
1/8" — — 1'-0"

SIZES

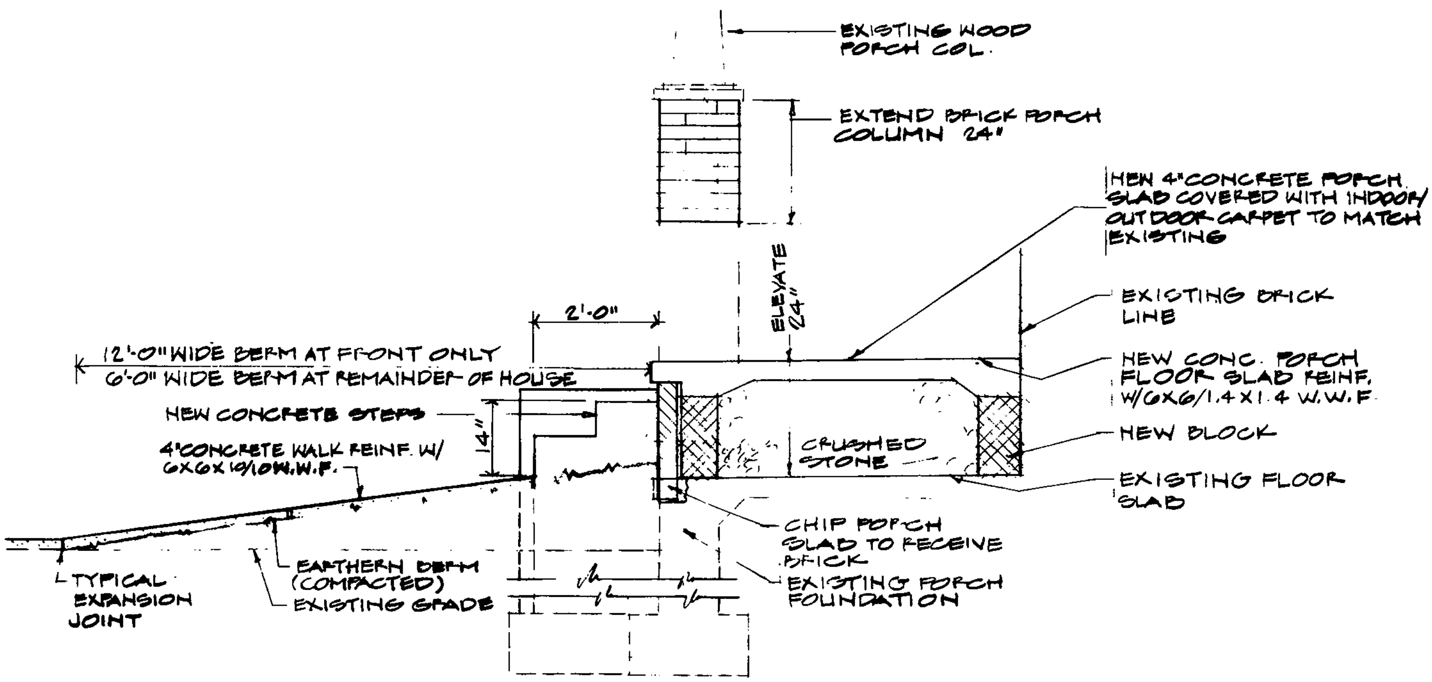
LIVING AREA	1362 S.F.
FRONT PORCH	148 S.F
SIDE PORCH	160 S.F.
CARPORT	203 S.F.



FOUNDATION PLAN
1/4" — 1'-0"
ALSO SHOWING PORCH AND CANOPY LOCATIONS.
SEE SHEET NO. 1 FOR COMPLETE FLOOR PLANS.



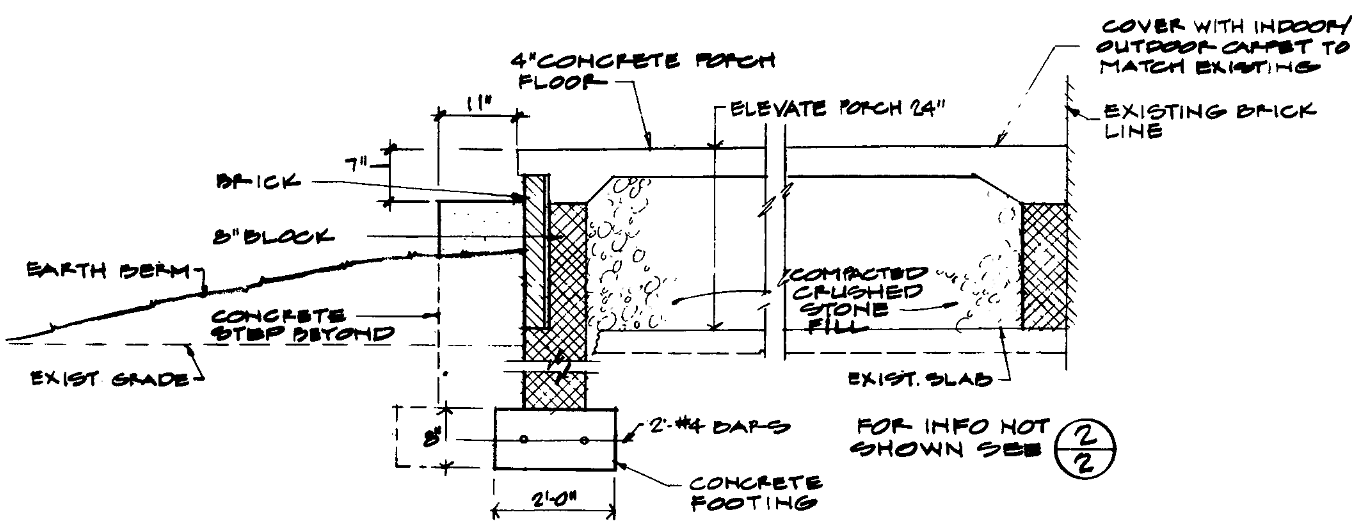
1/2 SECTION THRU FOUNDATION WALL
3/4" — 1'-0"
SHOWING EXTENDED FOUNDATION WALL



2/2 SECTION THRU FRONT PORCH

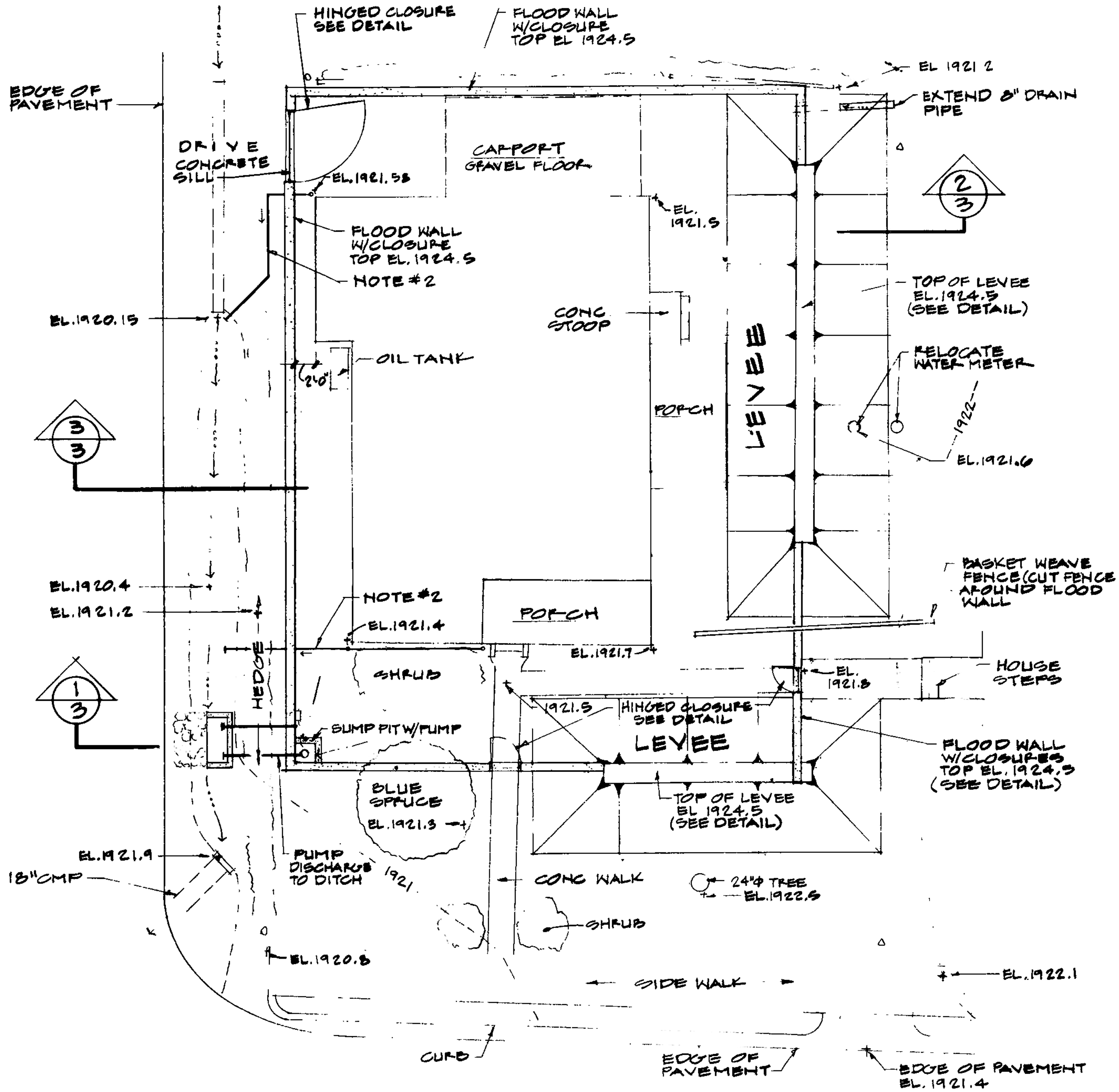
1/2" ——— 1'-0"

