



IIT ROORKEE



NPTEL ONLINE
CERTIFICATION COURSE

EARTHQUAKE RESISTANT DESIGN OF FOUNDATIONS

Lecture 29: Lateral Stability, Construction and Sinking of Well Foundation

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ERD of Foundations - Modules

1. Introduction
2. Shallow Foundations
3. Pile Foundations
4. Well Foundations
5. SSI for Deep Foundations



Module - 4

Well Foundations



Module -4: Chapters

1. Introduction
2. Lateral Stability of Well Foundations
3. Construction and Sinking of a Well
4. Tilting and Shifting of Wells
5. Numerical Problems



Chapters 2 Lateral Stability of Wells

Several methods are available:

Terzaghi (1943): Assumed a free, rigid bulkhead for lateral stability analysis

Pender (1947): The soil around the pier was assumed to behave like linear spring whereas stiffness increase with depth.

Banerjee & Gangopadhyay (1960): Utilized Pender's plastic flow concept with Terzaghi's rigid bulk stress distribution and subgrade modulus concept.

Indian Road Congress (IRC: 45-1972): Formulated recommendation for well in a cohesionless soil to estimate soil resistance below maximum scour level.

- Elastic Theory Method
- **Ultimate Soil Resistance Method**

Ultimate Soil Resistance Method

On the basis of elastic theory, the pressure on the sides and at the base under design loads were determined. However, to determine the actual factor of safety against failure, calculation of ultimate soil resistance is necessary.

For checking the ultimate load capacity of a well foundation, the applied loads are increased by multiplying them with suitable load factors for various load combinations and the ultimate resistance is reduced by appropriate strength factors. The two are then compared.

Ultimate Soil Resistance Method: Steps

Step 1. Compute the applied loads for various combinations of load factors.

$$1.1D \quad (1a)$$

$$1.1D+B+1.4(W_c+E_p+W \text{ or } S) \quad (1b)$$

$$1.1D+1.6L \quad (1c)$$

$$1.1D+B+1.4(L+W_c+E_p) \quad (1d)$$

$$1.1D+B+1.25(L+W_c+E_p+ W \text{ or } S) \quad (1e)$$

Where, D = Dead load, L = Live load including breaking effect, B = Buoyancy, W_c = Water current force, E_p = Earth pressure force, W = Wind force and S = Seismic force.

The method assumes the point of rotation at a height of 0.2 times the depth of well above the base of well. The bending moment should, therefore, be computed at the point of rotation instead at the base.

Ultimate Soil Resistance Method: Steps

Step 2. Check for maximum average pressure at base

$$\frac{W}{A} \not\geq \frac{q_u}{2} \quad (2)$$

Where, W = Total downward load acting at the base of the well including the self weight of the well, increased by suitable load factor as given in step 1.

A = Area of the base of well

q_u = Ultimate bearing capacity of the soil below the well base.

The diameter of the well should be increased if the condition given in Eq. (2) is not satisfied

Step 3. Calculate the resisting moment at the base, M_b at the plane of rotation

$$M_b = QWB \tan \phi \quad (3)$$

Where, B = Width parallel to the direction of forces in the case of square and rectangular wells or diameter for circular well. Q = A constant, depends on the shape of the well and the ratio of depth (D) to width. For a well with circular base, a shape factor of 0.6 shall be used. For rectangular well Q is given in the Table:

D/B	0.5	1.0	1.5	2.0	2.5
Q	0.41	0.45	0.50	0.56	0.64

Ultimate Soil Resistance Method: Steps

Step 4. Compute the ultimate moment of resistance on the sides of the well. The moment of resistance is due to, (i) passive soil resistance M_s and (ii) due to frictional resistance M_f .

$$M_s = 0.10\gamma D^3(K_p - K_A)L \quad (4)$$

For rectangular wells, $M_f = 0.18\gamma(K_p - K_A)LBD^2 \tan \delta \quad (5)$

For circular wells, $M_f = 0.11\gamma(K_p - K_A)B^2D^2 \tan \delta \quad (6)$

Where, γ = unit weight of soil

L = projected width of soil mass offering resistance. For circular wells, it will be 0.9 times the diameter

D = grip length below maximum scour level and

K_p, K_A = active & passive coefficient of earth pressure to be calculated using Coulomb's theory,

δ = The angle of wall friction as $2/3\phi$ but limited to a value of 22.5° .

