Jetted-in Driven Plate Anchors for Mooring Bridge Caissons

By Osama Safaqah

Driven Plate Anchor.

The new one mile long Tacoma Narrows suspension bridge connects the cities of Tacoma and Gig Harbor, Washington, and is supported by two main towers. The bridge towers are founded on two 80-ft by 130-ft caissons embedded 70-80 ft below the mudline in 130-150 ft of water. The mooring of the floating caissons during construction requires an anchoring system to resist large drag forces resulting from drafts up to 143 ft in 7-9 knots maximum tidal currents. For each caisson, the anchoring system consists of 16 lower anchors on a nominal 300-ft radius from the caisson center and 16 upper anchors on a nominal 600-ft radius.

Driven plate anchors offer significant cost savings in comparison to alternative systems, mainly because of their size and method of installation. Other significant advantages of these anchors are their high holding-capacity-to-weight ratio and their resistance to non-horizontal loading. Each anchor consists of a steel plate welded onto a section of structural steel beam to which a padeye is attached. The anchor is then connected to a follower (H-Pile) by a hydraulic clamp and is driven vertically into the sea floor using an underwater vibratory hammer. Because of dense soil, driving is aided by jetting ahead of the anchor.

After driving the anchor to the required depth, the follower is retrieved and the anchor is proof-tested. This process causes the anchor to rotate and "key in", which increases its resistance to pull out.

Anchor Installation System.

Geotechnical analyses have been conducted for the design and installation of driven plate anchors to determine their holding capacity, embedment ratio, and keying distance. These anchors are to be embedded 35-50 ft into dense to very dense silty sand or gravelly sand to achieve a design holding capacity of 1000 kip. Full-scale field tests have shown that this capacity is attainable. Drivability analyses have also been conducted to determine the size of the underwater hammer and the effectiveness of the jetting method.

For the anchorage system to work effectively, it is also important to take a proper account of (1) the anchor chain contribution to capacity, (2) required chain length, and (3) the amount of chain that cuts through the soil. The elaborate chain analysis used to determine the above factors also yields the profile of the catenary, the profile of chain embedded in the soil, and the attachment angle between the chain and the anchor.

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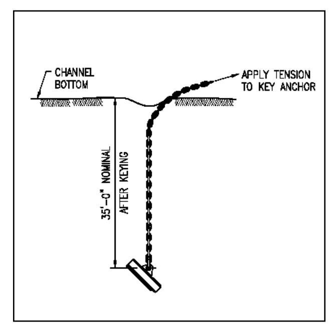

Plate anchor concept.

Gerwicknews

AN AFFILIATE OF COWI / July 2003

Competitive Edge and Profitability

By Robert Bittner

Providing the right engineering solution can make the difference between contractors who come in as low bidder or walk away as second bidder, contractors who make projected profits on a job or suffer significant losses, or satisfied owners coming back with work on a new project or leaving the relationship dissatisfied.

Ben C. Gerwick, Inc. has earned its reputation as a design firm that provides the right engineering solutions.

Founded in 1927 as a marine construction firm, Gerwick has delivered effective engineering solutions for many projects, including the incremental cofferdam approach successfully used to construct the South Tower foundation for the Golden Gate Bridge, and the pre-cast bell pier concepts used to build the Richmond San Rafael Bridge.

Ben C. Gerwick, Inc. currently performs a significant amount of work for contractors. We have designed permanent structures as part of contractors' design-build teams, and have designed temporary structures and construction equipment as part of contractors' construction-engineering teams. In all of these efforts, our objective at Ben C. Gerwick, Inc. is to provide sound engineering solutions that reduce construction cost and risk while improving the quality of finished structures. Our solutions give our clients the competitive engineering edge to win the position of low bidder, to complete projects within budget, and to enhance their reputations with satisfied owners. While some of these solutions involve innovation, in most cases they rely upon proven engineering methods and techniques that have been transferred from one field of construction to another.

