Construction Practices for Placing 48-Inch Precast, Prestressed Concrete Cylinder Piling in Deep Water

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The proposal to construct a structure across more than a mile of open water up to 80 ft deep was the beginning of an extensive engineering economic analysis to determine the type and length of structure to fit the site.

A composite I-beam structure 5655.5 ft long supported on a driven pile bent was chosen. The pile bents consisted of either 8 or 12 piles, with each pile 48 in. in diameter. Each of the 276 piles would be a prestressed, precast concrete cylinder piles. Soil borings indicated the length would vary from 25 to 176 ft. To withstand handling and driving, the wall thickness would be 5 in. with spiral reinforcing, stressing tendons and 8 No. 4 bars. Each of the sixteen $^{7}/_{16}$-in. diameter prestressing cables was tensioned to stress the 7000-psi concrete to 1100 psi. Driving specifications required the piling to be seated with 50 blows per inch by a 60,000 ft-lb hammer in Niobrara chalk. The contractor elected to cast the piling at the site.

The first method of pile placement used a three-finger jet to place the piling near chalk and a hammer to drive the pile into chalk. This method proved ineffective, and subsequently a single jet was attached to the pile and the pile jetted and driven simultaneously with the final seating for bearing after removal of the jets.

After each bent was driven the piles were backfilled with sand, Class C and Class A concrete. Some of the piles were driven a total of 7000 blows.

After the bents were completed, cracks were observed in the piling in January 1964. Inspection revealed 52 piles that would require repair. The damaged piles were opened up, cleaned and backfilled with dry-pack concrete, and a steel reinforcing shell was epoxied and bolted into place.

Successful use of these piles require a knowledge of the length to cast each pile and an accurate bearing estimation. During construction, proper supervision must be exercised to insure a sound pile.

•WHEN the U.S. Corps of Engineers planned the series of dams on the Missouri River in South Dakota, direct replacement at or near the original site was provided for all the existing bridges over the river except the Wheeler or Rosebud Crossing. At this site, the Corps provided a rerouting of U.S. 18 over the dam structure and considered it had fulfilled its obligation to the state. The state did not officially accept the crossing on the Fort Randall Dam as an adequate replacement for the Wheeler Bridge. In 1960, an appropriation was secured through the Corps of Engineers for the purpose of

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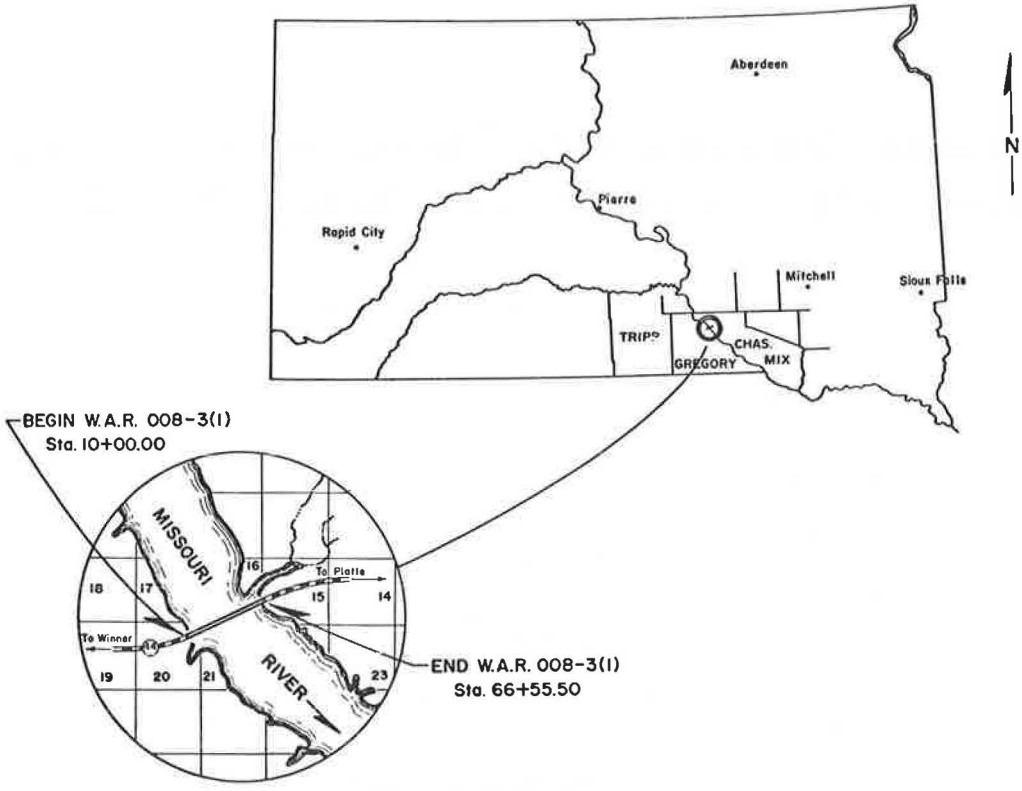


