STRUCTURAL ASPECTS OF FOX POINT HURRICANE BARRIER

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The design and construction of hurricane barriers are new engineering fields that the Corps of Engineers has become engaged in and the New England Division is pioneering this effort. This is particularly true when considering the structural aspects. It was found on initiating the Fox Point Design, that we could draw on very little past experience in the design of hurricane resisting structures. Also, some types of structures that we have successfully used for many years on local protection projects, would not withstand the heavy wave loadings.

The starting task, therefore, was the development of the loading and structural criteria by which the design of the various structures could be accomplished. First the nature of the hurricane loading was examined. This is composed of the wind, naturally, and also some type of water and wave loading. It was decided after considerable research of the available information on wave loadings that Technical Report No. 4 (Shore Protection and Planning) prepared by the Beach Erosion Board contained the best information for our use. This is a voluminous report that has just been reprinted after being out of print for some time. This report contains methods whereby the forces from three principal types of waves can be computed. These are the broken wave, breaking wave and a clapotis condition where the wave does not break but runs up the structure.

Figure 1 shows the force diagrams for the latter two conditions which were the most prevalent ones used. The left hand diagram shows the force from a breaking wave against a structure such as the street gates. This is a loading derived from the so called Minikin formula. The large parabolic force application is something to contend with as you can see. This formula has long been considered on the over con-

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servative side and often results in members or structures unreasonably large. It also does not adequately cover approach slopes that are almost flat. However, as the structures in the barrier are highly critical and a structural failure in any element could mean the loss of the protection we were forced to use it even though it might be over conservative. As far as Fox Point is concerned the structures did not become unreasonably large. Some were large to start with. The effects of breaking waves on structures is a good field for a research project to improve the present limited data.

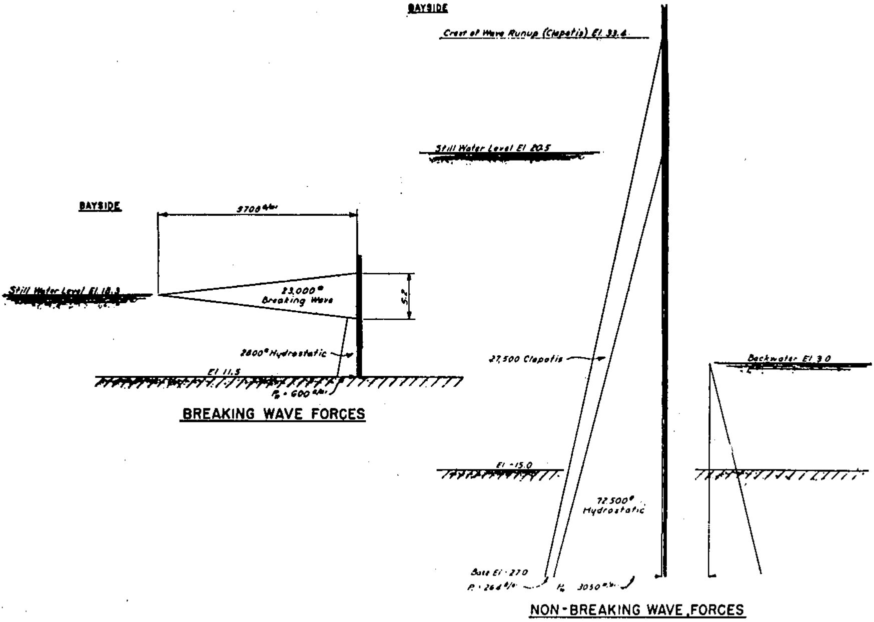


FIGURE 1.

The right hand diagram shows the maximum clapotis condition in the deep water. Here the stillwater is at the maximum design stillwater level of 20.5. The definition of clapotis is a deep water wave reflected from an obstruction, and the crest of the clapotis is the top of the wave. We might also say that it is the maximum run-up on the structure. The determination of this wave loading is by the Sainflou formula which is considered reasonably good.

The broken wave diagram is not shown, but is somewhat similar to the breaking wave but on a smaller magnitude and is a uniform force application instead of a parabolic one. The lateral forces applied to the structures are of considerable magnitude for all three cases. The question of when to use each of these type loadings is best answered by stating that in the deep water the waves will not break and the clapotis condition applies. When the stillwater level reaches the right depth where the wave will no longer sustain itself, it breaks and at that point the breaking wave force is used. Once the depth is such that the wave has broken, the use of the broken wave is obvious.