SLOPE NEW PORCH 1/8" PER FOOT



3/2 SECTION THRU SIDE PORCH

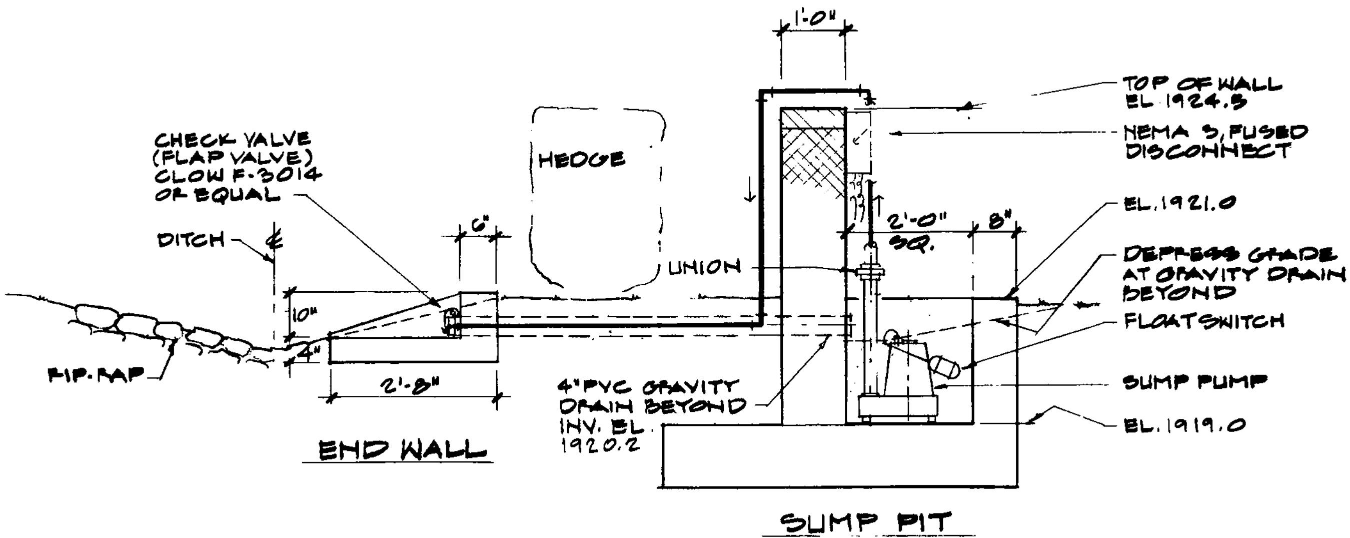
1/2" ——— 1'-0"



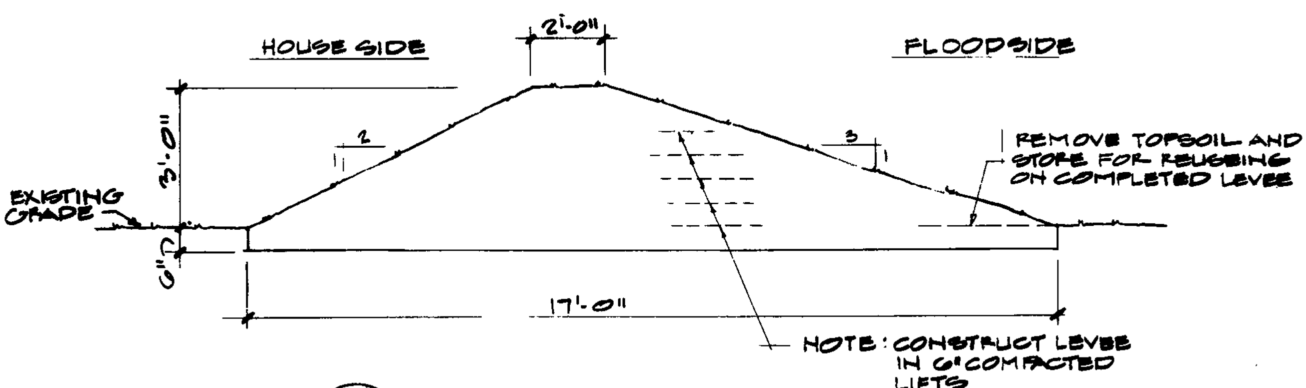
SITE PLAN

1" = 10'

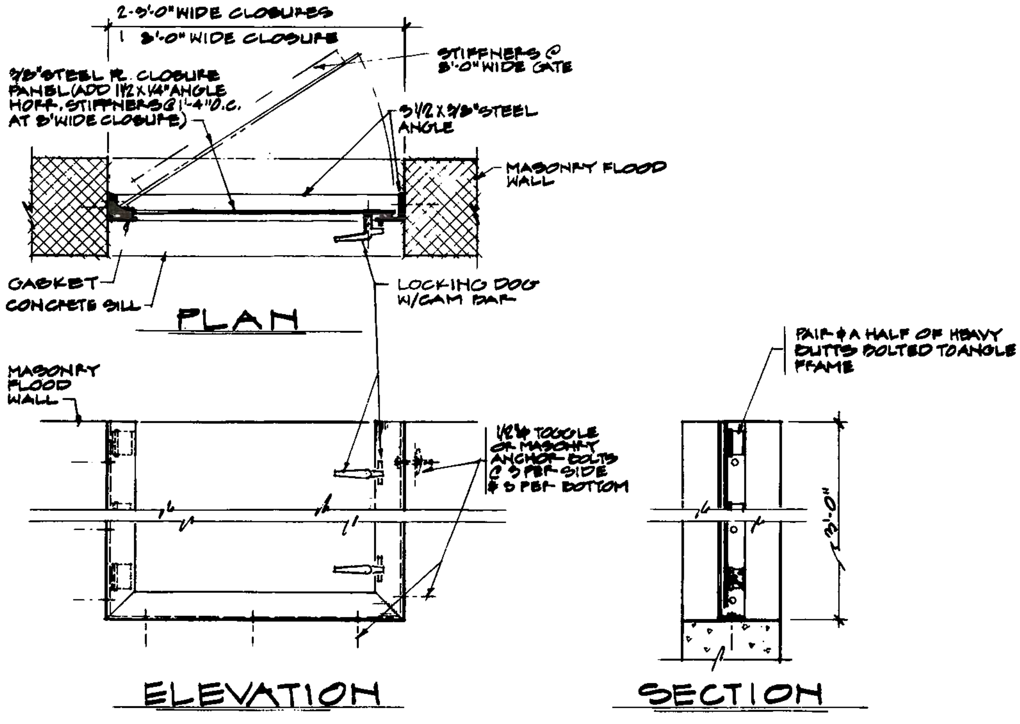
1977 FLOOD OF RECORD EL. ACCORDING TO OWNER (EL. 1922.4 APPROX.)



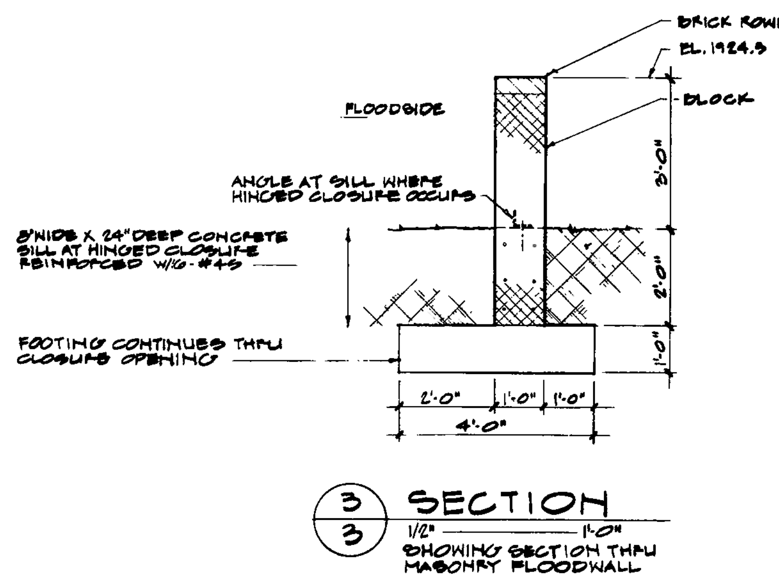
1/3 SECTION
1/2" ——— 1'-0"
SHOWING BEHIND THE LEVEE/FLOODWALL DEWATERING



2/3 SECTION
3/8" ——— 1'-0"
SECTION THRU EARTHERN LEVEE



HINGED CLOSURE DETAILS
1" ——— 1'-0"



NOTES

1. ALL DISTURBED AREAS TO BE RESEEDED.
2. PIPE UP ALL EXISTING ROOF DOWN SPOUTS WITH 4" PVC SCHED 40 PIPE. EXTEND PIPE IN VERTICAL UP 4' AND ANCHOR TO HOUSE.
3. A PORTABLE EMERGENCY GENERATOR SHALL BE STORED ON SITE.
4. THE 100 YEAR FLOOD ELEVATION AS DETERMINED FROM FLOOD INSURANCE MAPS IS 1923.3 (B.F.E.).

CASE STUDY REPORT #2

Description of the Residence and Flood Characteristics

Case Study #2 involves an older, 1½ story wood frame home that is common to the rural midwest. The surrounding area is wooded and hilly The rear of the property borders a moderately sized stream.

This location has experienced several minor floods. The worst flood reached a level approximately six inches below the first-floor elevation. The flood damaged the below-floor furnace and caused minor water damage to the building's foundation.

According to the Flood Insurance Rate Map for this area, the site's base flood elevation is one foot above the first-floor level. Flood velocity is considered to be in the moderate range, estimated to be roughly five feet per second. The rate of rise can be rapid, but not significant enough for flash flooding to be a problem. Erosion from flooding has not been significant in any of the previous flood events. Flood duration has never exceeded a period of several hours. While there has been some debris asociated with flooding, it has been of negligible size and amount.

This site is located within the regulatory floodway as designated on the community's Flood Boundary and Floodway Map. Regionally available soil data indicates that soils of the area near the site have average load bearing capacities, but nevertheless are permeable enough to call for special foundation considerations for structures.

The residence's building construction type consists of aluminum siding on standard wood frame walls. The foundation is 8″ concrete block on spread concrete footings. The floor framing system is made of rough cut 2″ × 6″ joists at about 24″ on center A supporting center girder consisting of three 2″ × 8″ members rests on concrete block piers at about 8′0″ on center The crawl space height is two feet. Floors are hardwood, vinyl tile, and carpet on plywood subflooring and underlayment. Interior walls are drywall on wood stud. The roof is made up of 2″ × 6″ rafters and consists of wood sheathing and asphalt shingles.

Selection of Retrofitting Options

Utilizing the decision matrix located in Section 11 1 and the previous structural and flood history descriptions, the various characteristics and the associated feasible retrofitting methods are identified on the completed Design Matrix B. From the above, it can be determined that, due primarily to the site being located in the floodway and the presence of permeable soil, the only feasible methods are elevation on piers, posts, or piles, or relocation. For this study, two alternatives were chosen. Alternative No. 1 is relocation, and Alternative No. 2 is elevation on piers.

Description of the Chosen Retrofitting Methods

Alternative No. 1. Relocation. The first step in a relocation process involves selection and preparation of a new site. Once this has been done, a new concrete block foundation will be constructed and utilities brought on site.

Next, the structure will be prepared for relocating. This includes moving some or all of the furnishings, arranging temporary housing for the occupants, and disconnecting all utilities, such as plumbing, gas piping, and electrical lines. In addition, the crawl space furnace will be removed and transported separately

The structure will be elevated roughly four feet, depending on the individual moving contractor's equipment. In order to do this, the flues and concrete porch and steps must be removed. The concrete porch at the front of the house will also be taken out to form a pathway to the street. Holes will be punched through the block foundation walls in order to insert steel lifting beams. After this, trenching will be required to allow room for the jacks used to lift the structure. Basically, the house will be elevated using the same bearing locations as the original foundation utilized for support. Additional steel members will then be inserted to support the concrete hearth and brick wainscot at the rear of the building. The contractor will have to also consider whether it would be more economically feasible to remove the hearth and brickwork and reconstruct these items at the new site. Once the house has been raised to the necessary elevation, a trailer will be moved into place under the structure.

The house will be lowered onto the trailer and safety chains will be used to secure the house in place. Site excavation will be necessary to form a smooth roadway Heavy timbers will be used as needed to support trailer tires in any soft areas. A dozer is normally employed to move the house and trailer onto the street.

