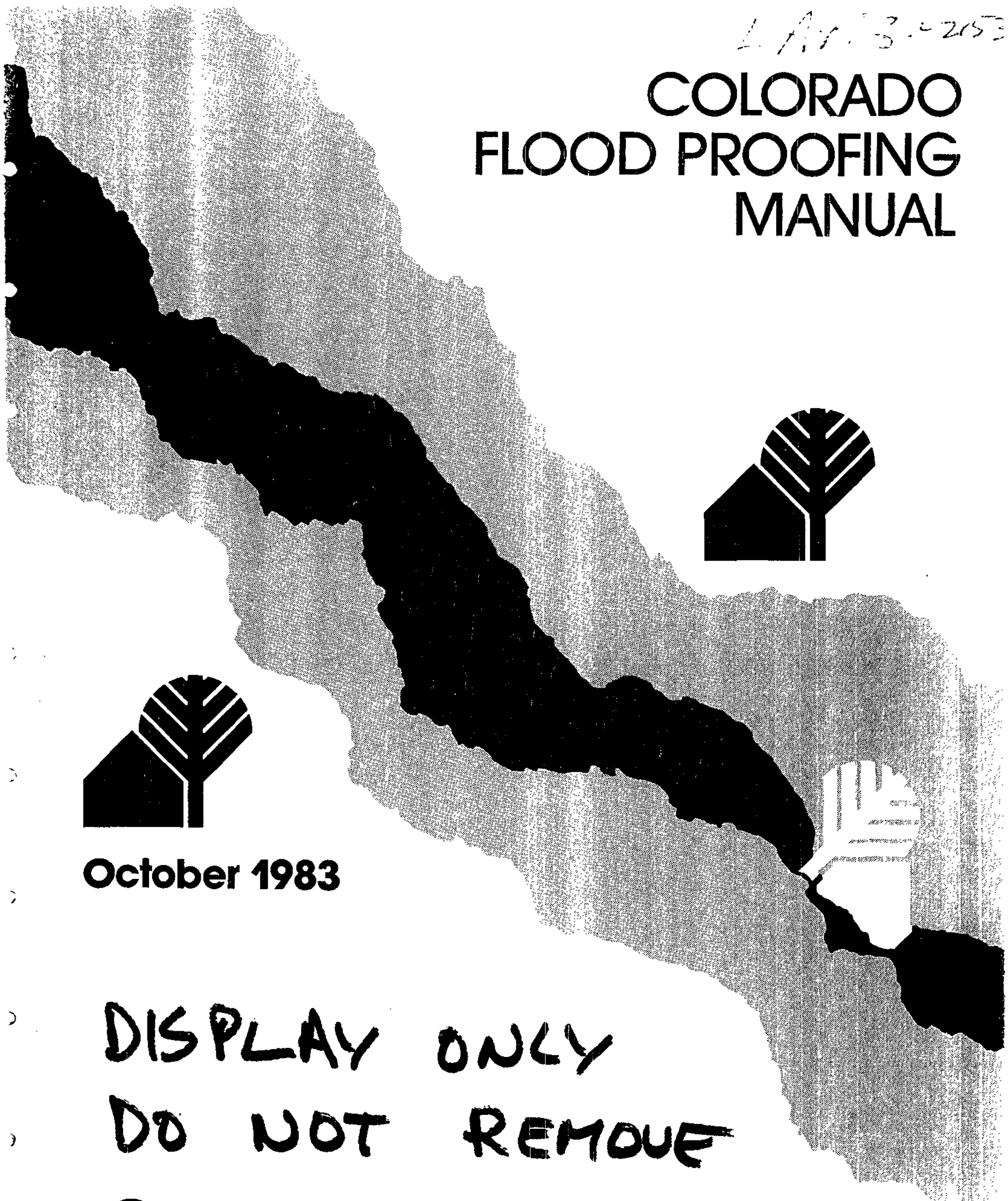
COLORADO FLOOD PROOFING MANUAL



October 1983

Department of Natural Resources
Colorado Water Conservation Board
J. William McDonald, Director

COLORADO FLOODPROOFING MANUAL

By
Colorado Water Conservation Board
and
Colorado Water Resource Research Institute
Colorado State University

Colorado Water Conservation Board
Colorado Department of Natural Resources

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PREFACE

General

This manual presents concepts and procedures for implementing flood plain management practices which will reduce the flood risk to life and property. Flood risks are reduced through modifications or adjustments to a building design, site location, or placement of contents. These techniques are referred to "floodproofing" measures which can range from elevating a structure to the intentional flooding of a basement during times of flood.

The purpose of the manual is to present construction techniques, designs, and building standards that are applicable for the protection of life, health, property, and the general public welfare by regulating and directing development activities in flood hazard areas. The provisions which are addressed in this manual are provided to achieve uniformity in the implementation of floodproofing procedures and practices. The manual has been formulated such that it will:

Provide a standard which local government adminstrators can adopt into a community's flood plain management program;

Provide a document which will be a design standard for the State of Colorado;

Provide a state-of-the-art analysis of design criteria for local flood plain administrators and professionals;

Provide a vehicle for assessing the economic costs and benefits of implementing floodproofing practices.

Today, flood-prone areas have been identified in 266 cities and towns and in all of the 63 counties. Most of the incorporated cities and towns and all counties in Colorado have some kind of river, stream, creek, or drainageway within their jurisdiction.

We estimate that five percent of the state's permanent population is vulnerable to flood risks. Over 6 billion dollars in property is now exposed to flood risks throughout the state. Approximately one-half billion of this amount has flood insurance coverage.

The key to reducing flood losses and the risk to life and property is "flood plain management". Flood plain management incorporates several measures to control development in flood plains. One small part of flood plain management is the use of floodproofing measures. Although development in flood plains is not encouraged, it is not always avoidable. Floodproofing measures provide some means of protection for structures already located within the flood plain. This manual attempts to provide the necessary information for using floodproofing as an alternative in flood plain management.

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SUMMARY

The primary objective of developing a floodproofing manual was to provide local flood plain administrators and professionals in governments and private business with procedures and design techniques to mitigate losses from flood. The manual illustrates examples of Colorado floodproofing measures, means for evaluating flood risks, procedures for designing a low risk flood structure, classifications of building materials, and the economics of implementing floodproofing measures. A chapter summary of the manual is as follows:

Chapter I - Introduction:

This chapter introduces the concept of floodproofing. It differentiates between flood control measures and defines the various classifications for floodproofing measures and floodproofed structures. Floodproofing measures are classified as permanent, contingent, or emergency. These classifications are based on the degree of action required to implement the measure and when the floodproofing measure is implemented in relation to the time of flooding.

Chapter II - Glossary:

This chapter explains all the flood-related terminology used in the manual and flood plain management.

Chapter III - Physiographic Considerations:

This chapter discusses the physiographic characteristics that should be evaluated when development in the flood plain is considered. The various characteristics include channel cross section and slope, vegetation, soil characteristics, erosion, and sedimentation and debris. The discussion relates to how these characteristics affect flooding characteristics, such as velocity and depth.

Chapter IV - Examples of Floodproofing:

This chapter presents pictoral examples of floodproofing practices which have been implemented by Colorado communities.

Chapter V - Natural and Inherent Methods:

This chapter addresses natural and inherent floodproofing measures that exist in flood plains. Floodproofing features include use of island development, natural building materials, existing streets, and embankments. These types of features create areas that are more feasible for floodproofing development by reducing velocities and depths or completely eliminating flooding.

Chapter VI - Water Loadings:

This chapter analyzes the various types of loadings (forces) that are present during flood. The specific water loadings and forces considered are hydrostatic, hydrodynamic, impact, erosion forces, and embankment stability. For each force a discussion of general consideration, application, and methodology is presented. The methodology gives the appropriate equations required to estimate the magnitude of the forces involved.

Chapter VII - Design Criteria:

This chapter presents criteria and general guidelines for general floodproofing measures, elevated structures, levees, and floodwalls. This chapter addresses dimensions of the fill for elevated structures on fill and general guidelines for structures elevated on posts, piers, or piles. General guidelines are provided for anchoring and waterproofing structures that will be submerged to some degree during flooding. A general discussion of types of levees and floodwalls is also given.

Chapter VIII - Closure of Openings:

This chapter explains the various types of closure of openings. Illustrations are shown with installation guidelines for different situations and design requirements.

Chapter IX - Internal Flooding:

This chapter addresses the measure of wet floodproofing or internal floodproofing.

Chapter X - Building Materials:

This chapter gives a classification of various building materials based on their ability to resist damage during flooding. All listed materials are rated to flood damage or loss by high risk, medium risk, and low risk.

Chapter XI - Basement Construction:

This chapter is a detailed presentation of structural requirements for basement walls and floor slabs. Illustrations and charts are shown which assist in computing allowable water depth based on typical wall and slab thicknesses and reinforcing. The intent of this chapter is to show the degree of structure strength needed to withstand the hydrostatic forces involved. Also, in this chapter, is a discussion of buoyancy forces and the major role they have in use of basements.

Chapter XII - Electrical:

This chapter provides instructions on the location of control panels, fixtures, and apparatuses.

Chapter XIII - Mechanical:

This chapter provides guidelines on the installation of heating, air conditioning, plumbing, and ventilating equipment systems.

Chapter XIV - Mobile Homes and Parks:

This chapter provides a detailed evaluation of mobile homes in flood plains. Discussions of various types of anchoring systems are given including helix, cross, and dead man anchors. A discussion of standarized anchor systems versus conventional cable and chain is presented. Methodology to estimate the required number of anchors based on mobile home size, water velocity, and depth of water above the floor level is given, along with an example calculation. A major consideration in selection and design of the anchoring system is in meeting the strength requirements of the Federal Emergency Management Agency. This chapter also discusses layout of mobile homes in relation to the flood plain.

Chapter XV - Economic Feasibility:

This chapter presents a procedure for economic evaluation of floodproofing. Example problems are provided comparing no floodproofing, floodproofing, and no floodproofing with insurance.

INTRODUCTION

1.1 Concept of Floodproofing

Floodproofing is a composite body of techniques and approaches for preventing flood damage to the structure and contents of buildings in flood hazard areas. Examples of floodproofing include the placement of levees, dikes, or walls around individual structures; watertight closures for windows, doors and other openings; wall reinforcement to resist lateral pressure and debris flow; elevation of building on pilings or fill; use of membranes; paint or other substances to reduce water seepage into buildings; installation of check valves at sewer and utility locations to prevent entrance of flood waters.

Floods are a major concern of Colorado's natural resources management activities. Despite the effort of federal, state, and local agencies to reduce flood damages through major flood control projects, the amount of flood damage that occurs each year is still increasing. Annually, between 10 and 20 floods larger than a 25-year magnitude and an average annual flood damage in the amount of $14,000,000 occur somewhere in Colorado. Over the past 90 years, over 350 lives have been lost and total property damage has exceeded 1.6 billion dollars. In Colorado, the amount of flood damages covered by flood insurance claims was $162,745 in 1981 and $1,134,189 in 1982.

Since the enactment of federal legislation in the late 60's and early 70's, local communities have been made aware of flood plain management needs and requirements. Flood plain management entails a wide range of measures to optimize the use of lands within designated flood plains to reach an ultimate goal of flood damage reduction. These measures of conventional flood control works include dams and reservoirs, levees and flood walls, and channel improvements and diversions. Nonconventional methods include zoning, building codes, subdivision regulations, and designated floodways and encroachment limits. However, flood plain management does not attempt to eliminate development in flood plain areas, but rather, it encourages wise flood plain development to lessen the adverse effects of floods.

Floodproofing measures are only a small part of a good flood plain management program. Floodproofing measures are instigated through development regulations and building codes. Floodproofing is the technique of building new structures on flood plains (or modifying existing structures) in such a way that the structures are, by their design and composition, afforded protection against floodwater and floating debris. Thus, floodproofing enables development in low-hazard areas of the flood plain where moderate flooding with low stage, low velocity, and short duration is experienced; when corrective flood protection is not feasible; where structures essential to activities dependent on riverine locations need some degree of protection; where a higher degree of protection than that provided by a flood-control project is desired; and for a reduction of flood insurance premiums.

A decision to use a particular floodproofing method to reduce flood damages must be based on the characteristics of the individual structure. It is important to understand that these techniques are not a guaranteed solution, but rather their success depends on how they relate to the structural condition of a building, local soil characteristics, and the type of flooding that will occur.

1.2 Classification of Floodproofing

Classification of floodproofing includes both classification of specific floodproofing measures and classification of floodproofed structures as a whole. Specific floodproofing measures are classified based on the steps required to implement them. Floodproofed structures are classified based on the degree of protection provided.

In classifying floodproofed structures, the classification is based on the level of protection (i.e. floodproofing) against the Base Flood. The Base Flood Elevation (BFE) is synonymous with Regulatory Flood (RF) and the 100-year flood event. The term Regulatory Flood Datum (RFD) refers to the Base Flood Elevation plus one foot freeboard as required for floodproofing by the Colorado Water Conservation Board (CWCB). Floodproofed structures are categorized into three classes: completely dry Class A, essentially dry Class B, and wet Class C. Table 1.1 gives a summary of the classification of floodproofed structures.

Table 1.1 - Classification of Floodproofed Structures

Classification	Definition
Class A	**Completely Dry Structures** designed to withstand all hydrostatic and hydrodynamic loads or elevated above the BFE. Walls and joints shall be impermeable to passage of water and water vapor or first floors cited above the BFE.
Class B	**Essentially Dry Structures** designed to withstands all hydrostatic and hydrodynamic loads. A maximum of four (4) inches of water depth may accumulate in a space during a 24 hour period.
Class C	**Wet Structures** are allowed to fill with either clean or flood water to counter-balance outside hydrostatic forces.

Specific floodproofing measures are classified as permanent, contingent, or emergency. Permanent measures are typically incorporated into the design of new structures and do not require any advance flood warning or availability of persons to initiate action. Permanent floodproofing, such as elevation on fill, is always in place and reduces the element of human error. Contingent or partial floodproofing measures, such as prefitted window and door closures, require some type of human action to make the floodproofing measures operational at the time a flood warning is announced. Contingent measures require someone to be at the site during the flood warning and that an adequate flood- warning plan for the community exists. Emergency floodproofing measures, such as sandbagging, are made operational during an actual flood event. Emergency measures are temporary and should be carried out according to a pre-arranged plan. Table 1.2 gives a summary of the classification of specific floodproofing measures.

Table 1.2. Classification of floodproofed structures

Classification	Definition	Examples
Permanent	Do not require any action to inititate. Usually incorporated into the design.	- water closures - flood walls - levees - elevation
Contingent	Require human action to initiate at time of flood warning.	- removable flood shields - watertight doors - movable flood walls
Emergency	Measures used and initiated at the time of flooding.	- sand bagging - temporary levees

1.3 Types of Structures

The type of structure is an important consideration in the application of floodproofing measures. Four basic types of structures can be identified: residential, commercial, industrial, and mobile homes. Differentation between the type of structures is based upon occupancy, structural integrity, and costs justified for floodproofing each. The following discussion is directed toward the building and floodproofing of new structures.

In general, the only practical method of floodproofing new residential structures is to elevate the structure above the BFE. Other methods of floodproofing should only be employed when there are no other alternatives. Residential structures typically do not have the structural integrity to resist hydrostatic forces and floodproofing measures are costly when the structure is located below the base flood. Another major concern is the uncertainty with respect to the occupant's safety. The Federal Emergency Management Agency (FEMA) requires enactment of ordinances that require new residential structures to have the lowest floor elevation (including the basement) at or above the BFE.

Commercial structures are not significantly different from residential structures when considering applicability of floodproofing measures. Small commercial businesses may not be able to justify costs and may not always have the personnel on hand at times when floodproofing measures need to be implemented. Also, due to the use of these types of structures by the general public, an adequate flood-warning system must exist to enable timely evacuation. Commercial structures are considered non-residential by FEMA.

Due to the capital investment often associated with industrial-type structures, it is much easier to justify the cost of floodproofing. Also, industrial structures generally have the structural capability to resist hydrostatic forces. Industrial plants that provide public and utility services need to operate and be accessible continually. Again, industrial structures are considered as non-residential by FEMA.

Mobile homes are considered separate because they are highly susceptible to flood damage and require special anchoring to keep them secure when located below the BFE. Further discussion of mobile homes can be found in Chapter XIV.

When evaluating the level of a structure in relation to the BFE for either residential or non-residential structures, the lowest level of the structure, including the basement, must be considered. Pictorial examples of different types of structures as defined in FEMA's Flood Insurance Manual are shown in the figures on the next few pages.

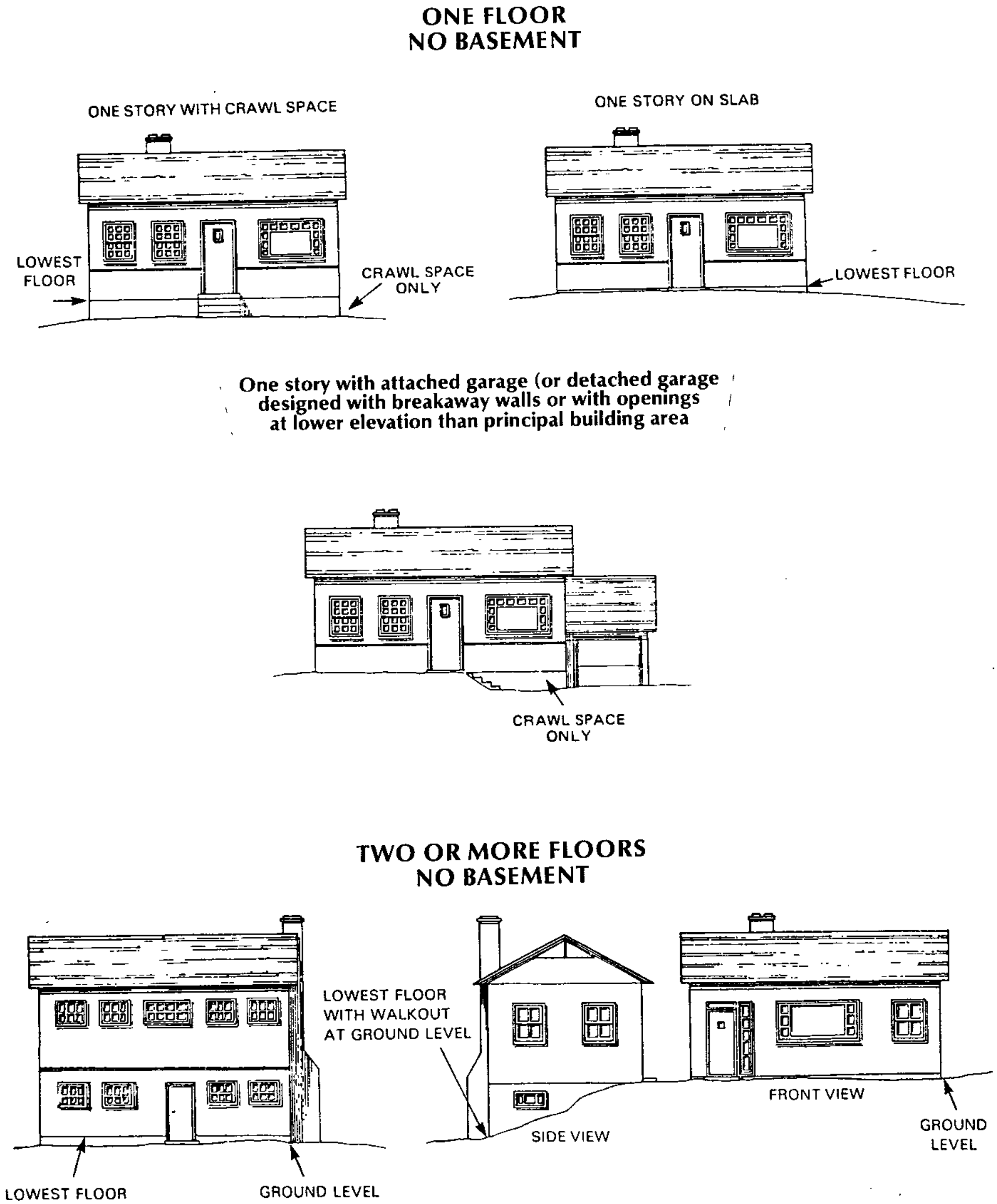
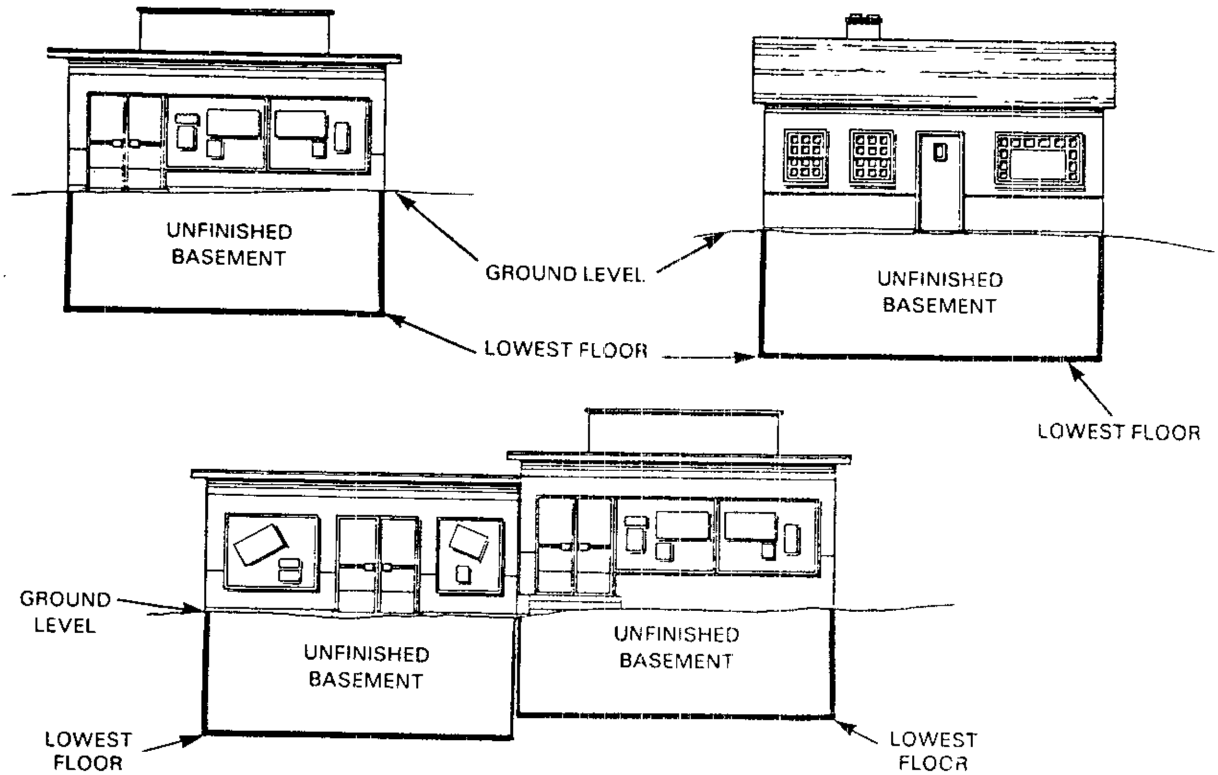
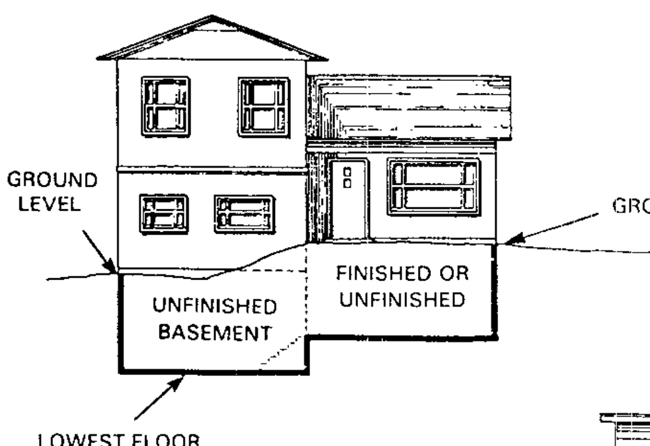


Figure 1.1. Examples of residential structures (Reference 10).

TWO FLOORS
UNFINISHED BASEMENT



SPLIT LEVEL
UNFINISHED BASEMENT



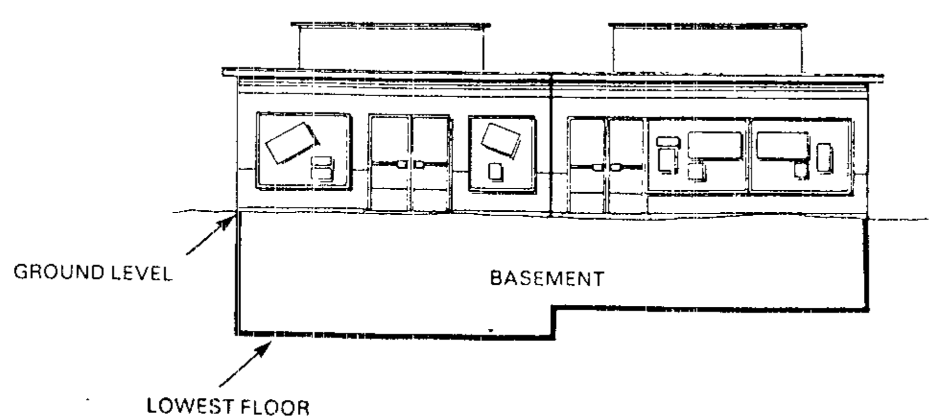


Figure 1.1. Continued

FINISHED BASEMENT

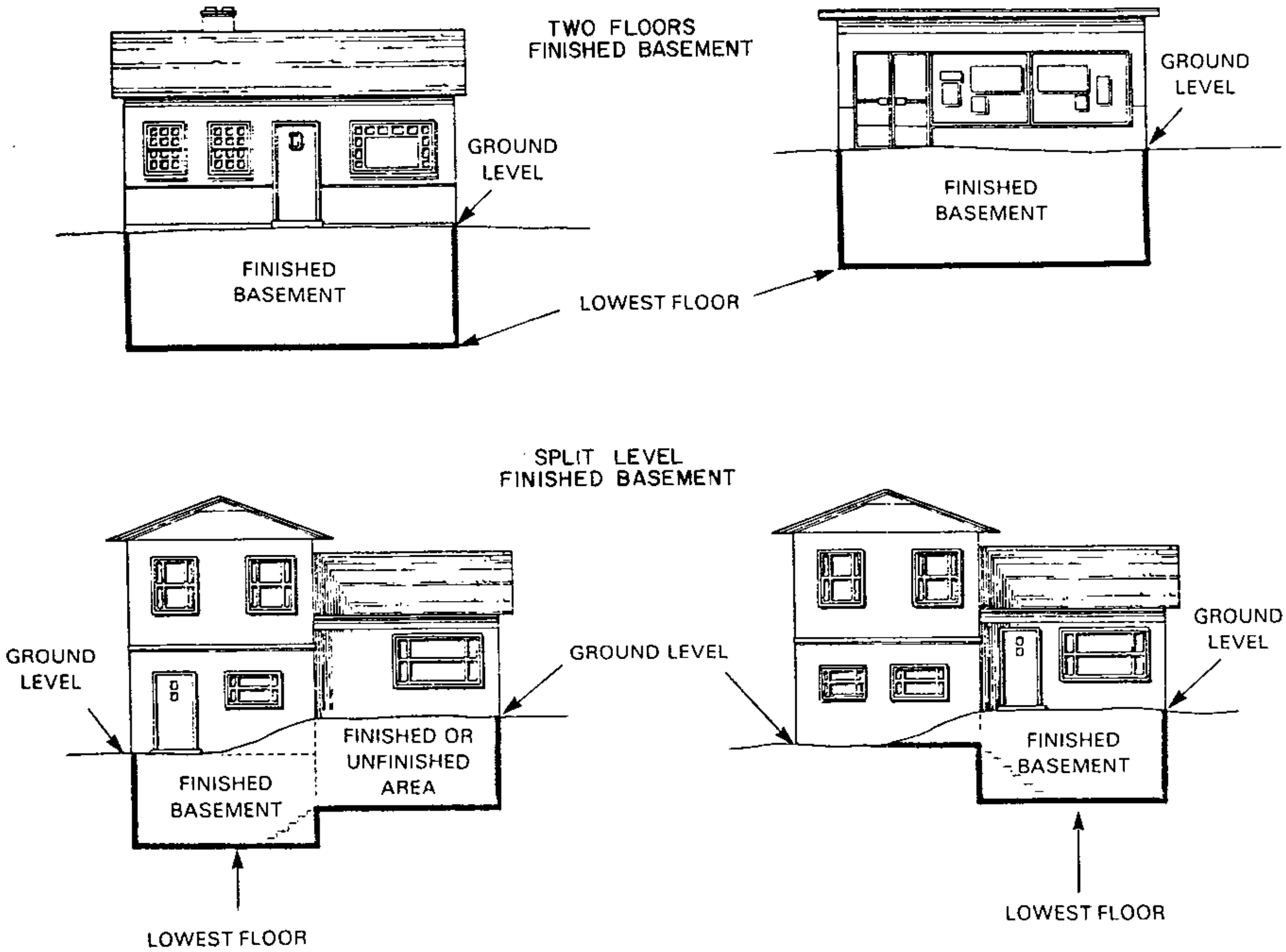
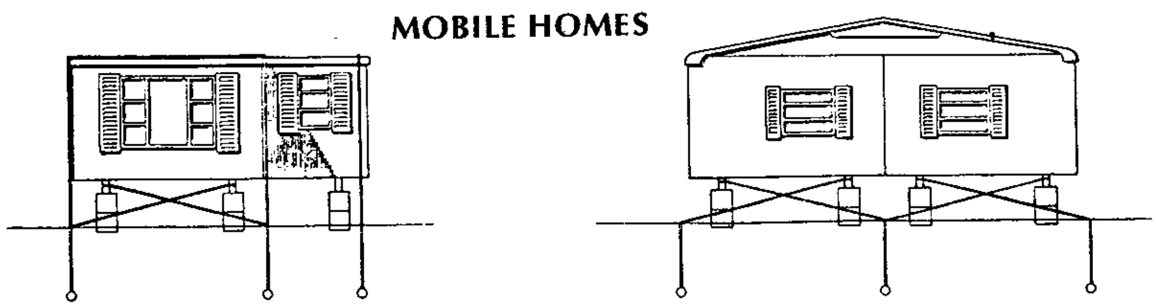


Figure 1.1. Continued

MOBILE HOMES



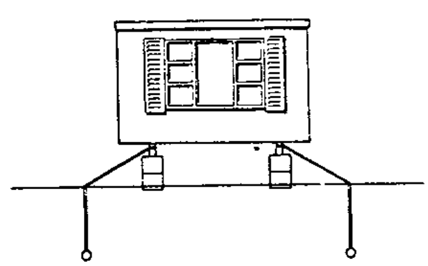


Figure 1.2. Examples of mobile homes. (Reference 10).

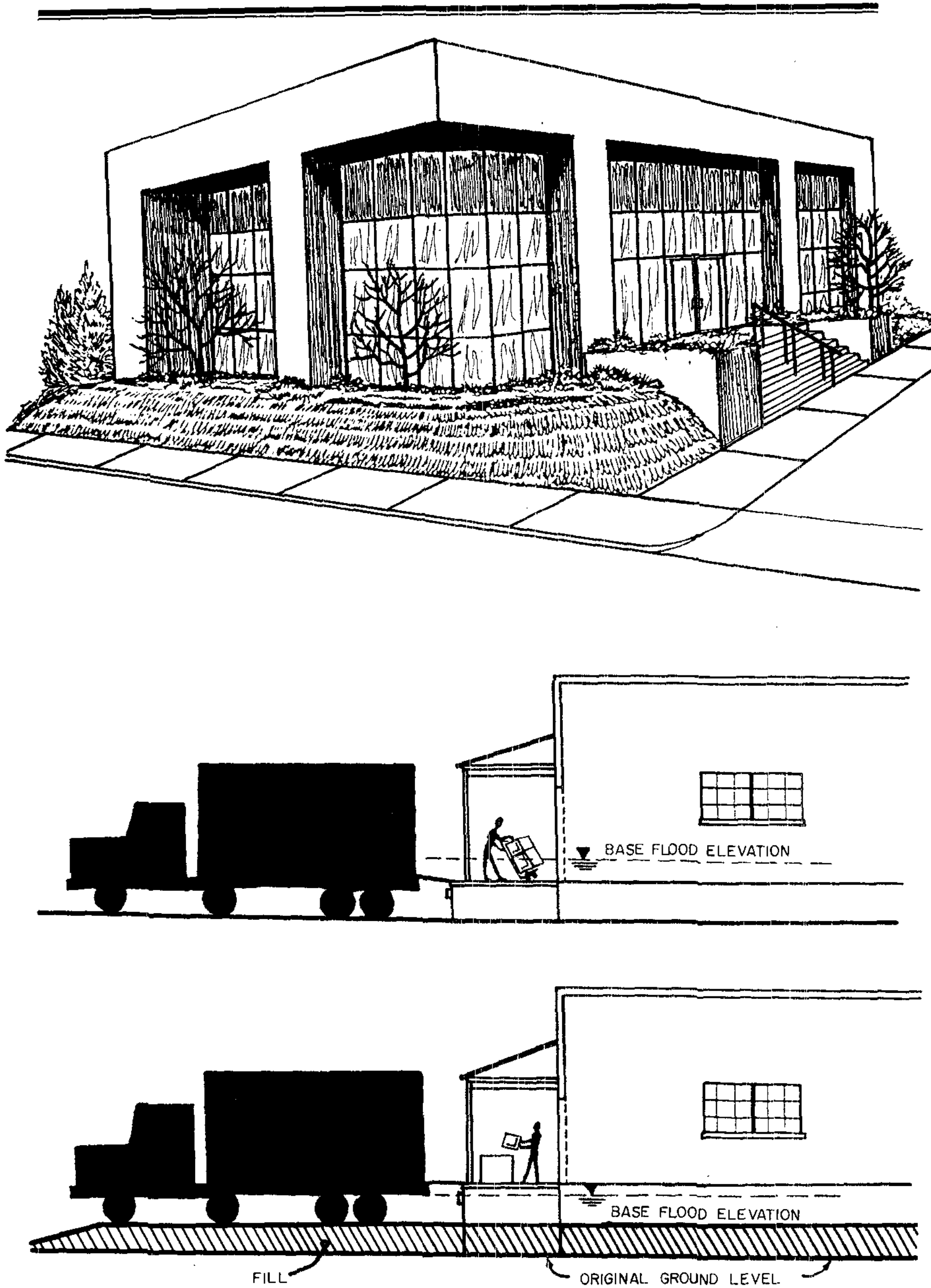


Figure 1.1. Examples of commercial and industrial structures. (Reference 8).

II. GLOSSARY

This section defines terms encountered frequently in flood plain management. The definitions are simplified to meet the needs of those who are not specialists in the field. More detailed and scientific definitions of these and other terms can be found in several of the publications listed in the bibliography.

Backwater Effect - The rise in water surface elevation caused by some obstruction such as a narrow bridge opening, buildings or fill material that limits the area through which the water must flow. Also referred to as "heading up".

Base Flood Elevation (BFE) - A term used by the State of Colorado and FEMA to indicate the minimum flood elevation to be used by a community as a basis for its flood plain management regulations; presently required by regulation to be that flood which has a one-percent chance of being equaled or exceeded in any given year. Also known as a 100-year flood or one-percent chance flood.

Base Flood Plain - The flood plain that would be inundated by a 100-year (one-percent chance) flood.

Basement Floor - The lowest floor level below the main floor of a building.

Basin - The total area from which surface runoff is carried away by a drainage system. Other comparable terms are "drainage area", "catchment area", and "watershed".

Building Code - Regulations adopted by a governmental body which set forth standards for the construction of buildings and other structures for the purpose of protecting the health, safety and general welfare of the public.

C.F.S. - Cubic feet per second. Used to describe the amount of flow passing a given point in a stream channel. One cubic foot per second is equivaent to approximately 7.5 gallons per second.

Channel - A natural or artificial watercourse with definite bed and banks to confine and conduct flowing water.

Channel Capacity - The maximum flow which can pass through a channel without overflowing the banks.

Cross Section - A graph or plot of ground elevation across a stream valley or a portion of it, usually along a line perpendicular to the stream or direction of flow.

Designated Flood Plain - The flood plain boundary delineated by the base flood elevation after it has been approved by Colorado Water Conservation Board and adopted by the local community.

Designated Floodway - The channel of a stream and that portion of the adjoining flood plain designated by a regulatory agency to be kept free of further development to provide for unobstructed passage of flood flows. The designated floodway is within the designated flood plain.

Design Flood - Commonly used to mean the magnitude of flood used for design and operaion of flood control structures or other protective measures. It is sometimes used to denote the magnitude of flood used in flood plain regulations

Erosion - The process of the gradual wearing away of land masses due to friction forces created between flowing water and the ground surface.

Existing Construction - For the purposes of flood plain management regulations requirements, existing construction means those structures in existence or on which construction or substantial improvement was started prior to the effective date of a flood plain management regulation adopted by a community. "Existing construction" may also be referred to as "existing structures."

Equal Degree of Encroachment - A rule, used in determining permissible flood plain encroachments, that the flood plain on each side of a stream must be capable of conveying a proportionate share of the design flood flow.

Flash Flood - A flood that reaches its peak flow in a short length of time (hours or minutes) after the storm or other event causing it. Often characterized by high velocity flows.

First Floor - The floor which is level with or immediately above the main point of entry into the building. For residences, it is additionally that floor which comprises the main living area of the dwelling.

Flood or Flooding - Temporary inundation of normally dry land areas from the overflow from the unusual and rapid accumulation or runoff of surface waters from any source. The rise in water may be caused by excessive rainfall, snowmelt, natural stream blockages, wind storms over a lake or any combination of such conditions.

Flood Control - Keeping flood waters away from specific developments and/or populated areas by the construction of flood storage reservoirs, channel alterations, dikes and levees, bypass channels, or other engineering works.

Flood Crest - The maximum stage or elevation reached or expected to be reached by the waters of a specific flood at a given location.

Flood Duration - The length of time a stream is above flood stage or overflowing its banks.

Flood Fighting - Actions taken immediately before or during a flood to protect human life and to reduce flood damages such as evacuation, emergency sandbagging and diking, and provision of assistance to flood victims.

Flood Forecasting - The process of predicting the occurrence, magnitude and duration of an imminent flood through meteorological and hydrological observations and analysis.

Flood Frequency - A statistical expression of the average time period between floods equaling or exceeding a given magnitude. For example, a 100-year flood has a magnitude expected to be equaled or exceeded on the average of once every hundred years; such a flood has a one-percent chance of being equaled or exceeded in any given year. Often used interchangeably with "recurrence interval."

Flood Fringe - The portion of the flood plain outside of the floodway but still subject to flooding. Sometimes referred to as "floodway fringe". Also used to refer to areas subject to flooding by water with velocities less than the floodway area.

Flood Hazard Areas - The lands adjoining the channel of a river, stream or watercourse which would be covered by flood water during the regulatory flood. These areas embrace those lands frequently designated as floodway and flood fringe or flood plain districts on the official zoning map of the municipality.

Flood Hazard Boundary Map - An official map of a community issued by the Federal Insurance Administration on which the boundaries of the flood plain (i.e., subject to the 100-year flood), mudslide and/or flood- related erosion areas having special hazards have been drawn.

Flood Insurance - Insurance on structures and/or their contents for restoration or replacement if damaged by floodwater. The term is usually applied to flood insurance under the National Flood Insurance Act of 1968, as administered by the Federal Insurance Administration.

Flood Insurance Emergency Program - A phase of the National Flood Insurance Program intended primarily as an interim program to provide a limited amount of insurance at federally-subsidized rates on all existing and new construction begun prior to publication of a detailed flood insurance study and rate map for an area.

Flood Insurance Rate Map - An official map of a community on which the Federal Insurance Administration has delineated the area in which the purchase of flood insurance is available under the Federal Insurance Regular Program and the actuarial rate zones applicable to such area.

Flood Insurance Regular Program - The phase of the National Flood Insurance Program under which actuarial rates have been determined and the amounts of coverage and increased, which are based on engineering determinations.

Flood of Record - The greatest flood recorded for a location.

Flood Plain - The low lands adjoining the channel of a river, stream or watercourse, or ocean, lake, or other body of standing water, which have been or may be inundated by flood water. The channel of a stream or watercourse is a part of the flood plain.

Flood Plain Management - The operation of a program intended to lessen the damaging effects of floods, maintain and enhance natural values, and make effective use of related water and land resources within the flood plain. It is an attempt to balance values obtainable from use of flood plains with potential losses arising from such use. Flood plain management stresses consideration of the full range of measures potentially useful in achieving its objectives.

Flood Plain Regulations - A general term for the full range of codes, ordinances, and other regulations relating to the use of land and construction within stream channels and flood plain areas. The term encompasses zoning ordinances, subdivision regulations, building and housing codes, encroachment line statutes, open-space regulations, and other similar methods of control affecting the use and development of these areas.

Flood Probability - A statistical expression of the chance (usually as a percentage) that a flood of given magnitude has of being equaled or exceeded in any one year (see flood frequency).

Floodproofing - A combination of structural changes and adjustments to new or existing structures and facilities for reducing or eliminating flood damages to the structures, contents and/or their sites.

Flood Warning - The issuance and dissemination of information about an imminent or current flood.

Floodway - The channel of a watercourse and those portions of the adjoining flood plain required to provide for the passage of a selected flood (normally the 100-year flood) with an insignificant increase in the flood levels above that of natural conditions.

Freeboard - A factor of safety usually expressed in feet above a design flood level for flood protection or control works. Freeboard tends to compensate for the many unknown factors that could contribute to flood heights greater than the height calculated for a selected size flood.

Habitable Room - A space used for living, sleeping, eating or cooking, or combination thereof; but not including bathrooms, toilet compartments, closets, halls, storage rooms, laundry and utility rooms, cellars, and similar spaces.

Human Intervention - Activation of flood protection systems by manual effort during floods as opposed to activation by automatic means.

Hydrodynamic Loads - Forces imposed on structures by floodwaters due to the impact of moving water on the upstream side of the structure, drag along its sides, and eddies or negative pressures on its downstream side.

Hydrostatic Loads - Forces imposed on a flooded structure due to the weight of the water.

Infiltration - The flow of fluid into a substance through pores or small openings. The term is commonly used to denote the flow of water into soil.

Impact Loads - Loads induced on a structure by solid objects carried by flood water. They can include trees, lumber, displaced sections of structures, tanks, mobile homes, and chunks of ice. Impact loads are difficult to predict accurately, yet reasonable allowances must be made for them in the design of potentially affected structures.

Level (Degree) of Protection - The greatest flood level against which a protective measure is designed to be fully effective; often expressed as a recurrence interval (e.g., 100-year level of protection) or as an exceedance frequency (e.g., one-percent chance of exceedance).

Local Scour - The scour that occurs at an obstruction in the flow is called scour. The local scour is due to the reduction of flow area and the resultant increase in velocity.

Mean Diameter - Is the diameter where 50 percent of the material has smaller diameters and 50 percent have larger (based on weight).

Mudslide (i.e. mudflow) - A condition where there is actually a river, flow or inundation of liquid mud down a hillside usually as a result of a dual condition of loss of brush and the subsequent accumulation of water on or under the ground (frequently caused by a period of heavy or sustained rain). A mudslide may occur as a distinct phenomenon while a landslide is in progress and will be recognized as such by FEMA only if the mudflow, and not the landslide, is the proximate cause of the damage that occurs.

Nonstructural Measures - All flood plain management measures excepting structural flood control works. Examples of nonstructural measures are flood warning/preparedness systems, relocation, floodproofing, regulation, land acquisition, and public investment policy.

One-Hundred Year Flood -A flood having a one-percent chance of occurring in any given year and which, over a very long period time, can be expected to be equaled or exceeded on the average of once very hundred years.

Permeability - The property of soil or rock that allows passage of water through it.

Profile - A graph or plot of the water surface elevation against distance along a channel. Also termed "flood profile" if drawn for a specific flood or level of flooding.

Recurrence Interval - A statistical expression of the aveage time between floods equaling or exceeding a given magnitude (see flood frequency).

Regulatory Flood - Same as BFE when approved by CWCB and adopted by local community.

Regulatory Flood Datum (RFD) - Is the BFE plus one foot free board.

Structural Measures - Flood control works such as dams and reservoirs, levees and floodwalls, channel alterations, seawalls, and diversion channels which are designed to keep water away from specific developments and/or populated areas to reduce flooding in such areas.

Watercourse - A natural or artificial channel in which a flow of water occurs either continually or intermittently.

Water Surface Elevation - The heights, usually in relation to mean sea level, reached by flows of various magnitudes and frequencies at pertinent points in the flood plain. This manual denotes the water surface elevation by the symbol

Water Table - The uppermost zone of water saturation in the ground.

II. PHYSIOGRAPHIC CONSIDERATIONS FOR FLOODPROOFING ACTIVITIES

3.1 *General*

Flooding and subsequent flood plains are a natural aspect of the hydrologic ecosystem. Flooding plays a positive role in the renewal of the earth's resources by replenishing soil moisture and depositing fertile silt from the river to the flood plain. Floods become a problem when combined with human development. Prior to any human development, the duration, magnitude, and frequency of flooding is based on the dynamic interaction between water runoff, and the physical characteristics of the watershed that convey the runoff. Thus, prior to the implementation of floodproofing measures enabling development in the flood plain, it is important to understand the physio- graphic characteristics that should be considered. These characteristics include channel cross section and slope, vegetation, soil characteristics, erosion and sedimentation, and debris.

3.2 *Channel Cross Section and Slope*

The channel cross section and slope of both the channel and the watershed have a significant affect on the type and extent of flooding that occurs. Steeply sloping areas and narrow, v-shaped channels are typically associated with the mountainous regions of the state. The type of run-off often associated with steep-gradient areas is short term with a rapid rise of water and high-velocity flows. With high-velocity flows, it only requires several inches of depth to sweep individuals off their feet. High velocities also produce the forces that enable the movement downstream of cars, structures, and debris. High velocities can also cause severe erosional damage. Flooding along larger rivers or the flat, downstream areas of rivers that originate in the mountains occurs at a slower rate and at a lower velocity than steep-sloped areas. Flooding in these areas is often predictable days to weeks ahead of time, and ample warning can be given. However, the duration of the flooding is much longer, and the extent of flooding is spread much wider.

In relation to the applicability of floodproofing measures, velocity is a significant component in the forces that must be considered in structural design. The duration of flooding is a concern in that access must be maintained for certain public services, and protection against seepage must be provided.

Another characteristic that is associated with the gradient of the channel is the formation of deltas and alluvial fans. They occur wherever there is a change from a steep to a flat gradient such as from a steep mountain stream to a flat open valley or where a steep tributary enters a main channel. As the sediment, bed material (larger stones and boulders) and water reaches the flatter section of the stream, the coarser material can no longer be transported because of the sudden reduction in both slope and velocity. Consequently, a cone, fan or delta builds out as the material is deposited. In these areas, the channel is very unstable and the potential for lateral movement of the channel is great. Thus, development in or near these areas should be avoided.

3.3 *Vegetation*

Vegetation plays an important role in several aspects of flooding and the flood plain. On the watershed, good vegetation cover, in the form of brush and trees, reduces the amount of runoff by intercepting rainfall, allows increased infiltration, and provides storage by reducing the rate of overland flow. Vegetation cover also reduces the amount of erosion from the watershed.

As flood waters exceed the channel capacity, they extend into the flood plain. In the flood plain, vegetation tends to reduce the velocity resulting in storage within the flood plain and reduction in the peak discharge.

Vegetation is also important along the banks of a river or a stream. Along the bank, good vegetation adds to the stability of the bank and thus reduces the bank erosion and lateral movement of the channel.

A major concern when developing in the flood plain is removing the natural vegetation and the protection it provides. When natural vegetation is removed, measures should be taken to replace it immediately or provide stability for the resulting unprotected areas.

3.4 *Soil Characteristics*

Soil characteristics are important in erosion, sedimentation, infiltration and seepage. Discussion of erosion and sedimentation is given in the next section. One of the most important soil characteristics is permeability, a measure of the ability of water to flow through a particular soil. Permeability, to some degree, controls the amount and rate of surface water infiltration, and the zone of saturation. A saturated soil condition occurs when water occupys all the available spaces, or voids, between individual soil grains. Soils with high permeability such as sands and gravels have higher infiltration rates then clayey soils. This implies a faster runoff from clay soils, whereas sandy soils may not permit surface runoff until saturated. However, more importantly, ground water and seepage are more active in sandy soils because of their rapid drainage characteristics.

Groundwater and seepage are major concerns when floodproofing and/or development in the flood plain is being considered. Groundwater level is a significant component of the hydrostatic forces that develop during flooding and must be considered in the structural design of footings, foundations and basement walls. Structures below the ground level must also prevent seepage into the building, thus, the seepage characteristics of the soil are an important consideration.

Another concern in regard to soil characteristics that should not be overlooked in areas with steep slopes is the possibility of landslides, land slumping or debris flow. As soils become saturated, they can loose their slope stability resulting in landslides or mudflow situations. Mudflow evaluation requires detailed analysis, however, a qualitative evaluation of an area can provide insight into the potential for mud or debris flow. In general, mudflows can occur where an accumulation of loose soil, rock and other debris on steep slopes become entrained (saturated) with water. The first characteristic to look for is a history of mudflows and how often have they occurred in the area. Areas where mudflows are formed are characterized by quite definite geological, geomorphological and climatic conditions of erosion processes and by the presence of mudflow forming centers. Specific characteristics include badly sheared and shattered bedrock which yields fine and poorly sorted micaceous fines upon weathering and some type of narrow rock gorge or ravine where the debris and weathered material can collect.

3.5 *Erosion and Sedimentation*

Erosion and sedimentation are processes that occur naturally during flooding. As the discharge and velocity of surface runoff increase, the erosional forces also increase. All fine material such as silts and sands become suspended in the flow. Larger rocks and boulders are rolled along the bottom of the main channel. The main sources of sediment being transported by the surface runoff are from the channel bottom and bank erosion. Sedimentation or deposition of the sediments being transported begins when the velocity of the surface runoff decreases to the point where the sediments can no longer remain in suspension. During flooding, much of the sediment is deposited on the flood plain due to slower velocities as water leaves the main channel.

Sedimentation can cause several problems. Low lying areas in the flood plain can become completely filled over with sediment. Sediment increases abrasive action and adds to the work and cost of cleanup. Sediment can also cause blockage of existing channels diverting water to new channels.

The major concern in relationship to floodproofing is adequate erosion protection of channel banks, earth fills, berms and levees. Where flood waters impinge upon or flow along earth structures, significant erosion can occur. Figures 3.1 and 3.2 show a sequence of bank erosion occurring during a flood and resulting in erosion of the bank and lateral movement of the stream to where the ground was eroded from under the house. Severe erosion, called local scour, can occur where flood waters impinge against piers or piles and around the edges of walls. These areas must be protected with adequate measures such as riprap to prevent erosion and failure of the structure.

3.6 *Debris*

Debris refers to floating material that is picked up and transported downstream by the flood waters. In a natural flood plain, debris consists mainly of brush and trees that fall into the channel. This occurs as flood waters erode and undercut channel banks. Eventually, the bank starts to slough and any vegetation or trees at the bank fall into the channel. With human development in the flood plain, debris can range from rags and fences to cars and parts of structures.

Like sediment, debris can cause blockage of the channel resulting in increased flow depths and diversion of flow from the original channel. The main concern is for the impact forces that occur when floating debris collides with a structure in the flood plain. Impact loads must also be considered when the structural design is being done.

Figure 3.1. Cache La Poudre River, 25-year flood event, June 13, 1983. Riverbank has already eroded 10-20 feet (note fence lines leading into river). Photo courtesy of the *Fort Collins Coloradoan*.