Ultimate Soil Resistance Method: Steps

Step 5. Compute the applied ultimate bending moment, M with the total ultimate moment of resistance, M_r

$$M_r = 0.7(M_b + M_s + M_f) \quad (7)$$

Where 0.7 is the reduction factor in the strength.

$$\text{Thus, } M_r \not\leq M \quad (8)$$

If this condition is not satisfied, the grip length of the well needs to be increased and computations redone. The equations used in the plastic theory are derived as follows:

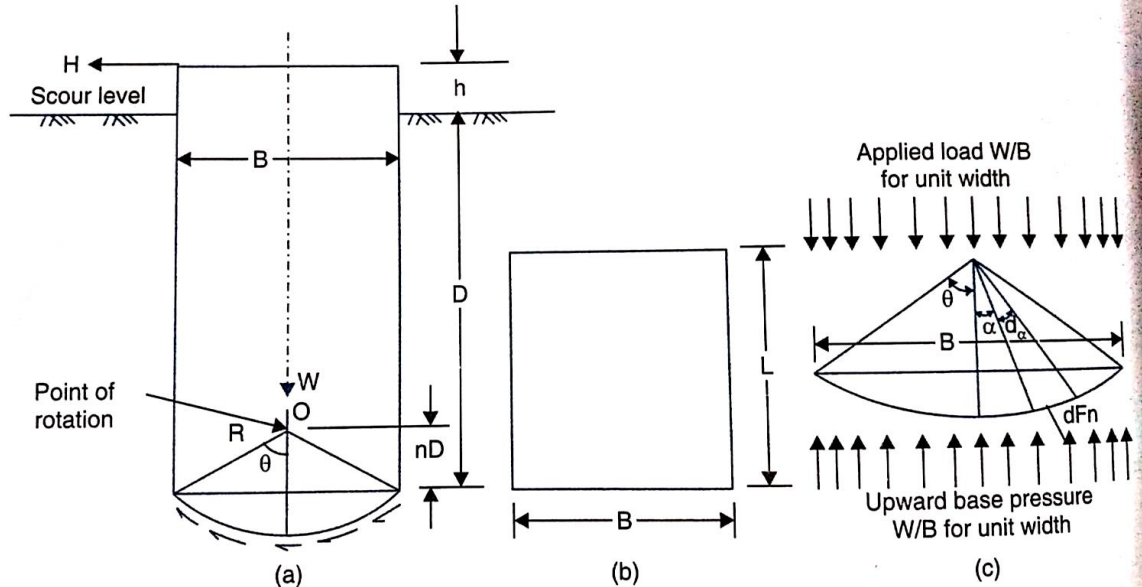
Base Resisting Moment, M_b is the moment due to the frictional force developed along the rupture surface at the base. The rupture surface for square wells is assumed to be cylindrical, passing through the corner of the wells. For circular wells, the surface of rupture is assumed to be a part of a sphere with its center at the point of rotation and passing through the periphery of the base [see Fig. in next slide].

Ultimate Soil Resistance Method: Derivations

Let W is total vertical load taking into account the modification due to load factors. The load per unit width will be W/B which will be equal to the upward pressure.

Consider a small arc of length $Rd\alpha$ at an angle α from the vertical axis. The vertical component of force on element =

$$Rd\alpha \cos\alpha \frac{W}{B}$$



Ultimate Soil Resistance Method: Derivations

Thus, the normal force developed at the element due to the vertical force

$$= dF_n = \frac{W}{B} R d\alpha \cos \alpha \cos \alpha \quad (9a)$$

Hence,

$$\begin{aligned} F_n &= 2 \int_0^\theta \frac{W}{B} R \cos^2 \alpha d\alpha = \frac{W}{B} R \int_0^\theta (1 + \cos 2\alpha) d\alpha \\ &= \frac{RW}{B} (\theta + \sin \theta \cos \theta) \end{aligned} \quad (9b)$$

From the Fig. as shown in previous slide,

$$\sin \theta = \frac{B}{2R}, \quad \cos \theta = \frac{nD}{R}, \quad \tan \theta = \frac{B}{2nD} \text{ and } R = \sqrt{\frac{B^2 + 4n^2 D^2}{4}}$$

