Module 9
(Lecture 40)

DRILLED-SHAFT AND CAISSON FOUNDATIONS

Topics

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CAISSONS

TYPES OF CAISSONS

Caissons are divided into three major types: (1) open caissons, (2) box caissons (or closed caissons), and (3) pneumatic caissons.

Open caissons (figure 9.30) are concrete shafts that remain open at the top and bottom during construction. The bottom of the caisson of the caisson has a cutting edge. The caisson is sunk into place, and soil from the inside of the shaft is removed by grab buckets until the bearing stratum is reached. The shafts may be circular, square, rectangular, or oval. Once the bearing stratum is reached, concrete is poured into the shaft (under water) to form a seal at its bottom. When the concrete seal hardens, the water inside the caisson shaft is pumped out. Concrete is then poured into the shaft to fill it. Open caissons can be extended to great depths, and the cost of construction is relatively low. However, one of their major disadvantages is the lack of quality control over the concrete poured into the shaft for the seal. Also, the bottom of the caisson cannot be thoroughly cleaned out. An alternative method of open-caisson construction is to drive some sheet piles to form an enclosed area, which is filled with sand and is generally referred to as a sand island. The caisson is then sunk through the sand to the desired bearing stratum. This procedure is somewhat analogous to sinking a caisson when the ground surface is above the water table.

Figure 9.30 Open caisson
Box caissons (figure 9.31) are caissons with closed bottoms. They are constructed on land and then transported to the construction site. They are gradually sunk at the site by filling the inside with sand, ballast, water, or concrete. The cost for this type of construction is low. The bearing surface must be level, and if it is not, it must be leveled by excavation.

Pneumatic caissons (figure 9.32) are generally used for depths of about 50-130 ft (15-40 m). This type of caisson is required when an excavation cannot be kept open because the soil flows into the excavated area faster than it can be removed. A pneumatic caisson has a work chamber at the bottom that is at least 10 ft (≈ 3 m) high. In this chamber, the workers excavate the soil and place the concrete. The air pressure in the chamber is kept high enough to prevent water and soil from entering. Workers usually do not counter severe discomfort when the chamber pressure is raised to about 15 lb/in² (≈ 100 kN/m²) above atmospheric pressure. Beyond this pressure, decompression periods are required when the workers leave the chamber. When chamber pressures of about 44 lb/in² (≈ 300 kN/m²) above atmospheric pressure are required, workers should not be kept inside the chamber for more than 1 1/2 hours at a time. Workers enter and leave the chamber through a steel shaft by means of a ladder. This shaft is also used for the removal of excavated soil and the placement of concrete. For large caisson construction, more than one shaft may be necessary, an airlock is provided for each one. Pneumatic caissons gradually sink as excavation proceeds. When the bearing stratum is reached, the work...
chamber is filled with concrete. Calculation of the load-bearing capacity of caissons is similar to that for drilled shafts. Therefore, it will not be further discussed in this section.

![Diagram of a pneumatic caisson](image)

**Figure 9.32 Pneumatic caisson**

**THICKNESS OF CONCRETE SEAL IN OPEN CAISSONS**

In section 3, we mentioned that, before dewatering the caisson, a concrete seal is placed at the bottom of the shaft (figure 9.33) and allowed to cure for some time. The concrete seal should be thick enough to withstand an upward hydrostatic force from its bottom after dewatering is complete and before concrete fills the shaft. Based on the theory of elasticity the thickness, \( t \), according to Teng (1962) is
Figure 9.33 Calculation of the thickness of seal for an open caisson

\[ t = 1.18R_i \sqrt{\frac{q}{f_c}} \]  \hspace{1cm} \text{(circular caisson)} \quad [9.48]

And

\[ t = 0.866B_i \sqrt{\frac{q}{f_c [1 + 1.6 \left( \frac{L_i}{B_i} \right)]}} \]  \hspace{1cm} \text{(rectangular caisson)} \quad [9.49]

Where

- \( R_i \) = inside radius of a circular caisson
- \( q \) = unit bearing pressure at the base of the caisson
- \( f_c \) = allowable concrete flexural stress (\( \approx 0.1 - 0.2 \) of \( f'_c \) where \( f'_c \) is than 28 - day compressive strength of concrete)
- \( B_i, L_i \) = inside width and length, respectively, of rectangular caisson

According to figure 9.33, the value of \( q \) in equations (48 and 49) can be approximated as

\[ q \approx H \gamma_w - t \gamma_c \]  \hspace{1cm} [9.50]
Where

\( \gamma_c = \text{unit weight of concrete} \)

The thickness of the seal calculated by equations (48 and 49) will be sufficient to protect it from cracking immediately after dewatering. However, two other conditions should also be checked for safety.