Once in the street, the trailer will be connected to a truck and the house will be moved to its new location. Prior planning is critical with utility companies and the local government in order to obtain necessary permits for the move.

When the house arrives at the new site, it will be positioned over the new concrete block foundation. It can then be lowered onto temporary supporting timbers so that the trailer can be removed. The trailer's pathway will be filled in with concrete block and the house lowered onto the foundation. The steel beams will then be removed and the remainder of the masonry work completed. All utilities will be connected and the furnace will be reinstalled. An access door in the foundation wall must be added to allow for installation and maintenance of the furnace. The new fireplace hearth and brick wainscot would then be installed. The new flues would also be installed, and interior repair work performed. New stoops and stairs will be constructed. Details on this process are shown on the accompanying drawings.

Estimated Cost for Alternative #1 (Prices Include Labor and Installation)

Elevation: beams, jacking, etc.		$2,500.00
Demolition of flues, stoops, and disposal of debris		1,000.00
Utility disconnection		200.00
Housing moving		4,500.00
Concrete flooting w/reinforcement for walls, piers, and flues	8 yds. @ $175/yd.	1,400.00
Block foundation wall and piers	703 .S.F @ $3/S.F	2,110.00
Concrete stoop and steps w/reinforcement	10 yds. @ $175/yd.	1,750.00
Access door		75.00
Foundation vents	8 @ $20 ea.	160.00
Treated plate		237.00
Anchor bolts		32.00
Steel clip angles at foundation connection		18.00
New utilities and connection fee		1,400.00
New concrete sidewalk		500.00
New block flue w/brick cap		400.00
New hearth and brick wainscot		300.00
Reinstall furnace		175.00
New brick flue		550.00
Cleanup, grading, and seeding		250.00
	TOTAL	$17,557.00

Alternative No. 2: Elevation on Piers. The elevation procedure to be employed is very similar to that described in Alternative No. 1 After the house has been elevated to a level slightly higher than the final pier height, the existing foundation wall and stoops are removed. The new piers will then be constructed and a concrete block room will be built around the existing furnace, as shown on the accompanying drawings. This furnace room will be fitted with a gasket-fitted access door, an operable foundation vent for combustion air to enter the furnace, and a sump pit with a sump pump.

The house will then be lowered onto the new foundation system, and anchor bolts and clip angles will be installed. Steel lifting beams and jacks will then be removed. New stoops and steps along with new flues are constructed. A new fireplace hearth and brickwork will also be installed, all service utility lines reconnected, and the furnace reconnected in the new furnace room. All newly exposed heating ducts must also be insulated.

The final step will be the installation of a new wood lattice wall between the piers to shield the lower area. Any necessary regrading and landscaping will then be performed to complete the process.

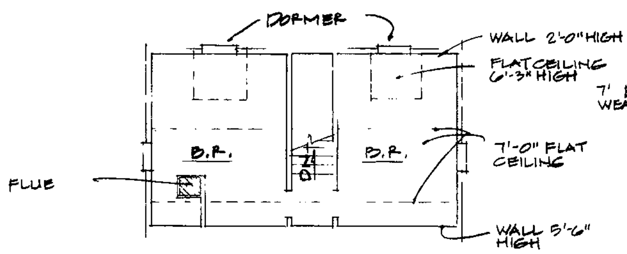
Estimated Cost for Alternative No. 2

Concrete piers	7.7 yds. @ $175/yd.	$ 1,348.00
New brick flue		550.00
New block flue w/brick cap		400.00
Elevation, beams, jacking, etc.		2,500.00
Demolition of flues, stoops, and disposal of debris		1,000.00
Utility disconnection		200.00
Concrete porch and steps w/reinforcement	10 yds. @ $175/yd.	1,750.00
Access door (double thickness w/gasket)		150.00
Anchor bolts		35.00
Steel clip angles		25.00
Reconnect utilities		400.00
New hearth and brick wainscot		350.00
Reinstall furnace		175.00
12" concrete block furnace room	195 S.F @ $3.50/S.F	682.00
Concrete floor @ furnace room	1.8 yds. @ $175/yd.	315.00
Sump pump including wiring/plumbing		875.00
Treated plate, anchor bolts, and additional blocking		175.00
Painted wood lattice	222 S.F @ $4/S.F	888.00
Insulate ductwork		150.00
Extend gutters, cleanup, and seeding		175.00
	TOTAL	$12,143.00

DECISION MATRIX B

RETROFITTING FACTORS		ELEVATION ON FOUNDATION WALL (CHAPTER 3.5)	ELEVATION ON PIERS (CHAPTER 3.7)	ELEVATION ON POSTS OR COLUMNS (CHAPTER 3.8)	ELEVATION ON PILES (CHAPTER 3.9)	RELOCATION (CHAPTER 4)	LEVEES (CHAPTER 4)	FLOODWALLS (CHAPTER 6)	FLOODWALLS WITH CLOSURES (CHAPTER 7)	SEALANTS AND	CLOSURES (CHAPTER 8)
FLOODING CHARACTERISTICS	**1 Flood Depth** Shallow (less than 3 feet) Moderate (3 to 6 feet) Deep (greater than 6 feet)	YES YES YES	YES YES YES	YES YES YES	YES YES YES	YES YES YES	YES YES NO	YES YES NO	YES YES NO	YES NO NO	YES NO NO
	2. Flood Velocity Slow (less than 3 fps) Moderate (3 to 5 fps) Fast (greater than 5 fps)	YES YES NO	YES YES NO	YES YES YES	YES YES YES	YES YES YES	YES YES NO	YES YES NO	YES YES NO	YES NO NO	YES NO NO
	3. Flash Flood Potential Yes No	NO YES	YES YES	YES YES	YES YES	YES YES	YES YES	YES YES	NO YES	NO YES	NO YES
	4. Long Duration Flooding Yes No	YES YES	YES YES	YES YES	YES YES	YES YES	NO YES	NO YES	NO YES	NO YES	NO YES
	5. Debris/Ice Floe Potential Yes No	NO YES	YES YES	YES YES	YES YES	YES YES	YES YES	YES YES	NO YES	NO YES	NO YES
SITE CHARACTERISTICS	**6. Site Location** Floodway or Coastal V-Zone Riverine Floodplain	NO YES	YES YES	YES YES	YES YES	YES YES	NO YES	NO YES	NO YES	NO YES	NO YES
	7 Soil Type Permeable Impermeable	NO YES	YES YES	YES YES	YES YES	YES YES	NO YES	NO YES	NO YES	NO YES	NO YES
BUILDING CHARACTERISTICS	**8. Building Foundation** Slab on Grade Crawl Space or Basement	YES YES	YES YES	YES YES	NO YES	NO YES	YES YES	YES YES	YES YES	YES YES	YES YES
	9. Building Construction Type Concrete or Masonry Wood	YES YES	YES YES	YES YES	NO YES	YES YES	YES YES	YES YES	YES YES	YES NO	YES NO
	10. Building Condition Excellent to Good Fair to Poor	YES NO	YES NO	YES NO	YES NO	YES NO	YES YES	YES YES	YES YES	YES NO	YES NO
TOTAL TIMES FEASIBLE		8	10	10	10	10	8	8	8	6	6

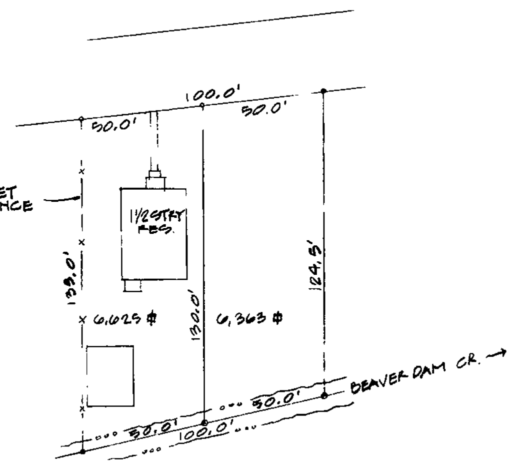
KEY USING THE RETROFITTING FACTORS, THE METHODS THAT COLLECT THE MOST FEASIBLE VOTES SHOULD BE EXAMINED IN DETAIL FOR RETROFITTING YOUR RESIDENTIAL STRUCTURE.



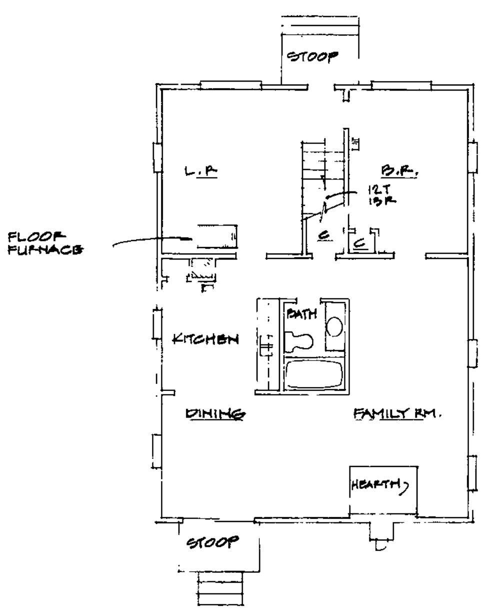
SECOND FLOOR PLAN
1/8" — 1'-0"

SIZES

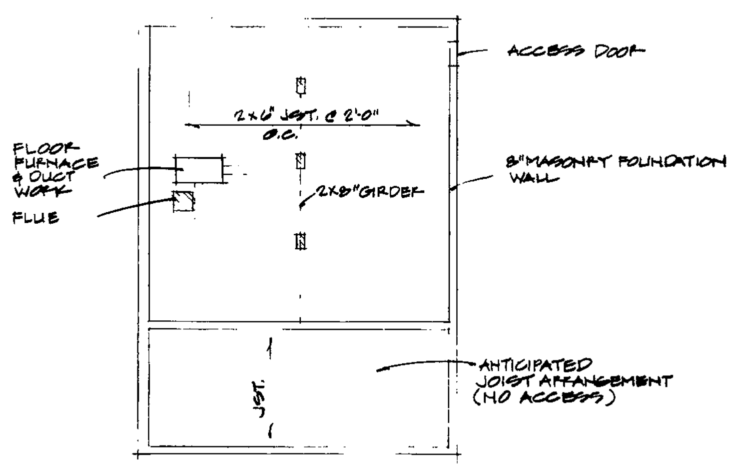
FIRST FLOOR LIVING AREA	958 S.F.
SECOND FLOOR LIVING AREA	335 S.F.
TOTAL LIVING AREA	1,293 S.F.