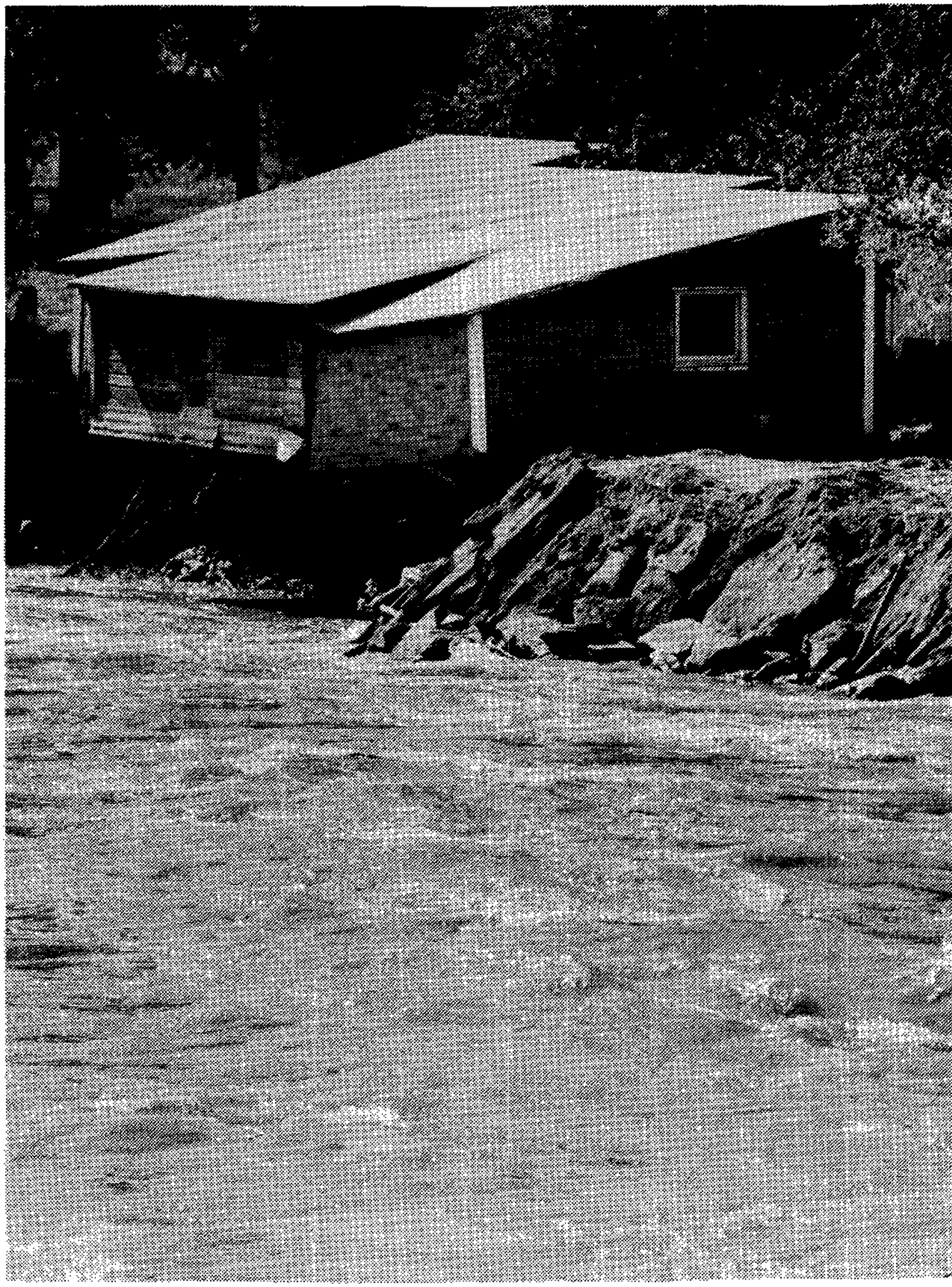


Figure 3.2. Cache Le Poudre River, June 22, 1983
Photo courtesy of the *Fort Collins Coloradoan.*

EXAMPLES OF FLOODPROOFED STRUCTURES

The benefit of floodproofing can be best illustrated by showing the damage that can occur during a major flood event. One of the most significant flood disasters to occur in Colorado happened on July 31, 1976, in the Big Thompson Canyon. During this flood, 145 people were killed and 418 homes were destroyed resulting in 35.5 million dollars in damages. Figures 4.1, 4.2 and 4.3 show homes and businesses that were damaged in the flood. The damaged home shown in Figure 4.2 would have only suffered minor damages if it had been elevated.

The application and use of floodproofing measures is becoming more common throughout Colorado. Figures 4.4 through 4.30 show examples of various floodproofing measures being used in Colorado. The pictures are grouped into main categories showing elevated structures, flood walls, levees and erosion protection. A short narrative below each picture describes the floodproofing measures or combination thereof and location of the structure.

Figure 4.1. Cedar Cover, Big Thompson flood, 1976.
Photo courtesy of David McComb.

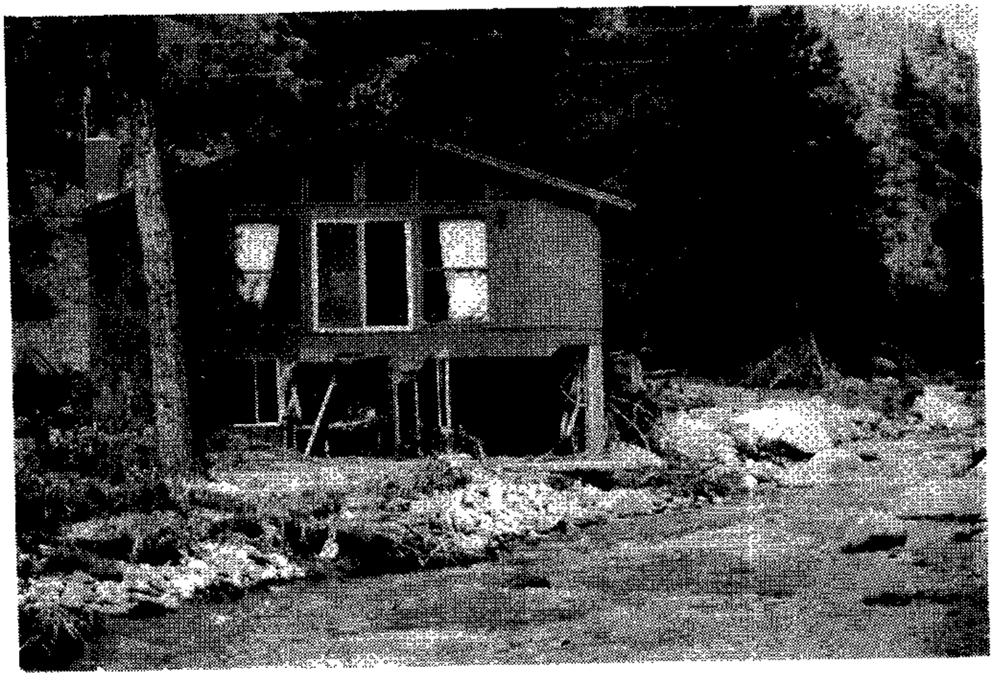


Figure 4.2. The water reached the second floor of this riverside house. Big Thompson flood, 1976. Photo courtesy of David McComb.

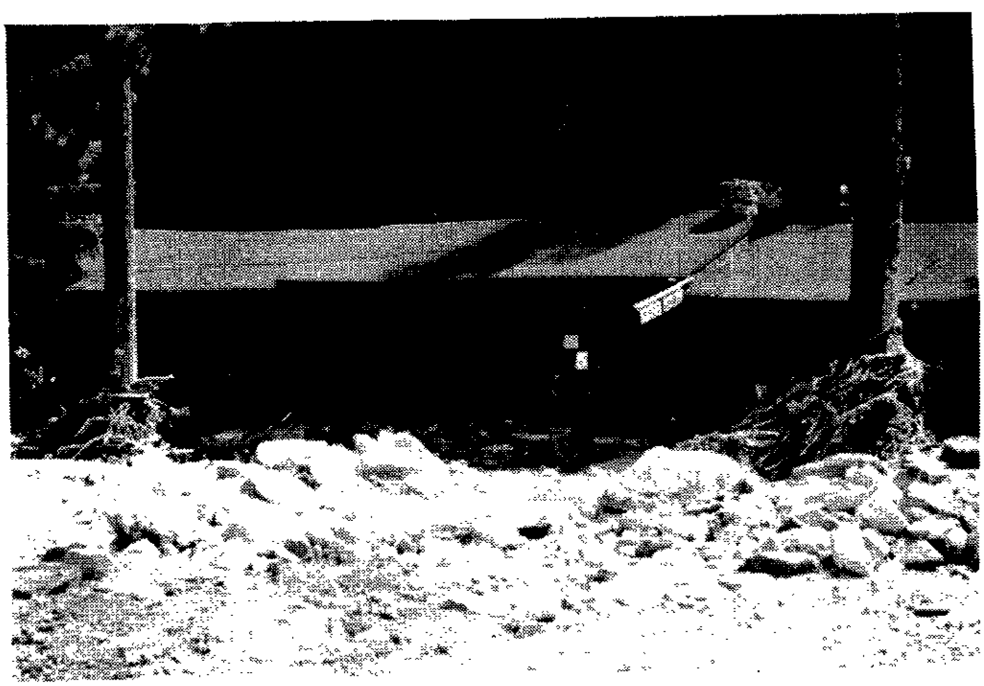


Figure 4.3. Flood damaged motel in Waltonia; Big Thompson flood, 1976. Photo courtesy of David McComb.

ELEVATED COMMERCIAL AND INDUSTRIAL STRUCTURES

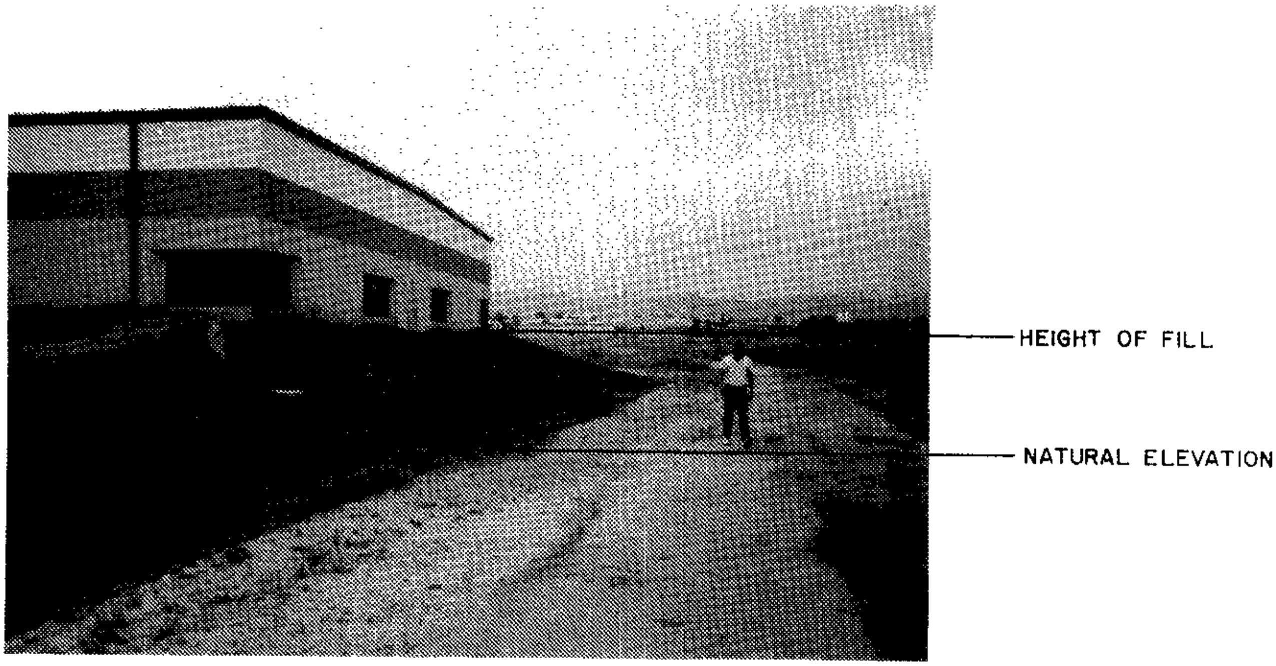


Figure 4.4. Fill elevated Spring Creek 100 year floodplain. Fort Collins, CO.

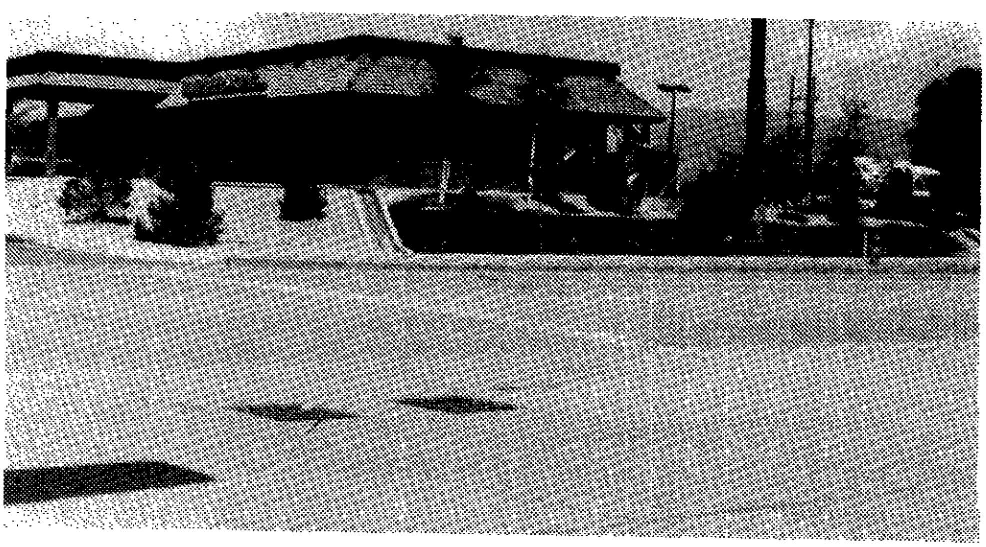
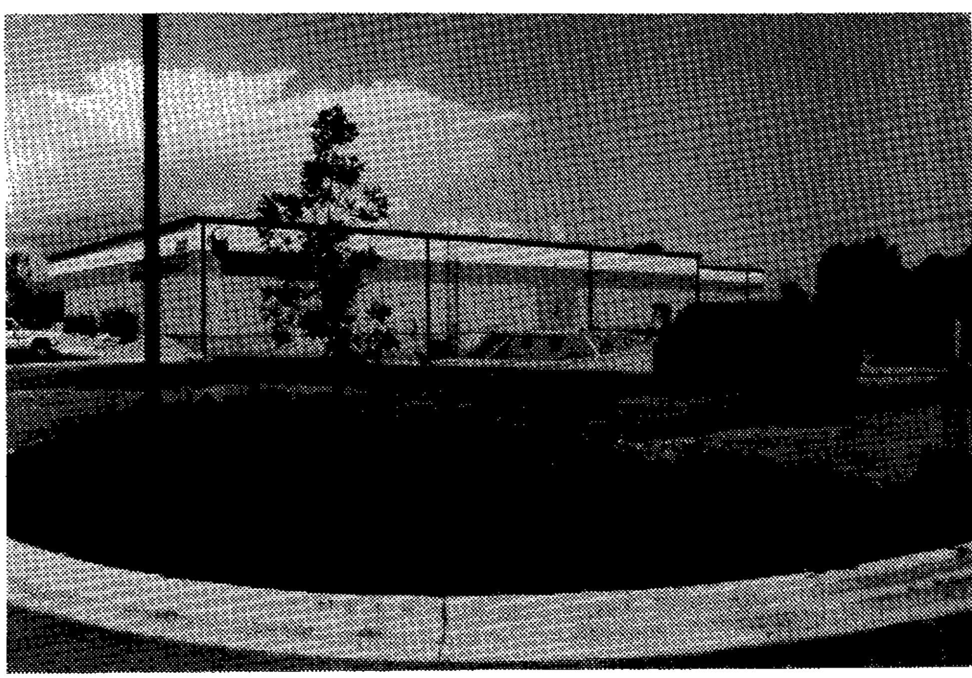


Figure 4.5. Fill elevated. Fountain Creek floodplain, Colorado Springs, CO.

ELEVATED INDUSTRIAL STRUCTURES

NATURAL
ELEVATION

Figure 4.6. Fill elevated. Spring Creek 100 year floodplain. Fort Collins, CO.



ELEVATED
FOUNDATION

Figure 4.7. Spring Creek 100 year floodplain. Fort Collins, CO.

ELEVATED COMMERCIAL STRUCTURE

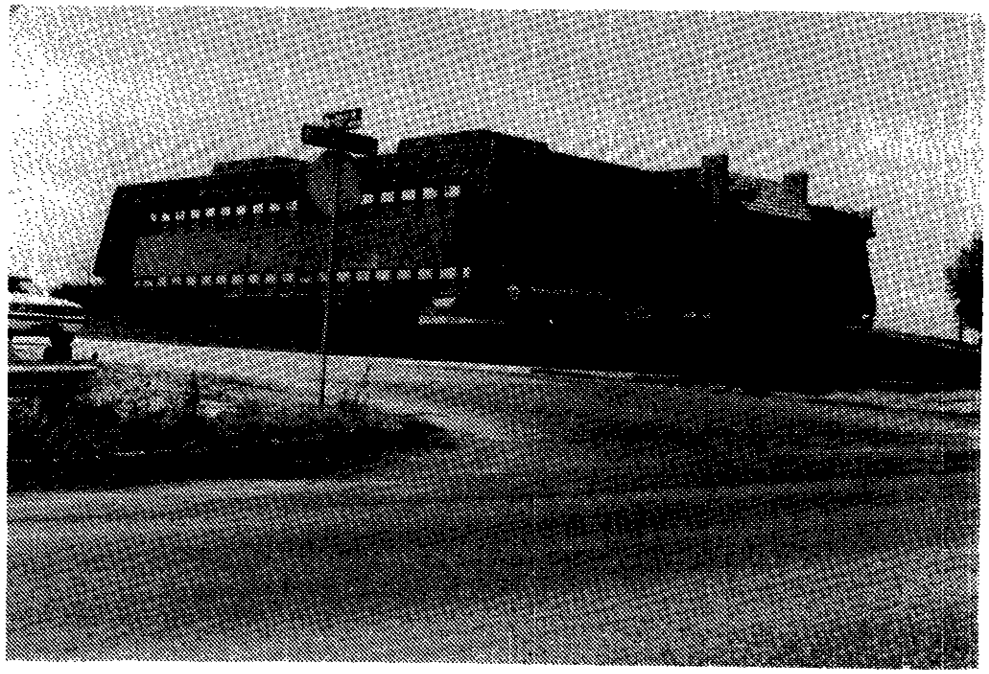


Figure 4.8. Fill elevated. Denver, CO.

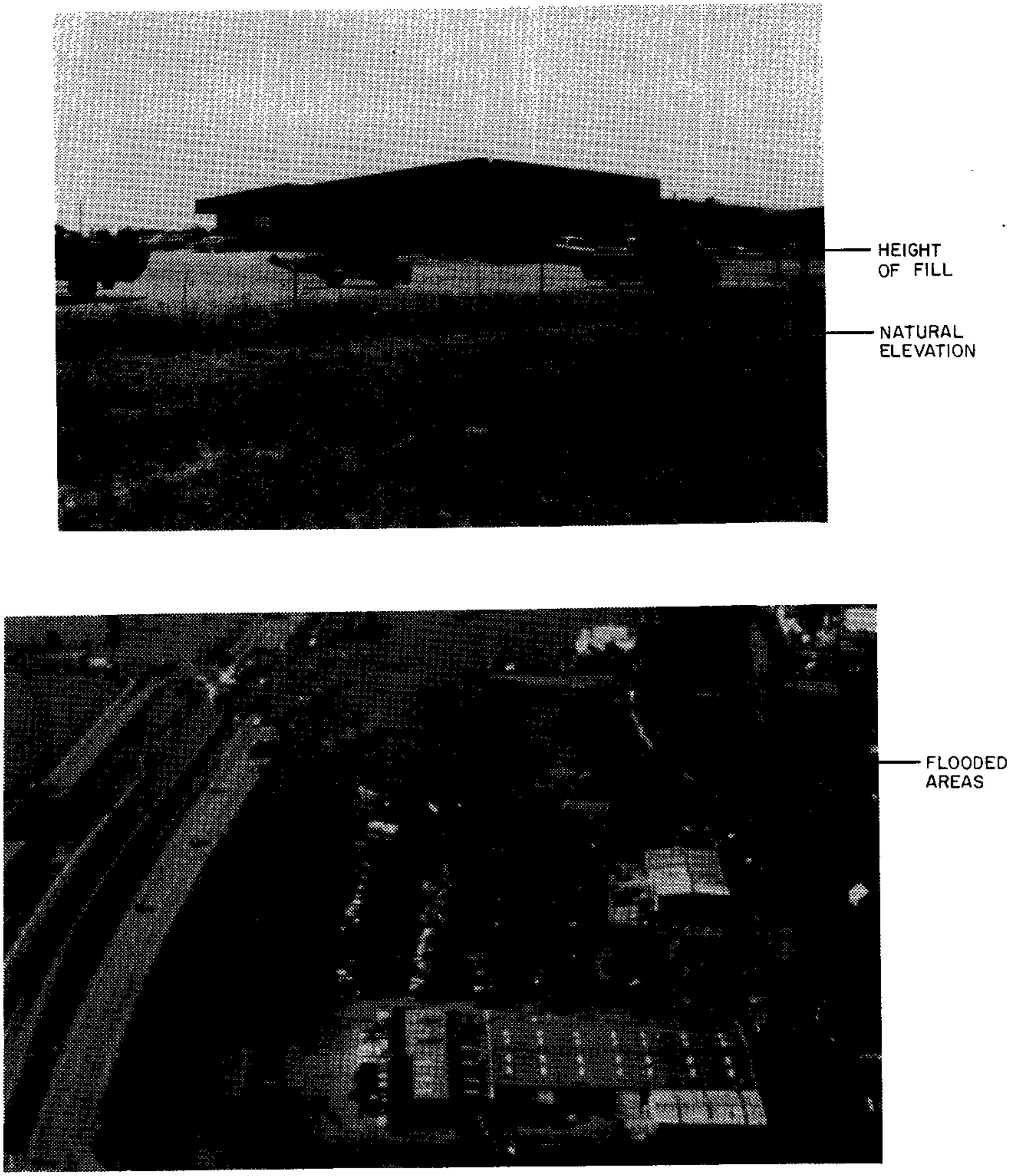


Figure 4.9. A WISE INVESTMENT, by Harold Law! These commercial buildings in Greeley, Colorado, were floodproofed by elevating the first floor. During the spring 1983 floods in the Cache La Poudre River, the buildings were not inundated as shown in the lower photograph.

FLOODPROOF COMMERCIAL STRUCTURES

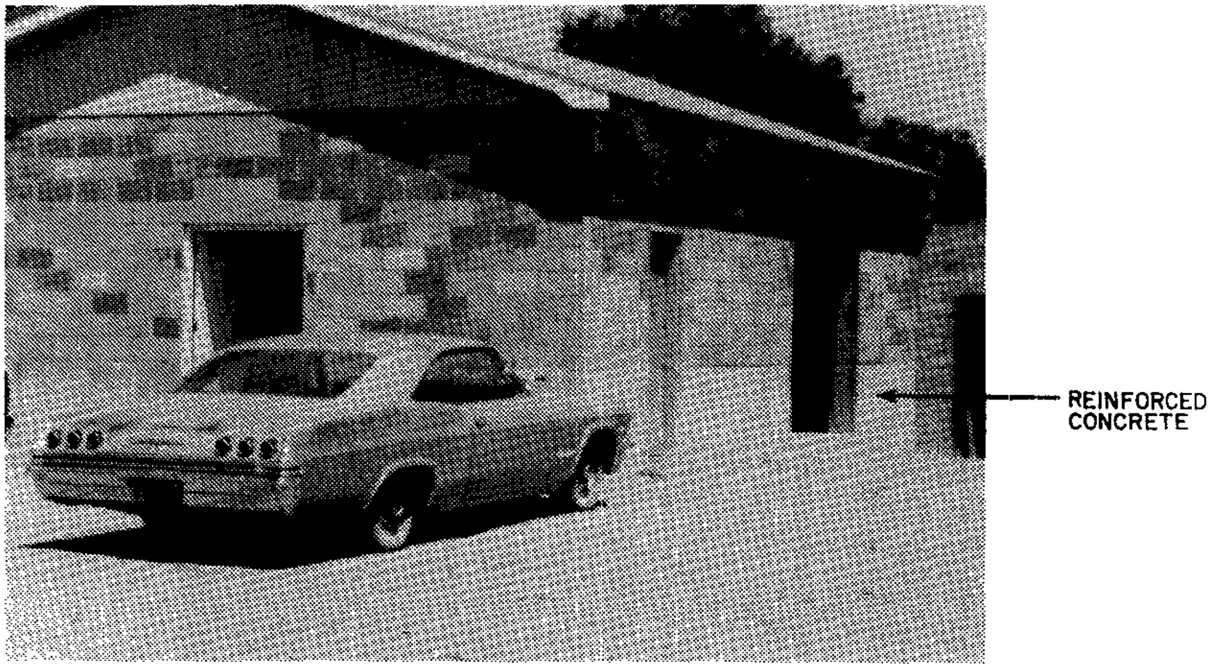


Figure 4.10.Plumbing supply business located on 2.5 feet of fill. Reinforced concrete extends 3 feet above ground, all doors are water tight. Note lack of windows. La Junta, CO.

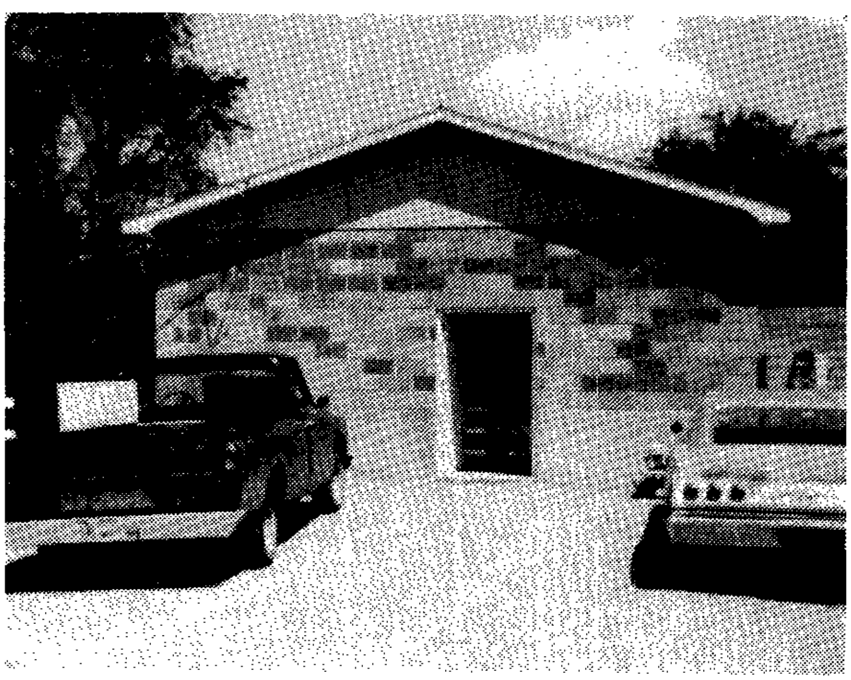


Figure 4.11. Same bilding as above.

FLOODPROOFED COMMERCIAL STRUCTURES

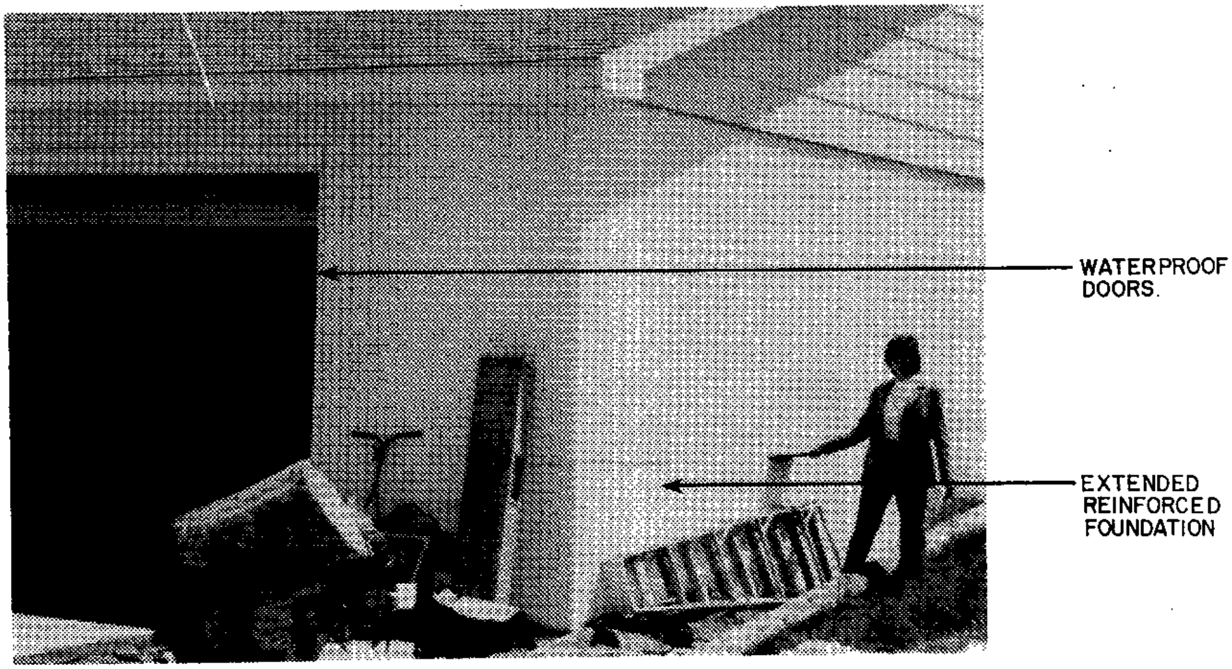


Figure 4.12. Small motor and lawnmower repair shop under construction. Floodproofed to an elevation of 6 feet. Doors will be fitted with rubberized seals.

ELEVATED RESIDENTIAL STRUCTURES

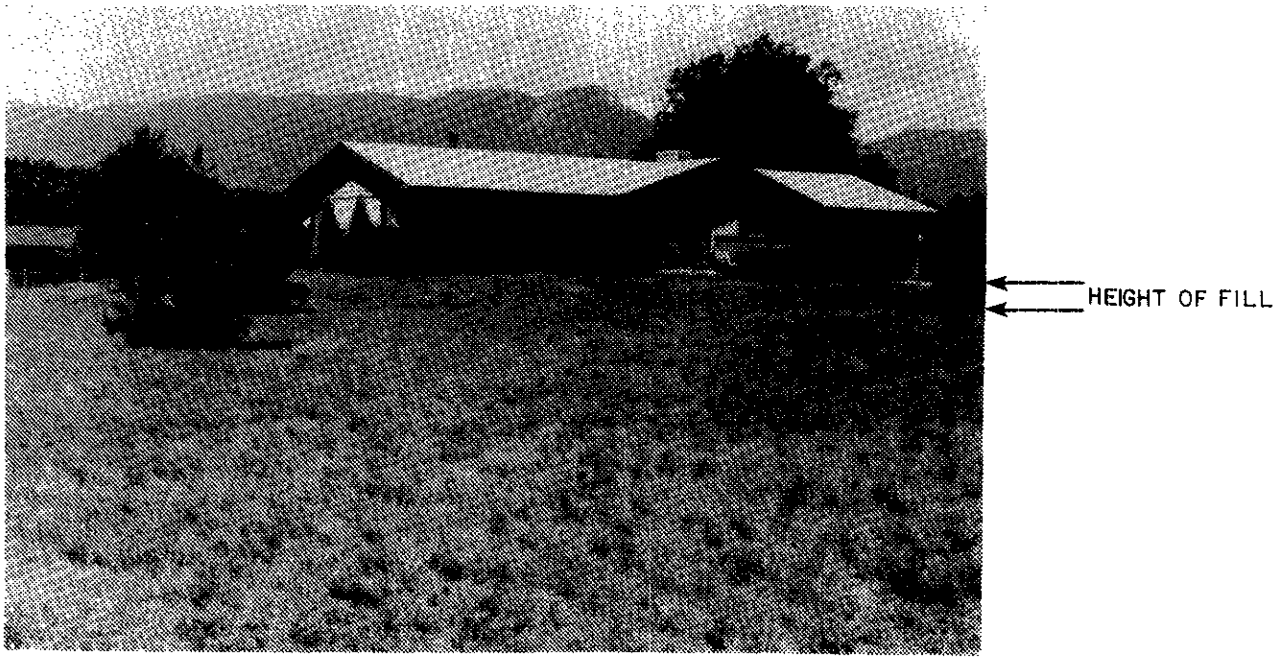


Figure 4.13.Fill elevation home in Monument Creek floodplain, Colorado Springs, CO.

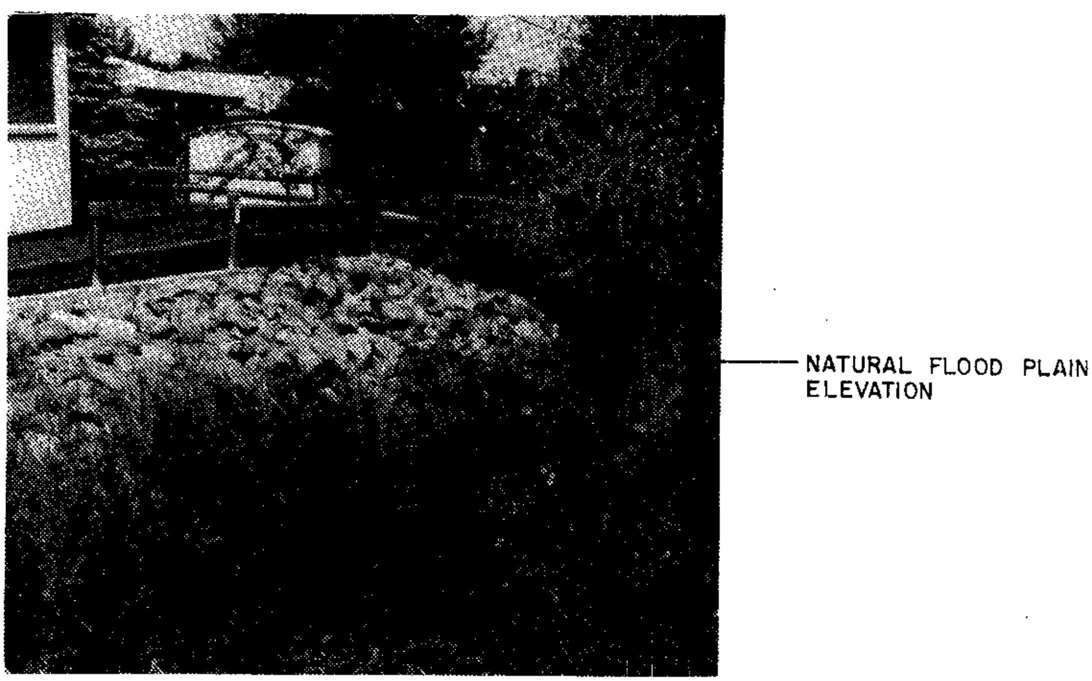


Figure 4.14. Fill elevation combined with erosion control.

ELEVATED STRUCTURES

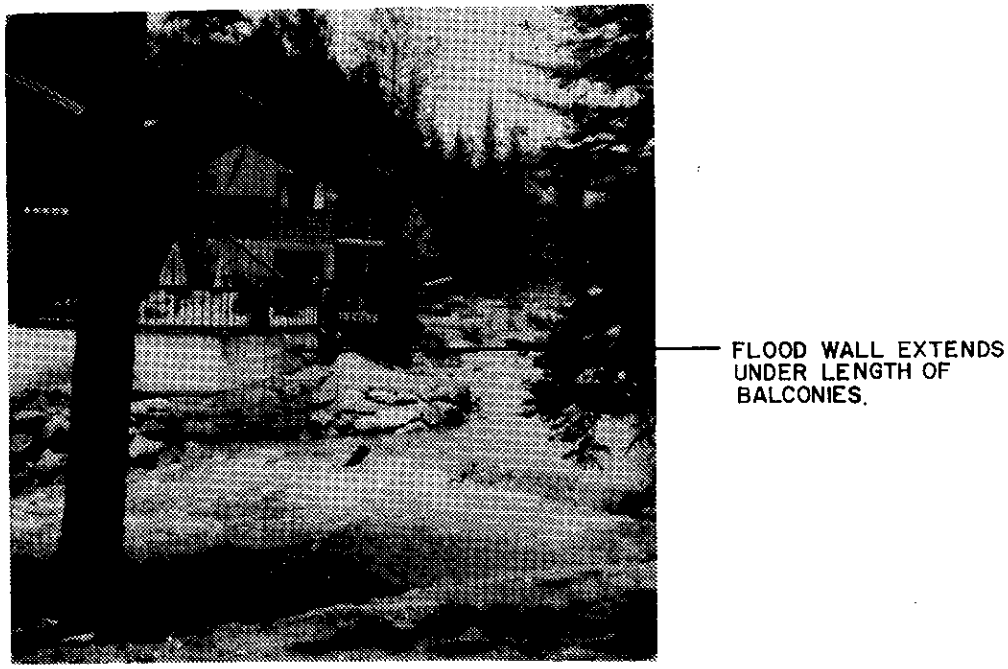


Figure 4.15.

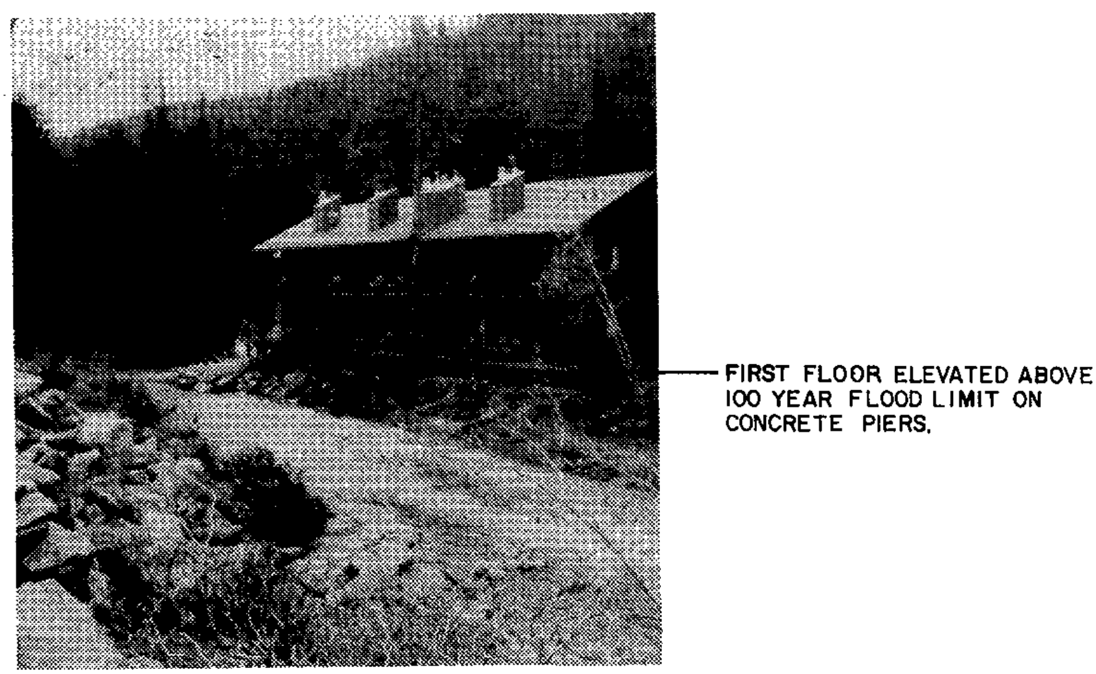


Figure 4.16.

Figure 4.15. and 4.16. are of the newly rebuilt Ponderosa Motel in Estes Park, Colorado. The original motel was destroyed by floodwaters.

ELEVATED RESIDENTIAL STRUCTURES

Figure 4.17Area around the residence is backfilled and sloped to increase the elevation by 4 feet. Note lack of basement. La Junta, CO.

MOBILE HOMES

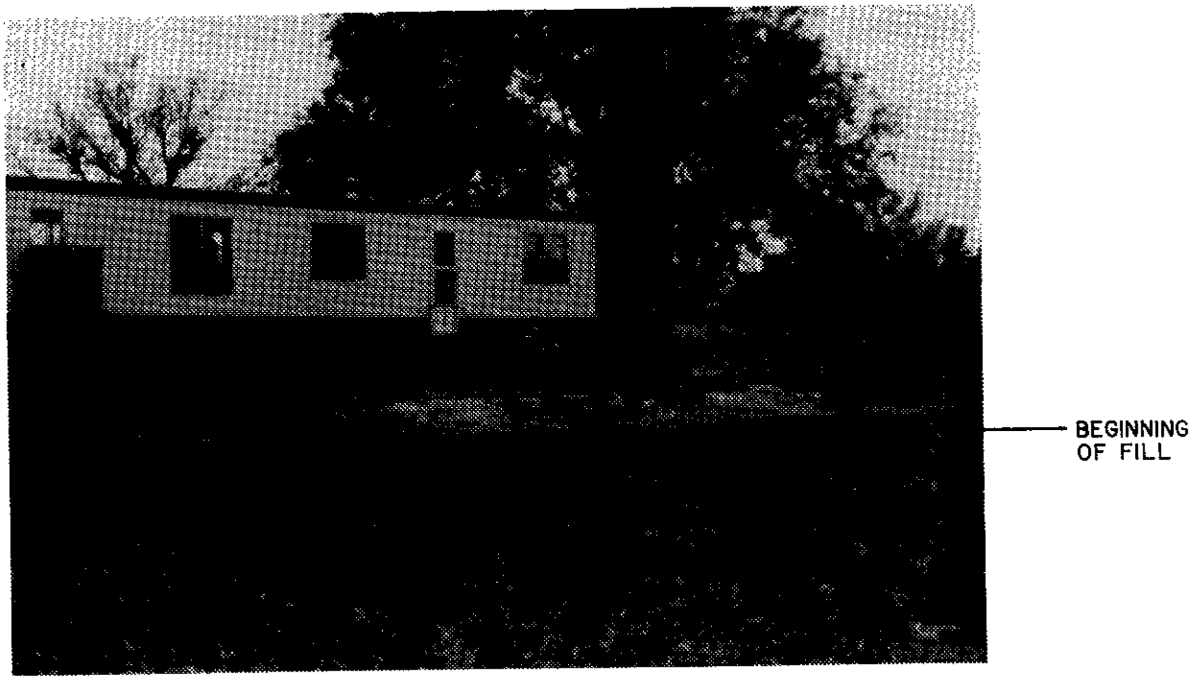


Figure 4.18. Elevated 3 feet on sloped backfill and concrete piers. Secured with tie-downs. La Junta, CO.

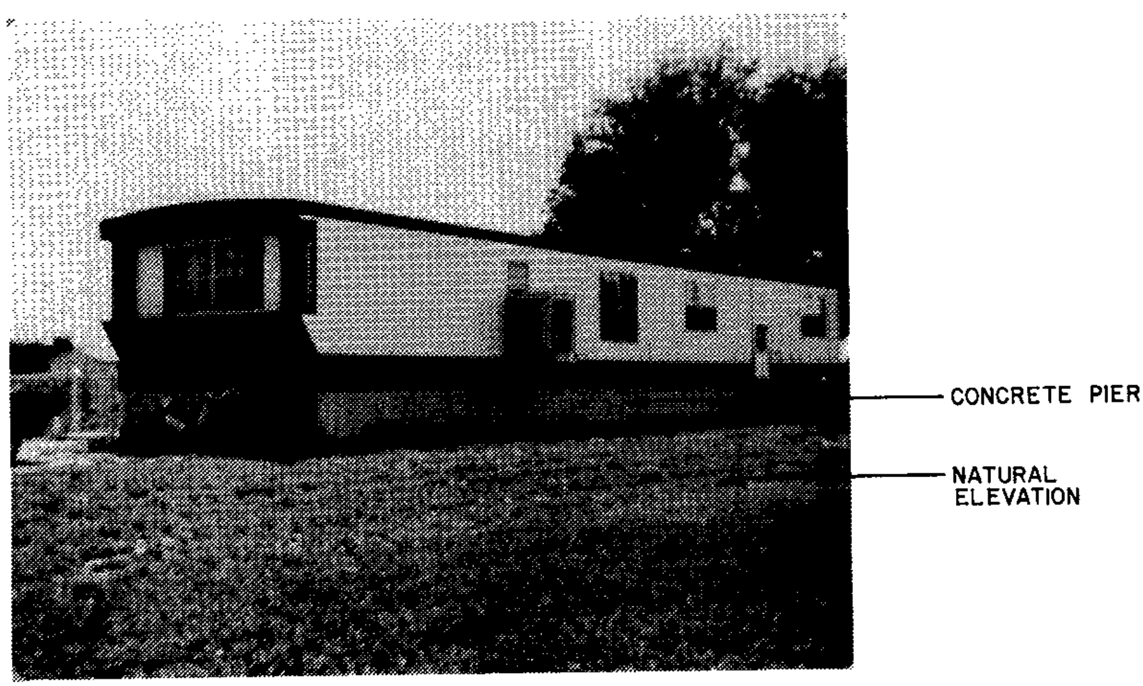


Figure 4.19. Same residence as above.

MOBILE HOMES

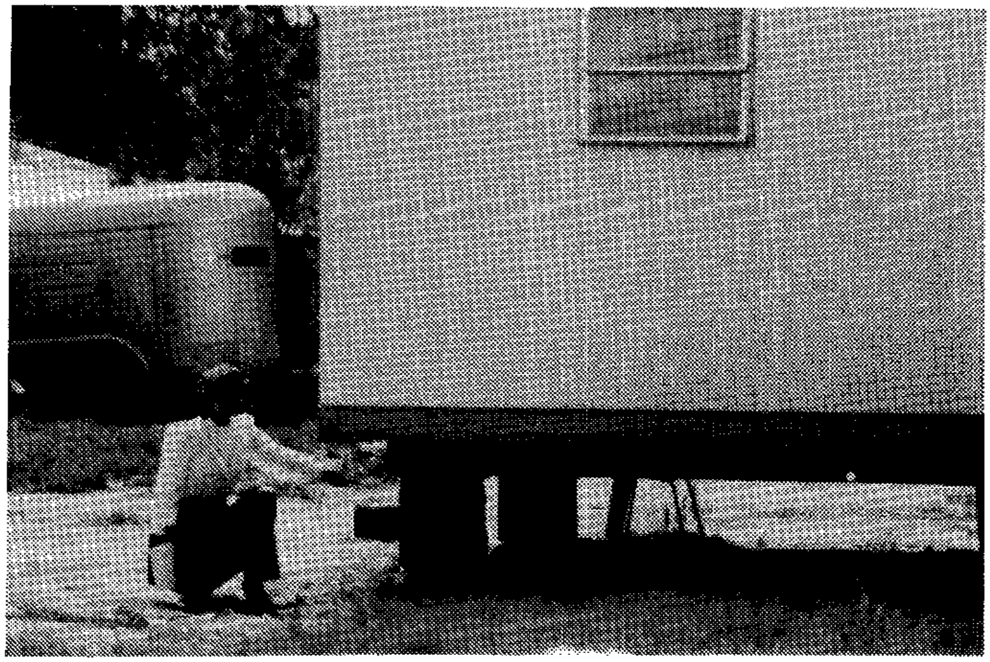


Figure 4.20. Elevated 3 feet on concrete piers. Secured with tie-downs. La Junta, CO.

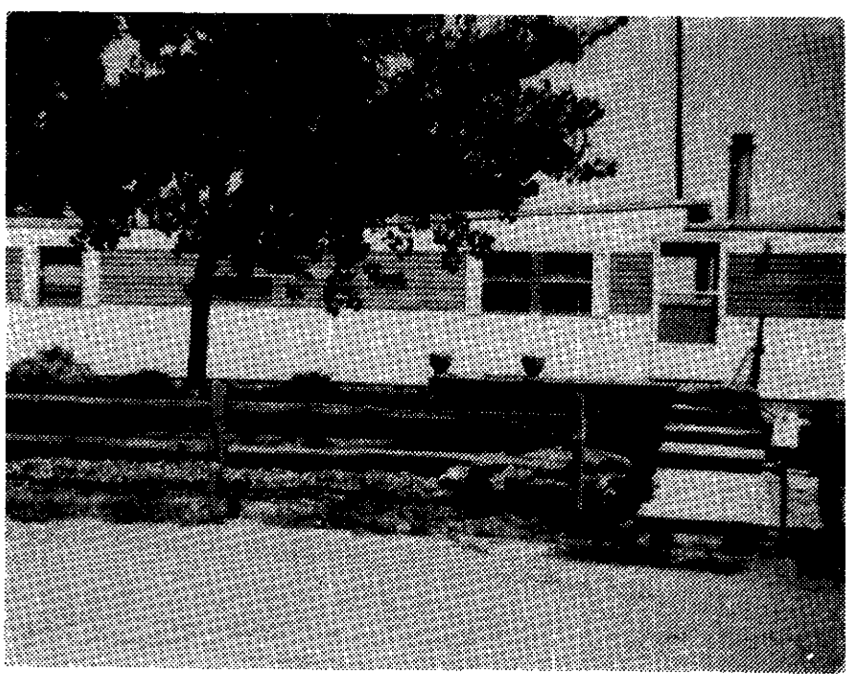


Figure 4.21. Floor is elevated on fill 3.5 feet above 100 year flood limit. La Junta, CO.

FLOODWALLS

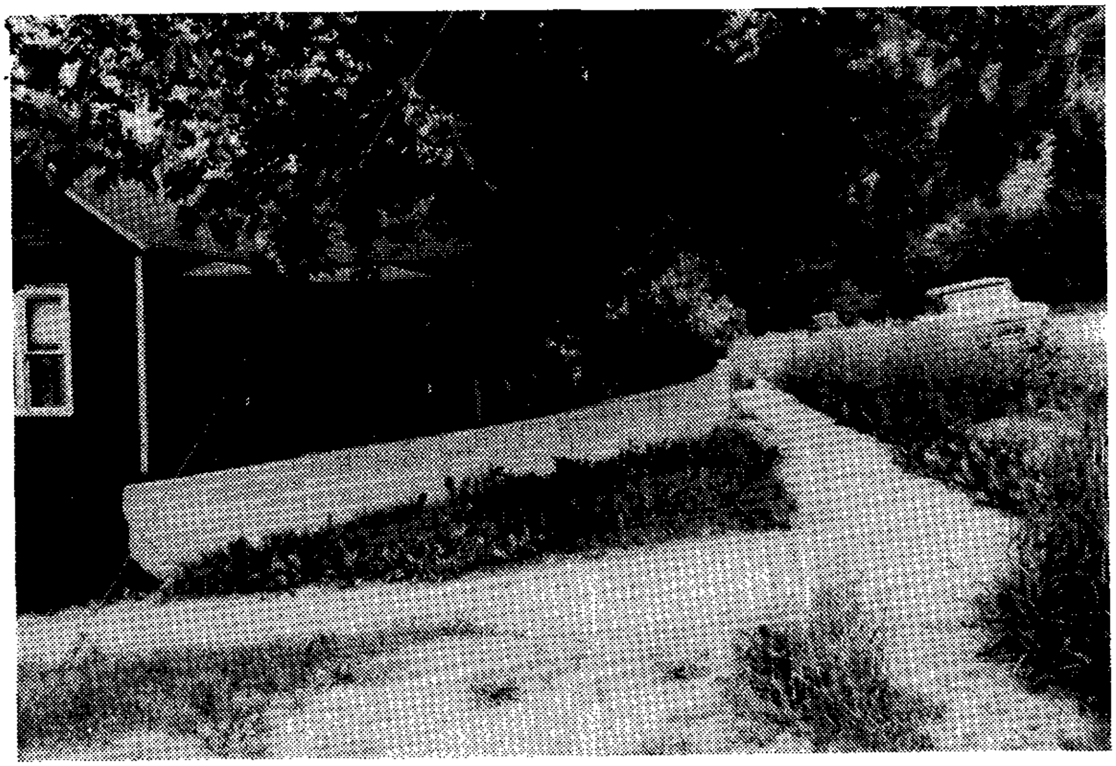


Figure 4.22.Concrete floodwall diverts flow around house, Ouray, CO.

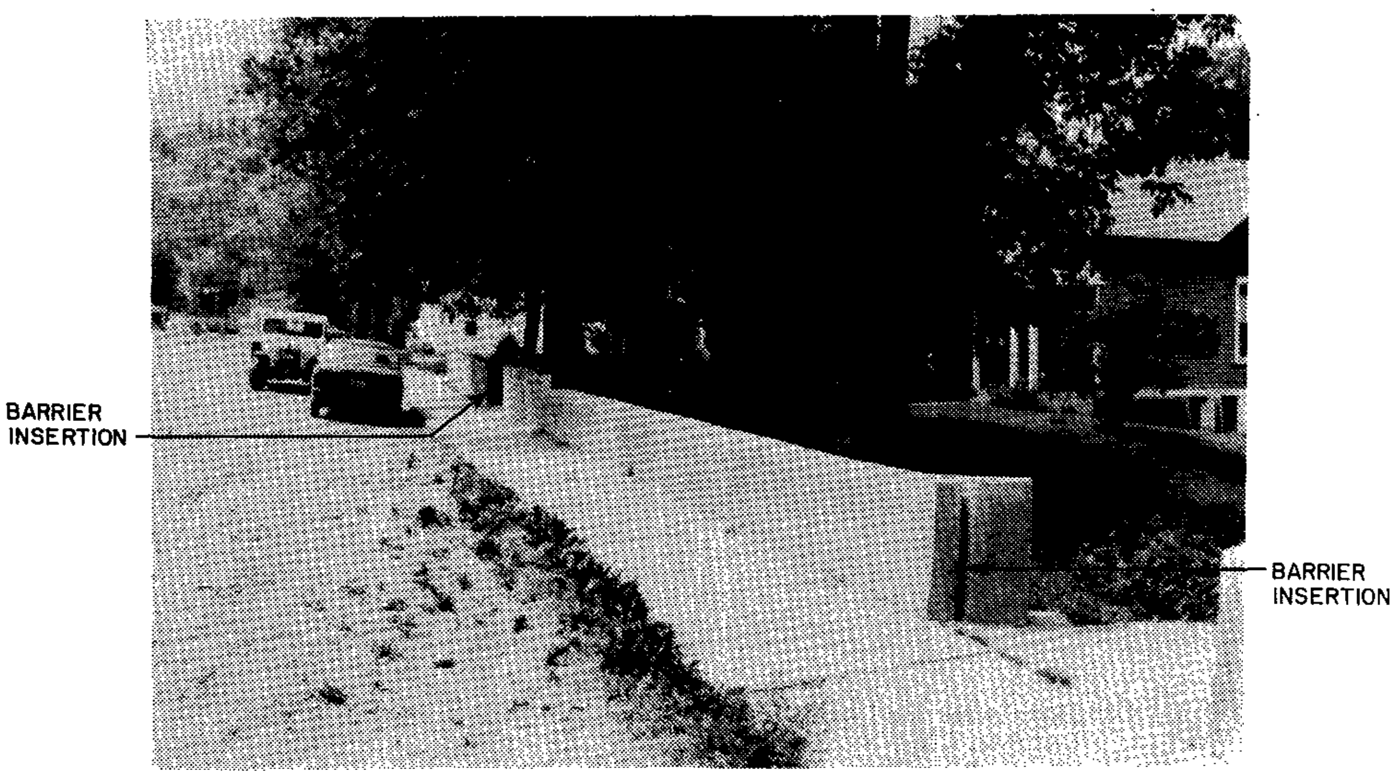


Figure 4.23.Floodwalls equipped to accept barriers across openings. Ouray, CO.

