



IIT ROORKEE



NPTEL ONLINE
CERTIFICATION COURSE

EARTHQUAKE RESISTANT DESIGN OF FOUNDATIONS

Lecture 30: Tilting and Shifting of Wells, Numerical Problems

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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

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



Tilting and Shifting of Wells

It is safer and economical to avoid tilting and shifting of wells by adopting the following preventive measures:

1. The outer surface of the well curb and steining should be level, straight, and smooth.
2. The radius of the well curb should be kept 2-4 cm more than the outer radius of the well steining.
3. The cutting edge should be sharp and of uniform thickness.
4. The steining should be built in lifts and the entire steining height should be built in one straight line from bottom to top at right angles to the plane of the curb.
5. Dredging should be uniform on all sides of the well. For a twin well, dredging should be uniform in both the wells.

Tilting and Shifting of Wells

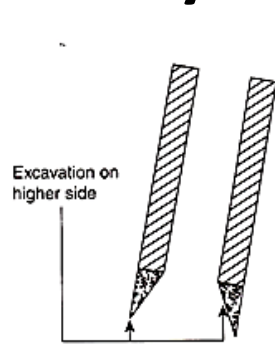
6. The well should be constructed in stages of small height increments.
7. The magnitude and direction of sinking of wells should be properly and carefully monitored on a continuous basis to identify any tilt or shift and adopt appropriate corrective measures immediately to rectify the same.
8. If the well shows a tendency for tilting, dredging should be done on the higher side. If this does not bring required improvement, sinking should be stopped and should be resumed only after the tilting is corrected.
9. Dredged material should not be deposited unevenly around the well.
10. When a Kentledge is used to provide additional sinking effort, it should be placed evenly on the loading platform.

Rectify Tilting and Shifting of Wells

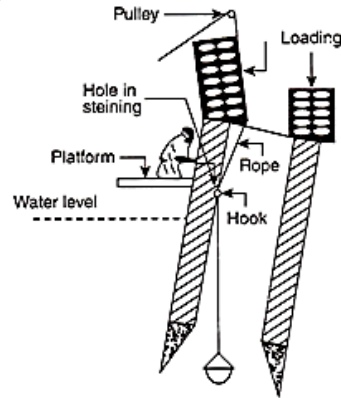
Continuous monitoring should be done to identify if any tilt or shift of the well occurs and following measures should be adopted as deemed appropriate as per the decision of the Engineer-in-charge:

1. Controlled dredging should be done more on the higher side, that is, on the opposite side of the tilt, as shown in Fig. (a). This method is helpful only in the initial stages of well sinking.
2. Eccentric loading is applied by using extra downward pressure on the higher side, as shown in Figs. (b) and (c).

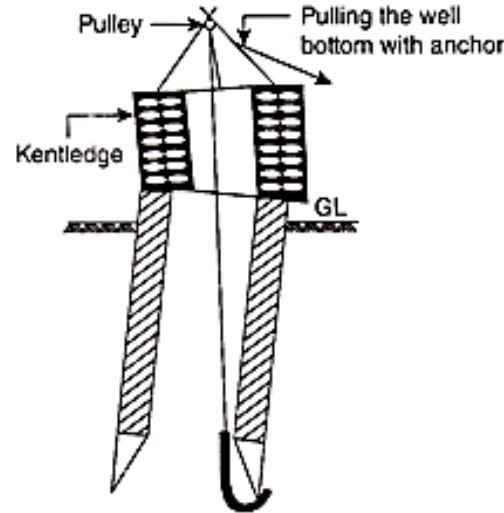
Rectify Tilting and Shifting of Wells:



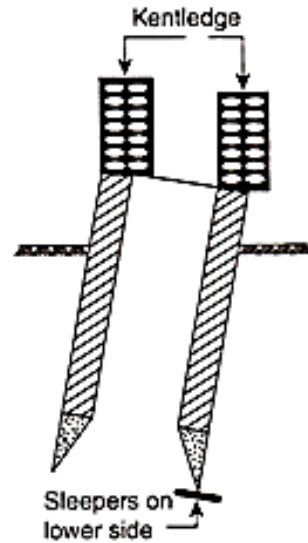
(a)



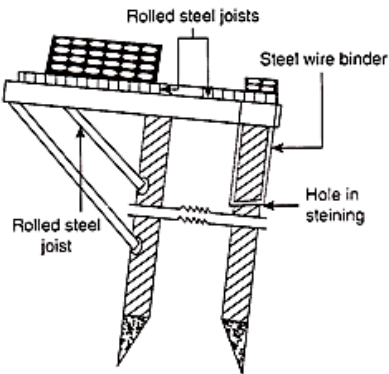
(b)



