With more and more utilities carefully evaluating the total environmental and economic impact of installing needed transmission lines, including not only structure but foundation costs, many have turned to the use of steel caisson foundations for their many inherent benefits. Steel caissons have recently been used to support single poles, tubular H-Frames, and lattice towers thereby realizing the many advantages and significant cost savings which they can provide.

The basic premise behind the use of steel caisson foundations is that in many applications a steel tube can be designed and installed more rapidly and economically than other, more conventional, foundation types providing a predictable and cost effective foundation system. It is usually integral to this premise that the soil conditions be such that installations can be accomplished by driving the steel caisson into the ground without excavation of the site.

This paper will attempt to outline the basic practical information available about steel caisson foundations, but is not intended to be an in-depth presentation of technical information.

**Size Parameters**

Four different variables must be evaluated in order that a steel caisson can be selected which will both support the above-ground structure and allow for proper installation and attachment.

The first variable to be considered is caisson diameter. A caisson diameter must be selected which will physically allow for the desired above-ground structure attachment (See Structure Attachment). If a "socket" type connection is to be used, a minimum cementing annulus of approximately three inches should be provided between the steel caisson's interior walls and the supported structure's maximum outside dimension. Providing a smaller space would make cementing difficult, while providing a larger opening would require greater volumes of cementing materials, and if taken to an extreme could result in unmanageable stresses in the in-place cement mixture.

If a "cap/base plate" type connection is to be used, the caisson must be of a diameter that will either allow for stud placement inside the caisson (type "A") or outside the caisson (type "B") without interference from the caisson's walls. The clearance distances provided should be kept to a minimum in order that the required thicknesses of the cap and base plates do not become excessively large from carrying the induced bending stresses.

The second variable which must be evaluated is the caisson wall thickness. When caissons are to be installed with a vibratory hammer (See Installation Techniques), a minimum wall thickness should be specified to prevent buckling or fatigue cracking during installation. When highly resistive or non-granular soils are anticipated, a minimum wall thickness of 3/8" should be specified. In extreme conditions, a 1/2" minimum wall thickness may be advisable. Unless caisson embedment depths are extremely short (less than 10 feet) a wall thickness of less than 1/4" should not be used for vibratory installed caissons, regardless of soil conditions.

Caisson wall thicknesses are also a function of the overturning moment, shear, and axial loads which they must carry. Allowable stress criteria are specified in several publications and will not be duplicated here. \(^1,2\) In essence, there is very little difference in the design philosophy applied to a steel caisson and that which is used to design and above-ground tubular steel structure. It should be noted, however, that the induced loads normally increase through the first few feet of embedment depth and since the steel caisson is of constant cross section, the associated stresses will also increase below the groundline.

The third size variable to be determined is the material strength. This value is determined in conjunction with the first two variables to meet loading criteria. When high strength steels are specified, Charpy "V" notch toughness properties may also be required to insure sufficient ductility to prevent cracking during installation or subsequent structure loading. Care should be taken to avoid specifying material grades which are not readily available or delays in foundation deliveries could result.

The final variable to be addressed in sizing the steel caisson is the required length. The length is a function of the required above-ground projection, if any, and the required embedment depth to resist the anticipated loads without excessive deflections.

To determine the embedment depth, a geotechnical
Technical Bulletin #1
The Use of Steel Caisson Foundations
For Supporting Electrical Transmission Line Structures

evaluation must first be performed to ascertain
the nature of the soils present along the proposed
transmission line. Soil borings must be taken at
regular intervals along the line and at suspected
poor soil locations. Borings should also be taken at
the sites of severely loaded structures. Undisturbed
samples of cohesive soils should be taken with
standard penetrations test made in cohesionless soils.
Laboratory testing should be performed to determine
unconfined compression, natural moisture content,
total unit weight, atterberg limits and grain size.

With the information obtained from the field borings
and the laboratory testing, a design analysis pf the
flexible steel caisson can be performed using various
methods to determine an embedment depth. The
embedment must provide a factor of safety of 1.5
to 2.0 against ultimate strength for normal loadings
with possibly a lesser factor of safety for maximum
transient type loadings. Applicable industry codes
should be consulted to determine appropriate
foundation design parameters. Anticipated
groundline deflections should also be calculated and
held to within acceptable limits (from 2”-5” under
maximum loading is commonly used).

Installation Techniques
Steel caisson foundations can be installed using
several methods. When only a small number
of foundations are required, installation using a
conventional drop hammer may be the most cost
effective approach. Jetting with either air or water
may also be used in granular soils and may, therefore,
reduce the strength of the in-place foundation. The
most effective method for installing steel caisson
foundations has proven to be the use of a vibratory
hammer. When using this technique, the vibratory
hammer grasps the steel caisson using hydraulic
rams on either side. The steel caisson is fitted with
reinforcing plates or drive “ears” during fabrication to
prevent damage and facilitate hammer attachment.
Hydraulic clamping forces of from 50 to 500 tons are
used depending on the size of hammer employed.
The hammer then “shakes” the caisson into the
ground with no need for excavation of the site. The
frequency and stroke amplitude used for vibrating in
the foundation also varies depending on the model
of hammer used, 400-1600 vibrations per minute are
most common with an amplitude of from 1/2” to 1-
1/2: being typical.