The next consideration was that of working stresses. In general, the working stresses set forth in the A.I.S.C., A.C.I. and in some instances the A.A.S.H.O., were used. When considering storm conditions and construction conditions the basic stresses were increased by $33\frac{1}{3}\%$ except for allowable pile loadings which were increased by 50 percent. The 50 percent increase in pile loading is arbitrary and it should be added that since the preparation of the design, test piles have been driven and loaded with at least twice the basic load before application of the increase, without appreciable deformation. As far as allowable unit stress in the steel bearing piles, the Boston Building Code value of 7500 lbs. per sq. in. was used for the compression piles and a value of about 200 lbs. per sq. ft. applied to the rectangular perimeter times the length was used in the determination of the tension for the tension piles.

Time will not permit a detailed discussion of the design of all the structural items composing this barrier so my remarks will be confined to the three principal structures. The first of these is the pumping station. The structure has been divided into four monoliths which was done principally to control shrinkage and expansion forces in the massive sub-structure and to also provide units that might facilitate the contractors work. These expansion joints do not go through the foundation mat which will be constructed as a single continuous mat approximately 214 ft. in length.

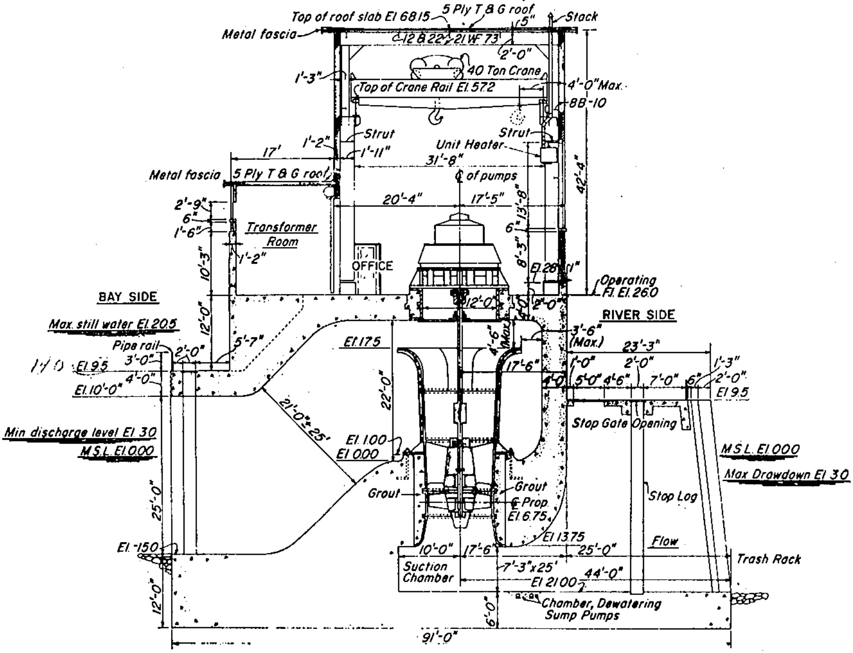
Figure 2 shows a typical cross section thru one of the pump bays showing the massiveness of the substructure. The presence of the platform at elev. +14.00 will trigger some waves so that they will break against the face of the structure.

There were six basic conditions investigated for stability.

Case I. The construction condition with just the dead weight of the structure and no lateral loading.

Case II. A storm condition using a breaking wave on the bayside and tailwater on the riverside at +3.0.

Case III. Also a storm condition using maximum wave with clapotis at elevation +33.3. A 30 lb. wind on the superstructure and tailwater at +3.0.



FOX POINT HURRICANE BARRIER

PUMPING STATION

FIGURE 2.

Case IV. Same as Case III, except the tailwater at elevation —3.0.

