STORM WATCH: SURVEY AND ANALYSIS OF SHORELINE STORM DAMAGE
AND ITS IMPLICATIONS FOR CONSTRUCTION AND ARCHITECTURAL DESIGN

DOUGLAS LEONARD LEMLE

Bachelor of Art, New York University
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Signature of Author

Department of Architecture

19 May 1978

Certified by

Edward Allen, Thesis Supervisor
Associate Professor of Architecture

Accepted by

Chester Sprague, Associate Professor of Architecture, Chairman
Departmental Committee for Graduate Students

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ABSTRACT

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and Its Implications for Construction and Architectural Design

Douglas Leonard Lemle

Submitted to the Department of Architecture on 19 May 1978 in
partial fulfillment of the requirements for the degree of
Master of Architecture.

The purpose of this thesis is to document and to analyse storm-caused structural
failures found in shoreline buildings. The goal of this analysis is to assemble a
catalogue of useful information and knowledge about methods of shoreline construction.

Thesis Supervisor: Edward Allen

Title: Associate Professor of Architecture
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Introduction

Throughout the ages man has shown an affinity for the sea. As vessels provide an immediate relationship to the sea, shoreline dwellings less directly allow us the opportunity to experience this immediacy. People have benefitted from the protection of an onshore position while being exposed to a wide range of weather and natural forces that makes shoreline living at once dramatically beautiful and unique. When, however, the sea becomes so violently offensive that shoreline structures are put under unusual stress, only a few can successfully withstand the onslaught.

Fact: The great hurricane of 1938 caused an estimated $56.9 million in damages to communities bordering Buzzards Bay and $6.7 million to the Cape Cod region.

Fact: In 1954, hurricane Carol caused damage of $46.9 million to the Buzzards Bay area and
$7 million to the Cape Cod region.

Fact: A single northeast storm in the winter of 1959 caused $2.7 million damage to Boston Harbor and about a half million dollars damage to South Shore communities.

Fact: Northeast storms in 1961 and 1972 respectively caused more than a quarter million dollars in damage to the Town of Scituate alone.

On February 6 and 7, 1978, a snow and wind storm assaulted the Northeast shoreline of Massachusetts with such tremendous devastation that it was declared one of the five worst natural disasters in United States history. The cost of the widespread damage still has not been computed, but the numbers will dwarf those of past storms.

The natural processes of the earth, its cycles, changes, movements, and growth, can hardly be classified a disaster. The disaster is that man is helpless and unprepared in the path of nature's power. Obviously, man cannot

Figure 1.

This shoreline house demonstrates what can happen when precautionary measures are neglected.
control the occurrence of such onslaughts, but he can attempt to understand what can be done to avoid such massive damage and destruction.

My own experience during this storm—and the fact that my house on the Nahant shoreline survived while some of my neighbors' homes were practically demolished—inspired this attempt to get at some of the fundamentals of sound shoreline construction methods and structural techniques.

There was little shoreline that was not affected by February's storm. The sea coast was especially hard hit and a new 100 year flood level was established. The Boston area usually has a 10.9' tide. Yet on these two days in February the tidal surge reached an unprecedented 16', and in some locations upwards of 18'—essentially 6' to 8' above normal. Although this was a large factor in the damage that followed, the major cause of this tidal surge was a wind blowing hurricane force at a steady 75 mph with gusts on the water up to 96 mph.

Coastal communities were not ready to cope with so much wind, water and snow. The flood plain level, which had been set at 11.9',
was inadequate for such an exceptionally high tidal surge. When a wave broke, the onshore surge and the run-up factor from the energy in the wave and the wind velocity was immense. (Run-up is that process by which a wave's energy is dissipated by the wave's movement inland, and, usually up a slope.) To understand the force of run-up one can simply look at some locations where there were many tons of stones ranging from small pebbles to 300 pound rocks that were carried inland 200 to 300 feet. Actually, these rocks created new landforms and in some places increased the ground level by as much as five feet.

Because hurricanes and northeast storms attack the coast from different directions (Figure 2) the magnitude of flood and erosion damage will vary with each community's exposure to the storm's approach. Of course, the vulnerability of individual stretches of coastline also will vary significantly with respect to landforms and exposure orientations.

Maximum flooding along a particular coastline will occur when storm winds blow onshore at or near the time of high tide (especially during spring tides) when the

Figure 2.
water elevations reach their highest levels. Strong winds exerting energy and pressure on the water's surface cause a piling up of water against the coast. This is known as the "storm surge." During a storm surge, the level of water can rise from 8' to 10' above the high tide levels. Large waves and storm surf augment the charging water carrying it further inland and increasing the probability
of flooding.

The majority of water damage in February's blizzard came from flooding. Behind a row of houses in Nahant is a flood plain with a dimension of about one-half mile by one-half mile. This whole plain had about six feet of standing water in it after the storm. Flood plains which are buffer spaces between the continent and the sea actually protect the shore, providing for the overflow of water along the continent's edge. The problem, of course, is that flood plains are viewed as prime waterfront property and people tend to overlook that in the face of a tidal surge buildings in these areas are struck first. And little has been done to protect these buildings from the extremes of tidal surge.

However, in these same highly exposed areas were buildings that weathered the storm's elements successfully, while others alongside them were destroyed. The apparent randomness of the storm's devastation was perplexing. The damage ranged anywhere from a few shingles missing to buildings which were blown or swept away. The buildings that were destroyed were not as interesting as the

Figure 4.

This photograph dramatically illustrates what happens to a poorly constructed house in a large storm. Poorly constructed buildings, regardless of materials used, are the principle source of loss in storm areas.
buildings which, although contiguous with the damaged ones, were in relatively good condition. These had something valuable to say. They held secrets from which better shoreline construction ideas could be abstracted. This thesis purports to describe some of these concepts.
THE SURVEY

Since there was a prodigious amount of material available, a controllable survey was necessary to handle the information.

The survey covered the North Shore from Rockport down the coast through Scituate and points south. Within these locations the areas hardest hit were noted on geologic maps. This information was used to analyze types of geologic conditions, especially beach forms which necessitated more dramatic protection. From this diagnosis (and photographs) assumptions could be made as to what types of construction could be dependably built.

Somewhere between 2500 and 2800 buildings were observed. Of these, approximately 200 necessitated data sheets (Figure 5) to carefully study their failures and/or successes. The survey and analysis of the travels along with the subsequent research is incorporated into the main body of this work.