FLOODWALLS AND EROSION CONTROL

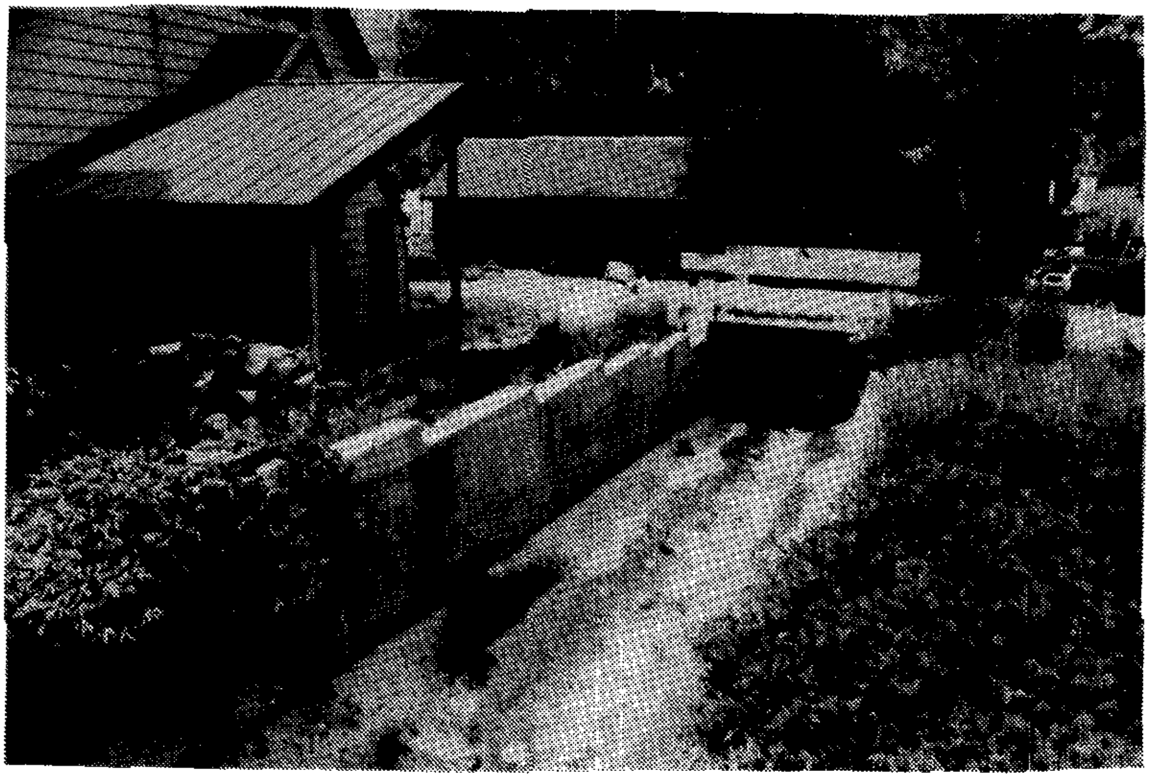


Figure 4.24.The floodway is contained by floodwalls and a concrete streambed. Ouray, CO.

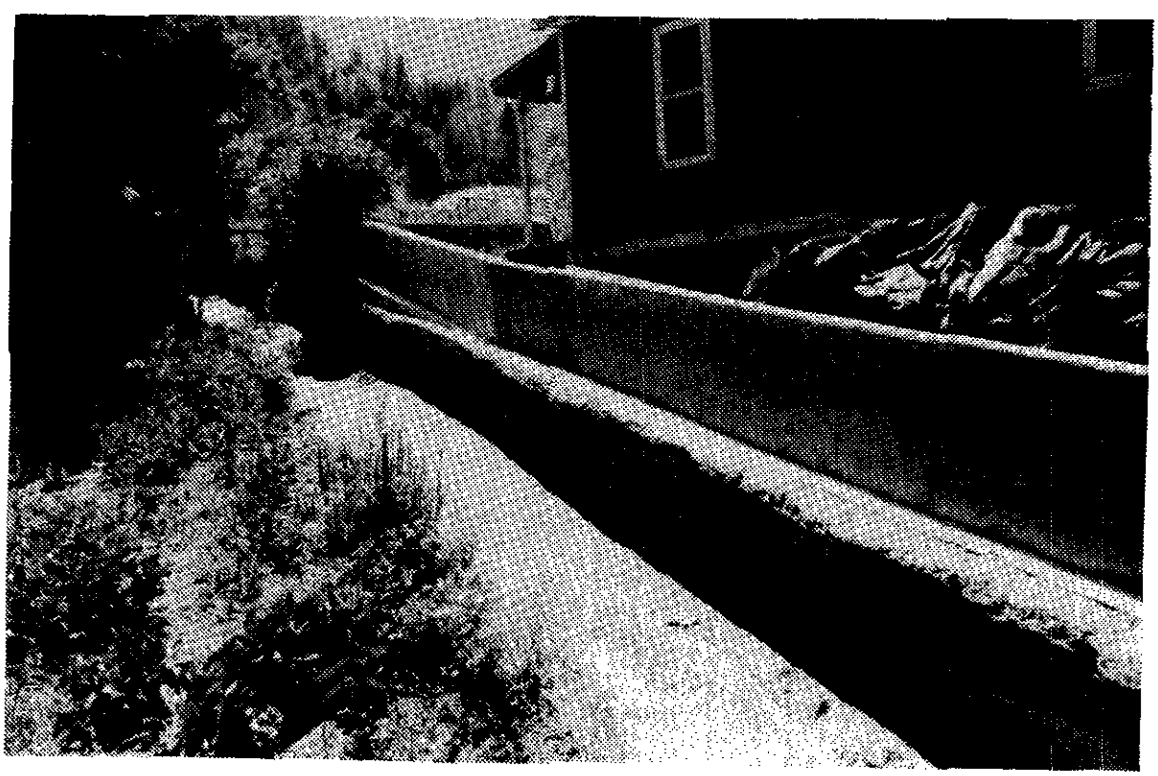


Figure 4.25.Concrete reinforced streambed and sides, with an additional floodwall. The floodwall extends around the front of the house, Ouray, Co.

LEVEES

Figure 4.26. Flood control dike (at center with road) designed for 100 year flood level. Protection for sanitary landfill. St. Vrain River, Longmont, CO.

Figure 4.27. Emergency flood control levee built in spring of 1983 to protect a wastewater treatment plant from a 25-year flood event on the Cache La Poudre River, Fort Collins, CO.

EROSION PROTECTION

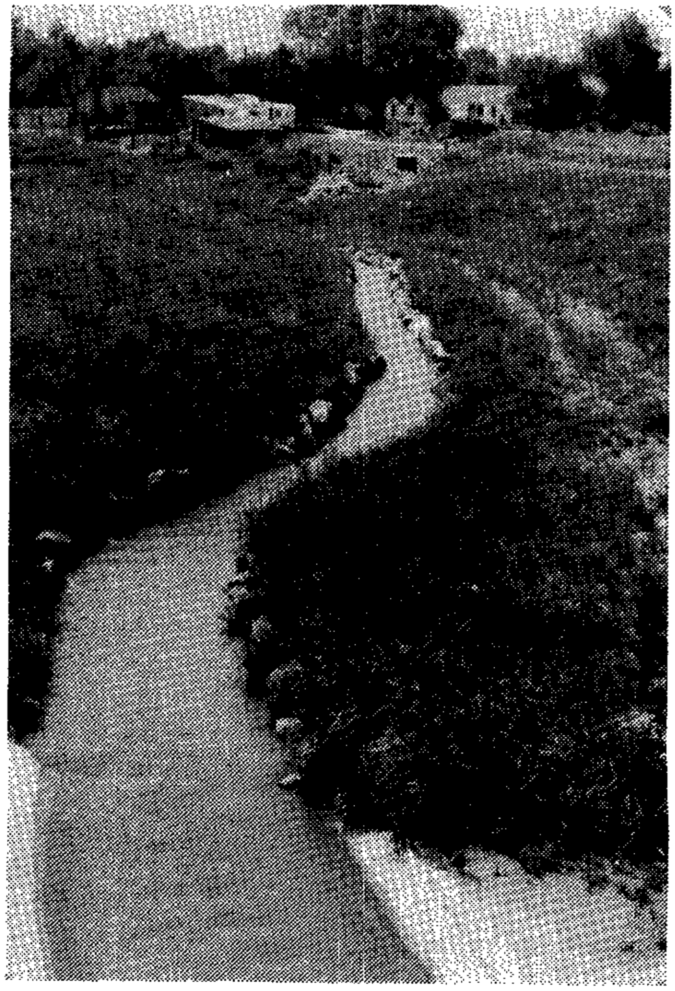


Figure 4.28. Low flow channel lined with rock for erosion control.

EROSION PROTECTION

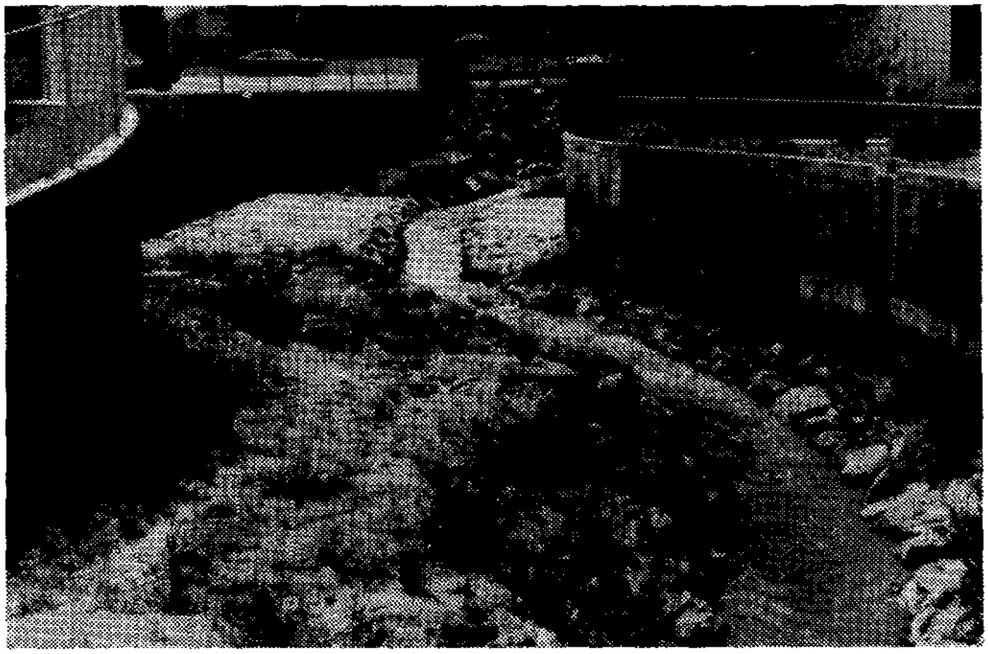


Figure 4.29. Floodwalls in combination with rock streambed lining for floodwater containment.

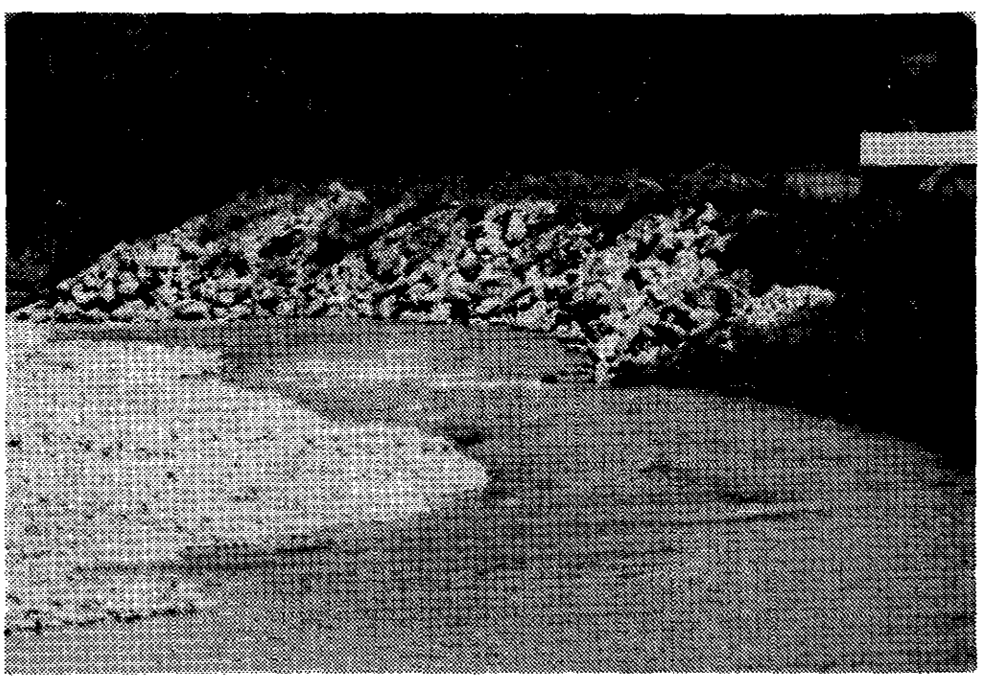


Figure 4.30. Stabilization of the riverbank with concrete rip-rap helps contain floodwaters and minimize erosion.

V. NATURAL AND INHERENT METHODS OF FLOODPROOFING

5.1 *General*

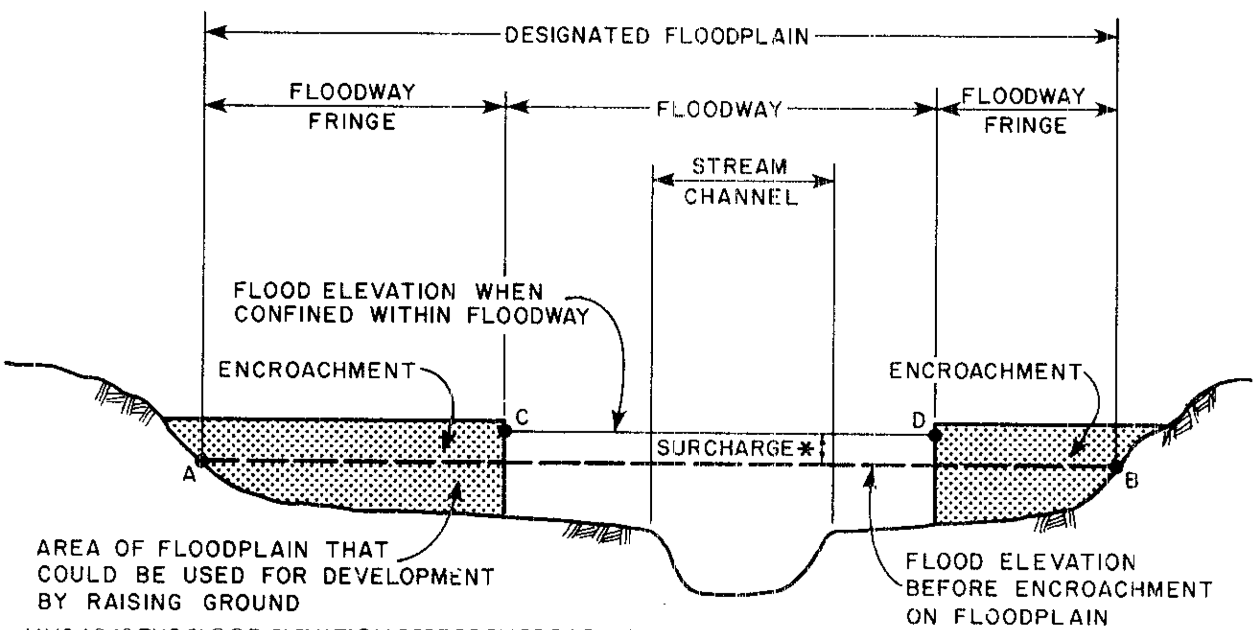
Inherent floodproofing characteristics refer to natural and developed features of a flood plain that in some way provide a degree of flood protection. Natural features include large islands, rock outcrops, shallow areas and thick vegetation. Developed features are structures that already exist in the flood plain from previous development, including embankments that are parallel to or cross the drainage channel and actual streets themselves acting as channels during flooding.

The main purpose in identifying these areas is that they can be incorporated into a floodproofing scheme and used to help minimize the overall costs of floodproofing and the damage that will occur during flooding. Every flood plain has its own characteristics and different features. The features discussed in subsequent sections are typical to many flood plains. However, they are not the only features that could help mitigate flood damage. The main characteristics of all features is that in some manner the velocity and depth of flooding are being reduced.

5.2 *The Flood Plain*

In evaluating the flood plain for development, it is important to know the different regulatory areas within the flood plain. The 100-year flood plain is also referred to as the designated flood plain within the state of Colorado. This is the area of land which is inundated by the base flood (100-year flood). The area outside the base flood that is affected by larger floods or by seepage and groundwater from the regulatory flood and is called the secondary flood hazard area (SFHA). This area of land lies between the 100-year and the 500-year flood plain limit boundaries.

The designated flood plain is broken down into two areas, the floodway and the flood fringe (see Figure 5.1). The floodway is the channel and the adjacent area required to pass flood flows without increasing the water surface elevation by a specified rise criteria above the existing BFE. No development is recommended within the floodway. The flood fringe is the remaining flood plain from the floodway boundary to the boundary of the BFE. Regulations apply to development within the floodway and the flood fringe in accordance with the Model Flood plain Regulations for local governments (Reference 22).



LINE AB IS THE FLOOD ELEVATION BEFORE ENCROACHMENT.
LINE CD IS THE FLOOD ELEVATION AFTER ENCROACHMENT.
*SURCHARGE IS NOT TO EXCEED 1.0 FOOT (FEMA REQUIREMENT) OR LESSER AMOUNT AS SPECIFIED BY STATE.

Figure 5.1. Floodway and floodway fringe

5.3 *Natural Features*

Natural features that can be incorporated as floodproofing include various naturally occurring structures in the flood plain. One very obvious feature is islands that occur within a flood plain which are not submerged during the regulatory flood. Two examples of this feature are shown in Figures 5.2 and 5.3. The figures show two different areas along the Gunnison River. Figure 5.3 shows the actual flood plain boundary around the island. As shown in the figures, it is important that access to such areas be designed and elevated above the regulatory flood.

A second type of natural floodproofing feature is rock outcrops and stone building materials. Large rock outcrops can be used as part of an anchoring system by securing the structure to the outcrop. Large stones are good building materials for both buildings and flood walls. Figure 5.4 shows a picture of the highway maintenance building, constructed partly of rock, which survived the Big Thompson Flood. Other structures that add weight and thus stability include rock chimneys, walls, and stairways. Placed on the downstream side of the structure, they can add significant stability.

Along with rock type structures, large trees and dense vegetation can be used on the upstream side of a building structure to divert flood flows and reduce velocities.

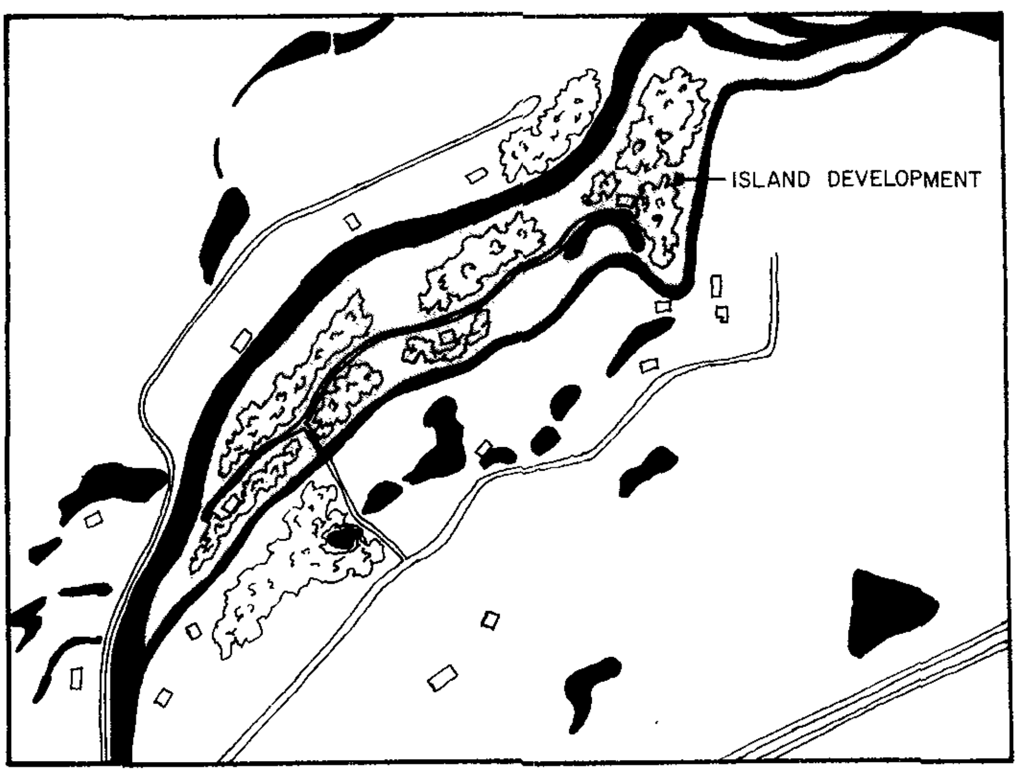


Figure 5.2. Island development

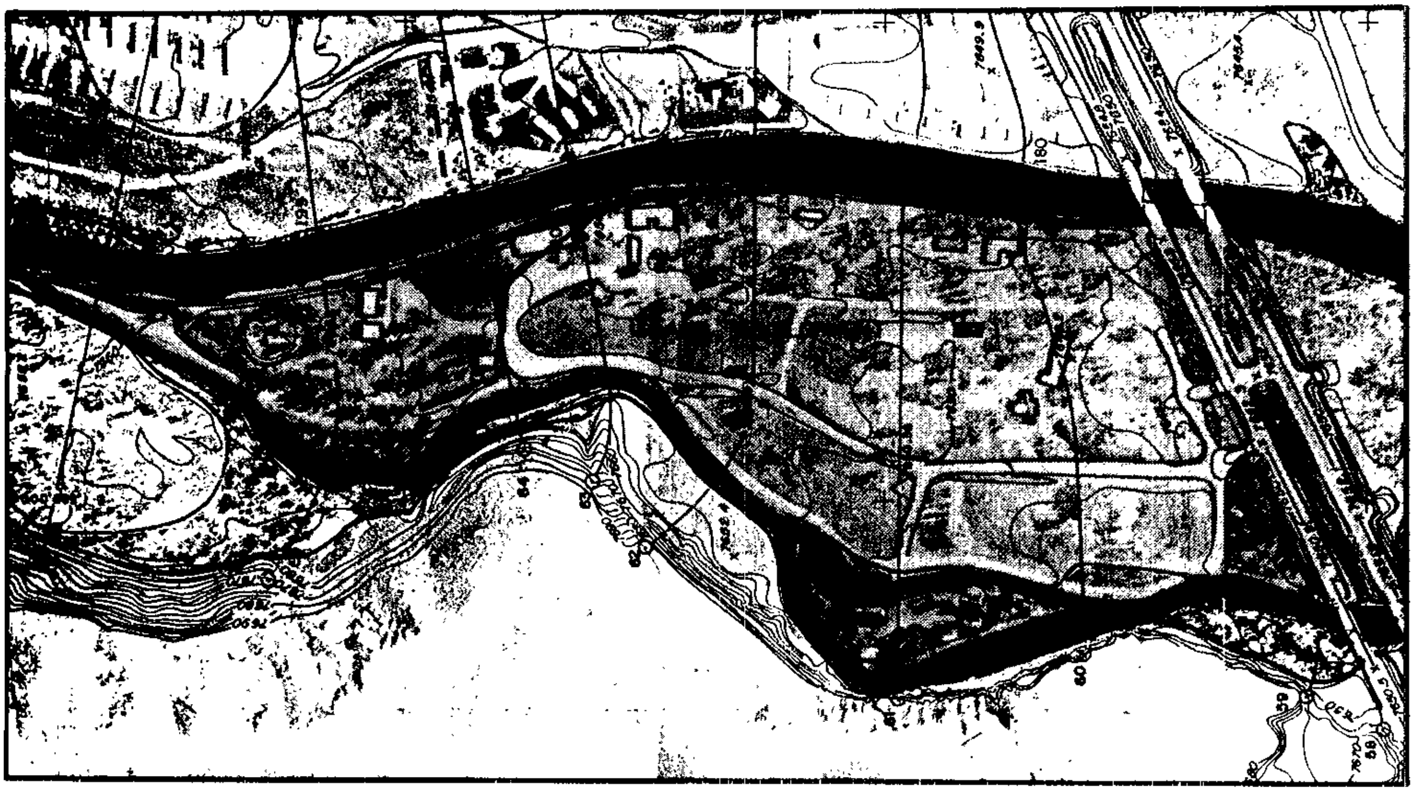


Figure 5.3. Island development

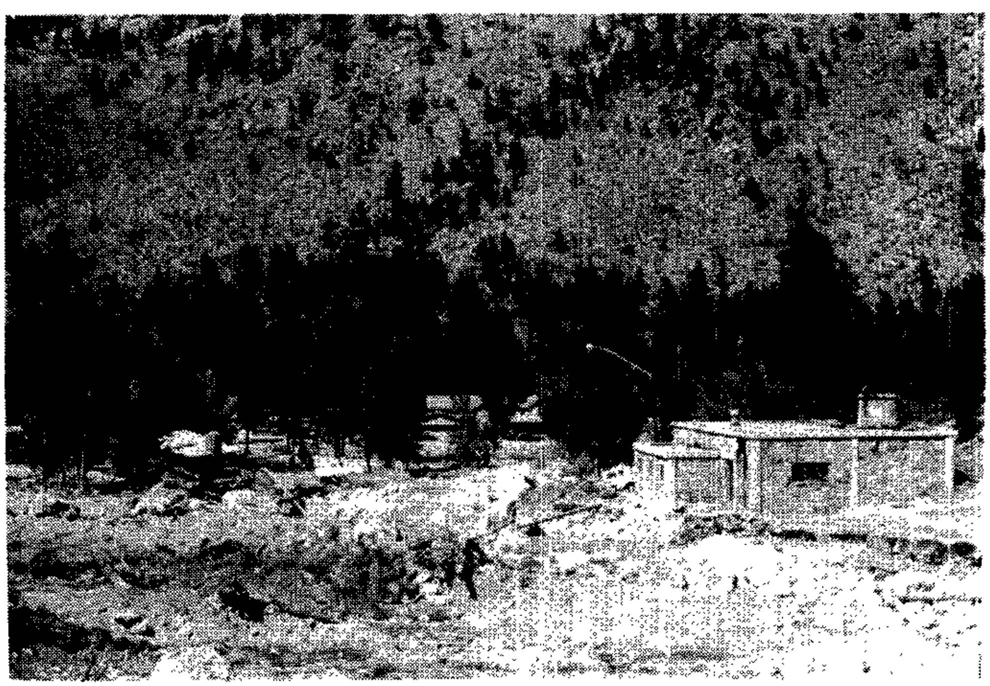


Figure 5.4. This area of Drake was once covered with small houses. The highway maintenance building survived the Big Thompson Flood, 1976. Photo courtesy of David McComb.

5.4 *Development Features*

Development features in the flood plain that reduce flooding can provide added flood protection for floodproofed structures. One of the most prominant features that exist in flood plains are various types of embankments. Highway, streets and railroads all require embankments and are often located parallel to major streams and rivers. Often times these embankments reduce or even eliminate flooding in nearby areas. The areas downstream of embankments generally have lower flood velocities and flood depths outside the main channel. Figure 5.5 shows an example of a large embankment which provides flood control protection on Dad Clark Gulch at Broadway Street Crossing in the Denver metropolitan area.

Another type of development feature that can be considered is streets. Streets by their nature have a capacity to carry water. As the grade increases, this capacity increases. Thus, streets paralleling and draining away from ponding areas can be used to reduce flood depths by eliminating standing and shallow flooding.

Development features to reduce flooding are not being advocated by the preceding discussion. However, when they do exist, the areas that are affected by the reduced flood potential can be considered as potential flood plain development areas.

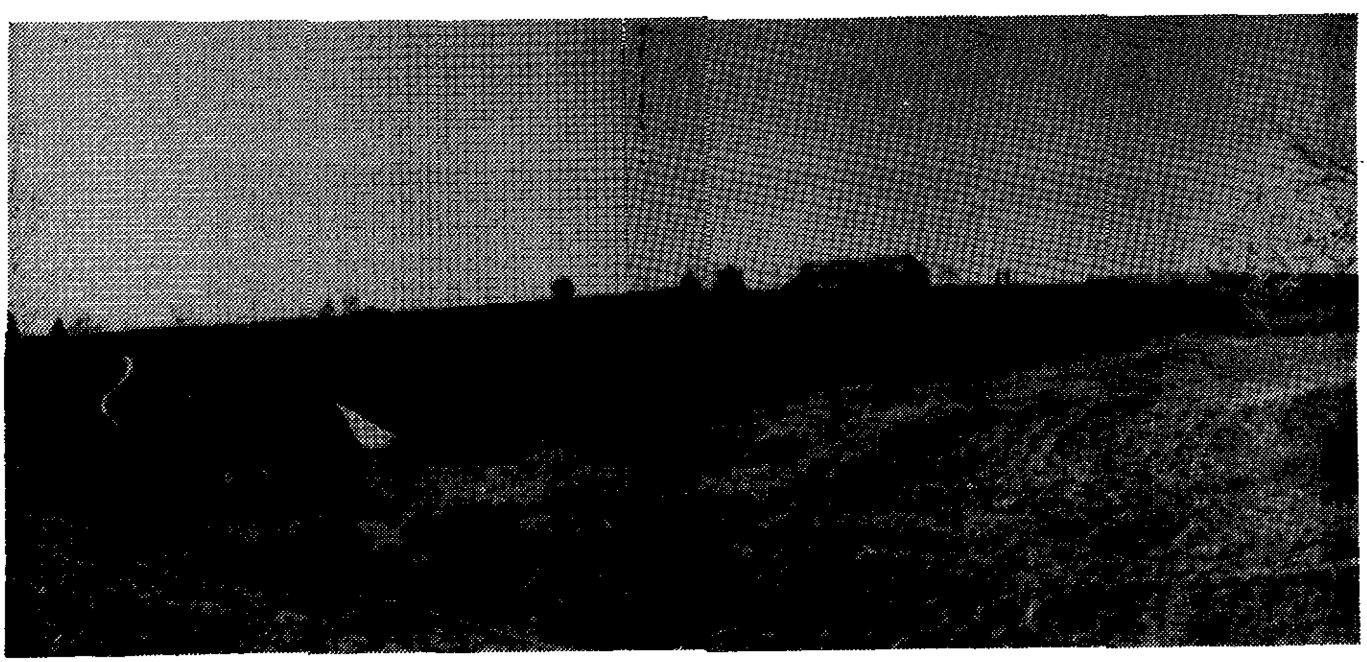


Figure 5.5. A roadway embankement which was designed and constructed to provide 100 year flood control protection to downstream floodplain lands. Broadway roadway crossing of Dad Clark Gulch in Douglas County, Colorado.

VI. WATER LOADINGS

6.1 *General*

Before any significant structure is built, investigation should be done to determine the expected loads that will be placed on it. Not just the magnitude, but also the point of application and the direction of the forces must be determined. The most common loads that are considered are dead load and gravity live load.

Dead load includes the weight of all permanent construction materials, equipment, and forces resulting from prestressing. Live loads act when the structure is in service and vary in magnitude and location. Another type of load, restraint, results from such things as swelling and shrinkage of structural components, differential settling, and creep.

This chapter will define and explain the additional forces which may be placed on a structure by the environment, specifically a floodwater environment. The forces can be of considerable magnitude. As a comparison with hurricane winds, a 100 mile per hour (mph) wind blowing on the side of a house has the same dynamic loading effect as 12 inches of water flowing at a velocity of 10 mph (14.7 fps). It is also possible to have a combination of forces, wind and water, for example, working against a structure at the same time. The structure must, therefore, be able to withstand the sum of all these forces and the normal structural loads already mentioned. The following sections present the additional loading conditions and forces that must be considered when a structure is located in a flooding environment.

6.2 *Hydrostatic Loads*

Water at rest will exert a pressure against a submerged surface. The resulting force is called a hydrostatic load and can occur above or below ground. The magnitude of such a load is equal to the water pressure times the surface area on which the pressure acts. Pressure at any point is equal to the specific weight of water (62.4 lb/ft^3 for average conditions) times the height of water above the point or times the height to which unconfined water would rise above the point. This convention uses atmospheric pressure as the zero datum and is valid for the problems dealt with in this manual. Hydrostatic pressure at any point is equal in all directions and acts normal 2 (perpendicular) to the surface of an object. A simple classification of hydrostatic forces groups them into vertical, lateral, and uplift forces.

6.2.1 *Types of Forces*

Vertical loads are simply caused by the weight of water and act downward on horizontal or inclined surfaces. Lateral hydrostatic loads act in a horizontal direction on vertical or inclined surfaces. They tend to cause lateral displacement or overturning of buildings or other objects. Uplift loads act vertically upward on the underside of objects. The net result of vertical and uplift force is called buoyant force and it always acts upward.

6.2.2 *Application*

Certain types of structures will be greatly affected by one kind of hydrostatic load and may not be affected significantly by other kinds of hydrostatic loading. Consider first a structure elevated on piers above the BFE. The net hydrostatic effect on the piers and structure is negligible. At the other extreme would be a relatively watertight structure totally submerged. All three forces defined above would be contributing greatly to the loading on the structure. A similar example would be an empty storage tank in a flooded basement. If such a situation is anticipated, the anchoring and/or bolting down of the tank may quite easily be designed to withstand the buoyant force. Another type of structure, a floodwall, may have only the lateral hydrostatic load on it if the ground below is not saturated.

The purpose of these examples is to show that it is possible to anticipate the kind of hydrostatic loading that will occur. Once that is determined, a design can be made that will accommodate those loads.

6.2.3 *Methodology*

The basic equations for analyzing hydrostatic forces are presented here. They will be used in examples and applications in the following chapters.

During a flooding condition, the buildup or depth of water a structure is subject to creates a hydrostatic pressure distribution where the pressure p^h acting at a point is

$$p = \gamma \bullet h$$

where p is in pounds per square foot, γ is the specific weight of water (62.4 lbs/ft^3) and h is generally the distance in feet measured vertically downward from the water surface to the point of action (see Figure 6.1). The resultant horizontal hydrostatic force F_H acting per lineal foot on a submerged wall or basement is the total area of the pressure distribution given by

$$F_H = \tfrac{1}{2} p \bullet h = \tfrac{1}{2} \gamma h^2$$

where distance h is from the water surface to the ground level or bottom of the wall, and F_H is in pounds per lineal foot. The resultant force is assumed to act horizontally at a point h/3 from the bottom (see Figure 6.1).

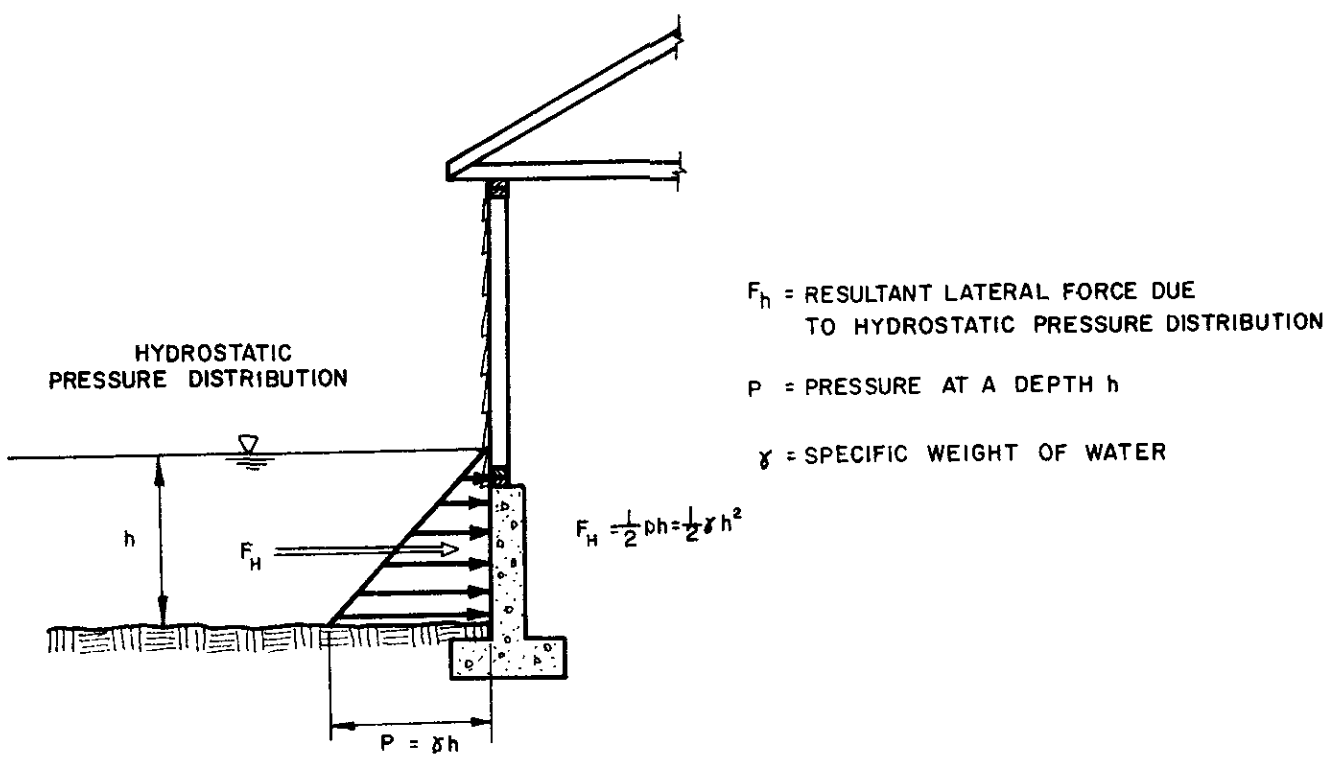


Figure 6.1. Hydrostatic force diagram.

This condition assumes that the structure or wall is completely above ground. When the wall is part of a basement that is below ground, the soil pressure must also be considered. The condition where lateral soil pressure must be considered is discussed later in this section.

The resultant of vertical forces is called uplift or the buoyant force and designated as F_B and is assumed to act at the center of a horizontal area. Buoyant forces are determined by calculating the volume of water displaced by the submerged or partially submerged object. The resultant buoyant force is simply γ times the volume of displaced water. Figure 6.2 depicts a house with a basement subjected to a saturated soil in addition to a water level surcharge equal to h. In this saturated condition, the soil particles are ineffective in transmitting any vertical pressure and the total vertical height of the wall in contact with soil and water is considered submerged, and $F_B = \gamma AH$.

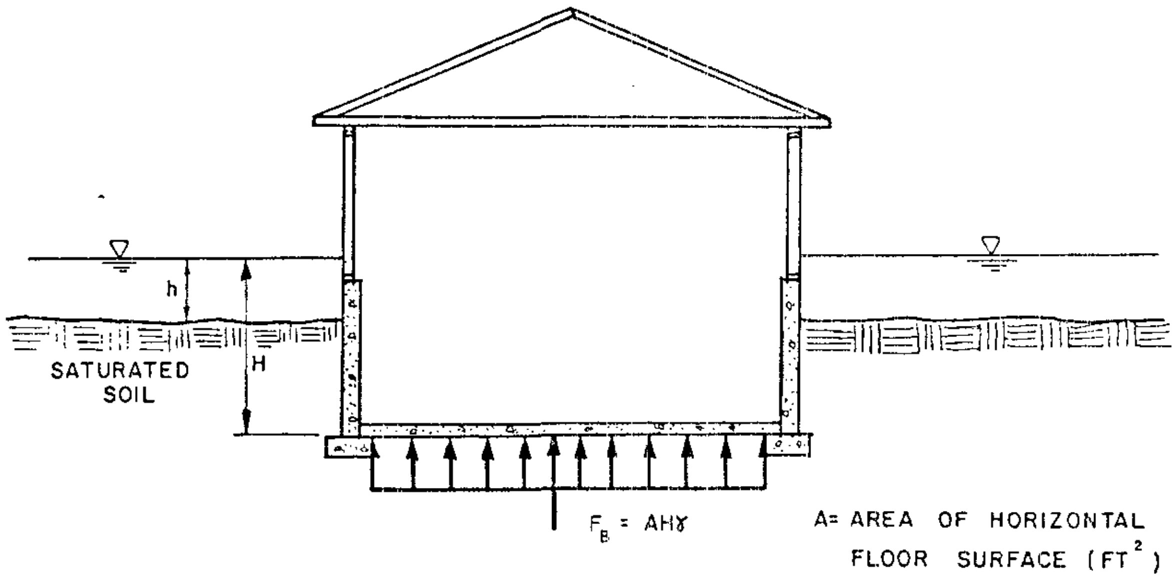


Figure 6.2. Buoyancy force diagram.

The special case of lateral water loading combined with soil loading requires a separate analysis. This situation occurs when 1) flooding is of a duration to allow saturation of the soil or, 2) the groundwater and seepage are above the level of the bottom floor elevation. The most common examples for this condition are structures with basements. The following methodologies to calculate the hydrostatic forces assume saturation of the soil around the structure. Two types of soil conditions are considered; granular and cohesive. For determination of combined soil and hydrostatic pressure, the Rankine Theory for active soil pressure is used. For a detailed discussion of this theory, the reader is referred to Reference 29.

Under normal loading conditions without flooding, the weight of soil around a basement creates a pressure distribution similar to the hydrostatic pressure distribution for water. During flooding conditions, and assuming saturated the effective soils, the effective weight of the soil is reduced due to buoyancy forces on the soil particles and the effective soil pressure is reduced. 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 combined specific weight of water plus the effective saturated weight of soil is called the equivalent fluid weight γ_{eq}. The equivalent fluid weight varies based on the water surface elevation in comparison to the ground surface elevation. Based on a typical basement wall height of eight feet, three conditions are assumed:

Condition One: The surcharge or height of water above ground level (h) is less than 25 percent of the total depth of soil and water loading H (see Figure 6.3).

Condition Two: The surcharge or height of water above ground level (h) s between twenty-five to seventy-five percent of the total depth of soil and water loading H (see Figure 6.3).

Condition Three: The surcharge or height of water above ground level (h) is greater than seventy-five percent of the total depth of soil and water loading H (see Figure 6.3).

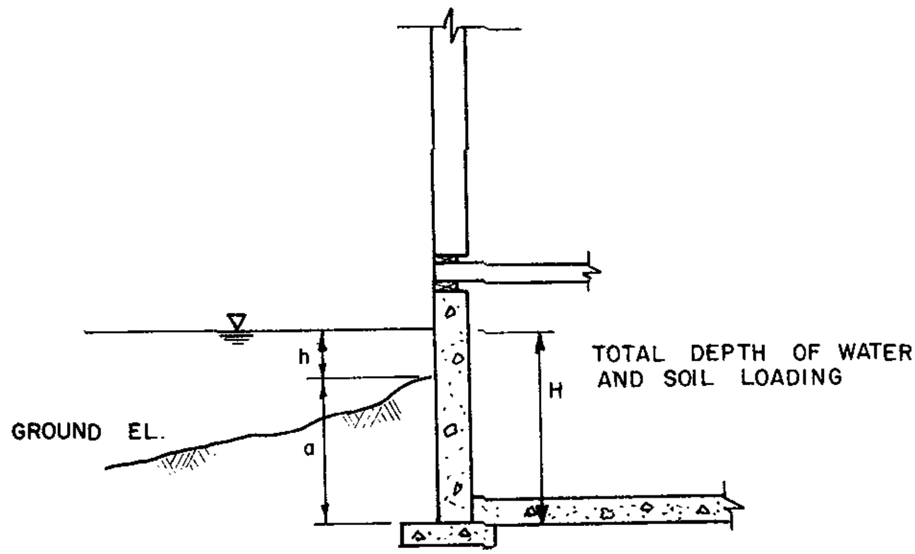


Figure 6.3. Combination soil/water loading.

All three conditions assume that height of surcharge, h, is measured from the water surface to the ground surface (see Figure 6.3) and the total loading height H does not exceed the height of the basement wall or eight feet. For condition one, it is assumed that the water surface elevation and ground elevation are equal (Figure 6.4). For condition two, the soil pressure is compensated for by multiplying the specific weight of water by a factor of 1.15 to obtain the equivalent fluid weight. For the third condition, the soil pressure becomes negligible and the specific weight of water is used for the equivalent fluid weight.

For condition two and three, the resultant horizontal force is calculated as shown in Figure 6.1 except that for condition two, γ_W is increased by a factor of 1.15. For condition one, where the ground elevation is assumed equal to the water surface elevation, the equivalent weight is calculated using the Rankine analysis for soil pressure.

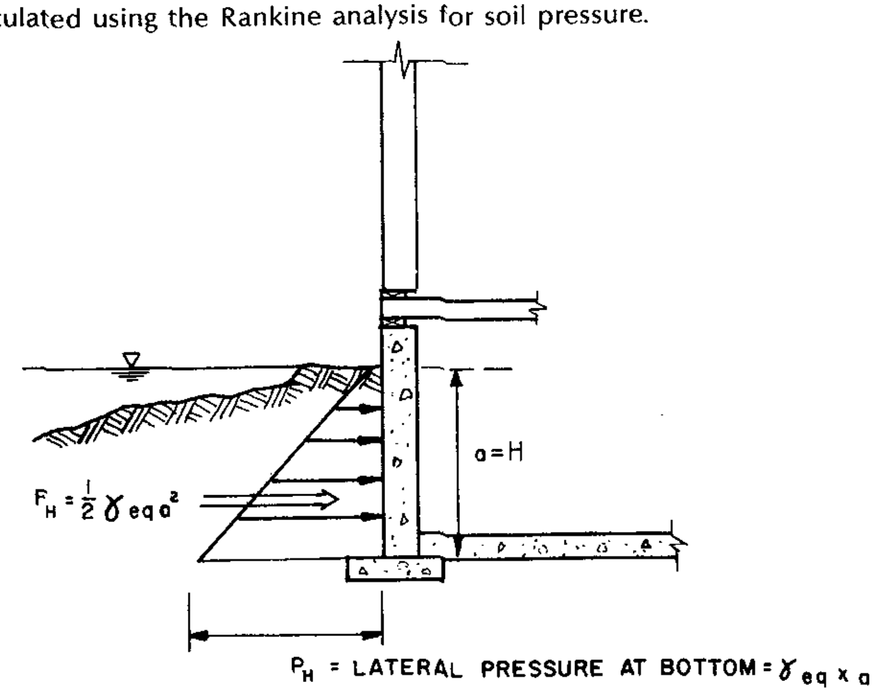


Figure 6.4. Soil/water force diagram.

Example: Calculation Equivalent Fluid Weight Condition One

By the Rankine analysis for a granular soil

$P_H = K_a P_V + P_W$

$= K_a[(\gamma_{sat} - \gamma) a] + \gamma_W a$

for $K_a = 1/3$
$\gamma_{sat} = 120$
$w = 62.4$

$P_H = (1/3 [120-62.4] + 62.4) a$

$P_H = 81.6 a$

Thus, $\gamma_{eq} = 81.6$ lbs/ft03

For cohesive, nonexpansive clays, the equation becomes

$P_H = K_a P_r - \sqrt{K_a}\ 2c + P_W$

$P_H = [K_a (\gamma_{sat} - \gamma_W) + \gamma_W] a - \sqrt{K_a}\ 2c$

$P_H = 81.6 a - \sqrt{K_a}\ 2c$

where K_a = Rankine active lateral pressure coefficient
a = Depth from saturated ground surface to point of pressure interest (ft)
P_H = Lateral pressure (psf)
P_V = Vertical soil pressure (psf)
P_W = Hydrostatic water pressure (psf)
γ' = Effective unit weight of soil (psf)
γ_{sat} = Unit weight of saturated soil (pcf)
γ_{eq} = Equivalent fluid weight (pcf)
c = Unit cohesion (psf) (Determined by laboratory tests on field samples)
γ_W = Unit weight of water (pcf)

Thus for nonexpansive cohesive soils, the net loading is slightly less. It should be pointed out that expansive soils can produce large loads when saturated. However, one should consult a soil engineer when dealing with all types of clay soils. Table 6.1 gives effective saturated soil weights and equivalent fluid weights for various types of soils which are classified in Table 6.2. Table 6.3 again presents the three conditions assumed for application to basement design. The equivalent fluid weights presented in this chapter will be used in Chapter XI for evaluation of basements in flood plains.

6.3 *Hydrodynamic Loads*

6.3.1 General

As water moves around a structure, it creates what is known as hydrodynamic loading. This loading or force is created by the moving water impinging on the structure and thus is highly dependent on the velocity of flow.

6.3.2 Application

The most frequently considered hydrodynamic loads are those that occur above ground where velocities may be relatively high. However, this kind of load can occur below the ground level if openings or conduits exist which allow free flow of the flood water. The important consideration for hydrodynamic loads during floods is velocity. For low velocities, especially below 5 fps, the effect is often relatively insignificant. Water velocities usually decrease with distance from the main channel of a stream. Because of this, the location of a structure within a flood plain may help determine whether to design for hydrodynamic load.

6.3.3 Methodology The equation for dynamic pressure P_d is:

$$P_d = C_d \rho \frac{V^2}{2}$$

where mass density ρ is normally equal to approximately 1.94 slugs/ft³for water. Velocity V is in feet per second and P_d will be in pounds per square foot. The drag coefficient C_d is dimensionless and depends on the shape of the object around which the water is flowing. Studies have shown the maximum C_d for mobile homes is 1.31. Unless a detailed analysis is performed for a particular structural shape, a value of 1.25 should be the minimum C_d used. 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 structure side perpendicular to the flow and the height is the depth of water above the bottom floor of the structure. Table 6.4 gives C_d values for different b/h ratios. Once the hydrodynamic pressure is known, it must be applied over the area upon which the water is impacting.

Table 6.1. Effective Equivalent Fluid Weights.

Soil Type*	Effective Weight of Saturated Soil, γ_{sat}	γ_{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 6.2 for soil type definitions

Table 6.2. Unified Soil Classification System (ASTM - D 2487)*

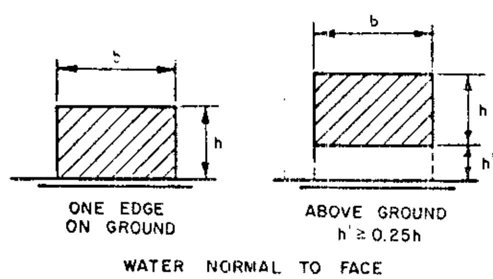
Soil Type	Group Symbol	Description
GRAVELS	GW	Well graded gravels and gravel sand mixtures, little or not fines.
	GP	Poorly graded gravels and gravel sand mixtures, little or no fines.
	GM	Silty gravels, gravel-sand-silt mixtures.
	GC	Clayey gravels, gravel-sand-clay mixtures.
SANDS	SW	Well-graded sands and gravelly sands, little or no fines.
	SP	Poorly graded sands and graveliy 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 or 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, micaceoys 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.

Table 6.3. Effective Equivalent Fluid Weight for Assumed Soil Water Loading Conditions.

Soil-water Loading Condition	Assumption	Yeq
h 0.25 H	Full soil height to elevation of free water surface (a=H)	Table 6a
0.25 h h 0.75H	Ignore soil and apply factor	1.15 x Y_w
h 0.75 H	Ignore soil	Y_w

Table 6.4. Drag Coefficients.



Width to height ratio, b/h		
Wall above ground	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: two feet of water hitting the broadside of a 50 ft by 30 ft house and a velocity of 7.5 fps. Based on depth of water versus width ratio of 25, the C_d factor is approximately 1.3.

$$P_d = C_d p \frac{V^2}{2}$$

$$= 1.30(1.94)\frac{(7.5)^2}{2}$$

$$= 70.9 \text{ lb/ft}^2$$

$$F_D = P_d \times \text{area}$$

$$= 70.9 \times (2) \times (50)$$

$$= 7{,}093 \text{ lbs}$$

The resultant force F_D is assumed to act at the center of its applied area, or at the one foot level_D in the example.

For cases when water velocities do not exceed 10 fps, dynamic effects of the water may be converted to equivalent hydrostatic loads. The calculation is:

$$dh = \frac{C_d V^2}{2g}$$

Acceleration of gravity, g, is 32.2 fps. The depth, dh, is in feet and is added to the design depth of water only on the upstream side of the building. This eliminates the separate treatment of hydrodynamic loads.

For the same previous example used to calculate P_D, the increased water depth for an equivalent hydrostatic load would be:

$$dh = \frac{C_d V^2}{2g}$$

$$= \frac{(1.3)(7.5)^2}{2(32.2)}$$

$$= 1.1 \text{ ft}$$

The effective depth would be 2 + 1.1 = 3.1 feet.

6.4 *Impact Loads*

6.4.1 General

An impact load results when any object or material which is carried by the flood water strikes a structure. It is very difficult to accurately predict the exact effect of impact loads. However, an estimate must be made of these loads when designing a structure in the flood plain. Impact loads may be classified as normal, special and extreme.