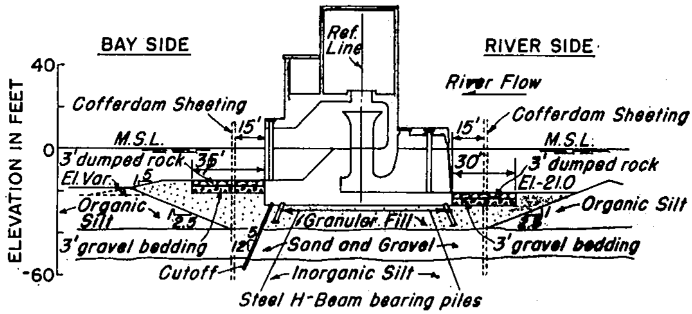
Case V. The normal everyday condition.

Case VI. An earthquake investigation as applied to the normal condition.

The stress analysis of the substructure was accomplished principally by analyzing a series of longitudinal sections and designing them as continuous frames. The superstructure utilizes built up steel columns stepped back to accommodate the crane brackets. The roof is a concrete slab on steel purlins framing onto the steel bents.

There is a deep band of inorganic silt overlaying till, beneath the structure which becomes fluid like quicksand when disturbed. It was decided we could not found any of the structures in this material or the material above for fear that future operations in the area might disturb the silt and cause our structures to settle.

Figure 3 shows a cross section through the pumping station show-



TYPICAL SECTION AT PUMP STATION

FIGURE 3.

ing the bottom treatment under the station. Heavy steel H piles were selected over concrete piles principally because of the necessity for battering them and because they would cause less disturbance of the inorganic silt when they were driven.

Figure 4 shows the method of analysis used for the steel piling. As can be seen the large horizontal forces require an arrangement of batter piling in each direction. This is an elastic center analysis known as the Vetter method which divides the piles into groups, substitutes a dummy pile for each group and graphically finds the elastic center of the groups. The resultant of the horizontal and vertical forces is then plotted. Basically it is then the old $P/A \pm Mc/I$ formula where P is the vector force in the direction of each batter group where M is the force times the distance to the elastic center, c is the measured distance between any pile and the dummy pile, and I is the polar moment of inertia of the piles about the elastic center. It was found that the maximum compression pile load is 252 kips, there were no piles in tension and that there would have to be 532 piles required for the pumping station. The piles are BP 14 89 lbs. and will be 70 to 80 ft. in length.

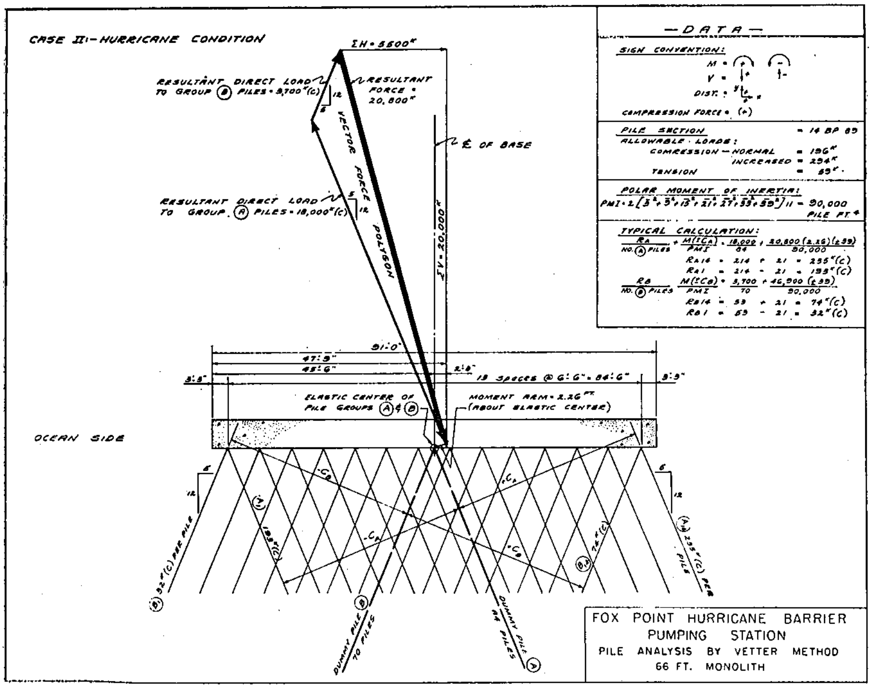
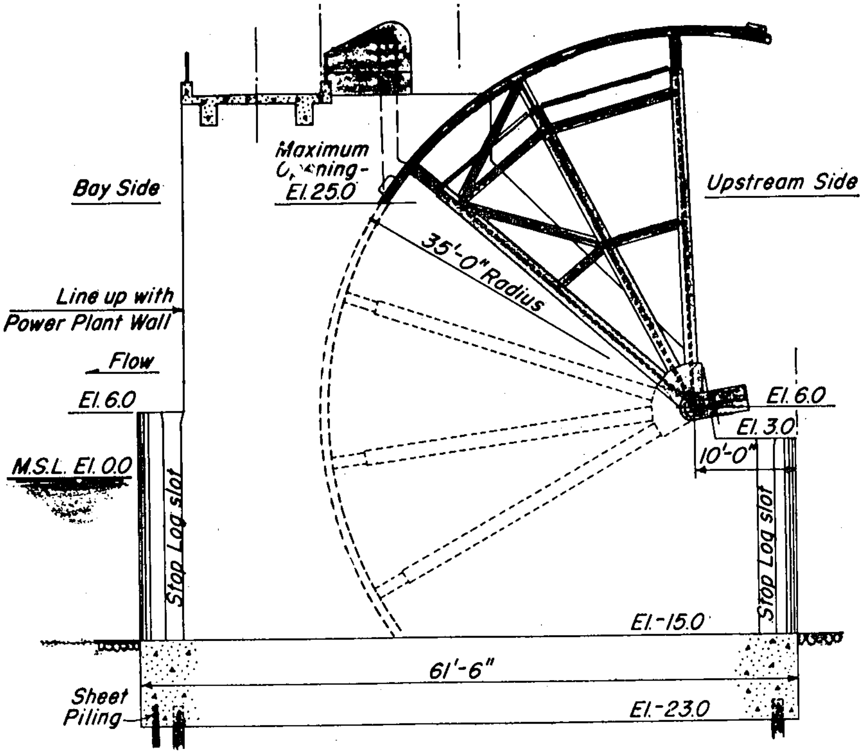