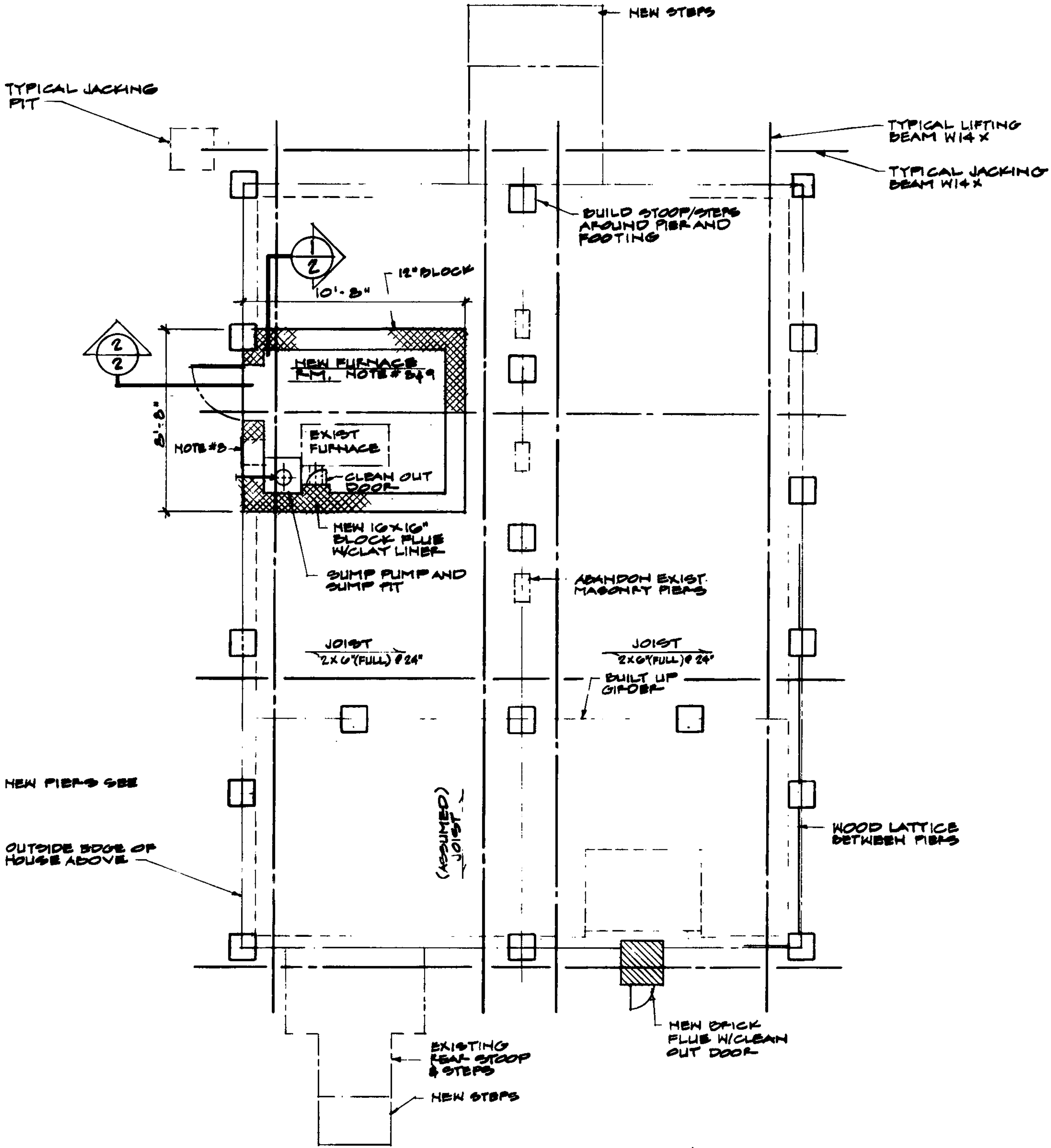
SITE PLAN
1" — 40'
LOT AREA = 12,988 S.F. (=.298 AC)



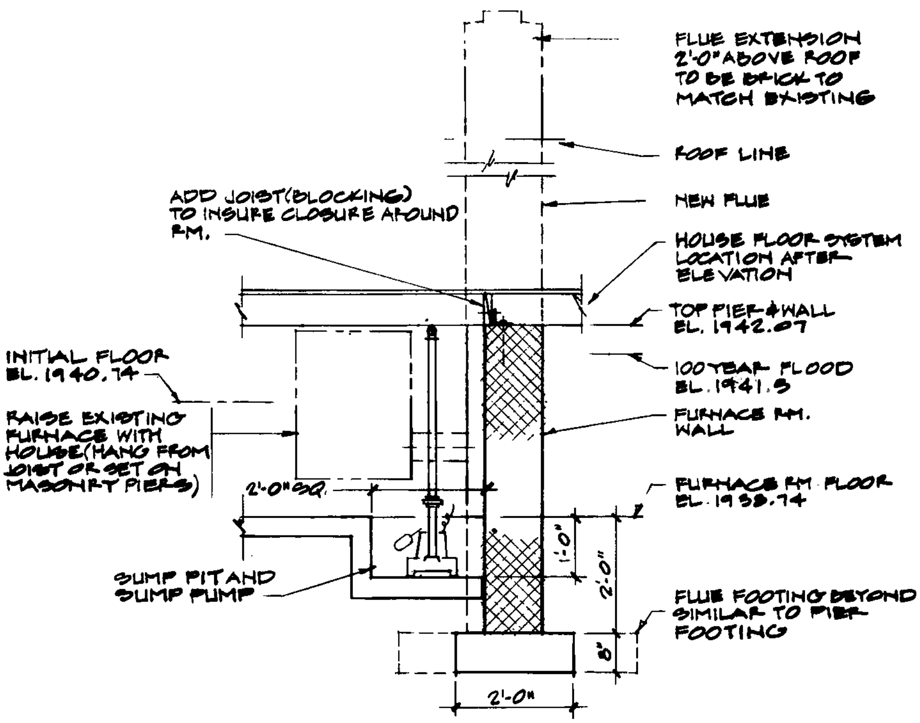
FIRST FLOOR PLAN
1/8" — 1'-0"



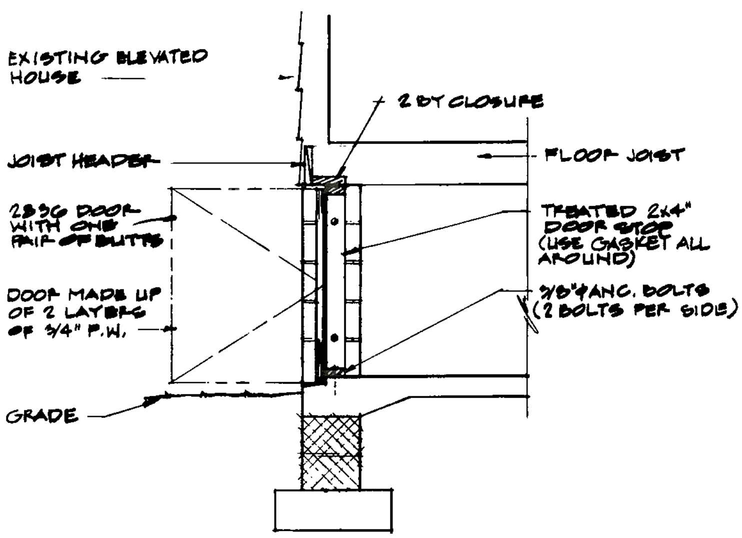
CRAWL SPACE PLAN
1/8" — 1'-0"



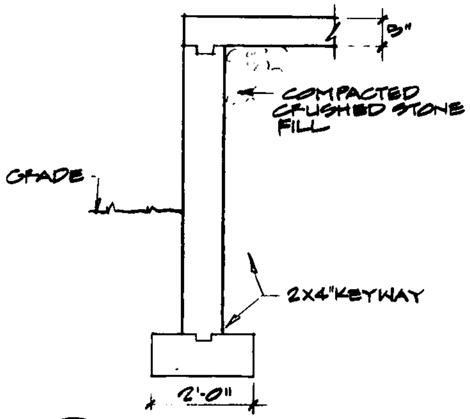
FOUNDATION PLAN
1/4" — 1'-0"



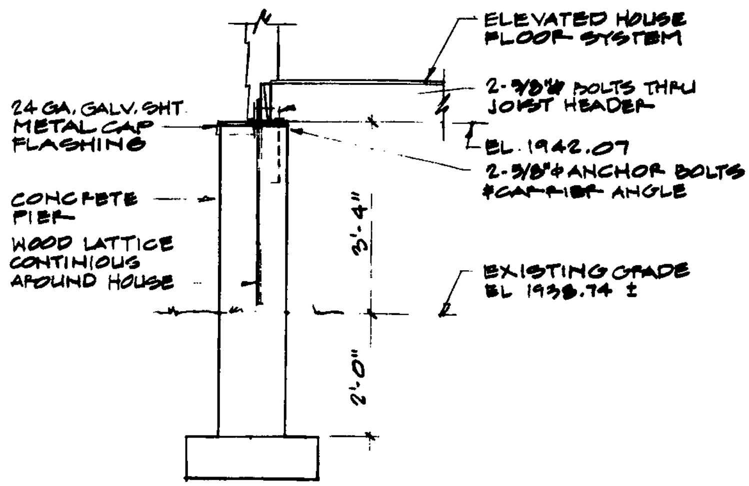
1 / 2 SECTION
1/2" —— 1'-0"
SECTION THRU FURNACE RM.



