CHAPTER 9: Well Foundations

9.1 INTRODUCTION

A '*Caisson*' is a type of foundation of the shape of a box, built above ground level and sunk to the required depth as a single unit. This terminology is popular in the U.S.A., and is used to refer to a water-tight chamber employed for laying foundations under water as in lakes, rivers, seas, and oceans.

9.2 Types of caisson foundations:

Caissons are broadly classified into three types, based on the method of construction:
(*a*) Open Caissons
(*b*) Pneumatic Caissons
(*c*) Floating or box Caissons

(*a*) *Open Caissons:* These are of box-shape, open both at the top and the bottom during construction. The caisson is sunk into position, and upon reaching its final position, a concrete seal is placed at its bottom in water. Finally, the inside is pumped dry and filled with concrete.

(*b*) *Pneumatic Caissons:* These are of box-shape, closed at the top, with a working chamber at the bottom from which water is kept off with the aid of compressed air. Thus excavation is facilitated in the dry, and the Caisson sinks as excavation proceeds. Finally, the working chamber is filled with concrete, upon reaching the final location at the desired depth.

(*c*) *Floating or Box Caissons:* These are also of box-shape, closed at the bottom and open at the top. This type of Caisson is cast on land, launched in water, towed to the site, and sunk into position by filling it with sand, gravel, concrete, or water.

Timber, Steel, and Reinforced Concrete are the materials used to construct Caissons, depending upon the importance and magnitude of the job. Timber is much less used these days than steel and Reinforced Concrete. Steel Caissons are made of steel skin plate, internal steel frames, and Concrete fill, the last one being meant only to provide the necessary weight to aid in the sinking process, which is more continuous, and relatively faster when compared with Caissons built of reinforced Concrete.

Reinforced Concrete Caissons utilise concrete for the dual purpose of providing the necessary strength and the dead weight for sinking. These must be poured in convenient heights, called 'Lifts', cured for the mandatory period, and each lift sunk into position. This necessarily involves some loss of time, the time required for the sinking operation being much more than that for a Steel Caisson. However, Concrete Caissons prove to be much more economical than Steel ones for large and heavy jobs.

Generally speaking, a Caisson is advantageous compared to other types of deep foundations when one or more of the following conditions exist:

(*i*) The soil contains large boulders which obstruct the penetration of piles or placement of drilled piers ('drilled piers' are nothing but large diameter bored piles.)
(*ii*) A massive substructure is required to extend below the river bed to resist destructive forces due to scour and/or floating objects.
(*iii*) Large magnitudes of lateral forces are expected.

Caissons are mostly used as the foundation for bridge piers and abutments in lakes, rivers, and seas, breakwaters and other shore protection works, and large water-front structures such as pump houses, subjected to huge vertical and horizontal forces. Occasionally Caissons, especially Pneumatic Caissons, have been used as foundations for large and tall multi-storey buildings and other structures.

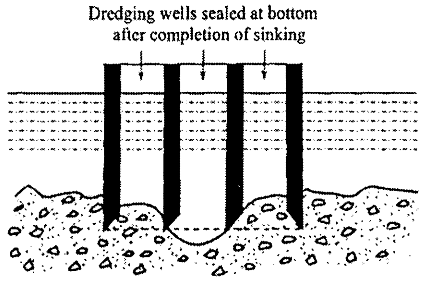


Fig. 12.1 Open caisson

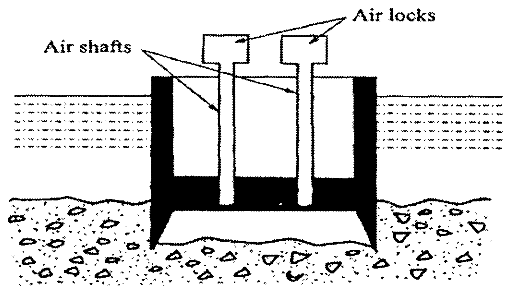


Fig. 12.2 Pneumatic caisson

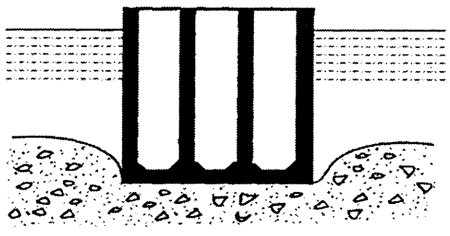


Fig. 12.3 Box caisson

9.3 Components of a Well Foundation

The elements of a well foundation are: (*i*) Cutting edge (*ii*) Curb (*iii*) Concrete seal or Bottom Plug (*iv*) Steining (*v*) Top Plug, and (*vi*) Well Cap. These shown in the sectional elevation of a typical well foundation of circular cross section.