6.4.2 Application

Normal impact loads are caused by such things as logs, ice blocks, or floatable objects of a size that are often encountered in flooding. The normal impact load that should be considered for design purposes is a concentrated load acting horizontally at the BFE or at any point below it, equal to the impact force produced by a 1,000 pound mass traveling at the velocity of the flood water and acting on a one square foot surface of the structure.

When large conglomerates of floatable objects, such as accumulation of ice floats or debris, strike a structure, it is known as a special impact load. In an area where these loads may occur, the design intensity should be 100 pounds per foot acting horizontally over a one-foot wide horizontal strip at the BFE or at any level below it. Special impact loads may be ignored if natural or man-made barriers exist which would effectively prevent the loads from occurring on the structure.

Loads which relate to large objects, such as runaway barges or collapsed buildings that are being moved by the water, are classified as extreme impact loads. In the vast majority of cases, it is impractical to design structures to withstand these loads. Therefore, these loads usually are not considered.

Methodology

The methodology is quite simplified using the criteria stated in section 6.4.2. Once the object or mass to be designed for is established, the impact due to the mass is calculated as the mass times velocity divided by the duration of impact. The duration of impact is usually assumed to be one second. Depending on the exact flood plain, characteristics in relation to the amount and type of debris present, a safety factor of 1.5 can be used. Calculation of impact loading is shown in the following example.

Assume a velocity of 5.0 feet per second and calculate the impact load for normal and special impact conditions.

Normal impact load: the normal impact load is a 1,000 pound mass traveling at the velocity of flow.

$$F_I = \frac{MV}{t} \qquad M = \frac{W}{g}$$

$$F_I = \frac{WV}{gt}$$

$$= \frac{1{,}000(5.0)}{(32.2)(1)}$$

= 155 lbs acting on any one foot square surface of the submerged area normal to the flow.

Special impact load: the special impact load is 100 pounds per foot of length normal to the flow. Assume the structure is 70 feet wide.

$$F_I = \frac{MV}{t} \qquad M = \frac{W}{g}$$

$$= \frac{WV}{gt} \qquad W = 100 \text{ lbs/ft} \times 70 \text{ ft}$$

$$= \frac{7{,}000(5.0)}{32.2(1)} \qquad = 7{,}000 \text{ lbs}$$

= 1,087 lbs acting on a one foot wide strip the length of the structure.

F_I = impact load (lbs)

M = mass $[\frac{lbs.sec^2}{ft}]$

W = weight (lbs)

g = acceleration of gravity (ft/sec^2)

6.5 *Erosion Forces*

6.5.1 General

Erosional forces along channel banks and fill embankments are greatly dependent on the direction of flow in relation to the embankment and the magnitude of the velocity. During flooding conditions, the direction of flow can change significantly due to the volume of water and diversion due to obstructions. Also during flooding, velocities are significantly increased and thus the potential for erosion is great.

Another important erosional condition that occurs during flooding is local scour. Local scour is generally caused by reduction in flow area inducing an increase in flow per unit width which results in higher velocities. This reduction in flow area or increase in velocity will occur at the corners of structures, at piers, piles and walls and along embankments that come in contact with the flow.

6.5.2 Application

Erosion and local scour should be a concern for all structures located in the flood plain. Another major concern for structures located close to the channel is bank erosion. However, bank erosion and protection are not within the scope of this manual and the reader is referred to several good references (Simons and Senturk, 1976, Criteria for Channels and Hydraulic Structures on Sandy Soils, 1981). Three general situations that can exist in the flood plain are considered in this section. The methods used are conservative and apply toward an individual structure that is not affected by nearby structures. In many flood plain situations the density of buildings and the diversion of flow from other structures must be considered. Thus, in a flood plain where the density of various structures is high, it is recommended that qualified engineers evaluate the situation.

The three typical situations that apply to different floodproofed structures are waterproofed structures that are at ground level; structures elevated on piers, piles, posts or walls; and structures elevated on fill. Water proofed type structures at ground level (see Figure 6.5) are subject to local scour as water is diverted around the corner of the structure. Piers, piles, posts or walls that are used to elevate structures are subject to local scour (Figure 6.6) and require adequate burial depth or protection against scour. Compacted fill used to elevate structures is subject to erosion along the face of the fill and local scour as the fill impinges into the direction of flow (Figure 6.7).

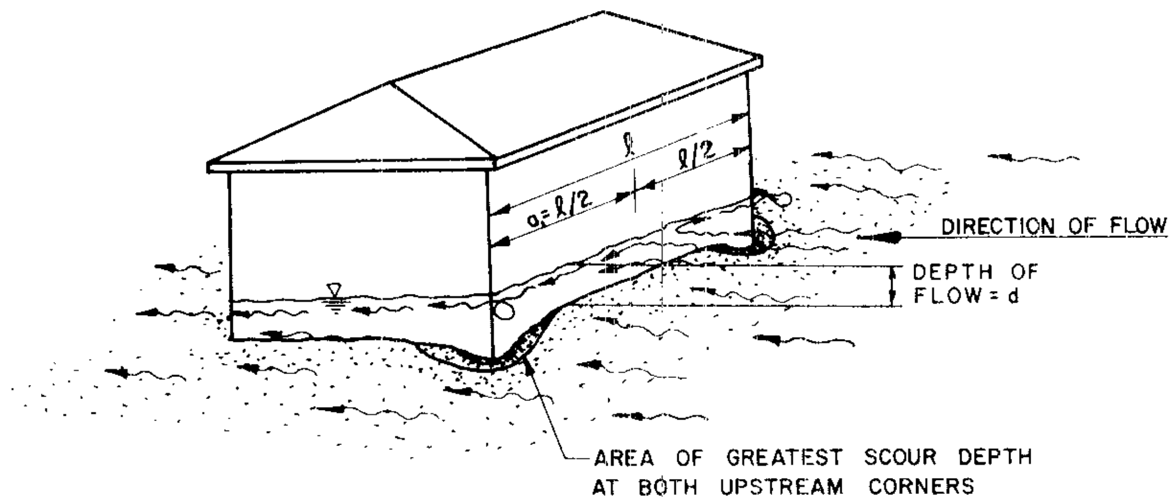


Figure 6.5. Scour action on a ground level building.

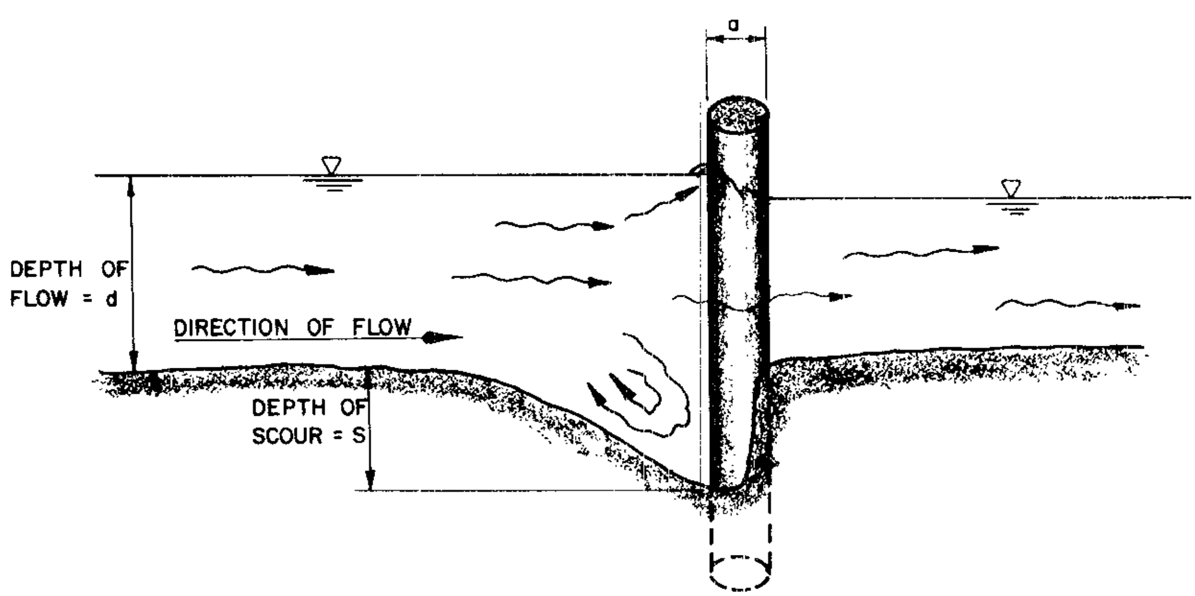


Figure 6.6. Local scoure at piers, piles, posts, and walls.

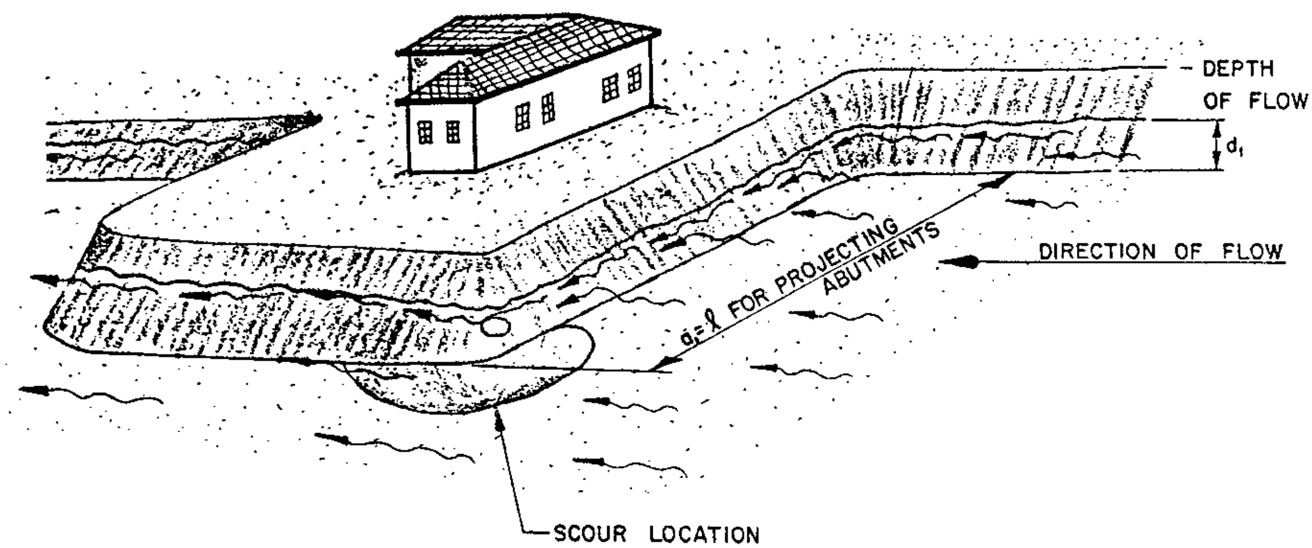


Figure 6.7. Scour on projecting abutments.

6.5.3 Methodology

The theory and physical model testing for erosion and local scour determination has been developed mostly for structures in or along the banks of channels. The major type of structures considered are bridges, embankments and abutments. However, the methodologies developed are quite applicable to the different types of structures in the flood plain. The following equations that estimate local scour are conservative. For very cohesive soils, it is likely that the scour depth will be less. For a detailed consideration of local scour and the development of equations presented here, the reader is referred to Simons and Senturk, 1976 (Reference 35).

6.5.3.1 ***Structures at Ground Level***

The local scour that occurs as flow is diverted around the corner of a building is calculated by

$$S = d \bullet \left[2.2 \left(\frac{a}{d}\right)^{0.65} \left(\frac{V\ 1}{\sqrt{gd}}\right)^{0.43} \right]$$

where S = depth of scour hole (ft)
d = depth of flow upstream of the structure (ft)
a = the flow length measured normal to the overall direction of flow (see Figure 6.5) (ft)
V = the velocity of flow approaching the structure (ft/sec)
g = acceleration of gravity (32.2 ft/sec^2)

Design of the foundation wall depths and/or footings must consider the expected scoure or some means of protection against scour must be provided.

6.5.3.2 ***Piers, Piles, Posts and Walls***

The calculation for scour at piers (refers also to piles, posts and walls) is based on the shape, width and nose of the pier. Three typical shapes that are associated with elevated structures are shown in Figure 6.8.

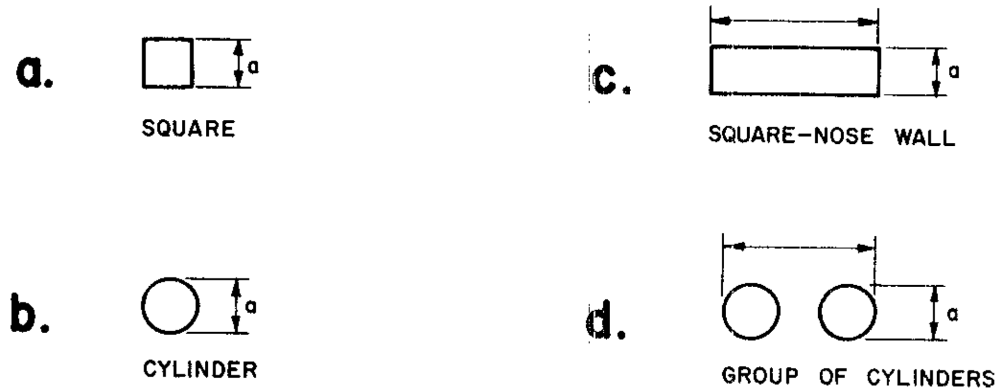


Figure 6.8. Typical pier shapes associated with elevated structures.

The scour at square and circular piers and square nosed walls parallel to the flow is calculated by

$$S = d \left[2.2 \left(\frac{a}{d}\right)^{0.65} \left(\frac{V_1}{\sqrt{gd}}\right)^{0.43} \right]$$

Another concern for walls is the angle or skew to the direction of flow. The estimated depth of scour should be increased by a factor given in Table 6.5 based on the angle of skew θ (Figure 6.9).

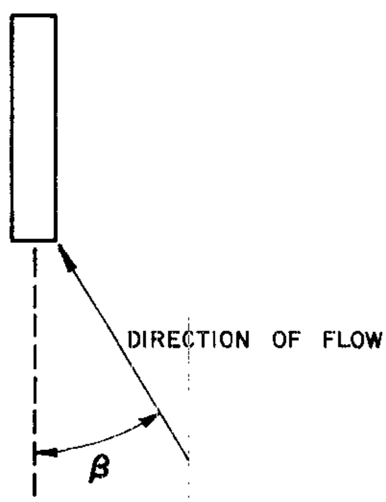


Figure 6.9. Determination of angle of skew attack.

Table 6.5. Multiplying Factors for depth of Scour S for Skewed Walls.

Horizontal Angle of Attack θ	Length to Width Ratio of Pier in Flow			
	4	8	12	16
0	1.0	1.0	10.	1.0
15	1.5	2.0	2.5	3.0
30	2.0	2.5	3.5	4.5
45	2.5	3.5	4.5	5.0
60	2.5	3.5	4.5	6.0

6.5.3.3 ***Fill Embankments***

Local scour at the toe of fill embankments is calculated in the same manner using

$$S = d \ [\ 1.1\ (\frac{a}{d})\ 0.4\ (\frac{V}{\sqrt{gd}})\ 0.33\ ]$$

where a is the distance in feet measured normal to the flow along the impinging edge of the fill (see Figure 6.7).

The second major concern along fill embankments is erosion protection of the fill slope. Particularly errosive currents occur at bends, slope changes, or other transition areas of channel banks. When available in sufficient size, rock riprap is usually the most economical material for protection against velocities greater than 5 fps. Where the velocity is expected to be less then 5 fps, vegetation using various types of grasses should be adequate. When riprap protection is used, an adequate design includes slope of riprap protection, adequate sizing, thickness of riprap and underlying filters. For detailed design of bank protection, the reader is referred to *Urban Storm Drainage Manual, Volume 2* and *Criteria for Channels and Hydraulic Structures on Sandy Soils.* (References 44 and 33, respectively)

6.6 ***Embankment Stability***

Embankment or slope stability is a major concern especially when the conditions result in saturated soils. The following discussion on slope stability is taken from "Floodproofing Non-Residential Structures, Preliminary Draft" (Reference 8).

Slope stability of an earth fill or levee embankment may be defined as the resistance of a given embankment to soil slippage or a tendency to move to a more stable (flatter) slope angle. Slope stability analysis techniques may be used to establish adequate safety factors to ensure that a given embankment will perform in a satisfactory manner. The "safety factor" is generally defined as the ratio of all stabilizing (resisting) forces to the driving forces (the forces tending to cause movement). The slope on the verge of failure is considered to have a safety factor of 1.0. For normal loading cases, an acceptable safety factor would be between 1.3 and 1.5. For extreme loading cases, it may be as low as 1.1. The stability analysis should be performed for the worst loading conditions that are expected to develop.

It is recommended that two modes of sheer failure be investigated, the rotational (Figure 6.10) approximated by circular arc and the translatory slide (Figure 6.11) that occurs along a definite plane of weakness near the base of the embankment.

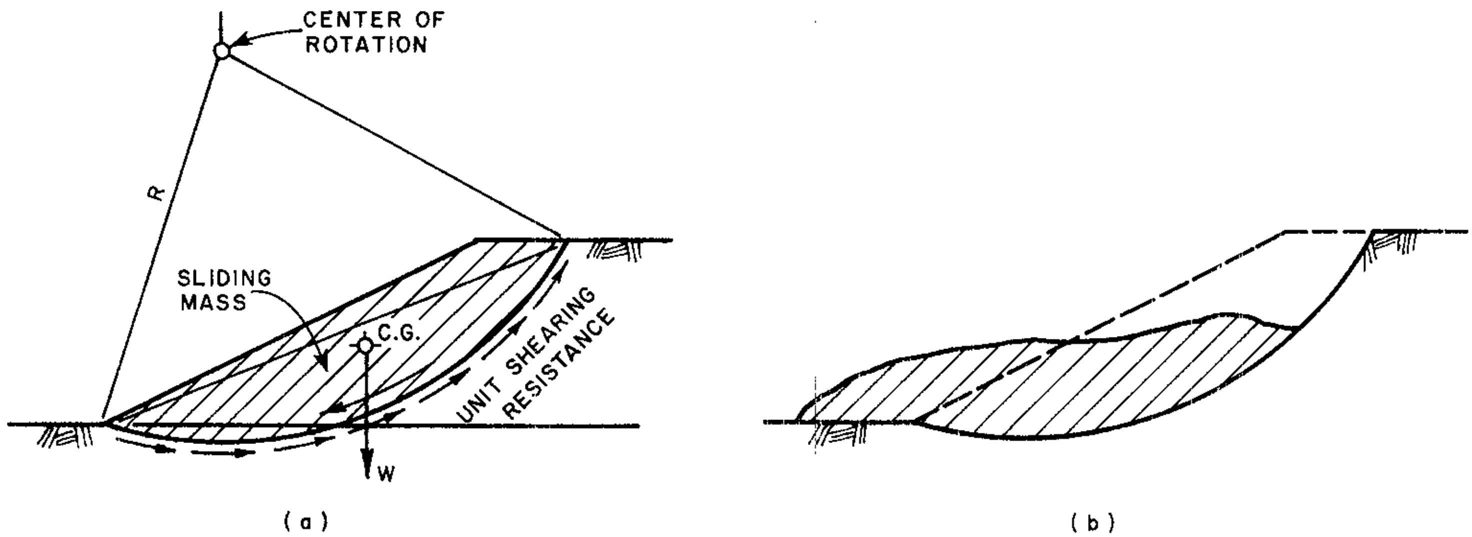


Figure 6.10. Characteristics of a rotational slide. (Reference 6)

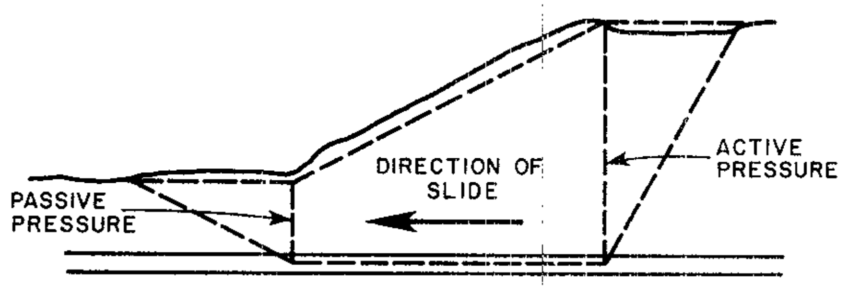


Figure 6.11. Translatory slide. (Reference 8)

Figure 6.10 illustrates a cross section of a sliding soil mass along a curved surface (rotational failure surface). The sliding tendency is developed by the moment of the mass about the center of the arc as shown. This moment is opposed by the total shearing resistance developed along the assumed sliding surface. Of course, when all available resistance is overcome, a progressive failure occurs.

Various numerical procedures, most involving possible curved failure surfaces have been proposed for evaluating the rotational slide, but a high degree of accuracy in defining a failure shape is inconsistent with other inherent features of the analysis (i.e., uniformity of soil, number of boring samples tested, possible judgment in computation of angle of friction or cohesion, the weight of soil, etc.). For this reason, the simple Swedish Slide Method or the Modified Swedish Method (method of slices) among others, are acceptable analysis techniques. Most geotechnical engineering firms have access to computer programs that can quickly evaluate embankment stability if a detailed analysis is required.

For more detailed information relating to slope stability analysis and other embankment design considerations, the reader is encouraged to refer to *Design and Construction of Levees*, EM 1110-2-1913 as published by the U.S. Army Corps of Engineers (Reference 40). However, for preliminary design and cost estimating purposes, a slope stability analysis is not generally required if standard slopes are maintained. The steepest slope that should be considered without detailed studies is a 2:1 slope ratio (2 horizontal to 1 vertical unit). Where conventional mowing equipment must be used to maintain the embankment, slopes should generally not exceed a 3:1 slope ratio and 4:1 is perferred. Riverside slopes may be less steep than the ranges presented above if erosion damage from waves or high velocity floodwaters is anticipated.

6.7 *Discussion*

The proceeding sections presented general discussion, application and methodology for calculating the loadings that must be considered in a flood environment. The main purpose of Chapter VI was to identify the additional loadings created during flooding and provide the methodology necessary to estimate the actual forces involved. This chapter also provides the background necessary to evaluate structural requirements for basement walls and floor slabs (Chapter XI) and tie-down requirements for mobile homes (Chapter XIV).

Although this chapter is technically oriented, the calculations are relatively easy to follow. Normal structural requirements of dead, live, and restraint loads must be considered along with the conditions imposed by flooding. A structure may be subject to hydrostatic, hydrodynamic, and impact loads. Erosion forces can occur along channel banks and fill embankments, while scour can locally erode the soil supporting a footing or foundation. Forces present in saturated soils can threaten the embankment stability of earth fills and levees. Table 6.6 summarizes the loadings that must be considered under flooding conditions. Application of these loadings can provide the developer with enough information to conceptualize floodproofing requirements and do an economic evaluation. Simple calculation of these loadings can also provide planning and regulatory persons information to check or review design loads used by designers.

Table 6.6 Loading Summaries under Flooding Conditions.

Load	Cause	Action
Hydrostatic	Weight of Water	Exerts pressure against submerged surface.
Lateral (F_H)	Weight of Water	Acts in horizontal direction on vertical or inclined surfaces.
Vertical (F_V)	Weight of Water	Acts in vertical direction on horizontal or inclined surfaces.
Buoyant (F_B)	Volume of displaced water	Acts upward on horizontal or inclined surfaces.
Hydrodynamic (F_D)	Moving Water	Exerts pressure on submerged surfaces.
Impact (F_I)	Floating debris	For of floatable object striking a structure.
Erosion	Velocity and direction of flow	Earthen fills, embankments are washed out.
Scour	Local reduction in flow area, increase in velocity	Severe erosion at corners of buildings and embankments, around piers, piles, and walls.
Embankment Stability	Increased weight of saturated soils	Slope failure or soil slippage of earth fills, levees.

VII. DESIGN CRITERIA FOR STRUCTURES

7.1 *General*

This chapter identifies general types of floodproofing construction and critical areas of concern for each. Floodproofing methods can be as varied as the hundreds of sites subject to flooding in Colorado; therefore design criteria for typical floodproofing methods are presented here. This will give a better understanding of what can and should be done in flood-prone areas.

Elevated structures, waterproofed structures, levees, and floodwalls are all frequently used in flood hazard areas. They are defined in the following sections. A freeboard requirement (in feet above the BFE) has been established for all of these methods. Table 7.1 presents the freeboard for each method. For a discussion of concrete and block masonry walls, the reader is referred to Chapter XI.

Table 7.1. Freeboard Requirements.

Freeboard (ft above BFE)	Type of Floodproofing
4	Dike or levee system 100 ft. upstream of a roadway embankment or bridge.
3	Dike and levee system for community protection.
1	Flood plain regulations.
1	Building site fill.
1	Closure of openings.
1	Floodproofing design of individual structures.
1	Retaining walls and/or floodwalls for individual structures.

7.2 *Elevated Structures*

The starting point for design of a structure in a flood-prone area is the consideration of site conditions. So it is with deciding on a technique to be used for elevating a structure.

In many cases, the most important site factor will be flood elevation. This will influence or may even dictate the landscaping measures as discussed in Chapter III and foundation design as discussed in basement design, Chapter XI. Direction of flood flow is also important and the surface area of walls exposed to flowing flood waters should be minimized when orientating a new building.

Methods available for elevating structures are many. They include raising on fill or raising on stilts such as posts, piles, piers, and walls.

7.2.1 *On Fill*

Elevating a structure on fill so that construction is above the design flood can be a good method for protection from flood damage. However, the fill material cannot generally be placed within a designated floodway for compliance with state and federal regulations.

If a structure on fill contains a basement and soil saturation is probable, hydrostatic pressures must be considered as explained in Chapter XI. For other structures, with all construction above the water level and saturation point, the critical component in this kind of design is the earth fill.

7.2.2 *On Stilts*

Sometimes when a structure is to be elevated, there are reasons why it should not or cannot be raised on fill. In some places, adequate fill material may not be available near the site. Also, as was mentioned, fill cannot be placed where it would encroach onto the floodway. A third reason for not elevating on fill relates to function. The space below an elevated structure may be used for some purpose such as parking.

Elevating on posts, piles, piers, or walls may be considered if one of the conditions above exists. The most important factors when designing these kinds of supports are superstructure loads, hydrodynamic loads, and impact loads as explained in Chapter VI. The structure should be raised high enough that water does not reach the lowest floor level. Buoyancy, then, becomes a less significant factor.

7.2.2.1 ***Posts and Piles***

Both posts and piles consist of long slender columns made of wood, steel or concrete. The round, square, or rectangular section is the most common of many available shapes. Posts are set in predrilled or predug holes, and then a backfill is placed. Using concrete for a portion or all of the backfill will increase stability. Pile supports differ in that they are mechanically driven into the ground. Vertical loads are supported by friction between the pile surface and the soil, and also by the end bearing capacity.

The depth of embedment for posts and piles is determined by soil conditions, anticipated loading and scour, and the spacing and size of the members. Wood posts are generally embedded deep enough to establish required bearing forces. Bearing forces depend on several soil characteristics and determination should be done using standard soil engineering procedures.

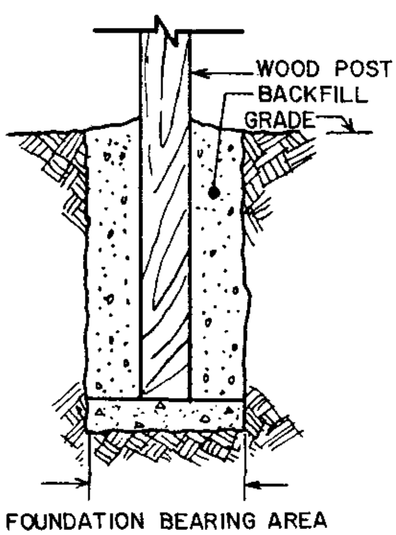


Figure 7.2.Concrete pad to increase bearing area. (Reference 7)

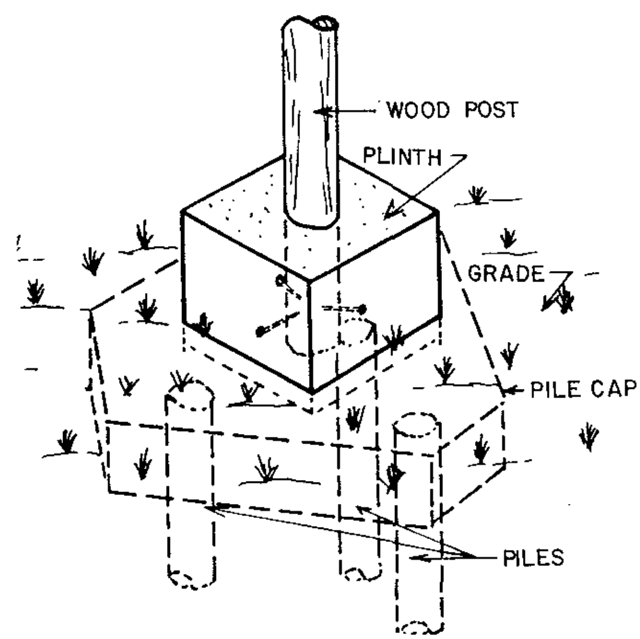


Figure 7.3.Post set on piles for very poor soils. (Reference 7)

Soil testing of a proposed fill area should be performed to establish bearing capacity of the foundation soil and requirement for the fill soil. Potential settlement should also be investigated with soil tests. The best preventive tool against excessive settlement is to ensure proper compaction when placing the fill material.

Soils with the best characteristics for use in a structure-supporting fill are well-graded sands and gravels, which may contain a small percentage of fine clay material. Undesirable soils include the highly plastic, swelling clays and also soils which are difficult to compact - cohesionless silts and very fine uniform sand. With proper methods, most inorganic soils will create an acceptable fill.

After a suitable fill material has been identified, placement should be done at or near the optimum moisture content for compaction. Using appropriate compaction equipment, such as pneumatic or sheepfoot rollers, the fill should be placed in layers no greater than 13 inches thick. Compaction 3 to 95 percent of the Standard Proctor density (defined below) in accordance with standard engineering practice will suffice for most building applications.

Standard Proctor(ASTM D 698-78, AASHTO T - 180-74): Twenty five blows of a 5.5 lb hammer falling 12 inches on each of three equal layers in a four inch diameter 1/30 ft3 cylinder.[c] The effort is 12,400 ft-lb/ft3, which is comparable to light rollers or very thorough tamping in thin layers.

[c] If the soil contains many particles larger than a No. 4 sieve, a six-inch diameter cylinder of the same height is used and the blows increased to 55 per layer.

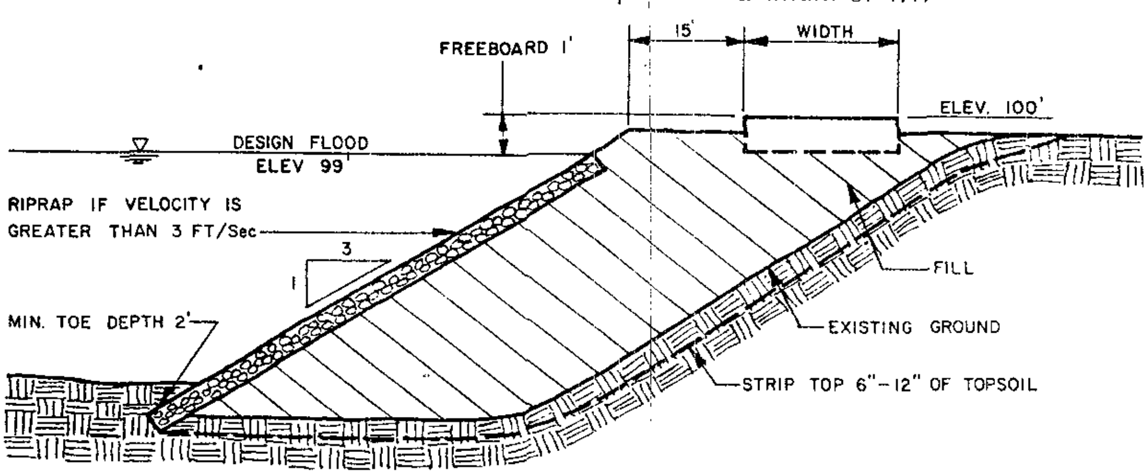
Figure 7.1 shows the geometry for a typical raised-on-fill construction. Some very general recommendations are given here

1.Local code requirements may vary, but the finished floor elevation should be a minimum one foot above the BFE.

2.Riprap should be placed on the slopes if the stream velocity will exceed three fps. General riprap requirements call for 12" to 24" mean diameter riprap with a unit weight from 150 to165 pounds per cubic foot, placed in a layer at least 1.75 times the mean diameter (Reference No. 44).

3.The minimum horizontal distance that the fill should extend beyond the exterior of the structure should be 15 feet. There is also an OSHA requirement for emergency exits.

4.Slope stability calculations are best done by a professional engineer with the specific soil parameters. Recommended fill slopes for riprap lined embankments are 2.5:1 to 3:1. For vegetation lined embankments the recommended fill slope is a maximum of 4:1.



FOR MOST SITUATIONS, ASSUME A RIPRAP LAYER OF 1.75 TIMES THE MEAN DIAMETER STONE.

Figure 7.1. Geometry for raised-on-fill construction

For large loads and/or poor soil conditions, a concrete pad should be placed in the bottom of the hole. This increases the bearing area and capacity as shown in Figure 7.2. For very poor soil, it may be necessary to use a group of piles and a pile cap to support each post as shown in Figure 7.3.

Possible backfill material includes sand, gravel, crushed rock, soil cement, concrete, and earth. Soil cement can attain strength nearly equal to concrete and is made by mixing earth with cement in a 5:1 ratio (earth:cement). All organic matter should be removed from the soil prior to mixing. If an earthen fill is used, it should provide good drainage away from the posts or piles so that deterioration is minimized.

By anchoring the posts, more resistance to overturning and uplift will be provided. A properly designed pile support will have sufficient frictional capacity such that added anchoring is not needed.

Posts may be anchored by either embedding them in concrete or fastening them to metal pieces which are embedded in concrete. Two methods are shown here (Figure 7.4). In either case, posts must be braced until the concrete sets.

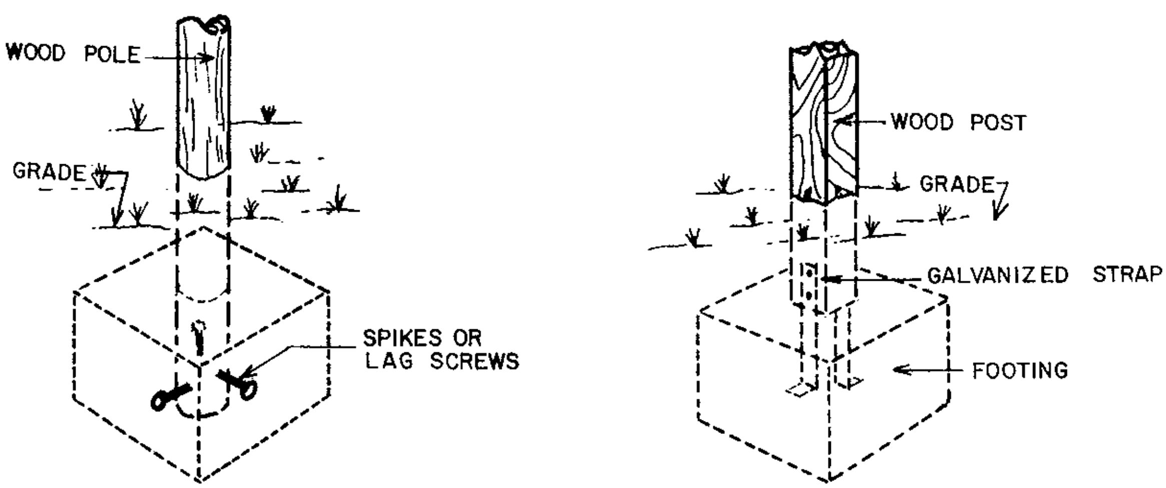


Figure 7.4.Posts anchored to concrete. (Reference 7)

If a post or pile system is incapable of resisting the expected lateral loads on their own, permanent bracing must be added. Two of the several methods are pictured here. The knee brace (Figure 7.5) is 2" by 6" lumber nailed or bolted between the floor joist and post or pile. Cross bracing is similar but extends from the top of one post or pile to the bottom of the adjacent one. Figure 7.6 shows cross bracing with the use of threaded rods. Such bracing should be in a plane parallel with the flood flow for the least obstruction, least potential for trapping debris, and most efficient use of material.

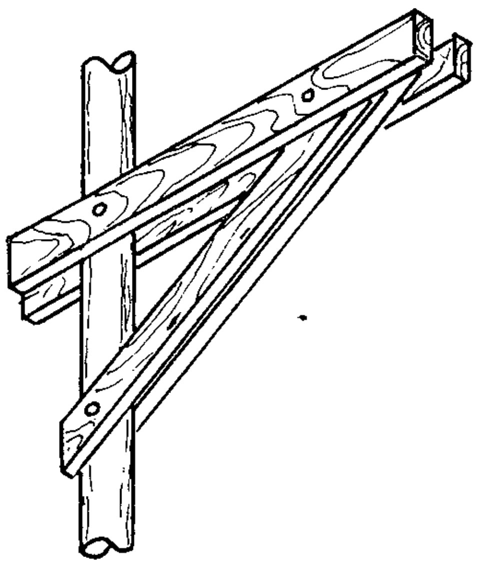


Figure 7.5. Knee brace (Reference 7)

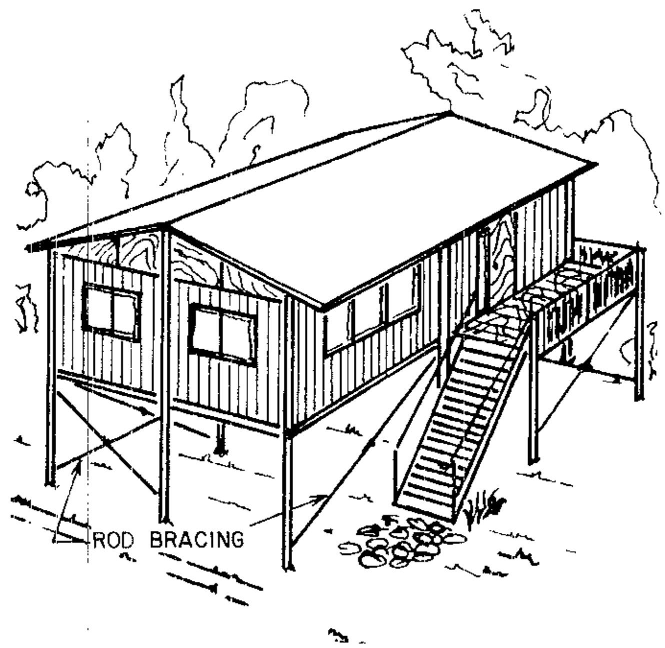


Figure 7.6. Cross bracing with threaded rods. (Reference 7)

There are two basic methods used to connect post or pile foundations with the framing system of a structure. The platform method involves cutting the post or pile off at the first floor elevation and having it directly supporting the floor beams. Posts or piles may also be extended up to the roof. This is known as pole frame construction. An advantage of this second method is that by connecting the posts at floor and roof level, strength is added against lateral loads. However, the method is mainly restricted to posts, because it is difficult, and sometimes impossible, to align piles so they fit well with the framing.

7.2.2.2 *Piers*

Piers are another type of stilts used to elevate structures in flood prone areas. They consist of columns made with brick, concrete, or concrete block, all of which must be reinforced. It is strongly recommended that an engineer be consulted for design of piers foundations. Minimum pier requirements are shown in Table 7.2.

The pier footing design will depend greatly on the soil bearing capacity. Along with bearing capacity, another consideration is footing depth, which should extend below the frost zone and below the anticipated scour depth. Certain soils undergo high volume changes. If this kind of soil is present, the design of footings and footing depth is further complicated. It is important, then, to get advice from a professional engineer. Footings, where needed, must always be adequately tied to the column by the reinforcement, as shown in Figures 7.7 and 7.8. The figures also show the anchoring elements used to make connections with the floor beams.

Table 7.2 - Minimum Pier Requirements

			Pier Spacing		
Pier Material	**Minimum Pier Size**	**Minimum Footing Size**	**Right Angle to Joints**	**Parallel to Joints**	**Useful Elevation Range**
Brick	12" x 12"	24" x 24" x 8"	8' o.c.	12' o.c.	18" to 6'
Concrete Masonry	12" x 12" or 8" x 16"	24" x 24" x 8" 20" x 24" x 8"	8' o.c.	12' o.c.	18" to 8'
Poured-in Place Concrete	Min. 12" dia. or 10" x 10"	20" x 20" x 8"			18" to 12'+

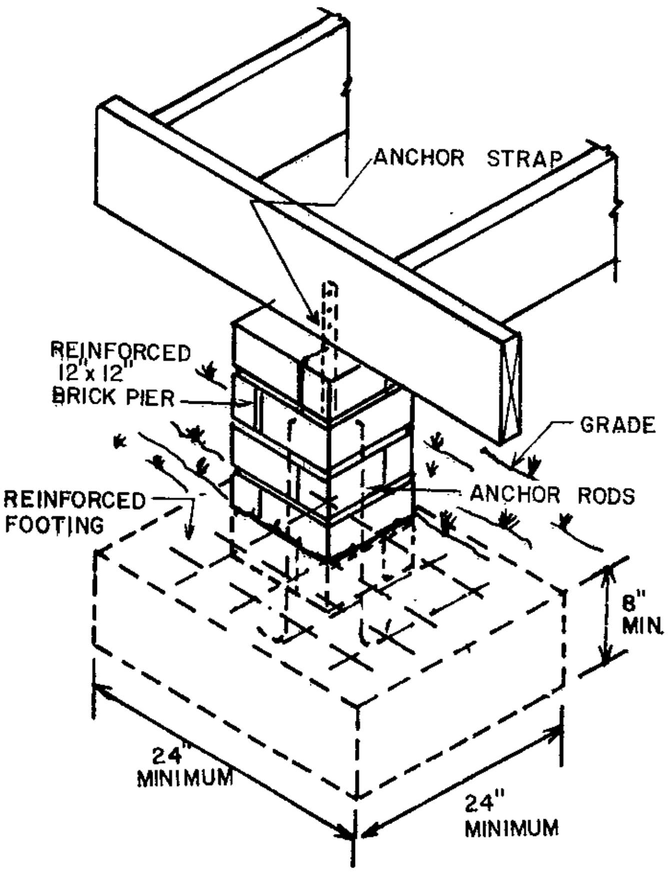


Figure 7.7. Column tied to footing with reinforcement. (Reference 7)

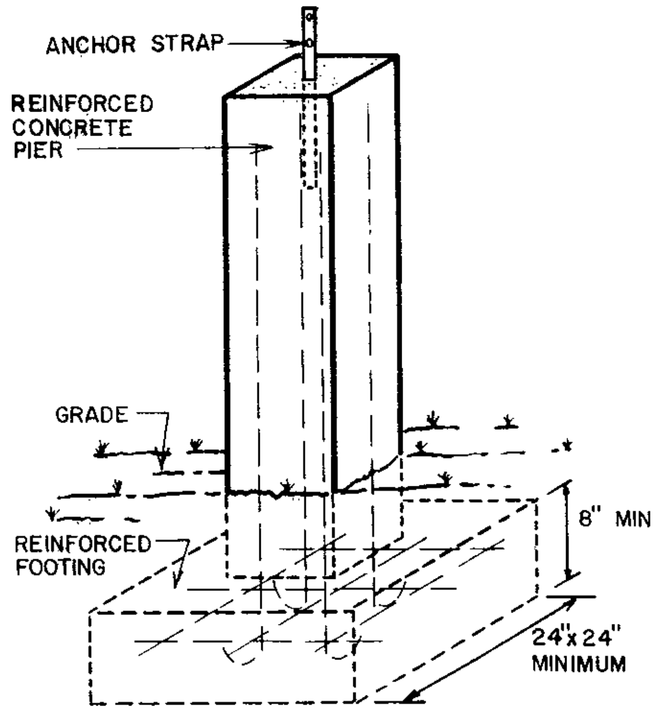


Figure 7.8. Columns tied to footing with reinforcement. (Reference 7)

If the loading on piers is very high, a reinforced pier wall may be needed rather than columns. The long dimension of the wall should run parallel with the direction of flood flow so that resistance to the water is minimized. The wall construction may also be used in conjunction with posts and piles.

7.3 *Waterproofed Structures*

7.3.1 *General*

Waterproofed structures include any structure that has its lowest floor elevation below the BFE. Waterproofed structures must be adequately designed to structurally resist hydrostatic and hydrodynamic loads, with adequate closure of opening below the BFE, and require adequate anchoring systems between structural components such as walls and footings, floor slabs and walls, and superstructure to walls. Another primary concern for waterproofed structures is that all joints and walls should be adequately sealed to prevent seepage of flood waters. Hydrostatic and hydrodynamic loadings were presented in Chapter VI and application to walls and floor slabs is discussed in Capter XI. In Chapter VIII, various types and requirements of closure of openings below the BFE are presented. Thus, the following sections will present and discuss recommended anchoring systems and guidelines for waterproofing seals.

In general, there are three types of structures to which the following guidelines are applicable. These include 1) one and two story buildings with a full basement, 2) with a crawl space or, 3) no basement with grade level foundation.

3.2 *Anchorage*

An intregal part of the design in any structure is the strength of the connections. Each part of a building may have adequate strength, but if they are not anchored together properly, an unnecessary failure can still occur. It is important in a building that the superstructure is firmly anchored to the foundation wall. Otherwise the building could slide off the foundation due to large hydrodynamic loads, or it could lift off the foundation due to large buoyant loads.

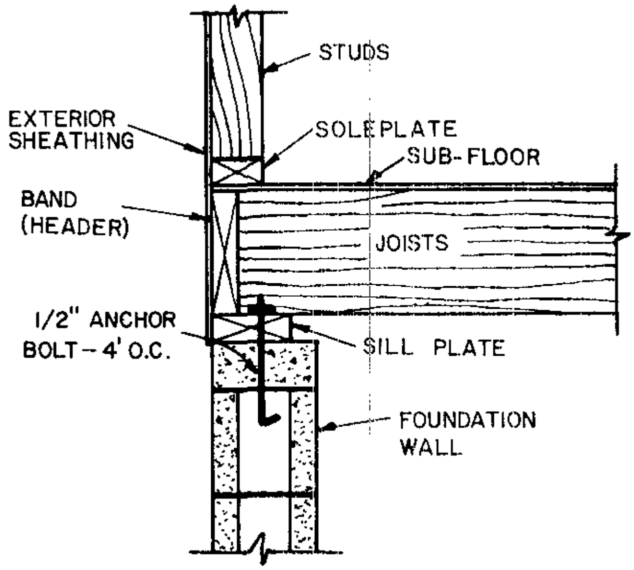


Figure 7.9. Typical sill assembly. (Reference 30)

The typical house will have the sill assembly shown in Figure 7.9. All components should be anchored together to avoid a separation when flooding conditions are present. Table 7.3 shows recommended type and spacing of fasteners.

Table 7.3. Superstructure anchorage fastening schedule (Reference 29).

Description of Building Materials	Number and Types of Fasteners	Spacing of Fasteners
Joist to sill plate, toe nail	2-16d	—
Header (band) to joist ends, face nail	3-16d	—
Subfloor to joists, face nail	8d-	6" o.c. along edges 8" o.c. along all intermediate supports
Sole plate to joist, face nail	2-16d	16" o.c.
Sole plate to band, face nail	16d	16" o.c.
Sole plate to studs, face nail or	2-16d	—
Stud to sole plate, toe nail	3-16d	—
Sheathing to studs, face nail	8d*	6" o.c. along edges 8" o.c. along Intermediate supports
Sheathing to header (band), face nail	2-8d*	In vertical rows at 8" o.c. horizontally
Sheathing to sill plate, face nail (Angle connector system and sole plate anchor system)	8d*	8" o.c.
or		
Sheathing to doubled sill plate, face nail (Doubled sill system)	208d*	in vertical rows at 6" o.c. horizontally

* Celotex and fiber sheathing as required by manufacturer.

Another important point of connection is the foundation footing. It must be secured to the foundation wall with dowel reinforcement. Also, as discussed in Chapter XI, the wall or footing should be tied into the basement floor slab if one exists. Figure 7.10 shows these two kinds of anchoring and the ACI 381-77 contains specific design criteria.

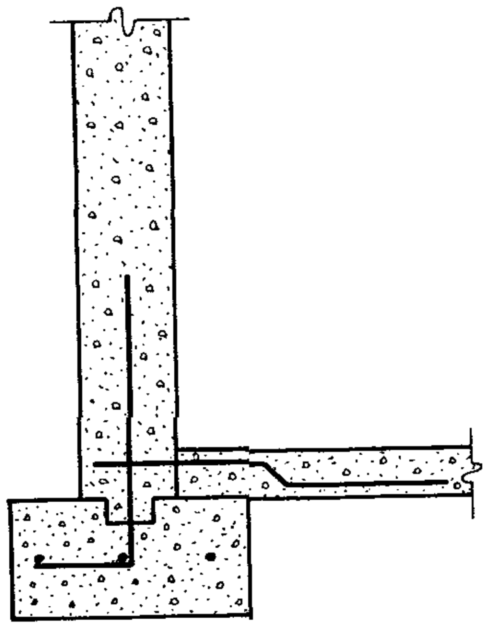


Figure 7.10. Wall, slab, and footing. Anchored to adt monolithicly. (Reference 8)

The idea behind all the kinds of anchoring presented above is to make the structure act monolithicly - that is, as if it were one solid mass. In some cases, such as with the floor slab and footings, the two parts may be placed at the same time to make them truly monolithic. This should be done when possible to eliminate joints. Joints require added attention during construction as explained in the following section.

he need for anchoring also applies to large miscellaneous objects. The most common item to be anchored is a tank such as those used to store fuel. These storage tanks are frequently seated on concrete floors. Anchor bolts such as the one shown in Figure 7.11 should be installed when the concrete is placed. The bolts should be 1/2" or larger diameter and embedded at least nine inches. For tanks that are bolted to free standing concrete, the following guidelines should be used:

Tank Capacity	Minimum Volume of
(gallons)	Concrete Needed
275	(yd3)
500	0.73
1,000	1.46
1,5000	2.92
	4.36

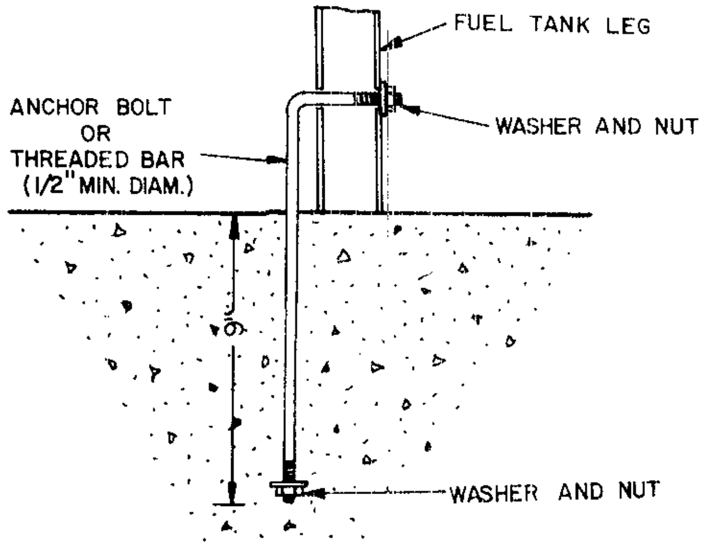


Figure 7.11. Anchor bolts for storage tanks. (Reference 30)

7.3.3 ***Waterproofing***

Waterproofing a structure involves the use of construction methods and materials to prevent water, water vapor, and waterborne contaminants from reaching interior spaces. The degree of water proofing may be classified as completely dry (Class A), essentially dry (Class B), or wet (Class C). The discussion which follows will be primarily limited to requirements for Class A. By Corps of Engineers's definition, waterproofed construction is completely impermeable when no more than three pounds of water pass through 1,000 square feet of membrane in 24 hours at 40 psi.

Three basic methods of waterproofing exist - external lining, internal lining, and integral waterproofing. An external lining should be continuous over a concrete floor slab and concrete or reinforced concrete masonry walls. The use of a continuous external membrane requires that floor slabs be rigidly connected with walls to act monolithically.

Materials used for external membranes should be layered sheet construction of tar/asphalt bitumen and felts, at least 3-ply in thickness neoprene coated nylon fabric. Other sheet material may also be approved if they meet all applicable American Standards for Testing and Materials (ASTM) standards, and they are designed for resistance to expected flood conditions. Plastic waterproofing materials that may be used include polyethylene, PVC, polyurethane, and polyisobutylene.

Points of concern when installing a membrane will be briefly listed here.

1. ***Turns.*** Turns at vertical or horizontal corners should be made with fillets of at least two (2) inches dimension on any side.

2. ***Seams.*** Membrane seams should be overlapped at least two (2) inches and thoroughly interleaved and protected.

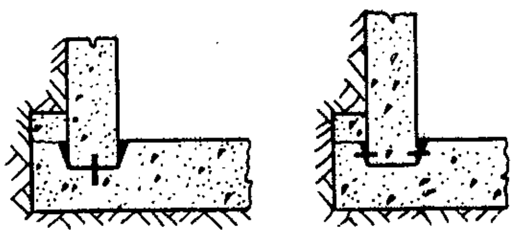
3. ***Pipes.*** Points where pipes or ducts penetrate a membrane must be made watertight.

