Appendix
Appendix A: Mitigation Techniques for Marginal Buildings
Appendix A

Mitigation Techniques for Marginal Buildings

A.0 General

This chapter describes some mitigation techniques for marginal/noncompliant buildings. This chapter does not explain engineering design procedures for mitigation, but rather describes some practices that are accepted by the industry and are currently being used. Mitigation techniques are described for roofs, masonry walls, structural stability and load path problems, weak spots in the exterior envelope, fenestrations and for increasing the flood resistance characteristics of a building.

A.1 Mitigation Procedures for Roof Systems

To counteract wind uplift, roof decks should be secured firmly to the walls, and roof coverings should be attached securely to roof decks. In many existing buildings, the connections between roof decks and the walls can be enhanced easily. However, the connections of roof coverings to roof decks can be difficult to improve unless re-roofing is undertaken. The following sections describe mitigation techniques for a number of different types of roof systems.

A.1.1 Plywood/OSB Panels on Wood Trusses or Rafters

These roof systems are comprised of (i) roof coverings (asphalt shingles, clay tiles, concrete tiles), (ii) roof underlayment (15# or 30# roofing felts), (iii) roof decking (plywood, oriented strand board), and (iv) roof support structures (trusses or rafters). Previous storm damage investigations for Hugo (1989), Andrew (1992) and other hurricanes have documented wide-spread failure of plywood/OSB roof systems.

Typically, poor performance is related to blow-off of coverings and uncertainties in the wind and moisture resistance of the underlayments used. It is important, while re-roofing, to provide a second line of defense against water intrusion. A double layer of 15-lb felt paper should be installed according to details given in Figure A.1. Alternatively, a single layer of 30-lb felt paper can be installed on hot-mopped asphalt (see Figure A.2). In either case, one-inch diameter tin tags should be used with each fastener installed on the roofing felt. The idea is that if the roof covering (shingles or wood shakes) are blown off or broken, the felt paper will remain in place and prevent water intrusion through the roof.
Figure 6.1 Double layer underlayment application

NOTE: NAIL WITH 1-IN. DIA TIN TAGS.
NOTE: NAIL WITH 1-IN. DIA. TIN TAGS
MOP WITH HOT ASPHALT PRIOR TO PLACING FELT UNDERLAYMENT

Figure 6.2 Single layer underlayment application
The common problems with plywood or OSB decking have been materials that are too thin, nails that are too small or have missed the underlying rafters or top chords of trusses. Better connections between sheathing panels and rafters are achievable with the use of spray applied foams and glues, for example, Foamseal™ or 3M™ Scotch-Grip Wood Adhesive 5230. These two particular products have been tested at the Clemson University and have been shown to provide adhesion that is three to four times stronger than that provided by 8d nails spaced 4 inches on center.

As an example for application, to use 3M™ Scotch Grip Wood Adhesive 5230, place one-inch x two-inch by six-inch long wood blocks at 15 inches on center, on both sides of the rafter, at the intersection of rafter and roof sheathing, as shown in Figure A.3. Static pressure tests conducted at Clemson University showed that the wood blocks and adhesive increased the wind uplift resistance by a factor of three. A quarter inch bead of adhesive six inches long is applied at the intersection of the roof deck and a roof support element (rafter or truss chord). The wood block is then pressed into the adhesive, ensuring the adhesive is dispersed evenly. Adhesive and blocks are placed on each side of the roof elements at 15 inches on center, as shown in Figure A.3.

The gable end wall typically is formed by placing a roof truss over the top of the end wall and attaching wall sheathing to the truss. Under these circumstances the end truss is subjected to inward and outward forces. To improve wind resistance of roof gable end wall systems, provide eight foot long braces fastened to the bottom chord of the truss and the adjacent trusses (see Figure A.4). These braces should be perpendicular to the end truss, and spaced at six foot on center. Also, provide 2"x 4" blocking between the truss top chord at the ridge (see Figure A.5).

Examine the roof sheathing for rotted boards or sheathing. Replace as needed. Roof sheathing should be fastened more securely in roof corners and along the ridge and eaves. Highly localized pressure exists within about four feet of the corners, eaves and ridges. The nailing pattern should be at a recommended minimum. The uplift resistance is proportional to the number and size of fasteners. An alternative to additional nailing is to use screws. Add additional nails or screws to achieve the required uplift resistance. The advice of an architect or engineer is required to obtain the needed uplift resistance.