Figure 1. Project location.

constructing a bridge over Fort Randall Reservoir on a general line west of Platte. The South Dakota Highway Commission proposed that Route 44 cross Lake Francis Case west of Platte near the mouth of the Snake Creek (Figs. 1 and 2). The reservoir width at the proposed site is 5400 ft, with the water depth varying between 40 ft at the low water pool in winter and a maximum of 82 ft in spring and summer months. This water depth required a choice, based on an engineering economic analysis, between five types of construction: (a) conventional deep water construction utilizing man-excavated cofferdams; (b) use of tremie seal watertight removable forms; (c) use of precast concrete section piles filled with structural tremie-reinforced concrete without dewatering the form during placement; (d) use of steel shell forms left in place as in item c; and (e) use of prestressed pile piers driven to an anchor in the chalk.

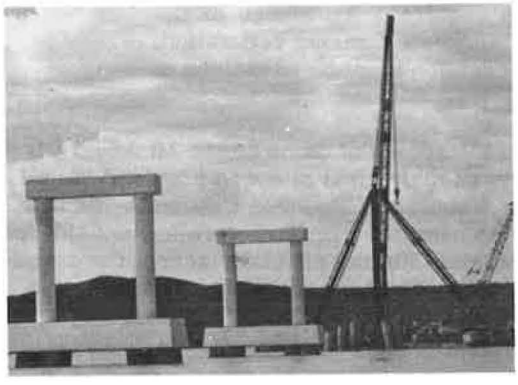
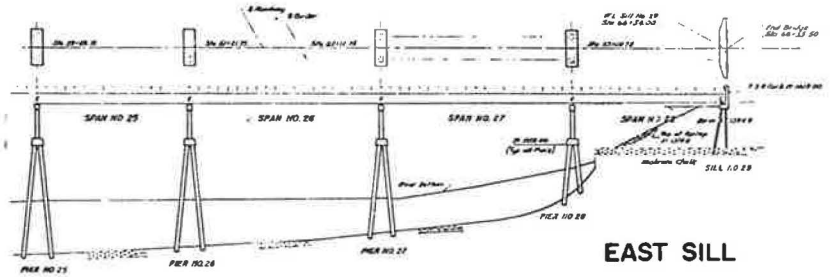
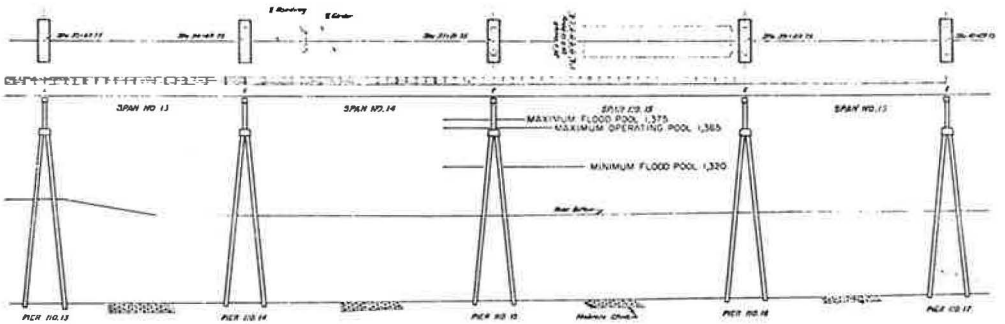


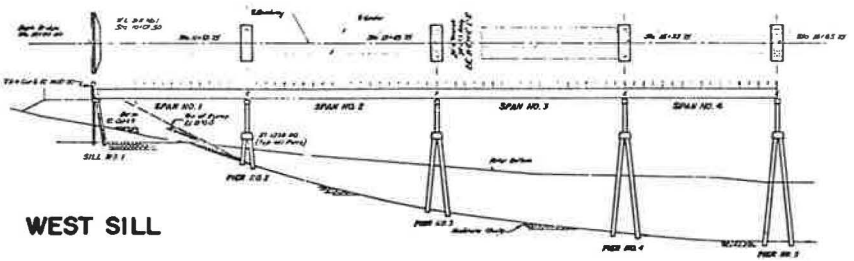
Figure 2. Stiffleg derrick working on Bent 19 with completed Bents 20 and 21 in foreground.

The state, after an intensive investigation directed toward securing the most economical structure, determined that a bridge could be build within the limits of the authorized amount. The structure would be a continuous deck plate girder bridge, founded on precast, prestressed concrete piles driven to refusal in the Niobrara chalk strata that underlie the reservoir. The structure length was 5,655.5 ft.