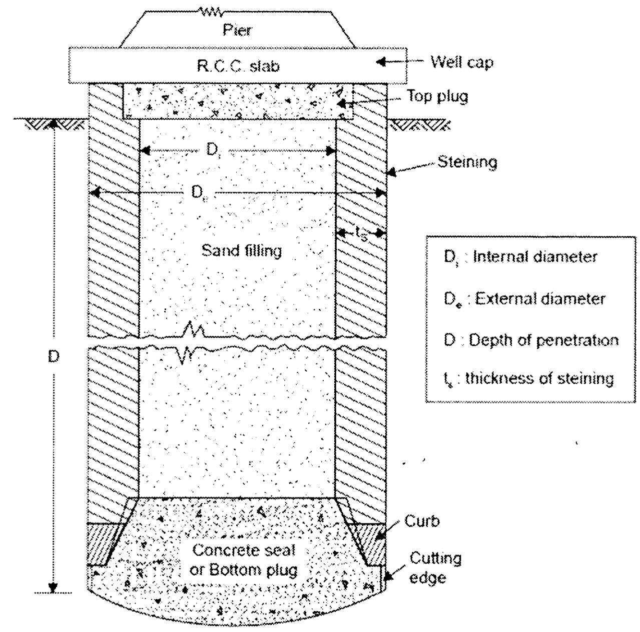


Fig. 9.2: Components of well foundations

(*i*) *Cutting Edge:* The function of the cutting edge is to facilitate easy penetration or sinking into the soil to the desired depth. As it has to cut through the soil, it should be as sharp as possible, and strong enough to resist the high stresses to which it is subjected during the sinking process. Hence it usually consists of an angle iron with or without an additional plate of structural steel. It is similar to the sharp-edged cutting edge of a caisson shown in Fig. 9.2.

(*ii*) *Steining:* The steining forms the bulk of the well foundation and may be constructed with brick or stone masonry, or with plain or reinforced concrete occasionally. The thickness of the steining is made uniform throughout its depth. It is considered desirable to provide vertical reinforcements to take care of the tensile stresses which might occur when the well is suspended from top during any stage of sinking.

(*iii*) *Curb:* The well curb is a transition member between the sharp cutting edge and the thick steining. It is thus tapering in shape. It is usually made of reinforced concrete as it is subjected to severe stresses during the sinking process.

(*iv*) *Concrete Seal or Bottom Plug:* After the well foundation is sunk to the desired depth so as to rest on a firm stratum, a thick layer of concrete is provided at the bottom inside the well, generally under water. This layer is called the concrete seal or bottom plug, which serves as the base for the well foundation. This is primarily meant to distribute the loads on to a large area of the foundation, and hence may be omitted when the well is made to rest on hard rock.

(*v*) *Top Plug:* After the well foundation is sunk to the desired depth, the inside of the well is filled with sand either partly or fully, and a top layer of concrete is placed. This is known as 'top plug'. The sand filling serves to distribute the load more uniformly to the base of the well, to reduce the stresses in the steining, and to increase the stiffness of the well foundation. However, as this adds to the weight and load transmitted to the foundation stratum, the engineer has to consider the desirability or otherwise of providing the sand filling from the point of view of bearing power and settlement. The top plug of concrete serves to transmit the loads to the base in a uniform manner.

(*vi*) *Well Cap:* The well cap serves as a bearing pad to the superstructure, which may be a pier or an abutment. It distributes the superstructure load onto the well steining uniformly.

9.4 Shapes of well or caisson foundations:

Caissons are constructed with practically straight and vertical sides from top to bottom. The shape of a Caisson in plan may be Circular, Square, Rectangular, Octogonal, Twin-Circular, Twin-Rectangular, Twin-Hexagonal, Twin-Octogonal, or Double-D as shown in Fig. 9.1. Sometimes, the choice of shape of a Caisson is influenced by its size (for example, the shape is governed by the outline of the base of the superstructure, especially for large superstructures; smaller ones may, however, be made circular for convenience in sinking and achieving economy), and by the shape of the superstructures (for example, oblong shape may be preferred for the superstructure either to avoid restriction of flow or for convenience in navigation; or circular or pointed shape may be preferred on the upstream side to minimise the possible impact from large and heavy floating objects or ice floes). Twin-Circular, Twin- Rectangular, Twin Hexagonal, Twin-octogonal, and the Double-D types are used to support heavy loads from large bridge piers.