Improving the roof and top of the wall connections and anchorage in a wind load path is difficult because of limited access to the ends of the roof framing and to the bottom of the stud walls. These areas are normally covered by sheet rock on walls and the ceiling on the interior, and wall cladding and the soffit board on the exterior. In order to gain access for installing straps or hurricane clips, the roof sheathing should be removed around the perimeter of the roof to reveal the top of the wall. In addition, the soffit and exterior cladding near the top of the wall may need to be removed to reveal the
Figure 6.3  Installation of wood strips and adhesive to improve roof deck uplift resistance

Apply 1/4" bead of adhesive 6" long. Push wood strip into place dispursing the adhesive evenly.
Figure 6.4  Gable end wall detail for wood stud walls

Figure 6.5  Gable end wall bracing details
top 12 to 18 inches of the wall. If the exterior cladding is brick veneer, the top three or four courses may also need to be removed to gain access to the space needed to install the straps and clips.

If trusses are used, the truss must be tied to the top plate and the top plate anchored to the wall stud. Alternatively, the truss can be strapped directly to the wall stud. The clips or straps should be positioned so that nails are stressed in shear under uplift forces. Figures A.6 illustrates several ways to anchor a roof to the top of a wall with straps and connections. In some buildings it may be possible to install hurricane clips at the roof-to-wall connection by removing soffit board at the overhang, exposing the top plate of the wall and the ends of the joists and rafters. Figure A.7 shows three examples of how hurricane clips might be installed through the soffit of the overhang.

A.1.2 Mitigation for Roof Coverings

Wide spread damage to roof coverings: built-up roofs with ballast, single ply, pavers, shingles, concrete and clay tiles have been documented in windstorms. Poor performance typically is related to inadequate design attention, deficient material properties (which sometimes are related to aging), inadequate test methods for determining resistance of roof coverings and poor workmanship. Retrofitting existing roof coverings is extremely difficult. However re-roofing projects can substantially improve the resistance of roof coverings. Some mitigation techniques recommended by National Roofing Contractors Association (NRCA) are presented below:

A.1.2.1 Re-roofing Mitigation Techniques

When re-roofing, the tear-off of the existing membrane and insulation is recommended. After tear-off, the roof deck and/or framing should be inspected for deterioration. It should be ensured that the roof deck is adequately attached and deteriorated panels are repaired or replaced. Because of the great potential for missile-induced damage to roof coverings and subsequent leakage, it is recommended that the roof system incorporate a secondary waterproofing membrane. This can be a spray applied polyurethane foam (PUF) roof, or be a protected membrane with heavy-weight concrete paver ballast as described below:

For systems other than PUF, or those protected with pavers, it is recommended that a minimum of two inches of insulation occur between the roof membrane and the secondary waterproofing membrane. The purpose of the insulation is to serve as missile protection for the secondary membrane. The secondary membrane could be a two-ply built-up membrane (as commonly used when constructing a hot-applied vapor retarder), or other suitable system. The secondary membrane should be sealed at perimeters and
a) Connection between top plates and stud

b) Connection between roof framing and wall

Figure 6.6  Typical anchorage between roof framing and wall
Figure 6.7  Various placements of hurricane clips
penetrations to maintain water tight integrity.

This recommendation is also applicable to steep-slope systems (including metal roofing). However, depending upon the system components, elimination of the insulation between the roof coverings and secondary membrane may be appropriate. For example, if metal panels occur over wood sheathing, use of a secondary membrane such as self-adhering modified bitumen without insulation, would likely be sufficient. Although a missile could puncture the secondary membrane, significant leakage with a membrane of this type on a steep-slope roof would be unlikely.

Because of the difficulty in assuring that the waterproof membrane integrity would be maintained, mechanically attached single-ply systems are not recommended unless a special secondary membrane is used that will ensure watertight integrity at fastener penetrations. (Note: Fasteners that are dynamically loaded are much more likely to promote leakage at the secondary membrane, compared to fasteners that are not dynamically loaded, e.g., insulation fasteners)

It is recommended that brittle roof coverings (e.g., slate or tile) not be utilized on HES buildings. These coverings can be broken by missile impact and generate additional missiles.

For PUF systems, if the coating is damaged by missiles the need for secondary membrane is unlikely due to the foam’s resistance to water penetration. The foam should be a minimum of two inches thick, in order to decrease the potential of missiles puncturing all the way through the foam.