INTERMEDIATE SECTION



WEST SILL

Figure 3. Typical structure layout.

DESIGN CONSIDERATIONS

The following design data were assumed for this bridge (Fig. 3). The floor was to have an elevation of approximately 1411 ft and a level grade clear across the reservoir pool. The maximum operating pool given by the Corps of Engineers was 1365. Minimum operating pool in the winter was given originally at 1340, but was later lowered to 1320. The design bearing for the chalk to support the piling was 50 ton/sq ft. The major deviation from AASHO Standard Specifications was the ice load, which was set at 15,000 lb/lin ft of contact to be applied in either transversed longitudinal or quarterly in the direction with wind thrusts. This pile bent would require a stiffener cap at or near the average operating pool elevation with columns to support the plate girders for the roadway.

Driven Pile Bents

The design considerations resulted in two types of bents. The first bent has 8 piles; the second, 12 piles. The 8-pile bents (Fig. 4) were used in a combination of 5 piers with a span of 180 ft between each pier, coupled to form one continuous unit. The 12-pile bents (Fig. 5) were used in a combination of 5 piers spaced 225 ft to form a continuous unit.

On each bent, the stiffener cap was set at elevation 1358 and was 6 ft thick to form a footing for columns to support the I-beam unit of the roadway.

The unit on top of the footing would be similar to other structures of this type: the height being 26 ft; the column diameter, 4 ft; and cap, 4 ft thick. This design required a bearing capacity of 350 tons per pile. The founding material in the river was required to support this load on end bearing or distributed through the river alluvium by skin friction. The pile lengths were predicted on this bearing capacity and penetration data determined by a foundation investigation.

Pile Lengths

After establishing the bridge design criteria, the next step was to make a deep water foundation investigation. All sampling and testing operations had to be conducted from a drilling barge, as the water varied from 4 to 82 ft deep. A 25- by 100-ft barge was

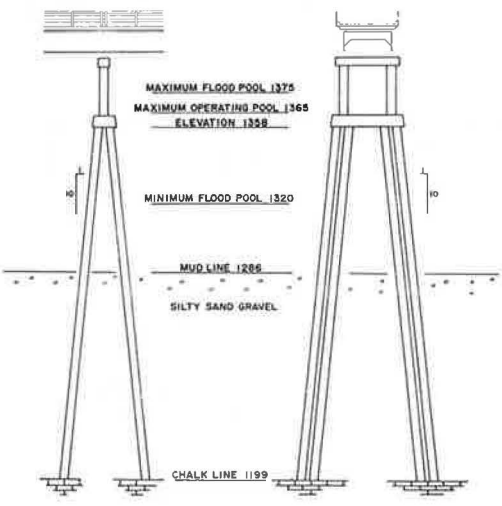


Figure 4. Typical 8-pile bent.

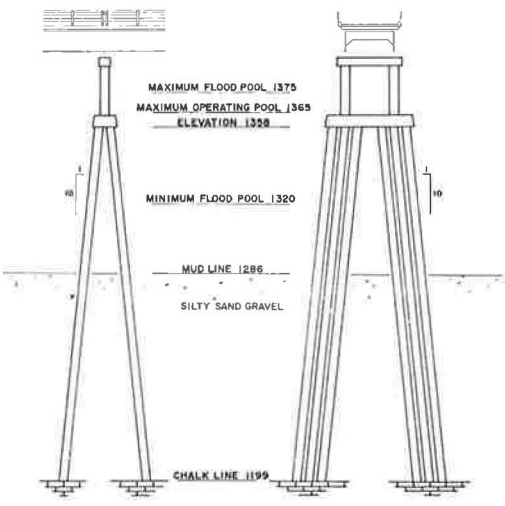


Figure 5. Typical 12-pile bent.

used as a drilling platform. A second barge was used to handle anchors, anchor cables, winch drums, marker buoys and miscellaneous equipment required to position the drilling equipment. Drive tests and wash borings were made to obtain undisturbed samples for laboratory analysis. Size analysis and unconfined compressive strength tests were performed in the laboratory and typical results were recorded on the plan and profile sheet (Fig. 6). Penetration resistance was measured as the number of blows required by 470-lb hammer dropped 30 in. to drive a $2\frac{7}{8}$-in. retractable plug sampler 1 ft. Skin friction was measured by a dynamometer as the number of pounds pull required to start the drill stem out of the hole. A second method of testing was wash boring to the Niobrara chalk and then taking a drive core sample. Twenty-four locations were tested.