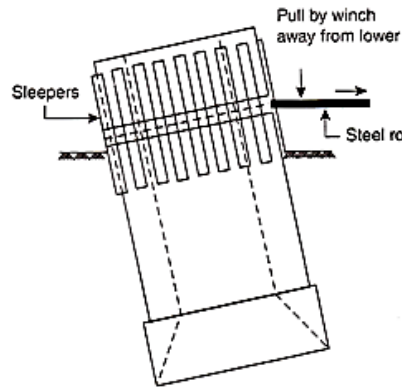
(c)



(d)



(e)



(f)

Rectify Tilting and Shifting of Wells:

3. Pulling the well from the higher side in the opposite direction of tilting is also effective in rectifying the tilt. The pull can be applied by winding steel wire rope around the well through an anchor. Wooden sleepers are used during pulling to avoid damage to the well steining, as shown in Fig. (d). The pull can also be applied by using an anchor below the cutting edge on the higher side, as shown in Fig. (e).
4. Push can be applied to the well from the lower side to rectify the tilt. Care should be taken so that pulling or pushing does not cause a shift of the well.
5. Water jets may be used on the higher side, near the bottom of the well, to remove the soil partially, thereby reducing the frictional resistance on the higher side.

Example-1

A circular well of 4.5 m external diameter and 0.75 m steining thickness is embedded upto a depth of 12m in a uniform sand deposit. The angle of shearing resistance of sand and the submerged unit weight are 30° and 1.0 t/m^3 , respectively. The well is subjected to a resultant horizontal force of 50 t and a total moment of 400 t-m at the scour level. Assuming the well to be a light well, compute the allowable total equivalent resisting force due to earth pressure. Factor of safety of 2 may be adopted for soil resistance. Determine the magnitude and point of maximum bending moment in the well steining. What will be the change in computed values for a heavy well when the well is assumed to rotate about the base?

Solution:

Height of the point of application of horizontal load above scour level

$$H = \frac{M}{Q} = \frac{400}{50} = 8\text{m}$$

Total Height $H_1 = H + D = 8 + 12 = 20\text{m}$

From Eq.17.7

$$2D_1 = 3H_1 \pm \sqrt{9H_1^2 - 2D(3H_1 - D)}$$

Substituting the values given in the problem

$$2D_1 = 3 \times 20 \pm \sqrt{9(20)^2 - 2 \times 12 \times (3 \times 20 - 12)}$$

$$D_1 = 5.26\text{m}$$

For $\phi = 30^\circ$, $K_A = 0.33$, $K_P = 3$,

For a light well with rotation above the base of well

$$q_{\max} = \frac{1}{2} \gamma D (K_P - K_A) (D - 2D_1)$$

Substituting values in Eq. 2 (Terzaghi's Theory)

$$\begin{aligned} q_{\max} &= \frac{1}{2} \times 1 \times 12 \times (3 - 0.33) (12 - 2 \times 5.26) \\ &= 23.68 \text{ t/m length} \end{aligned}$$

$$\begin{aligned} Q_a &= \frac{q_{\max} \times L}{F} \\ &= \frac{23.68 \times 4.5}{2} \\ &= 53.28\text{t} \end{aligned}$$

Solution

The point of maximum bending moment will be at the location where the shear force is zero. Let the point zero shear be located at x m below scour level. Then,

$$\left(\frac{1}{2}\gamma'x^2\right) \times \frac{L}{F}(K_P - K_A) = Q$$

$$x = \left[\frac{2FQ}{\gamma'L(K_P - K_A)} \right]^{\frac{1}{2}}$$

Substituting suitable values,

$$x = \left[\frac{2 \times 2 \times 50}{1 \times 4.5 \times (3 - 0.33)} \right]^{\frac{1}{2}} = 4.08\text{m}$$

$$\begin{aligned}\text{Hence, max. bending moment} &= Q(H + x) - Q\frac{x}{3} \\ &= QH + 2Q\frac{x}{3}\end{aligned}$$

$$= 50 \times 8 + 2 \times 50 \times \frac{4.08}{3} = 536\text{t-m}$$

For heavy well,

$$\begin{aligned}q_{\max} &= \frac{1}{6}\gamma'(K_P - K_A)\frac{D^3}{(H + D)} \\ &= \frac{1}{6} \times 1 \times (3 - 0.33) \frac{12^3}{20} \\ &= 38.4\text{t/m length}\end{aligned}$$

$$Q_a = 38.4 \times \frac{4.5}{2} = 86.4\text{ t}$$

Example-2

The following data refers to a well foundation for a single line railway bridge:

- a) Net downward load on well including self weight = 1400 t
- b) Horizontal force at scour level = 200 t
- c) Moment at scour level = 4150 t-m
- d) Depth of well below scour level = 15 m
- e) Saturated unit weight of sand = 2.0 t/m^3
- f) Angle of shearing resistance of subsoil = 35°
- g) Angle of wall friction = 20°
- h) External diameter of well = 8.5 m
- i) Internal diameter of well = 5.5 m
- j) Allowable bearing pressure = 55.0 t/m^2

Check the lateral stability of the well as per the procedure laid down by IRC: 45 (1972)