Figure 5.
Coastal Dynamics

The shoreline is in a continuous dynamic state. Much of the coastline's attractiveness comes from nature's changing ways and her constant shaping and reworking of the shoreline. Thus, beaches, sand dunes, barrier beaches and other landforms are always changing. During normal longshore (littorial) drift, the wave action and current are in relative equilibrium, which propagates beaches as well as erodes them. The sands of the coast move perpendicular to the beach. These go onshore during the summer months when low energy waves exist and move offshore during the winter when high energy storm waves prevail. The shifting configurations of beaches, therefore, keeps a fairly consistent profile.

During a wave approach onshore, an oblique wave will tend to parallel itself to break on the shore. Usually the longshore current equalizes this direct shorebreak to maintain beach material equilibrium. During a storm, the wave approach and its potential
for carrying material is far more powerful than the longshore current, and the surge in waves regardless of the wind direction will break parallel to the shore. It is at these times that landforms go through their most dramatic transformations. If the winds and the waves are co-incident in direction, the forces of change are even more accelerated.

While the increased reliability of storm warning services and evacuation preparedness plans have substantially reduced the threat to lives along the coast, similarly building development in hazard prone areas exposes more and more structures to direct attack from storms. A great deal of the damage from flooding and erosion could be avoided if developers and owners of shoreline property would respect the value of the natural buffers which the coast provides.

The role of coast landforms and coastal processes as protection of the continent from the ocean has only recently begun to be understood. In short, all coastal systems function in a state of dynamic equilibrium to withstand wave and wind forces. Coastal landforms, when left to develop and evolve...
BAR AND BEACH FORMS

Figure 7.
naturally, function to buffer and weaken the high energy effects of storm forces. But while these landforms offer the continent excellent protection, they offer manmade buildings very little.

The four kinds of landforms within this system function distinctly. They are sand beaches and dune systems, barrier beaches, offshore bars, sand and clay bluffs, and tidal plains.

Sand beaches and dune systems:

The gradual slope of the beach face dissipates wave energy and the sand deposited by littoral drift is transported by the wind to form dunes. These dunes, subsequently stabilized by beach grass, serve a natural buffer to protect inland areas from wave attack.

Barrier beaches:

Overwashing of the dunes during storms causes the depositing of sediment. This sediment distribution (a slow process) plays a role in marsh development and in maintaining the height of backshore areas. Even though bar and beach forms are temporary formations, they have strong ecological
Figure 8.
influences--breaching inlets to form laggoons and salt ponds. When opened they become harbors and marsh lands.

Offshore bars:
The submerged bars also help dissipate wave energy, and further function as storage depots for the replenishment of sand beaches and dunes.

Sand and clay bluffs:
The erosion of these bluffs provides sediment material for the rebuilding of beaches down shore.

Tidal plains:
The gradual slope of the marsh beds together with the vegetation that stabilizes the sediment also dissipates wave energy during storms and tidal surges. These beds are repositories of extra material. Marshes also act as storage areas for flood waters.

All of these landforms serve a necessary and vital function. Man must respect and be
conscious of the dynamics of coastal evolution and transformation. His large works should not interfere with these dynamics for the consequences could have serious effects on equilibrium.
STORM WAVE DYNAMICS

Storm waves are characterized by their many different wave lengths. From their inception the small period waves grow quickly until they reach an unstable steepness, at which stage they break. This breaking process adds energy to the longer waves, which grow more slowly. For any given wind velocity, a steady wave condition can be reached when the energy being transferred from the wind to the sea is being dissipated at an equal rate by all the waves except the longer breaking ones.

The important aspect here is the excessive steepness of the waves within the fetch, the distance from the shore that a wave has to build up its size and speed. Each train of wave contains a large volume of water greater than the mean sea level and so exerts a special influence when it is virtually poured onto the beach.

While waves are experiencing the force of the winds they are tilted forward. This tends towards instability and hence promotes breaking as the shallower depths are reached.
Figure 10.
This ready formation of surf has its unique influence on the beach cycle.

Another characteristic of storm waves is the many directions in which the various waves travel at once. This arises from the mode of generation. The smaller period waves present will, in general, be angled more obliquely to the average wind direction, while the orthogonals of the longer waves will be more closely aligned to it. The key factor which magnifies the multi-directional nature of storm waves is the motion of the storm center itself. The fetches bringing waves to a specific point on the coast are changing location and direction very rapidly. Thus, throughout a storm cycle waves can arrive from a wide fan of directions.

The random direction of approach of storm waves together with their relatively short duration throughout the year (compared to the more persistent swell), results in their having little influence on the movement of sediment along the shore. However, they effect a prodigious transfer of beach material laterally to the offshore zone, which at times becomes a repository.
As waves reach depths of about half their deep water length they begin to disturb the bottom. Longer-period waves do so before the shorter ones. The mass-transport associated with this disturbance forces particles in the direction of the advancing wave, which accounts for the tremendous amounts of material deposited along the shores.
Primary Protection

Next to the natural geologic configurations of the land and their natural defenses against the sea, man's attempts at shore protection are somewhat amusing. Anybody who has ever witnessed the buffeting of a wrecked ship or the effects of a storm upon man-made constructions, or even the solidity of natural rocks, boulders and cliffs can appreciate the enormous power of sea waves. It would seem that any human attempt to resist them would be to no avail, but at the same time there is evidence to the contrary. On the shoreline there are examples of structures that have resisted storm surges and large breakers. Therefore, when an abnormal amount of damage occurs the conditions must have been favorable to destruction. The structures were somehow defective in either form, position or construction.

The energy stored in storm waves pounding on a small length of coastline is tremendous. Depending on the wave length, height, speed and period, recordings have placed
horizontal impact pounding at everywhere from 2000 pounds to 6600 pounds per square foot. Building against loads such as these may seem impossible, yet engineers have been successful in countering these forces with major sea defense works. For the individual property owner the problem is what measures can be taken within reasonable time and expense. Here no attempt will be made to describe how to build massive primary sea defenses but rather to make sound suggestions for those buildings which are behind such structures and for those buildings which are not. Moreover, suggestions will be made for the secondary defenses to help counter the elements which the primary wall cannot. These secondary defenses have more to do with the building and flood protection than with shore protection per se. The importance of this cannot be understated. Much of the damage occurred to buildings behind successful and durable sea defenses. It was shown during this past storm that reliance simply on the primary protection is not enough. It is within these areas that secondary defenses and precautions should be taken by the property owner to

Figure 12.
Although this house was damaged, a prow shaped concrete caisson and patio protected it against total destruction.
insure the durability of his buildings. The bulk of this work later pertains to those other measures.