Vertical control was based on the Corps of Engineers record of pool elevations kept at the power house in Ft. Randall. Horizontal control was maintained by triangulation from base lines on each shore. With limitations on the time allotted for the preliminary investigation, no attempt was made to place the borings on the centerline of each bent; instead, a regular spacing of the holes across the reservoir was made to determine the general subsurface geology at the site.

At first, difficulty was experienced in driving the drill stem, with the attached retractable plug sampler, to the chalk. This was attributed to the extreme water depth and the resistance presented by sands in the river alluvium. Five wash borings were put down using a positive displacement pump operated at 500 psi, and no difficulty was experienced in penetrating to the chalk. From these wash borings, it was determined that when the blow count reached 250 blows per foot a core could be cut with reasonable assurance that it would be in chalk. Most chalk cores were 4 in. long, and required 250 blows to cut and a pull in excess of 33,000 lb to extract the drill stem. Based on this subsurface investigation, the pile lengths determined for each bent varied from 50 ft on the east bank and 25 ft on the west bank to a maximum of 176 ft in the middle of the channel.

Pile Design

The foundation investigation indicated a need for a total of 37,764 linear feet of piling. The structure is supported on 276 prestressed, precast concrete piles, 48-in. diameter. Each pile has a wall thickness of 5 in. and is reinforced with $\frac{1}{4}$-in. spiral steel using a 2-in. pitch 3 ft from each end and a 6-in. pitch for the remaining length of pile.

Prestressing was provided by sixteen $\frac{7}{16}$-in. cables stressed to provide 1100 psi in the concrete section. To provide lateral stiffness 8 No. 4 rebars were added. Each pile was designed to be filled in 3 units: the L3 section, or the lower portion of the pile, was to be filled with sand; the L2, with Class C concrete; and the L1 section, 20 ft from the top of the piling, with Class A concrete. A reinforcing cage of No. 8 bars was used to tie the piling to the footing cap. All Class A concrete was required to reach 7,000 psi in 28 days. This was an unusual requirement for the Highway Department, as Class A concrete is generally 4,000 psi in 28 days. However, it was felt that the right aggregate could produce this 7,000-psi strength requirement with no difficulty to the contractor. Subsequent events forced the contractor to change from his first pit that contained some soft aggregate to another pit that consisted of sharp, angular, hard rock to meet the 7,000-psi requirement consistently.

CONSTRUCTION

In the fall of 1961, the South Dakota Highway Commission advertised for bids on the foundation for this structure. Plans and specifications called for driving 37,764 lin ft of 48-in. prestressed, precasted concrete piling and 1,008 ft of 12 BP 53-lb bearing piles in sill 1 and 29. Work was to be completed in two construction seasons.

Plans Quantities

The contractor was given the option of using a multi-unit pile, similar to the type manufactured by the Raymond Pile Corporation or a single-unit type used by Concrete Technology of Tacoma, Washington. The contractor elected to cast the piling at the site, using a single-unit pile.