As an alternative to the two approaches described above, the membrane could be protected by a layer of extruded polystyrene insulation with heavy-weight concrete paver ballast (weighing a minimum of approximately 22 psf). With this alternative, it is recommended the system be designed in accordance with ANSI/ARMA/SPRI RP-4.

A.1.2.2 Mitigation Techniques for Existing Roof Coverings

Existing roof coverings, such as built-up roofs, single ply, concrete or clay tiles, and shingles, can also be strengthened by spraying polyurethane foam. A particular product of interest is an isocyanate and polyol combination that is mixed at the site using spray equipment. This product has been tested by the Factory Mutual Research Corporation and is also recommended by NRCA. An illustration of an asphalt shingle roof with spray applied PUF is shown on the next page. The resulting foam is about two feet thick and has a density of 2.8 to 3.0 pcf. The foam requires a protective coating on its top surface. A water based 100% acrylic coating is available that can be applied to top surface. This product has been applied to various types of roof coverings as a recover/retrofit effort in the last three years at several locations in Texas and Florida.
A.1.3 Pre-cast Concrete T-beams

The dead weight of precast concrete units helps to keep the roof deck in place. However, at roof corners and along perimeters, combined external and internal pressures can overcome gravity loads and produce net uplift. One way to improve the uplift resistance of precast panels, when panels are resting on masonry walls, is to drill a hole through the rib of the T-section as well as two holes in the tie beam adjacent to the rib of the T-section. U-bolts or U-shaped straps can then be inserted through the hole and anchored to the tie beam using epoxy or bolts. Another method, when T-sections are attached to walls, is to shoot web straps to the sides of the rib of the T-beam, bringing them down to the wall and connecting them to the wall using powder driven bolts. Also, fasten or weld a clip at the joint between two precast panels to enable the panels to act together for resisting wind uplift.

A.1.4 Metal Decks on Open Web Bar Joists

Metal decks are connected to load-bearing open-web-bar joists with puddle welds, spot welds or screws. Due to wind uplift and cyclic loading, tear out of metal decking at these points has been documented in the damage studies of many hurricanes. A 22 gauge or thicker metal deck will reduce the tear out problem. For existing buildings, however, connections between metal decks and bar joists can be improved by welding joists to the metal roof decks. This can be easily accomplished if the underlying ceiling is removed temporarily. To achieve a better connection, a clip should be welded between the metal deck and the top chord of the bar joist. These connections should not be farther apart than four feet on center.

Open web bar joists should also have wind bracing (bridging) that prevents lateral movement and lateral buckling of bar joists. Typically, an angle, ½ inch rod, or plate is welded to top and bottom chords of bar joists in a direction perpendicular to the span of the bar joists. Wind bracing can be easily installed if the ceiling is removed. A six to eight feet spacing should be adequate to provide stability in the lateral direction. Any bracing added to a roof system should be approved by a structural engineer.

Reverse bending and vibrations of long span roof can be reduced by adding additional column supports. If additional column supports are added a structural engineer should be consulted for strengthening the web section of open web bar joists at the support points. Addition of columns can induce tensile stresses in the top chord of bar joists, therefore revised design calculations and strengthening of bar joists will be needed.
A.2 Mitigation Measures for Unreinforced Masonry walls

Many old building are built with unreinforced concrete masonry block walls. A typical 10 foot high masonry wall should have #5 rebar#s four feet on center to develop adequate tensile bending strength to resist uniform wind loads. It should also have at least metal lath and stucco to resist the missile impact. Therefore, mitigation measures are needed to improve the wind and impact resistance of concrete block walls.

To place vertical reinforcement in existing masonry walls, knock off the face shell for two bottom and two top courses of the masonry wall (see Figures A.8a and A.8b). Using an 11/16" drill bit drill holes in the footing as well as tie beam at the top of the masonry (see Figure A.8b). Fill the holes with commercial grade epoxy and place 16" long #5 bars in the holes (see Figure A.8a). After placing the rebars thread two #3 bars in the core and tie them to the anchored bars. Cover the broken face shells with plywood and the place grout in the core. Note that the additional grouting and rebar may require additional strengthening of the footer, as shown in Figure A.8c. Construction drawings showing strengthening of an existing masonry wall are shown in Figure A.8d.