4. ***Joints.*** Membranes should be continuous across construction joints, which should have waterstops of rubber, copper or plastic (Figure 7.12).

5. ***Protection from Perforation.*** To protect membranes during backfill operations, at least one-half inch of cement parging, plastic sheets or similar material should be provided.

3 6. ***Elevation.*** Membranes should extend at least one (1) foot above the BFE and be attached or covered at its upper termination.

Membrane waterproofing is shown in Figure 7.13.



(a) (b)

NON-RIGID PERIMETER WALL AND FLOOR SLAB CONNECTIONS

Figure 7.12. Membrane and waterstop at joints. (Reference 40)

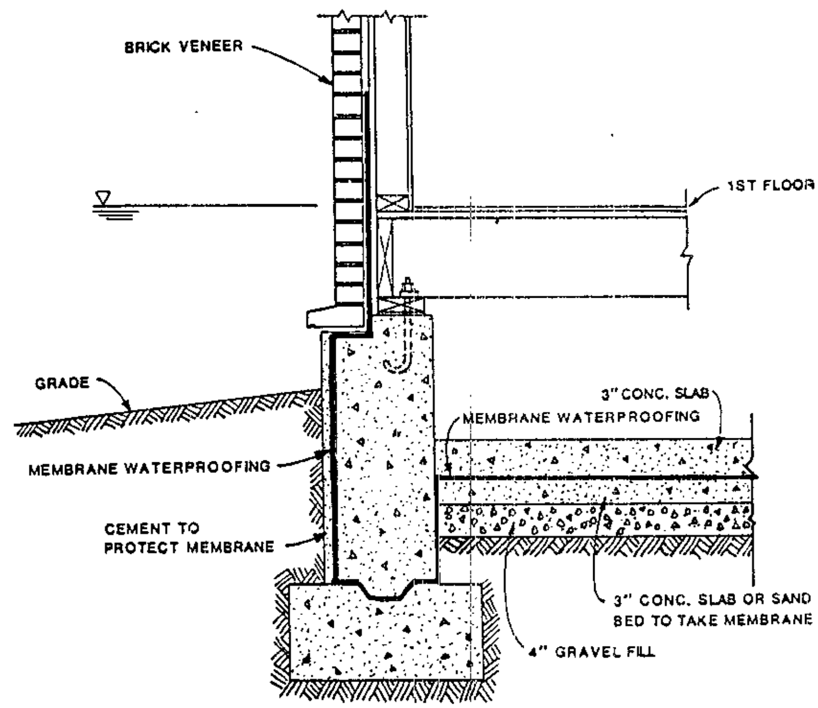


Figure 7.13. Membrane waterproofing. (Reference 8)

Structural requirements and concerns regarding continuous internal membrane lining are very similar to those for external membranes. In general, water leaks can form more easily with internal linings. This is because water pressure helps keep exterior linings tight against the wall or slab. With internal linings, the water is allowed to penetrate to the inner part of the wall or slab to where the membrane is attached. Deflection is more important when internal linings are used, and it should be limited to 1/500 of the length of the shorter span of the wall or slab.

The third method of waterproofing involves addition of the waterproofing agent to the concrete mixture. This method, like the other two, requires that slabs and walls act together monolithically. Deflection of any wall or slab should be limited to 1/500 of its shorter span.

Integrally waterproofed concrete should have a seven day compressive strength of 3,000 psi and a 28 day compressive strength of 4,000 psi. Approved admixtures should not reduce the compressive strength of the concrete. They should act as a densifier and increase workability.

For existing structures which are considered for remodeling or rehabilitiation, waterproofing can be achieved through the use of special building materials and fill when it is not feasible to elevate a structure by raising the foundation. The use of treated framing and sheathing materials must be considered if backfill material is placed against the structure (Table 10.2). Figure 7.14 illustrates the concept of using treated building materials for protection against the deterioration of structural members while the fill material provides protection from floodwater inundation. This floodproofing practice should be considered for flood inundation depths generally less then two feet.

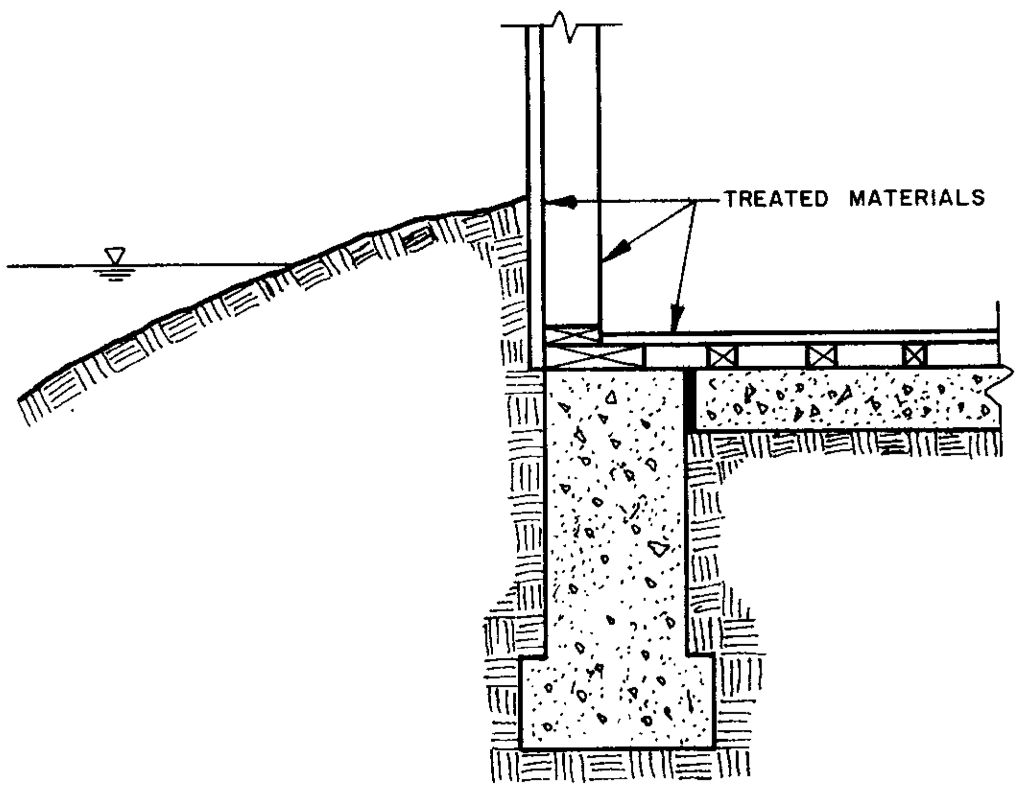


Figure 7.14. Use of treated building materials for protection against deterioration.

Protection of concrete from groundwater may be required for 14 calendar days after placement. Where groundwater conditions make this necessary, the groundwater may be temporarily removed or a temporary membrane may be used.

The above discussion of waterproofing is intended to serve as guidelines for "completely dry" waterproofed construction. Essentially dry construction is another alternative. By definition, essentially dry means a maximum of four (4) inches of water depth may accumulate in a space during a 24-hour period if no water is removed. However, sump pumps should be used when this rate of seepage occurs. Essentially dry construction may be upgraded to completely dry construction by adding external or internal continuous membranes.

7.4 *Levees*

In some locations, it may be economically unfeasible to adequately floodproof each structure near a river. In such areas, a levee system may be the best means of protection from floodwaters. Levees are embankments which prevent a flood from reaching a structure or land area. The fill that is used must be capable of resisting the imposed loads after it is properly placed and compacted. A freeboard allowance must be incorporated in the design of a levee (Table 1).

Two of the factors that must be investigated when constructing a levee are slope stability and erosional effects. They will require soil testing and determination of water forces and velocities. Slope stability and erosion are discussed in Chapter VI.

The availability of suitable fill material is another important concern. The borrow area should be at or near the construction site, and the material should be tested before it is approved for use. Foundation material must also be tested to determine its characteristics. The properties of both fill and foundation materials will help to determine what seepage and drainage control measures, if any, should be used.

Where foundation material is excessively permeable, a cutoff may be used to reduce seepage. Different kinds of cutoffs include sheet pile walls, fabric reinforced membrane, concrete walls, or a grout curtain. Where seepage is not large enough to require a cutoff, the seepage may be collected with drainage blankets, pervious trenches, or perforated pipe drains. Any pipe within the levee must be capable of resisting all loads that will be applied on it. Cross sections of levees and dikes are shown in Figure 7.15.

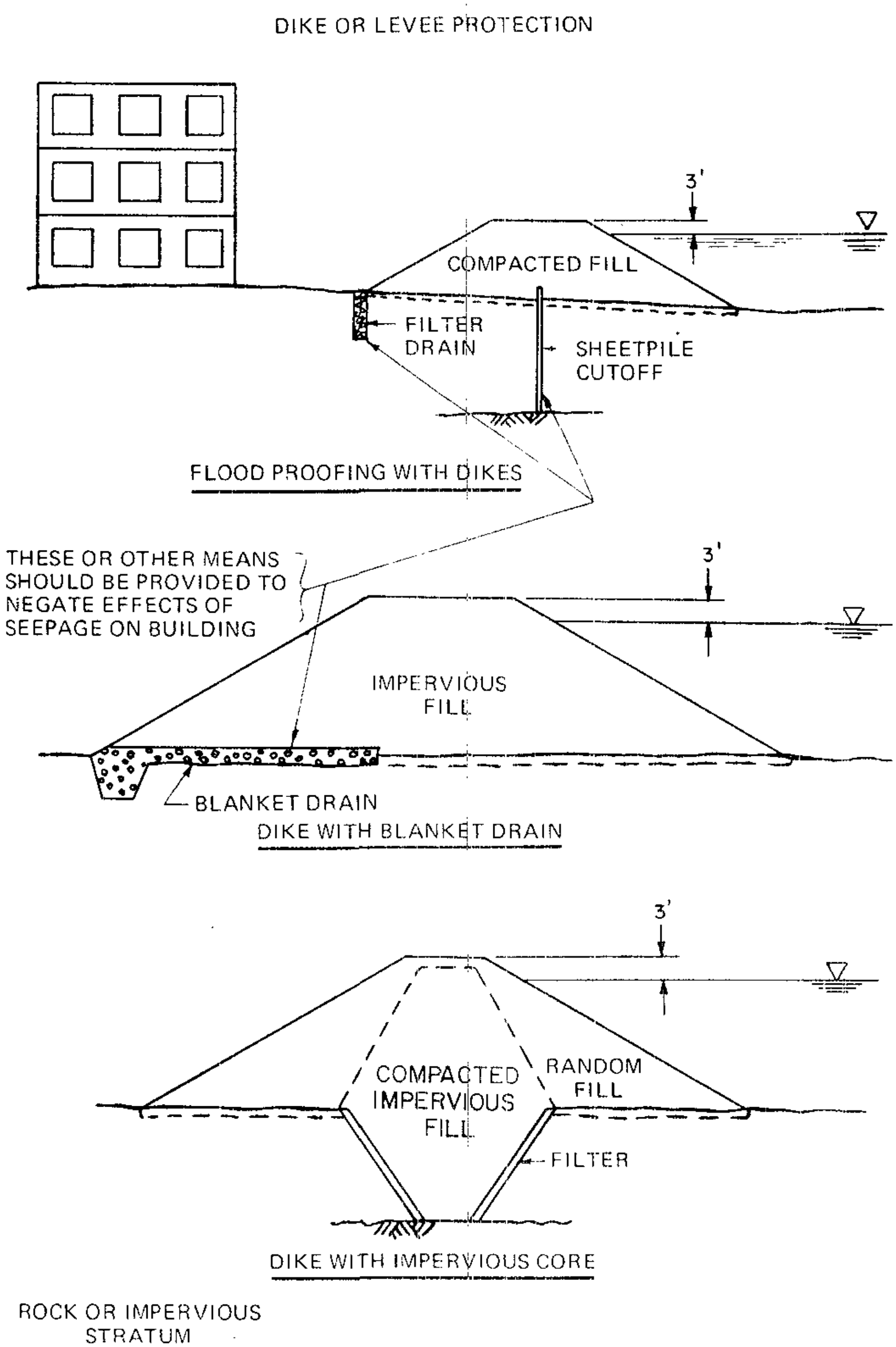


Figure 7.15. Levees and dikes. (Reference 39)

7.5 *Floodwalls*

The purpose of floodwalls is similar to that of levees - to keep water out of an area. They are subject to hydraulic loading on one side with little or no earth resistance on the other side. Cantilever walls, cellular walls, buttress walls, and gravity walls are different kinds of floodwalls shown in Figure 7.16. Possible modes of failure for floodwalls are overturning, sliding, or failure of underlying soil. If competent rock formations are present, the floodwall should be keyed into the rock for extra protection against failure.

Cutoffs and drains should be provided to carry away any significant amount of seepage. However, the presence of drains should not lessen the design for uplift pressures. Also, drain pipes should not be placed directly under the base of a floodwall.

Two general application guidelines will be mentioned here. Gravity walls are most appropriate for low, lightly loaded walls. They are easy to design and construct, but the large volume of concrete can become a prohibitive factor in economic considerations for large heads of water. The cantilever wall is a more complex design, but requires much less concrete. It is suitable for many situations, especially where a moderately high wall is needed. The cantilever wall's base may be supported on drilled piers or piles if soil conditions are very poor. A final point in the design of this kind of floodwall is freeboard. The freeboard requirement depends on whether a single structure is being protected or a big area of a community. Freeboard requirements were given in Table 7.1. The design and construction of floodwalls should only be done with experienced, professional engineering direction.

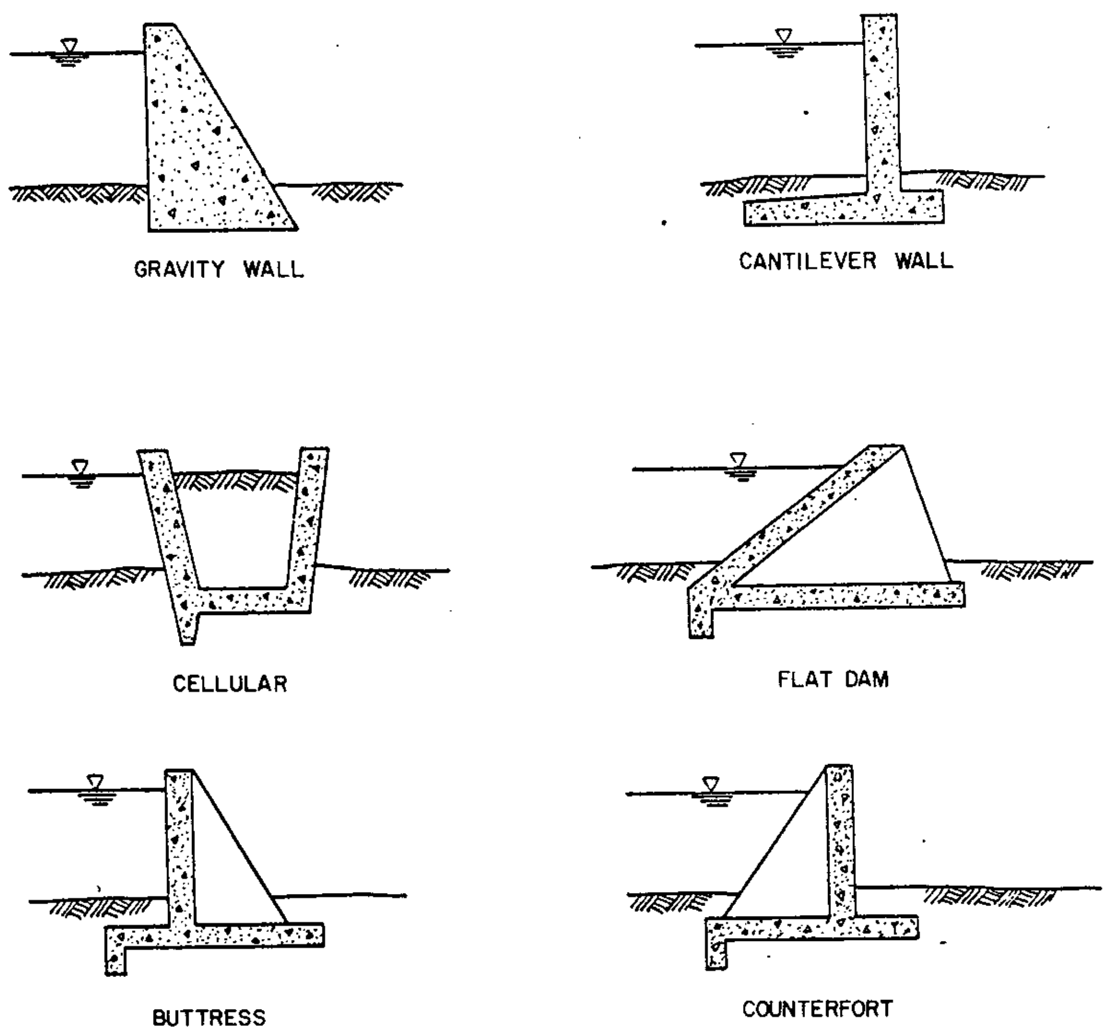


Figure 7.16. Floodwalls. (Reference 8)

VIII. CLOSURE OF OPENINGS

8.1 *Introduction*

Attention should be devoted to any doors, windows, vents, or other openings in a structure that are below the BFE. If an existing opening below the BFE can be eliminated without making the building less functional, it should be permanently closed. The permanent closure should be completely impermeable and may require added reinforcement. All other openings below the BFE must be provided with some type of closure that can be put in place easily when needed. This kind of temporary closure equipment is called a flood shield. Closures must provide protection to one foot above the BFE.

Closure of openings, as a floodproofing method, is most applicable to structures that meet certain criteria. First, the wall of the structure should be brick, brick veneer, concrete, cement block, stone, or other relatively impermeable materials. The structure should have a small number of openings, unless low outdoor walls are the floodproofing method to be used. Another mandate is that the walls themselves have the structural strength to resist the water forces up to the top of the closures. Finally, the structure should have a sump pump that can take care of seepage during the flood.

A comment on the availability of flood shields is in order. Some custom sheet metal businesses will make shields if given the proper drawings and dimensions. Strength requirements should be calculated for such shields. There is also at least one company that specializes in flood shields and it is listed in the acknowledgements. Because flood shields are custom designed and engineered for each application, it is difficult to make any general statements regarding prices. They may vary greatly from one manufacturer to another.

8.2 *Material for Shields*

Any durable material that can withstand the design flood loads may be used. Aluminum is often the best choice because it has the necessary strength, is usually readily available, and its relatively light weight permits easy and quick installation. Steel and exterior grade plywood are other materials that are used.

8.3 *Installation of Shields*

Shields are usually attached to a metal frame for the most reliable connection. The frame must be capable of evenly transferring the panel loading into the wall. If the frame brackets are an appearance problem, it may be desirable to have a removable trim covering for the frame. Shields may be set on hinges, slide track rollers, or vertical pulley systems. Some circumstances may require that they be stored away from where they will be used.

In order to assure complete watertightness, gaskets or other types of seals must be used between contact surfaces of the shield and frame. Seals should be of the pressure type and permanently attached to either the frame or the shield. Inflatable seals are available through some manufacturers.

Another consideration is the type of latching device to be used on the shield. Standard bolts, T-bolts, latching dogs, wedge assemblies, or other means may be used. Whichever fastener requires the minimum time effort and skill is the best choice.

Whether the shield is put on the outside or inside will depend on the user and each situation. The advantage of putting the shield on the outside is that the water pressure will help create a tighter seal between the shield and frame to which it is attached. On the other hand, a shield on the inside will probably be more accessible for placement and correction of any problems.

Closure devices should be inspected annually and maintained to preserve structural and waterproof qualities. To improve the effectiveness of this type of floodproofing measure, it is recommended that an operations plan be developed and placed on the site. The plan should include, but not limited to, the following considerations:

The warning time required to install closure devices must be determined.

Drills must be conducted to make sure that closure units and fittings are on the site.

Inspections must be conducted to assure that opening sealants are present for all openings.

Sewer and drain lines must be equipped with backflow devices.

8.4 ***Illustration of Closure Types***

Openings are grouped according to function, and different possible closure types are illustrated for windows, Figures 8.1 through 8.6; doors, Figures 8.7 through 8.10; vents and shafts, Figures 8.11 and 8.12. Other closure types are shown in Figures 8.13 through 8.16. Some arrangements may be modified for other applications. The more frequently used closures for residential, commercial, and industrial structures are shown. For vertical openings, the closure may cover the whole opening or only enough of the opening for adequate flood protection. A one foot freeboard allowance above the BFE should be included in this kind of closure.

Low outdoor walls may be considered a closure method when built around basement stairwells, or when used to protect a structure, or a portion of a structure, with many openings.

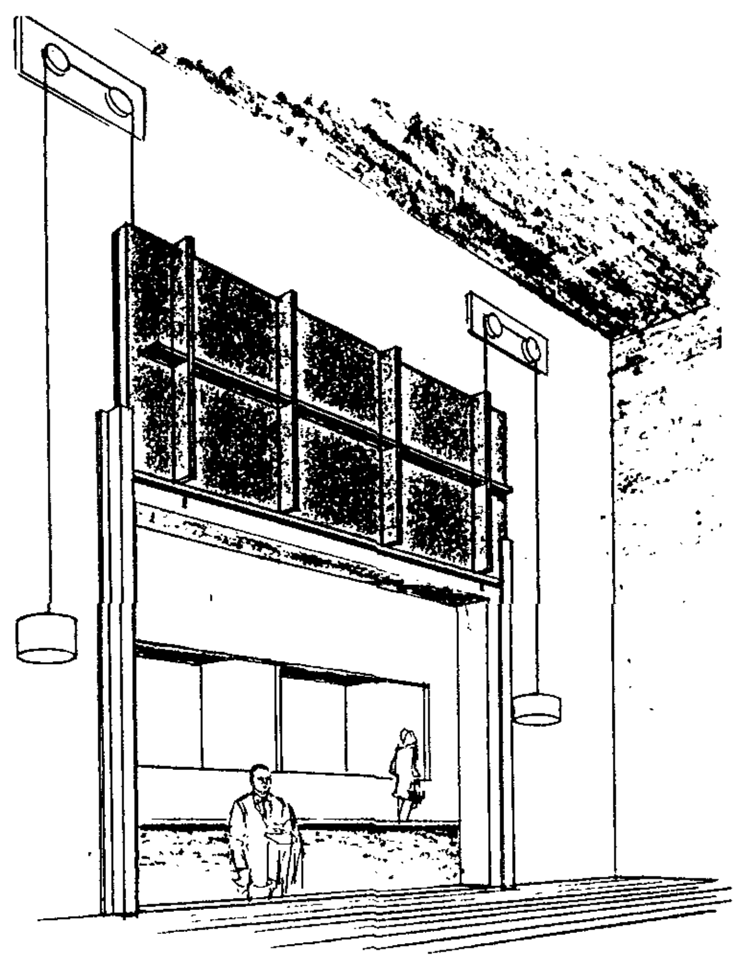


Figure 8.1. Display window shield lowered by pulley system. (Reference 33)

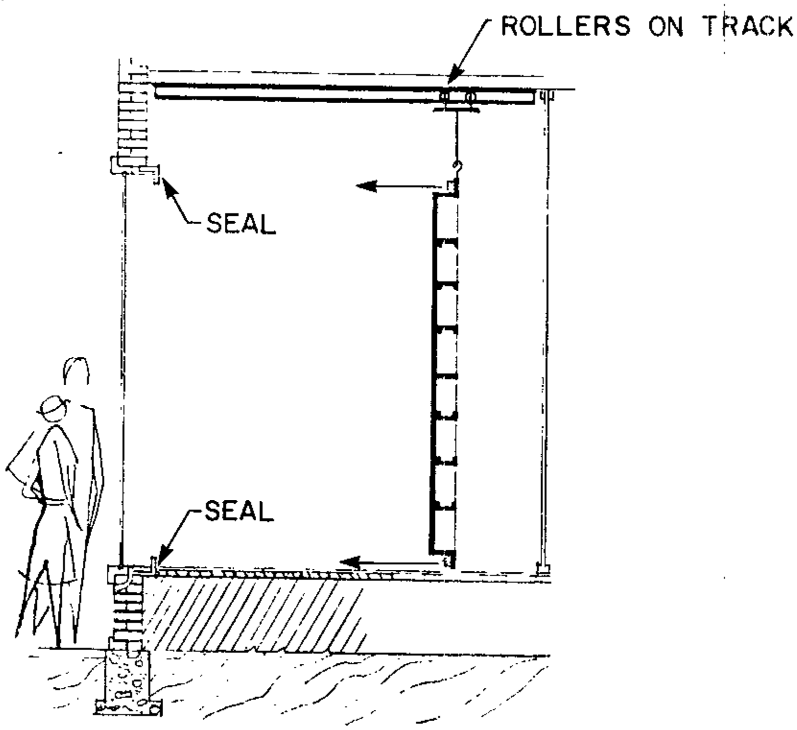


Figure 8.2. Display window flood shield, rolled forward to protect window when necessary. (Reference 32)

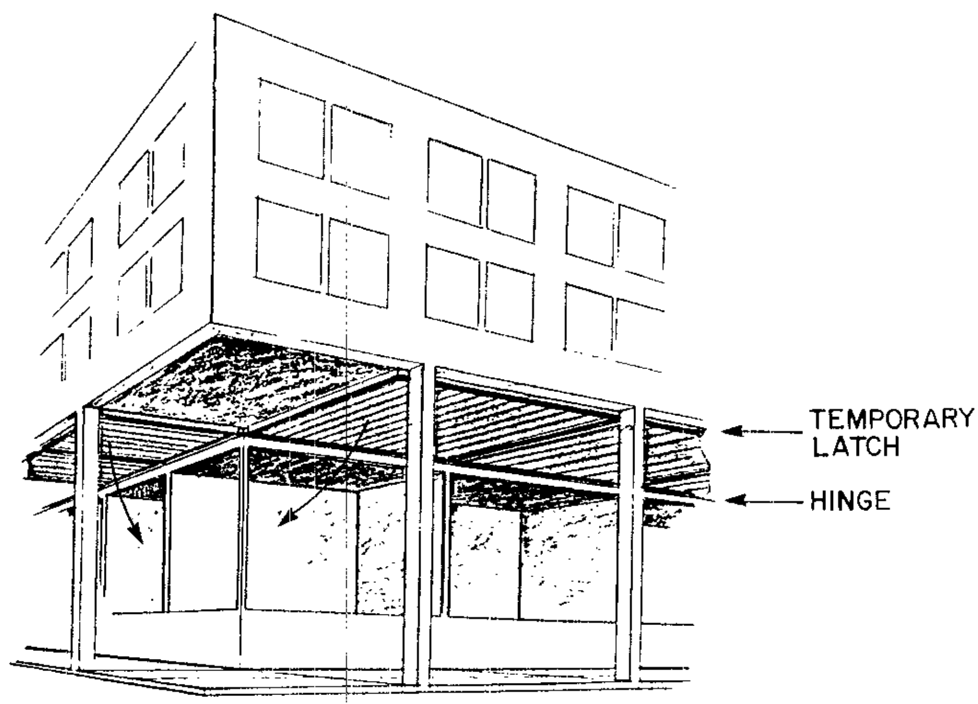
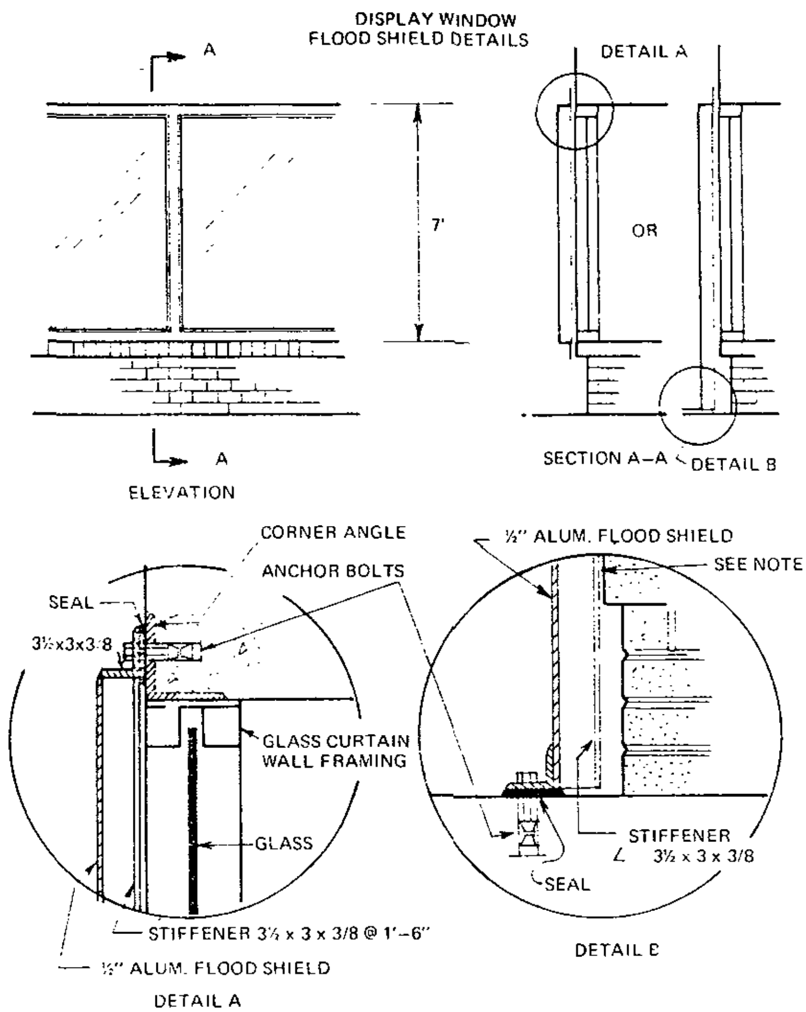


Figure 8.3. Display window flood shield. Rigid shields swing down to cover windows. (Reference 33)



NOTE.
SUPPORT IS ASSUMED AT THIS LOCATION. WHERE SUPPORT IS NOT AVAILABLE, INCREASE SIZE OR NUMBER OF STIFFENERS AND PROVIDE SUPPORT AT BOTTOM.
MEMBERS ARE SIZED FOR WATER LEVEL AT TOP OF DISPLAY WINDOW.

Figure 8.4. Window flood shields. (Reference 40)

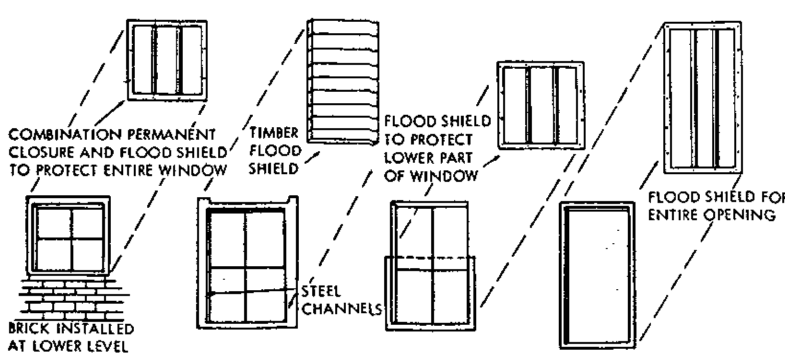


Figure 8.5. Window flood shields. (Reference 33)

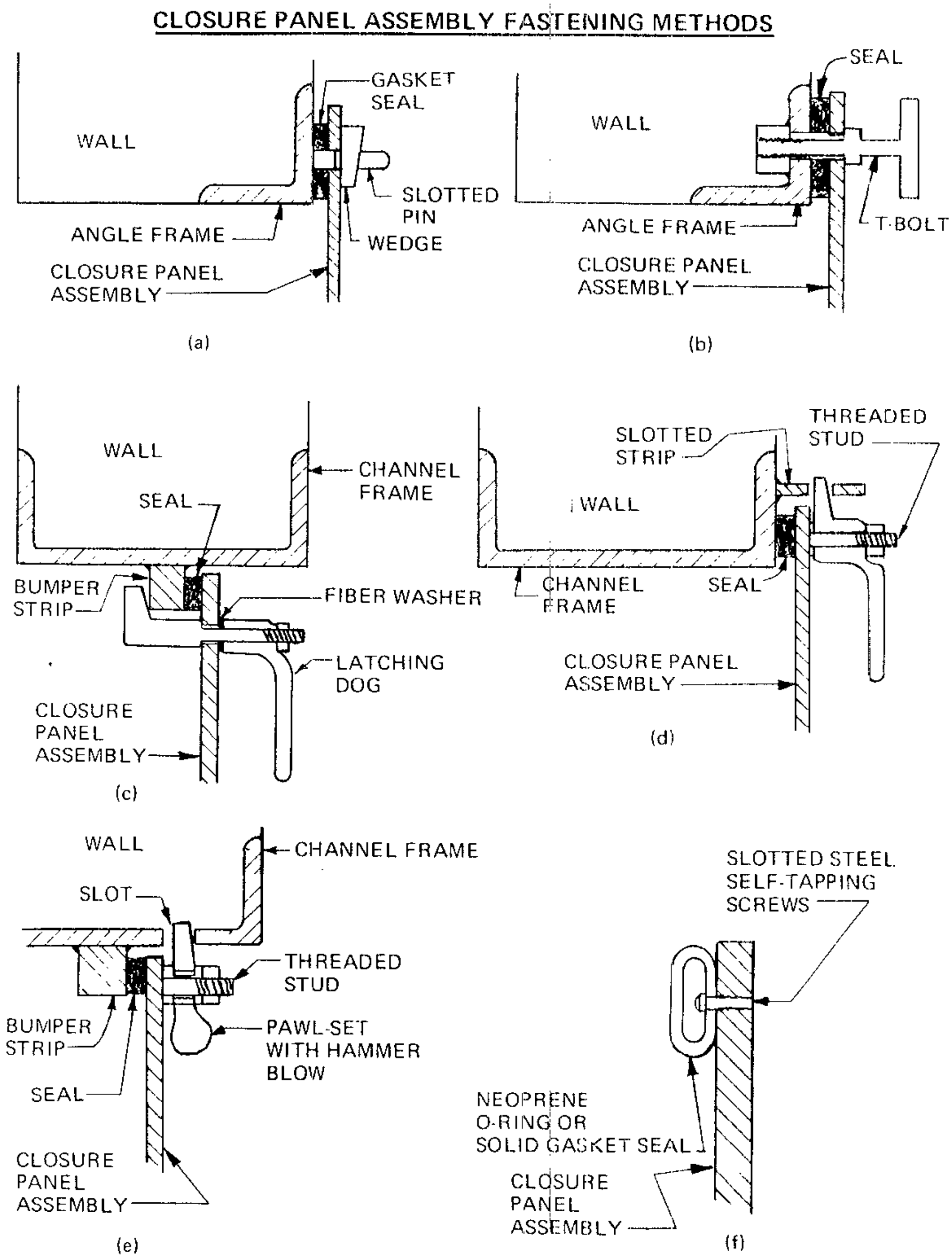


Figure 8.6. Fastening details for window flood shields. (Reference 40)

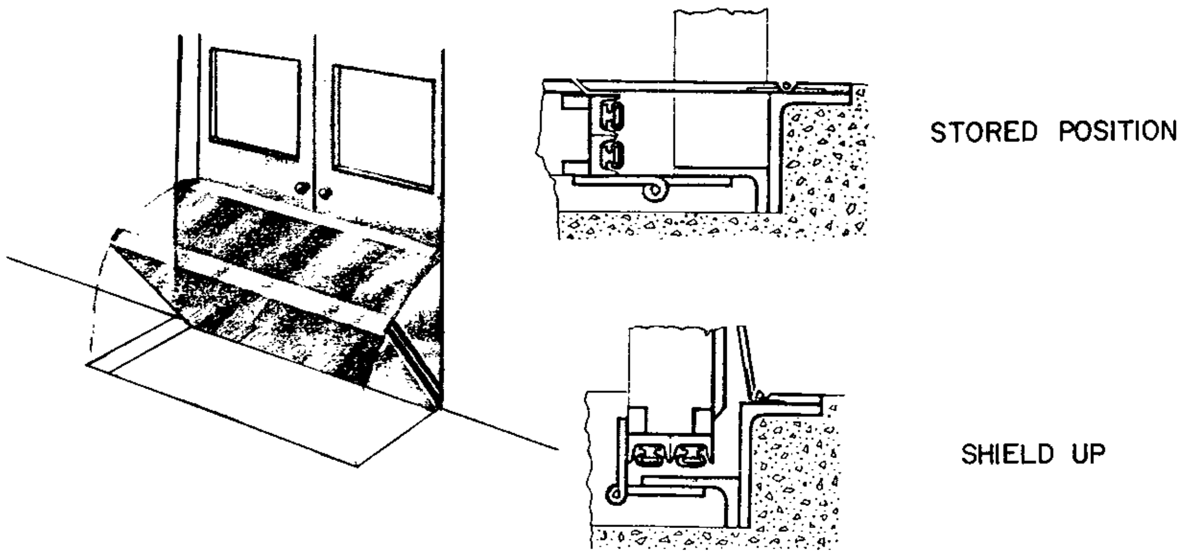


Figure 8.7. Door flood shield and sealing mechanism storage in floor. (Reference 32)

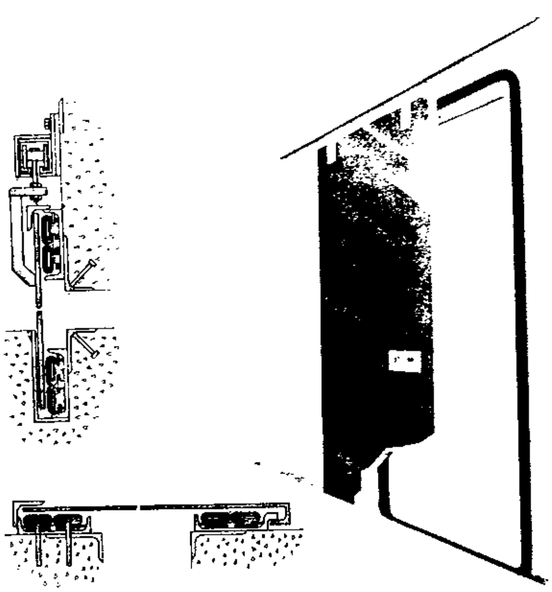


Figure 8.8. Commercial/industrial sliding door shield. (Reference 32)

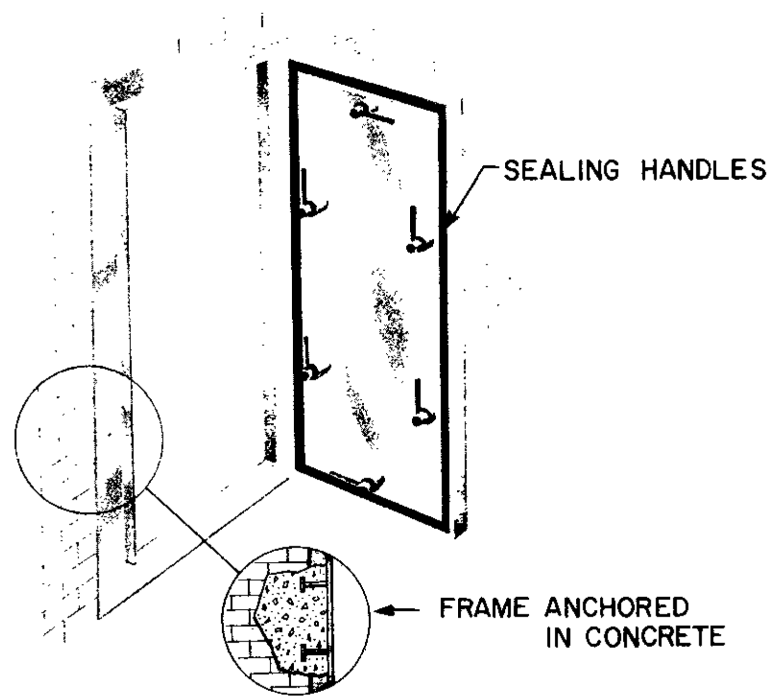
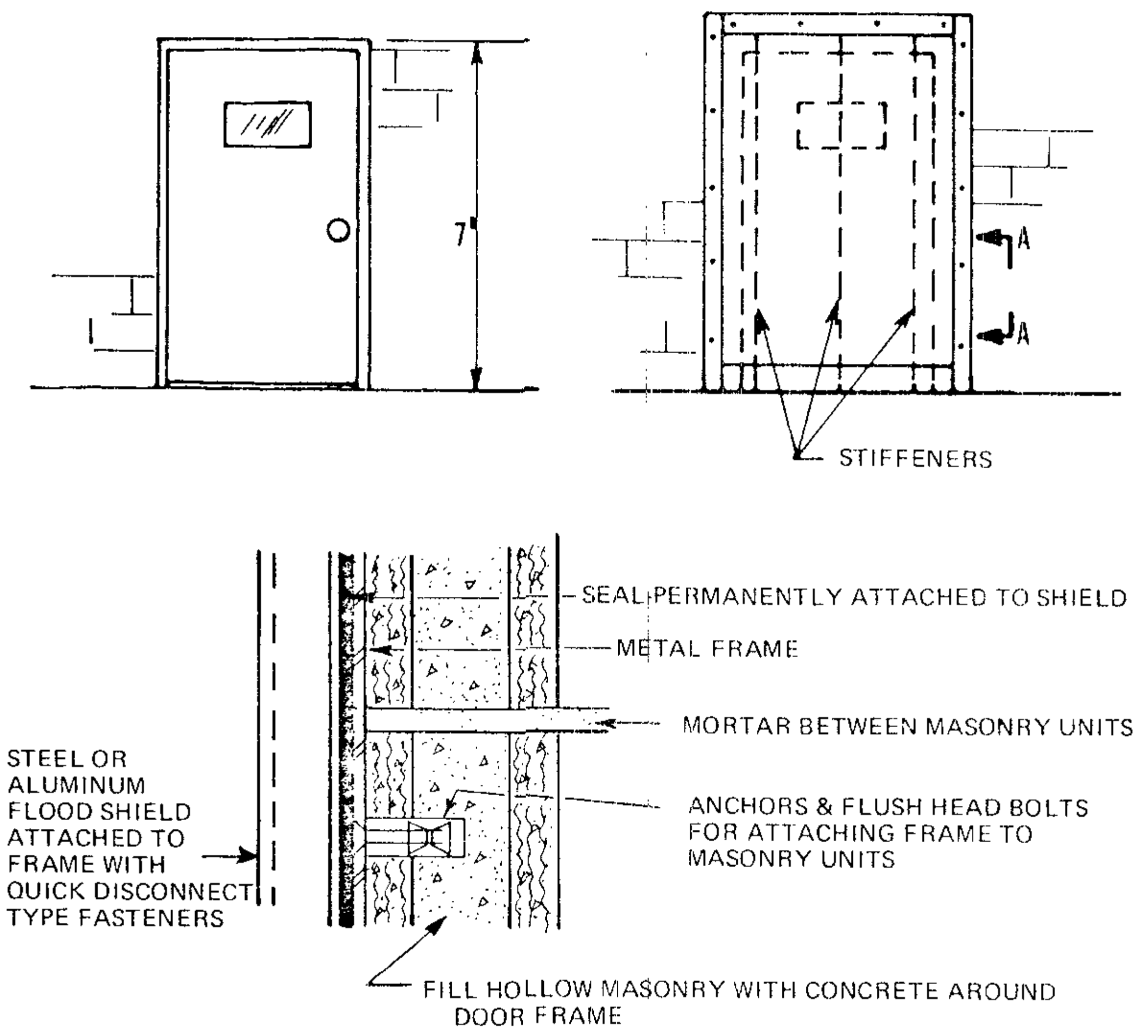


Figure 8.9. Industrial door shield. (Reference 32)

TYPICAL DOOR



SECTION A–A

ALL CELLS AROUND OPENINGS IN HOLLOW MASONRY CONSTRUCTION SHOULD BE FILLED WITH CONCRETE. LARGE OPENINGS SHOULD HAVE BOND BEAMS, VERTICAL REINFORCEMENT, AND METAL FRAMES AROUND OPENING.

MORTAR JOINTS THAT LIE WITHIN FLOOD SHIELD SHOULD BE STRUCK FLUSH WITH THE MASONRY UNITS SO THERE WILL BE A BETTER SEAL.

Figure 8.10. Door shield reinforcement detailing. (Reference 40)

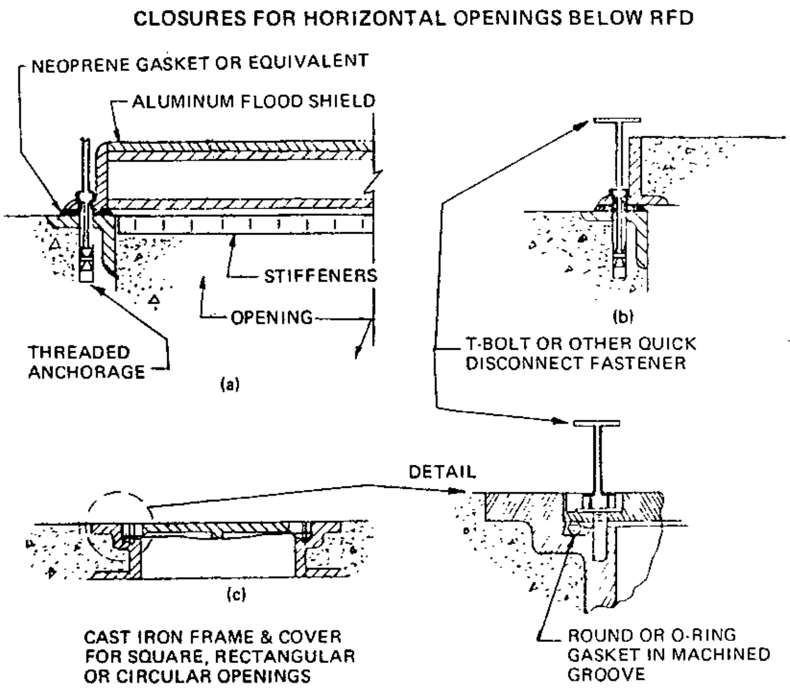


Figure 8.11. Shields for vents and shafts. (Reference 40)

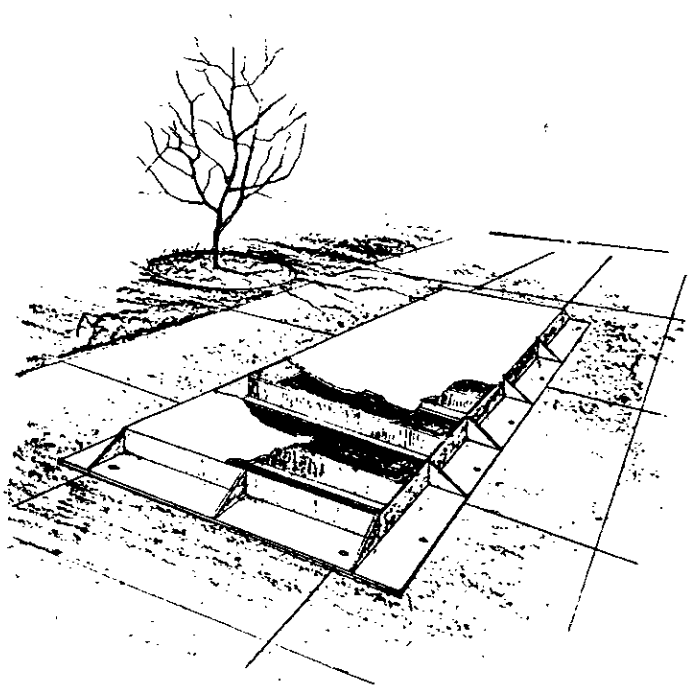
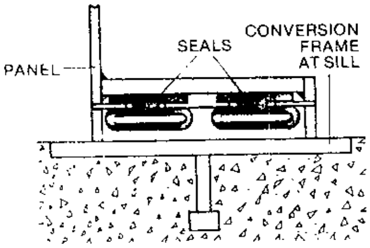


Figure 8.12. Flood shield for air vent manual placement prior to flooding. (Reference 33)



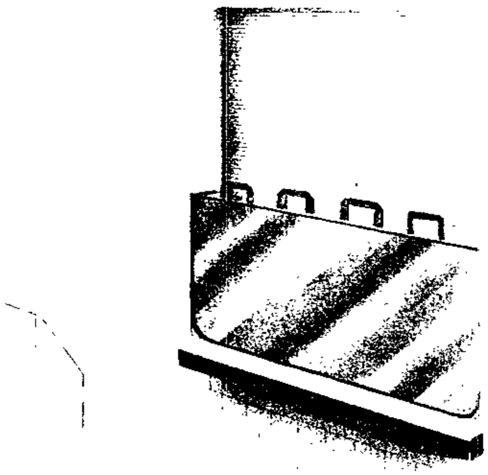


Figure 8.13. Commercial/industrial opening. Removable shield. (Reference 32)

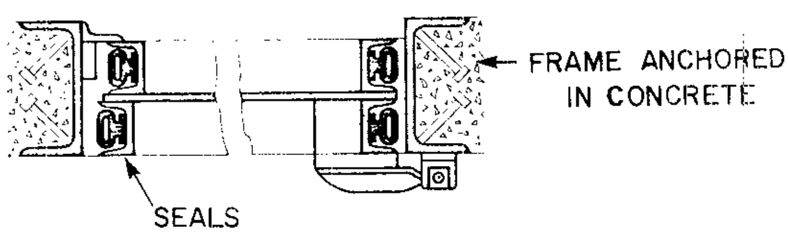


Figure 8.14. Gate used as flood barrier. (Reference 32)

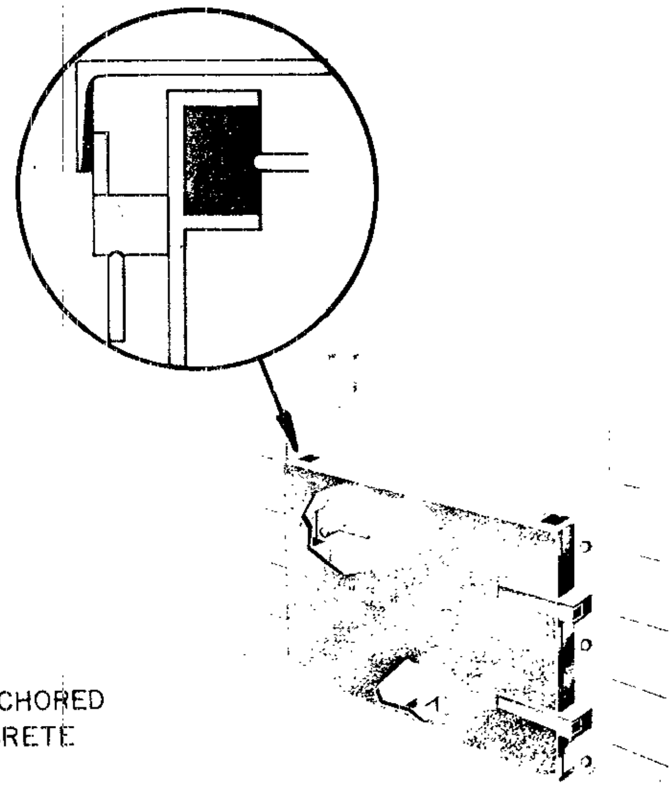


Figure 8.15. Gate used as flood barrier. Detail for sealing. (Reference 32)

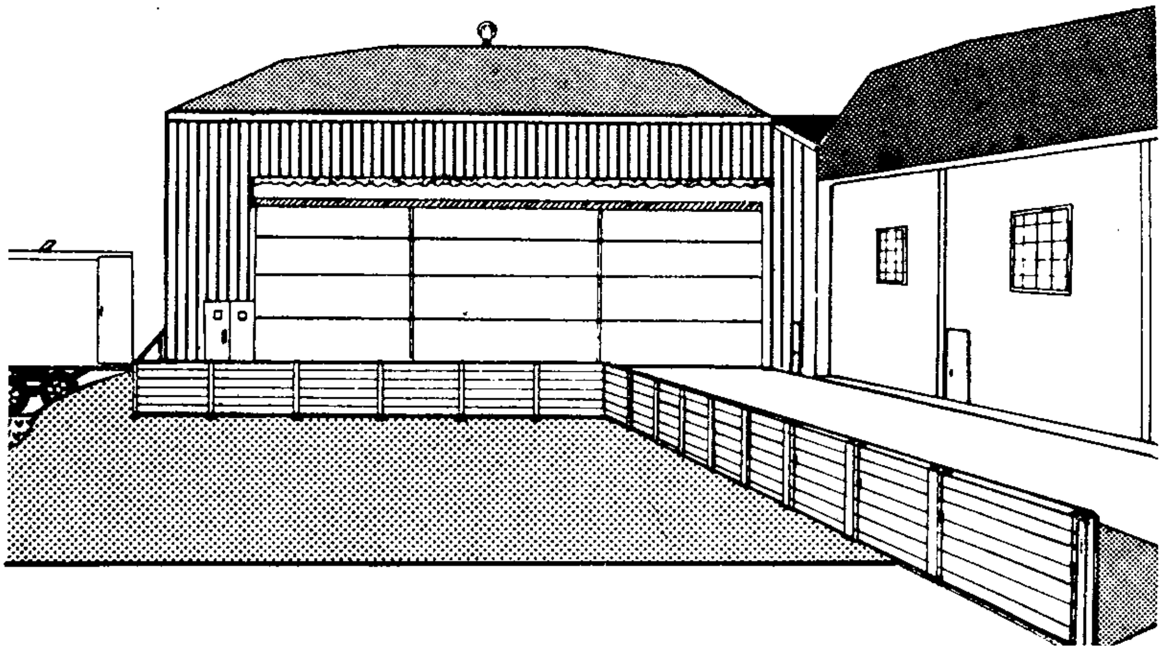


Figure 8.16. Low outdoors walls as a flood shield for large openings. (Reference 12)

IX. INTERNAL FLOODING

9.1 *Introduction*

As floodwater builds up on the outside of a structure, it creates a pressure which acts inward against the structure. If a structure has walls, slabs, or internal bracing that lack the strength to resist this load, a structural failure can occur. A method that is sometimes used to prevent this kind of damage is called internal flooding. Water is either intentionally let in or pumped into the structure. As Figure 9.1 shows, the water inside creates hydrostatic pressure directed outwardly to balance the pressure acting inwardly.

