

CHAPTER 143

DESIGN AND CONSTRUCTION OF HUMBOLDT JETTIES, 1880 to 1975

by

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ABSTRACT

In the Chief of Engineers annual report of 1877, it was concluded that "The only way...in which a safe entrance could be obtained into this harbor would be by the construction of two parallel jetties, of very heavy stone, about 500 yards apart, from the north and south spits at the entrance."

In 1882, a special Board of Engineers concluded that the "occupation of the south breaker spit by a structure...carried to low water and running from the south head (spit) in a north-westerly direction..." be built. Construction of the south jetty began in 1889 and of the north jetty, subsequently authorized, in 1891.

Due to the severe wave action, a number of rubble-mound construction techniques including stone, concrete cubes, tetrahedrons, and finally dolos armor units have been used. A description will be given of the construction and associated results. Experience with the reinforced and unreinforced concrete dolosse units will also be discussed.

INTRODUCTION

A 19th-century Corps of Engineer report contains a description of the Humboldt Bay entrance area by the San Francisco District Engineer as follows:

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"It has been reported by masters of vessels that no such heavy seas have been encountered elsewhere in the world, unless perhaps south of the Cape of Good Hope and Cape Horn. Waves have been seen to break in 8 or 10 fathoms of water. It was originally believed that no jetties or such construction could possibly withstand the forces brought to bear by waves during storms, so that the improvement was undertaken with great misgiving."¹

A very vivid description indeed of the severe wave conditions encountered by navigators and those engaged in attempting to provide a stable entrance to Humboldt Bay.

The Humboldt Jetties are two of the oldest manmade structures on the Pacific coast subjected to extreme wave attack. Inasmuch as these structures have been constructed and maintained over a long span of time and have used a variety of design and construction techniques, they represent a significant coastal engineering case history. The material presented here represents a summary of all known information on these jetties; however, any additional information on this subject from readers of this paper would be welcomed by the authors.

GENERAL DESCRIPTION

Humboldt Bay, a land-locked harbor on the coast of Northern California, is about 420 kilometers (225 nautical miles) north of San Francisco and about 290 kilometers (156 nautical miles) south of Coos Bay, Oregon. The entrance is protected by two rubble-mound jetties, which are about 0.7 kilometers (0.5 mile) apart and extend from the ends of two long and narrow sand spits separating the bay from the ocean. The width of the bay varies from 0.8 kilometers (0.5 mile) to about 6.5 kilometers (4 miles), and the length is 23 kilometers (14 miles). The southern portion of Humboldt Bay extends about 6.5 kilometers (4 miles) south from the entrance, widening gradually from 0.8 kilometers (0.5 mile) to 3.6 kilometers (2.25 miles) in width. A dredged channel extends for some 3 kilometers (2 miles) from the entrance to Fields Landing, which lies about midway along the east side of the South Bay. Humboldt Bay is shown on Figure 1.

The entrance is dredged to a 12.2 meters (40 feet) depth. Inside Humboldt Bay north of the entrance, a fairly deep natural channel closely follows the north spit. A 10.7 meters (35 feet) channel is dredged for almost 3 kilometers (2 miles) along the waterfront of the City of Eureka.

The tides are semidiurnal with a range between mean lower low water and mean higher high water of 1.95 meters (6.4 feet) at the south jetty and 2.04 meters (6.7) feet at Eureka. The entrance channel is exposed to high waves generated by local coastal storms accompanied by high winds, and to high waves or swell produced by offshore, distant, Pacific Ocean storms, unattended by high winds. Both types of waves generally occur during the period from November through April

with the critical area of approach being from southwest through northwest. More detailed information on Bathymetry and wave climate is given in Magoon and Shimizu,² and in model studies by the Waterways Experiment Station in Vicksburg, Mississippi, U.S.A.³ There is also a paper on channel shoaling by Noble.⁴

The initial Federal investigation of Humboldt Bay looking toward a possible improvement of the entrance by jetties was made in 1878.⁵ This report states:

"This bay affords fine shelter after vessels have once got into it, but it is a bar-harbor, the bar being composed of shifting sands, with heavy breakers even in moderate summer weather.

