Vibratory Caisson: A Case Study in the Southwestern Desert

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Abstract

Most of waterways in the southwestern United States are dry except during the local monsoon season, where sudden down pours of rain can result in quick and large runoffs. In such circumstances, construction sites and supporting equipment are exposed to potential of damage or washing away. The use of vibratory caisson provides an opportunity to get into a dry wash, install the foundation, and leave the hazard area before any water flow. This paper will describe the first transmission line utilizing vibratory caisson in the southwestern United States, including planning, permitting, environmental issues, foundation design, and structural design. This paper will also capture manufacturing, installation equipment, and construction challenges, and how these were mitigated. This paper will conclude with lessons learned from the above experience as well as any continuing discussion revolving around the use of vibratory caissons.

1. Introduction

Tucson Electric Power Co. is a municipality in southwestern U.S., located in the city of Tucson, Arizona. It operates overhead lines that include 46 kV, 138 kV, 345 kV, and 500 kV.

The subject of this paper is replacement of structure #30 and its foundation using a vibratory caisson. This structure is part of TEP Line-114, North Loop - Rillito 138 kV, located in Rillito Creek, Tucson, Arizona.

The replacement structure was an 85 ft tall tubular steel pole with “desert sage” color painted finish. This structure was to support a 5.7 degrees deflection angle while carrying two 138 kV circuits, although only one circuit was in place.

The structure weighed 9,600 lb.

The vibratory caisson initially planned for was 80 ft in length and used a base plate for its connection to the replacement pole above it.

The caisson material was A-572, Grade 60-65 steel. The caisson was galvanized and then coated on both inside and outside surfaces using CorroCote, 35 mills, and minimum average.

In an effort to get the structure replaced as soon as possible, assumptions were made on the required length, which were later modified.

Once geotechnical investigation and scour analysis were both complete, then the caisson length was reduced by 20 ft while still at the manufacturing. The final caisson length was 60 ft.

The caisson weight = 35,250 lb. initially and 27,800 lb. (after alteration in length).

The top 30 ft had 7/8" PL and its bottom 50 ft was 1/2" PL. The polygonal caisson had a diameter that was 57.25" as measured across the flats.

The objective was to drive the caisson 50 ft into the riverbed and have 10 ft left above it, so that the base of the structure would be above full river flow.

The caisson was vibrated 45 ft, before hitting refusal. The caisson was left with 15 ft above the surface of the riverbed.
Design required 44 ft of burial depth. Figure 1 shows the white mark indicating 50 ft depth on the caisson.

2. What is a Vibratory Caisson?

A vibratory caisson is a hollow end tubular steel shaft with typically zero taper. The cross section may be polygonal or round. A hydraulic hammer mounted on top of it (see Figure 2) accelerates/vibrates the caisson until the soil in contact with the caisson reduces its axial capacity enough to become effectively liquefied, and this allows the caisson to drop through the soil. Once the hammer is turned off, the soil returns to its natural post vibration state and the foundation is ready for use. Figure 3 is a diagram of the caisson described in this paper. Figure 4 is a photo of the caisson unloaded on the riverbed.
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Figure 3. Diagram of vibratory caisson assembly.
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Figure 4. Photo of vibratory caisson unloaded on the riverbed.

There are no data sources that would indicate if vibratory caissons are better suited for one type of soil or another; however, their use in cohesion-less soils, does eliminate a need for securing the excavation walls during construction.

Many vibratory caissons are installed for transmission line applications along the southeastern United States in Louisiana, Georgia, Mississippi, South Carolina, Florida and Texas; however, this does not limit their usage in this area of the country.

Vibratory caissons have been used for single shaft structures subject to overturning moments as well as x-braced multi shaft structures subject to compression and uplift loads. They have been used in swamps and bays, as well as dry lands. They are not intended for use in rocks.

The connection between the supporting structure and vibratory caissons is typically made in one of three methods: drop-in type, flanged type, and slip-jointed type. These methods are illustrated in Figure 5.
3. Design Considerations

A. Site Geotechnical Investigation

Geotechnical investigation of the site consisted of only one boring taken on May 27, 2008. The boring was extended to a depth of 86.5 ft.