Of particular interest are those places where little or no major sea defenses were erected. Of course the people who built at these locations were required to build at positions dictated by the last 100 year flood level. This was not simply due to common sense but also to directives from building codes and general ordinances prescribed by various coastal management agencies.

These places tended to be beach locations and these structures were built well above the high water mark. Precautions suggested here (for periods of storm surges and high winds) should insure some durability to structures built near the sea as well as prevent erosion damage and destruction.

Beach areas were the hardest hit of all regions. Of course, this was because the only major protection was the beach itself. At times it was found that some people had built small 3' to 5' sea walls out of concrete with proper footings, but it was not clear whether they were constructed for exceptional

Figure 13.

An addition on this house was destroyed because it was built on a stone rubble with a mortar joint foundation. The rest of the house was built on a concrete foundation faced with stone.
high tides, storm surges, or property delineators. Rarely did they seem to be effective during the recent storm surges. If they did help to protect a building it was a fortunate coincidence because the precautions taken were to maintain the integrity of the wall not the home. The usual failure of these small walls was due to the undercutting or undermining of the earth beneath the walls. Thus, the reason many buildings were damaged was because their sea walls broke away when the earth or backfill behind them eroded.

Once the backfill is removed there is nothing to buttress the wall against the impact of storm waves running up the beach. In many instances, there was a sea wall and a slab poured for patio between the building and the sea wall. Once erosion set in from beneath, the slab would collapse and create a pocket or depression behind the sea wall. This would aggravate the water coming in and increase the erosive capabilities of the moving water.

In order to prevent erosion and undermining the Army Corps of Engineers uses sheet piling at the toe of a sea wall. (Figure 15)
Usually concealed by sand or rubble, this maintains the ground onto which a sea wall is built and stabilized and is one of the most important aspects of good construction. This same design should be employed by the property owner.

Not only is sheet piling essential in front of the wall but also behind it to avoid the withdrawal of ground. Sheet piling can be built from either wood, steel, concrete, concrete block and so on. Sheet piling itself, without the aid of grade beams of dead-man anchorage, cannot withstand strong lateral and horizontal forces. It can withstand strong lateral and horizontal forces, provided it is large enough and designed to take those loads, such as those used for cofferdams, but this type of sheet piling would be too large for the domestic range and the cost would be too prohibitive. One thing is certain, the integrity of the sheet piling is maintained by the ground around it.

A very good construction technique and protective measure for a single structure is the concrete caisson. These are large
enclosed containers made of concrete, a box if you will. (Figure 16) The sides are poured concrete usually 12" to 20" thick. The box is then filled with smaller rocks and boulders and sand, and then covered with a poured slab. This slab is connected to the side walls by steel reinforcement. The vertical steel protruding from the side walls is bent over to a horizontal position. Then more re-bar is lapped to the steel (min. 30 bar diameters) to support the slab. Wire mesh is then used conventionally before the slab is poured. An added measure is to pour a slab on the bottom of the caisson to insure that the fill stays in the box.

An interesting device seen on a few beaches was a small sea wall, approximately 3' to 4' thick, behind which was a wooden fence made of 8" x 8" wooden posts sunk at least 6' into the ground, 8' to 10' on center. Across these were 2" x 10" or 2" x 12" planks laid horizontally. The wooden posts were braced about half way up with 8" x 8" wood members which were imbedded diagonally into the ground. These fences took an intense pounding and while many of
the horizontal members failed, overall the fence fared well and the buildings behind survived. (Figure 17) This type of defense evidently has a flexure and resiliency capable of withstanding heavy impact and shock. The bottom of the posts at the ground were protected from horizontal shear by the small concrete wall in front, which also transferred to the ground much of the wave energy, so subsequently the wood post absorbed diminished energy.

Figure 17.
This simple protection saved these buildings in the storm.
Overtopping

In the design of buildings behind primary protections the problem of wave overtopping is an important consideration. Since little quantitative work has been done on this subject, predictions on the amount of water overtopping structures from wave action has been made with little information. The amount of overtopping is important not only from the standpoint of designing adequate drainage and pumping systems to remove overtopping water and prevent flooding, but also to reduce damage to buildings behind primary protection. Under storm conditions overtopping water blown inland can cause significant damage.

The use of secondary short vertical walls a distance back from the main protective wall will help to re-route water back into the ocean or divert it away from the building. (Figure 18) Although secondary walls do not have to withstand the tremendous force and impact which the first wall receives, they
should go down below grade 5' or 6'. At this depth and depending on the wind direction, a wave breaking against a sea wall may come down further inland of the first wall. The effect of this action, wave after wave, on the ground will produce a massive dislodging and loosen and remove by erosion large quantities of earth. If too much earth is removed, there exists the possibility of undermining the deck or slab or primary seawall from behind, which would result in even more damage. In building a secondary wall it would be advisable to connect this wall to the slab with a re-inforcing rod or wire mesh.

Areas highly prone to erosion and subsequent extensive damage are the ends of seawalls. Water running up against a seawall tends to have a "venturi effect" at the end. This "effect" occurs when a volume of water is obstructed. It will then increase its speed around that corner creating a turbulent effect and a circular vortex on the inland side of the wall, increasing the erosive capabilities tremendously. To insure against this type of failure make a return at the end.

Figure 19. A return at the end of a seawall.
of the wall. (Figure 19) These returns, called counterforts, besides adding strength against impact, also divert the onrushing water to go inland without enabling it to scour and undermine the end of the wall. Counterforts should also be used intermittently along the entire length of the seawall to strengthen it. Counterforts also limit the erosive capabilities of earth removal. In the event of a large storm and tidal surge, counterforts would act like groins maintaining the earth behind the seawall. They are built at approximate right angles to the wall and their depth should be equal to the depth of the seawall. Their length is variable. They also could run inland and become part of the building's construction.