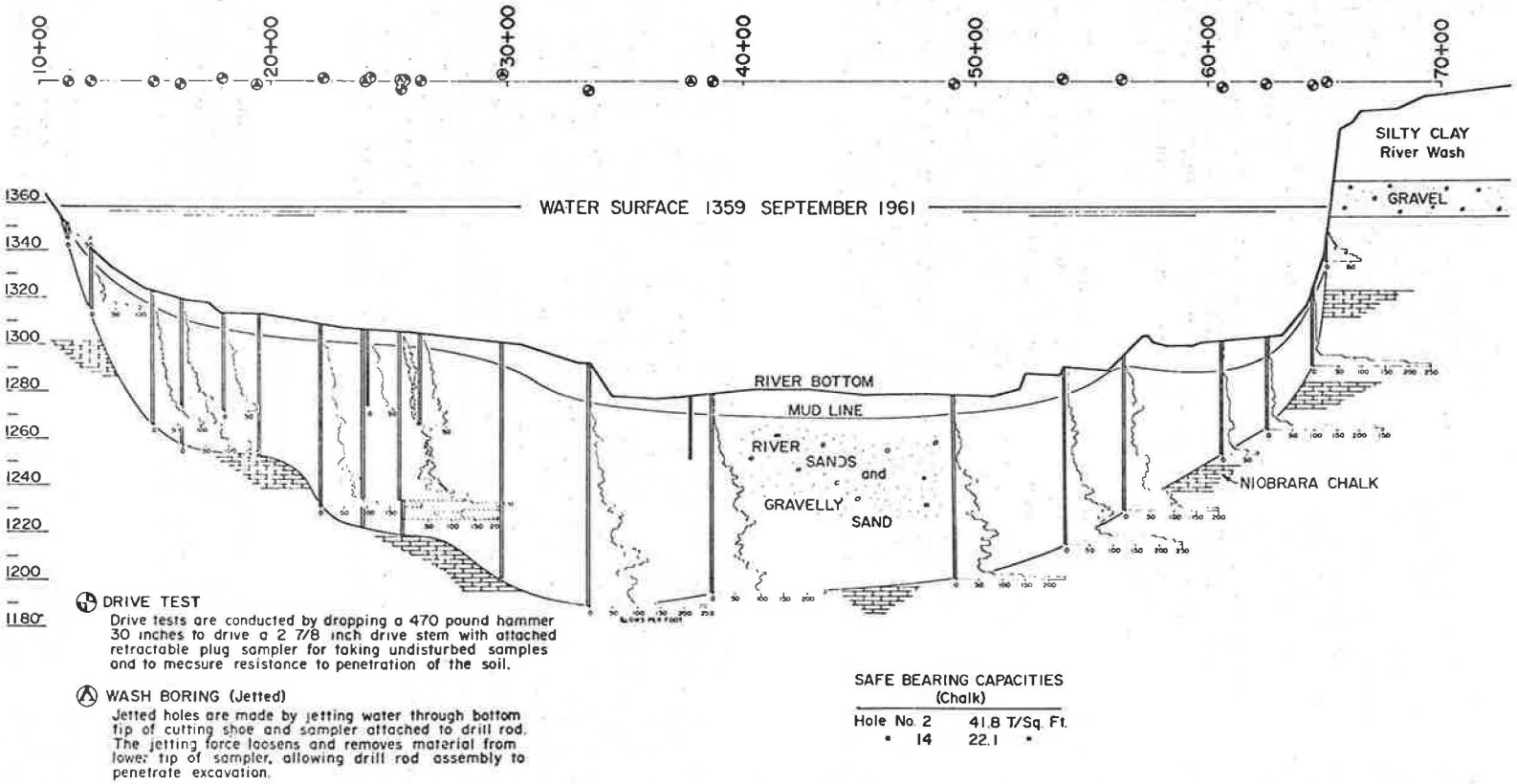


Figure 6. Subsurface profile.

Pile Construction

The contractor selected a location in Snake Creek Bay to build a casting yard (Fig. 7). The casting yard consisted of two casting beds 425 ft long. At one end was a rack containing 16 spools of prestressing cable; the other end contained a jacking frame for stressing the cable. A small overhead gantry crane was used for placing the concrete as well as extracting the piles from the forms. While the concrete was being placed in the form, a vibrating mandril was pulled through the center of the form at a speed sufficient to compact the concrete; therefore, no interior forming was necessary.

Figure 7. Casting yard: vibrating mandril, twin casting beds and gantry—pile storage at left.

In using the mandril as an internal form, a stiff no-slump concrete mix was required. Care in placing this dry mix at headers and on the ends was exercised to prevent the pile from collapsing and requiring patching. The pile was cured with a fog to maintain high humidity and kept at a temperature between 70 and 85 F.