1. Check for Perimeter Shear an Contact Face of Seal and Shaft

According to figure 9.33, the net upward hydrostatic force from the bottom of the seal is \( A_i H \gamma_w - A_i \gamma_c \) (where \( A_i = \pi R_i^2 \) for circular caissons and \( A_i = L_i B_i \) for rectangular caissons). So the perimeter shear developed is

\[
v \approx \frac{A_i H \gamma_w - A_i \gamma_c}{p_i t} \]

[9.51]

Where

\( p_i = \text{inside perimeter of the caisson} \)

Note that

\[
p_i = 2\pi R_i \quad \text{(for circular caissons)} \]

[9.52]

And that

\[
p_i = 2(L_i + B_i) \quad \text{(for circular caissons)} \]

[9.53]

The perimeter shear given by equation (51) should be less than the permissible shear stress, \( v_u \), or

\[
v (\text{MN/m}^2) \leq v_u (\text{MN/m}^2) = 0.17\phi \sqrt{f'_c} \quad (\text{MN/m}^2) \]

[9.54]

Where

\( \phi = 0.85 \)

In English units,

\[
v (\text{lb/in}^2) \leq v_u (\text{lb/in}^2) = 2\phi \sqrt{f'_c} \quad (\text{lb/in}^2) \]

[9.55]

Where
\[ \phi = 0.85 \]

2. Check for Buoyancy

If the shaft is completely dewatered, the buoyant upward force, \( F_u \), is

\[ F_u = \left( \pi R_d^2 \right) H \gamma_w \] (for circular caissons) \[ 9.56 \]

And

\[ F_u = (B_0 L_0) H \gamma_w \] (for rectangular caissons) \[ 9.57 \]

The downward force, \( F_d \), is caused by the weight of the caisson and the seal and by the skin friction at the caisson-soil interface, or

\[ F_d = W_c + W_s + Q_s \] \[ 9.58 \]

Where

- \( W_c \) = weight of caisson
- \( W_s \) = weight of seal
- \( Q_s \) = skin friction

If \( F_d > F_u \), the caisson is safe from buoyancy. However, if \( F_d < F_u \), dewatering the shaft completely will be unsafe. For that reason, the thickness of the seal should be increased by \( \Delta t \) [over the thickness calculated by using equation (48) or (49)] or

\[ \Delta t = \frac{F_u - F_d}{A_i \gamma_c} \] \[ 9.59 \]

**Example 10**

An open caisson (circular) is shown in **figure 9.34**. Determine the thickness of the seal that will enable complete dewatering.
Solution

From equation (48),

\[ t = 1.18R_i \sqrt{\frac{q}{f_c}} \]

For \( R_i = 7.5 \) ft,

\[ q \approx (45)(62.4) - ty_c \]

With \( y_c = 150 \text{ lb/ft}^3 \), \( q = 2808 - 150t \) and

\[ f_c = 0.1f'_c = 0.1 \times 3 \times 10^3 \text{ lb/in}^2 = 0.3 \times 10^3 \text{ lb/in}^2 \]

So

\[ t = (1.18)(7.5) \sqrt{\frac{2808-150t}{300 \times 144}} \]

Or

\[ t^2 + 0.07t - 5.09 = 0 \]
t = 2.2 ft
Use t ≈ 2.5 ft

**Check for Perimeter Shear**

According to equation (51),

\[
v = \frac{\pi R_0^2 H_{yw} \cdot \pi R_i^2 t y_c}{2 \pi R_i t} = \frac{(\pi)(7.5^2)[(45)(62.4) - (2.5)(150)]}{(2)(\pi)(7.5)(2.5)} \approx 3650 \text{ lb/ft}^2
\]

\[
= 25.35 \text{ lb/in}^2
\]

The allowable shear stress is

\[
v_u = 2\phi \sqrt{f_c} = (2)(0.85)\sqrt{300} = 29.4 \text{ lb/in}^2
\]

\[
v = 25.35 \text{ lb/in}^2 < v_u = 29.4 \text{ lb/in}^2 - \text{OK}
\]

**Check Against Buoyancy**

The buoyant upward force is

\[
F_u = \pi R_0^2 H_{yw}
\]

For \( R_0 = 10 \text{ ft} \),

\[
F_u = \frac{(\pi)(10^2)(62.4)}{1000} = 882.2 \text{ kip}
\]

The downward force, \( F_d = W_c + W_s + Q_s \) and

\[
W_c = \pi (R_0^2 - R_i^2) y_c(55) = \pi (10^2 - 7.5^2)(150)(55) = 1,133,919 \text{ lb} \approx 1134 \text{ kip}
\]

\[
W_s = (\pi R_i^2 t y_c) = (\pi)(7.5^2)(1)(150) = 26,507 \text{ lb} = 26.5 \text{ kip}
\]

Assume that \( Q_s \approx 0 \). So

\[
F_d = 1134 + 26.5 = 1160.5 \text{ kip}
\]

Because \( F_u < F_d \), it is safe. For design, assume that \( t = 2.5 \text{ ft} \).