

PIN PILES SAVE SILOS

PAUL B. GRONECK
DONALD A. BRUCE
JAMES H. GREENMAN
GEORGE BINGHAM

When a deteriorating timber pile foundation threatened to shut down a major West Coast grain-export facility, underpinning with small-diameter, high-capacity pin piles provided new foundation support without interrupting operations.

The United Grain Corp. annually ships about 200 million bushels of wheat and other grains to destinations around the world from its leased facility on the Columbia River at Vancouver, Wash. Central to the operation is the A House facility, which includes a main elevator structure and three silos, two built in 1934 and the third in 1939, with a combined capacity of 2.3 million bushels of grain.

The complex was originally built for the Spokane, Portland and Seattle Railroad (now part of Burlington Northern Railroad), which wanted a terminal in this location to provide a connection between Washington's Inland Empire, then served largely by rail, and deep water shipping—and wanted it fast. Eight months after drawings for the A House facility were started, the complex was well filled with grain and operating in all departments.

At the time, this was hailed as a record for construction of a facility of this size. However, the emphasis on speed precluded use of treated foundation piling. The absence of preservatives led to progressive deterioration of the timber piles—until, almost 60 years later, they had to be completely replaced or the complex shut down.

The timber piles were driven on a 2 ft 6 in. grid pattern through the upper soft dredged sand and silt layers and are founded in dense sand and gravel layers 40–50 ft below grade. In all, some 4,050 piles lie beneath the complex. The timber piling supports 24–30 in. thick reinforced concrete mats, which form the silo basement slab. Hollow concrete box columns rest on the mat slabs, supporting the 100 ft tall silos. Belt conveyors to unload grain occupy aisles between the box columns in the basement.

In 1980, large cracks were noticed in the roof of the silos and the walls of the cupolas that run the full length of the silo roofs. Monitoring for further settlement went on for two years, then was discontinued after no significant advance was observed. In 1987, the differential settlement caused a sky bridge spanning a 20 ft gap between two of the structures to punch through the wall of one of the buildings. Considerable concrete cracking was evident at many locations. Differential settlement reached 5 in., sending one of the structures 4½ in. out of plumb.

The bridge was repaired, and the current owner, the Port of Vancouver, initiated an investigation into the cause of the settlement. The owner's engineer, Haner, Ross & Sporseen, Inc., Portland, and then geotechnical consultant L.R. Squier & Associates, Portland, advanced 14 investigative soil borings around the perimeter of the structures to determine the nature of the underlying soils.

Along with the soil bearings, 10 caissons sunk along the side of the structures, with short tunnels extending beneath the foundation mats, allowed visual inspection of the upper 10 ft of the piles below the foundation mat and above the water table. The pilings were damaged at all 10 inspection points. In some cases, the tops of the piles were entirely missing. The only sign of their presence was a round pocket in the bottom of the foundation mat. It was obvious that the foundation support for all three storage houses must be replaced if the silos were to remain in service.

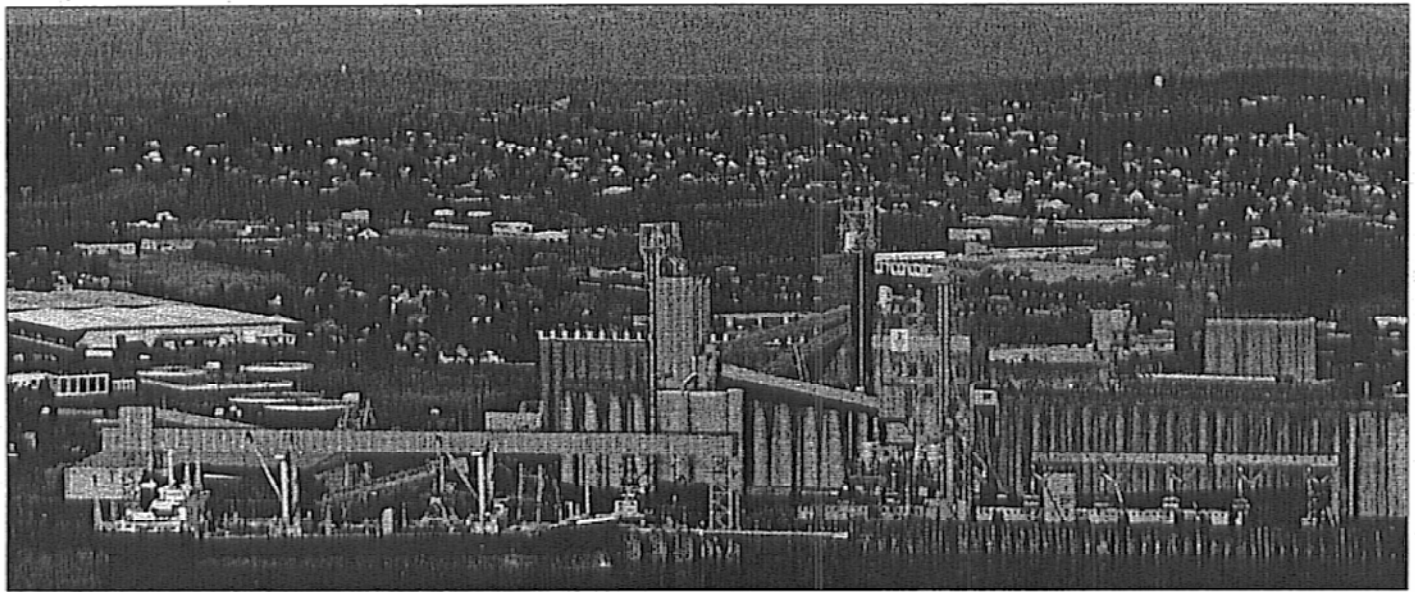
Several methods of underpinning were considered, including driven piling, drilled caissons and jet grouting. Many difficult