Substituting the values in Eq. (9b)

$$F_n = \frac{W}{2} \sqrt{1 + \frac{4n^2 D^2}{B^2}} \left[\tan^{-1} \frac{B}{2nD} + \frac{2nBD}{B^2 + 4n^2 D^2} \right] \quad (9c)$$

Ultimate Soil Resistance Method: Derivations

Hence the moment of resistance of the base about the point of rotation, M_b is given by

$$M_b = F_n \tan \phi R \quad (10)$$

IRC: 45 (1972) recommends a multiplication factor of 0.6 to Eq. (10) to account for the surface of rupture being a part of sphere.

In both the case, assuming the point of rotation at 0.2D (as shown in previous Fig.), the moment of resistance at the base can be expressed by

$$M_b = QWB \tan \phi \quad (11)$$

Where, B = Width parallel to the direction of forces in the case of square and rectangular wells or diameter for circular well.

Q = A constant depending on the shape of the well and D/B ratio.

For a well with circular base, a shape factor of 0.6 shall be used.

Ultimate Soil Resistance Method: Derivations

Side Resistance Moment, M_s : The ultimate soil pressure on the front and back face of the well are shown below Fig. The point of rotation is assumed at $0.2D$ above the base.

From similarity of triangles $D_1 = \frac{1}{3}D$

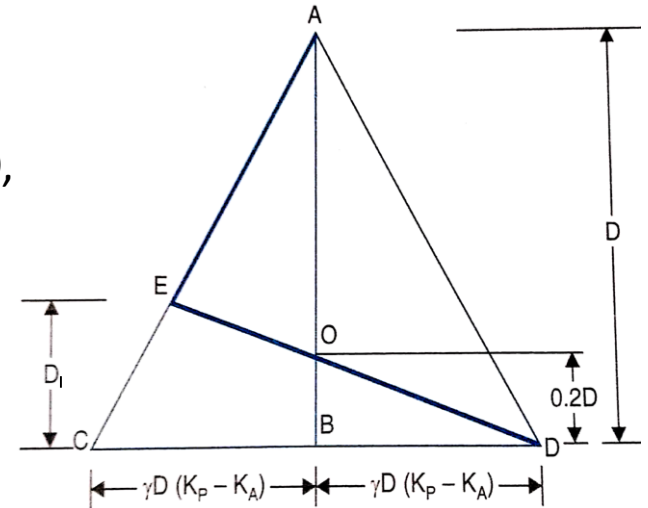
Taking moments of forces about the point of rotation O,

Moment per unit width

$$\begin{aligned} M_s &= 0.096D^2\gamma D(K_p - K_A) \\ &= 0.1\gamma D^3(K_p - K_A) \end{aligned}$$

Hence, for a width of L,

$$M_s = 0.1D^3\gamma(K_p - K_A)L$$



Earth pressure on well

Ultimate Soil Resistance Method: Derivations

Friction resisting moment, M_f

The passive pressure acting on the front and back of the wall gives rise to frictional force in the vertical direction, which provide resisting moment, M_f . Neglecting the influence of active earth pressure,

Total frictional force per unit width = (Area of ΔAOE + Area of ΔBOD) $\sin \delta$

Earth pressure at

$$E = \frac{2}{3} \gamma D (K_P - K_A)$$

$$\text{Hence, area of } \Delta AOE = \frac{2}{3} \gamma D (K_P - K_A) \frac{0.8D}{2}$$

$$\text{and area of } \Delta BOD = \frac{0.2D}{2} \gamma D (K_P - K_A)$$

$$\text{Thus =, total frictional force per unit width} = \frac{1.1}{3} \gamma D^2 (K_P - K_A) \sin \delta$$

Ultimate Soil Resistance Method: Derivations

For a rectangular well of width L , the moment about the center of rotations given by

$$\begin{aligned}M_f &= \frac{1.1}{3} \gamma D^2 (K_p - K_A) \sin \delta \frac{B}{2} L \\&= 0.183 \gamma (K_p - K_A) L B D^2 \sin \delta \\&\approx 0.180 \gamma (K_p - K_A) L B D^2 \sin \delta\end{aligned}$$

