



DEEP FOUNDATIONS

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**Deep Piles at
Challenging Site Near
Golden Gate Bridge:
An OPA Contender**

**SPECIAL
ISSUE: LANDMARKS**





Exceptionally long and heavy rebar cages

Doyle Drive – Extreme Pile Installation

The south access road to San Francisco's Golden Gate Bridge, known as Doyle Drive or Presidio Parkway, needs to be replaced. Built in 1936, it is the primary highway and transit linkage through San Francisco between counties to the north and south. The roadway is tucked into the natural contours of the Presidio and the Golden Gate National Recreation Area, one of the nation's largest urban parks.

The old steel truss structure will be replaced by a new concrete cast-in-place bridge. The foundation design of the new bridge is based on drilled mono shafts below each bridge column. Most shafts required large diameter permanent steel casing installed under strict vibration limitations since several historic landmarks are near the project alignment. Malcolm Drilling decided to use the largest oscillator in the world to install the piles.

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The area occupied by the Presidio is generally hilly, sloping down northwards to San Francisco Bay. In the western half of the project route, two bluffs rise steeply to about 80 ft (25 m). The bluffs are separated by a valley 60 ft (18 m) deep and 1,500 ft (457 m) wide, which is spanned by the old and new bridge. Overburden soils in this valley are made up of artificial fill, slope debris, ravine fill and Colma Formation, a fine to medium-grained sand unit with clay beds. The Bay Muds encountered in the project area are typically soft clayey silts, becoming medium stiff with depth.

The basement rocks underlying the overburden belong to the Franciscan Formation, described as shale, sandstone, serpentine and greywacke, it is extremely variable in hardness, fracturing and weathering. The material can vary from very hard to very soft, can be slightly to very intensely fractured and almost not weathered, to totally decomposed within relatively short distances both laterally and vertically. Rock strength can vary from too weak to be tested to serpentine layers with unconfined compressive strength of 15,000 psi (103MPa) or higher. Groundwater levels in the area are typically no more than 10 to 20 ft (3 to 6 m) below the ground surface.

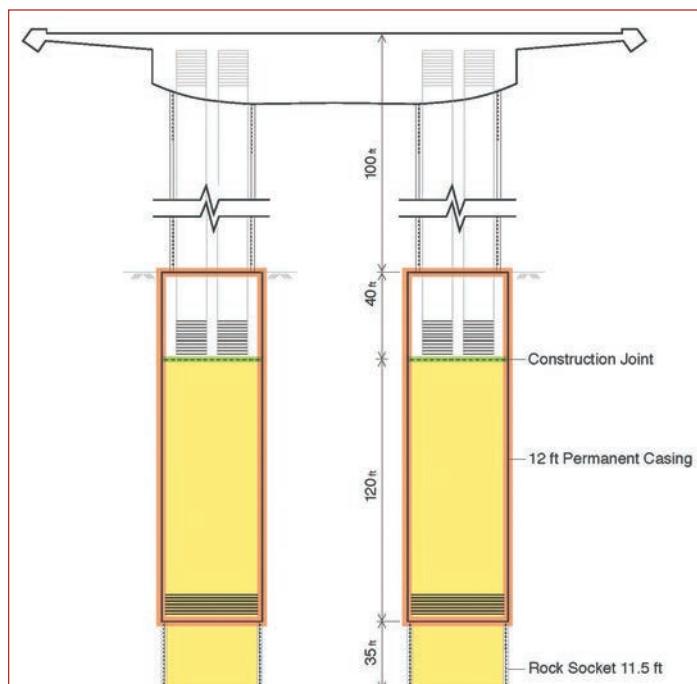
Construction

The main viaduct bridge is supported on 6 bents with one 12 ft (3.7 m) shaft underneath each bent. Abutments and one on-ramp are supported by smaller diameter shafts not discussed in this article.

The Doyle Drive Viaduct is the first highway bridge structure in California supported by 12 ft (3.7 m) diameter drilled shafts.