Our last issue of Gerwick News focused upon two of our current design-build efforts: the Navy's new carrier pier in San Diego and the new Cooper River Bridge in Charleston, South Carolina. This issue features two of our most recent construction engineering projects: the new Skyway section of the San Francisco-Oakland Bay Bridge and the new Tacoma Narrows Bridge in Puget Sound.

The driven plate anchor system used to anchor the caissons for the new Tacoma Narrows Bridge (shown on the cover of this issue) is our latest example of the right engineering solution.

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Ben C. Gerwick, Inc.
is an internationally known civil/structural consulting firm based in San Francisco specialized in the construction of major marine structures for more than 75 years, first as a heavy construction company, and as consulting engineers since 1971.

In 1988, Ben C. Gerwick, Inc. joined COWI Consulting Engineers and Planners AS, an engineering company with headquarters in Denmark, founded in 1930. The parent company of Ben C. Gerwick, Inc. operates from 28 offices and employs more than 2,800 people worldwide. The firms augment one another's strengths and share resources to benefit their clients.

Cover Photo
The driven plate anchor system used to anchor the caissons for the new Tacoma Narrows Bridge.

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Mooring Analysis: Egypt LNG Project at Idku — Marine Facilities

By Mads P. Jorgensen

Egypt's underground holds considerable reserves of natural gas. A number of projects are currently under way in an effort to develop the country's gas industry for export to the international market. Natural gas currently represents roughly 25% of the total energy consumed worldwide today, with an estimated annual demand of 130 million tons. In 2001, construction of a Liquefied Natural Gas (LNG) plant with a capacity of 4 million tons per year was initiated at Idku, and is now entering the construction phase.

COWI A/S is designing the marine facilities for the LNG Project at Idku that includes a 7,940-ft trestle and loading platform sheltered by a 2,600-ft breakwater in 40 ft of water. The terminal will accommodate liquefied gas carriers 70,000-140,000 m^3 in size, between 800 and 960 ft long, with breadths of 112-126 ft, and typical drafts of 30-38 ft.

Ben C. Gerwick, Inc. performed static mooring analyses and seakeeping analyses for the 70,000-140,000 m^3 liquefied gas carriers berthed at the loading platform of the Idku LNG terminal. The study included analysis and review of proposed mooring layouts, assessment of ship manifold excursions, mooring line loads, and recommendations for optimization of the mooring systems.

Analysis and planning by Ben C. Gerwick Inc. engineers, along with the simulation tool OPTIMOOR were utilized to perform the mooring and seakeeping analyses. Static mooring analyses focused on vessel motions for static mooring conditions and the maximum excursion of the manifolds during loading, covering the full range of tidal elevations and the change in vessel draft and trim during loading under the effects of wind, current and waves. The analyses considered 70,000-140,000 m^3 vessels in mooring configurations using 12-16 mooring lines under various loading conditions.

The seakeeping analysis evaluated the short-period vessel motions for the six degrees of vessel movement: surge, sway, yaw, roll, pitch, and heave due to wind, current and waves, taking into account shallow water effects.

Based on vessel motions, engineers determined the maximum motions of fairleads, mooring line tensions, and forces on fenders and dolphins. The calculations made use of Response Amplitude Operators (RAOs), which provided accurate analysis of the vessels response to first-order wave effects, wave drift forces, and near-bed proximity effects.

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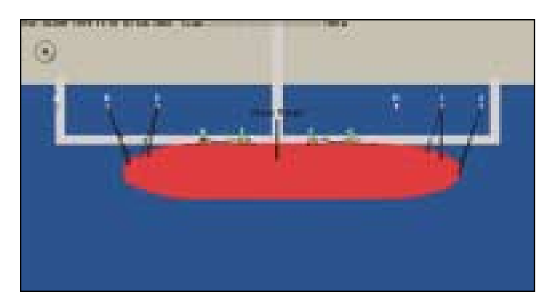

Simulation of vessel and manifold movements for 137,000 m^3 gas carrier when berthed at the Idku LNG Terminal.