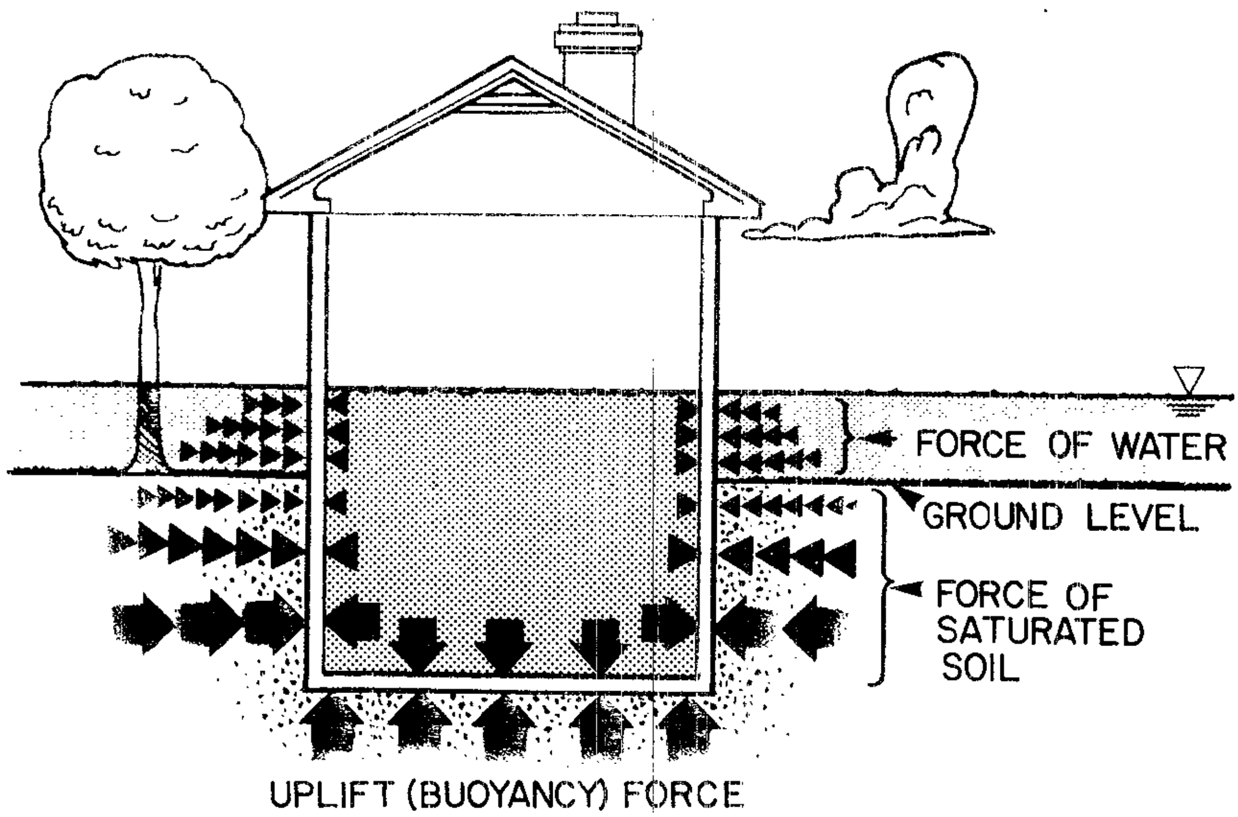


Figure 9.1. Balanced forces by internal flooding. (Reference 12)

9.2 *Implementation Considerations*

In addition to pumping, there are two other common methods to get the water inside. One simply involves letting the water come in through windows and door openings. The windows may be opened or designed to fail when a certain head of water exists. A potential problem that can arise when floodwaters are let in is contamination of the flooded area with bacteria and alkali or acidic sediment. Another method uses a floor blow-out plug (see Figure 9.2). This plug should be at least one foot square, and the section should be one piece cut all the way through the slab. When replacing the plug, the joint can be sealed with tar or asphalt one-inch deep into the crack. The soil around the basement walls and under the floor slab should be of a permeable nature to allow adequate inflow. The plug will the be pushed in by the outside water pressure, and slab failure will be averted.

This form of wet floodproofing, internal flooding, requires that all parts of the structure below the base flood level be constructed and fitted with water-resistant materials and finishes. Surfaces that will contact water should be nonporous to facilitate cleaning. Cleanup will also be easier if clean water is pumped into the space rather than using floodwater.

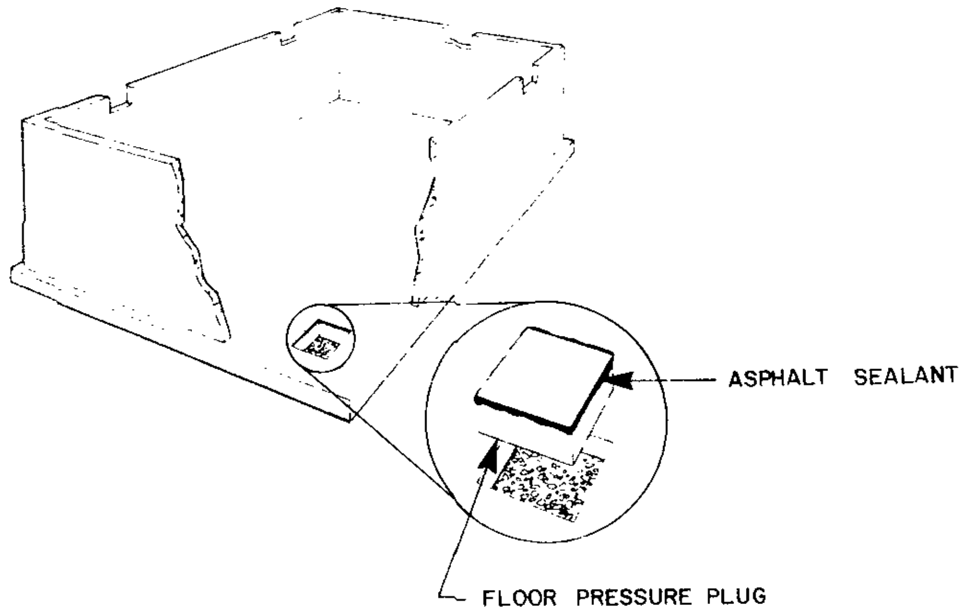


Figure 9.2. Basement floor blow-out plug. (Reference 9)

However, even if a potable water flooding system is used, it is best to have a backup system using floodwater for emergencies. All spaces, including cavity walls, must be allowed to fill with water and should be easily drainable as water recedes.

When using internal flooding, it is imperative that utilities and mechanical systems be either located above BFE or waterproofed and firmly secured in place. Fuel and chemical storage tanks must be located above the BFE. Valves that maintain equalized water pressure and cleanup equipment must be included in an internal flooding system.

This method of wet floodproofing will obviously not lessen contents damage to any significant degree. Applications where it would be most useful are certain industrial buildings, existing structures, and limited-use basements.

Before cleanup begins, precautions should be taken to insure the safety of all utilities that could be affected by the flood. When removing the inside water after the flood, an automatic draining system should pump water out at a rate that keeps inside water elevations approximately equal to the receding floodwater elevation.

9.3 *Insurance Considerations*

Although internal flooding may be useful in some situations, it is not recognized as a valid floodproofing method by the Federal Emergency Management Agency. On the Floodproofing Certificate, it is asked whether floodproofing is achieved with human intervention. Human intervention is defined as allowing water to enter the building, or filling of foreign waters, when a flooding condition is occurring. When this type of measure is implemented, the following flood insurance rating considerations should be acknowledged:

> Intentional flooding is not recognized as a rate reduction measure for residential structures regardless of type of procedure.
>
> Measures that require human intervention are not normally permitted for residential structures, but are for non-residential structures, and rate reductions can be obtained.

However, wet floodproofing (intentional flooding) is permitted for non-residential structures, but no rate reductions are granted.

X. BUILDING MATERIALS AND COVERINGS

10.1 *Introduction*

The use/risk classification of a building material or covering is rated high, medium or low according to its susceptability to flood damage or loss. A high rating means the material has a high susceptability to flood damage and a low rating means it has a low susceptability to flood damage. Common materials used in residential, commercial-industrial, and mobile home construction have been evaluated as an aid in identifying potential flood damage in existing flood plain structures and in providing criteria for less vulnerable materials for future flood plain construction. The definition for each risk rating is given in the next section followed by Tables 10.1 and 10.2 showing ratings of various materials.

10.2 *Classes of Floor, Wall and Ceiling Materials*

1. ***High Risk.*** Materials designated high risk experience extensive loss and damage when exposed to floodwaters and do not offer any waterproofing protection. The vulnerability of these products results from use of adhesives which are water soluble or not resistant to alkali or acid in water, including ground seepage and vapor. Safe use of high risk materials is limited to floodproofed spaces classified as completely dry.
2. ***Medium Risk.*** Medium risk materials do not offer any waterproofing protection, but are not as easily damaged as high risk materials. The majority of materials in this class are susceptible to flood damage and loss as a result of containing wood, wood products, gypsum products, or other material which dissolves, deteriorates, loses structural integrity, or is adversely affected by water. Safe use of medium risk materials is limited to dry or essentially dry floodproofed spaces which may be subject to water vapor and slight seepage.
3. ***Low Risk.*** Floor, wall and ceiling materials in this class are waterproof and usually do not require special treatment or protection from floodwaters. Safe use of these materials is recommended for any floodproofed structures.

Special Considerations: Several materials in this class are noted as impervious to clean water but may degenerate due to alkali or acid present in floodwater. An additional risk may be associated with materials which absorb or retain water excessively after submergence and cause structural damage due to water loads.

Table 10.1. Flooring Materials.

Material	Susceptablity to Flood Damage or Loss: High Risk	Medium Risk	Low Risk
Asphalt Tiles	x		
with asphaltic adhesives*			x
Carpeting (glued-down types)	x		
Carpeting (nailed, waterproof synthetic fibers)			x
Cement/bitumenous, formed-in-place			x
Cement/latex, formed-in-place			x
Ceramic tiles	x		
with acid and alkali-resistant grout*			x
Chipboard	x		
Clay tile			x
Concrete, precast or in situ			x
Concrete tile			x
Cork	x		
Enamel felt-base floor coverings	x		
Epoxy, formed-in-place			x
Linoleum	x		
Magnesite (magnesium oxycholoride)	x		
Mastic felt-base flood coverings	x		
Mastic flooring, formed-in-place			x
Polyurethane, formed-in-place			x
PVA emulsion cement	x		
Rubber sheets	x		
with chemical-set adhesives			x
Rubber tiles	x		
with chemical-set adhesives			x
Silicone floors, formed-in-place			x
Terrazzo			x
Vinyl sheets (homogeneous)	x		
with chemical-set adhesives			x
Vinyl tile (homogeneous)	x		
with chemical-set adhesives			x
Vinyl tile or sheets (coated on cork or wood product) backings	x		
Vinyl-asbestos tile (semi-flexible vinyl)	x		
with asphaltic adhesives			x
Wood floorings or underlayments			
solid or plywood with exterior glue		x	
particle board	x		
Wood composition blocks, laid in cement mortar		x	
Wood composition blocks, dipped and laid in hot pitch or bitumen		x	

* not resistant to akali or acid in water

Table 10.2. Wall and Ceiling Materials.

Material	Susceptability to Flood Damage or Loss		
	High Risk	Medium Risk	Low Risk
Asbestos-cement board**			x
Brick, face or glazed**			x
common		x	
Cabinets, built in			
Wood		x	
Metal**			x
Cast stone (in waterproof mortar)**			x
Chalkboards			
Slate, porcelain glass, nucite glass**			x
Cement-Asbestos		x	
Composition, painted		x	
Chipboard	x		
Exterior Sheathing Grade		x	
Clay tile			
Structural glazed**			x
Ceramic veneer, ceramic wall tile-mortar set			x
Ceramic veneer, organic adhesives		x	
Concrete** (porous concrete must be seal coated)			x
Concrete block**			x
Corkboard	x		
Doors			
wood hollow		x	
Wood, light weight panel construction		x	
Wood, solid		x	
Metal, hollow**			x
Metal, Kalamein			
Fiberboard panels,	x		
Sheathing grade (asphalt coated or impregnated)		x	
Otherwise	x		
Gypsum products		x	
Gypsum board			
Standard	x		
Waterboard		x	
Keene's cement on plaster		x	
Plaster, otherwise, including acoustical		x	
Sheathing panels, exterior grade		x	
Glass (sheets, colored tiles, panels)			x
Glass blocks*			x
Hardboard			
Tempered, enamel or plastic coated		x	
All other types		x	
Insulation			
Foam or closed cell types			x
Batt or blanket types	x		
All other types		x	
Metals, non-ferrous (aluminum, copper or zinc tiles)*			x
Ferrous**			x
Mineral fiberboard	x		
Plastic wall tiles (polystyrene, urea formaldehyde, etc.) with waterproof adhesives, pointed with waterproof grout*			x
Set in water-soluble adhesives		x	
Paint			
Polyester-epoxy and other waterproof types			x
All other types	x		
Paperboard	x		
Partitions, folding			
Metal			x
Wood		x	
Fabric-covered types	x		
Partitions, stationary			
Wood frame		x	
Metal**			x
Glass, unreinforced			x
Reinforced			x
Gypsum, solid or block		x	
Rubber, mouldings and trim with epoxy-polyamide adhesive or latex-hydraulic cement			x
All other applications	x		
Steel, (panels, trim, tile) with waterproof applications**			x
With non-waterproof adhesives		x	
Stone, natural solid or veneer, waterproof grout**		x	
Stone, artificial non-absorbent solid or veneer, waterproof grout**			x
All other applications	x		
Strawboard			
Exterior grade (asphalt-impregnated kraft paper)		x	
All other types	x		
Wooden materials (60 psi treatment with copper chromium arsenate)			
Framing	x		
Sheating	x		

* Not resistant to alkali or acid in water.
** May absorb or retain water excessively and cause structural damage due to water loads.

XI. BASEMENT CONSTRUCTION

11.1 *Introduction*

The design and construction of basements can be a complicated procedure with many alternatives. As with most design work, certain assumptions are made and only commonly-used construction is considered. This reasonably simplifies the design and construction tasks. For further explanation of methods and application, the reader is referred to the *"Manual for the Construction of Residential Basements in Non-Coastal Flood Environs"* NAHB Research Foundation 1977 (Reference No. 24).

The purpose of this portion of the manual is not to design every basement for every application. Rather, the standard calculations and construction will be discussed, including the approximate extreme loading conditions that different basements can accommodate. If loading conditions are expected to exceed those levels, a special design should be done by a qualified engineer experienced in that type of work.

Maximum loading conditions are often governed by buoyancy which is discussed following strength design for walls and floor slabs.

Based on the following calculations and examples, it should be evident that the allowable water loadings on basements is quite limited. Walls and floor slabs may be specially designed for higher water elevations, but their design is logically limited because buoyancy consideration governs when water depth reaches five feet above the floor slab. The allowable water loading is the lowest elevation at which one of the following will occur: wall fails, floor slab fails, house becomes buoyant or floats.

11.2 *Types of Basements*

Modern basements are usually constructed of structural plain concrete, reinforced concrete, unreinforced masonry block, or grouted reinforced masonry block.

A plain concrete wall is typically eight inches thick without temperature or shrinkage reinforcement. The wall's ability to withstand lateral loads is limited by its tensile strength which varies approximately linearly with compressive strength. Concrete compressive strengths are usually designated as 2,500 psi or 3,000 psi for basement walls.

Reinforced cast-in-place concrete walls are typically eight inches thick for residental construction and contain both vertical steel bars for load resistance and horizontal steel bars for temperature and shrinkage control. This type of construction is the best method when large lateral loads are anticipated. Commercial and industrial construction typically uses ten-inch wall thickness or greater. For the example in this section, we have used an eight-inch and ten-inch wall thickness. For other wall thicknesses one should go through the procedures outlined for design.

Unreinforced masonry block walls are eight or ten inches thick and simply consist of block units set in mortar with no reinforcement. This type of wall should only be used for minimal loading; it is not suitable for large lateral loads.

Masonry block walls may be reinforced by adding vertical reinforcing bars which are grouted into the block cavities. Horizontal wire reinforcement may also be added at regular intervals between some of the block courses. This kind of wall can provide the necessary strength for large lateral loads.

Other wall types that have been used include cut stone, rubble stone, and cribbing and planking. These are no longer commonplace, and therefore design guidelines are not presented for them.

11.3 *Design Procedure*

The design procedure presented in this chapter follows a logical sequence of steps resulting in the final selection of a wall and slab design. The various steps involved are:

1. Assumptions

   Step one involves making assumptions pertaining to water surface elevation in relation to the basement floor, surcharge condition (i.e., depth of water above soil), wall and slab support conditions and design control parameter(s).

2. Computation of loadings

   Step two is simply applying the methodology presented in Chapter VI to compute the lateral and uplift (bouyant) forces acting on the basement.

3. Wall design

   The third step is design of the basement wall. The wall design is determined by the bending moment created by the soil/water loading. The soil/water loading is determined by the calculation of γ_{eq}. Thus, the resulting wall design or bending moment equation is set up in terms of γ_{eq} allowable.

4. Compare allowable γ_{eq}

   Step four is comparison of the actual computed γ_{eq} with γ_{eq} allowable. γ_{eq} allowable is equal to the working load γ_w determined from the design curves.

5. Slab design

   Based on a completed wall design the depth of water above the basement floor is known. From the known water depth, the slab design is selected.

6. Typical section illustration

   As a final step in the design procedure typical section detail illustrations are given in Figures 11.20 through 11.23.

11.4 *Assumptions*

11.4.1 Water Surface Elevation

The first assumption to make is the water surface elevation in relation to the basement floor. When basements are being considered within the flood plain, the BFE must be sited one foot below the first floor. Thus, in relation to an eight-foot basement the maximum depth of water above the basement floor will be seven feet. This condition is illustrated in Figure 11.1.

11.4.2 Surcharge Condition

Surcharge condition refers to the depth of water above ground. As discussed in Section 6.2.3, three surcharge conditions were identified for determination of the equivalent fluid weight. The surcharge condition is determined by determining what percent of the total loading depth is the surcharge depth. In Figure 6.3, a is the height of soil loading above the basement floor, h is the height of water above the ground (surcharge) and H is the total loading height or a plus h. The percent of the total loading height (H) made up by the surcharge (h) is simply:

$\frac{h}{H} \times 100$ = percent of surcharge

Knowing the percent of surcharge, one can easily determine the actual equivalent fluid weight (γ_{eq}) following the methodology given in Section 6.2.

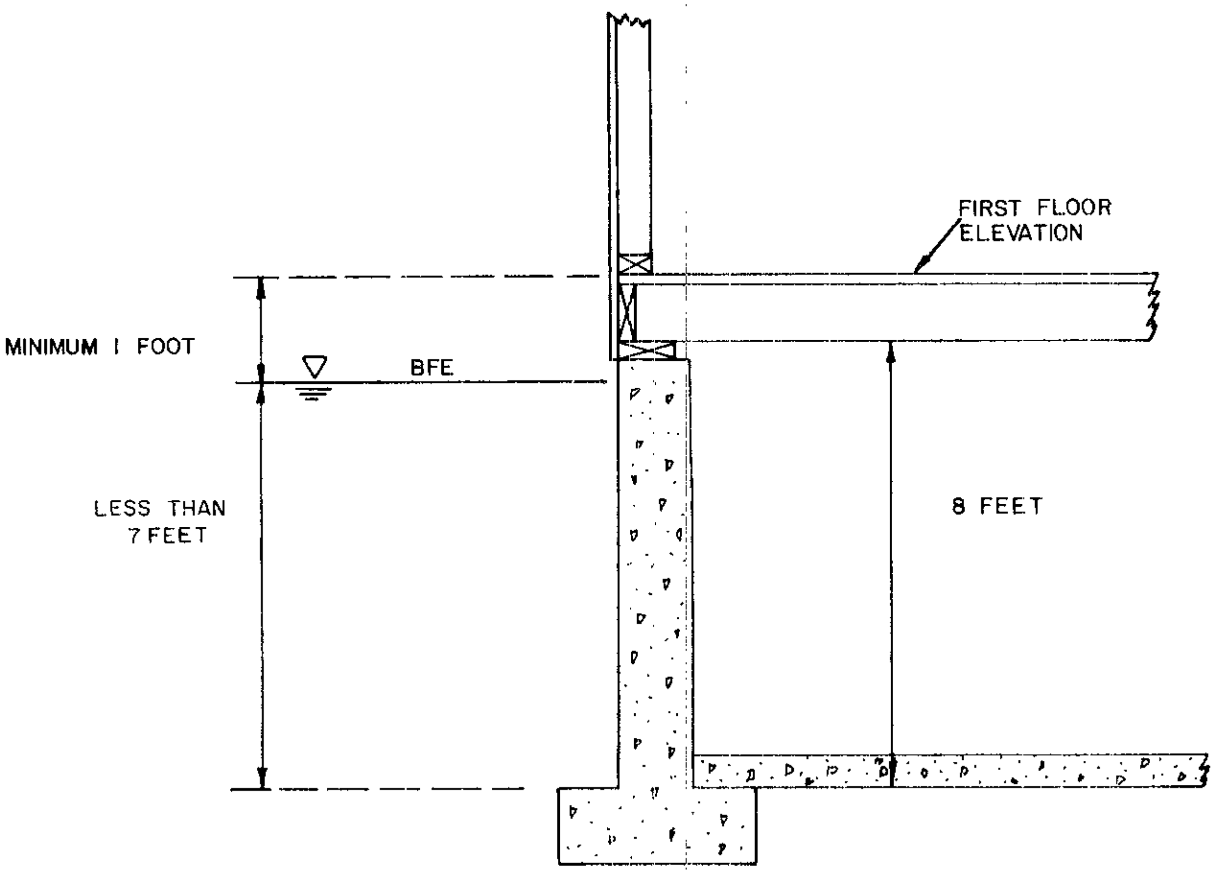


Figure 11.1. Maximum water surface elevation above basement floor.

11.4.3 Wall Support Conditions

An important factor in basement design is the wall support condition that exists. Wall support condition refers to the kind of reactions that balance the force imposed on the wall. The kind of wall support at the top and bottom of the wall will determine the location and magnitude of the maximum bending moment that occurs due to a given loading condition. The maximum bending moment, in turn, governs the actual structural design. The three support conditions that might be assumed are shown in Figure 11.1 and given below:

1. The wall is simply supported, that is, no moment at either end.

2. The bottom of the wall is a fixed end while the top is simply supported.

3. The bottom of the wall is a fixed end and the top is a free end with no support. Such a support condition is called a cantilever.

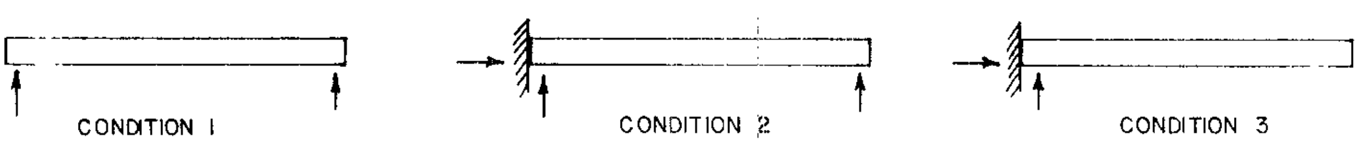


Figure 11.2. Support conditions with reactions, Wall is shown horizontally.

The support for most basement walls is probably a condition that falls between Conditions 1 and 2, shown in Figure 11.2. However, by assuming the wall is simply supported, the resulting design will be conservative in that it will accommodate a larger positive moment than if one end were assumed fixed. In order to assume a fixed end for the bottom of the wall, the wall-to-footing connection must be designed to act monolithically. In such cases, a professional engineer should be consulted to consider all factors involved with the particular site and building. Construction of a monolothic wall-to-footing connection is not typical. Another area of concern would be the size of footing needed to resist the large moment created.

The design guidelines in this chapter have been developed based on the assumption of simply suppported end reactions. This means that the top and bottom of the wall must have support that resists inward movement. Because the floor structure is what provides that support, it must be continuous between exterior walls. Also, the loading on opposite exterior walls must be approximately the same.

If the conditions above are not met, a specialized design must be developed based on all the site and building conditions. For example, if there are large openings or many small openings in the first floor, due to such things as stairs or a split-level concept, there may be very little, if any, lateral support of the top of the basement wall. Another case where such lateral support is missing would be if one side of the house has a walk-out basement. If the other side of the building is acted upon by saturated soil pressure, the wall on the walk-out side could act as if hinged and failure would be imminent without a special design. Figure 11.3 shows walls with and without adequate support.

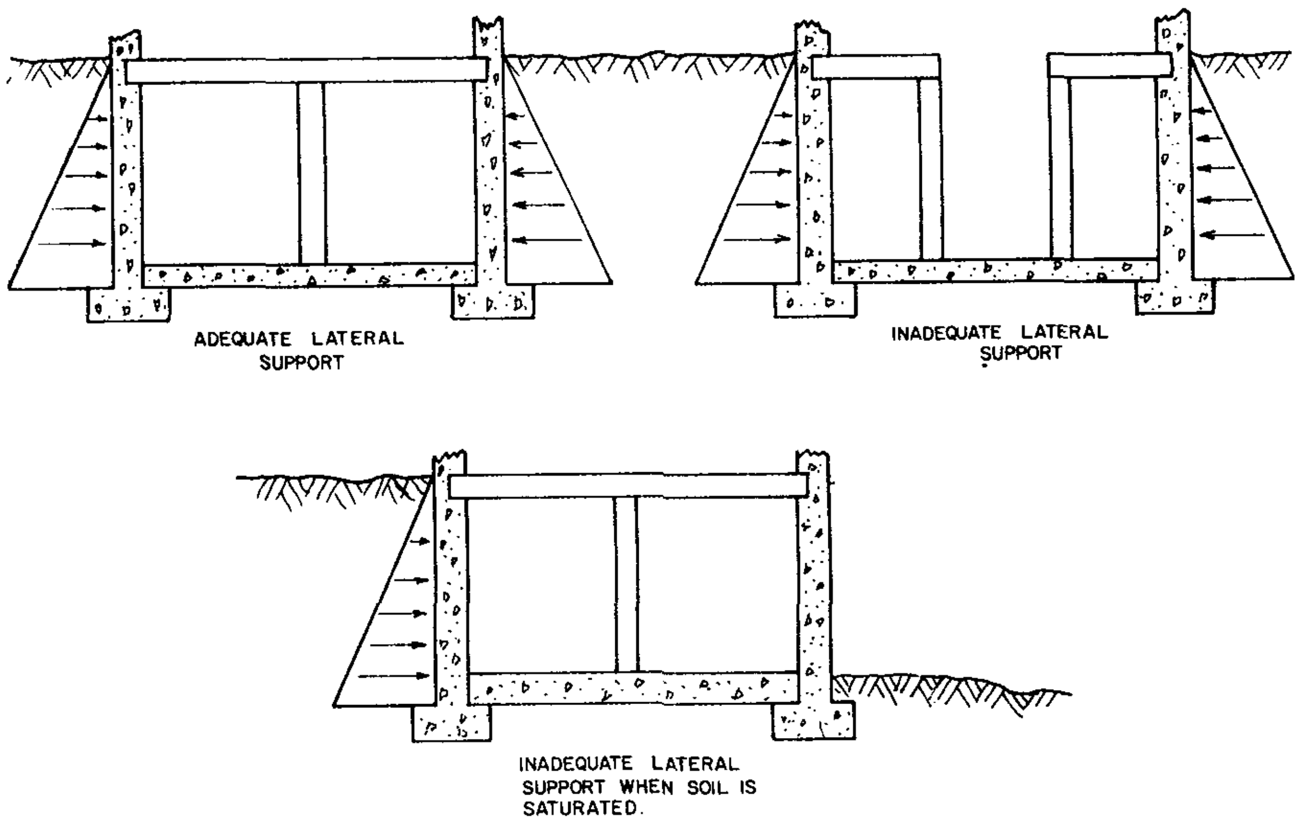


Figure 11.3. Adequate and inadequate lateral support.

11.4.4 Slab Support Condition

The basement floor slab, like the basement wall, is assumed to be simply supported at the junction with the wall. In order to accommodate widths for typical houses, it is assumed that there is a center, longitudinal bearing wall in the basement to which the slab spans for support at mid-house location.

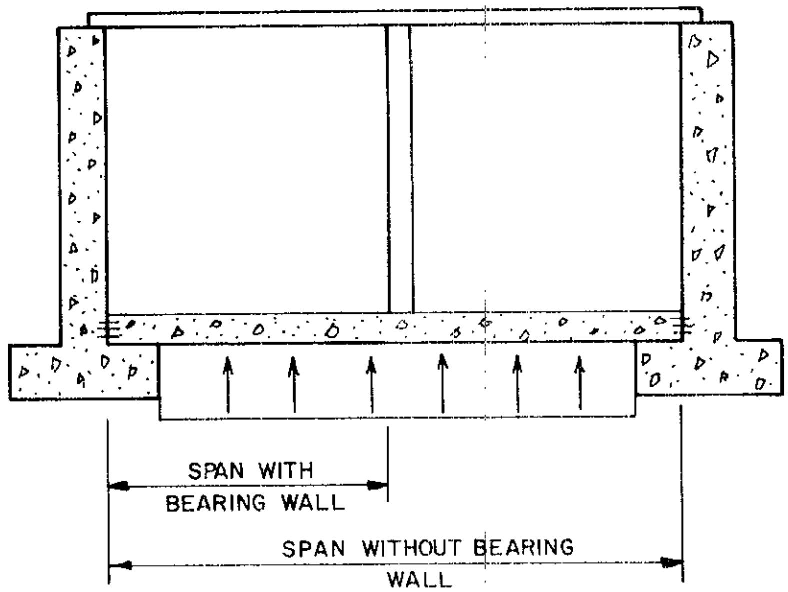


Figure 11.4. Bearing wall and slab support.

This breaks the total width into two shorter spans. Without the bearing wall, practical slab designs would only allow very narrow basements. Figure 11.5 shows four different kinds of bearing walls. The curves established for slab design consider three different span widths. A bearing wall or some other type of structural mid-span support must be incorporated into the design of a basement floor slab is using the guidelines in this chapter. It is further assumed that the slab edge is tied to the exterior basement walls so that the connection is not the weakest point of the slab. Soil beneath the slab is assumed to be undrained. In other words, for this location it is not practical or desirable to use a sump pump to keep water away from the basement walls.

11.4.5 Design Control Parameter

The design control parameter was chosen so that the forces causing the loading on the wall can be easily related to the design of the wall. The wall design is based on the bending moment created within the wall. The bending moment with the wall is due to the external soil and water loading. Chapter VI gives the methodology for determining the equivalent fluid weight (γ_{eq}) that represents the soil and water loading condition. In Section 11.6, wall design equations are set up in terms of the working load equivalent fluid weight ($\gamma\omega$). The working load equivalent fluid weight can also be referred to as the allowble equivalent fluid weight for any particular wall design. Thus, in the final analysis the actual equivalent fluid weight $\gamma\omega$ can be used to select a wall design or the allowable equivalent fluid weight $\gamma\omega$ for a specific wall design is compared with γ_{eq} so that γ_{eq} does not exceed $\gamma\omega$.

11.5 *Computation of Loadings*

Two approaches to the design of a basement wall and slab are possible. The first approach would be a detailed design computing a lateral and uplift forces in accordance with Chapter VI and then using the ACI codes referenced for calculation of the bending moment and then design of the wall and slab.

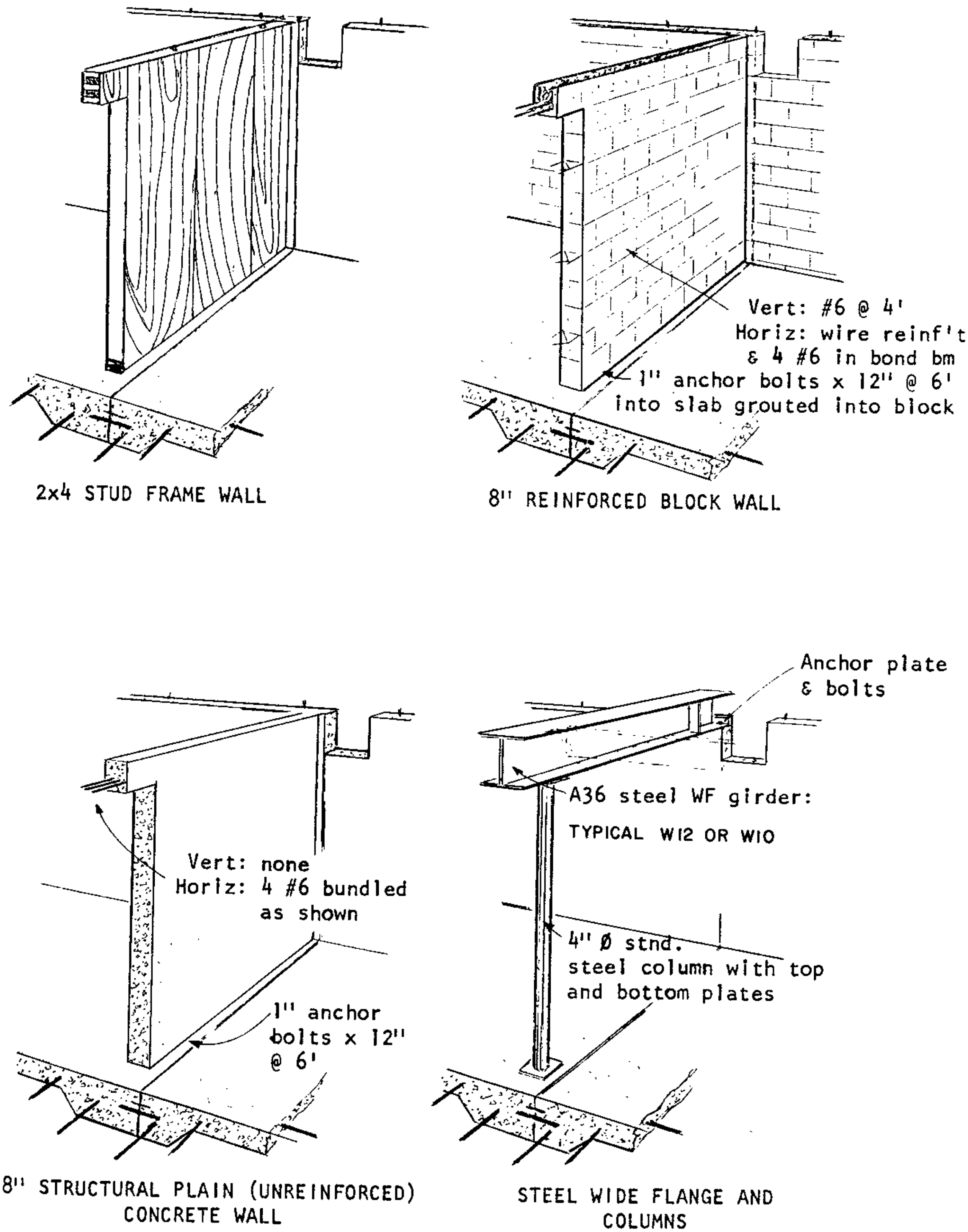
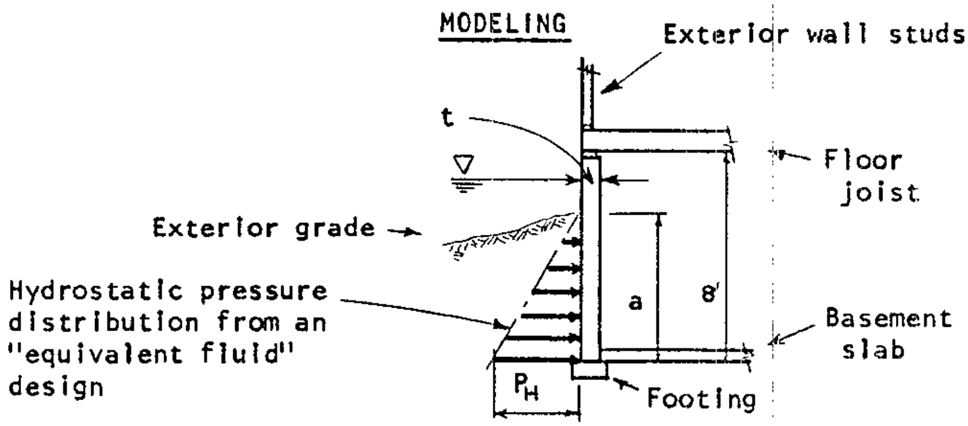


Figure 11.5 Buoyancy wall design. (Reference 26).

A. BUILDING MODEL, DIMENSIONS, AND LOADING



B. STRUCTURAL ANALYSIS MODEL (WALL)

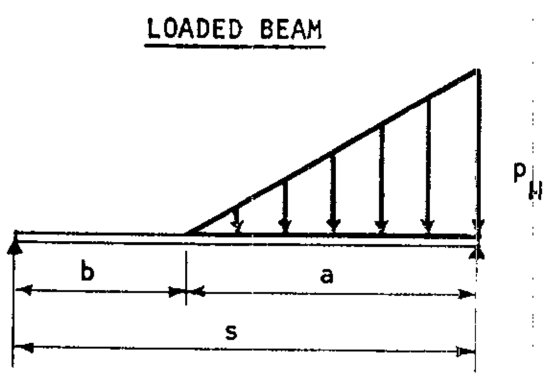


Figure 11.6 Design loading conditions for basement walls. (Reference 26).

s = 8' - 2"

$$M_u = \frac{P_H a^2}{6} \left(\beta + \frac{2\alpha}{3}\sqrt{\alpha/3}\right)$$

Where:

- a = Height of soil/water loading (ft.)
- s = Design span length for simply supported beam (wall) (ft.)
- b = s - a (ft.)
- 8' = Height from bottom of basement slab to bottom of floor joist (ft.)
- M_u = Ultimate bending moment caused by triangular (hydrostatic) loading P_u (ft.-lb.)
- P_H = Lateral wall pressure at top of footing, equal to $\gamma_u \times a$ (lb./ft.^{2} or lb./ft. per lineal ft. of wall)
- β = b/s (dimensionless)
- α = a/s = 1 - β (dimensionless)
- γ_u = Equivalent fluid unit weight which causes M_u (lb./ft.^{3})
- γ_ω = Equivalent fluid unit weight for "working load" conditions, equal to γ_u/U (lb./ft.^{3})
- U = Load factor = 1.4
- t = Wall thickness (inches)

The second approach makes use of the design curves presented at the end of this chapter. To make use of the design curve, the user need only determine the actual equivalent fluid weight (γ_{eq}) based on the assumed surcharge condition (Section 6.2). For slab design all that is required is the depth of water above the basement floor.

11.6 *Wall and Slab Design*

11.6.1. Walls

Lateral forces from soil and water are calculated as described in Chapter VI, and then applied to the walls as follows. The walls may be treated as a beam with a triangular load assuming ground and water surface elevations coincide as shown in Figure 11.7. The maximum bending moment that can occur in the "beam" is M_u. The calculations that follow are for a beam. However, the wall has four edges contributing support, not just two. Because of this ability to act somewhat as a plate, the moment that must be resisted, M_u, may be reduced by ten percent. In ultimate strength design, a load factor of 1.4 is used to provide a margin of safety. Both the load factor and moment reduction may be included in the M_u equation by applying them to the equivalent fluid weight as follows

$$\gamma_u = \frac{1.4}{1.1}\,\gamma\omega$$

The "working load" equivalent fluid weight then becomes

$$\gamma\omega - 0.786\,\gamma_u$$

Equivalent fluid weight was introduced in Chapter VI. It is the fluid unit weight to be used in calculations that will account for both soil and water loadings.

By substitution and rearrangement of the M_u equation:

$$\gamma\omega = \frac{4.716\,M_u}{a^3\left(B + \frac{2\alpha}{3}\sqrt{\frac{\alpha}{3}}\right)}$$

The value that is computed, $\gamma\omega$, is the equivalent fluid unit weight that can be resisted by all the given conditions, incorporating the load factor discussed above.

The equation for $\gamma\omega$ then takes on a slightly different form for each type of wall. Developed equations for each type of wall are presented below (Reference No.24).

Type: ***Reinforced Concrete (Ultimate Strength Design)***

$$\gamma\omega = \frac{4.244\,bd^2f'_c q(1 - 0.59q)}{a^3\left(B+\frac{2\alpha}{3}\sqrt{\frac{\alpha}{3}}\right)12} \qquad q = \frac{A_s f_y}{bdf'_c}$$

Where

b = Width of "beam". Calculations are per one foot width of wall.

d = Effective depth; distance from compression face to centroid of tension steel.

A_s = Cross-sectional area of steel per b width, expressed as square inches.

F_y = Yield strength of steel in psi.

F_c = Compressive strength of concrete in psi.

Type: ***Structural Plain Concrete (Ultimate Strength Design)***

$$\gamma\omega = \frac{4.716(3.25\sqrt{f'_c} \ll 7)\ 2t^2}{\alpha^3 (B\ \frac{2\alpha}{3}\ \sqrt{\frac{\alpha}{3}})\ 12}$$

Type: ***Plain Masonry Block (Working Stress Design)***

No Grout

$$\gamma\omega = \frac{(1.1)(6.0)(s_t)(24/12)}{\alpha^3\ (B + \frac{2\alpha}{3}\ \sqrt{\frac{\alpha}{3}})}$$

Solid Grout

$$\gamma\omega = \frac{(1.1)(6.0)(s_t)(41/12)}{a^3\ (B + \frac{2\alpha}{3}\ \sqrt{\frac{\alpha}{3}})}$$

Type: ***Reinforced Masonry Block (Working Stress Design)***

$$\gamma\omega = \frac{(1.1)(6.0)(30.37d^2)(1{,}000)}{a^3\ (B + \frac{2\alpha}{3}\ \sqrt{\frac{\alpha}{3}})\ 1{,}000}$$

Based on a particular wall design, and the allowable $\gamma\omega$ the allowable height of soil/water loading has been calculated. This has been done for an eight foot high wall for each type of wall construction. The information has been plotted and is shown in Figures 11.8 through 11.14 along with cross sections. A simple step-by-step procedure for using the design figures is listed here prior to an example.

1. Compute γ_{eq} for site.

2. Go to figure for desire type of wall.

3. Move vertically upward from equivalent fluid weight to intersection with curve of the desire wall thicknesses. Then move horizontally left to find allowable height of soil/water loading.

4. If loading height is lower the desired for a building in the design stage, try one or more of the following: a) select the higher strength concrete, f_c' @ 3,000 psi.; b) select the greater wall thickness; c) select a stronger wall type; d) select the smaller spacing for reinforcement.

5. If loading height is greater than five feet, see discussion of buoyancy considerations, Section 11.7.

Example:

A house with basement is being designed for a particular site. The homeowner desires a basement of 12-inch thick plain masonry block with solid grout in the cavities. He wants to know how deep he may put the basement. Assume a soil/water loading condition of h less than 0.25 (Chapter VI). From Table 6.1 assume a γ_{eq} is chosen for the kind of soil at the site and that value is 97 pcf.

Enter Figure 11.9 at γ_{eq} of 97, move up to the curve for solid grout, then move over to find the allowable loading height of 4.8 feet. This is less than the limit for buoyancy, so the homeowner may place the bottom of the wall up to a maximum of 4.8 feet deep.

11.6.2 Slab

The design considered here for basement floors will be for a reinforced concrete slab. Ultimate strength design theory is used. First, the loads must be calculated or assumed. Let the effective load per square foot on the slab be called w. The determinants for w are water height, partial superstructure load transferred to the slab, and slab dead load.

w = 62.4 H « ΔF - t/12 (150

H = height of water above bottom of slab in "feet"

t = slab thickness in "inches"

ΔF = shift in superstructure load from footing to slab due to decrease in bearing capacity and increase in settlement of footing due to pore pressure from flood water

$$\Delta F = \alpha \frac{\text{(Superstructure load to footings)}}{\text{Area of slab}}$$

α = 1/4

Now, using ACI318-63, method 3, table 2, case 6:

M_u = 1.4M (actual) = $(1.4)(0.061wA^2)$ for A/B 0.5

For ultimate strength design, the capacity moment equation becomes:

$$M_u = \Phi[bd^2f'_c(1 - 0.59q)] \text{ (capacity)}$$

b = 12" f'_c = 2,500 psi fy = 40,000 psi

$$q \quad \frac{A_s f_y}{bdf'_c} = d = t - 3/4'' - 1/2\,(3/4)'' = t = 1\tfrac{1}{8}''$$

$$A_s \text{ @ } \overline{\text{bar } A_s} \times \frac{12}{Sp} = Sp = \text{bar spacing in "inches"}$$

When actual M_u equals capacity M_u, the equation becomes:

$$1.4(0.061)(62.4b + 23 - 12.5t)A^2 \quad \frac{0.9}{12} \quad [12(t-1.125)^2.$$

$$2{,}500 \frac{\overline{\text{bar } A_s}\,(12)(40)}{Sp(2.5)(12)(t - 1.125)} \bullet (1 - 0.59 \times \frac{\overline{\text{bar } A_s}\,(12)(40)}{(Sp)(2.5)(12)(t-1.125)}\;]$$

The variables A, slab span; t, slab thickness; b, height of water loading; and $\overline{\text{bar } A_s}$, single bar cross-sectional area may all be assumed, and the equation may be solved for bar spacing. This has been done for 12-ft, 15-ft, and 18-ft spans using #4 or #6 reinforcement, and the results are plotted and shown in Figures 11.14 through 11.19 (Reference No. 26).

The design figures may be used as follows:

1. A maximum loading height has already been determined for soil/water loading on the basement wall. Use the water surface elevation associated with that loading condition as the starting point for slab design.

2. Enter the figure with the appropriate span length and reinforcement size.

3. For the depth of water, move horizontally to the right to intersect the curve with the desired slab thickness. Then look straight down to find the required spacing of the reinforcement.

Example:

Continuing with the example for basement wall design, the starting point here is water depth of 4.8 feet assuming the owner had the basement wall installed to that depth. Assume the basement is 24 feet wide with two 12 foot spans. The decision is made to use #4 reinforcing bars. Entering Figure 11.14 at a 4.8 foot depth of water, there are three possible choices. For a four-inch thick slab, the bar spacing would be five inches (nearest half inch). If a five-inch slab is used, the bar spacing would be 8½ inches. Or, an 11-inch spacing could be used if the slab were six inches thick.

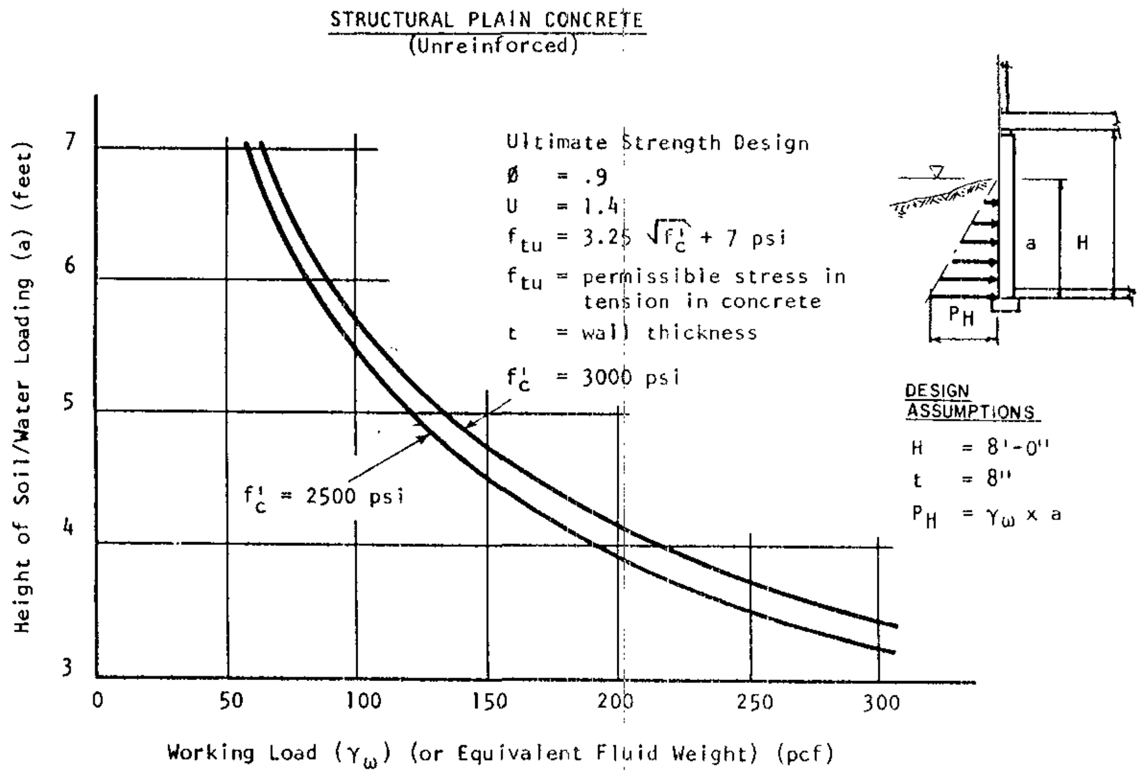


Figure 11.7 Ultimate strength design example for 8" unreinforced concrete walls. (Reference 26).

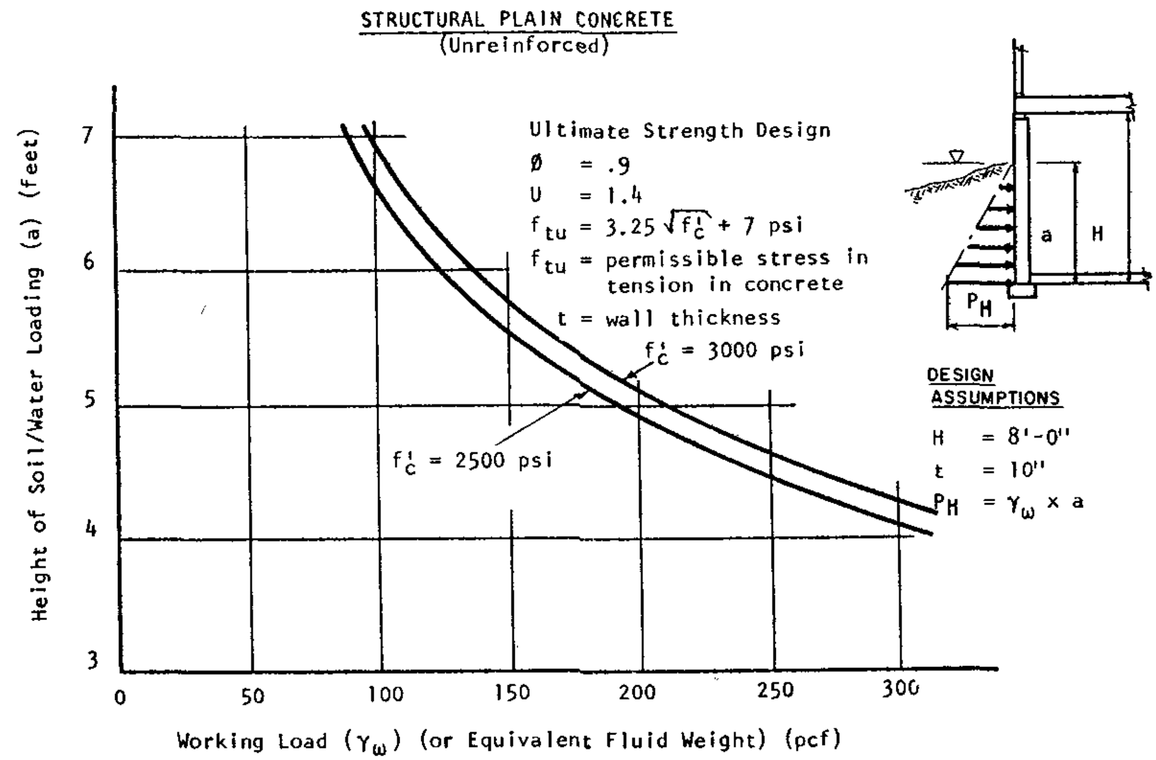


Figure 11.8 Ultimate strength design for 10" unreinforced concrete walls. (Reference 26).