Another procedure is to break the face shell in all courses of the masonry wall to create a continuous slot (vertical) for placement of rebar. If a continuous slot is created, holes can be drilled in the footing and the tie beam easily. Rebar is inserted in the vertical column, the tie beam and footing holes are sealed with commercial grade epoxy and grout is poured in. However, in such a procedure the wall will have to be formed for placement of grout. In addition, lateral reinforcement may also be needed. As in all the techniques above a structural engineer should review the planned procedure for a particular building for placement and number/types of reinforcement, and to determine the impact on the structural integrity of the target building.

A.3 Mitigation Measures for Structural Stability and/or Loadpath Condition

A building will be structurally stable if it has adequate hold down connections for sidewalls, adequate shear resistance in the shear walls and a continuous load path for transfer of wind load forces to the ground. Improper connections between the roof and the top of walls and between wall and foundation will compromise the integrity of the entire wall and roof system.

Walls generally are covered by stucco, siding or other wall coverings. It will therefore be necessary to remove siding/wall covering near bottom of the wall. If there are no anchors, the following retrofit procedure should be followed. Drill holes through
Figure 6.3a  Knocking off the face shell at two bottom courses
Figure 8b Knocking off the face shell at two top course and drilling hole in the tie beam
Figure 6.3c  Strengthening of existing footing by addition of rebar and concrete
Figure 6.3d  Construction drawings for strengthening masonry walls
existing sill into the concrete foundation for anchor bolts. A commercial grade epoxy may be used to install the anchor bolts. The minimum bolt spacing, force analysis of the shear and uplift loads must be determined by an engineer.

The shear strength of concrete block walls will improve if continuous vertical reinforcement is placed and grouted. The vertical tensile strength as well as shear strength can be improved if the entire wall is grouted (see Figure A.9). A fully grouted masonry wall has two to three times more tensile bending strength compared to a similar ungrouted masonry wall. Shear strength of concrete masonry buildings can also be improved by adding additional wall segments to exterior walls or by constructing additional shear walls in the building. A structural engineer should be consulted when such retrofit measures are taken.

Many old wood frame walls have no exterior sheathing under the wall covering/siding. Shear strength of such walls can be improved by first removing siding and then installing exterior grade 5/8" plywood sheathing before replacing the siding.

The most common methods for increasing the shear resistance of an existing concrete frame building are: (i) addition of shear wall to existing frame, (ii) addition of bracing to existing frame, (iii) increasing dimensions of existing frame members, and (iv) addition of exterior structures to the existing structure. A structural engineer should be consulted for the selection of suitable options for a particular building.

A.4 Mitigation Measures for Wind and Impact-Resistance of Typical Non-Fenestrations

Mitigation techniques need to be carried out to improve the wind and impact-resistance of typical non-fenestration "soft spot" conditions, e.g., Exterior Insulation and Finish Systems (EIFS), masonry opening infill, cantilever wall conditions, etc.

For EIFS, it would be best to replace the existing EIFS systems with reinforced masonry or metal panel systems or pre-cast structural concrete. Another way to retrofit EIFS systems is to install a brick or stone veneer, to improve their impact and wind resistance.

Masonry opening infill needs to be reinforced by inserting flat metal bracings in the walls. In some cases it might be feasible by bracing the infill from inside by some kind of bracing, or pour them solid. Sometimes they will have to be replaced by reinforced masonry infill.

To mitigate cantilever wall conditions, the cantilever walls need to be braced by
Figure 6.9  Strengthening of entire masonry wall by grouting
putting shear walls on either side to eliminate cantilever condition.

A.5 Mitigation Measures for Wind and Impact-Resistance of Typical Fenestrations

The wind and impact-resistance of typical fenestrations, e.g., personnel entry doors, large overhead doors, windows, and store-front windows, also can be improved.

To resist wind and impact loads, metal doors without glass should be preferred. Replace personnel entry doors by metal doors without glass as far as possible. The glass on doors and windows should be replaced by glass or protected by systems that meet the wind load and impact resistance standards in the SBCCI Standard SSTD 12-94, or the Dade County version of the South Florida Building Code (Sections 2314.1, 2314.5, and 2315.1-2315.4). This will reduce vulnerability of the windows and building to windborne debris and subsequent interior damage. Exterior doors should have adequate insulation. Large overhead doors should have heavier gauged steel. Change all aluminum louvers to stronger steel or concrete louvers. Provide shutters on louvers and windows. Provide anchor bolt locations to facilitate placement of temporary shutters which will be placed on the louvers and windows when the building is being used as a HES. Roll down shutters also can be used on the exterior of louvers. Tracks should be strengthened by providing angle braces. All these systems should meet the above standards for windload and impact resistance.