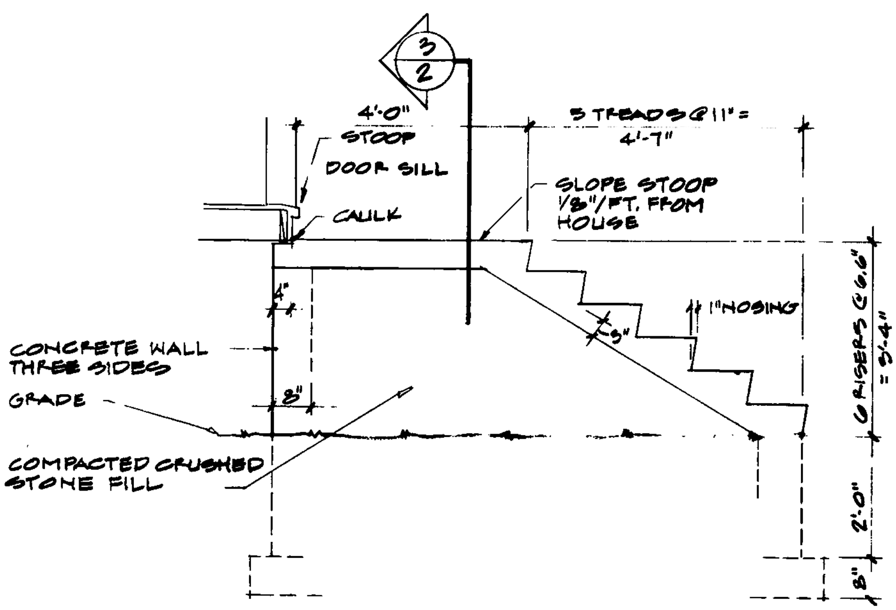
2 / 2 SECTION
1/2" —— 1'-0"
SHOWING SECTION THRU NEW FURNACE RM. DOOR



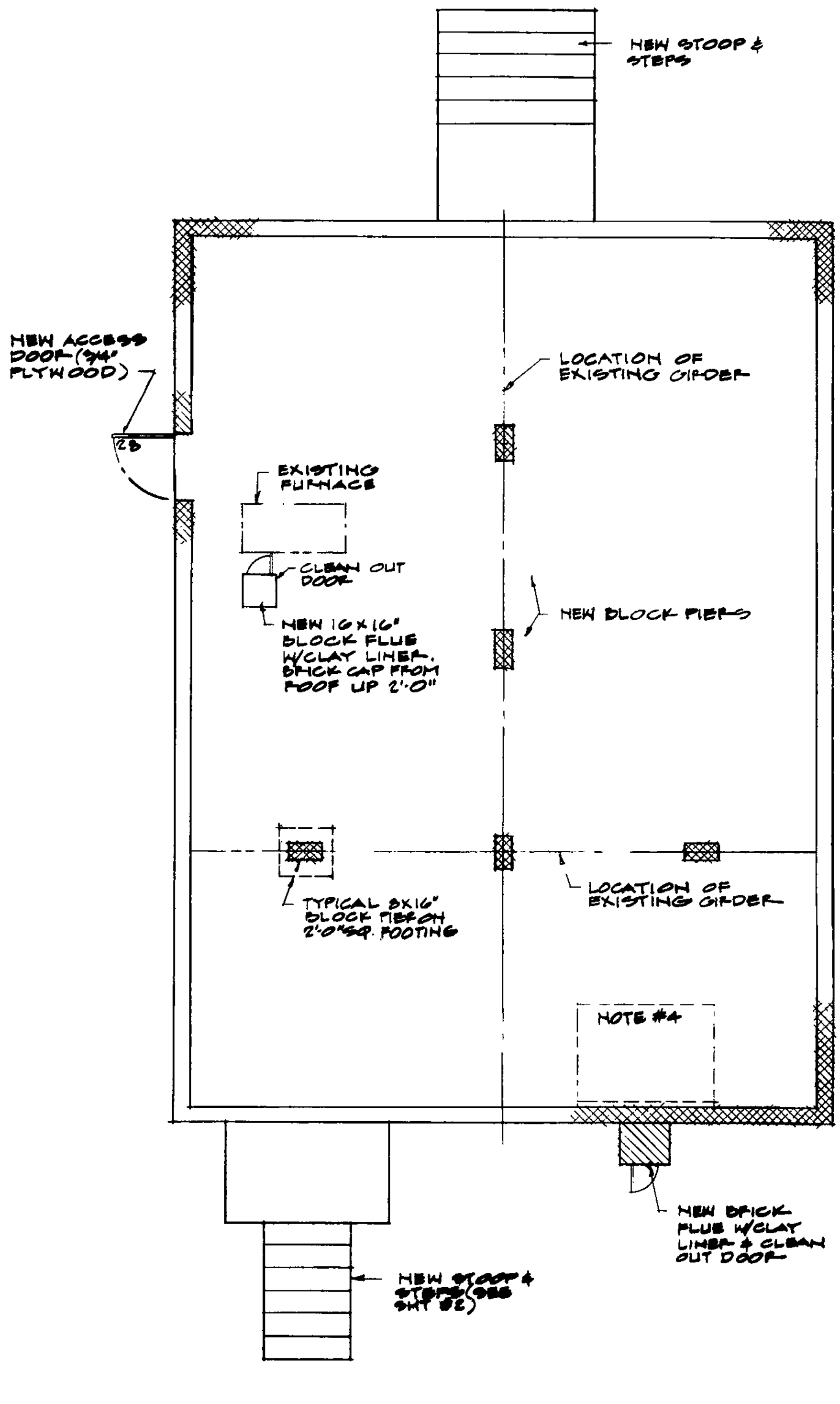
3/2 SECTION
1/2" — 1'-0"
SECTION THRU STOOP WALLS



TYPICAL PIER DETAIL
1/2" — 1'-0"



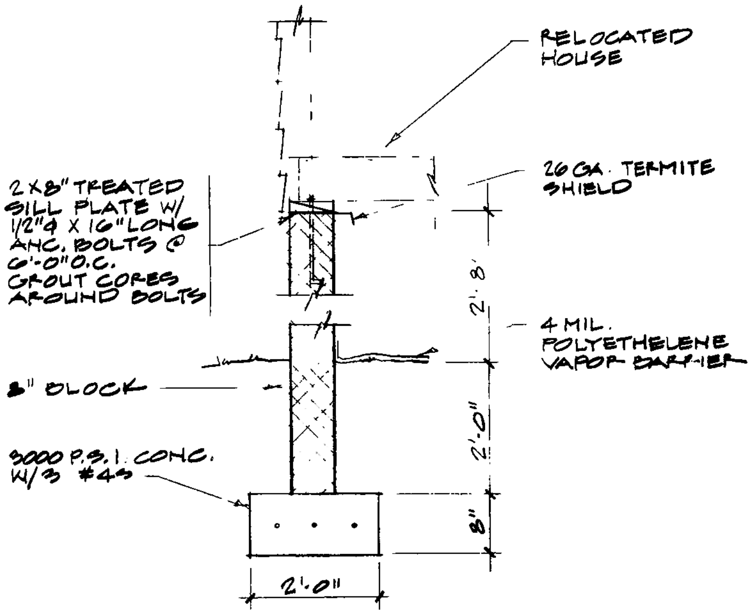
ELEVATION OF FRONT STOOP
1/2" — 1'-0"
REAR STOOP SIMILAR EXCEPT ON RISER TALLER



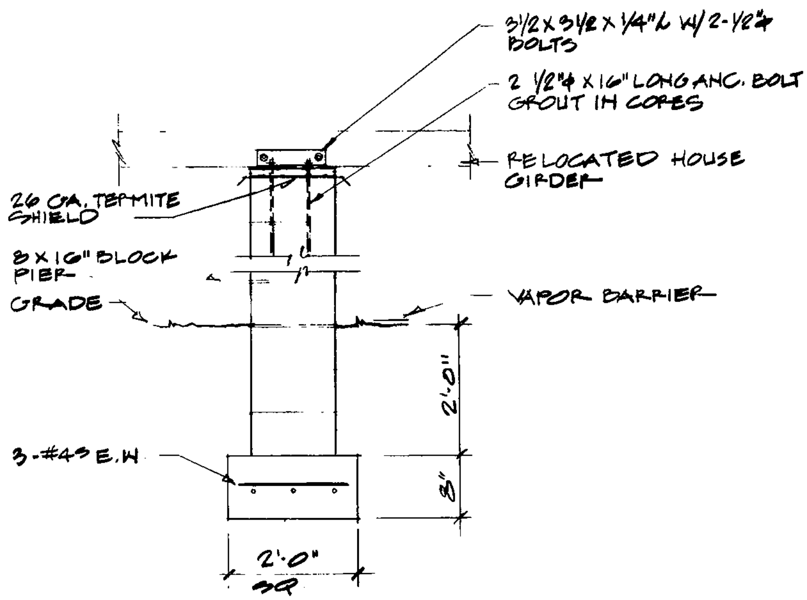
FOUNDATION PLAN

1/4" ——— 1'-0"

SHOWING PROPOSED FOUNDATION PLAN FOR RELOCATED HOUSE



TYPICAL FOUNDATION WALL
1/2" — 1'-0"



TYPICAL PIER DETAIL
1/2" — 1'-0"
FLUE FOOTING SIMILAR EXCEPT 3'-0" SQUARE

CASE STUDY REPORT #3

Description of the Residence and Flood Characteristics

Case Study No. 3 is a single story, brick veneer on wood frame structure that was built in three different sections. The first section has a full basement, which houses an oil-fired furnace and utilities. The second and largest section is built over a crawl space, while the third section is a slab-on- grade recreation room. The house is located in a suburban section of a moderately sized Western U.S. city. The surrounding area is somewhat mountainous.

This house has been flooded three times in the past ten years. The worst occurred in 1977, when flood levels reached 1,069 feet mean sea level (MSL), roughly seven feet above the grade and the recreation room floor, and five feet above the original first floor According to the Flood Insurance Rate Map, the base flood elevation at this site is 1,071 feet MSL, or two feet above the 1977 flood.

Observed flood velocity has been significant and should be rated as fast. Due to the mountainous terrain, the rate of rise can also be significant, and the potential for flash flooding exists at the site. Flood duration rarely exceeds one day Erosion has been minor in past flood events and is not considered a problem. Past flood events, however, have included appreciable amounts of debris, and this fact must be considered in selecting a retrofitting method.

Examination of soils at the site indicates adequate drainage and load bearing capacity, according to regional soils information. However, some borrow fill has been added next to the existing retaining wall.

As previously described, this structure was built in three sections. For all three sections, construction type was brick veneer on wood frame walls. The majority of the house is built on brick veneered concrete block foundation walls. The floor system, which is above both crawl space and basement, consists of either 2″ × 8″ or 2″ × 10″ wood joists. Support is provided by various doubled 2″ × 10″ cross members bearing on exterior masonry walls and on similar 2″ × 10″ girders that bear on masonry block piers spaced eight feet apart. The only exception is the latest addition, which is of concrete slab-on-grade construction. Interior flooring consists of hardwood, tile and carpet. Interior walls are drywall and wood paneling on 2″ × 4″ studs. The roof consists of wood sheathing and asphalt shingles on wood joists.

Selection of Retrofitting Options

Using the decision matrix in Section 11.1 and the above structural and flood descriptions, the allowable retrofitting methods can be identified as shown on Decision Matrix C. From this analysis, the only methods feasible are elevation on columns and relocation. Due to economic considerations raised by the homeowner, elevation on columns was determined to be the most feasible option.

Description of the Chosen Retrofitting Method

Elevation on Columns. The residence in this case must be elevated roughly ten feet to ensure adequate clearance for removal of the existing foundation walls and construction of the new structural columns. In order to elevate the structure, holes must be punched through the existing foundation walls to allow for the placement of the lifting beams. All anchor bolts at the slab-on-grade portion and other areas must be cut.

Special considerations will be required when lifting the slab-on-grade portion of the building. Holes should be cut through the walls immediately above the sole plate and lifting beams then slid through these openings. The beams will extend completely through the structure and protrude from both sides of the house to receive jacking beams. Immediately above each beam and covering the length of each room, a 2″ × 10″ wood member is fastened to each wall stud with three 16d nails. These wood members transfer wall and roof loadings to the lifting beams. Some slight excavation may be required for jack clearance. In addition, concrete porches must be disconnected and removed and steel lifting beams used to support the porch roofs.

After the building has been elevated, the support columns will be constructed, carrier members and bracing rods installed, and a floor system built for the recreation room on the support columns. In addition, utility equipment in the basement will be removed and the basement demolished and filled in. The structure will then be lowered onto the new column system (see plans) and all utilities will be reconnected. New porches, stairs, and walls will be constructed, and wood lattice walls installed between the columns in front of steel bracing rods to close off the lower area.

The existing utility room must be remodeled as shown in the accompanying plans to house the washer, dryer, and electric water heater The basement stairway may be removed to provide the required space for these items plus the new electric panels. Existing electric panels will be abandoned due to their condition after being flooded, and wiring will be installed to hook up the new panels.

The condition of the existing oil-fired burner does not appear to warrant its relocation from the basement, nor is constructing a watertight room around the furnace economically feasible. Therefore, a new furnace will be installed in the utility area. Heating ductwork will have to be altered to reach the furnace's new location.