To give an idea of the great height of waves rolling over this bar, we will state that when the Board of Engineers for the Pacific Coast arrived off the bar, in the Coast Survey steamer Hassler, the weather was very moderate, with only the usual summer wind from the northwest, yet, although there was 20 feet of water on the bar at the time, the pilot refused to take in the Hassler, drawing only 12 feet of water at the time, stating that he could not do so without running the risk of the vessel striking bottom and her possible loss in the breakers.

The shores on both sides of the entrance are low and sandy, and there is no stone in the immediate vicinity.

The only way, as it appears to the Board, in which a safe entrance could be obtained into this harbor would be by the construction of two parallel jetties of very heavy stone, about 500 yards apart, from the north and south spits at the entrance.

If such jetties were built, the very large area of the inner bay would probably afford sufficient tidal prism to keep open a deep channel over the bar, against all drifts from the action of sea-waves. But such construction would be attended with immense difficulties and enormous expense. It is a question even, with the members of the Board, whether such construction would be physically possible, and one, too, upon which we dare not express an opinion without a searching examination of all the contingencies upon which the stability or instability of such works would hinge. We have not, therefore, made any plan or estimate of cost for a breakwater at this place, deeming it, if not impossible of execution, highly improbable that a breakwater or jetties will be attempted here at the present time."

This report correctly identifies the major problems that have continued until the present: "shifting sands", "high waves", "lack of stone in the immediate vicinity", and lack of understanding of structure stability. The report also notes that if two jetties could be built, there would probably be sufficient tidal prism to keep the jetties open.

Jetty layout and construction on the Pacific Coast is mentioned by Symons⁶ in 1893 who indicates that the Humboldt Jetties were designed to be high tide jetties and that their construction was similar to that at other Pacific Coast harbors, but was "done by single broad gauge track" rather than the double narrow gauge track. He also expresses his desire to see the construction of a "single curved jetty, concave to the channel, instead of a pair of nearly parallel jetties, with the hope that a good and satisfactory channel would be developed, as along the concave bank of a river." The concept of a single "reaction breakwater" which would develop the potential energy of the ebb currents, rendering them kinetic, and applying them locally on the crest of the bar where they are needed for scour was discussed in detail by Haupt in 1899.⁷ Perhaps because of the above subsequently stated interest in the single jetty concept, the Chief of Engineers recommended the construction of a single jetty at the Humboldt Bay south spit—a low enrockment (rising to the level of ordinary low water) of rubble stone. A length of 6000 feet and a depth of 6 feet were assumed to be necessary (73,000 tons of stone) in addition to "an enlargement of the sea head" and beach and shore protection (17,000 tons of stone). The report also notes that from 1851 to 1882, the entrance channel had varied in width from 2200 to 4200 feet and in depth from 21 feet to between 10 to 12 feet.

INITIAL CONSTRUCTION

The initial contract for construction of the south jetty was let in 1888.⁸ By 1890 it was realized that the southern end of the north spit was eroding rather than holding firm and providing a deep entrance. The Chief of Engineers Annual Report of 1891⁹ states:

"In October, 1890, a Board of Engineers was convened to consider and report upon a project for the improvement of Humboldt Bay. The board met at Eureka on December 11, 1890. After study of the subject, it was decided to modify the existing project so as to embrace shore protection work on the north spit, and the construction of a jetty starting from there and running seaward nearly parallel to the jetty on the south spit, both jetties to extend out to the 18-foot contour and be raised to the plane of high water, thus confining the tidal flow within definite bounds and securing the full benefit of its scouring capacity."

It was also apparently concluded that the jetties would have to extend to "high water."

By late 1891 an additional contract had been completed, and the south jetty was about 4000 feet long, and the north jetty about 1500 feet long. This latter contract used 28,000 cubic yards of brush mattresses and 100,000 tons of stone.

The jetties were built from a timber trestle which was constructed with an overhanging pile-driver revolving on a turntable. The trestle

consists of four-pile bents sixteen feet apart supporting two standard gauge tracks of forty-pound T rails and is designed to last only long enough to complete the jetty beneath it. A typical pile bent is shown in Figure 2.

Filter material used was a layer of brush mattresses approximately forty-four feet wide.

"A mattress is built upon two piles swung under the trestle by wire cables made fast to the cap timbers. First is laid upon these sling-piles a grillage of poles bound at every intersection with strong wire. Upon the grillage are placed in successive layers bundles of brush about twelve feet long, the bundles in each layer being at right angles with those of the next. When the brush has a thickness of about six feet, another grillage is placed on the top. The two grillages are made to compress the brush to two-thirds of its original volume by means of long screws extending through the mattress. The grillages are then bound together by numerous wires, previously brought up through the brush from the bottom. The screws are removed, and the mattress is ready.