The toe of seawalls are also prone to erosion. If the earth or rubble is removed from the toe, subsequent movement and collapse of the wall is possible. The Army Corps of Engineers at times use what they call a "blanket" of boulders heavy enough so that wave action will not disturb them. (Class B, 100 lbs. to 4 tons) Sheet piling at the toe also serves to protect. Sometimes in
extreme locations both types are used. Depending on where the seawall is located, the property owner in designing his defense should take all precautions to halt the undermining of the toe. A way to do this is to pour large amounts of concrete as sheet piling below the footing of the wall. The depth requirement to protect the toe is a function of wave mechanics. It should go down below the level of the beach more than the maximum depth of the water at the storm surge level. As a rule of thumb method, the maximum depth of scour (erosion at the foot) below the natural bed may be approximated as being equal to the height of the maximum unbroken wave that can be supported by the original depth of water at the structure's toe. This is for ocean front locations. For shallow bays it is less.
Foundations

The entire well being of any building is dependent on its foundation. Yet people still take short cuts and skimp on their foundations. This is somewhat understandable for the foundation of a building is rarely seen and its visual delights hidden. People often tend to invest money in the more visible cosmetic aspects of their homes.

Of the 2500 shoreline buildings studied in the aftermath of the Blizzard of '78 more often than not the severe wind and wave damage that resulted was due directly to inadequate foundation design and construction. Along with occasional extreme weather conditions, shoreline buildings additionally face the inherent problems of beach erosion and decay of materials from salt air as well as from fungus and marine bore.

The fundamental idea in shoreline construction is to take protective measures and to build solid durable sea defenses to inhibit water from coming inland and destroying buildings. The first problem arises in shoreline construction is to take protective measures and to build solid durable sea defenses to inhibit water from coming inland and destroying buildings.
in that most protective devices are built to withstand the forces and conditions of the extreme 100 year flood level. This is not enough of a design plan because 100 year flood levels change, as was evident in this last storm.

Reliance simply on a sea wall or other primary protective measure does not assure that a building is safe. For instance, for beaches. The bulkheads and revetments protected from the direct impact of the waves by a permanent beach berm tend to prohibit wave run-up. However, under certain storm conditions some seemingly permanent protective beaches have eroded so severely that little or no protection was afforded the wall. Consequently, even in the case where beaches seem permanent, it is advisable to either build considerably back further than at first planned or to install sheet piling in front of the building.

One common misunderstanding is to assume that when a building is behind a major sea wall or other primary protection defense it will be safe against a surge. Of all the damaged regions visited, the majority of
most of the damage existed behind such walls. The overtopping effect and the run-up factor was too much and badly constructed buildings behind these walls suffered. Either the upper portion of the buildings were damaged by waves breaking against them or from wave wash being blown inland, or their foundations were ripped apart and destroyed by the large amounts of water pushed inland. So these buildings were getting hit from two places, from below and from above. The one major lesson learned from these areas was that no emphasis should be placed on major sea defenses as absolute protection from the sea.

If a building is relying solely on the protection from a primary sea wall defense then a problem exists because sea walls break. The idea is to build a structure so that when the primary protection fails and water does come over or through that the structure's survival will be guaranteed. If a building is well anchored to a sturdy foundation there exists a good possibility that the building will survive with minimum damage.

In deciding which type of foundation to use a decision in philosophy must be made.

Figure 22.

This photograph demonstrates what happens to a concrete caisson that is not completely enclosed with reinforced concrete. The water was able to get behind and erode the fill away.
One can impede and stop the flow of overtopping water, or one can divert it or let it flow through. If one wants to impede the flow, then all efforts should be made to build an excellent foundation. Efforts should also be made to prevent withdrawal of ground around the foundation during a storm. With turbulent water moving rapidly inland, erosion can occur very quickly.
In shoreline building construction two different types of piles were used, wood and concrete, and both worked equally as effectively. The depth of the piles varied between 8' and 16' deep, and often they were imbedded in a concrete footing. The buildings varied in height above the ground from 3' to 8'. This type of construction seemed to fare very well. The reason was that instead of trying to build a foundation strong enough to withstand wave and flood action, these homeowners simply chose to allow flood water to flow underneath and through.

Although this approach was taken by many and overall their buildings did well, four types of failures were observed. The most prevalent was insufficient or lack of adequate anchorage of the building to the pilings. Often buildings were either pushed back off their pilings or lifted up and off their pilings by the wind. Some of these buildings appeared undamaged save for their displacement.

Figure 23.
These three houses were pushed back into each other because they were built on unbraced wood piles.
Another situation noticed was damage to the rear side of a building while the ocean-facing front was intact. The problem here was a mixing of philosophies. When one decides to build with pilings he is assuming that the water will flow through and under the building. But when one then builds a porch, entrance or addition on the inland side, he must remain true to the original concept. Often, the added rear structure was built with unit masonry or post and piers. At times it was just a set of stairs. All these additions were attached to the original building and water flowing underneath tore them away from the primary structure. Even when these adjunct spaces were well-attached to the main building the result was often considerable damage to the rear of the building. On a few buildings it appeared that the entire building had been pulled and not pushed off its foundation by the adjunct additions on the rear side being pushed by water. If one is to use piles as a foundation, then any additional construction should be consistent with this system. Another alternative would be not to attach secondary

Figure 24.

Water flowing under this house on a pile foundation destroyed the rear structure which was built on the ground.
rear structures like stairs to the building but rather build them independently and let them float away during a flood.

Another type failure was the building and piles being pushed back, sometimes completely and sometimes partially. In these instances either the piles were not set deep enough below grade or the soil condition warranted good sturdy diagonal bracing. Good diagonal bracing should be employed whenever pile foundations are used.

One other type of failure was building damage or collapse due to erosion of the soil which held the piles. When water is flowing and an obstacle is in its way, the effect created is an increased flow around the obstacles. Thus, erosion is increased and accelerated. So, rather than digging deeper for pile setting, the use of grade beams connecting the piles would assure that even if the piles were totally exposed to erosion, they could not move laterally, and the building would remain stable.

Figure 25.

These three houses were pushed back into each other because they were built on unbraced wood piles. The eaves were once five feet apart.
POST AND PIER

Buildings constructed with post and piers, sometimes known as stilt construction, generally did not perform too well. Not that this type of construction is not suitable, but rather this class of foundation is usually limited to inexpensive seasonal structures. Many beach cottages were built this way. Not much attention to stability or anchorage was noticeable. On the other hand, those few structures that did incorporate sound construction and attention to good detailing fared better.