Similarly, for a circular well,

$$M_f = \frac{1.1}{3} \gamma D^2 (K_p - K_A) \sin \delta \frac{B}{\pi} L$$

Since for a circular well, $L = 0.9B$

$$\begin{aligned}M_f &= \frac{0.33}{\pi} \gamma (K_p - K_A) D^2 B^2 \sin \delta \\&= 0.105 \gamma (K_p - K_A) D^2 B^2 \sin \delta \\&\approx 0.11 \gamma (K_p - K_A) D^2 B^2 \sin \delta\end{aligned}$$

Construction and Sinking of a Well

Construction of well foundation consists of the following stages

1. Laying the Cutting Edge
2. Alignment Control
3. Construction of Well Curb
4. Construction of Well Steining
5. Well Sinking.

Stage 1. Laying the Cutting Edge

Well foundations are constructed in stages by sinking under self-weight as well as dredging the soil inside the dredge hole and on the sides outside. The first step in the construction of a well foundation is to lay the cutting edge and well curb. If the river bed is dry, the cutting edge is placed in position after removing the top loose layer of sand.

Construction and Sinking of a Well

Stage 2. Alignment Control:

The centerline of the wells should coincide with the centerline of the abutments and piers and of the bridge. Masonry pillars are constructed on the centerline of the bridge to serve as station points for checking the alignment of the abutments and piers.

Stage 3. Construction of Well Curb:

The well curb is assembled on wooden blocks or sand bags placed at suitable intervals so that it does not sink, while assembling the curb. Concreting is done after placing the reinforcement. M15 or richer grade concrete is used for the well curb. The well curb is then allowed to set for a week before sinking is started. The well curb is allowed to sink alone before raising the steining above it.

Construction and Sinking of a Well

Stage 4. Construction of Well Steining:

The grip length of the well is very small at the beginning of the sinking operation and the chances for tilting are more. The steining should not be raised too high in the initial stages of well sinking, which would otherwise lead to increasing the tilting further. Hence, the well curb is first allowed to sink alone and the steining is then raised in small heights of 1.5 m at a time, allowing minimum 24 hours before adding the next height of steining.

The steining can be raised in installments of about 3 m, once the well has sunk to a sufficient depth to get a minimum grip length of 6 m. The steining masonry should be constructed perfectly vertical to ensure vertical sinking of the Well. Straight edges of about 2 m length should be used for this purpose along the outer periphery of the steining at suitable intervals. When the steining is raised by this height, the straight edges are removed and fixed at a higher level and the entire height of the steining should be raised using this procedure.

Construction and Sinking of a Well

Stage 5. Well Sinking:

The soil in the dredge hole is excavated to facilitate sinking of the well. A large-size spade, known as jham, is used for excavation under water. Jham consists of a sector-shaped steel pan with edges connected by a rope and wooden bullies. When Jham is used, excavation is done manually and hence well sinking is slow. Alternatively, automatic grabs or dredgers can be used for excavation operated by a winch and crane. Bell's dredger is commonly used for sandy soils.

As the sinking proceeds, more depth of the well foundation will be below the scour level, increasing the frictional resistance between the steining surface and the surrounding soil. The steining is loaded with kentledge through a suitable platform and with sand bags piled on it to aid well sinking, overcoming this frictional resistance. The platform for the kentledge is constructed in such a way that it does not obstruct the dredging process. Air and water jets are also used in addition to the kentledge to further overcome the frictional resistance. These jets consist of G.I. pipes of 2.5-5 cm diameter with a nozzle at one end.

Construction and Sinking of a Well

Well sinking may stop and tilting may also occur when the cutting edge encounters an obstruction below it. The obstruction can be removed by dewatering the well using pulso-meter pumps and blowing of sand into it. The dewatering process should be continuously watched and should be suspended if there is a tendency for tilting of the well. Dewatering also should not be used unless the well has sunk to a sufficient length of a minimum of 9 m.

References

1. Gopal Ranjan and A S R Rao (1991) “Basic and Applied Soil Mechanics” New Age International, New Delhi, India. (Third Edition 2016)
2. BIS 3955 : 1967 “Code of Practice for Design and Construction of Well Foundations” Bureau of Indian Standards, New Delhi, India.