Buildings have generally either double or single entry doors. Solid wood, or hollow metal doors generally are strong to resist wind pressures and impact loads of debris generated in windstorms. The doors, whether single or double, should have at least three hinges and a heavy duty dead bolt security lock. Double doors should have at least three hinges and a heavy duty dead bolt security lock. Double doors should have a positive anchorage at top and bottom where the two doors come together. Otherwise, double doors have the same strength and hardware requirements as single doors. To enhance the wind resistant capabilities of double entry doors, attention should be paid to the connection at both the header and the threshold. It is important that the surface bolt extend into the door header and through the threshold into the subfloor. Sometimes, doors have windows or side lights. These should be protected as other windows in the building. Check the anchorage of door assemblies and if necessary install anchors as needed to resist the expected wind forces.

The windows should be tested and listed for debris impact resistance. Large areas of glass are very vulnerable to windborne debris. Therefore these windows should be equipped with permanent or temporary shutters. Temporary shutters may be made of metal panels. If they are, the tracks should be securely attached to the building walls and the panels should have been tested for impact resistance. Also check if any permanent shutters are in operable condition and have been tested and certified to resist debris.
impact.

In general all exterior doors, window protective systems, and other fenestration protective systems should conform to the wind load and impact resistance standards in the SBCCI Standard SSTD 12-94, or the Dade County version of the South Florida Building Code (Sections 2314.1, 2314.5, and 2315.1-2315.4). A complete listing of Dade County approved protective systems is maintained by the Building Code Compliance office of Dade County. This list can be accessed at www.buildingcodeonline.com on the internet, or can obtained by calling (305)375-2901.

A.6 Mitigation Measures for Improving Flood Resistance

Mitigation techniques to improve the shallow (up to 3 feet of inundation depth above ground floor level) flood resistance of a building exterior envelope needs to be carried out. There are different ways for retrofitting buildings against flood damage. Some are discussed below. While some brief descriptions are provided below, more substantive information is provided in two FEMA documents. These are the Design Manual for Retrofitting Flood-prone Residential Structures (FEMA 114/September 1986) and the Floodproofing Non-Residential Structures (FEMA 102/May 1986).

A.6.1 Waterproofing Existing Concrete or Masonry Walls

Concrete or masonry walls are generally not impermeable unless special construction techniques are applied. Waterproofing can be accomplished by use of (a) high quality concrete, (b) sealant materials, and/or (c) impermeable membranes.

The membrane method of waterproofing consists of surrounding all flood-prone surfaces of a structure with an impermeable membrane. Common membrane materials include PVC sheets, or coating of felt, canvas or similar materials that are set in layers of hot bituminous coatings (coal tar, pitch, or asphalt). The membrane method of waterproofing is applicable to all types of masonry and concrete construction. To be effective, the membrane must be continuous and it should be protected against injury by a layer of brick concrete or sand. An existing building may be water proofed on the inside by applying a membrane and then constructing an additional wall and slab within existing wall and slab (see Figure A.10).

A.6.2 Elevation of Structures

Elevating a structure to prevent floodwaters from reaching damageable portions is
The best way to seal an existing brick-faced wall is to add an additional layer of brick with a seal in between. Just sealing the existing brick is also an option.

Figure 6.10 A wrapped house sealing system can be used to protect against low level flooding.
an effective retrofitting technique. The structure is raised so that the lowest floor is at or above a designated flood protection elevation (FPE). Heavy-duty jacks are used to lift the existing structure. Cribbing supports the structure while a new or extended foundation is constructed below. In lieu of building new support walls, open foundations such as piers, columns, posts, and piles are often used. Elevating a structure on fill is also an option in some situations.

While elevation may provide increased protection of a structure from floodwaters, other hazards must be considered before implementing this strategy. Elevated structures may encounter additional wind forces on wall and roof systems, and the existing footings may experience additional loading. Extended and open foundations (piers, piles, posts, and columns) are also subject to undermining, movement, and impact failures caused by seismic activity, erosion, ice or debris flow, mudslide, and alluvial fan forces, among others.

A.6.3 Elevation on Solid Perimeter Foundation Walls

Elevation on solid perimeter foundation walls is normally used in areas of low to moderate water depth and velocity. After the structure is raised from its current foundation, the support walls can often be extended vertically using materials such as masonry block or cast-in-place concrete. The structure is then set down on the extended walls. While this may seem to be the easiest solution to the problem of flooding, there are several important considerations. Depending on the structure and potential environmental loads (such as flood, wind, seismic, and snow), new, larger footings may have to be constructed. It may be necessary to reinforce both the footings and walls using steel reinforcing bars to provide needed structural stability.