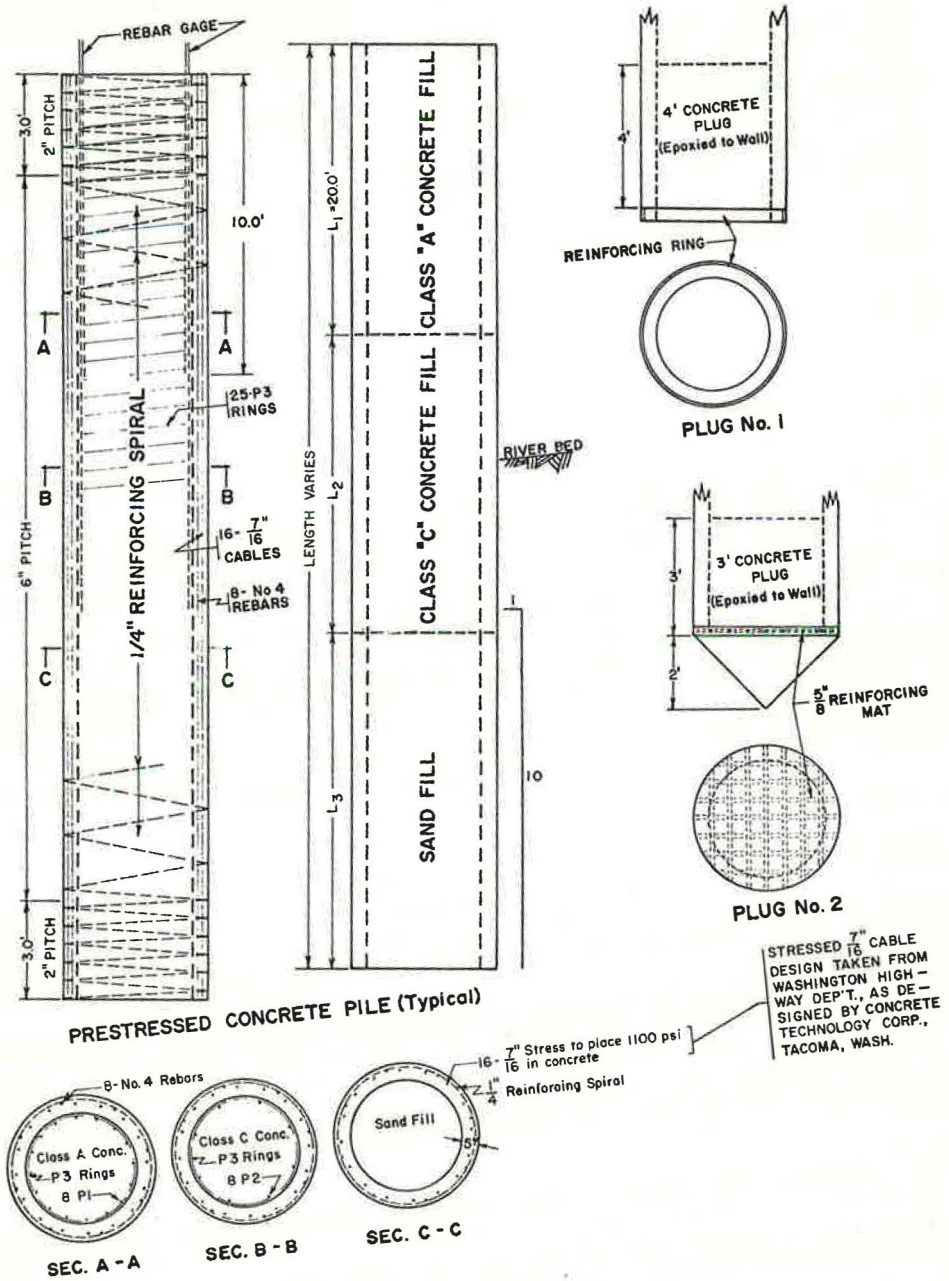
After the concrete had cured to 5,000 psi, pick points were drilled through the pile shell and the pile extracted from the form. The pile was placed in a storage yard by the water. At this time, plugs were cast into one end of each pile. Two types of plugs were used: one was a 4-ft flush-end plug; the other was a tapered plug, having 3 ft of concrete in the end of the pile with a 45-deg 2 ft long taper (Fig. 8). Both plugs were epoxied into the pile at the time the plug was cast. At this time, the pick points were epoxied and filled with a stay-crete mixture. After the piles had cured to 7,000 psi, they were moved to the launching rail and taken to the stiffleg driving unit. For moving each pile, one end near the pick point was set on a flex float unit, and the other pick point was held by a small A-frame with a winch line attached.

Pile Placement

When the pile arrived at the driving site, two methods were used to align it on the compound 1 on 10 batter. The first method used a stay lath unit 15 ft under water with a second unit at the barge level. By setting the pile into the predetermined position, a compound 1 on 10 batter was achieved. This method was used until a storm destroyed the lower stay lath unit. The contractor then computed the distance out from the centerline to the point where the pile point would intersect the mud line. He placed the pile point at that intersection point and leaned it into the upper stay lath unit. The pile was either jetted or jetted and hammered to the final accepted bearing capacity. The original specifications required the piling to be seated with 50 blows per inch into the chalk by a 50,000 ft-lb hammer. To achieve this specification, the contractor used a three-finger jet with each nozzle set 90 degrees from the others. This three-finger jet was used to put the piling down as far as possible. Then the pile was hammered to the chalk. However, this method proved ineffective because the three-finger jet washed a hole at the wrong angle and tended to concentrate any large gravel found in the sandy zones into a nest of boulders that the pile could not penetrate.

A second method of placing the pile used a single-bar jet placed on the pile before positioning. The single-bar jet was strapped with quick snap releases to the pile so that the jet worked directly ahead of the pile tip. The hammer could be used at the same time, allowing the pile to be jetted and hammered simultaneously. This method proved quite effective. With the three-finger jets, it often required a full shift to place one pile. With the single-bar jet and simultaneous hammering, it required approximately 55 minutes to place a pile.

