Performing work over water has always been more difficult and expensive than performing the same work on land. And when the work is performed below water, the difficulties and cost difference can increase geometrically with the depth at which the work is performed. The key to carrying out marine construction work efficiently is to minimise work over water, and perform as much as possible on land. The use of float-in cofferdams to construct marine bridge foundations is a successful application of this principle and one of the first projects on which it was used was the Bath-Woolwich Bridge in Maine, over three years ago (Bridge issue no 14). Caltrans recognised the advantages of this construction method and applied it to the design of the main tower foundations for the new suspension bridge across the Carquinez Strait.

The contract for the new bridge was awarded in early 2000 to a joint venture between PCI Constructors and Cleveland Bridge California. Specialist consultant Ben C Gerwick was then appointed to modify Caltrans's float-in cofferdam concept and further reduce the amount of on-site work.

The foundation design for the new bridge requires six 3m diameter drilled shafts under each of the four main tower legs. Because of the very high lateral stiffness of these piles, it was possible to elevate the four tower footing blocks - 5.4m deep and 18m by 20m in plan - up off the bottom of the strait. At the north tower, the footing block is positioned 30m off the bottom with the lower edge of the footing at 2.34m below mean sea level.

How did they do that?

The important features of the new design that allowed the system to work successfully were:

- A cast and launch system for the four cofferdams and two connecting ties
- A shallow draught for the float-in cofferdams that allowed them to be floated in over the top of the pre-installed drilled shafts during a single high tide cycle
- A positioning system for the drilled shafts that allowed tight tolerances on the horizontal position of the casings, and thereby, ensured proper mating of the precast float-in cofferdam to the drilled shaft casings
- A system for cutting the drilled shaft casings off under water but in the dry
- A guide system, attached to the drilled shaft casings that allowed fast, accurate positioning of the float-in cofferdams in deep water and high tidal currents
- A temporary support system for quickly landing the cofferdam on the drilled shaft casings during slack tide
- A sealing system between the drilled shaft casings and the oversized holes in the bottom of the float-in cofferdam that allowed dewatering
- A second support system to handle the weight of the cofferdam plus the added weight of the footing fill concrete while providing clearance for the heavily reinforced pile-top-footing connection
support for the float-in cofferdam and infill concrete, and risk was also reduced as a result of decreasing exposure time of a partially completed cofferdam and footing to storm conditions.

Cofferdams and connecting ties were cast on a flat-deck barge, 22m wide by 76m long and 4.6m deep, which was positioned at the dockside within reach of a shore-based crane. The surface of the barge was prepared by casting a 150mm concrete slab to provide a level and smooth casting surface. In order to ensure that the cofferdams would lift off the barge at launch, the surface of the casting slab was sprayer with a bond breaker that created a polished surface. As an added precaution, water pressure was applied to the contact surface between the top of the slab and the underside of the cofferdams. This was performed a week after casting and before the six 3.8m diameter pile top blockouts were flooded with a head of 3m for launching. Complete release from the casting bed was confirmed when water seeped out at the perimeter of the cofferdam.

For the launch operation, a site was selected in the Carquinez Strait approximately 2km upstream from the bridge. The primary criteria was that the site should have a level bottom and a water depth at low tide of about 6.7m. The barge was towed to the site and positioned alongside a derrick barge on anchors. In order to maintain sufficient stability of the casting barge and cofferdams during the launch, the barge was ballasted down one end at a time. The stern of the barge was first set down on to the bottom during low tide, and then, as the tide turned, the bow was gradually ballasted down allowing the cofferdams to float free one at a time. Following launch, each cofferdam was towed to the dockside and stored afloat until the drilled shafts at the first tower were completed.

The modified design incorporated a number of features essential to the success of the project.

With the cut-off elevation of the drilled shaft casings at 1.55m below mean sea level, it was necessary to limit the draught of the float-in cofferdams to 2m. This was accomplished by various means: the wall thickness of the float-in cofferdam was decreased, semi-lightweight concrete with a specific gravity of 2 was used, and Styrofoam blocks were used to form the bottom ribs of the cofferdam. Each pile-top block-out in the bottom slab (located over the top of each pile position) was capped with an air tight 3.8m diameter steel cylinder and the water was forced out of the pile compartments with compressed air.