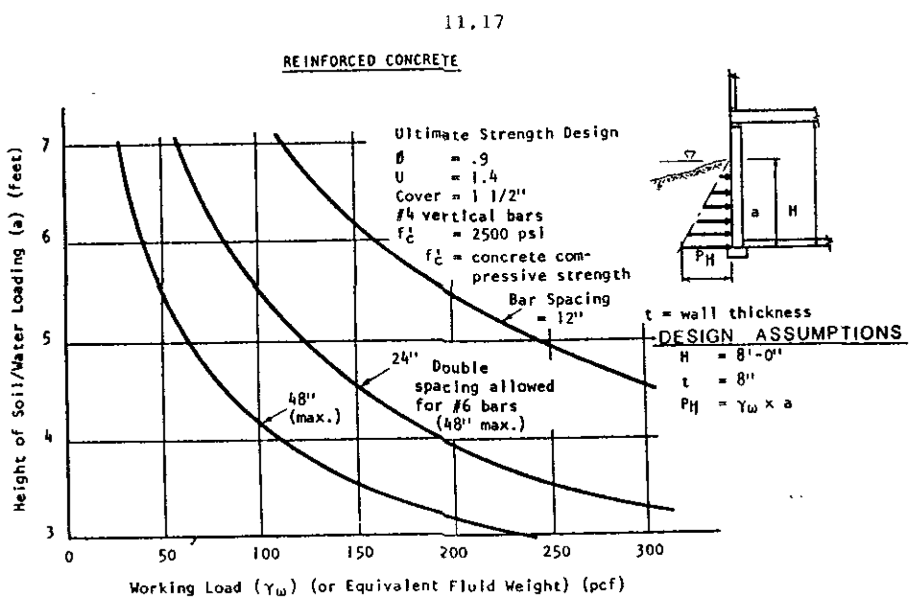


Figure 11.9 Ultimate strength design for 8" reinforced concrete walls. (Reference 26).

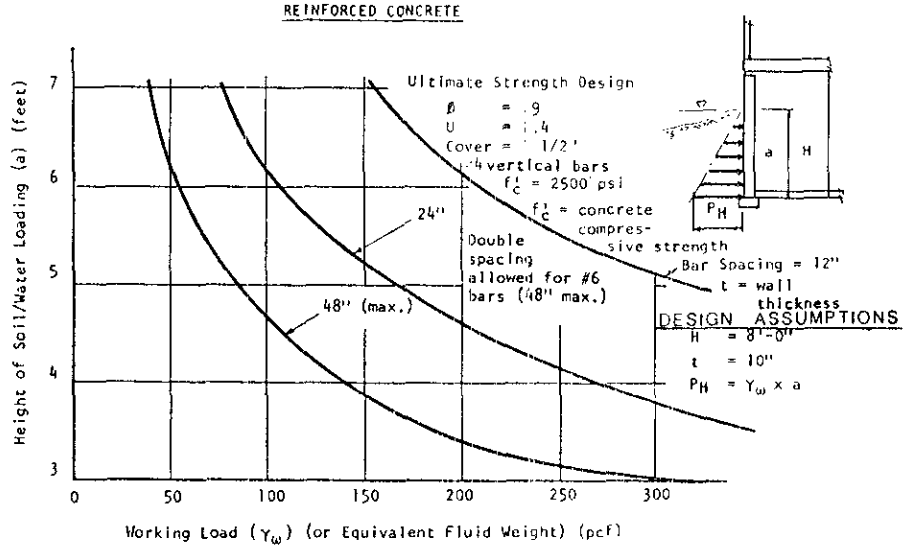


Figure 11.10 Ultimate strength design for 10" reinforced concrete walls. (Reference 26).

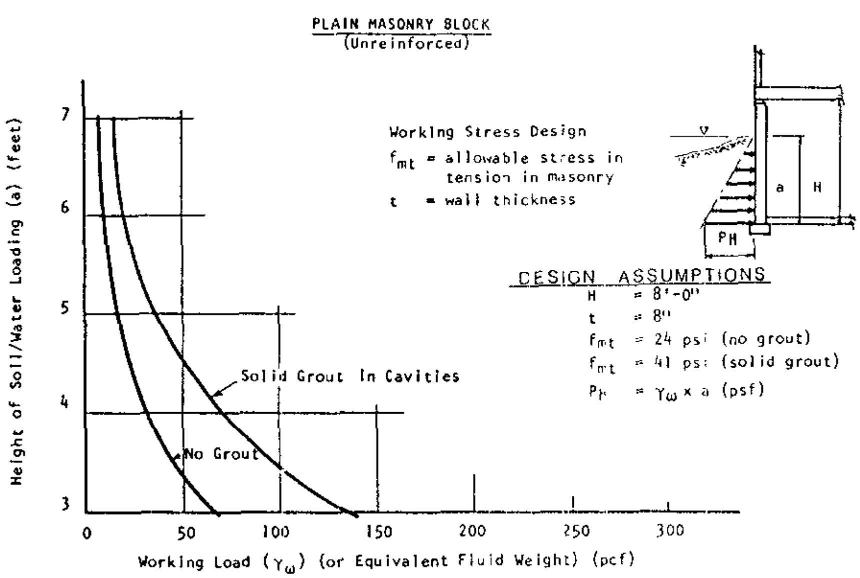


Figure 11.11 Working stress design for 8" unreinforced masonry block walls. (Reference 26).

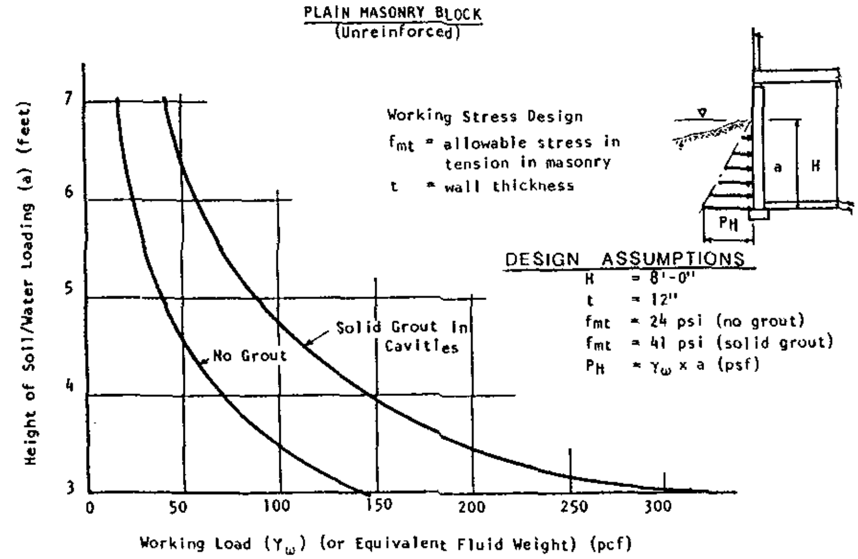


Figure 11.12 Working stress design for 12" unreinforced masonry block walls. (Reference 26).

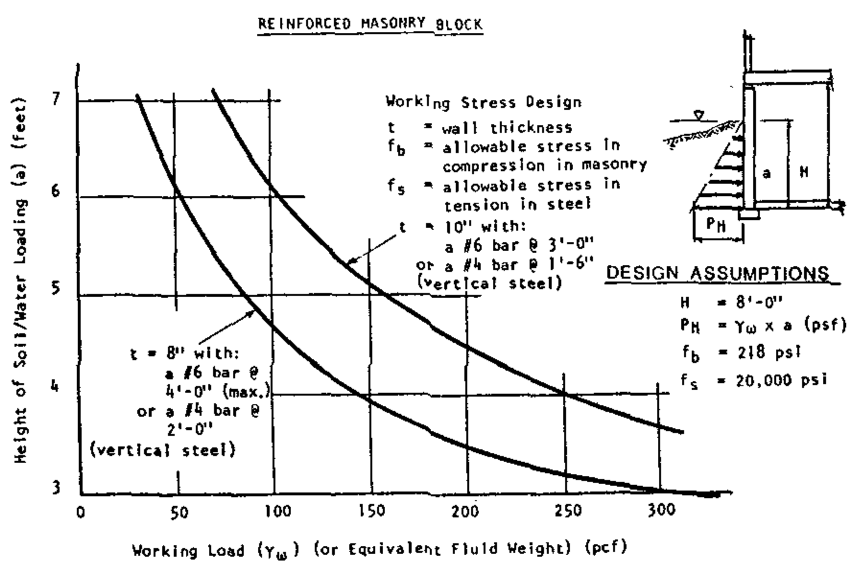


Figure 11.13 Working stress design for 10" reinforced masonry block wall. (Reference 26).

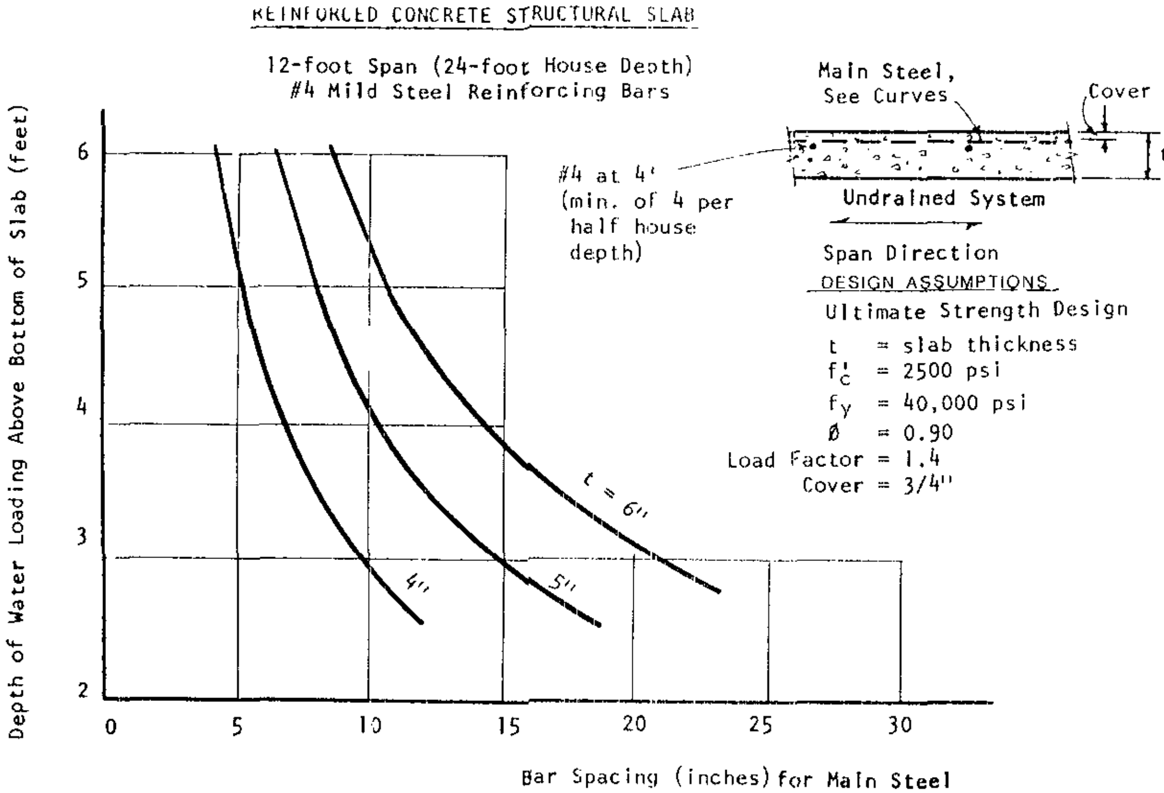


Figure 11.14 Slab reinforcement design, #4 steel reinforcing bars. 12 foot span. (Reference 26).

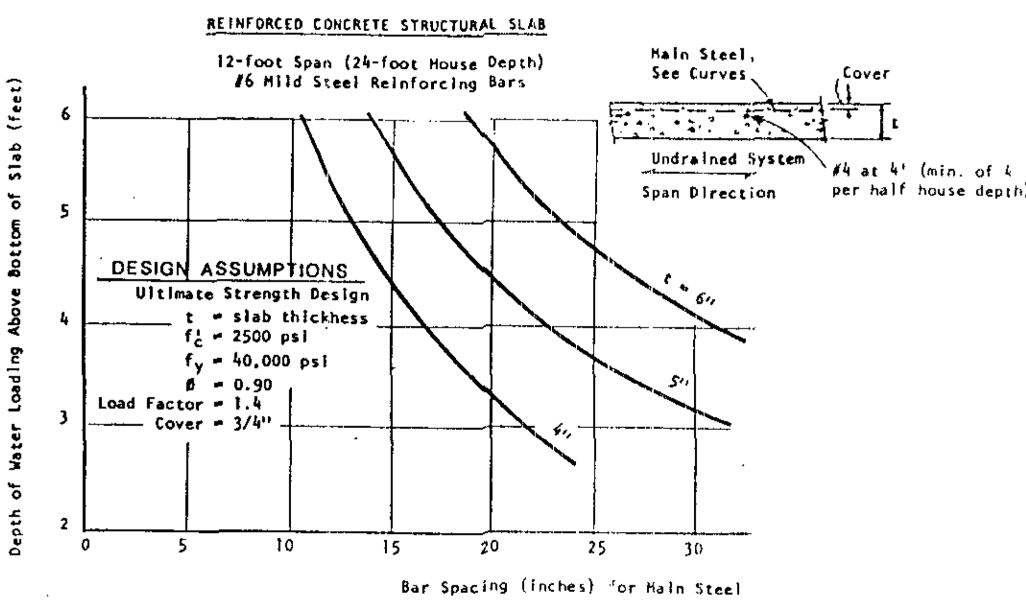


Figure 11.15 Slab reinforcement design, #6 steel reinforcing bars, 12 foot span. (Reference 26).

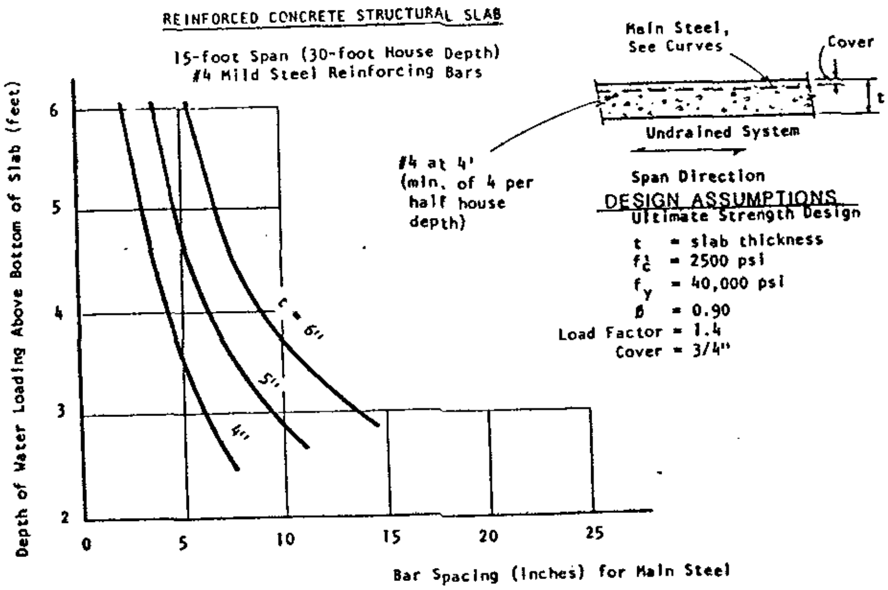


Figure 11.16 Slab reinforcement design, #4 steel reinforcing bars, 15 foot span. (Reference 26).

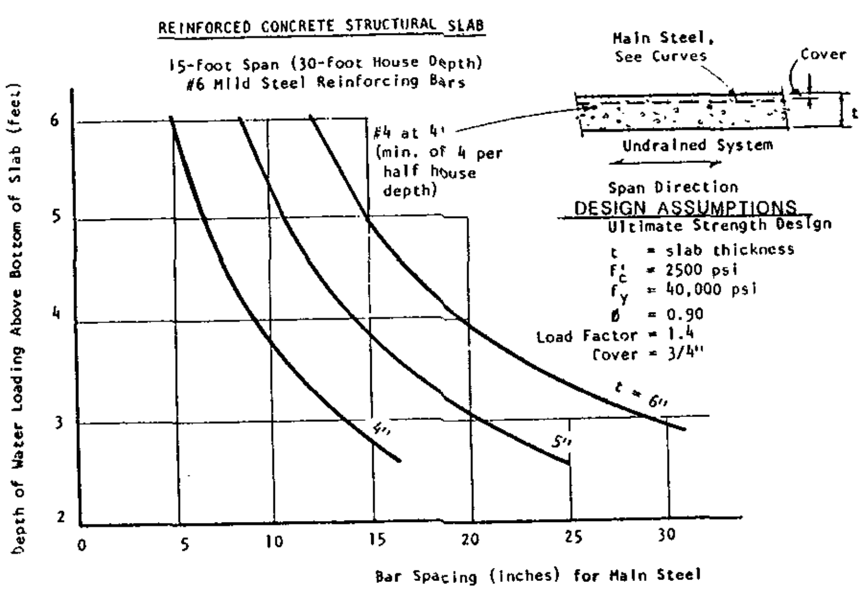


Figure 11.17 Slab reinforcement design, #6 steel reinforcing bars, 15 foot span. (Reference 26).

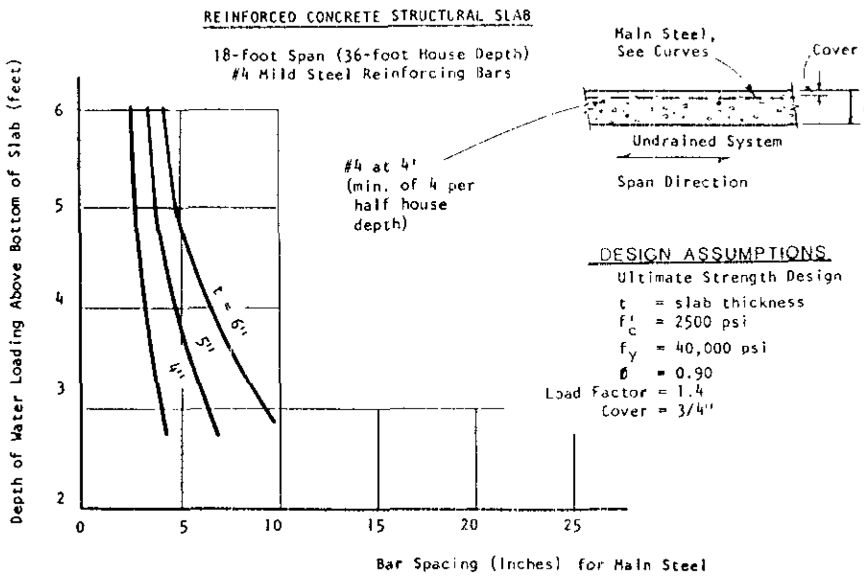


Figure 11.18 Slab reinforcement design, #4 steel reinforcing bars, 18 foot span. (Reference 26).

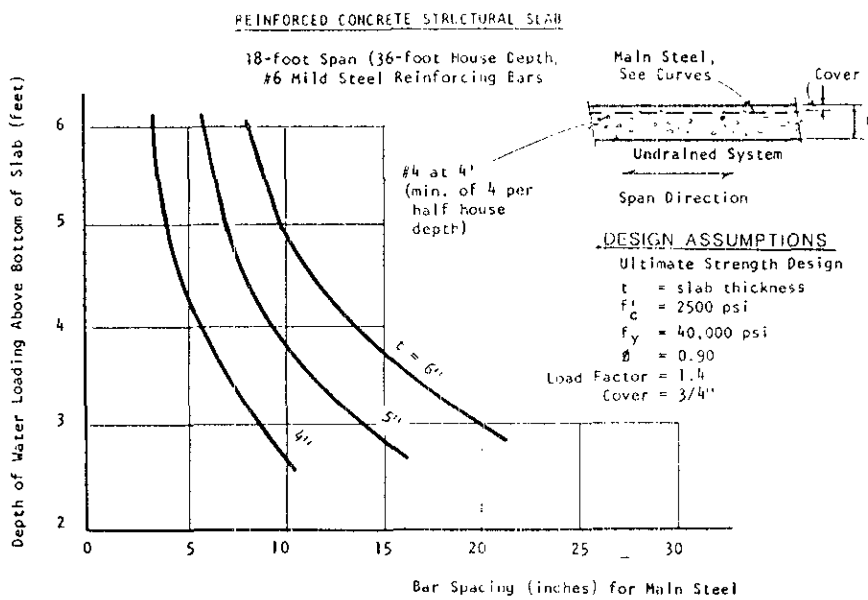


Figure 11.19 Slab reinforcement design, #6 steel reinforcing bars, 18 foot span. (Reference 26).

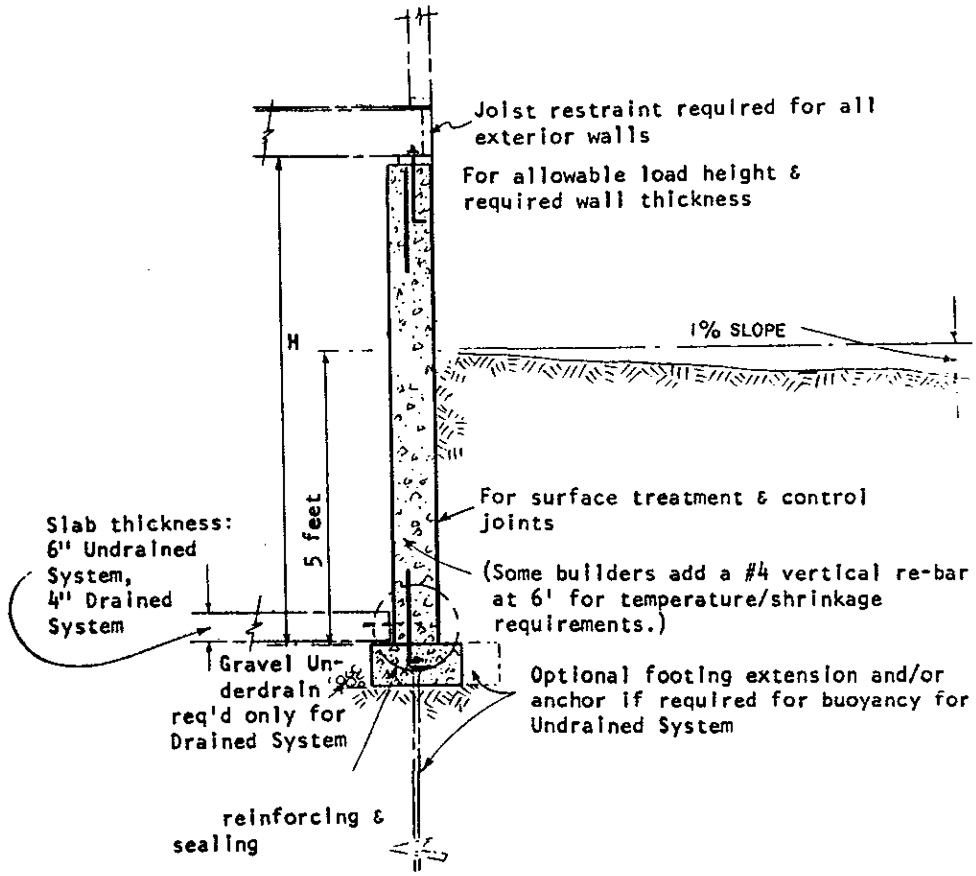


Figure 11.20 Unreinforced concrete wall design. (Reference 26).

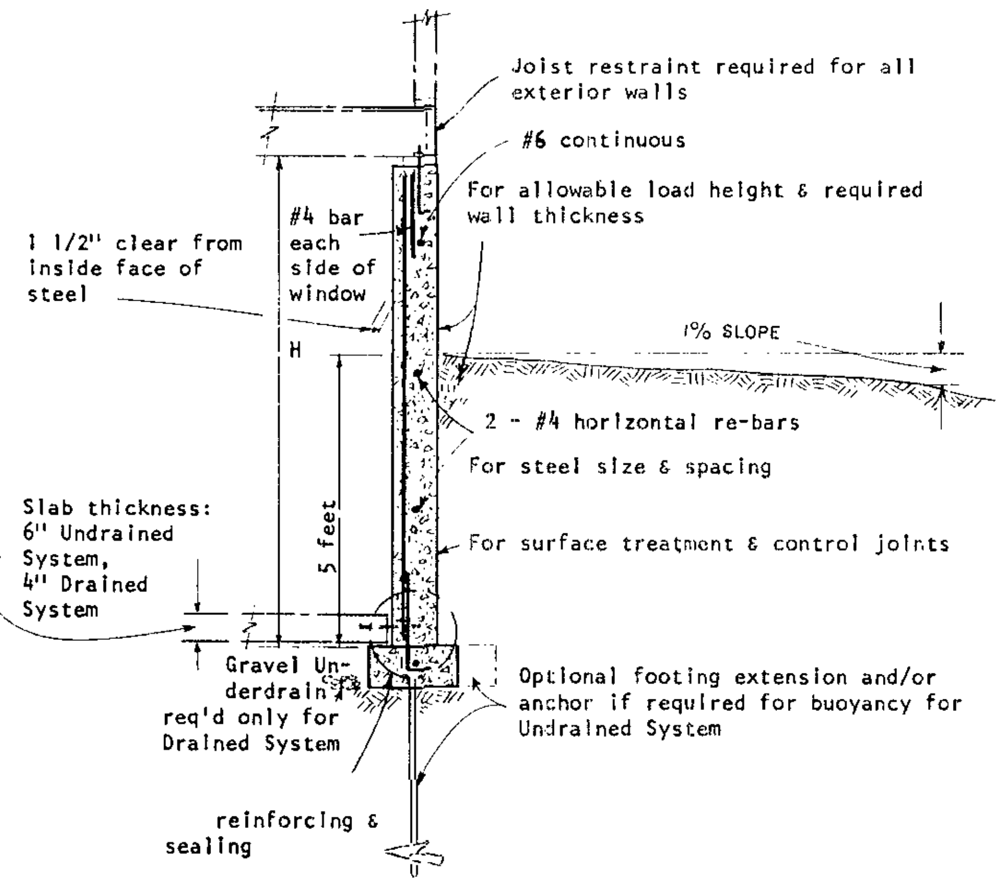


Figure 11.21 Reinforced concrete wall design. (Reference 26).

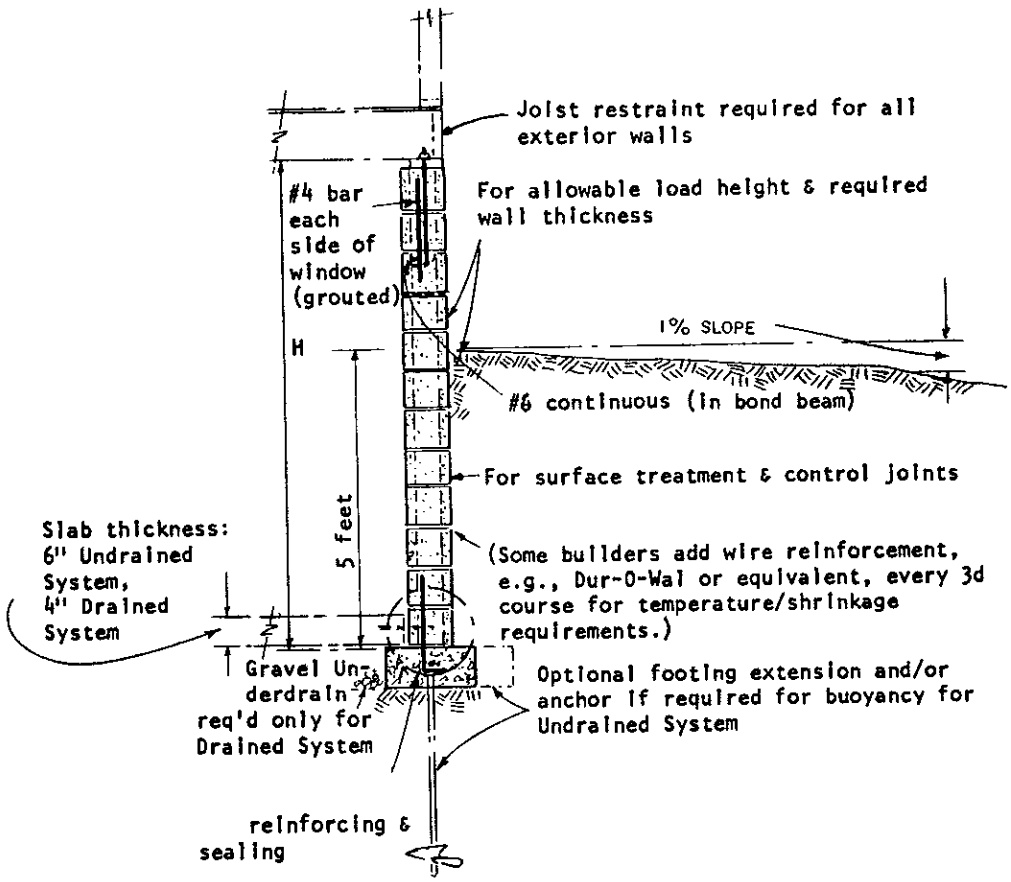


Figure 11.22 Unreinforced masonry block wall design. (Reference 26).

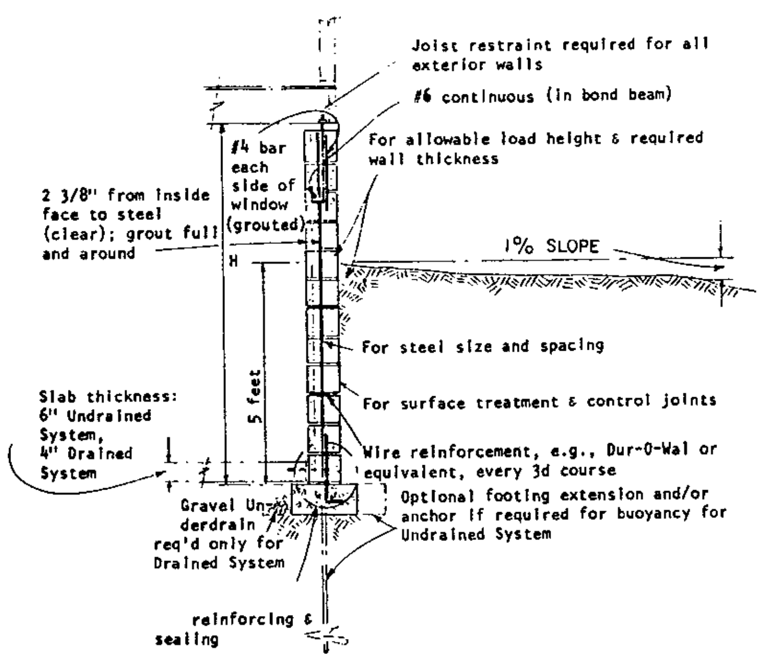


Figure 11.23 Reinforced masonry block wall design. (Reference 26).

1.7 ***Buoyancy***

11.7.1 General

Buoyancy considerations will usually limit the soil/water loading to a height of five feet above the bottom of the basement slab. This level corresponds roughly with the bottom of basement windows. It may be desired to use this relationship such that internal flooding will begin when water reaches the five foot level. The loading allowed for buoyancy must be compared with that loading which is allowed by wall and slab strength. Internal flooding should commence at the lowest of these levels.

The following calculations serve as an example by illustrating the maximum water surface elevation a typical house can withstand before becoming buoyant. The loads used in this example are not meant to be representative of every structure. Local codes should be consulted to provide the necessary design load requirements. Because loading conditions may vary greatly from one structure to another, it is desirable to perform calculations such as the following for each particular site and structure.

11.7.2 Example Calculations

First, assume a single story house, 30 by 50 feet in plan with a 6-foot rise for the trussed roof and a distance from floor level to eave of 10 feet.

Loads

Roof			
	Mechanical and electrical		1 psf
	Structural		4 psf
	Roofing		psf
		Total	8 psf
Attic Floor			
	Mechanical and electrical		1 psf
	Structural		3 psf
	Floor		2 psf
	Live Load		1 psf
		Total	7 psf
First Floor			
	Mechanical and electrical		2 psf
	Structural		4 psf
	Floor		2 psf
	Live Load		10 psf
		Total	18 psf
Bearing Walls			7 psf

Let W = Roof Attic Floor + First Floor + Walls = Total Load

Roof - 8 psf x 32.2′ x 50′	= 12.88 kips
Attic Floor - 7 psf x 30′ x 50′	= 10.50
First Floor - 18 psf x 30′ x 50′	= 27.00
Walls (including interior)	
3 (7 psf x 10′ x 50′) +	
4 (7 psf x 10′ x 30′)	= 18.90
	69.28^{K}

SW = Weight of basement slab and walls

6" Slab: 150 pcf x 6/12 ft x 1,500 sq. ft.	= 112.5K
Exterior Walls: 100 psf (avg for concrete and block) x 8' x 160'	= 128.0
Interior Walls: 35 psf (avg) x 8' x 50'	= 4.0
	SW = 254.5

Forces shown in Figure 11.20 are defined as:

B = Buoyant Force = 0.0624 D/ft³ x b x 1,500 sq. ft.
C = Basement contents weight
V = Soil shear load
b = Height of water table above slab bottom (ft.)

Uplift will be impending when: B = W + SQ C V

If C and V are assumed zero:

(0.0624)(b)(1,500) = 69.28 + 254.5
b = 3.46'

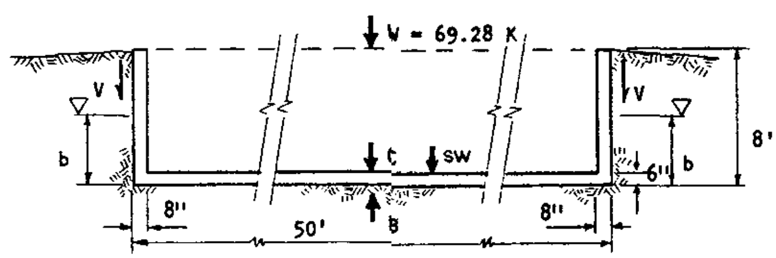


Figure 11.24 Bouyant force calculations.

Estimates for soil shear may be made:

v clay = 0.2 KSF

v sand = $\frac{0.04}{2}$ $\frac{K}{ft^3}$ x b x K_A x f

K_A = coefficient of active earth pressure. (0.33).

f = coefficient of soil frictions. (0.33).

v sand = $\frac{0.04}{2}$ $\frac{K}{ft^3}$ 5' x 0.33 x .33 = 0.01 KSF

Conservatively, then V = v x A = (0.01 KSF)x(5' x 160') = 8.0K

Basement contents may also be estimated:

C = 0.003 KSF x 1,500 sq. ft. = 4.5K

Including soil shear and contents, the allowable depth becomes:

$$b = \frac{3.23.8 + 8.0 + 4.5}{.0624 \times 1,500} = 3.59'$$

Assume a second story is added to the house from the preceding example.

W = 69.3K + second floor ceiling + first floor + 8' walls

W = 69.3K + 1 psf x 1.500 sq. ft. + 27K + 3(7 psf x 8' x50') + 4(7 psf x 8' x 30')

$W = 12.9\ K$

$$b = \frac{W + SW}{(0.0624)(1{,}500)} = \frac{112.9 + 254.5}{93.6} = 3.92'$$

With V and C included

$$b = \frac{112.9 + 254.5 + 8.0 + 4.5}{93.6} = 4.06'$$

An outward reinforced extension of the footing of one foot will allow an increase in the water table of slightly more than one foot. This, then, shows the basis of five feet being used as maximum height of water loading.

XII. ELECTRICAL

12.1 *Main Power Service*

The incoming main power service equipment, including all metering equipment, must be located above the Base Flood Elevation (BFE) where power can be disconnected at a single location. The main switch should control all electrical circuits throughout the structure except for emergency lighting circuits. Structures that will be isolated by water during flooding should have a remote disconnecting switch at an accessible point above the BFE. The freeboard requirement for electrical control panels and main switches is one (1) foot.

12.2 *Stationary and Portable Equipment*

All major electrical control panels, transformers, elevator power equipment, and other stationary equipment should be located above the BFE. Switches, outlets, or wiring below the BFE can be isolated on flood-vulnerable circuits and should be well marked as such on the circuit breaker box. Permanently installed electrical equipment at below the BFE must be of the submersible type.

Portable electrical equipment may be located below the BFE, provided it is equipped with submersible quick disconnects. If possible, all movable equipment should be moved out of potentially flooded spaces at the time of a flood warning and before the floor where the equipment is located becomes wet.

12.3 *Emergency Lighting*

For structures that would require emergency evacuation operations or personnel to occupy the building during flooding conditions, an emergency lighting system should be installed. The system should be installed above the BFE with a separate distribution panel and should have a separate power source which cannot be affected by a water elevation at the BFE.

Battery operated lighting units should be completely self contained and should indicate the state of charge at all times. The emergency lighting units should automatically provide light when the normal source of lighting is de-energized. The emergency lighting should permit personnel a safe exit to an area above the BFE.

12.4 *Wiring*

All electrical wiring systems installed below the BFE must be suitable for continuous submergence in water and all splices must be submersible type. Where there are electrical conduits subject to flooding, they should be self draining

12.5 *Elevators*

The electric power equipment of elevator systems must be located above the BFE. Automatic type elevators should have a home station above the BFE to which the elevator will automatically return after use.

12.6 *Sump Pumps*

Structures utilizing sump pump equipment should have a float-operated warning alarm that acts independently of float devices used to start and stop pumping equipment. Automatic starting standby generators, located above the BFE, should also be provided. The standby generator must be capable of continuous operation for at least 125 percent of the estimated duration of flooding.

XIII. MECHANICAL

13.1 *Introduction*

Heating, air conditioning, ventilation, and plumbing systems should be installed in spaces above the BFE. The freeboard required is one (1) foot. In some multi-story commerical structures, it may be most practical to locate all mechanical and electrical controls on an upper top floor. When mechanical equipment must be placed below the BFE, the following guidelines should be used. Electrical components and connections of mechanical systems should conform to guidelines in Chapter XII of this manual.

13.2 *Heating and Air Conditioning Systems*

When fixed heating and air conditioning equipment cannot be installed above the BFE, diking around them can be used to exclude floodwater and also help protect them when intentional internal flooding is performed to protect parts of the structure. Diking would be a permanent measure that is functional at all times. A dike wall with removable shield is shown in Figure13.1.

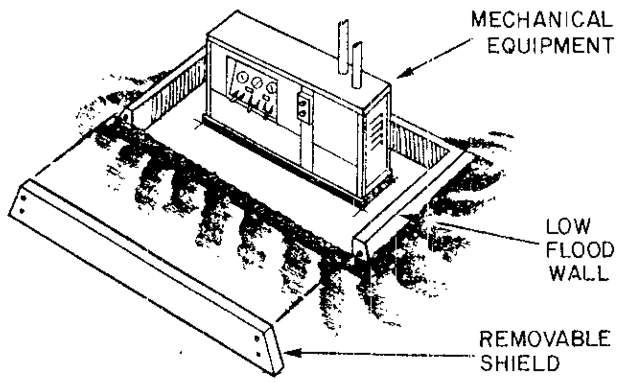


Figure 13.1 Dike wall with removable shield. (Reference 12).

The fuel supply line of gas or oil operated systems located below the BFE should contain automatic shutoff valves that are activated by rising floodwaters. Also, there should be a manually operated shutoff valve for the fuel supply, which can be controlled from a point above the BFE. Fuel lines must be attached to furnaces by flexible or swing type couplings.

The heating equipment and fuel storage tanks should be securely anchored to prevent flotation and to withstand hydrodynamic and impact forces. All heating equipment and fuel storage tanks should be vented to an elevation above the BFE.

13.3 *Ventilation*

All ventilation duct work that is below the BFE should have openings which allow internal flooding and drainage of the ducts. The openings should have covers that are kept closed by gravity force during normal operation. Where duct work below the BFE passes through a waterproof wall or floor, or connects to heating or air conditioning units, the duct shall have a mechanical closure assembly which is operated from a location above the BFE.

13.4 *Plumbing*

Components of plumbing systems below the BFE must be designed to minimize loss of stability or tightness that could permit infiltration of floodwaters or permanently impair the functioning of the system. Plumbing lines and fixtures should, therefore, be secure from possible damage due to stored materials or items in the vicinity which may be shifted by floodwaters.

13.4.1 *Contamination*

Contamination of the water supply and backup of contaminated water lines are of great concern during a flood. Water lines below the BFE should be designed so that they always contain pressure which is greater than the maximum expected hydrostatic pressure of the floodwater.

13.4.1.1 *Water Supply Wells*

Water supply wells, tanks, filter, softeners, and heaters should be protected by using covers, walls, copings, or castings. Vents should be extended to a point above the BFE.

Private potable wells should not be developed from any source capable of being directly polluted by floodwater. Private wells should have protection in the form of a watertight casing that is sealed at the bottom of the well in an impermeable stratum. Alternatively, the casing must extend several feet into the water-bearing stratum.

13.4.1.2 *Backflow Prevention Devices*

Installing automatic backflow prevention devices on the main water service lines at all building entry locations will help prevent floodwater backflow or siphonage that can occur with a water line break. Manually operated shutoff valves that can be operated from above the BFE should be installed as a safety feature to be used in case of failure of the automatic device. Storm drainage and sanitary sewer lines that enter a structure below the BFE should also have a backflow prevention device.

13.4.2 *Sanitary Sewer Systems*

Included in the design of sanitary sewer systems that must remain in operation during high floodwaters should be a sealed holding tank and necessary mechanical controls to prevent discharge during the flood. Vents from such a system must have the outlet raised above the BFE. The design of individual sewage disposal or treatment facilities in a flood hazard area should take into consideration the following: location of water supply wells, water table, soil characteristics, and topography. Cesspools and seepage pits should not be allowed as a permanent installation in a primary flood hazard area.

13.4.3 *Disinfecting Water Systems*

Should floodwater contaminate a water supply system, all potable water equipment, piping, water storage tanks, etc. should be disinfected with a chlorine-water solution. Disinfected systems must be flushed thoroughly with clear water before use. Various solution strengths and their standing times are given below (Reference No.28).

Standing Time (hrs)	Parts per million of Chlorine
24	50
3	200
3	200*

*For swabbing interior of water storage tanks.

XIV. MOBILE HOMES AND PARKS

14.1 *Anchoring Systems*

Mobile homes that could be susceptible to damage by floodwaters should be adequately anchored. For someone seeking federal flood insurance for their mobile home, this is a prerequisite. The purpose of anchoring is threefold; it helps prevent flotation, collapse and lateral movement.

Many manufacturers of tiedowns are meeting the FEMA requirement for 4,800 pound (sometimes stated at 4,725 pounds) strength in their equipment. It should not be assumed that all equipment will meet this requirement. Dealers and manufacturers must be questioned regarding their products before installing the anchoring system.

The minimum anchoring system that is considered should always meet or exceed all local or federal requirements. The 4,725 pound criteria will be used here as will the generally accepted factor of safety of 1.5. One further note should be made on the load limits for anchors. Deflection of the anchor/strap connection should not exceed two inches during maximum loading conditions.

The two types of anchoring that are used are frame ties and over-the-top tiedowns. Some regulations state that over-the-top tiedowns may not be necessary if the mobile home design provides the equivalent structural strength when anchored according to the manufacturer's specifications, and meets the minimum FEMA requirements. However, it is best to use both kinds of ties to insure adequate protection against lateral and buoyant forces. Any canopies or additions to a mobile home should be secured with over-the-top tiedowns.

14.1.1 Straps

Basic Equipment. The component of an anchoring system which passes over the mobile home top or fits around the frame I-beam is commonly a metal strap. The metal strapping should conform to American National Standards Institute (ANSI) AII9.1 (Reference 3) specifications. In general, all metal strapping from mobile home equipment suppliers conforms to the ANSI specifications. However, this fact should be verified when purchasing metal strapping. Two feasible alternatives to the standard metal strapping are cable and chain. The main considerations for cable are flexibility and protection against corrosion. Protection against corrosion is provided by galvanizing. Flexibility of cable is based on the number of and subsequently the size of strands used to make up the cable. The more strands, the more flexible the cable. The use of chains simply requires that the chain be capable of withstanding the 4,800 pound strength requirement of FEMA. Table 14.1 gives various chain and cable sizes and strengths in comparison to metal straps. Other alternatives which have been used include manila or nylon rope; but these are not in common use and manufacturer standards are not being developed for them. However, if these other materials are used, they must be sized to meet the FEMA strength regulations. The metal straps are becoming standardized by the industry and many newer mobile homes come equipped with them from the factory. The factory installed straps have the advantage of not being visible when the mobile home is set up and skirted. Owner installed straps are visible and require roof brackets at the edge of the roof.

The exterior exposure of anchoring brings up another important consideration. All anchoring equipment including straps, brackets, buckles, and anchors must be able to withstand the corrosive forces of the environment. In order to maintain the required strength for the life of the structure, components should be galvanized. New recommendations are for a minimum of 0.067 ounces of zinc per square foot of steel surface. Manufacturers also may soon have to put their stamp on their products.

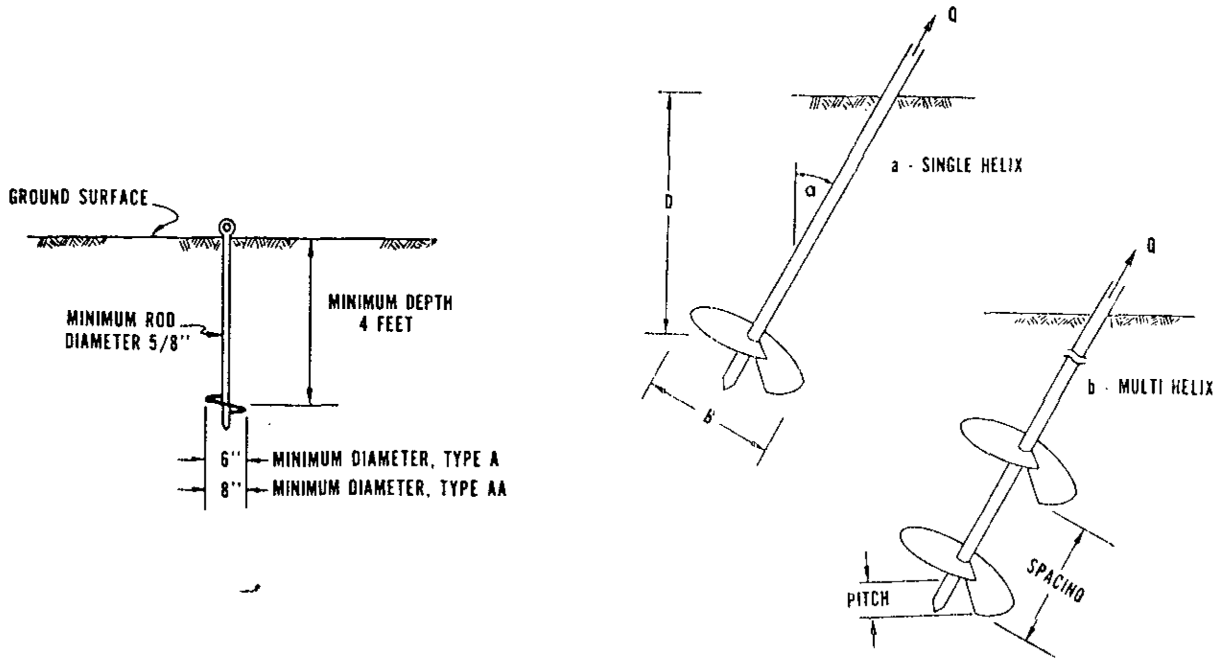
14.1.2 Anchors and Accessories

The second part of the anchoring system to be discussed is the anchor itself. There are many kinds, but the most common one is the helix, or disc, anchor. The minimum rod diameter for this anchor is 5/8" and disc diameters are usually four or six inches. The helix and x-type anchors are pictured in Figure 14.1. The x-type is also useful, but only in rock. It should not be used in other soils. Dead man and concrete slab anchors are shown in Figures 14.2 and 14.3, but they are not often used. Some of the typical frame anchoring system equipment that might be needed for some systems is also shown (Figure 14.4).

Table 14.1. Chain and cable sizes and strengths, *1983* dollars

Type of Material*	Size	Working Load (lbs)	Unit Costs ($)
Metal Strap	1.25" by 0.035"	4,800	0.21/ft
Galvanized Strand Cable (1x7) Extra-High Strength Grade	3/8"	15,400	0.14/ft
	1/2"	26,900	0.27/ft
Galvanized Rope (6x19)	3/8"	13,590	.76/ft
Galvanized Aircraft Cable (most flexible) (7x19)	3.8"	14,400	.67/ft
	1/2"	22,800	.99/ft
Chain Grade 70 6-7	5/16"	4,700	5.18/ft
	3/8"	6,600	6.64/ft
Grade 40 highest	3/8"	5,400	3.28/ft
	7/16"	7,200	4.19/ft
Grade 30 Proof coil	5/8"	6,900	5.98/ft

*Two 3/8" steel clamps, Grade 40, or equivalent must be used when fastening chain, rope, or cable to frames and anchors.



TYPE A – A SCREW AUGER OF MINIMUM AUGER DIAMETER OF 6" WITH A MINIMUM 5/8" DIAMETER ROD INSTALLED WITH A MINIMUM DEPTH OF 4 FEET. ALSO 8" SIZE ARROWHEAD ANCHOR.

TYPE AA – SAME AS TYPE A EXCEPT MINIMUM AUGER DIAMETER IS 8". ALSO 10" SIZE ARROWHEAD ANCHOR.

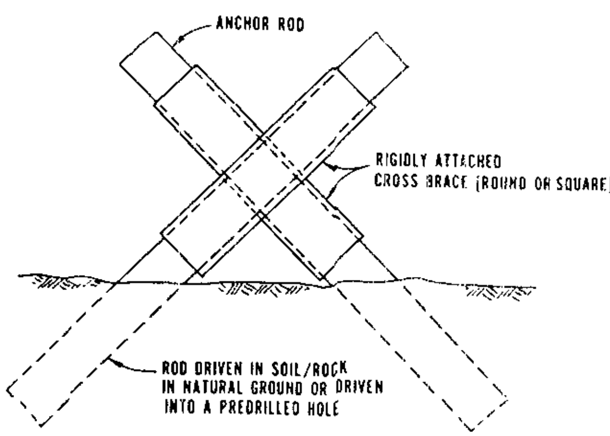


Figure 14.1. Helix (disk) type soil anchor and x-type (crossdive) rock anchor. (Reference 19).

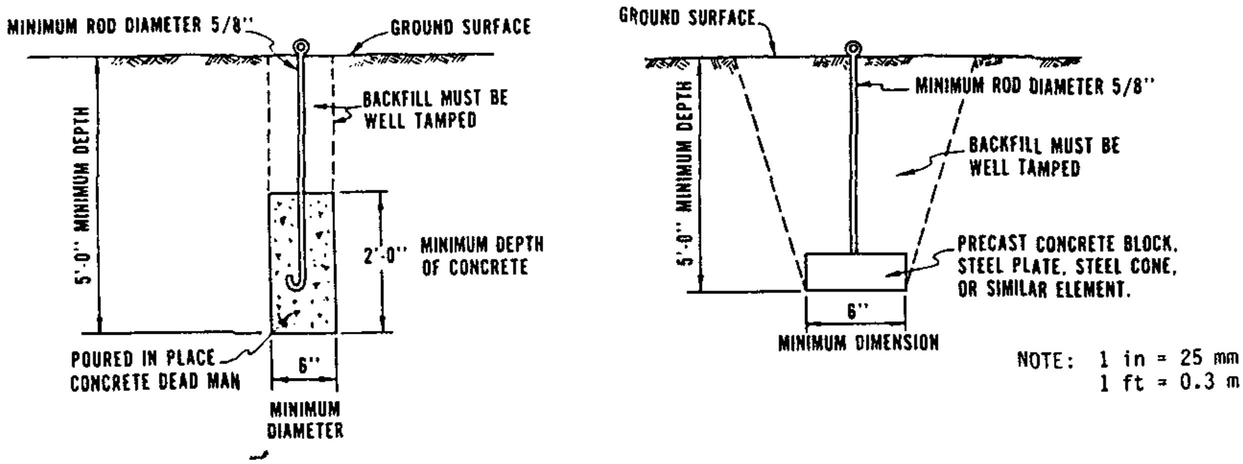


Figure 14.2. Dead-man anchors. (Reference 19).

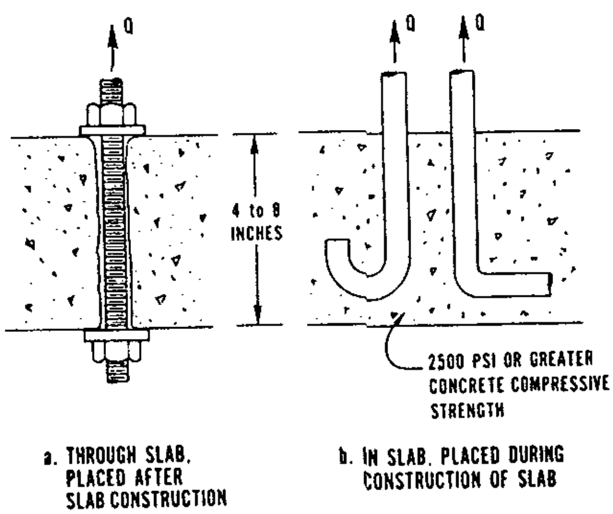


Figure 14.3. Slab anchors. (Reference 19).