Vibratory installation is most easily accomplished in
less than five minutes. When more resistant soils are
encountered, driving times may exceed one hour and
the technique of pre-auguring the hole has often
been used effectively. When pre-auguring, a digger
with an augur smaller than the caisson is run into the
ground first and then extracted leaving the disturbed
soil in the hole. This disturbed soil allows for some
relaxing of the materials inside the steel caisson
leading to more rapid driving.

Steel caissons can usually be vibrated through buried
rubble and, when fitted with a reinforcing collar at
the lower end, have broken through rocks up to
two feet in diameter. Should a steel caisson prove
to be undrivable at a particular site location, it can
be extracted with vibratory hammer and moved to
another location or installed in the same manner as a
direct embedded pole and then back-filled.

Vibratory hammer were originally developed for use
near other structures where peak particle velocities
must be held below 2.0 inches per second to prevent
damage to normal structures. Actual peak particle
velocities have been measured while installing steel
caisson foundations and did not exceed 0.12 inches
per second at a distance of 50 feet from the pile. The
velocities were, in most cases, less than 0.18 inches
per second at a distance of only 25 feet from the
pile. It is believed that, due to the length of diving
time, vibrations may be more critical where clays
are present. It is advisable that where vibrations are
considered critical, they should be monitored during
pile installation since peak particle accelerations as
low a 0.20 inches per second may be unpleasant to
humans and cause complaints. 1

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Structure Attachment

The above-ground structure can be secured to the foundation using either a “socket” type attachment (See Figure 1) or a “cap/base plate” arrangement (See Figure 2). Both joint types have advantages and costs which should be weighed by the specifying engineer prior to selection.

When a “socket” type attachment is used, pile cap and structure base plates are not required. The elimination of these heavy plates, and the 100% penetration welding required for attaching them, greatly reduces the cost of both the steel caisson foundation and the above-ground structure. The load is transferred using a cemented overlapping joint. The above-ground structure is telescoped inside the foundation for a distance of approximately 1-1/2 times its diameter where it then rests on a loose plate which is supported by clip angles welded inside the steel caisson. The structure is secured in place and plumbed by the use of eight alignment bolts provided for this purpose. A thru-bolt, passing through both the above-ground structure and the foundation, is also often specified if large uplift loads are anticipated, as in the case of multi-legged frame structures. After plumbing, the annulus between the caisson and the above-ground structure is cemented with a concrete mixture containing a 1/2” maximum size aggregate to allow for placement in the narrow opening. The minimum space between the structure and the steel caisson should be approximately three inches.

The “socket” type connection is by far the most economical method for attaching the above-ground structure to the foundation. However, its use does restrict the foundation diameter to a narrow range and make subsequent replumbing or structure removal difficult.

When a “cap/base plate” type connection is specified, the above-ground structure is fitted with a base plate just as it would be for a conventional concrete foundation. The holes provided in the structure base plate need not be oversized to the extent normally specified for a concrete foundation since a hole 1/4”-3/8” larger than the required bolt diameter should be adequate to insure proper alignment. The steel caisson foundation is fitted with a matching steel cap plate during fabrication. Fully threaded studs are secured to the steel caisson foundation cap plate by hex nuts located on each side of the plate after caisson installation. A third hex nut is threaded onto each stud bolt ad the above-ground structure is then rested on these nuts and secured with a fourth hex nut.

Final structure plumbing can be easily accomplished by adjusting the nuts which are on either side of the structure base plate. If welded drive “ears” are located where they interfere with the structure placement, they should be removed and the damaged area coated prior to attempting structure erection.

When lattice towers are to be supported with steel caisson foundations either stub angles or anchor bolts can be cast into a concrete socket at the top of each caisson. The steel caisson can also be fitted with a welded cap assembly for attachment of the tower stub angles or anchor stud bolts if desired.

Corrosion Protection

Protecting the buried steel caisson foundation from corrosion is an important part of insuring structural integrity throughout the design life of the line. A careful evaluation of the corrosiveness of the soil should be made.

Soil resistivity can be measure either in the lab by the use of a soil box or in the field using the Wenner Method (four-pin method). If soil resistivity is sufficiently high (over approximately 12,000 ohm-centimeters) a galvanized caisson, with 14 to 18 mils of coal tar epoxy applied near the groundline, should provide adequate protection. When soil resistivity is below this level, additional protection, through the use of anodes, may be required.

Anodes can be either directly attached to the caisson, as with diamond ribbon anodes, or can be located near the caisson and connected with a lead wire. Zinc anodes should be used wherever possible since they tend to be self-regulating and require no adjustments after installation. When soil resistivity exceeds 3000 or 4000 ohm-centimeters, magnesium anodes may be needed.