Example of a 137,000 m^3 liquefied gas carrier.

Tackling the Narrows

By Marc C. Gerin

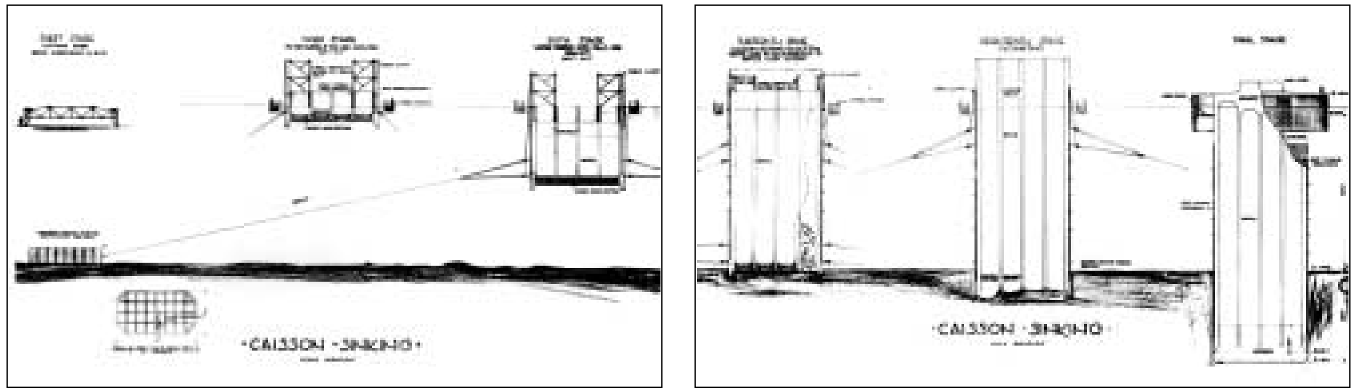

Figure 1: Caisson construction method.

The Tacoma Narrows in Western Washington — a strait made famous by images of its long thin suspension bridge twisting and undulating to self-destruction — is being bridged once again. Tacoma Narrows Constructor (TNC), a Bechtel/Kiewit Pacific joint venture, is building a new

When it opens in 2005, the new crossing will parallel the existing one, which opened in 1950.

suspension bridge across the Narrows. Ben C. Gerwick, Inc. is designing the anchorage system to hold the main foundation caissons in place during on-site floating construction. This anchorage system must withstand the Narrows' gale force winds, 9-knot current, and 15-ft tides.

The first bridge that spanned the Tacoma Narrows — a 5,400-ft suspension bridge — was opened in 1940 to access the spectacular and sparsely populated Olympic Peninsula. Following the historic collapse of its main span only four months later, this bridge was completely dismantled except for its foundations. These foundations were used as the starting point for a replacement bridge that opened in 1950. Today that bridge carries 90,000 cars per day, which is 50% more than its original design capacity. The increasing volume of traffic from the now populous Olympic Peninsula requires construction of a second bridge.

Two large concrete caissons located within the Narrows, in 130 ft and 150 ft of water, will support the new main towers. To resist the strong current and seismic forces while supporting the bridge above, the caissons will be embedded about 70 ft into the seabed.

To construct the caissons, an initial "raft" equipped with a cutting edge and a false bottom is first towed to the site. Construction then proceeds on-site with the caisson sitting deeper and deeper in the water as each concrete lift is placed. The cutting edge eventually penetrates the seabed, pushed in by the caisson's weight. At this point, the false bottom is removed and soil beneath excavated through interior cells, allowing the caisson to embed itself deeper. Once the target depth is reached, a bottom concrete seal is poured and a concrete cap is placed on top to support the towers.

Construction of the caissons is remarkably similar to the method used in 1939 (Figure 1). The wood and canvas false bottom has been replaced by steel half-domes, and the transits have been replaced by GPS positioning but otherwise the method used today is the same as it was 64 years ago.