Calcins set one horizontal positioning tolerance for the 3m diameter drill shaft casings at ±150mm, but site conditions including water depths of up to 32m and tidal currents up to 3m/s made meeting this criterion difficult. In order to meet the specified tolerances under these conditions, a steel guide template with four spud piles was installed at the south tower and a template attached to the pile driving barge was used on the north tower. As an added precaution against fit-up problems during landing of the cofferdams, the size of the blockouts in the bottom of the float-in cofferdams was increased to 3.6m. This provided a theoretical clearance around the pre-installed drilled shafts of 330mm.

The system for cutting the drilled shafts under water included a 4.5m diameter cylindrical cofferdam that fitted over the top of the drilled shaft. The cofferdam sealed to the casing at about 1m below cut-off elevation by means of an inflatable rubber O-ring that fitted inside a circular recess at the bottom of the cofferdam. Following inflation of the seal, the cofferdam was dewatered and the drilled shaft casing was cut off in the dry to a precise elevation. This cut-off cofferdam also allowed access for welding a steel ring to the exterior of the casing; the ring was used to provide a watertight seal between the float-in cofferdam and the drilled shaft casings. It also provided the necessary shear resistance for the support of the cofferdam during the concrete infill operation.
High tidal currents in the Carquinez Strait meant there was only about an hour of slack tide during which the cofferdams could be landed. Hence it was necessary to install a guide system to allow rapid positioning and landing. Because the water was more than 32m deep, the guide system was attached directly to the 3m diameter drilled shaft casings. The guides were L-shaped wide flange brackets attached to the casing just below the landing support bracket and extended above high tide so they could be used for visual positioning of the cofferdams.

The 4.5m diameter cylindrical cofferdam allowed the tops of the casings to be cut off at a precise elevation. This provided an excellent bearing surface for the landing of the cofferdams. Caltrans' initial design showed the top of the casing protruding through the 3.2m diameter holes in the bottom of the cofferdam and cut off flush with the bottom floor of the precast cofferdam. Landing support was provided by steel beams spanning across four of the bottom slab openings and bolted flush to the floor of the precast cofferdam. The actual bearing surface was the top edge of the drilled shaft casing and the underside of the steel beam.

In order to dewater the cofferdam it was necessary to create a watertight seal between the six drilled shaft casings and oversized holes in the bottom of the cofferdam. This was accomplished by pre-welding doughnut-shaped steel rings - 12mm thick by 700mm wide - to the casings just below the cut-off elevation, at the finished bottom elevation of the cofferdam. These plates were attached in the dry by using the same 4.5m diameter cofferdam used for casing cut-off.

At the outer edge of the steel doughnut, an inflatable O-ring was bonded to the plate. As the void space around each casing was dewatered the hydrostatic pressure pushed up on the bottom of the steel plates and the rubber O-rings provided the necessary seal. In areas where the seal did not seal properly, vertical hangar bolts were available to pull the 12mm plate tight to the bottom of the cofferdam and compress the seal.

The initial support system for landing the cofferdams was simple and allowed a quick landing, but it was directly in the path of both the vertical extension of the drilled shaft reinforcement and the horizontal reinforcement in the bottom footing mat, hence it had to be replaced before the reinforcement could be installed.

Final support was provided by placing infill concrete in the void spaces between the 3m diameter drilled shaft casings and the oversized 3.6m diameter holes in the bottom of the float-in cofferdam. The 3.6m diameter cans positioned over the top of each hole provided access to this area and the seal system described above allowed the cans to be dewatered and the infill concrete to be placed in the dry. Hanger rods 25mm in diameter and spaced at 600mm along the centre of the void space provided shear reinforcement and the fillet weld connecting the 12mm plate to the drilled shaft casing provided the necessary shear resistance.

After the concrete in the void space had reached the specified strength, the entire cofferdam was dewatered, the 3.6m diameter cans were removed from each drilled shaft location, and the initial support beams were removed. At this point the area over the top of each drilled shaft casing was free and open for extending the drilled shaft vertical reinforcement up into the footing, and installation of the footing bottom reinforcement mat.

The first set of float-in cofferdams were installed at the north tower in March this year, and the second set are being stored on the deck of the barge where they were cast and will be installed following completion of the south tower drilled shafts. The entire bridge is scheduled for completion in late 2002.

These cofferdam techniques used on the new Carquinez Bridge will be applicable to two new bridges coming out for tender this year in the San Francisco Bay area: the Benicia-Martinez Bridge and the new eastern crossing for the San Francisco-Oakland Bay Bridge. Both projects plan to use large diameter steel cylinder piles and footing blocks located at or just below the water line.

Robert Bittner is vice president and chief engineer at Ben C Gerwick