Cars filled with small rock are brought, and a layer of stone is thrown by hand upon the mattress to serve as ballast. Six men are stationed on the cap timbers. They stand with uplifted axes ready to cut the lashings and free the cable ends. Others stand by the car doors ready to release the rock. The word is given. With a cracking and a crash, the mattress strikes water. In a second a rattling volley of rock drives it out of sight to the bottom."⁸

These jetties resulted in a fixed channel, at least 700 feet wide and 25 feet deep until 1905. As the jetties deteriorated from lack of maintenance, the channel shoaled and by 1907, the outer ends of the jetties were completely buried in the sand.

REBUILDING OF JETTIES

Between 1911 and 1915 the south jetty was reconstructed. Between 1915 and 1925 the north jetty was rebuilt. The new jetties were built on the foundations derived from the old structures. Due to the inability of driving piles for a new trestle through the old stone "foundation," the new structures were built by the "cap method." The crane that was used has a capacity of 20 tons at a 35-foot radius, with a maximum reach of 50 feet. The crane operates in a 17-foot gauge track, placed on wooden ties imbedded usually in about 18 inches of concrete cap. In the original reconstruction, no parapet stones were used on the jetty.

"The concrete cap method has proved a success. While used as an incident of construction to prevent the tracks from being washed away,

it was found, as anticipated, to retard the action of the sea in tearing down the jetty structure. The average cost of the concrete cap, 22 feet wide and 18 inches deep, was about \$20 per linear foot, including tracks and foundation of stone. No forms were used after 1914.

The plant for concrete mixing consists of one standard-gauge flat car and a Foote batch mixer of 21-cubic-foot capacity, end discharge, and steam-operated. The concrete is placed by a foreman and four laborers, the regular stone unloading crew. A section of this concrete cap is usually built in two hours, including the leveling of the foundation and placing of ties and standard-gauge rails. Difficulty is experienced during rough weather in protecting fresh concrete from being washed out by the waves. This condition was improved by placing a parapet of larger stone seaward of it, and covering the fresh concrete with canvas and boards weighted down with old rails.

When the south jetty was completed in 1915, a concrete monolith weighing about 1,000 tons was built at the end for the protection of the jetty head, the most exposed and vulnerable part. The concrete block was 30 by 30 by 14 feet, with the base at five feet above mean lower low water. It is reinforced with old 60-pound steel rail made fast with old cables and U-bolts. When the work of reconstruction was completed, the depth of water at the sea end was 31 feet, instead of 18 feet as before. The bottom of the block was laid at about high-water elevation. The top of the block was at an elevation of 19 feet above low water. The concrete block has proved a success in protecting the sea end."

The next phase of construction of the north jetty began in late 1915. Armor stones were from 6 to 20 tons and the larger stones were placed in the upper layer on a slope of 1 on 2 on the exposed side and 1 on 1-1/2 on the protected side. The crest was raised to about 19 feet above mean lower low water, and a reinforced concrete monolith 32 feet wide, 14 feet thick (above high water), and 32 feet in length. Steel reinforcing consisted of old railroad rails. Seaward of the monolith a 7 foot thick by 32 foot wide by 30 feet long slab was placed, and large stones were placed around the slab and monolith. A typical section of the north jetty is shown in Figure 3.

LATER CONSTRUCTION ACTIVITIES

Due to the adverse sea conditions at the site, floating equipment could not be utilized for construction or repairs of the jetties, thus all work was conducted from the jetty crest. With these limitations the sizes of stones or shape that could be placed in the jetties were limited to the capacity of the available equipment or additional other methods were improvised to place larger armour protections. Generally, the structures could not be built from the seaward toe upward. Prior to 1970, the weights of stones and shapes were limited to about 20 tons. Since units of sufficient sizes to provide the required protection could not be placed effectively, the jetties at Humbolt Harbor have required constant maintenance during the past years. Sources of

stone over the years have been generally located in surrounding areas of fairly close proximity, however, stone has been brought in from as far away as Oregon. A record of the maintenance work conducted at the jetties is presented in Table 1 at the conclusion of this report.