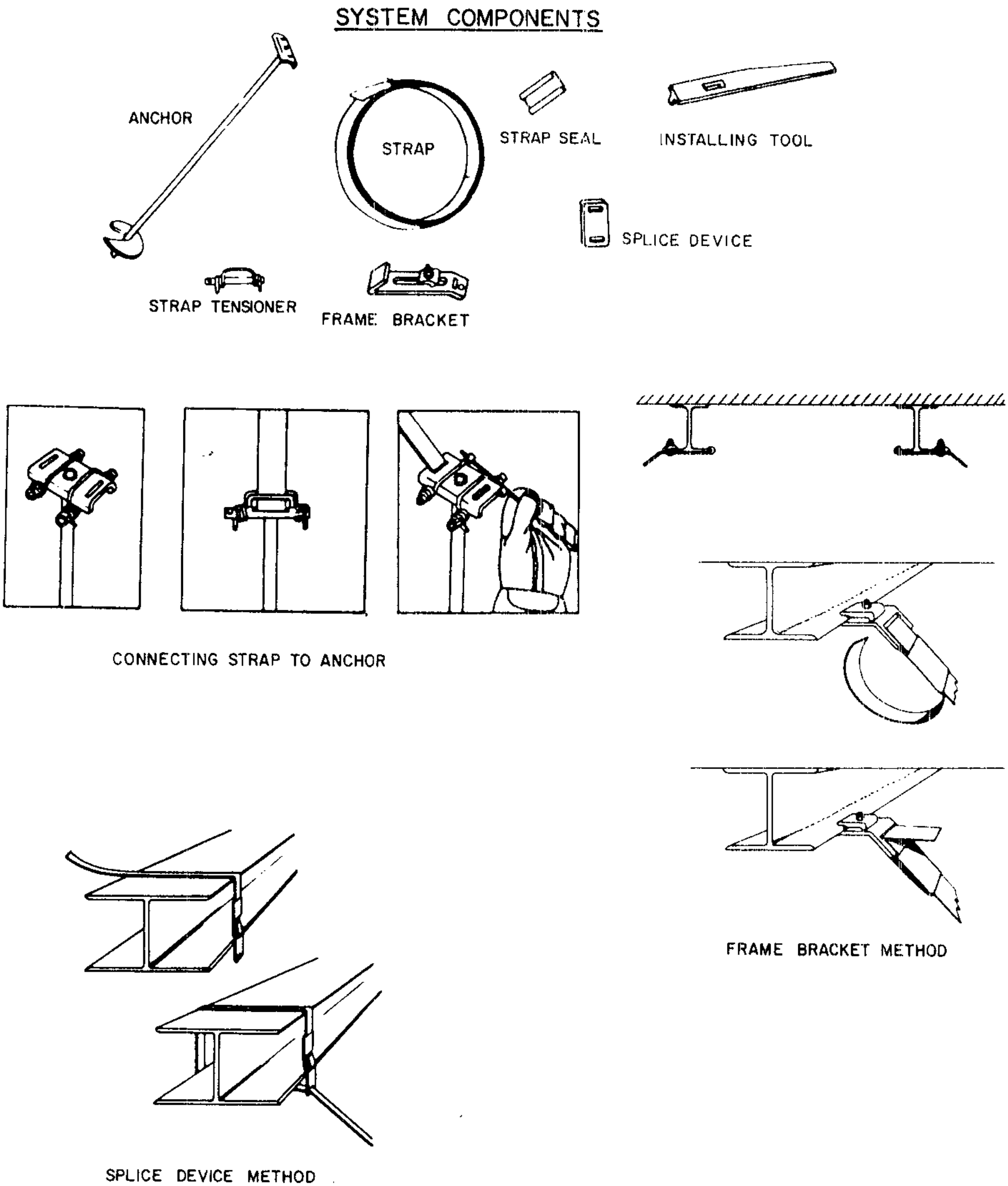


Figure 14.4. Anchoring system equipment. (Reference 18, 30).

14.2 ***Strength Design for Anchoring***

Local and federal government requirements already exist for the number and spacing of ties for mobile homes. The FEMA regulation requires that all mobile homes placed within Zone A on a community's Flood Hazard Boundary Map (FHBM) shall be anchored to resist flotation, collapse, or lateral movement by providing over-the-top and frame ties to ground anchors. Specific requirements are that *"(i) over-the-top ties be provided at each of the four corners of the mobile home, with two additional ties per side at intermediate locations, and mobile homes less than 50 feet long require one additional tie per side; (ii) frame ties be provided at each corner of the home with five additional ties per side at intermediate points, and mobile homes less than 50 feet long require four additional ties per side; (iii) all components of the anchoring system be capable of carrying a force of 4,800 pounds; and (iv) any additions to the mobile home be similarly anchored."*

14.2.1 Water Loadings

From the calculated water loadings, the required tiedown force in pounds per linear foot of mobile home will be determined. Several assumptions must be made about the anchoring system. As shown in Figure 14.5, the mobile home is assumed to be tied down only at the bottom outside edges, as would occur with an over-the-top tiedown. This is necessary because with both frame and over-the-top straps the structure would be statically indeterminate and could only be solved by knowing the flexural characteristics of the mobile home. Such complex calculations, involving experimentally determined values, are not justified.

After the requirements are computed for the statically determinate model, frame and over-the-top straps may be assumed to carry approximately equal loads. Then, the number of anchors can be determined.

Figure 14.5 shows the forces acting on a mobile home during a flood. Further assumptions are also noted. Variables used in calculating the forces are defined here.

F_{H1} and F_{H2}	Hydrostatic Forces
F_D	Hydrodynamic Forces
F_{B1} and F_{B2}	Buoyant Forces
Wt	Weight of Mobile Home
W	Width of Mobile Home
T_v	Vertical Tension in Upstream Tie
T_H	Horizontal Tension in Upstream Tie
T_T	Total Tension in Upstream Tie
h_1	Water depth, upstream side
h_2	Water depth, downstream side
γ	Specific Weight of Water, 62.4 lb/ft^3
C_d	Drag Coefficient, 1.31
ρ	Mass Density of Water, 1.94 slugs/ft^3
V	Velocity of Water in fps

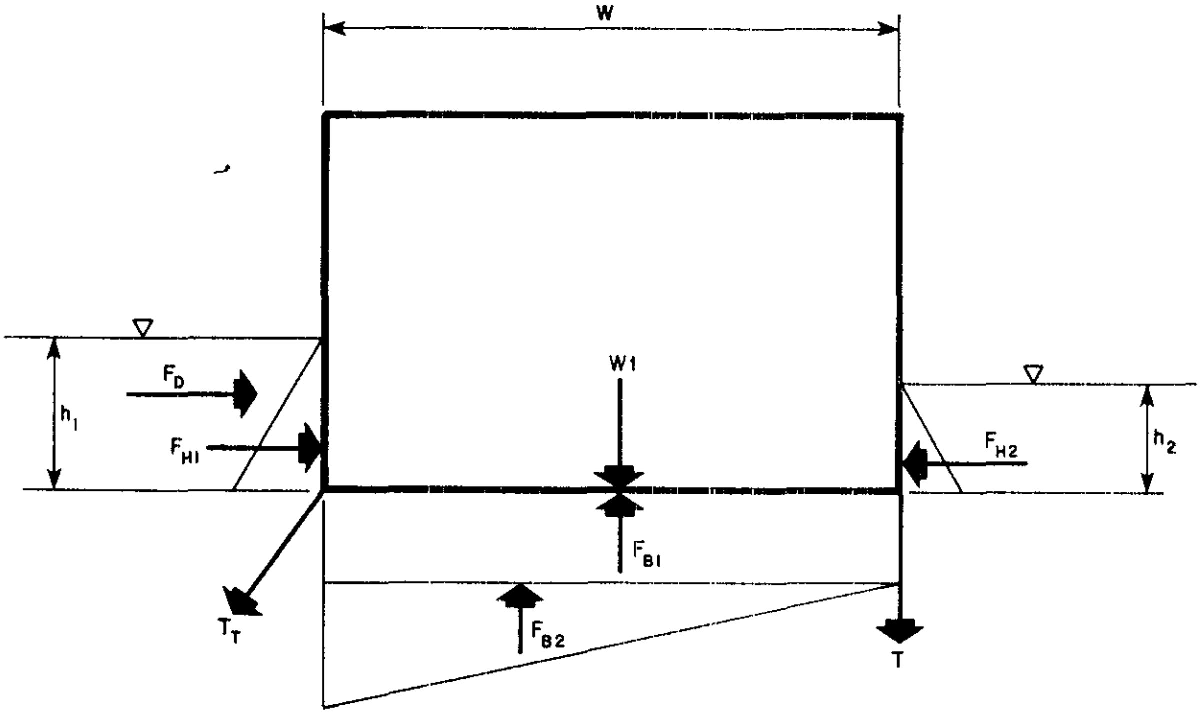


Figure 14.5. Mobile home water loading diagram.

Assumptions:

Water is moving perpendicular to long side of the mobile home. For low velocities, buoyant force governs and direction of flow is relatively unimportant. Friction on supports becomes zero. Water is free to get under the mobile home. Depth $h_2 = h_1$ - 0.5 feet: There will be some drop, but a larger drop results in less required tension in the strap, this assumption should result in a conservative design.

Mobile home plus load weighs 21 lb/ft² (Reference 19).

Drag coefficient is 1.31 (Wind forces on mobile homes Robert H. Harris, Reference 14).

Strap on downstream side is vertical so as the mobile home becomes buoyant there will not be added horizontal force on straps.

The following equations are used to calculate required tiedown force per linear foot of mobile home.

1. $F_{H1} = \frac{\gamma}{2} h_1$ 2. $F_{H2} = \frac{\gamma}{2} h_2$ 3. $F_D = C_d \rho \frac{V^2}{2} h_1$

4. $F_{B1} = h_2 \gamma W$ 5. $F_{B2} = (0.5) \frac{\gamma}{2} W$ 6. $Wt = W(21)$

7. $T_V = [F_{H1}(\frac{h1}{3}) - F_{H2}(\frac{h2}{3}) + F_D (\frac{h1}{2}) + F_{B1}(\frac{W}{2}) + F_{B2}(\frac{2W}{3}) - Wt (\frac{W}{2})] \bullet W$

8. $T_H = F_D + F_{H1} - F_{H2}$ 9. $T_T = \sqrt{T_V^2 \quad T^2_H}$

The mobile home weight and water loads may all be accurately assumed or calculated for various conditions. Required tiedown force is then calculated per linear foot of mobile home. The two unknown forces that remain are the tiedown tension forces. The upstream tie will have the greater tension, so it is solved for by first, summing moments about the lower right hand corner in Figure 14.5 (eq. 7). This gives the vertical tension component in the tie. Summing forces in the horizontal direction gives the horizontal tension component in the tie (eq. 8). Now the total tension, or required tiedown force is calculated (eq. 9). Figure 14.6 shows the required anchoring force per linear foot for each side of a 14 foot wide mobile home under different conditions. The number of required anchors for specific mobile home lengths is also shown. Figure 14.7 presents anchoring information for 24 foot wide mobile homes.

14.2.2 Number and Spacing of Anchors

Current standards say all anchoring components should be capable of carrying a 4,725 pound force. To account for the safety factor of 1.5, the expected force on each anchor should not be allowed to exceed 3,150 pounds.

Example: Calculation Number and Spacing of Anchors

(1) Assume a 14 x 66 foot mobile home with an expected water depth of two feet and a velocity of five feet per second. From Figure 14.6, 14 anchors would be required. The spacing is computed as 66 divided by (14-1) 5 feet. Fourteen minus one is used as the divisor because an anchor must be located at each corner.

(2) Assume a 14 x 56 foot mobile home with an expected water depth of one foot and a velocity of 10 feet per second. From Figure 14.6, 270 lbs. of anchoring force per linear foot is required. The total anchoring force on each side is (56)x(270) or 15,120 lbs. The number of properly installed anchors would be 15,120 divided by 3,150 4.8 or five per side. The spacing is computed as above.

These examples may be compared to the total ties pe' side required by FEMA regulations, which is eleven. Obviously, the required tiedown strength for some situations would be greater than the minimum government standard. Also note that, according to the methods of calculations used here, there does not seem to be justification for the FEMA requirement of additional ties for mobile homes shorter than 50 feet. However, typical conditions that the FEMA regulations apply for a 70' x 14' mobile home are, 1) water depth 1.6' and velocity 5 fps; 2) water depth 1.5' and velocity 10 fps; and 3) water depth 1.2' and velocity 15 fps.

The required anchoring force on the downstream side of a mobile home may be less than the upstream side, but it is best to keep the anchoring system symmetrical. As in the last example above, five anchors on each side would be directly across from each other.

Note that at some point, it becomes unrealistic to try to anchor a mobile home. The anchors may be designed for a strength that far exceeds the wall and floor strength of the mobile home. It may also be observed that, for low to moderate velocities, the velocity of the water is not usually as critical as the depth, and hence, buoyant force. Velocities lower than 5 fps do not significantly change the required anchoring force.

As long as the force on an anchor does not exceed 3,150 pounds, both a frame and over-the-top strap can be connected to it. The frame strap can be slanted up to 45° from vertical so that it will carry the lateral loads that might be present.

14.2.3 Soil Strength

The strength of the equipment used in anchoring may be predicted fairly well. Not so easily determined is the pull out capacity of the soil in which the anchor is embedded. Soils are often classified by the Soil Test Probe value. The higher the test value, the more holding power the soil will have. It is important to know that the test value can change seasonally. Although soil class descriptions may vary by state, a commonly used system is:

		Test Probe Torque Values
A.	Hard Rock	NA
B.	Very dense and/or cemented sand, coarse gravel and cobbles, preloaded silts and clays	550 lbs. in and up
C.	Medium dense coarse sands, sandy gravels, very stiff silt and clays	350-549 lbs. in
D.	Loose to medium dense sands, firm to stiff silts and clays, alluvium fill	200-349 lbs. in

Based on the test values, an anchor of the proper size can be selected that will withstand the loading requirement. Most of the time, charts and other information from the manufacturer must be relied upon to choose the anchor that is needed. That anchor must be capable of holding 4,800 pounds when installed in the particular soil at the site where it is used. Pull-out capacity increases with increasing embeddment depth and increasing disc diameter.

Data from experimental tests on soil pull-out capacity are available and further investigation is ongoing. However, the best source of information for local characteristics is someone who has previous experience with that particular soil and location.

The best general recommendation for anchors is to use a helix anchor at least four feet long with a six-inch diameter disc. A shorter anchor length will cause a greatly reduced soil resistance. Also recommended would be a field test of pul -out strength under saturated conditions.

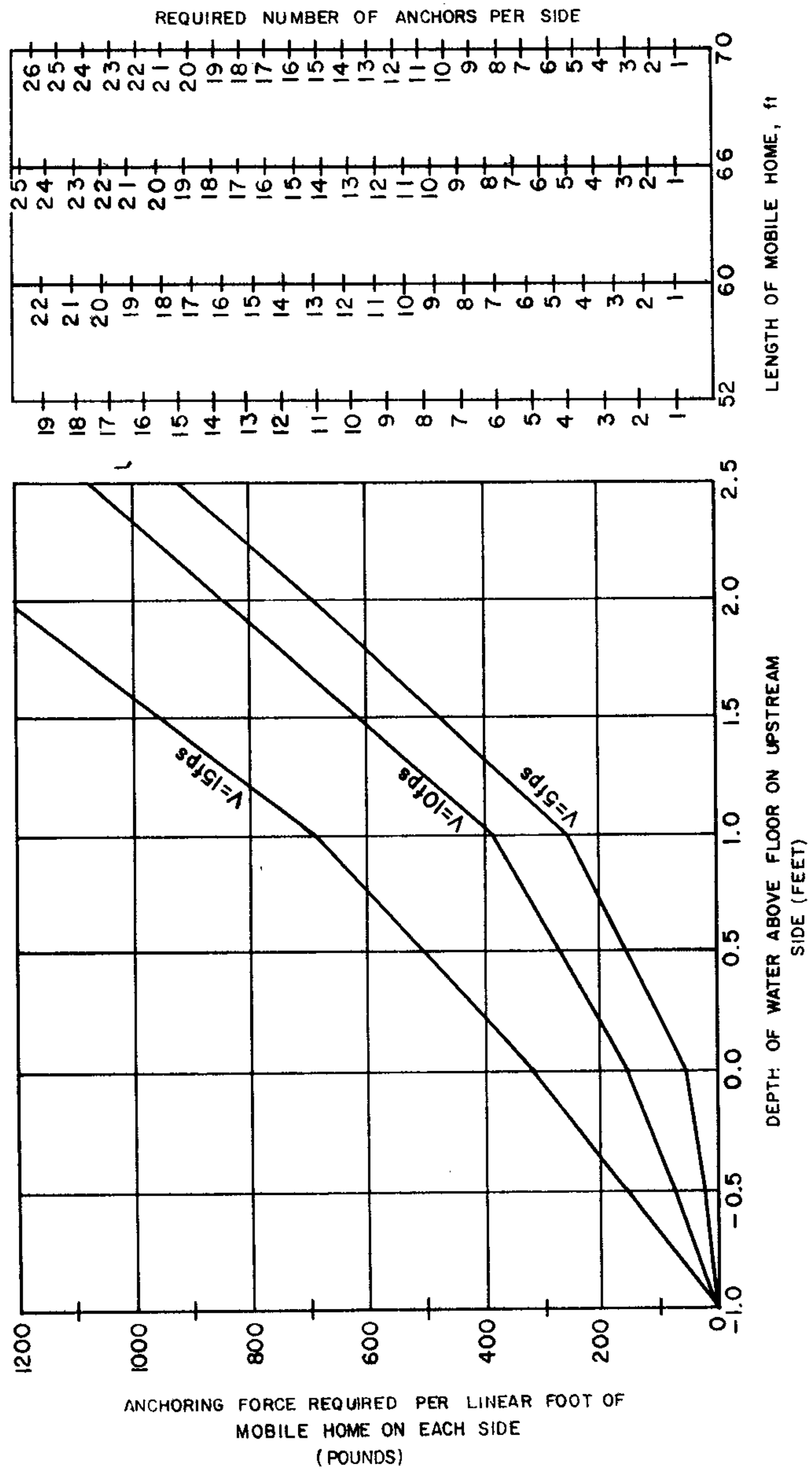


Figure 14.6. Anchoring forces per linear foot of 14′ wide mobile homes, selected lengths with number of anchors.

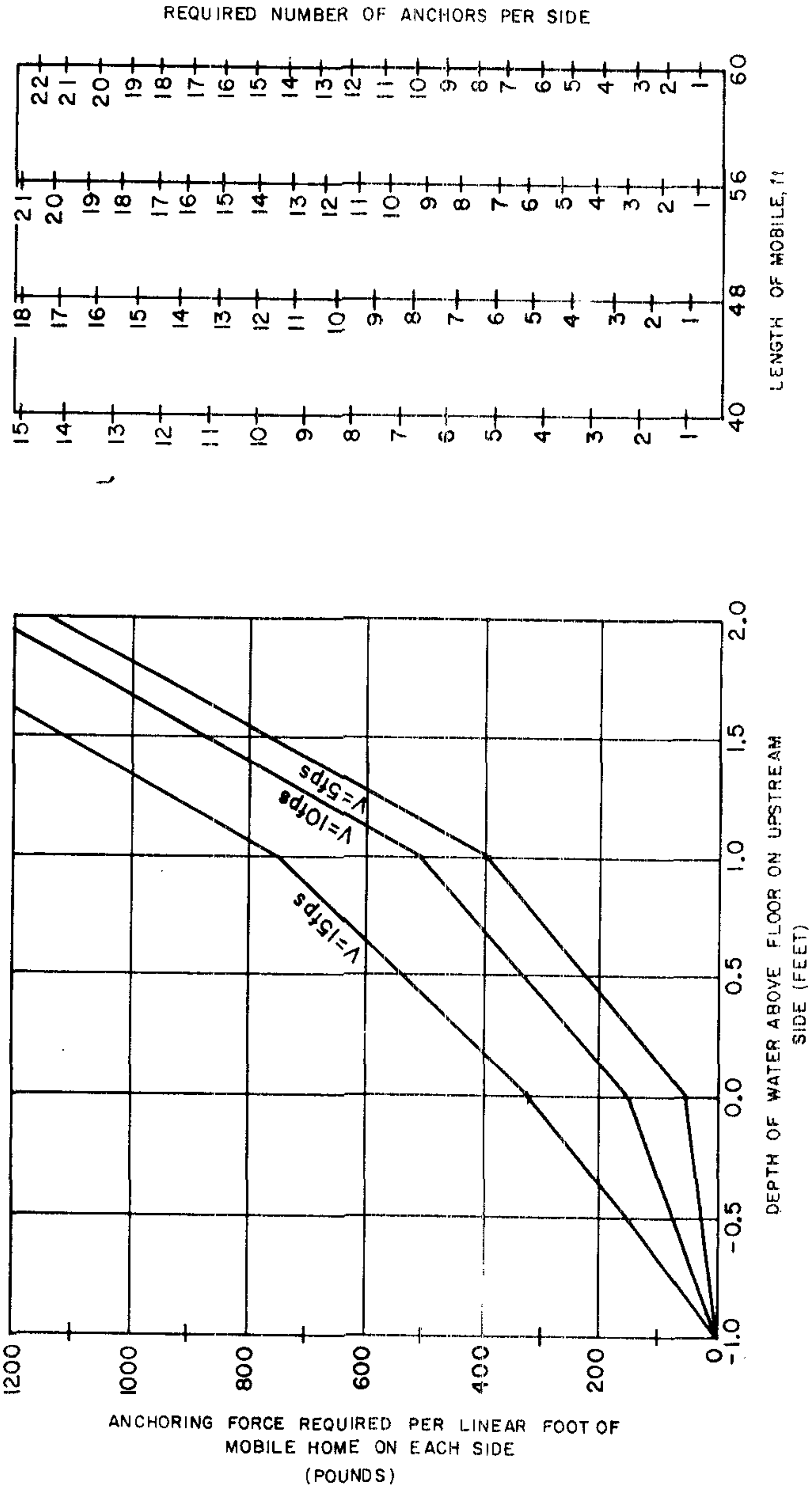


Figure 14.7. Anchoring forces per linear foot of 24′ wide mobile homes. Selected lengths with number of anchors.

14.2.4 Concrete Requirements for Anchors

As stated earlier, anchors embedded in concrete are not very often used. If they are used, a minimum amount of concrete is necessary. An example for approximation of the concrete volume needed can be obtained as follows.

Multiply the required anchoring force per linear foot times the length of the mobile home. This is for one side, so double the value. The net anchoring force of the concrete is $\gamma_c - \gamma_w = 82.6\ lbs/ft^3$ ($\gamma_c = 145\ lbs/ft^3$, $\gamma_w = 62.4\ lbs/ft^3$). Divide the total anchoring force needed by 82.6 lbs/ft to arrive at the volume of concrete that is needed. A factor of safety of 1.5 should be used. For the 70-foot mobile home considered earlier:

Total Anchoring Force Needed $(330\ lbs/ft^3)(70\ ft)(2) = 46{,}200\ lbs$

Volume of Concrete $(46{,}200\ lbs - 82.6\ lbs/ft^3) \times (1.5) = 839\ ft^3$

$= 31.1\ yd^3$

As with all floodproofing measures, the economic feasibility should be considered. In this case, the cost of concrete anchors can be compared with the cost of disc-type anchors. Table 14.2 gives a summary of three anchoring possibilities for the examples in this chapter.

If sixteen separate concrete dead-man anchors are used, they would be about 2 yd^3 each in volume. At \$50 per yd^3, then concrete cost would be \$100 per anchor. The metal component embedded in the concrete costs about \$4. A total of \$104/anchor is definitely exorbitant when compared with about \$8 materials cost for one of the sixteen disc-type anchors that could be used.

Table 14.2 - Anchor System Alternatives for a 70′ x 14′ Mobile Home, *1983* dollars

Anchor Type	Equipment	Cost
Helix Anchor	Anchor	$ 7.38
	Strap Tensioner	1.20
	Strap Coil 60′	12.50
Reference 18	Strap seal	6.23
	Split devices	0.96
	Frame bracket	3.42
	Subtotal	31.69 x 16
		$ 507.04
	Hand installation tool	35.19
	TOTAL	$ 542,23
Individual Concrete Anchors	2 cy concrete	$ 100.00
	concrete anchor	3.51
	Auger hole excavation	3.50
	strap tensioner	1.20
	Strap coil 60′	12.50
	Strap seals	0.23
	Spice devices	0.96
	Frame bracket	3.42
		$ 125.32 x 16
	TOTAL	$2,005.12
Structural Concrete Slab	Anchor bolts	$ 3.51
	Strap tensioner	1.20
	Strap coil 60′	12.50
	Strap seals	0.23
	Spice devices	0.96
	Frame bracket	3.42
		$ 21.82 x 16
		349.12
	Structural slab	$1,960.00
	TOTAL	$2,309.12

14.3 *Installation of Anchoring*

Installation of tiedowns requires additional considerations beyond the necessary strength and spacing. Over-the-top straps should be placed along the wall stud locations and should not connect to anchors directly beneath windows or other openings. Also, all straps should be checked seasonally for proper tension, especially in areas where frost heave occurs.

Different possible arrangements for connecting ties are shown in Figure 14.8. The type of set up used will affect the loading of the anchoring components.

Mobile home equipment suppliers will have the equipment that has been mentioned and also electric drive machines for installing disc-type anchors. Putting in disc-type anchors by digging a hole, then backfilling is not generally recommended because disturbed earth loses much of its shear strength. Methods used to install anchors or attach anchoring equipment to mobile homes should always be in accordance with the manufacturers instructions.

14.4 *Layout of Mobile Home Parks*

The alignment of mobile homes within a mobile home park should be done with certain points kept in mind. The performance of natural drainage lines and other features which help control runoff should not be hindered. Also, to minimize both the hydrodynamic force on each home and the backwater created, mobile homes should run lengthwise approximately parallel with the flow direction of the floodwater.

Following is a summary of suggested criteria for new mobile home parks or expansions of existing mobile home parks:

a) Ground anchors provided for tiedowns
b) Mobile homes anchored to prevent flotation during flooding
c) Lots elevated on compacted fill
d) Adequate surface drainage provided
e) Necessary space provided for access by a mobile home hauler

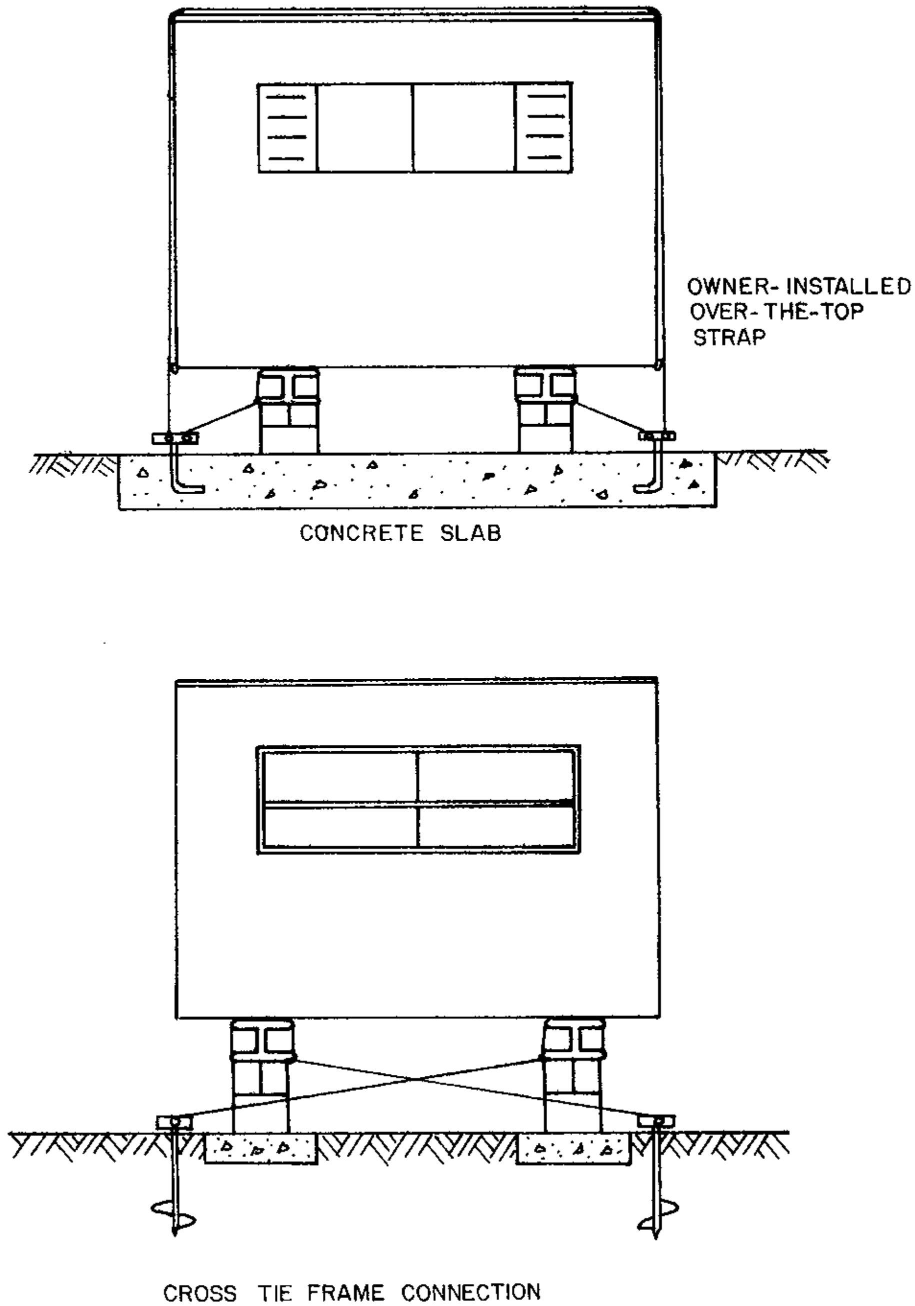
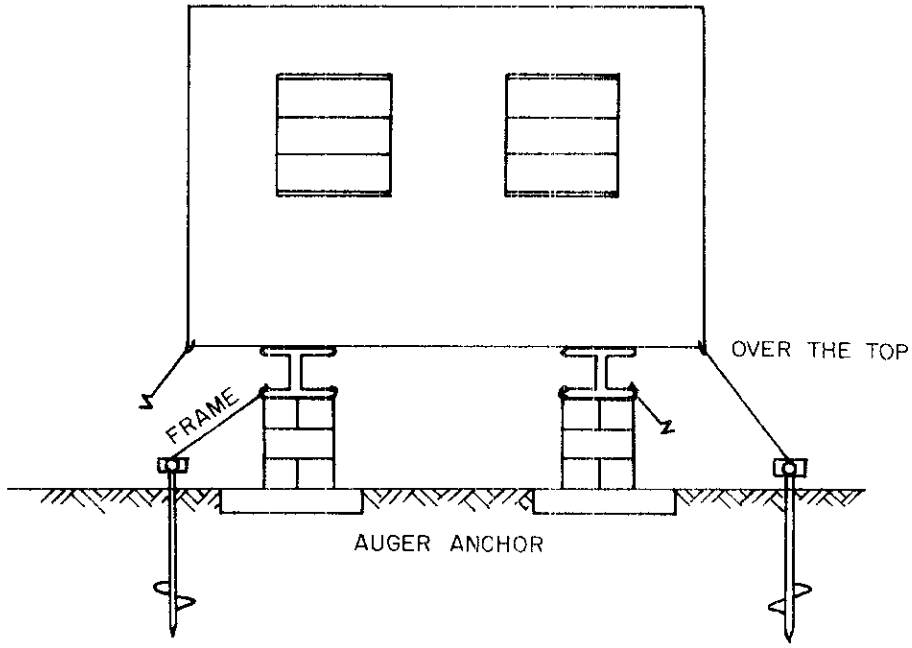


Figure 14.8. Mobile home anchoring systems



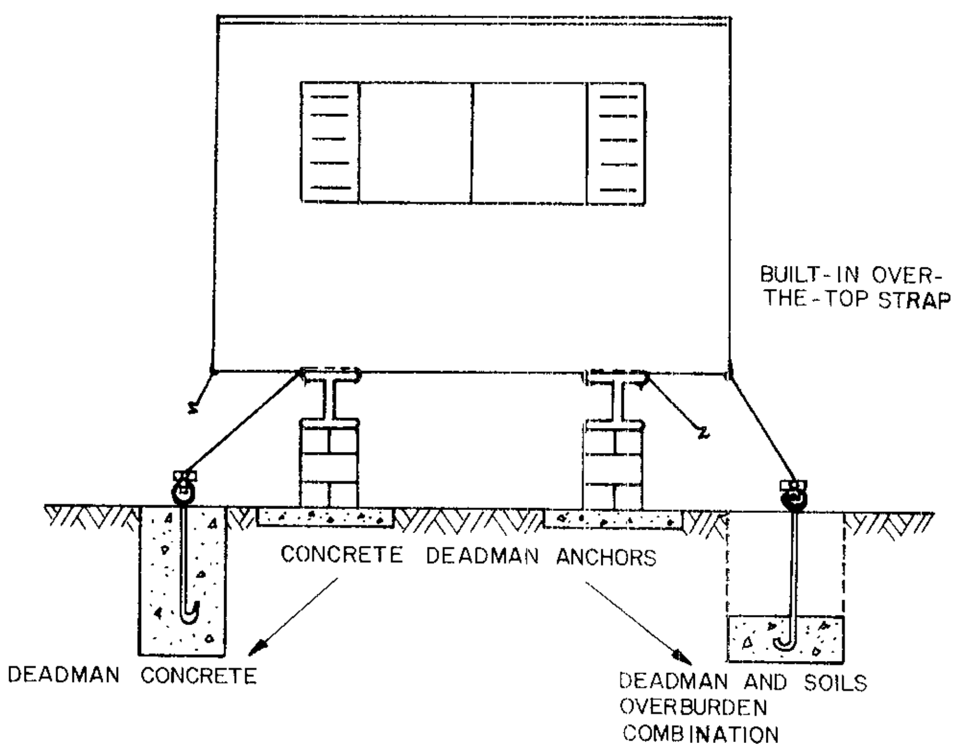


FIGURE 14. 8. CONTINUED.

14.5 *Other Considerations for Mobile Homes*

All other considerations for mobile homes in flood prone areas will follow the guidelines set forth in previous chapters of this manual.

Water Loadings

Follow the guidelines set forth in Chapter VI.

Structural Designs

Follow the guidelines set forth in Chapter VII.

Closure of Openings

Follow the guidelines set forth in Chapter VIII.

Building Materials and Coverings

Follow the guidelines set forth in Chapter X.

Electrical Systems

Follow the guidelines set forth in Chapter XII.

Mechanical Systems

Follow the guidelines set forth in Chapter XIII.

XV. ECONOMIC FEASIBILITY OF FLOODPROOFING

15.1 *Introduction*

The tools of economic analysis can provide the potential floodproofing user with important information on the comparative benefits and costs of various floodproofing methods. This chapter presents the procedure for eval- uating the economic feasibility of floodproofing under two different condi- tions: when floodproofing costs are compared to either the flood insurance premium rates (where available), or to the probable estimated flood damages experienced by an unprotected structure. Information on flood plain data and flood insurance is publicly available through the Colorado Water Conservation Board (CWCB), and the Federal Emergency Management Agency (FEMA).

Economic evaluations provide the most accurate answers when all comparisons are reduced to equivalent dollar amounts. Floodproofing often deals with highly subjective and intangible costs such as loss of life, risk of injury, or destruction of cherished property. The user is cautioned to carefully consider these aspects when interpreting a benefit/cost (B/C)analysis. A B/C ratio less than one is normally interpreted as an undesirable economic condition; however, the practice may be certainly acceptable in a life- threatening flood hazard area.

15.2 *Floodproofing Benefits Versus Probable Flood Damages*

The economic feasibility of floodproofing is evaluated by comparing the total cost of the floodproofing (installation, operation, and maintenance) to the amount of money that will be required to repair flood damages that are likely to occur if the structure is not floodproofed. The amount of the reduced flood damages is equivalent to the economic benefits of floodproofing.

A simplified example of floodproofing a single family residence by elevation on compacted fill is presented as a reference illustrating the following approach to economic analysis (see Example I).

15.2.1 *Benefits of Floodproofing*

To estimate future flood damages, two sets of information are necessary: (1) a graph of the frequency of flooding versus elevation of flooding at the site (Figure 15.1), and (2) the relationship of flood depth to structure damage (Figure 15.2).

The flood elevation versus frequency curve is obtainable through CWCB. The depth-to-damage ratio tables are developed by FEMA and based on damages previously experienced by structures of similiar size, construction, and use. Depth-to-damage ratio tables have also been developed for building contents. Our example does not include an estimation of con- tents damage, but the user is encouraged to develop these additional cost factors.

Careful consideration should address other site-specific or personal factors identified with flood damages: loss of access to property, disruption to utility services, loss of life or limb, loss of business profits for commercial structures, loss of livestock, or the emotional hardship of anticipating harm or hardship due to major flood.

All flood-related damage costs should be reduced to an equivalent annual amount. Example I converts the estimated structural damage to a percent per $100 of structural value related to each flood frequency level. The annual benefits attributed to floodproofing are equal to the damages that the floodproofing method would reduce.

15.2.2 *Costs of Floodproofing*

The cost of floodproofing varies with the type of structure, method of floodproofing, the degree of desired flood protection, material and labor costs, and the site location. After the total lump sum project cost is estimated, it is necessary to ammortize the cost over the economic life of the structure.

Example I addresses the cost of floodproofing by elevation on compacted fill. Fill costs are extremely variable and depend on length of haul, moisture condition, and volume of fill. Excavation companies contacted in the Denver area could give only broad price ranges without the necessary site- specific information. Ranges of $5-9 per cubic yard of fill were estimated, and $7 per cubic yard is used in Example I. Fill prices can increase to $10-15 per cubic yard for sites located in mountainous area.

15.2.3 *Comparing Benefits to Costs*

In order for a floodproofing method to be economically acceptable, the benefits of the proposed floodproofing method must be greater than the cost. This results in a benefit-to-cost ratio greater than one. The higher the B/C ratio, the more economically desirable the floodproofing method. A B/C ratio of less than one should be carefully considered in instances where the benefits include safety considerations.

15.3 *Floodproofing Costs Compared to the Benefits of Reduced Flood Insurance Premiums*

The benefits associated with floodproofing in an area where flood insurance is available are computed as the reduction in premium rates for a floodprooded structure. Any combination of floodproofing and insurance coverage may be used to cover any portion of a structure's value and contents (up to maximum limits). Example II compares the benefits of purchasing flood insurance for the total value of the structure to the cost of floodproofing by elevation on compacted fill.

Flood insurance protects against only direct physical loss of a structure (and its contents if desired). Flood insurance will not reimburse for many other flood-related losses such as: damages to landscaping, swimming pools, or access driveways; loss of business; or living expenses incurred while an insured building is being repaired or replaced. The user should consider the impact of these possible losses when evaluating the benefits of flood insurance.

15.3.1 *Determining the Benefit of Reduced Insurance Premiums*

A Flood Insurance Rate Map (FIRM) delineates the Flood Hazard Zone and the BFE for a particular site within a flood plain. The proposed elevation of the lowest floor of the structure must be determined by a site survey. The FEMA insurance rate tables are entered for a specific building type and flood hazard zone rating, and insurance rates are listed for various floor elevations above the BFE. To qualify for reduced insurance rates, the lowest floor must be elevated 1 to 2 feet above the BFE.

Insurance rates are broken into two major classes: pre-FIRM construction elevation rates for buildings constructed prior to December 31, 1974, and post-FIRM construction elevation rates for buildings constructed after December 31, 1974. Post-FIRM structures must submit applications to the National Flood Insurance Program (NFIP) for ratings if the lowest floor elevation is more than one foot below the BFE, or if the lowest floor is at the BFE for single-family mobile homes.

The annual benefits of floodproofing a structure to a given elevation above the BFE are equal to the insurance rate reduction available to the floodproofed structure. The maximum benefit usually occurs when 2 floodproofing methods protect to or raise the lowest floor 1-2 feet above the BFE.

15.3.2 *Floodproofing Costs*

Annual floodproofing costs are discussed in Section 15.2.2. Example II illustrates the cost of floodproofing by elevation on compacted fill.

When comparing floodproofing costs to insurance reduction rates, the floodproofing protection is estimated to extend to the level necessary to qualify for the desired reduced rate.

15.3.3 *Comparison of Rate Reduction Benefits to Floodproofing Costs*

After all costs and benefits are reduced to annual amounts the B/C ratio is computed. The value of the B/C ratio is discussed in Section 15.2.3

15.4 *Summary*

Values for floodproofing costs, and the corresponding benefits, are extremely site- and method-dependent. The examples and information presented in this chapter are meant to aid the potential floodproofing user in identifying and systematically evaluating the several options available for flood protection.

EXAMPLE I - ECONOMIC ANALYSIS OF FLOODPROOFING. NO FLOOD INSURANCE IS AVAILABLE.

Construction within a flood plain is planned for a 1,500 sq. ft. split level single-family residency valued at $90,000. A site survey shows the ground elevation to be 1,017.5 feet above MSL (mean sea level). No basement is planned, therefore the ground elevation will be the first floor elevation. The economic benefits of floodproofing by elevation on compacted fill are considered in this example.

Calculate the Annual Benefits of Floodproofing = to the Probable Annual Flood Damage Costs:

Probable flood damages are calculated by preparation of Table 15.1. The steps to construct this table follow.

1. Plot the planned floor elevation of 1,017.5′ on the Flood Elevation versus Frequency curve (Figure 15.1). A vertical line drawn from the floor elevation to the intersection with the elevation-frequency curve represents the depth of flood water which would occur above the planned floor level. Enter this depth in column 1, and the corresponding frequency in column 2.

2. Probability of a flood occurrence = frequency 1 . Enter in column 3.

3. The difference between successive probability values is computed in column 4.

4. The building range ratio table for a split level, no basement, is shown in Figure 15.2. A curve is constructed from this data for better damage estimates from untabled water depths. Enter in column 5 the percent of damage due to the corresponding water depth in column 1.

5. Average successive damage percent in column 6.

6. The average damage rate for a given flood occurrence is equal to the change in probability multiplied by the average damage percent (Column 4 x column 6 = column 7).

7. The total damage is the sum of all average rates up to the desired flood depth or frequency.

Calculated Benefits:

Usual floodproofing protection extends to the 100-year flood level, or BFE, which for this structure would be 2.5′ above the first floor. Summing column 7 up to the 100-year flood yields an estimated annual damage rate of $0.59/$100. The benefits of floodproofing then become $531 per year for a $90,000 home.

Flood damages can be calculated up to any known flood occurrence. As shown in Table 15.1, the damages due to a 500-year flood would be $0.78/$100 of structure value, or an annual total of $702. Floodproofing this home up to the 500 year level, or 4.4' above the lowest floor, would represent benefits of $702 per year.

Annual Cost of Floodproofing by Elevation on Compacted Fill:

For protection up to the 100-year flood occurrence, elevate the lowest floor 2.5'. The one-time project cost of constructing a compacted fill must be reduced to an annual cost:

1. Determine the volume of fill necessary to elevate the house 2.5'. (Refer to Chapter 7)
   For a 1,500 square-foot house, elevated 2.5', volume of fill = 574 cubic yards.

2. Cost of fill = 7/cu. yd. (includes loading, hauling, placing, and compacting)

3. Project cost total = $7/cu. yd. x 574 cu. yd. = $4,018

4. Convert $4,018 to an annual or amortized cost:
   The amortization factor varies with the interest rate and the economic life of the structure.
   At a 12% interest rate and a 30-year expected economic life, the amortization factor is 8.06.

   The amortized cost of the floodproofing project = $\frac{\text{Total Cost}}{\text{Amortization Factor}}$

Calculated Costs

The annual costs for floodproofing this house up to the 100-year flood level by elevating it 2.5' are:

$$\frac{\$4{,}018}{8.06} = \$499$$

Comparison of Benefits to Costs:

The annual benefits of floodproofing this house up to a 100-year frequency flood would equal $531. The annual cost of the floodproofing method of elevation on fill would be $499. As defined in this approach, the economic benefits of floodproofing this structure exceed the cost. This desirable economic relationship is reflected by a benefit/cost ratio greater than 1, and for this example:

$$\frac{B}{C} = \frac{531}{499} = 1.06$$

EXAMPLE II - ECONOMIC ANALYSIS OF FLOODPROOFING, FLOOD INSURANCE AVAILABLE

A 1,500 sq. ft. split level residence valued at $90,000 is planned for a location within a flood plain. A FIRM (Flood Insurance Rate Map) shows the site is within a flood hazard zone rated A15, with a BFE equal to 1,020 feet above MSL. A site survey reveals the ground elevation of the house (no basement is planned) will be at 1,019 feet above MSL. Compare the costs of elevating on compacted fill to the benefits of flood insurance.

Annual Benefits of Floodproofing = Reduction in Cost of Flood Insurance Premiums

Using Post-FIRM* Construction Elevation Rates for Buildings, the insurance rates per $100 of value are listed below. The total maximum insurable value for a single-family structure may not exceed $185,000. Basic insurance rates are applied towards the first $35,000 in value; additional rates cover value up to the insurable limit.

Rate/$100 Basic/Additional	Elevation of Lowest Floor Above BFE	TOTAL COVERAGE COST Basic	+ Additional	= Total
0.10/0.06	+3	$ 35	+ $ 33	$ 68
0.10/0.06	+2	$ 35	+ $ 33	$ 68
0.13/0.06	+1	$ 45.5	+ $ 33	$ 78.5
0.22/0.06	0	$ 77	+ $ 33	$110
0.60/0.50	-1	$210	+ $275	$485

* Post-FIRM rates apply to construction after Dec. 31, 1974.

This table shows that if the first floor remained at the original elevation of 1,019 feet or one foot below the BFE, total coverage would cost $485 per year. Elevating the first floor to two feet above the BFE, or 1,022 feet, would reduce the yearly premium to $68 per year.

The benefits of floodproofing are the reduction in premiums:

485 - 68 = $417 per year

Annual Costs of Floodproofing

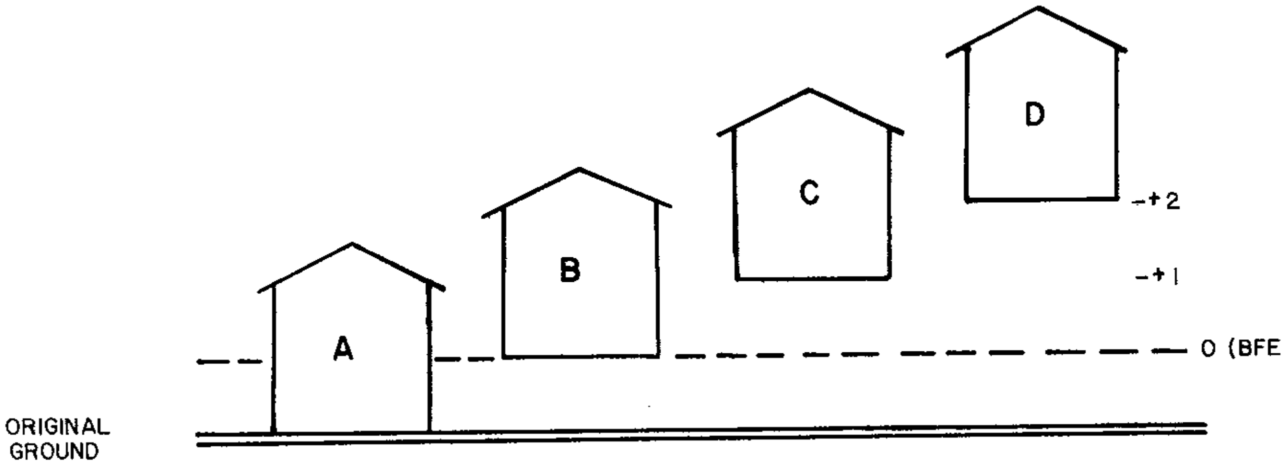
The cost of floodproofing by elevation on fill follows the calculation methods in Example I.

In order to qualify for minimum insurance premiums, this structure must be elevated two feet above the BFE of 1,020 feet. Given a site elevation of 1,019 feet, the elevation of the fill must equal three feet. Volume of fill is calculated to be 720 cubic yards, and total price = $7 x 720 = $5,040. Amortized costs of 5,040/8.06 = $625 are calculated by the same procedure shown in Example I.

Comparison of Benefits to Costs

The benefits of floodproofing this house to two feet above the BFE are equal to $417 in reduced flood insurance premiums. The annual cost of floodproofing by elevation on fill is $625.

From the economic factors addressed in this problem, the costs of floodproofing outweigh the benefits, and therefore appear economically unfeasible. The benefit/cost ratio of 417/625 = 0.7 reinforces this conclusion.



ELEVATION (ft.)	-1	0	+1	+2
FLOOD INSURANCE PREMIUM	$485	$110	$78.5	$68
REDUCTION IN PREMIUM (BENEFIT)	—	$375	$ 406.5	$417
COST OF FILL	—	$172	$381	$625
BENEFIT/COST RATIO	—	2.2	1.1	0.7

OPTION B APPEARS AS THE MOST ECONOMICALLY ATTRACTIVE ALTERNATIVE.

Figure 15.1. Annual benefits and costs for elevating on fill A split level, single family, in zone A25. No basement.

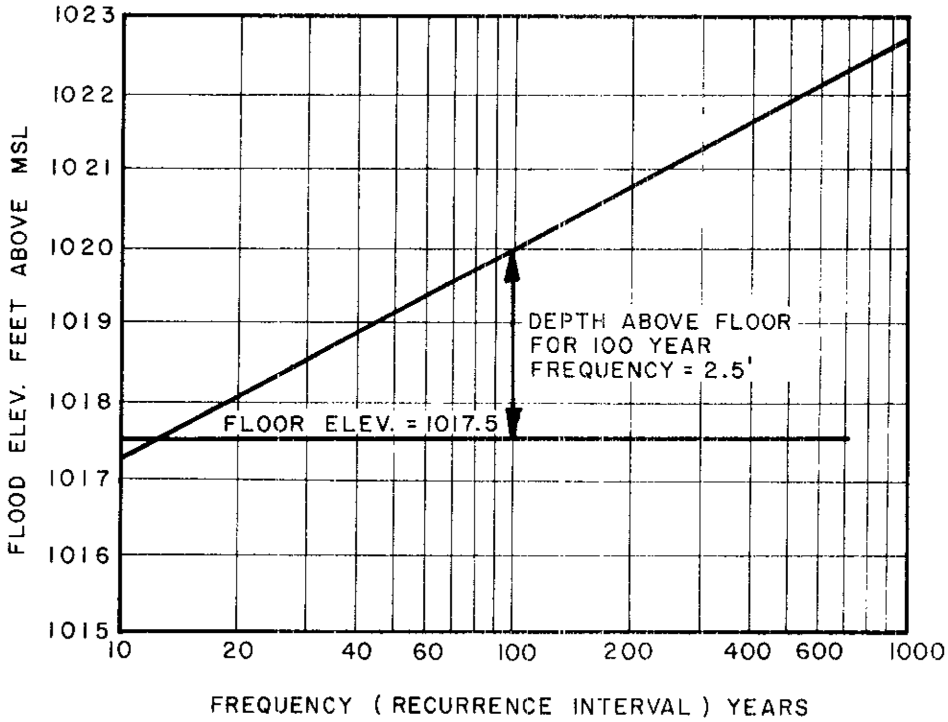


Figure 15.2. Frequency of flooding versus elevation of flooding.

Water depth above floor	Damage ratio, % of total value
-1	0
0	3
1	9
2	13
3	25
4	27
5	28
6	33
7	34
8	41
9	43
10	45
11	46
12	47
13	48
14	49
15	50

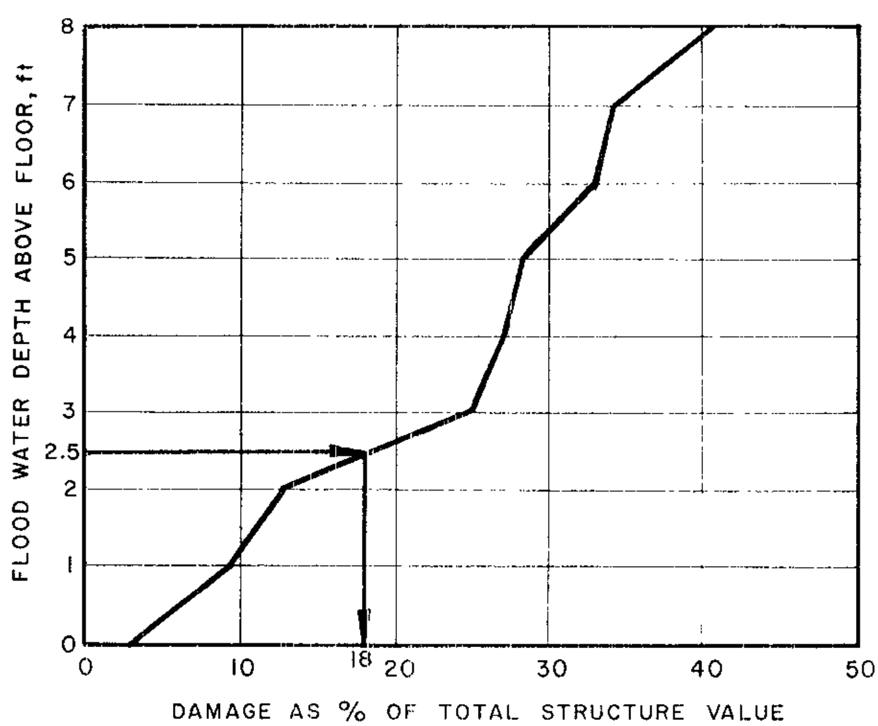


Figure 15.3. Flood elevation versus damage to structure.

Table 15.1 - Calculation of Probable Flood Damages

(1) Flood Water Depth Over Floor (ft)	(2) Frequency of Flood Depth (yrs)	(3) Probability = 1 / frequency	(4) Change in Probability	(5) Damage % of Total	(6) Average Damage	(7) Average Damage Rate (4) x (6)
0	12	.0833		3		
			.0245		4.5	.1102
.5	17	.0588				
			.0231		7.5	.1732
1	28	.0357		9		
			.0206		11.0	.2266
2	66	.0151		13		
			.0051		15.5	.0790
2.5	100	.0100		18		
			.0034		21.5	.0731
3	150	.0066		25		
			.0036		26.0	.0936
4	330	.0030		27		
			.0010		27.25	.0272
4.4	500	.0020		27.5		
						.7829

Total Damage Rate = \$0.78 per \$100 value

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