FIGURE 4.

Figure 5 shows a cross section thru the river gates. There are three 40 ft. wide tainter gates which when in a closed position block the river from elev. +25.0 to —15.0. The side frames are inclined in order to reduce moments in the longitudinal face beams. The skin plate will vary in thickness from 3/8″ to 1/2″ and spans between vertical tee sections. The anchorage of the gate will be accomplished by using a post tensioned system of rods where under no condition of loading will the concrete under the thrust girder be in anything but compression. Tensioning will be accomplished at the thrust girder end and after tensioning the tubes will be filled with grout. The concrete in this area will be 4000 lb. concrete. This is an anchorage system recently adopted by the Corps for new projects and which has already been incorporated into several large projects. It is a great improvement over the old type anchorage which employed a steel grillage system carrying the gate thrust in tension down some distance into the pier.

This is a relatively light structure to be carrying the large horizontal loads applied under a hurricane condition. Here again systems of batter piling in tension or compression and analyzed by the Vetter method were used. The design of the base slab was a sizeable problem because of the light weight of the structure. The base slab was de-



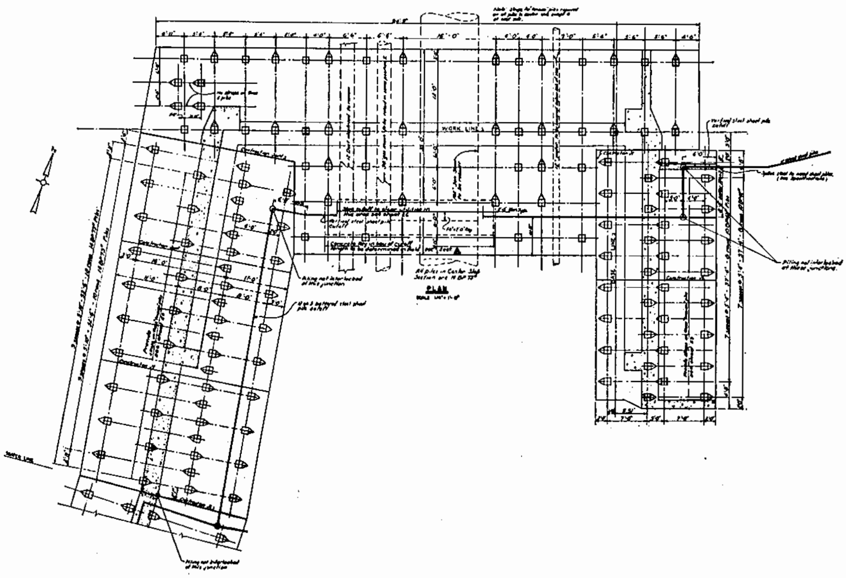
FOX POINT HURRICANE BARRIER

TYPICAL SECTION RIVER GATE

FIGURE 5.