The most prevalent failure occurred in structures with inadequate diagonal bracing for the posts. Under pressure from the wind and waves, these lightweight structures racked easily and consequently collapsed. Another reason for failure was lack of or insufficient connection of the post to the pier. Often, the piers were found in place and the original building yards from the original site.

Another significant post construction

Figure 26.

This house on stilts, with foundation posts securely fastened to deep concrete footings and good lateral bracing, remained intact in an area where most of the houses were badly damaged or destroyed. Waves washed under the house but were not high enough to seriously damage the upper structure.
problem overlooked by many builders is that during a storm surge with extreme high winds there is the probability of debris being carried by flood waters smashing into any obstacles with great force. A post construction is usually built with relatively thin members, and are not substantial enough to withstand impact of floating debris. The precautionary measure would be to use either larger posts or steel posts, or to incorporate both using steel lower down and wood at the upper portion. (Figure 27)

Anchorage is also a problem with posts to piers. This is usually the weakest part of the construction. The problem is not so much the anchor coming loose, but rather the wood post failing at the connection. The interface between the ground and the air is the zone most susceptible to decay. Attention to preservatives and keeping the connection either well above grade or well below grade is advisable.

If a pin connection is used (Figure 28), steel or aluminum straps around the bottom of the posts would insure against the post splitting away from the pin. This type of
Figure 28.
Post anchorage—stitching bolts or metal straps.
belting is also recommended for post anchors.
Another means of accomplishing this same
safety precaution is the use of stitching
bolts at the connection points. (Figure 28)
Here the bolts go through the members and
act as horizontal pins to help strengthen
the wooden post.
CONCRETE BLOCK

Without question, most foundation failures were those built with concrete block. Moreover, there failures inevitably occurred where there was no horizontal or vertical steel reinforcement. Concrete block is effective in vertical compression but a mortar joint is simply not sufficient against lateral loads. Even in instances where there were numerous jogs and returns in a wall, it did not necessarily insure against failure.

Even when the block wall was solidly reinforced, there was little concern for quality footing and the movement of water quickly eroded the bedding so that first the footing failed and then the block wall did. Since the possibility of erosion from tidal surge exists and since the soil condition of the sea shore is relatively unstable, extra care must be taken to build adequate footings. (Figure 38) This would assure that if any undermining or settling (long or short term) occurred, it would at least be uniform and maintain some of the integrity of

Figure 29.

This block foundation illustrates the way it fails when no vertical or horizontal joint reinforcement is used.
the foundation.

The most widespread block failure was the breaking away and collapse of the block. Primarily this was due to the lack of vertical steel reinforcement in the hollow cavities of the block. At times, the block walls had sufficient grout but no steel, so these walls also had a tendency to fail. When vertical steel is used it should be imbedded into the concrete footings and be buried at least thirty bar diameters. If the footing is not deep enough to take this depth of steel, the steel bars should be bent at the bottom at a right angle of three inches. (Figure 33) This would give the concrete the necessary slip resistance needed for secure holding. It is also important to remember that when steel is placed vertically in a block wall, it is imperative that the cores be filled with grout. Preferably with high slump concrete that should be jabbed down in place with a stick or rod to eliminate air pockets and insure proper bonding to the re-bar.

Another excellent precaution against block failure is to introduce horizontal
joint reinforcement. This would protect against strong lateral pressures and maintain the wall's integrity during horizontal tensile stress. One building left standing in a severely hard hit area had a non-reinforced block wall foundation. Most of the block had collapsed except for a few sections that had concrete buttresses on the inside of the foundation. These buttresses ran the height of the wall and were tapered from top to bottom, where they were thickest. (Figure 32) Every other course had connecting plates tying the buttress into the block wall.

A few buildings had implemented small steel I-beams imbedded vertically against the wall. On one occasion steel rails were used instead of I-beams.

Another good device for insuring the stability of concrete block walls under lateral loads is the use of bond beams. Bond beams are made from blocks cast as channel sections or by the use of special blocks that have their center and side members cut in such a way that they can be "knocked out" to create a channel section. (Figure 33) Bond
Figure 32. Two means of buttressing a block foundation wall.
beams of this nature have been conventionally used for either the top course of the wall or for spanning openings (windows and doors) in foundation walls. Occasionally they have been used to increase the lateral and tensile strengths of walls under those loads. On the shore it would be advisable to use the bond beam on every second course and on the top one. This not only ties the entire wall together integrally but also increases the wall's tensile strength capabilities. Usually two 1/2" re-bars are used for the horizontal steel reinforcement and 1/2" or 5/8" for the vertical.

On the whole, concrete block walls proved satisfactory only when they had a good footing which did not erode, good and frequent vertical steel reinforcement and grout in the cores. Those block walls which were solidly reinforced withstood the onslaught successfully.
Figure 33. The bond beam and proper steel reinforcement placement.
Unless a building is superbly protected from shoreline forces the use of brick walls, foundations, and piers, etc., as building materials and a technique for security against the wind and water can be summed up easily—a mistake. In buildings heavily exposed the use of brick as cavity walls, veneer, facing or foundations usually resulted in either major damage or total losses. The problem was plainly stated in the previous section—a mortar joint simply does not have the strength to withstand the impact of horizontal and lateral loads. Furthermore, the continuity of a brick wall is difficult and almost impossible to maintain during horizontal loading. Under wave action, only one brick has to come loose for the damage to escalate.

For cavity walls with sufficient cross ties the problem is a little different. When a wall made of brick is loaded by wind and/or waves, the entire wall acts as a diaphragm, and a brick wall has virtually no capabilities for this type of movement. But when the brick

Figure 34.
This brick veneer house was some 200' back from the ocean yet wave action still ripped the brick away. The mortar bond was insufficient against the waves.
is used as a veneer on say a wood frame build-
in there exists a differential in bending
capabilities between the two walls. The wood
frame wall deflects and retains its integrity
while the brick wall readily fails.

A few buildings that used brick walls
for the bearing of the roof were total or
near losses. Even when brick is under
direct vertical compressive loading, which
makes it more difficult for the bricks to
come loose, all that is needed for the damage
to progress geometrically is for a few bricks
to come loose. And, as soon as some of the
bearing walls fail, so does the roof, followed
by the entire structure.