Solution

Elastic Theory method

Projected width of well,

$$L = 0.9B = 0.9 \times 8.5 = 7.65\text{m}$$

$$I_B = \frac{\pi d^4}{64} = \frac{\pi \times 8.5^4}{64} = 256.24\text{m}^4$$

$$I = I_B + mI_V(1 + 2\mu'\alpha)$$

Assuming $m = \frac{K_H}{K_V} = 1$

$$\mu' = \tan \delta = \tan 20^\circ = 0.364$$

$$\alpha = \frac{\cancel{d}_B}{\pi D} = \frac{8.5}{\pi \times 15} = 0.18 \quad \alpha = \frac{B}{\pi D}$$

$$I_V = \frac{LD^3}{12} = \frac{7.65 \times 15^3}{12} = 2151.56\text{m}^4$$

Substituting values in Eq.1

$$I = 256.24 + 1 \times 2151.56(1 + 2 \times 0.364 \times 0.18) \\ = 2690.33 \text{ m}^4$$

$$r = \frac{D}{2} \frac{I}{mI_V} \\ = \frac{15}{2} \times \frac{2690.33}{1 \times 2151.56} = 9.38 \text{ m}$$

To ensure

$$H > \frac{M}{r}(1 + \mu\mu') - \mu W$$

Elastic Theory method

$$\begin{aligned}\frac{M}{r}(1 + \mu\mu') - \mu W &= \frac{4150}{9.38}(1 + \tan 35^\circ \tan 20^\circ) - (\tan 35^\circ) \times 1400 \\ &= 555.20 - 980.29 \\ &= -425.09, \text{ hence safe.}\end{aligned}$$

$$H < \frac{M}{r}(1 - \mu\mu') + \mu W$$

$$\begin{aligned}\frac{M}{r}(1 - \mu\mu') + \mu W &= \frac{4150}{9.38}(1 - \tan 35^\circ \tan 20^\circ) + (\tan 35^\circ) \times 1400 \\ &= \frac{329.68}{106.18} + 980.29 \\ 1309.96 &= 1086.47, \text{ hence safe.}\end{aligned}$$

$$K_p = \frac{1 + \sin \phi}{1 - \sin \phi} = \frac{1 + \sin 35}{1 - \sin 35} = 3.69$$

$$K_A = \frac{1}{K_p} = 0.271$$

To check the elastic state:

$$\begin{aligned}&\frac{mM}{I} \not\geq (K_p - K_A) \\ &1 \times \frac{4150}{2690.33} \not\geq 1.0 (8 - 0.24) \cos \delta \\ &1.54 \not\geq 7.29, \text{ hence safe.}\end{aligned}$$

$$\begin{aligned}&\frac{mM}{I} < \gamma(K_p - K_A) \\ &\frac{1 \times 4150}{2690.33} < 1.0(3.69 - 0.271) \\ &1.54 < 3.417, \text{ hence safe}\end{aligned}$$

Elastic Theory method

$$\sigma_1, \sigma_2 = \frac{W - \mu'P}{A} \pm \frac{MB}{2I}$$

$$P = \frac{M}{r} = \frac{4150}{9.38} = 442.52 \text{ kN}$$

$$= \left[\frac{1400 - 0.364 \times 442.52}{\left(\pi/4 \times 8.5\right)^2} \right] \pm \left[\frac{4150 \times 8.5}{2 \times 2690.33} \right]$$

$$= 21.83 \pm 6.56$$

$$= 28.39 \text{ t/m}^2, 15.27 \text{ t/m}^2$$

$\sigma_1 < 55 \text{ t/m}^2$ and $\sigma_2 > 0 \text{ t/m}^2$, hence safe.

Ultimate resistance method:

$$\frac{W}{A} \not\geq \frac{q_u}{2}$$

$$\frac{1400}{\frac{\pi}{4} \times 8.5^2} \not\geq \frac{55}{2} \times 3$$

24.57 $\not\geq$ 82.5 t/m², hence safe.

$$M_b = QWB \tan \phi$$

for $\frac{D}{B} = \frac{15}{8.5} = 1.75$ $Q = 0.53$ (Q from Table)

$$M_b = 0.53 \times 1400 \times 8.5 \times \tan 35^\circ$$

$$= 4416.2 \text{ t-m}$$

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

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

$$= 0.10 \times 1.0 \times 15^3 (3.69 - 0.271) \times 0.9 \times 8.5$$

$$= 8827.43 \text{ tm}$$

$$M_f = 0.11 \gamma B^2 D^2 (K_p - K_A) \sin \delta$$

$$= 0.11 \times 1.0 \times 8.5^2 \times 15^2 (3.69 - 0.271) \times \sin 20$$

$$= 2091.04 \text{ tm}$$

$$M_r = 0.7(M_b + M_s + M_f)$$

$$= 0.7(4416.2 + 8827.43 + 2091.04)$$

$$= 0.7 \times 15334.67$$

$$= 10734.28 \text{ tm} > M(4150 \text{ tm})$$

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.