The north and south jetties were completed to their full lengths in 1925 and 1927, respectively. During this period the parapet wall was constructed and the concrete cap was placed on the crest of the jetties. Concrete was also placed on the channel-side slope of the jetties to hold the armour stones together.

When construction was completed, the side slopes of the jetties were approximately 1 vertical to 1.5 horizontal with a crest width of approximately 20 feet. The elevation of the crest varied from about 12 feet to 19 feet msl at the seaward end. The parapet walls were located on the south sides of the jetties and were about 4 feet in height and 6 feet in width. Above msl elevation the armour stones of the side slopes were imbedded in concrete. The parapet walls were located on the south sides of the jetties due to predominant waves from the southwesterly direction and the wide channel being approximately 3,000 feet in width.

Emergency repairs and periodic maintenance works were required during 1930 and 1957. Primarily, work consisted of using mass concrete to fill the eroded areas in the crest and imbedding the armour stones on the side slopes and the replacement of armour stones in areas that were breached or washed out. To provide the necessary protection, concrete blocks weighing over 100 tons were used as early as 1932. These blocks measured 11 by 11 feet and were cast on the crest at the site of the repair work on greased or oiled sheet board. The jetty side of the sheet platform was picked up and the blocks were launched by compressed air into washed-out areas of the slope. Actual placement of these blocks could not be accomplished due to lack of equipment that would handle these size units. It should be noted that many of these 100-ton blocks broke when they hit the water. They did not appear to break as often, however, when they struck other blocks or stone. In the 1930s and 1940s 12-ton tetrahedrons were also used for repairs. These units were considerably smaller than we would now consider stable.

During the winter of 1957-1958, severe storms deteriorated the north and south jetties to such an extent that repair work constituted a major construction project. The repairs of the north jetty commenced in 1960 and were completed in 1961. The south jetty was repaired during 1962 and 1963. The trunk portions of the jetties were repaired by mass concrete and 12-ton stones were placed on 1 vertical to 1.5 horizontal slopes in the eroded areas. The heads of the jetties were varied to about elevation 25 feet. Construction of the heads was accomplished by using 20-ton blocks for perimeter forming and placing mass concrete within block forms. The concrete was reinforced with large reinforcing bars and track rail. The heads were protected with 12-ton stones placed on 1 vertical to 1.5 horizontal side slopes with a cover layer

of 100-ton cubic concrete blocks. Most of the 100-ton blocks were washed away during the winter storms of 1964-65. Both the north and south jetties progressively deteriorated due to wave action. By 1970 the heads of the jetties were totally destroyed and another major rehabilitation work was required.

Extensive model studies were conducted for this rehabilitation work. Various concrete shapes were investigated. The adopted design consisted of placing 42 and 43-ton dolosse on 1 vertical to 5 horizontal slopes against the heads of the jetties. The placement slope was dictated by the existing conditions around the jetty heads which were covered with stones and concrete blocks from the jetties. The dolosse were to be placed a maximum of 230 feet from the heads of the jetties in two layers, placed at random with 11 dolosse per 1,000 square feet of slope area. The dolos units were to be placed from the toe to the head in two layers.

The rehabilitation work² on the south jetty was accomplished in 1971 and the north jetty in 1972. The Model VC 4600 Monitowac Crane, "Ringer," was used for the placement of the dolosse. Prior to construction, the Contractor made scale models of the dolos to study the placement of the dolos. Then the locations for each dolos to be placed to provide the necessary coverage were plotted and predetermined. The boom angle of the crane provided the distance from the head and the deflection of the boom from a given line provided the exact location for each dolos. The dolosse were picked up in the center of the trunk by a wide two-prong claw, lifted, the boom was moved to the deflection and lift angles, and the dolosse were lowered and placed. When placed the dolosse of the lower layer were positioned to locate the standing fluke seaward and the trunk in line with the direction of the waves where possible. The dolosse in the upper layers were placed and positioned to provide the greatest interlocking stability.

The dolosse have been in place for 5 and 4 years for the south and north jetties, respectively, and although there has been some breakage of the dolos units¹⁰ and settlement of perhaps 5 feet at portions of the south jetty head, the structural integrity of the jetties is not endangered.