The riverbanks were soil cemented for protection and they extended 10 ft above river bottom at the time of investigation. Figure 6 shows the location of structure #30 in the riverbed.

Water was not encountered at the time of boring; however, it was considered in the design.
The soil on-site changed from Sand and Gravel to Gravelly Sand with varying layers of cemented clay in between. During the installation a thin layer of cemented clay was encountered around 30 ft and then a thicker layer around 45 ft.

Geotechnical boring showed blow counts of around 94 at 30 ft, 59 at 45 ft and 81 at 50 ft depths. Below surface varying size, boulders are not unusual to come across of in a riverbed and the initial location selected for the caisson came across one. The caisson was then vibrated out and relocated.

The boring logs of the site are shown in Figure 7.

![Figure 7. Soil boring logs.](image_url)

**B. Foundation and Structural Designs**

i. **Design Loading**

Design Loads at top of caisson:

Axial=17 kips  
Shear=27 kips  
Moment=1,862 kip-ft  

Caisson Weight = 35.35 kips (initially) and then 28.7 kips (after it was cut).

Top 20 ft of caisson exposed to 460 psf flowing water pressure.
The rest of caisson to its scour depth exposed to 30 psf flowing water pressure.

ii. Foundation Design

The Federal Highway Administration (FHWA), various departments of transportation, and the American Association of State Highway Transportation Officials (AASHTO) provide varying degrees of guidelines on design of piles, driven or vibrated, even ones with open-end cross sections; however, these are intended for roadway structures subject to heavy axial loads. There are not any clear guidelines for design of vibratory tubular caissons of diameter noted in this report intended for support of transmission line structures subject to overturning moments due to wind and water flow.

The foundation design for this caisson was not approached any differently than other deep foundations. The geotechnical firm working on the project provided two separate designs, which were based on Broms methodology [1]. These design alternatives are listed below:

- Depth of 22 ft below scour for 0.5 degree rotation.
- Depth of 15 ft below scour for 1.5 degree rotation.

Impact of Vibration on the Coefficient of Friction for Soil/Caisson Interface:
The vibration is likely to densify or loosen the soil immediately adjacent to the caisson, which in turn would affect the resulting coefficient of friction.

The drag or negative shear stress is one potential of relative settlement of caisson to the surrounding soil during the liquefaction. The potential of liquefaction impact post-installation was considered in the design; however, not during the installation.

Another relevant question was behavior of soil confined within the walls of caisson. This was considered in the structural design of caisson.

As of early 2018, CEATI was attempting to form a study group on Vibratory Caisson Design.

iii. Structural Design of Foundation

The manufacturer was asked to design the caisson’s moment capacity to match the loads calculated based on the foundation analysis, which included the maximum moment below scour depth as well as above it.

Design of Connection for Mounting of the Hammer:
Mounting plate connections were provided on the caisson based on the request by the vibratory hammer operator. Four plates were provided 90 degrees apart as shown in Figure 8.
iv. Other Design Considerations

*Design for Scour:* For development of scour depth, a 100-year flow was evaluated. The installation required a Flood Control Use permit. During the permit process, the Pima County Regional Flood Control District identified a lower flow velocity based on their latest hydrology models. This resulted in a scour depth change from 29 ft to 22 ft, with a F.S. = 1.3.

*Torsional Rotation of Caisson during Installation:* During the installation, the caisson rotated about its vertical axis. Design needs to consider adjustment for this rotation so that all attachments end up along the right orientation. In this case, four options were considered and one was ruled out. These options were:

- Oversized holes in base plate by 3/8"
- Rotating the pole one or more flats and welding new jacking nuts on
- Drilling additional holes thru the pole along the right orientation for the line post insulators
- Slotting the holes in base plate

While the fourth option, slotting the holes in base plate, was also reviewed, the additional cost of making the baseplate thicker did not justify it. This option would be beneficial for a pole with steel arms where the proper orientation may require the pole to be cut at its base and re-welded back on.
Combination of Impact by Floating Objects and Corrosion:
The caisson wall needed to be 3/8" thick to carry the impact of design loads. However, 7/8" thick plate was used for the top 30 ft of the caisson and 1/2" thick plate for the balance due to the following reasons:

- To account for limited floating objects.
- Corrosion: In case both CorroCote and galvanizing finishes failed, then at the corrosion rate of the site, the structure would have sufficient steel to last another 15 years.