Although elevation on columns with breakaway lattice will solve flooding problems, it does cause heating, piping, and plumbing supply lines to be exposed to the elements. As a result, these will require insulation. Supply piping to plumbing fixtures will require electric heat tapes incorporated into the pipe insulation. Downtime of the heating system during freezing weather will require some planning.

Final cleanup of the site and seeding of any disturbed areas will complete the elevation process.

Cost Estimate for Elevation on Columns and Breakaway Walls		
Insulate existing heating pipe		$ 1,200.00
Alter heating piping to new furnace		375.00
New oil-fired furnace installed*		9,500.00
Alter existing utility room to double as furnace room including electrical and plumbing changes		1,600.00
Elevate existing A/C condenser		450.00
Relocate existing electrical from basements including new panels which were flooded		1,900.00
Relocate existing water heater including alternate piping		275.00
Disconnect and reconnect all utilities (insulate and heat tape cold water line)		350.00
Extend downspouts		150.00
Demolish existing foundation walls, piers, basement walls and sidewalks, including removal of all debris		5,500.00
Fill in existing basements using material hauled from borrow area		1,450.00
New flue w/brick cap		800.00
New stairs @ $45 L.F × 60 L.F		2,700 00
New porches and deck 3.25 S.F × $338/S.F		1,098.00
New porch post		550.00
New porch rail 60 L.F × $22/L.F		1,518.00
New concrete walks		300.00
Concrete foundation for steps		175.00
Elevate house, approx. $2,000 per 1,000/S.F		5,400.00
New floor framing system for playroom area $3.75/S.F × 575 S.F		2,156.00
New columns including excavation, backfill, footing bracing rods, and carrier angles. Columns spacing based on eight-foot spans		
38 exterior columns @ $355		13,490.00
21 interior columns @ $215		4,515.00
Wood lattice @ $2/S.F × 2,940 S.F		5,880.00
Steel beams at center spans		1,500.00
Steel beam @ garage opening head		700.00
New carpet @ playroom		650.00
	SUBTOTAL	$64,182.00

*Existing furnace not feasible to relocate

If brick is elevated with house, add approximately $4,000 to elevation price.

TOTAL (Brick elevated with House) $68,182.00

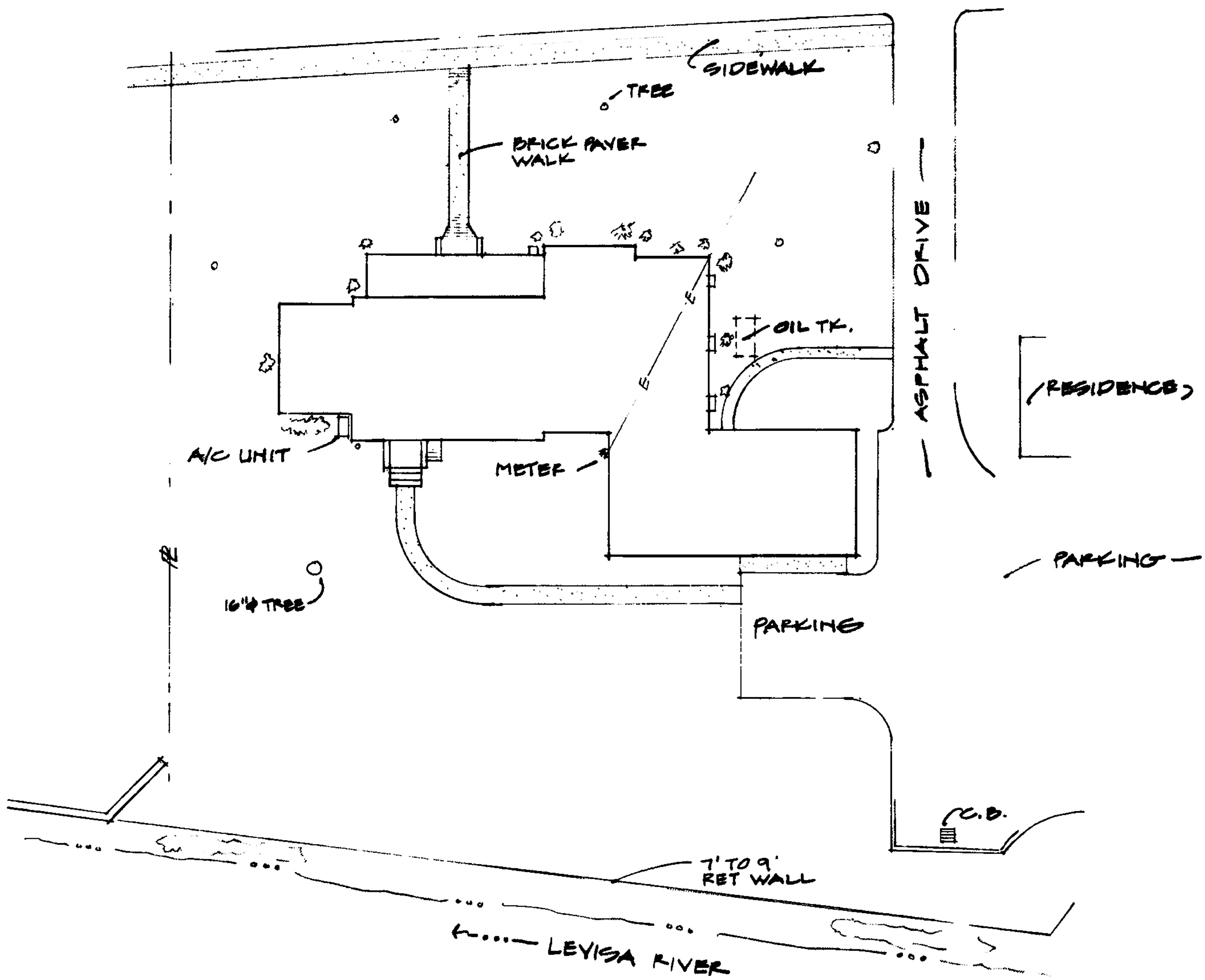
If existing brick is removed during elevation and replaced after elevation is accomplished, the following costs would be added:

Remove existing brick 2,648 S.F @ $1.71/S.F	$ 4,528.00
Lay new brick 2,648 S.F @ $4.55/S.F	12,048.40
TOTAL (Brick removed and relayed)	$80,758.40

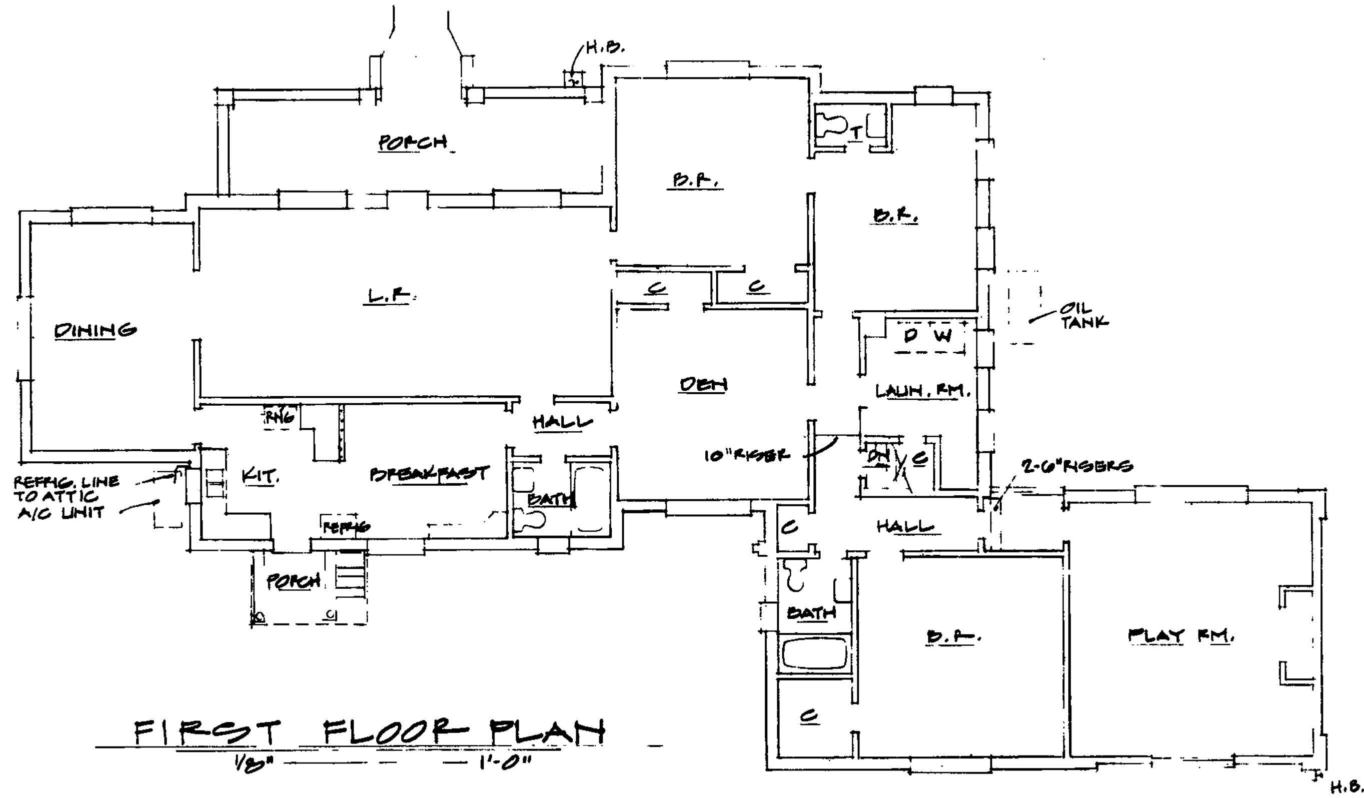
DECISION MATRIX C

	RETROFITTING FACTORS	RETROFITTING METHODS									
		ELEVATION ON FOUNDATION WALL (CHAPTER 3.5)	ELEVATION ON PIERS (CHAPTER 3.7)	ELEVATION ON POSTS OR COLUMNS (CHAPTER 3.8)	ELEVATION ON PILES (CHAPTER 3.9)	RELOCATION (CHAPTER 4)	LEVEES (CHAPTER 4)	FLOODWALLS (CHAPTER 6)	FLOODWALLS WITH CLOSURES (CHAPTER 7)	SEALANTS AND	CLOSURES (CHAPTER 8)
FLOODING CHARACTERISTICS	**1. Flood Depth** Shallow (less than 3 feet) Moderate (3 to 6 feet) Deep (greater than 6 feet)	YES YES YES	YES YES YES	YES YES YES	YES YES YES	YES YES YES	YES YES NO	YES YES NO	YES YES NO	YES NO NO	YES NO NO
	2. Flood Velocity Slow (less than 3 fps) Moderate (3 to 5 fps) Fast (greater than 5 fps)	YES YES NO	YES YES NO	YES YES YES	YES YES YES	YES YES YES	YES YES NO	YES YES NO	YES YES NO	YES NO NO	YES NO NO
	3. Flash Flood Potential Yes No	NO YES	YES YES	YES YES	YES YES	YES YES	YES YES	YES YES	NO YES	NO YES	NO YES
	4. Long Duration Flooding Yes No	YES YES	YES YES	YES YES	YES YES	YES YES	NO YES	NO YES	NO YES	NO YES	NO YES
	5. Debris/Ice Floe Potential Yes No	NO YES	YES YES	YES YES	YES YES	YES YES	YES YES	YES YES	NO YES	NO YES	NO YES
SITE CHARACTERISTICS	**6. Site Location** Floodway or Coastal V-Zone Riverine Floodplain	NO YES	YES YES	YES YES	YES YES	YES YES	NO YES	NO YES	NO YES	NO YES	NO YES
	7. Soil Type Permeable Impermeable	NO YES	YES YES	YES YES	YES YES	YES YES	NO YES	NO YES	NO YES	NO YES	NO YES
BUILDING CHARACTERISTICS	**8. Building Foundation** Slab on Grade Crawl Space or Basement	YES YES	YES YES	YES YES	NO YES	NO YES	YES YES	YES YES	YES YES	YES YES	YES YES
	9. Building Construction Type Concrete or Masonry Wood	YES YES	YES YES	YES YES	NO YES	YES YES	YES YES	YES YES	YES YES	YES NO	YES NO
	10. Building Condition Excellent to Good Fair to Poor	YES NO	YES NO	YES NO	YES NO	YES NO	YES YES	YES YES	YES YES	YES NO	YES NO
	TOTAL TIMES FEASIBLE	7	9	10	10	10	8	8	6	5	5