The client designed all 6 viaduct shafts with permanent 1.5 in (38 mm) wall thickness steel casing. The total weight of the longest 170 ft (52 m) casing was in excess of 400,000 lbs (181 tonnes) and required multiple splices to facilitate handling. Full penetration welding for such large casings takes time even while employing multiple welding crews. The risk of casing freeze-up during such extended welding time increases the risk of not advancing the casing to depth. The ground conditions on site included massive layers of non-cohesive materials which further increases this risk. Installing such long 12 ft (3.7 m) diameter steel casings by vibratory methods was ruled out due to noise and vibration issues. Moreover, even without these restrictions, using the largest vibro hammer would have been a major challenge. Impact driving was also considered very risky since the vibrations limits that the adjacent historic brick structures could withstand may be exceeded by the required powerful pile driving hammers.

To eliminate the risk of vibration entirely, Malcolm decided to use the largest available oscillator to advance the casings without inducing any ground vibration. The oscillator method also enables the casing to be turned during the splicing operation to reduce set-up. This was the first time such a large oscillator was used throughout the world. Therefore no comparable performance data was available. To complicate matters, schedule and site lay-out restrictions required the deepest shaft to be constructed first. One can imagine that almost everybody involved in the project anxiously awaited the first casing installation.



Viaduct cross section

The crew used a spherical grab to excavate the overburden within the casing. The grab was operated by a brand new 200 ton (180 tonne) duty cycle crawler crane, equipped with 2 synchronized 33 ton (30 tonne) winches for the extraction of this 44 ton (40 tonne) tool. The client designed the permanent steel casing to prevent caving in the upper, very loose dune sands and soft clay layers and to provide the best possible means for a defect-free construction of such large mono-shafts. The advantage of the oscillator installation method offers by using temporary instead of permanent casing was not utilized by the client in the shaft design or installation procedure. The design required all casings to be installed 5 to 10 ft (1.5 to 3 m) into the underlying Franciscan formation. Through the casing, the drilling contractor would then drill an "open hole" rock socket an additional 35 to 45 ft (10 to 14 m) into the bedrock.

Specifications required the mandatory use of polymer drilling fluid for all cased shafts as well as the uncased rock socket. Since material strength in the Franciscan Formation can vary widely, the casing tip is the most vulnerable section when penetrating the rock. The team decided to attach additional carbide reinforced teeth to the casing tip to aid the installation and to provide sufficient cutting clearance.

To drill the 11.5 ft (3.5 m) diameter rock sockets up to a maximum depth of 200 ft (61 m) below grade, Malcolm used one of the largest rotary drilling rigs, a Bauer BG 40. Several tools had to be custom built or shipped from overseas for these extreme shaft dimensions.



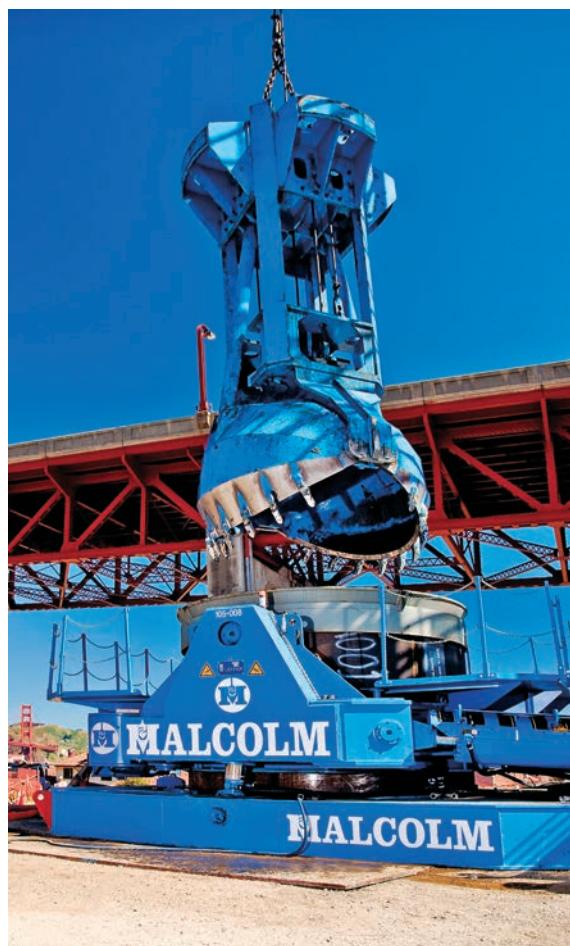
The world's largest Leffer Oscillator VRM 3800