signed as a series of longitudinal bands. The pile reactions and the piers were treated as loads on the bands. The slab will be 8 feet thick and will use No. 14s and No. 18s reinforcing rods to take care of the very high moments developed. The use of smaller size rods would have resulted in additional layers of steel at a close spacing and might have given considerable difficulty in placing the concrete. Lap splicing of the large bars has been eliminated and it will be accomplished by welding using the thermit type weld.

The street gate structure required to close off Allens Ave. and South Main Street also developed into major structural problems. At Allens Ave. where the clear distance between abutments is 67 feet, there had to be some type of gate structure developed that could be closed in as rapid a time as possible. Figure 6 shows the foundation



FOX POINT HURRICANE BARRIER
ALLENS AVE. STREET GATE
FOUNDATION PLAN
FIGURE 6.

plan of the Allens Ave. gate. The wave application is at an angle to the gate and the shape of the center monolith crossing the roadway is worth noting. The Tee shaped section was selected so as to eliminate the wing wall projections which are at right angles to the gate. If the wing walls had been made a part of the gate section there would have been wave forces in two directions making the pile analysis considerably more difficult. By this arrangement all the wave forces on the gate are directly up the street in the case of the center slab and normal to the wing walls for the side monoliths. This makes the resultant force parallel to the pile groups although not necessarily concentric with the group and makes the analysis readily computed.

Figure 7 shows two elevations of the gate framing. There are

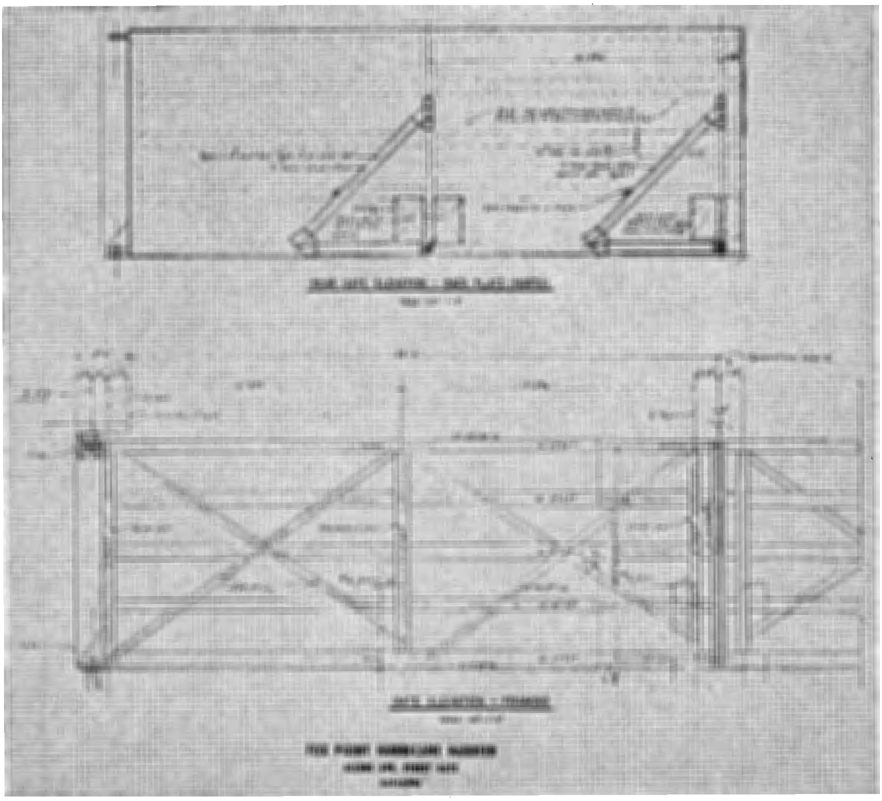


FIGURE 7.