conditions had to be accounted for in planning the project.

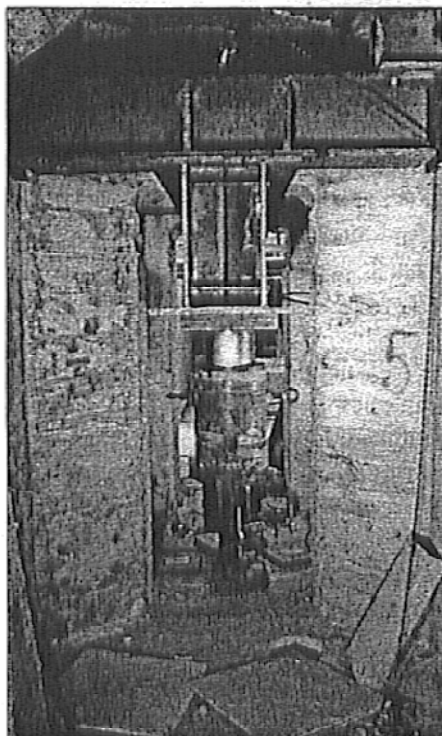
- Operation of the silos could not be interrupted. This precluded removing the conveyor belts to provide interior access or disrupting the almost continuous railcar-unloading activity occurring along one side of the facility.
- Access was also limited for work in the basement of the silo structures.
- The explosive nature of the grain dust prohibited use of combustion engines and any metal welding, cutting or grinding in the basements.
- Extending the underpinning elements among the existing timber piles—which were very competent below the top of the water table—down to the competent bearing soils would be difficult.
- There was a potential for overstressing of the minimally reinforced concrete walls and slabs resulting from the concentration of the foundation support around the columns and walls.

PIN-PILE CONSTRUCTION

Considering these difficulties and wishing to take advantage of qualified contractors' experience and techniques, the Port pursued a design-build proposal. The final request for proposals prepared by Haner, Ross & Sporseen envisioned jet-grouted columns or friction piles as alternatives. As recommended by geotechnical consultant Applied Geotechnology, Inc., Portland, all the systems were to be embedded in the dense sands and gravels. Load factor and maximum settlement requirements were specified, along with a thorough preproduction and production load test program. Major emphasis was placed on the bidding contractors' establish-