Extreme seismic loads and very tall bridge columns resulted in a very dense reinforcement configuration with individual shaft cages weighing up to 150 tons (136 tonnes). Malcolm designed a custom tipping frame and unique suspension system to handle and splice these exceptionally long and heavy rebar cages. The site crew also attached additional stiffener rings to each cage section to safely support and transfer the cage loads. They also suspended the pile rebar cages over the casing using a custom built suspension frame and hydraulic jacks. Loads added to the suspension system by the fresh concrete were factored into the capacity of the system.

The concrete supplier developed a mix with special emphasis on maintaining workability for the extended duration of the tremie placement operation. Total placement duration was not controlled by the extraction of casing since it was permanent, but by the successful supply of concrete transported across the city of San Francisco. Traffic restrictions, as well as unforeseen road blockades due to accidents, rallies or simple day-by-day rush hour traffic were the challenges. The high-performing concrete mix had the characteristics of a self-consolidating concrete (SCC). About 50% of the Portland cement was replaced by a blend of ground granulated blast furnace slag and fly-ash that improved the workability and remarkably reduced the bleeding and segregation tendency. The 0.5 in (1.7 cm) crushed stone represented about 50% of the total aggregate in the mix. A variety of chemical admixture was used to control and maintain the workability for the extended placement duration. Concrete trial tests a month ahead of the first pour were required to develop the

This was the first time such a large oscillator was used throughout the world.

mixture and fine-tune the dosage of all four different admixtures. The mix proved to be one of the most successful high-performance concrete mixes used by Malcolm Drilling and is now a standard mix throughout the company.



The spherical grab for 12 ft (3.7 m) dia. excavations

Quality Control

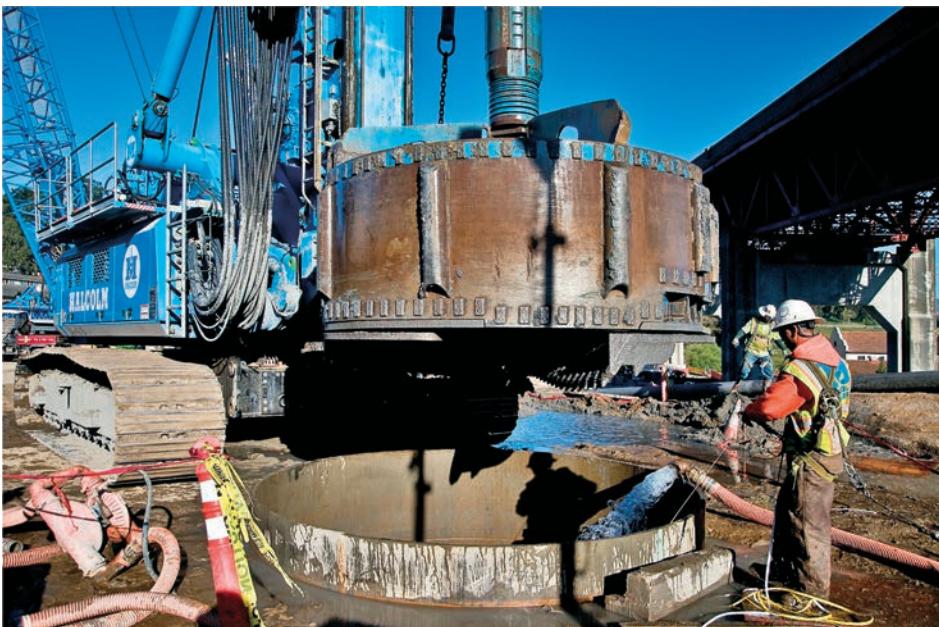
Standard specifications for any transportation project in California require the integrity testing of every shaft constructed with the Slurry Displacement Method including Gamma-Gamma NDT testing.