The following tabulation presents a historical summary of the quantities of stone placed for new construction and maintenance (including concrete and special concrete armor units) from initiation of construction activities in 1889 to the present time. These records have been obtained from annual reports prepared by the Office, Chief of Engineers, U. S. Army, dating from 1891, and from early reports.

Table 1
SUMMARY OF NEW WORK AND MAINTENANCE QUANTITIES,
1889 - 1973

YEARS	NEW WORK		MAINTENANCE		REMARKS
	Quantity		Quantity		
	Stone (tons)	Concrete (c.y.)	Stone (tons)	Concrete (c.y.)	
1889-1899	1,150,000	—	—	—	North and south jetties, including shore protection.
1911-1921	855,713 ^{1/}	473	132,979	—	Includes provision of 950-ton reinforced concrete monolith at the seaward head of the south jetty in 1915-16.
1922-1931	196,393 ^{1/}	—	442,612	10,221	Includes reinforced concrete monolith at the seaward end of the north jetty, completed in 1925 and weighing 1050 tons.
1932-1941	—	—	10,340	68,729 (plus 43,853 tons)	Includes restoration of jetty ends with mass concrete and placement of precast concrete blocks on slopes.
1942-1951	—	—	—	40,693	Includes placement of 100-ton blocks on both jetties
1952-1961	—	—	34,205	3,142	Includes six 100-ton blocks
1962-1971	—	—	232,839	20,919	Excludes 225 20-ton concrete-form blocks, 116 100-ton concrete form blocks, 2,259 42- & 43-ton concrete dolosse & 5,257 20-ton concrete form blocks.
1971-1973	—	—	64,622	2,740	Excludes 2,533 42- & 43-ton concrete dolosse and 95 20-ton concrete form blocks.

^{1/}Although the major jetty rebuilding activities of this period were classified as "new work," the quantities could be considered as maintenance figures since the original jetty structures had long since been completed.

CONCLUSIONS

Engineering decisions made over a period of nearly a century by competent people in search of solutions to the Humboldt Bay entrance problem have shown that corrective actions are available and can be applied with an increasing degree of confidence given today's technology. The design of protective structures for severe wave climate areas such as Humboldt Bay is a difficult and challenging, but certainly not insurmountable, task.

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Figure 1. Humboldt Bay.

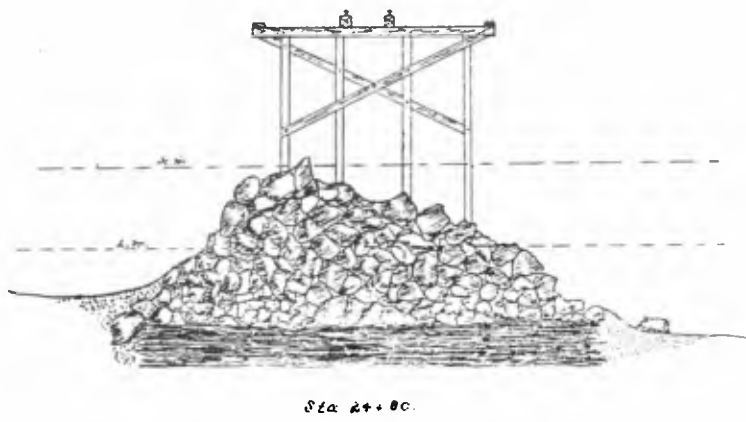


Figure 2. Typical pile bent.

The Military Engineer

Vol.



Figure 3. Typical section of the north jetty.



Figure 4. Jacoby Creek Quarry



Figure 5. Monitor at Jacoby Creek Quarry



Figure 6. Locomotive crane switching car—Jacoby Creek Quarry.



Figure 7. Hauling stone to ferry.



Figure 8. Landing stone at north jetty.



Figure 9. Typical pile driver.

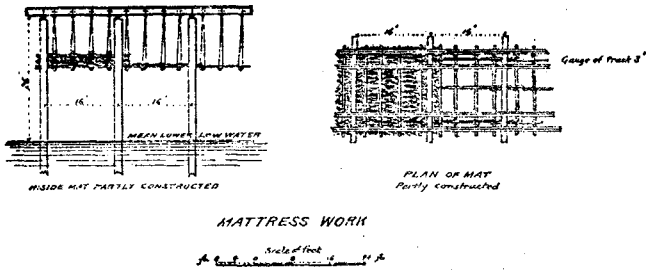


Figure 10. Construction of mattress.