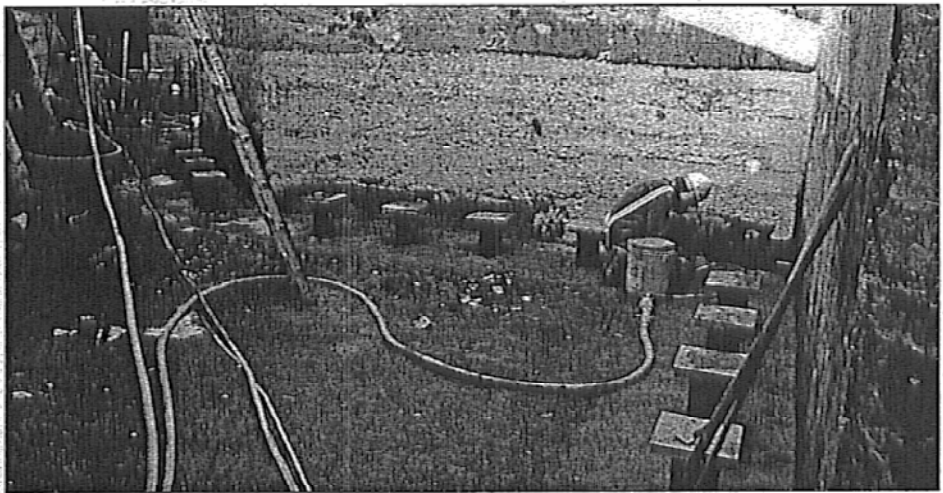


CONSTRUCTION OF THE A HOUSE GRAIN-EXPORT FACILITY IN VANCOUVER (ABOVE) SET RECORDS FOR SPEED, BUT USE OF UNTREATED TIMBER PILES FOR THE FOUNDATION LED TO PROGRESSIVE DETERIORATION.



IN A PRODUCTION PILE LOAD TEST (LEFT), A 375 TON HYDRAULIC JACK APPLIES THE LOAD AND STEEL BEAMS BOLTED TO THE ADJACENT BOX-COLUMN WALLS DISTRIBUTE THE LOAD REACTION TO THE STRUCTURE.

EXTERIOR PILES WITH THE TOP BEARING PLATE INSTALLED (BELOW): THE CONCRETE WALLS HAVE BEEN ROUGHENED AND DRILLED FOR THE DOWELED REINFORCING BARS FOR PILE-CAP INSTALLATION.



ing their experience and qualifications. A complete set of design plans and calculations had to be submitted with the proposal pricing.

Nicholson Construction Co., Tacoma, Wash., which was the responsive low bidder at \$6,168,400, proposed a design that called for the installation and connection of approximately 840 high-capacity pin piles. Structural engineer on the project was Anderson Bjornstad Kane Jacobs, Seattle, which helped prepare the proposal package and final design.

The pin piles are constructed by drilling a thick-walled 7 in. diameter high-strength steel casing until it is embedded a minimum of 30 ft into the lower dense soils (an average total depth of approximately 70 ft from grade), then placing neat cement grout under high pressure while extracting

the casing out of its embedment. The upper portion of the pile is ultimately reinforced by the steel casing, with the lower, pressure-grouted portion reinforced by a heavy steel reinforcing bar. The pin piles were installed around the outside perimeter of the silo structures and inside and around the interior concrete box columns.

Doorways cut through the concrete walls of the box columns created access corridors into the interior of the box columns and through the basement areas. Interior headroom ranged from 8½ ft to 12 ft, with work room inside the columns as little as 5 ft by 7 ft. Nicholson installed the interior piles through 10 in. diameter holes cored through the basement slab, drilled using two small hydraulic drill rigs specially constructed for the project.

The drills were skid-mounted and hoisted around using picking points bolted into the walls and ceiling. They were moved through the 3 ft by 7 ft doorways by tipping them on their sides and rolling them on rubber-tired carts. These carts were also used for the constant delivery of casing and reinforcing bar lengths to the drill locations and to remove the heavy concrete door cutouts.

The diesel power units for the drills were placed outside to avoid a source of ignition for the grain dust. The lengths of steel casing and reinforcing bar were coupled mechanically, eliminating the need for any welding.

The interior piles were connected to the mat slabs by grouting the pile tops into the core holes. Reinforcing bars doweled into the column walls and a 2 ft thick concrete

mat poured on top of the basement slab help distribute the support of concentrated pile groupings inside of the box columns and reduce induced stresses on the floor slabs and column walls. The access doorways were closed with reinforced concrete fill upon completion of the work.

Large-track-mounted drill rigs installed exterior piles around the perimeter of the silos. Concrete pile caps doweled to the exterior basement walls and the edge of the basement slab connect the piles to the structure. Where access was difficult, such as between the silo structures, the small indoor rigs were also used for exterior pile installation, with excavation and backfill done with a backhoe or by hand.

Construction commenced in February 1992 and was substantially complete in January 1993. Ultimately, 840 pin piles, totaling 55,000 ft, were installed, incorporating 42,000 cu ft of neat cement grout. Pile installation involved drilling through over 3,000 ft of wood piling. For the two silos built in 1934, which measure 317 ft by 57 ft and 300 ft by 53 ft, 336 and 324 pin piles were installed. Some 180 pin piles support the silo added in 1939, which measures 139 ft by 76 ft.