4. Public Outreach

A. Vibration Impact
Residents adjacent to the area were notified. The vibration could not be felt at distances of 40 ft to 50 ft away.

B. Noise Impact
Most of the generated noise was muffled by the heavy traffic in adjacent River Avenue and the distance separating construction site from residences.

No sound recording was made of the area prior to or during the installation. In hindsight, this would have provided useful reference data for future projects.

5. Construction Sequence

A. Environmental Restrictions
Vehicles needed to avoid driving on vegetation in the riverbed as much as possible, but were permitted to do so as long as they were not tracked, as these tend to uproot vegetation. For areas to be traversed by tracked vehicles, the riverbed had to be matted.

The contractor did not own a hammer; therefore, they rented one from a company in California. The rental agreement included a supervisor from the hammer company to travel to construction site for guidance on assembly and use of the equipment.

The contractor did excavate a 5 ft deep hole for aligning the caisson. The hammer was then lifted using a crane and secured in place on top of caisson using the mounting plates.

Figure 9 shows the excavation hole for alignment and to the right of it, the caisson as it was getting aligned.
During the installation, a boulder was encountered. The caisson was vibrated out and relocated 5 ft, then vibrated back in.

It took 18 minutes for the hammer to drive the caisson 45 ft deep into the riverbed, where a thicker layer of hardened clay stopped the progress.

The actual driving time for the caisson was 8 minutes, while the other 10 minutes was spent unsuccessfully trying to keep the caisson from rotating about its axial length as it was driven through.

6. Cost Analysis

Installation cost for the vibratory caisson and the caisson itself was $87,400 for labor and rented hammer plus $45,000 for caisson itself, for a total of $132,400.

The caisson was installed in one day and line crew installed the structure in the following day. Figure 10 shows the completed installation.

The hammer used was a 250 ton-ft rated hammer, rented for $4,000. A 600 ton-ft hammer could have been rented for an additional $600. Figure 11 shows the 250 ton-ft hammer that was used.

Installation cost for an equivalent conventional reinforced concrete foundation was $140,000 for conventional foundation, plus $2,500 for anchor bolts, based on the various quotations that were received.

It had been estimated that a conventional foundation would take four days to install and 28 days to cure.
Figure 10. Installation complete.

Figure 11. Vibratory hammer getting installed.
7. Lessons Learned/Benefits & Disadvantages

A. Lessons Learned

- Addition of below grade coating such as CorroCote requires special care, particularly over galvanized surfaces. Addition of such coating inside and outside of the caisson requires even more scrutiny. The manufacturer may require special procedure for such applications.
- Request enough borings during the geotechnical investigation so that you can develop a profile of the site, in case you need to move the structure. The majority of the cost of such investigation is on the mobilization end rather than additional borings.
- Review your load case combinations; combining worst case flooding with worst case overhead scenario may be excessive, particularly if the flooding scenario is only on a short-term basis. It typically takes a bit of lag time for the flooding to form following the storm.
- Review the hammer selection with your contractor and its associated cost; it may prudent to pay more for a bigger hammer.
- It would be prudent to take noise level readings before and during construction.

B. Benefits of Vibratory Caisson

- Quick installation; no need to wait for the foundation to cure; it is usable the moment you turn off the hammer.
- Minimal disturbance (no excavation or drilling, and no spoils to remove), which minimizes the environmental impact on sensitive areas.
- If access is an issue, helicopter-lifted caissons and hammers may be an option to consider. This will also reduce environmental footprint further.
- Depending on the location and access to a hammer, the cost for deep foundations (70 to 100 ft) may be competitive to conventional reinforced concrete foundations. In some areas, it may even be less expensive.

C. Disadvantage of Vibratory Caisson

- It falls in a unique construction category, so not every construction company deals with vibratory hammers or have ready access to them.
- More design guidelines are needed – hopefully, the CEATI program will provide this.
- Sufficient guidelines on selection of the hammer are not available.
- No data is available on any that have been installed and removed after 30 years.

8. References