Figure 35.

Brick walls have little ability to bend under
wave force, and the consequence is collapse.
These walls were bearing the roof before the
wall gave.
CONTINUOUS Poured CONCRETE

Far and away the most satisfactory kind of foundation found on the shoreline were those of continuous poured concrete. This type fared extremely well considering the lateral loads of pressure they had to withstand periodically. The failures observed were due either to overlooked or neglected details of proper concrete construction. On some occasions, the problem of erosion undermined the footings which held the foundation above. Moreover, other serious shortcomings can be laid to the lack of any kind of reinforcement in the footings themselves.

The importance of steel reinforcement for footings in shoreline construction cannot be stressed enough. There are two reasons. First, the basic make-up of the ground along the coast is usually small rocks, gravel and sand deposited by littoral wave action and by general coastal dynamics. No matter how strong soil tests say the stability is, inherent in the word coastline is change.

Figure 36.
A well constructed house that withstood many storms. A poured, reinforced concrete foundation and good construction gives an excellent account of itself in storms.
Second, it should be understood that no matter how well the shore has been defended buildings and foundations along the coast are susceptible to very severe poundings from wave action during storms. Defenses are only as good as the last 100 year flood level and often the foundation of a shoreline building becomes the secondary defense against the sea. Unlike the piling foundation which lets the flood water through, a concrete foundation stops the flow and becomes an obstacle. So, besides the tremendous forces of water movement, one also must consider the possibility of debris being carried rapidly by water and a poured concrete foundation tests well against such impact.

Another failure with concrete foundations was some incidental spalling, especially at the corners. This spalling should be patched up to prevent the steel inside from rusting and also insure against any further damage from wear, erosion or frost wedging.

At times entire poured concrete foundations were observed completely intact and yet no signs of any structure above. This has to do with proper anchorage, which will
be discussed later.

Figure 38. Rule of thumb formula for minimum footing size.
While poured concrete foundation walls did well, concrete slabs did not. The usual problem was that the slabs, ostensibly patios, were used to control erosion of the ground either in front of the house or around it. More often than not the slabs were simply poured directly over graded ground without any reinforcement. This was especially true of slabs laid on the inland side of the primary protective defenses.

The problem is that when flowing water reaches an edge of a slab it produces a small vortex which augments the erosive qualities of the flow. The undermining of the ground below the slab is relatively quick. The idea here would be to reinforce the slab with wire mesh and in some severe locations to include a re-bar. Along with reinforcement, special care must be taken to insure that ground withdrawal is prevented. This can be accomplished by turning the edge of the slab downwards into the grade.

Small garden walls at the edge of the

Figure 39.

Water was able to get underneath these slabs and undermine the concrete caisson. The house was pushed back off its foundation by waves.
slab which are set deep enough, say a few feet, will insure maintenance of the slab. The exact depth that the wall should go down would depend directly on the steepness of the grade, the soil condition, and the types of obstacles impeding the flood waters' flow. Small garden walls, besides providing resistance to undercutting, add much to the sense of a defined outdoor space. Another excellent quality of these slab edge walls is their ability to direct and divert flooding waters around and away from the building. (Figure 40).

Figure 40. Various garden wall shapes which divert overtopping water.
Anchorage

Whatever type of foundation is used, whether pilings, concrete, post and pier, or block wall, proper anchorage is most essential. The importance of anchorage cannot be overstated. Too many structures succumbed in the storm because of no anchorage or inadequate anchorage. At times, entire foundations were left intact yet superstructures were blown back or completely pushed off their foundations.

A number of anchorage failures were discovered in structures with excellent poured concrete foundations. Some of these had no anchorage whatsoever and had solely relied on the weight of the superstructure to secure the building to its foundation. Many of these buildings had survived other storms. The February blizzard put a near constant lateral wind load on the building's side, followed by a large wave hitting the building. This coupling of high winds and wave impact increased the lateral loading capacity beyond reasonable expectations. For
protection, this coupling necessitates the use of more anchorage and larger sills.

The standard procedure for the anchorage of concrete foundations is the placement of anchor bolts periodically along the wall. This method works providing enough bolts are deployed to guarantee sound hold down and an even distribution of the load. Often proper sill to foundation detailing was used, but the loads were so severe that defects occurred in the sill itself. Standard sills as thick as 2" x 4" and 2" x 6" proved not thick enough to withstand such force and larger members are advised.

At other times foundations with bolts still in their proper places were found, but the sill and the wall had been torn loose. Here the defect usually was in the center of the sill and the sill had been ripped parallel to the grain, which suggests one of two things. Either not enough bolts were installed or the sill was not large enough to absorb the loading. A suggestion for shoreline construction is that the sills be a minimum of 4" x 4", but preferably 4" x 6" or even larger. Also, the bolts should be placed

Figure 42.

Even though the front of this house sheared away from the anchor bolts, this buffer space protected the main part of the house from major damage.
at a minimum of every three feet, and even better yet two feet on center.

There were also a few houses that were bolted properly and the problem was the washer cupping or mushrooming from the uplift forces. Sometimes it was only the washer and sometimes it was the soft or decayed material of the sill. The addition of larger washers below the original one or a steel plate would help avoid this type of failure. (Figure 43)

Another way to displace the load and strengthen the sill at the bolt locations would be to incorporate a spiked plate connector, which are standard members for wood truss fabrication. A hole could be drilled in these and placed over the bolt hole. The plate then could be hammered into place and the bolt tightened. This would substantially strengthen the point of bearing.

Another anchorage failure was wall to sill separation. Even though there was proper anchorage of the sill to the foundation, the separation occurred between the joist to sill or at the wall to floor interface. There are a few techniques for strengthening this joint. First, one can take precaution by
nailing the wood sheathing or plywood sheathing all the way down to the sill. This would insure that the entire wall, header plate and sill are tied adequately together. (Figure 44) If boards are used as sheathing, they should run diagonally, not vertically or horizontally. This gives better connection to the sill and moreover greatly increases the building's resistance to deformation as well as racking.

Another technique is to use metal strap anchors, which wrap from below the sill and upwards onto the studs. For adequate protection this strap should be nailed across the face of the header, on the sole plate, and then up the stud for 12" to 18". (Figure 45)

Another suggestion would be to incorporate metal inserts or steel angles, embedding them in the foundation itself and running them up a sufficient distance to tie in the joists, sole plate and part of the stud.