TESTING AND QUALITY ASSURANCE

The preproduction test program required the successful loading of three test piles to 200% of the working load (considered 150 tons), held for a minimum of 12 hours. The ultimate load value of 300 tons was the highest ever attempted by Nicholson for pin piles installed in soils, although this was less than loads previously attained for piles founded in rock. The initial three piles failed before the 12 hours were up, but after structural adjustments the second group passed the test, attaining ultimate loads up to 375 tons after passing the 200% load hold criterion. The successful test piles established the structural detailing for the production piles and criteria for minimum embedments into the competent soils.

To provide additional verification of the pin-pile capacity, 3% (25, later reduced to 10) of the production piles were tested to 200% of working load. The final calculated working loads varied from 126 to 146 tons depending on pile location. Deflection of the pile tops at a test load of 150 tons averaged approximately $\frac{3}{8}$ in., with an average deflection at 200% working load of $\frac{7}{8}$ in. In addition, two mockups of the structural

connection between the pile and foundation slab were pull-out load tested to up to 300 tons.

Soil strata depth encountered, pile depth, grout quality and grout pressures attained were monitored and recorded for each pile installation to assure quality. When a structural defect was found in a pile during installation, the pile was load-tested to a minimum of working load. Two of these tests were done; one pile failed to hold the test load and was replaced.

Varying amounts of wood piling were encountered during pile installation. Nicholson's use of inner drill rods and special bits to prebore ahead of the casing allowed successful drilling through up to 40 ft of wood (down the center of a wood pile). Production pile load tests demonstrated that the presence of the wood had no discernible effect on the ultimate capacity of the piles.

UNDERPINNING PERFORMANCE

Operation of the silos continued uninterrupted during installation of the underpinning except for the allowed maximum of 500,000 bushels of empty storage capacity. That was kept empty where connections between the piles and the silos were being completed, to allow pile connection to the structure without the elastic deflections that are present when the silos are loaded with grain.

The weight of the grain was a considerable portion of the pile design load, making up approximately two-thirds of the silos' total weight. The magnitude of the grain weight became particularly evident during production testing of the piles: the silos above the test pile had to be loaded with grain to avoid the jacking up and cracking of the structure. Large steel beams provided additional distribution of the test loads to adjacent box columns.

An automated settlement-monitoring system continuously checks movements of the silos, with secondary measurements from weekly surveys of the silo perimeter. No significant additional settlements occurred during the construction period. Monitoring will continue to verify performance of the system within the specified criteria, which allow additional maximum differential settlements of up to $1\frac{1}{2}$ in. in 100 ft, and additional maximum uniform settlement of 6 in. There should be no problem meeting the specification, considering the measured pile performance of $\frac{3}{8}$ in. deflection at working load.

PIN-PILE BENEFITS

Pin piles provided a somewhat less expensive solution than jet grouting, the next likely option. An advantage over jet grouting was that pin piles' strength was not affected by the upper layers of soft soils or by timber pile obstructions. Mixing the soft soils into the jet grout material would have had a negative impact on compressive strength of the grout-soil mixture. Also, the shadowing effect on the jet grout columns from the existing timber piles would have added an unknown to the actual area of the grout column. Pin piles are not affected in this manner, because the grout-filled thick-walled casing carries the load through the upper layers down to the competent soils.

The special drilling techniques employed by Nicholson limited problems caused by the high density of the lower gravel and cobble soils and the maze of timber piling. These conditions would have provided a significantly greater obstacle to pile installation by driving, auger-cast or open-hole techniques.

The use of partnering also greatly aided the success of this challenging project. At the start of the project, all the involved parties signed a very simple one-page agreement stating the common goals of safety, successful and timely completion, uninterrupted operation of the facility, and maximization of the contractor's profit. This helped establish positive attitudes and an open level of communication.

The underpinning construction was completed on Jan. 29. On March 25 the area experienced an earthquake with a magnitude of 5.6 on the Richter scale. Its epicenter was approximately 44 mi distant. Observations that were taken after the quake revealed new settlement at several points. This settlement, which was nowhere greater than that expected from load transfer from timber piles to pin piles, caused no damage to the structures. Given the questionable condition of the timber piles, it is likely that serious damage would have occurred had the pin piles not been in place. ▽

Paul B. Groneck, P.E., is chief engineer with Nicholson Construction Co., Tacoma, Wash. Donald A. Bruce is technical director in Nicholson's Bridgeville, Pa. office. James H. Greenman, P.E., is president and George Bingham, P.E., is project manager with Hanner, Ross & Sporseen, Inc., Portland, Ore.