Several problems occurred during the placement of the piles. Slipped plugs required a change in plug type; pick points popped out. A question arose as to how many blows



NOTE:
L_1 = Constant
L_2 = Difference between L_1 & L_2
L_3 = Normally taken as the lower $\frac{1}{3}$ of Pile

Figure 8. Prestressed concrete pile.

per inch a pile would stand without damage during the driving operation. One pile was driven as a test pile to a total of 1,792 blows for 20 in., and then pulled (Fig. 9). Inspection indicated the pile had sustained a longitudinal crack approximately 70 ft in length and that the reinforcing ring on the end had been stripped off. However, this pile would have been acceptable if it had been backfilled properly. Later studies of driven piles revealed that many piles in the various bents had been driven over 5,000 blows to get acceptable bearing. For example, in Bent 20 the pile in position 5 was driven 1,251 blows to place it. Pile 9 was driven 5,237 blows to get acceptable bearing. Both of these piles sustained no visible damage at the time of acceptance. On the other hand, in Bent 24, pile 7 was driven 327 blows and on inspection it contained 30 ft of water. Pile 8 was driven 1,710 blows in a total of 77.5 in. and contained 75 ft of water at the time of acceptance. Both of these piles were inspected by divers and had longitudinal cracks in the area where concrete had been placed into the form. These piles were pumped dry and backfilled with Class C concrete to an elevation of 1358. In Bent 16, pile 2 was reported as having water gushing out of the pile hammer helmet during the driving operation. An attempt to pump this pile dry failed. On inspection by divers, it was discovered that a pick point patch had come loose admitting the water from the jets. Since these pick points were about 6 in. square, considerable water could be admitted to a piling under pressure when one failed.

Figure 9. Test pile 2-24—113 ft long cast from 7300 psi concrete. Pile driven filled with water; seated with 1792 blows for 20-in. penetration. Pile shows plug in place, banding torn loose and a split 70 ft long in section where concrete was placed in the form.

During the fall of 1962, the piling for Bents 26, 25, and 24 (in that order) had been driven. At Bent 24 a test pile was loaded to 375 tons with little measured deformation. During the winter months examination of the pile driving records on Bent 24 disclosed 4 piles with slipped plugs (a flat-end 4-ft concrete plug epoxied into the pile). These piles and 4 piles that had broken by freezing of water which had been left in them were unacceptable to the state.

Later in the spring of 1963 when layers of cobbles and boulders were encountered between Bents 17 and 24, the contractor decided to change from a flat plug to a pointed-type plug, which was extended 2 ft beyond the end of the pile and was cast on a 45-deg angle (Fig. 8). The plug facilitated driving, but caused problems in alignment. This pointed-end piling tended to deviate from the compound 1 on 10 batter more than the flat-end type piling.

During the summer of 1962, when the contractor was assembling his equipment and testing it between Bents 17 and 24 he used three-finger jets to determine the chalk elevation at various bents. This jet moved large volumes of material at relatively low pressures and, in so doing, tended to sort the material in the river bottom. This material was described originally as a sandy gravelly alluvium river deposit. Boulders tended to concentrate at the places where piling would have to be driven later.

In 1963, when the contractor returned to place piling in these bents he encountered considerable difficulty because of this concentrated boulder zone. However, in all bents, with exception of Bent 18, the contractor was able to place the piling. At Bent 18, he had to blast and clam to remove the boulder concentration in order to place piling. In spite of popped pick points, hard driving and boulders, the contractor placed 35,882 lin ft of concrete piling. Inasmuch as the plans called for 37,765 ft, this is a computed decrease of 5.02 percent in plans quantities.

Figure 10. Bent 22 pile 4—cracks as found January 1964. Length 138 ft, 7000 psi concrete—driven a total of 6897 blows. Pile was pumped dry before filling with sand and Class C concrete.

Pile Filling

After driving each bent, the final step was filling each pile. The fill was of two types. The first type used with piling cast from 7,000-psi concrete was according to plans (Fig. 8). The other type consisted of installing a No. 8 reinforcing cage and filling the pile to the top with Class A concrete. The second type became necessary when the state permitted the contractor to use piling cast from concrete that failed to reach 7,000 psi. Approximately 41 pilings were cast with strengths between 5,500 and 6,500 psi, and these were placed in various bents during the summer of 1963. While little or no precautions were taken in placing the sand, all Class C and Class A concrete was required to be placed by tremie methods. The Highway Department felt that dropping the concrete a long distance would allow segregation and bridging to occur; this could be prevented by using tremie methods. However, in some of the piling, with popped pick points where it was impossible to dewater them, the tremie method of concrete placement was necessary for proper filling of the pile.