A corrosion expert familiar with the local soil conditions should be consulted prior to selecting the investigative and preventative measures to be taken on a given project.
Technical Bulletin #1
The Use of Steel Caisson Foundations
For Supporting Electrical Transmission Line Structures

Costs

Installed costs of steel caisson foundations very greatly depending upon foundation loadings and soil conditions. A comparison between a “socket” type steel caisson foundation and a conventional anchor bolt and drilled pier foundation on a typical 230kV single pole structure will show savings approaching 50% in favorable soil conditions. Savings are even higher if special installation techniques, such as casing, are required for the concrete foundation. Each job should be evaluated based upon soil conditions, construction schedules, accessibility, and foundation loadings to determine what, if any, cost savings may be obtained using steel caisson foundation. In general, however, savings of from 30% to 40% can be expected in favorable soil conditions.

Other Evaluation Factors

1. Foundation installation time is substantially reduced when vibratory techniques can be used. Steel caisson foundations can be installed at a rate of from 8 to 14 per day as opposed to 1 to 2 per day when poured in place concrete foundations are used. This time savings allows for a much later starting date, thereby postponing right-of-way and contractor expenditures.

2. The use of steel caisson foundations allows for much greater control over the resulting foundation quality by eliminating the variances present in the concrete placement and critical control of water content. Surrounding soil conditions are actually improved due to a consolidation caused by vibratory foundation installation.

3. An additional problem is also resolved since access road quality need not be as great as would be required for the use of concrete trucks. In most cases “roadless construction” techniques can be utilized.

4. Disposal considerations, as needed for concrete slurries and removed dirt, are also no longer necessary.

5. Helicopter delivery to the structure location is greatly facilitated by the lighter weight of steel caisson foundations as well as the equipment required for their installation. This consideration may make structure installation far less expensive than would be experienced when using prefabricated or poured in place concrete foundations.

For more details regarding steel caisson foundations, contact your Thomas & Betts sales representative.

References


Technical Bulletin #1

The Use of Steel Caisson Foundations
For Supporting Electrical Transmission Line Structures
Technical Bulletin #1

The Use of Steel Caisson Foundations
For Supporting Electrical Transmission Line Structures

SPECIAL INFORMATION

1. MATERIAL SPECIFICATION: SEE STANDARD DRAWING SS0001. GENERAL INFORMATION NOTE 1A FOR STEEL SPECIFICATIONS FOR GALVANIZED POLES, UNLESS NOTED BELOW. EXCEPTION: NONE

2. PLATE TESTING:
HEAT Lot:
SEE SHEET SS0001. GENERAL INFORMATION, NOTE 2.

3. FINISH (GALVANIZED)
CAISSONS – BLAST PER SSPC-SP7.
RELEASES “A, B, D & L” CAISSONS – HOT DIP GALVANIZED PER ASTM A-123.
RELEASE "C" CAISSONS – GALVANIZE TUBE SECTION W/O CAP PLATE PER ASTM-123.
WELD CAP PLATE ONTO TUBE AFTER TUBE HAS BEEN GALVANIZED.
CAP PLATE TO BE METALLIZED.

COATING – AFTER GALVANIZING COAT THE TOP 7’-0” OUTSIDE
SURFACE OF THE CAISSON WITH CORROCOAT 1 CLASSIC.
PNT 219A AND 219B (2) COATS, 8.0 MIL EACH,
15-16 MIL DRY FILM THICKNESS.

DO NOT CORROCOAT CAP PLATE AND GROUND PLATE.

BOLTS – HOT DIP GALVANIZED PER ASTM A-153
NUTS – HOT DIP GALVANIZED PER ASTM A-153

4. VENT HOLES:
GALVANIZE TO FILL VENT HOLES WITH SILICONE SEALANT AFTER GALVANIZING.

5. WARNING:
MARK STRUCTURE # ON TOP OF CAP PLATE WITH 2” WELD BEAD.

6. PROVIDE A 45° BEVELED EDGE AT THE BOTTOM OF ALL CAISSONS AROUND ENTIRE PERIMETER.

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FIELD ASSEMBLY DETAIL

<table>
<thead>
<tr>
<th>STEEL STRUCTURES GROUP</th>
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<tbody>
<tr>
<td>INSIDE BOLT CIRCLE</td>
</tr>
<tr>
<td>CAISSON W/CAP PLATE</td>
</tr>
</tbody>
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REV. DESCRIPTION DRAFT/DATE ENGINEER:
Technical Bulletin #1
The Use of Steel Caisson Foundations
For Supporting Electrical Transmission
Line Structures

Vibratory Installation and Alignment
Technical Bulletin #1

The Use of Steel Caisson Foundations
For Supporting Electrical Transmission Line Structures

Base Plated Caisson Installation
Technical Bulletin #1
The Use of Steel Caisson Foundations
For Supporting Electrical Transmission Line Structures

Single Pole Structures Using ‘Socket’ Type Attachment

Structure Using ‘Cap/Base Plate’ Connection
Technical Bulletin #1

The Use of Steel Caisson Foundations
For Supporting Electrical Transmission
Line Structures

Vibratory Installation of 500kV H-Frame Caissons

Anchor Bolt Attachment
Technical Bulletin #1

The Use of Steel Caisson Foundations
For Supporting Electrical Transmission Line Structures
Technical Bulletin #1

The Use of Steel Caisson Foundations
For Supporting Electrical Transmission Line Structures

Notes