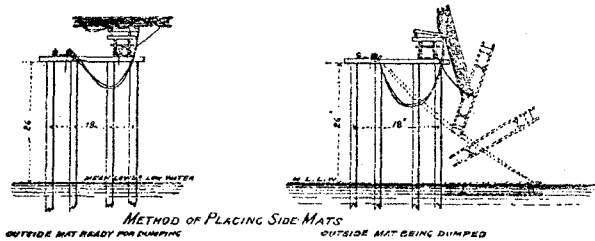


Figure 11. Placement of side mats.

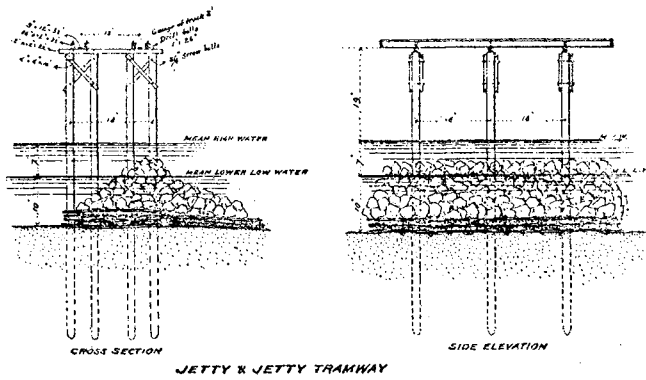


Figure 12. Jetty tramway.

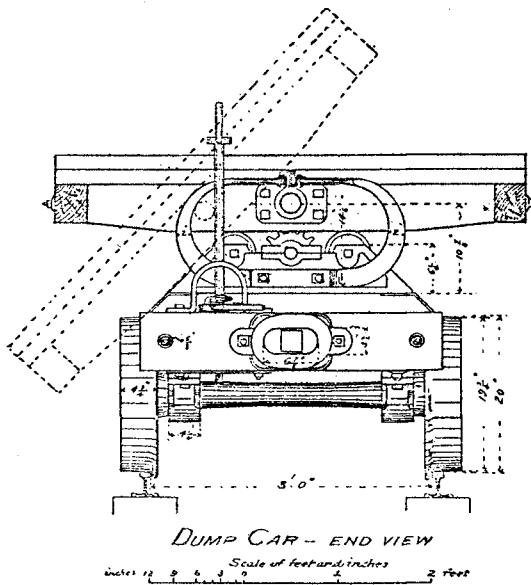


Figure 13. End view of dump car.



Figure 14. Constructing brush mattresses.



Figure 15. Compressing the mattress.



Figure 16. Dropping mattress.



Figure 17. Lifting stone.



Figure 18. Jetty construction.

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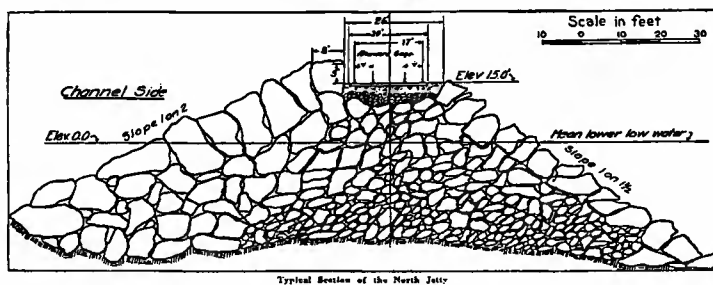


Figure 19. Typical section of north jetty with concrete cap.



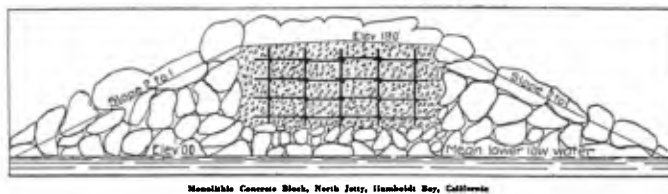
Figure 20. Placing stone from cap.



Figure 21. Truck delivery of stone and concrete.



Figure 22. Sea face of south jetty with 20-ton pre-cast concrete blocks (1932).



Monolithic Concrete Block, North Jetty, Humboldt Bay, California

Figure 23. Monolithic concrete block, north jetty



Figure 24. Monolith form blocks.



Figure 25. Pouring monolith.



Figure 26. Preparing to launch 100-ton cubes.