Broken Piling

By November 1963, the contractor had substantially completed the substructure as required by contract. However, in January 1964, inspection disclosed that numerous piles had ruptured to the extent of breaking the steel reinforcement and knocking pieces out of the pile shell. A hasty agreement

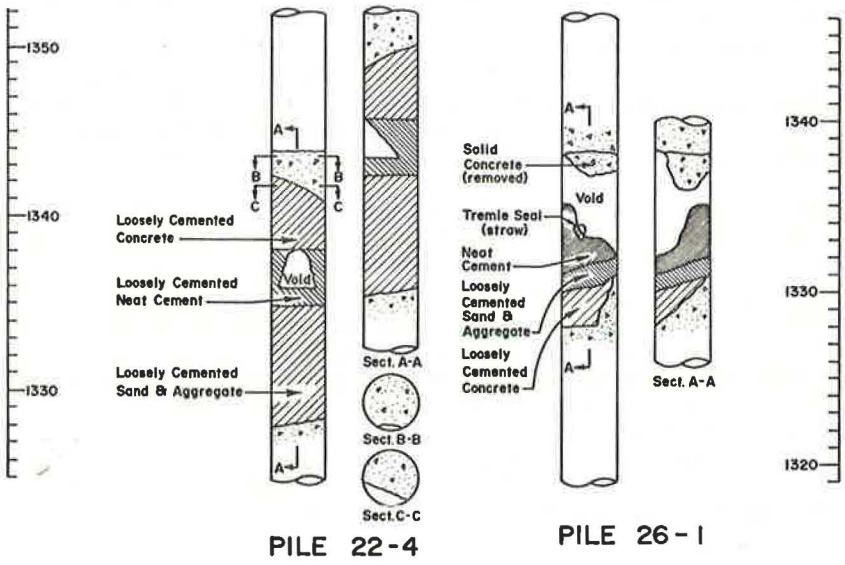


Figure 11. Repair Log Bent 22 and Bent 26.

Figure 12. Cracked piling Bent 26. Large hole and crack in Position 7; pile in Position 1 was driven a total of 308 blows; dry when filled with sand and Class C concrete.

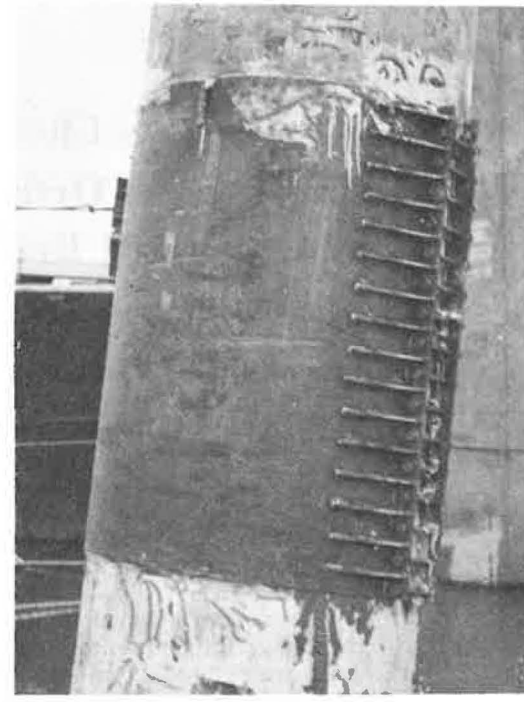


Figure 13. Steel reinforcing band as placed on pile 1 Bent 26—epoxied and bolted in place after deleterious material had been removed and replaced with dry pack concrete.

was concluded with the contractor to inspect all damaged piling using sonic methods and core drilling. This inspection determined that 52 piles were damaged to the point where repairs were necessary.

In piling that required repairs, zones up to 14 ft thick consisting of segregated concrete, silt, sand, gravel, hay and even an 8 x 8 timber were removed. Typical of the piling repaired were the following: In Bent 22 pile 4, 14 ft of loosely cemented aggregate, neat cement, low-strength concrete and a void were cleaned from the pile shell and replaced with dry-packed concrete. After cleaning the exterior shell a steel reinforcing band of ⅜-in. steel was epoxied and bolted into place (Figs. 10 and 11). Bent 26 pile 1 had 6 prestressing cables exposed with a 3-ft void where the water around the pile had washed out unconsolidated material. Ten feet of loose material including a straw tremie seal was removed and replaced with dry pack. The exterior of this pile was banded with a reinforcing unit, epoxied and bolted into place (Figs. 11, 12, and 13). All piles that were repaired were reinforced by banding to replace the steel that had been cut out to gain access to the pile core.

CONCLUSIONS

Prestressed, precast concrete cylinder piling provided an economical foundation for this 5655.5-ft structure in deep water. However, successful use of this type of piling requires the ability to predict its correct length and bearing capacity. This is accomplished by performing adequate foundation studies, especially penetration tests and estimates of skin friction values. During the construction phase, proper control must be exercised to coordinate the action of jetting and the hammer for maximum placement of piling. Finally, extreme care in backfilling must be taken by requiring a full tremie backfill that has been vibrated and checked by random coring or sonic testing methods to insure a sound pile that will withstand the rigors of weather extremes and perform as a structural member.