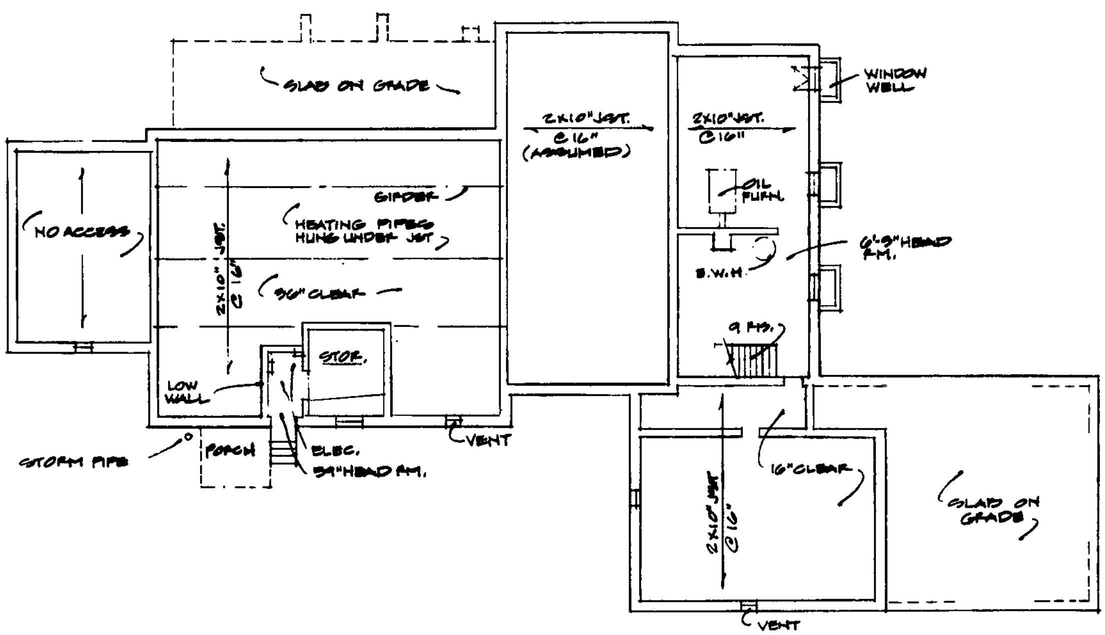
KEY: USING THE RETROFITTING FACTORS, THE METHODS THAT COLLECT THE MOST FEASIBLE VOTES SHOULD BE EXAMINED IN DETAIL FOR RETROFITTING YOUR RESIDENTIAL STRUCTURE.



SITE PLAN
1" — 20'
APPROX LOCATIONS
.4 ACRE (APPROX)



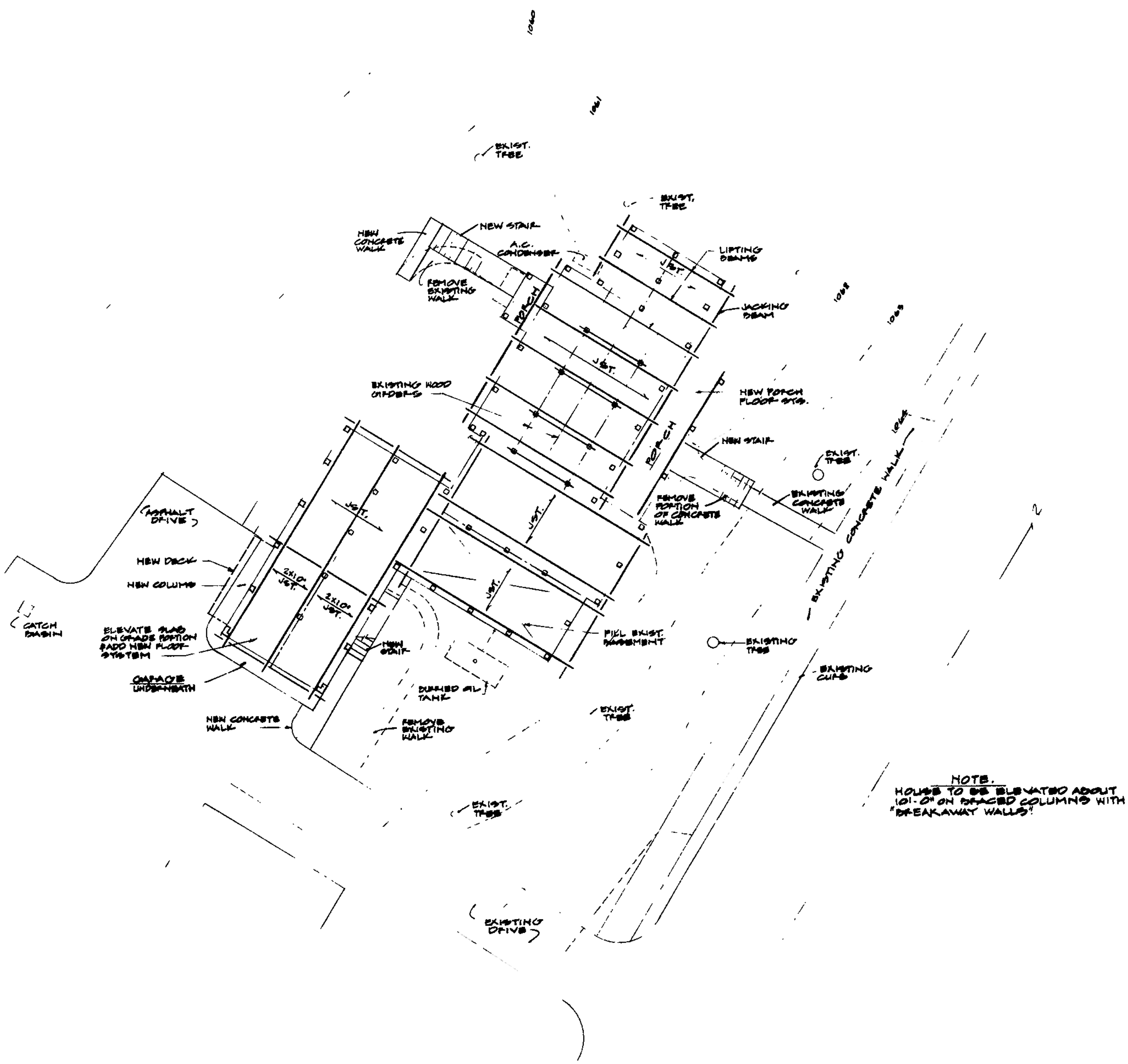
FIRST FLOOR PLAN
1/8" — 1'-0"



CRAWL SPACE PLAN
1/8" — 1'-0"

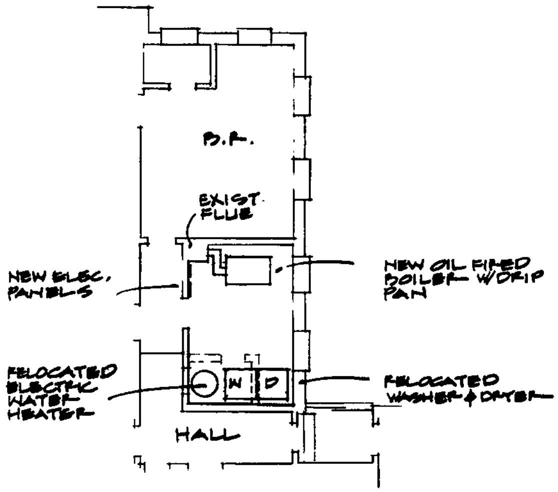
SIZES

FIRST FLOOR LIVING AREA	2664 S.F.
BASEMENT AREA	336 S.F.
FRONT PORCH AREA	212 S.F.
BACK PORCH AREA	30 S.F.

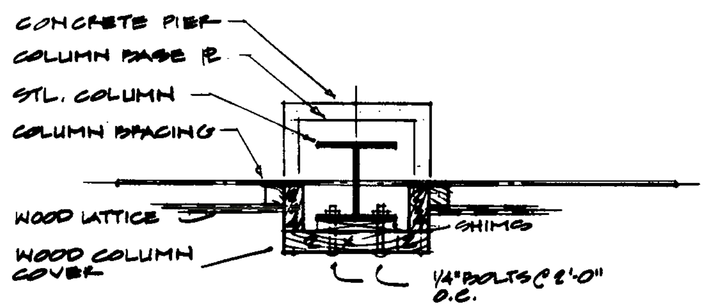


SITE PLAN

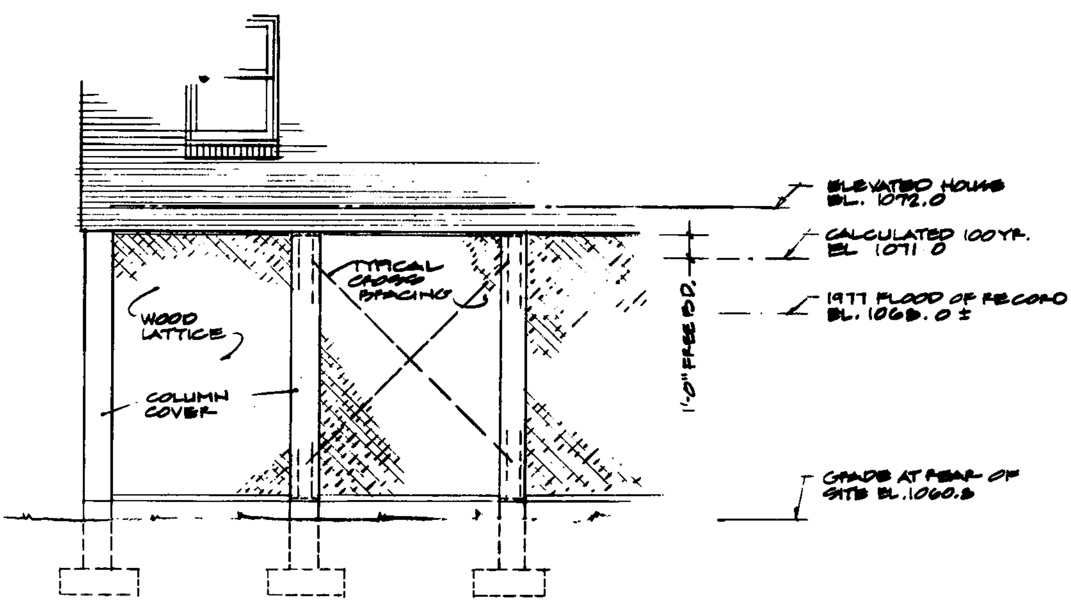
ALSO SHOWING NEW COLUMN LOCATIONS, LIFTING & JACKING BEAM ARRANGEMENT, NEW STAIRS, ETC.