The May 1939 issue of Roads and Streets stated: "the major construction problem is the control of the caissons and construction equipment in the high-velocity, rough, deep water of the Narrows." This observation is particularly relevant today, since the existing caissons substantially increase hydrodynamic loading on the new caissons during floating construction.

Ben C. Gerwick, Inc. engineers designed the mooring system for the caissons to meet the anchor line layout and design load requirements provided by TNC. Each new caisson is held by 16 lower 300-ft anchor lines and 16 upper 600-ft anchor lines in a spread mooring configuration. The lower anchor lines are 4-in stud link chain and the upper anchor lines are 3.5-in diameter bridge strand. At the caisson, each anchor line is connected to a block and tackle bridle that divides the 1000 kip design load to two attachment points. The lower blocks attach to fixed brackets

continued on p.7

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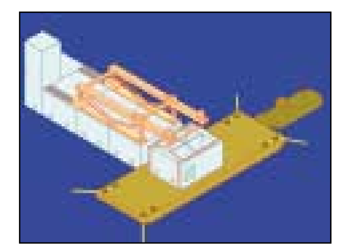
Chickamauga Lock: Innovative Concept Design

By Sam Yao

A joint venture of Ben C. Gerwick, Inc. and Bergmann Associates is currently working with the Nashville District of the US Army Corps of Engineers on the Chickamauga Lock Replacement Project. Owned by the Tennessee Valley Authority and operated by the Corps of Engineers, the Chickamauga Lock on the Tennessee River was constructed in the 1930s. Since then, the structure has been plagued with a concrete volume expansion problem due to alkali-aggregate reaction. This problem has resulted in significant volume growth



Lift-in Construction Method for Lock Wall Construction.

and cracking in the concrete, incurring high maintenance costs and requiring frequent lock outages. Feasibility studies have recently been completed for construction of a new lock using both the conventional cofferdam construction method and the innovative in-the-wet construction method.

The A/E has been responsible for identifying and developing innovative design concepts that provide the most favorable and feasible alternative for the project. Ben C. Gerwick, Inc. engineers proposed a float-in construction concept and a lift-in construction concept, both of which used in-the-wet construction technologies.

The A/E also performed a screening-level evaluation among four innovative lock construction options. This evaluation took various cost-related factors and non-cost related factors into consideration, including assessment of prefabrication, construction staging area and utility relocation, transport route, positioning and installation methods, and construction materials.

Based upon the initial screening, Ben C. Gerwick, Inc. provided preliminary cost estimates for both float-in and lift-in concepts so that direct comparisons could be made between the various innovative construction methods and the conventional cofferdam construction method. Cost estimates were contingency-based and primarily derived from historical cost data of marine projects using similar construction methods.

The cost estimates indicate that the float-in and lift-in concepts are nearly equal in cost; both have the potential to achieve up to $10 million in savings over the conventional cofferdam construction for the lock structure alone. In addition to the cost savings, the study selected

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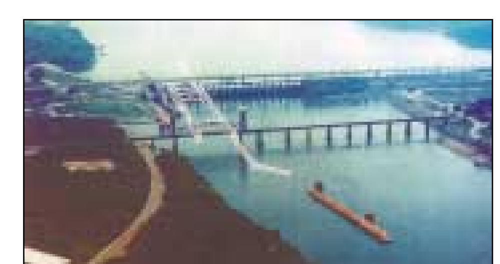
the lift-in design concept as the recommended option among the four alternatives based on the following considerations:

(1) Existing lock operational outages and potential impacts on the navigation industry.

(2) Inherent risk in the method of transport and erection of precast lock elements, including the potential effect of this risk on both the navigation industry and efficient execution of the lock construction work.

(3) Constructibility issues associated with alignment, contraction joints, underwater foundation preparation, logistics, and sequence.

(4) Economies of scale, whereby the proposed construction methods could be effectively applied to other portions of the project (e.g., the guide walls) as cost saving measures.



The new Chickamauga Lock location at the Site.

Profile:

Sam Yao, Ph.D., P.E.