five horizontal beams required to transmit the wave forces into the A frames and the abutments. The skin plate is 9/16″ thick hi-strength steel and frames to the 16″ WF horizontal members. The lower hinge will take the weight of the gate and the upper hinge the pull when it is being swung. The A frames are shown here as folded back against the gate as they will be when in the stored position. When the gate is pulled out into the road the A frames swing out and are fastened down to a weldment in the road as shown on Figure 8. The tie down bolt at the gate is hooked into another weldment in the road and brought up tight. In addition, jacks contained in the gate are screwed down onto the sill taking the weight off the hinges. Although this is a heavy gate, each leaf of which weighs 10 tons, there are few assembly parts to be fastened at time of use and with proper training of crews, the gate should be in place in short order.

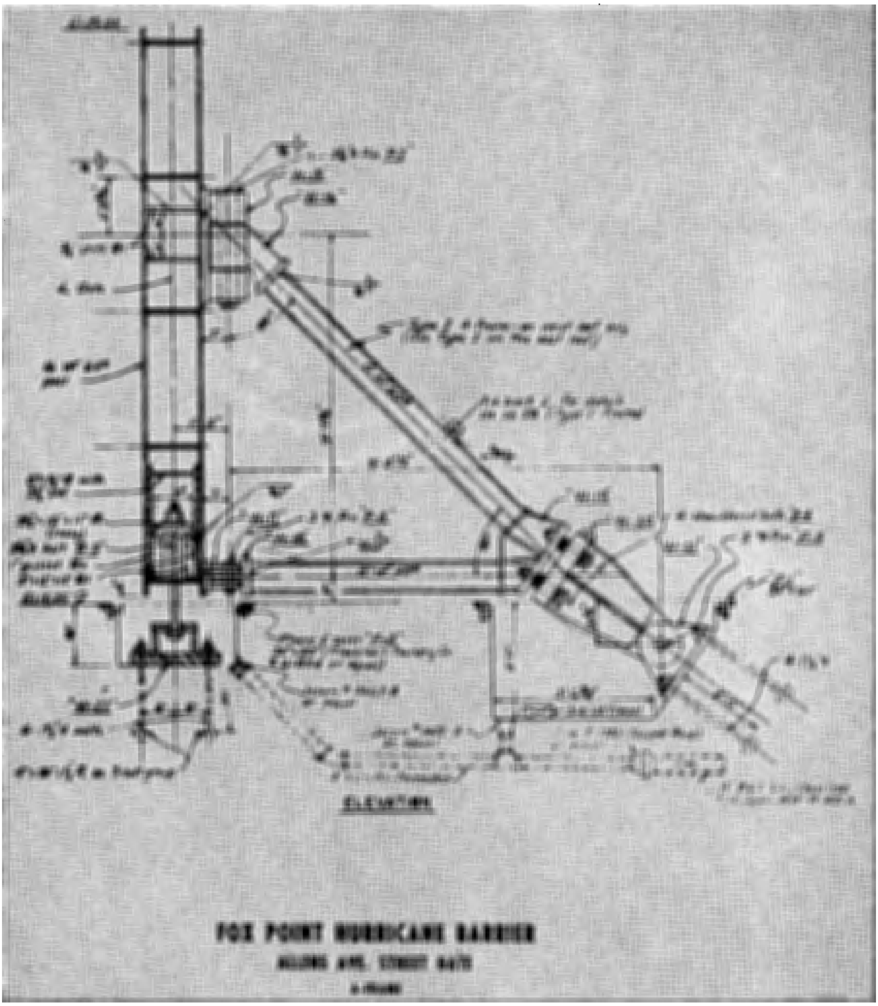


FIGURE 8.

In closing it should be stated that this first hurricane design was a challenge structurally. The wave loading and criteria developed and used are considered sound and the type and shape of structures selected such as the street gates are considered adequate to resist the battering they could receive from a hurricane. It should also be stated that our present projects are even more of a challenge but we expect to improve several of the features, such as street gates so that the closing time can be reduced to an absolute minimum.