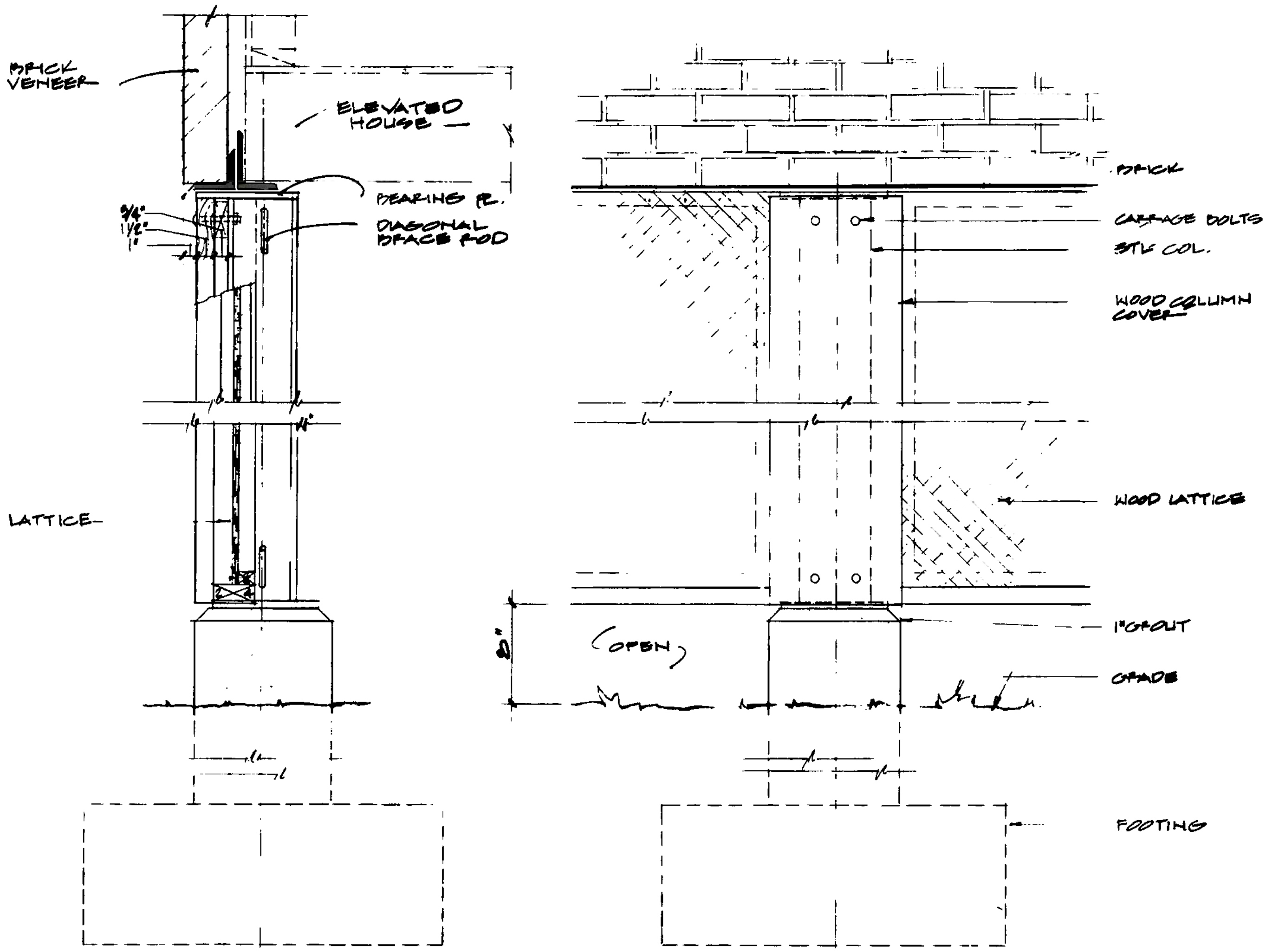
PARTIAL FLOOR PLAN
1/8" — 1'-0"
SHOWING REARRANGED LAUNDRY RM. & RELOCATED EQUIPMENT FROM BASEMENT



PLAN OF COLUMN
1 1/2" — 1'-0"



ELEVATION
1/4" — 1'-0"



SECTION

PARTIAL ELEVATION

TYPICAL EXTERIOR COLUMN

1 1/2" ——— 1'-0"

INTERIOR COLUMNS SIMILAR EXCEPT NO COVER

DECISION MATRIX

RETROFITTING FACTORS		ELEVATION ON FOUNDATION WALL (CHAPTER 3.5)	ELEVATION ON PIERS (CHAPTER 3.7)	ELEVATION ON POSTS OR COLUMNS (CHAPTER 3.8)	ELEVATION ON PILES (CHAPTER 3.9)	RELOCATION (CHAPTER 4)	LEVEES (CHAPTER 4)	FLOODWALLS (CHAPTER 6)	FLOODWALLS WITH CLOSURES (CHAPTER 7)	SEALANTS AND	CLOSURES (CHAPTER 8)
		RETROFITTING METHODS									
FLOODING CHARACTERISTICS	**1 Flood Depth**										
	Shallow (less than 3 feet)	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
	Moderate (3 to 6 feet)	YES	YES	YES	YES	YES	YES	YES	YES	NO	NO
	Deep (greater than 6 feet)	YES	YES	YES	YES	YES	NO	NO	NO	NO	NO
	2. Flood Velocity										
	Slow (less than 3 fps)	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
	Moderate (3 to 5 fps)	YES	YES	YES	YES	YES	YES	YES	YES	NO	NO
	Fast (greater than 5 fps)	NO	NO	YES	YES	YES	NO	NO	NO	NO	NO
	3. Flash Flood Potential										
	Yes	NO	YES	YES	YES	YES	YES	YES	NO	NO	NO
	No	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
	4. Long Duration Flooding										
	Yes	YES	YES	YES	YES	YES	NO	NO	NO	NO	NO
	No	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
	5. Debris/Ice Floe Potential										
	Yes	NO	YES	YES	YES	YES	YES	YES	NO	NO	NO
	No	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
SITE CHARACTERISTICS	**6. Site Location**										
	Floodway or Coastal V-Zone	NO	YES	YES	YES	YES	NO	NO	NO	NO	NO
	Riverine Floodplain	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
	7 Soil Type										
	Permeable	NO	YES	YES	YES	YES	NO	NO	NO	NO	NO
	Impermeable	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
BUILDING CHARACTERISTICS	**8. Building Foundation**										
	Slab on Grade	YES	YES	YES	NO	NO	YES	YES	YES	YES	YES
	Crawl Space or Basement	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
	9. Building Construction Type										
	Concrete or Masonry	YES	YES	YES	NO	YES	YES	YES	YES	YES	YES
	Wood	YES	YES	YES	YES	YES	YES	YES	YES	NO	NO
	10. Building Condition										
	Excellent to Good	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
	Fair to Poor	NO	NO	NO	NO	NO	YES	YES	YES	NO	NO
TOTAL TIMES FEASIBLE											

KEY USING THE RETROFITTING FACTORS, THE METHODS THAT COLLECT THE MOST FEASIBLE VOTES SHOULD BE EXAMINED IN DETAIL FOR RETROFITTING YOUR RESIDENTIAL STRUCTURE.

DECISION MATRIX

		RETROFITTING METHODS									
	RETROFITTING FACTORS	ELEVATION ON FOUNDATION WALL (CHAPTER 3.5)	ELEVATION ON PIERS (CHAPTER 3.7)	ELEVATION ON POSTS OR COLUMNS (CHAPTER 3.8)	ELEVATION ON PILES (CHAPTER 3.9)	RELOCATION (CHAPTER 4)	LEVEES (CHAPTER 4)	FLOODWALLS (CHAPTER 6)	FLOODWALLS WITH CLOSURES (CHAPTER 7)	SEALANTS AND	CLOSURES (CHAPTER 8)
FLOODING CHARACTERISTICS	**1 Flood Depth**										
	Shallow (less than 3 feet)	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
	Moderate (3 to 6 feet)	YES	YES	YES	YES	YES	YES	YES	YES	NO	NO
	Deep (greater than 6 feet)	YES	YES	YES	YES	YES	NO	NO	NO	NO	NO
	2. Flood Velocity										
	Slow (less than 3 fps)	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
	Moderate (3 to 5 fps)	YES	YES	YES	YES	YES	YES	YES	YES	NO	NO
	Fast (greater than 5 fps)	NO	NO	YES	YES	YES	NO	NO	NO	NO	NO
	3. Flash Flood Potential										
	Yes	NO	YES	YES	YES	YES	YES	YES	NO	NO	NO
	No	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
	4. Long Duration Flooding										
	Yes	YES	YES	YES	YES	YES	NO	NO	NO	NO	NO
	No	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
	5. Debris/Ice Floe Potential										
	Yes	NO	YES	YES	YES	YES	YES	YES	NO	NO	NO
	No	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
SITE CHARACTERISTICS	**6. Site Location**										
	Floodway or Coastal V-Zone	NO	YES	YES	YES	YES	NO	NO	NO	NO	NO
	Riverine Floodplain	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
	7 Soil Type										
	Permeable	NO	YES	YES	YES	YES	NO	NO	NO	NO	NO
	Impermeable	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
BUILDING CHARACTERISTICS	**8. Building Foundation**										
	Slab on Grade	YES	YES	YES	NO	NO	YES	YES	YES	YES	YES
	Crawl Space or Basement	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
	9. Building Construction Type										
	Concrete or Masonry	YES	YES	YES	NO	YES	YES	YES	YES	YES	YES
	Wood	YES	YES	YES	YES	YES	YES	YES	YES	NO	NO
	10. Building Condition										
	Excellent to Good	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
	Fair to Poor	NO	NO	NO	NO	NO	YES	YES	YES	NO	NO
TOTAL TIMES FEASIBLE		___	___	___	___	___	___	___	___	___	___

KEY· USING THE RETROFITTING FACTORS, THE METHODS THAT COLLECT THE MOST FEASIBLE VOTES SHOULD BE EXAMINED IN DETAIL FOR RETROFITTING YOUR RESIDENTIAL STRUCTURE.

Sources of Field Information/Photographic Credits

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- New England District
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- Portland District
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