Doctor Sam Yao is a project manager with Ben C. Gerwick, Inc. Born and raised in Shanghai, China, Sam came to the United States for his graduate education, and received his M.S. and Ph.D. degrees in civil engineering from University of Illinois.

Since joining Gerwick in 1993, Sam has led or extensively participated in numerous major marine projects. The focus of his work has been design, rehabilitation, and construction engineering of bridges, locks and dams, piers/wharfs, and intake structures. In 1997, Sam and Ben Gerwick, Jr. received the Excellence Award from ICRI for managing the rehabilitation project at the Diablo Canyon Nuclear Power Plant.

During the past five years, Sam has also participated in development of innovative in-the-wet technologies for construction of navigation structures. He co-authored eight technical reports on underwater concrete technologies, precast concrete thin-wall structures, heavy lift marine equipment, and positioning and installation techniques in float-in/lift-in construction.

In addition, Sam has served as an expert witness or an investigator on many construction litigation cases involving tremie concrete, corrosion of reinforced concrete, cracking and leakages in water-containing structures, drilled shafts, slurry walls, and pile foundations.

San Francisco-Oakland Bay Bridge Skyway Project

By Ted Trenkwalder

Near the approach to the San Francisco-Oakland Bay Bridge, a fleet of cranes and barges are busy dredging, installing cofferdams, placing three-story tall foundation pile caps, and driving 8-ft diameter by 300-ft long pile sections.

Construction of the Skyway portion of the project was awarded to Kiewit, FCI, and Manson (KFM), a joint venture, early last year. The new skyway portion will replace the existing structure damaged in the 1989 Loma Prieta earthquake.

Ben C. Gerwick, Inc. is providing construction engineering support to KFM. Tasks range from designing bubble curtains for protection of the fish habitat during pile driving, to analyzing foundation boxes for hurricane conditions during transport from the Gulf of Mexico. The bulk of Ben C. Gerwick, Inc.'s efforts, however, have been directed towards placing the Pile Cap Lifting Beams and Screeding System for the Cofferdams.

These tasks involve lifting and installing foundation pile caps within a 2-in tolerance. The foundation pile caps vary in size and weight. The larger pile caps are octagonal in plan and have outside dimensions of 56 ft by 64 ft, weighing approximately 2,000 tons.

The steel pile caps are used as templates to drive the foundation piling at varying angles and as forms for new concrete piers that will support the concrete bridge roadway. Pile caps are set at prescribed elevations (either in cofferdams or on the pile cap support frame) to balance the foundation stiffness for earthquakes.

Catamaran barge/lifting beams supporting Box 15 prior to transport to cofferdam.

KFM workers connect lifting beam to Box 15 eyepads.

Pile Cap Lifting Beam

Manufactured by Kiewit Offshore in Texas, the pile caps are being towed through the Panama Canal and up the coast to the project site. (The first pile caps to arrive reached the project site in December 2002 and experienced their design wave height of 30 ft during transit.) Once the pile caps arrive on site, they are lifted from the transport barges with a catamaran derrick barge and placed within the cofferdam or on the pile cap support frame.

A pile cap lifting beam was required to account for pile cap geometric constraints and catamaran derrick barge limitations. Constraints included a sloping deck and sloping vertical stiffeners. The catamaran has limited lifting height and fixed blocks. These restraints required either a beam approximately 28 in deep with padeyes on the top flange and a moment capacity of 9,200 kip-ft to lift the boxes or an alternative solution. Working with KFM, we were able to use two existing W40x593 beams spaced approximately 1 ft apart to allow the catamaran lifting tongue to slip 12 in down between the two beams, which provided greater lifting capacity and improved headroom. The catamaran tongue was connected to the beams with a 10-in pin.

A box beam on top of the lifting beam facilitated the rotation and translation of the picking point to accommodate final lifting eye locations. Once final design constraints were determined, KFM, Oregon Iron Works, Sheedy, and Ben C. Gerwick, Inc. completed the design, fabrication, and load test within 21 working days.