A.6.4 Elevation on Piers

The most common example of an open foundation is piers, which are vertical structural members that are supported entirely by reinforced concrete footings. But the piers are primarily designed for vertical loading; when exposed to flooding, they may also experience horizontal loads due to moving floodwater or debris impact forces. For this reason, piers used in retrofitting must not only be substantial enough to withstand vertical load of structure but also must be sufficient to resist a range of horizontal forces that may occur. Piers are normally constructed of either masonry block or cast-in-place concrete. In either case, steel reinforcing should be used for both the pier and its support footing.

A.6.5 Elevation on Posts or Columns

Elevation on posts or columns is frequently used when flood conditions involve moderate depths and velocities. Made of wood, steel, or precast reinforced concrete, posts are generally square-shaped to permit easy attachment to the building structure. Set
in pre-dug holes, posts are usually anchored or embedded in concrete pads to handle substantial loading requirements. Concrete, gravel, earth or crushed stone is backfilled into the hole and around the base of the post. While piers are designed to act as individual support units, posts normally must be braced. There are a variety of bracing techniques such as wood knee and cross bracing, steel rods, and guy wires.

A.6.6 Elevation on Piles

Piles differ from posts in that they are generally driven, or jetted, deeper into the ground. As such they are less susceptible to the effects of high velocity floodwaters, scouring, and debris impact. Piles must either rest on a support layer, such as bedrock, or be driven deep enough to create enough friction to transfer anticipated loads to the surrounding soils. Piles are often made up of wood, but the most effective for retrofitting would be steel and reinforced precast or pre-stressed concrete. Similar to posts, they may also require bracing.

Several innovative methods have been developed for setting piles. These include jetting exterior piles in at an angle using high pressure water flow, and trenching, or auguring, holes for interior pile placement.

A.6.7 Floodwalls and Levees

Another retrofitting approach is the construction of localized barriers between the structure and the source of flooding. There are two types of basic barriers: levees and floodwalls. They can be built to any height but are usually limited to four feet for floodwalls and six feet for levees due to cost, aesthetics, access, water pressure, and space. Local zoning and building codes may also restrict use, size, and location.

A levee is typically a compacted earthen structure that blocks floodwaters from coming into contact with the structure. To be effective over time, levees must be constructed of suitable materials (i.e. impervious soils) and with correct side slopes for stability. Levees may completely surround the building or tie to high ground at each end. Levees are generally limited to buildings where floodwaters are less than 5 feet deep.

Floodwalls are engineered barriers designed to keep floodwaters from coming into contact with the structure. Floodwalls can be constructed in a wide variety of shapes and sizes but are typically built of reinforced concrete and/or masonry materials. A floodwall can surround an entire structure or depending on the flood levels, site topography, and design preferences, it can protect isolated structure openings such as doors, windows or basement entrances.

Types of Floodwalls

A-23
A - Gravity Floodwalls

A gravity floodwall depends upon its weight—as its name suggests—for stability. The gravity walls structural stability is attained by effective positioning of the mass of the wall, rather than the weight of the retained materials. The gravity wall resists overturning primarily by the dead weight of the concrete and masonry construction. It is simply too heavy to be overturned by the lateral flood load. See Figure A.11.

B - Cantilever Floodwall

A cantilever wall is a reinforced-concrete wall (cast-in-place or built with concrete block) that utilizes cantilever action to retain the mass behind the wall. Reinforcement of the wall is attained by steel bars embedded within the concrete or block core of the wall. Stability of this type of wall is partially achieved from the weight of the soil on the heel portion of the base, as shown in Figure A.12.

C - Counterfort Floodwall

A counterfort wall is similar to a cantilever retaining wall, except that it can be used where the cantilever is long or when very high pressure are exerted behind the wall. Counterforts, or intermediate traverse support bracing, are designed and built at intervals along the wall and reduce the design forces. Generally, counterfort walls are economical for wall heights in excess of 20 feet.
Figure 6.11  Stability of Gravity Floodwalls

A = Height of Floodwall  
C = Width of Top  
L = Width of Bottom  
P = Dead Weight

Figure 6.12  Concrete Cantilever Floodwall Reinforcement

Concrete Footing

Optional Key for Sliding Resistance