Figure 44.
Figure 45. Metal straps for additional security against uplift.
**Buffer Space**

A buffer space is that space between the primary superstructure and the ocean. These can either be rooms, porches or any adjunct space. There are many ways of better incorporating these spaces to act as a safety device to protect a majority of the building if primary or secondary defenses break down.

During the blizzard those spaces which were added on or attached and not an integral part of the framework had a tendency to be weak against wind driven water. Most of the connections for these spaces are simple nail joints, so when the entire adjunct space is under a lateral load it has a tendency to pull or rip away from the large structure rather easily.

Those spaces whose framework was an extension of the building's framework survived much better. The reason for this is that the framework had moment connections which can handle a variety of loads in a far superior manner than simple butt connections.

At times adjunct space must be added on.

![Figure 46.](image)

Adjunct space which was constructed by extending the floor framing survived. The porch which was added on was destroyed.
When this is the case, extra care should be taken to make strong and durable connections. This entails precautionary detailing. Whether the buffer space is added on in the middle of a wall or at a corner or both, good connections are always essential. Bolts, steel angles, metal plates, metal splice plates of different varieties and added wood cleats are all means for strengthening joints. Even if one were to use and make timber frame joints such as lap, mortise and tenon and so on, the addition of metal plates and angles is suggested. The idea is to resist loading in all possible directions and the use of these devices would help.

Buffer spaces are well worth considering. Even in buildings where buffer spaces were destroyed, the amount of damage to the primary structure was reduced or insignificant. In comparison, buildings whose first or front walls failed that did not have a buffer space, suffered major damage to their primary structure. An important factor here is that these spaces should not bear a load from the main building. The proper attitude toward built buffer space is that they be

![Figure 47.](image)

Although damaged, this buffer space protected the majority of the building from extensive damage.
Another important aspect of buffer spaces is that they be well built. Since this space is going to take the brunt of the forces, good fits, strong joints and extra care in weather tightening is critical. Glass windows and glass doors, besides having storm shutters which can be easily shut, should be made of a minimum of 1/4" plate glass. The shutters should also be small enough so that if they have not been put in place before a storm comes, then they are able to be closed in high wind. Large shutters cannot be handled in high winds. Doors which lead into the buffer space should swing outwards. The door jamb and frame will then take the load rather than the hardware of the door.

Observations were that once a part of a building failed, say one window, then the progression of damage accelerated. An example of this is a small hole in a roof in a light rain. If the hole is not patched soon, water starts to leak in and then spreads throughout the structure.
Upward buckling of floors due to swelling of immersed soil beneath floor.

Racking due to horizontal force caused by fast moving water.

Housing unit washed off foundation.

Figure 49. Some of the results of forces on the shore.

Because of the extraordinary forces of nature in coastal areas, the construction and framing of the superstructure of shoreline buildings should be approached somewhat differently than in conventional houses.

(Figure 49)

The major areas of weakness exist in the joints of the framing. Thus, from the foundation sill through the rafters and roof,
the joints should be strengthened. This can be accomplished by either the addition of metal straps and well placed bolts, or by detailing the framing in a more expensive and intense manner. For instance, timber frame construction is excellent for one, because of the sizes of the members, and two, the manner in which the pieces are put together. There also is heavy use of mortise and tenon, half lap, and scarf joints, which are all stronger than the simple butt joint used in conventional wood framed buildings.

In conventional framing, use of bracing is necessary. Bracing stiffens framed construction and helps it resist winds, storm, twisting or strain stemming from any cause. Good bracing keeps corners square and plumb and prevents warping, sagging and shifts resulting from lateral forces that would otherwise distort the frame and create badly fitting doors and windows.

There are two approaches to stiffening a building. The rigid frame uses moment resistant connections to counter horizontal forces from acting on a building. Bracing
uses diagonals to absorb these forces and to avoid bending of the frame. Braced buildings have greater capacity for controlled deformation. Such resiliency is desirable in shoreline buildings. For this reason balloon framing is better because the forces are directed towards the framing members and absorbed by them rather than by the connections as in platform framing.
Primary Form Considerations

The primary protection against the sea, such as sea walls and revetments are essential in certain locations. The designs of these walls are many and varied throughout the world. From the tremendous sea defense works of the Netherlands and Great Britain, which take the thunderous pounding of the North Atlantic and North Sea, to simple temporary sand bag defenses on the Mississippi, the actual type, size, design face and materials to be used are local decisions based on site, geologic considerations, and budget. Whatever scales these take, there are definitely optimal forms in response to particular conditions. Sea walls and revetments do not have to be disconnected events. From these singular decisions emerge constructions with small dimensional use zones around them. These events do not afford an interaction in
affecting and influencing other decisions.

It has been shown that earth mass behind sea walls works well to absorb wave energy. The constructions to maintain this backfill—such as slabs and smaller secondary walls and walls which divert overtopping water—make the sea wall more three-dimensional. (Figure 51) This gives the defense spatial qualities and creates fortuitous physical components of the built landscape.

What is being suggested is an actual integration of the primary protections within the territory of the building. Since the design and construction of the primary protection is an extension of the ground itself this ground can work its way into the building and may also become a strong organizing and aesthetic factor in the building's design.

For example, this attitude could lead one to pull some of the counterforts well back from the sea wall. These counterforts could then become part of the building. This practice, besides having unique and appealing architectural qualities, would
in effect strengthen the building itself. Since they are at approximate right angles to the sea, and since most buildings are oriented to it, these counterforts could serve as effective shear walls within the structure, and provide additional strength against both lateral and uplifting movements.

The level changes from the slab or patio as a secondary defense can be used to good advantage by incorporating these ground forms as integral elements in the definition of space. Similarly, the small garden walls which have been suggested for use in diverting overtopping and uprushing water can serve an additional function in terms of providing territories and zones of containment.

The essential presence of a primary defense can initiate and evoke responses and reactions to them. The varieties of ways of interacting with these forms, defenses, secondary protections, slabs, garden walls, and level changes, all offer opportunities of playing additional roles and can accommodate many different decisions. If one thinks of these man-made forms as part of the physical context, it would enrich the environment which
is built there. The shore embodies the concept that component parts participate with each other to form constant and necessary equilibriums. To extend this coastal zone dynamic and co-operation to the designers' attitude would make his or her other decisions sympathetic to the shore and to the buildings they place within that zone.