Screeding System for the Gravel Cap Support in the Cofferdams

Precise leveling of the support rock within the temporary cofferdams is critical to the accurate positioning and support of the foundation pile caps. Gerwick engineers adapted a concept from an earlier Kiewit project to provide the means necessary to screed the foundation aggregate to the proper elevation ± 1 inch.

Catamaran barge/lifting beams picking Box 15 off of the transport barge.

The screed system consists of a 66-ft long by 12-ft wide traveler and a 96-ft by 36-ft rectangular frame, constructed of 12-ft deep pipe trusses, surrounding a 74-ft by 26-ft open area. The traveler supports 10 hydraulic winches and a 60-ft by 6-ft screed bar weighing 13 tons. In addition, there are four 24-in corner pin piles that have hauling sheaves at the screed level to pull the screed bar through the gravel and strike the gravel at design elevation. Without the pin piles (spuds), the entire screed system weighs 208 kips.

Two winches on the traveler raise and lower the screed bar and hold it at the design grade. Four of the winches position the screed bar directly below the traveler and are locked to hold that position. These four lines pull the screed bar as the traveler moves. The other four winches move the traveler from one end of the screed frame to the other.

After placing the gravel with a clamshell bucket, the screed is hauled from one end of the cofferdam to the other, striking the gravel at the prescribed elevation, and the screed bar is advanced with the traveler. The gravel can cause eccentric loading of the screed bar, which results in eccentric loading of the traveler. The traveler is kept in its proper orientation by a "cross wire system" which prevents the traveler from skewing.

Primary design considerations included: (1) keeping the system to a weight that could be lifted by available floating cranes; (2) keeping deflections to a minimum to stay within design elevation tolerances; and (3) handling eccentric loading of the screed bar.

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Tackling the Narrows

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located above the cutting edge of the caisson. The upper blocks attach to a heavy steel beam that can slide vertically in a series of brackets on the caisson face. As construction proceeds and the caisson extends lower, the beams will be lifted to keep the mooring point near the surface.

A short section of 4" chain connects the 3.5" bridge strand to the anchors.

At the seabed, each anchor line is attached to a driven plate anchor. Based on a design used by the Navy, these are 8-ft by 5-ft plates embedded into the seabed. Using equipment designed by TNC and Ben C. Gerwick, Inc., TNC is currently driving these anchors 50 ft into the seabed, in 90 to 180 ft of water and 3 knots of current, taking only 10 minutes for each anchor.

New Publications, Presentations & Awards

Publications:

Sam Yao and Ben Gerwick
"Positioning Systems for Float-in and Lift-in Construction in Inland Waterways"
U.S. Army Corps of Engineers Publication, ERDC/GSL TR-02-22, 2003

Presentations:

U.S. Army Corps of Engineers 2003 Infrastructure Systems Conference
Las Vegas, Nevada. May 2003.
"The Chickamauga Lock Project – An Innovative Solution"
James E. Gunnels and Sam X. Yao, Ph.D., P.E.

U.S. Army Corps of Engineers 2003 Infrastructure Systems Conference
Las Vegas, Nevada. May 2003.
"Underwater Repair of Lower Monumental Dam"
Stephan B. Tatro and Sam X. Yao, Ph.D., P.E.

ACI Spring Convention 357 Committee
Vancouver, British Columbia, Canada. April 2003.
"Recent Advances in Marine Structures"
Sam X. Yao, Ph.D., P.E.

Nanjing Hydraulic Research Institute
China, December 2002.
"Durability Design and Repair of Marine Structures and Hydraulic Structure"
Sam X. Yao, Ph.D., P.E.

6th International Symposium on Field Measurements in GeoMechanics
Oslo, Norway.
September 15-18, 2003.
"Development and Implementation of the Downhole Freestanding Shear Device"
Osama Safaqah, Ph.D.

University of California Seminar on Ocean Engineering
Berkeley, California.
February 7, 2003.
"Underwater Concrete"
Ben C. Gerwick, Jr. P.E.