This test uses a radioactive probe lowered into a single (PVC) access tube and measures the amount of reflected photons. These are related to the energy level of the surrounding material and can be calibrated to the relative concrete density in a 2 to 4 in (5 to 10 cm) radius around the probe. Since access tubes are placed at the shafts perimeter, any sudden change in density might reveal a potential anomaly on the outside of the shafts, affecting the structural integrity of the entire shaft.

Additional Cross-Hole-Sonic-Logging (CSL) testing might then complement the Gamma-Gamma testing to determine the extent of the potential shaft anomaly through the core of the shaft. The CSL method is using ultrasonic waves that travel between access tubes across the shaft

core and measure the signal arrival time and transferred energy. Sudden signal time or energy changes along the shafts length will reveal variable concrete density and might therefore indicate potential anomalies in the shafts concrete core. The client tested all shafts on this project with both methods and they revealed only very little potential for anomalies. One minor near-surface concrete repair had to be performed and some so called "administrative deductions" for minor anomalies without any structural risk were imposed by the client.

Since the shaft design was based entirely on load transfer in the rock socket section, one of the main focuses during construction was directed towards the cleanliness of the shaft socket. The client used a Shaft Inspection Device (SID) camera for every shaft. The acceptance criteria were very strict with less than 0.25 in (63 mm) of sediment over a maximum of 50% shaft base. These criteria required the use of specially fabricated cleaning buckets, polymer sedimentation aids and air lifting to ensure contract compliance. Given the nature of the soil-type material rather than a classic hard-rock socket at the shaft base, there is definitely the need for material specific criteria to avoid unnecessary and potentially harmful shaft base cleaning procedures in the future.



Drilling of 11.5 ft (3.5 m) diameter rock sockets

Challenges

Engineers know the Franciscan Formation to be very variable in strength and sometimes, especially in large excavations, showing caving rock behavior. Local instabilities can easily create unstable excavation conditions that cannot be retained with drilling slurry and could jeopardize the entire shaft construction. This condition occurred in one shaft that required partial backfilling of the rock socket with lean concrete and the re-drilling of the rock socket to the specified depth and diameter. Predictable drilling conditions and procedures as well as efficient cleaning of the shaft tip are keys to successful completion and compliance with the specification in such ground conditions.

Such large shafts with single concrete volumes of up to 600 cu yds (460 m^3) also require detailed planning for every construction step. Equipment is getting bigger and requires not only a sufficient footprint for set-up, but also stable working platforms. At times, support piles are required to transfer the installation forces. Oscillators able to install 12 ft (3.7 m) casings can induce up to 990 tons (900 tonnes) of downward pressure into surrounding soil immediately adjacent to the shaft being drilled.

Support equipment like service cranes and slurry holding tanks soon exceed the “normal” dimensions and numbers our industry is familiar with when constructing “extreme” shafts. Lay-down areas have to be planned and constructed with extreme care and foresight.

Conclusions

Drilled shafts of this diameter and depth require a different perspective and approach than the “normal” foundation pile due to size and weight of all materials as well as required installation equipment. They also require special considerations of the borehole wall stability, both in caving soils and potentially caving rock. The new 12 ft (3.7 m) diameter oscillator has proven that it can effectively advance steel casings to such extreme depth of 170 ft (52 m) using a vibration free method.

This installation method does not only allow construction in environmental sensitive areas, but further enables the replacement of commonly used permanent steel casings with reusable temporary segmental drill casing. Temporary drill casings could also be further advanced into unstable or soft rock conditions, as previously demonstrated on the 7 ft (2.1 m) diameter shafts for the Benicia Martinez Bridge in California.

With the new generation of powerful hydraulic rotary drill rigs, shaft sockets can be drilled in fractured rock formations to extended depths even deeper than 200 ft (61 m). Malcolm demonstrated that temporary and permanent casing installation methods provide a superior construction technique in regards to pile integrity. This method has the best track record in anomaly-free pile installation as compared to other slurry displacement methods.



The Doyle Drive Viaduct in front of the Golden Gate Bridge



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Doyle Drive: Outsize Oscillator Debuts at San Francisco Site An OPA Contender