The building which is to be built has an opportunity of working co-operatively with the landform and the physical built ground. The building, made up of its component parts, can function together to absorb the forces of the shoreline environment and the severe forces and stresses it is subjected to. Awareness to the fact that a different approach to the building and its site is essential. Consciousness of the site and the structures and constructions to be placed there may be integrated in a secure and aesthetic manner.

There are a few locations where the type of building and foundation may want to be raised off the immediate ground. This is the philosophy of stilt construction. However, stilt construction is usually for
seasonal structures whose lives tend to be short. Two types of locations may warrant stilt construction—beaches which are barrier bars and highly prone to either erosion or large waves, or those places whose elevations are not high enough above sea level. At times these are easily recognized by sea walls which have been built higher and bigger from storm to storm. These places are distinguishable because the natural topography is not high enough to be able to backfill a seawall sufficiently. The sea wall sticking out of the ground is an obstacle between the ocean and the marsh. An example of this situation is Minot Beach in Scituate where a monolithic sea wall has been rebuilt 18 times since 1931. Besides the ridiculous expense of walls like this, they virtually cut off the ocean from the people who live there. Types of buildings which could endure storms, floods and ground migration and allow direct access to the beach are those that could be elevated up on concrete posts and beams. (Figure 54) These can be precast and assembled at the site or poured in place. These columns and beams would be large and
Figure 54.
just a few could support the structure. A strong footing under the column carrying the concentrated load would be necessary and should be placed at a depth considerably lower than the frost line and lower than the maximum erosion possible.
Summary

The aforementioned information implies certain problems for the design of the primary defenses. The first defense must be strong and durable and not susceptible to decay from salt water or marine bore. The toughest and most durable material is reinforced concrete, which has excellent resistance to the compression, tension, frost wedging and shear strain to which it will most certainly be subjected. This first wall must have a footing with a means of controlling scour at the toe in the form of sheet piling or an extension of the footing itself. This concrete toe protection must reach at least a depth equal to the maximum height attained by an unbroken wave at its most extreme height.

Where the wall ends, there should be a return somewhat perpendicular to the shoreline to divert the oncoming water well past the wall and any other structures requiring protection from erosion. This first wall would be sound if it were a minimum of 18"
to 20" thick with well placed horizontal and vertical steel reinforcements.

The inland side of the seawall must be backfilled and all precautions for the maintenance of this fill should be taken. A 6" concrete slab will work adequately, as will sheet piling placed in the ground. If a slab is to be used, wire mesh and re-bar should be incorporated to maintain its integrity. The edges of the slab must be protected from undercutting, which can be accomplished by edge walls or garden walls.

Protection against the effects of wave overtopping by secondary wall defenses is extremely advisable. These walls are small in comparison to the first. The amount of wave overtopping differs dramatically with each location and local decisions will determine the wall size. Anywhere from a couple of feet to as much as four feet is not extraordinary. The depth below grade of these walls is also important to maintain them from erosion. This overtopping water should be diverted either back into the ocean or around the protected building. If back wash is a factor, then measures to avoid this action
should be implemented, such as garden walls on the inland side of the building. To augment the secondary defenses the building's first floor should be raised and shielded by a front wall or small cassion of poured concrete. (Figure 52) This would protect it from any water that does come over the secondary wall. Wind blowing water inland can make the first two walls useless in which case the foundation of a building becomes a defense.

The choice of foundations is an option. Either let the water flow under and through or impede its flow but mixing philosophies is a mistake. If poured concrete is not used, then every sound and durable construction precaution must be taken.

Anchorage of the superstructure to its foundation is paramount. The concept of too much anchorage for buildings on the coast does not exist. Extra care in the framing of the building to counter extreme lateral, horizontal and uplifting forces is necessary. The framing must counter the forces of racking and shear failure. Plywood for subfloors and plywood shear panels as sheathing in
excellent. Diagonal bracing works well also. Diagonal bracing for post and pier and pile construction will prevent movement and deformation.

Adjunct spaces should, wherever possible, be an extension of the major framing. If that cannot be accomplished, then the way in which it is connected warrants close attention. Metal straps and carriage bolts should be used. The shape and form of these spaces is dependent on local conditions and the forces it will be subjected to. Lightweight overhangs and railings should be overbuilt.

The buildings' exterior material can be conventional. Synthetic siding does not fair well on the shore. When a section of this type siding fails, it has a tendency to roll back and off. Shingle siding should be nailed well and only four inches should be exposed to the weather. This assures that each shingle will have three sets of nails in them and good layment. Vertical and horizontal siding should also minimize the exposure to weather by maximizing the overlap and use more nails or screws than
normally.

Glass windows that are exposed to water and stones coming inland should be a minimum of 1/4" plate for small openings and correspondingly thicker for larger openings. Doors facing the ocean should swing out. This assures that forces against the door will be absorbed by the jamb and frame and not the hardware.

Roofing material should have adhesive put along the edges of the overlap, thus minimizing the exposure to the weather and increasing the materials' ability to stay down.

An additional old time technique for excellent protection is the use of storm shutters for windows, doors or any other openings.

Awareness of the site, understanding of the local conditions, and respect for the shoreline is a good beginning point. The construction of a primary sea defense should at once be sympathetic to the landscape and also offer protection from the high energy waves. Guaranteeing the maintenance and integrity of this wall is next. Secondary defenses and diverting control of overtopping
and run-up water follows. A well-thought out and thoroughly constructed foundation, preferably of reinforced concrete with serious concern for anchorage, is essential. The construction and framing of the superstructure should be able to withstand considerable horizontal, impact and uplift forces. The materials used should be preserved against the elements of shoreline decay, and the attachment of these materials should be done with care and precision. Special care in the construction of adjunct space is important, too. Moreover, these spaces should be viewed as buffer zones protecting the major building. Doors and windows must be able to withstand extraordinary attack, impact and weathering.

If the suggestions in this paper are followed by and allowed to instruct the designer or builder, then maintaining a sound and durable building and assuring its survival on the shore is a probability. If these are taken for granted and taken lightly, a short stroll along virtually any coast that was hit by the Blizzard of '78 will alter that attitude radically.