The size of a Caisson is governed by the following factors:

(*i*) *Size of Base:* The size of Caisson should be such that the Caisson has a minimum projection of 0.3 m all-round the base of the superstructure; this would help take care of a reasonable amount of inevitable tilting and misalignment.
(*ii*) *Bearing Pressure:* The area required is obviously governed by the allowable bearing pressure of the soil (dealt with in later subsections).
(*iii*) *Practical Minimum Size:* A minimum size of 2.5 m is considered necessary from the point of view of convenience in sinking and economy in construction; smaller sizes of Caisson frequently prove more expensive than other types of deep foundation.

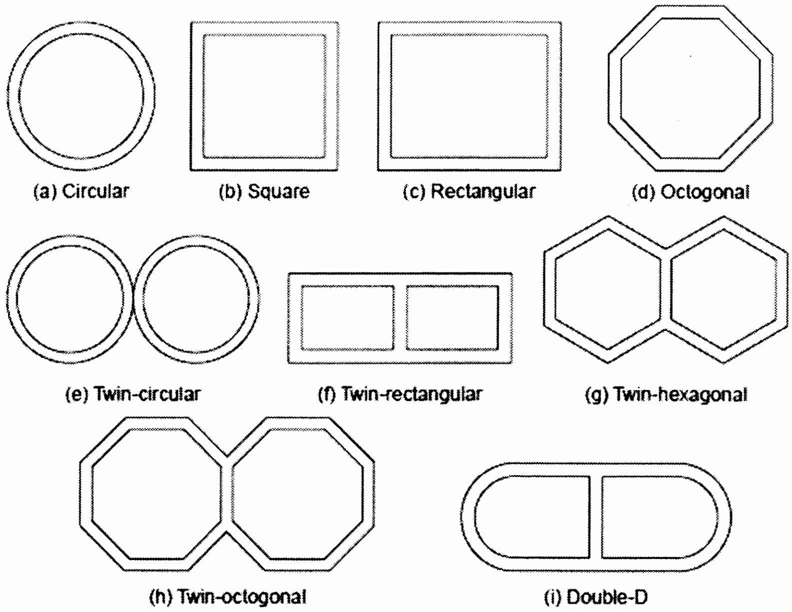


Fig. 9.1: Various shapes of well foundations

9.5 Depth of well foundation:

- In order to resist lateral forces acting on the well it should be placed at sufficient depth below maximum scour level
- Depth of well foundation is chosen by considering grip length and bearing capacity.
- The depth of bottom of well below max. Scour level is known as grip length.
- The max. and min. pressure developed on base should be within permissible limit.

The depth of scour can be ascertained by sounding near proposed site immediately after flood. (The max. scour would be greater than measured scour as design discharge is greater than flood discharge and there is increase in velocity due to obstruction to flow by construction of bridge.)

In case the first approach of taking soundings is not feasible, the second approach may be used and the normal depth of scour may be calculated by Lacey's formula:

$$d = 0.473(Q/f)^{1/3}$$

where d = normal scour depth, measured below high flood level (m),

Q = design discharge (m^3/s),

and f = Lacey's silt factor.

The silt factor may be calculated from the equation

$$f = 1.76\sqrt{d_m}$$

where d_m = mean size of the particle (mm).

The regime width of the waterway, w, can be computed as

$$w = 4.75Q^{1/2}$$

If the actual waterway, L, is less than the regime width, the actual scour depth, d', is given by

$$d' = d(w/L)^{0.61}$$

Recommended values of Lacey's silt factor, f, for particular particle sizes in the ranges of coarse silt to boulders are given in the Indian Standard Code of Practice:

IS:3955-1967-"Indian Standard Code of Practice for Design and Construction of Well Foundations".

Values of maximum scour depth as recommended by IRC (1966)* and IS:3955-1967 are given in Table 9.1

Table 9.1 Maximum scour depth recommended by IRC

S.No.	*River Section*	*Maximum Scour Depth*
1.	Straight reach	1.27 d'
2.	Moderate Bend	1.50 d'
3.	Severe Bend	1.75 d'
4.	Right-angled bend or at nose of Pier	2.00 d'
5.	Upstream nose of guide banks	2.75 d'
6.	Severe Swirls (IS:3955-1967 only)	2.50 d'

The grip length for wells of railway bridges is taken as 50% of maximum scour depth, generally, while for road bridges 30% of maximum scour depth is considered adequate. The base of the well is usually taken to a depth of 2.67 d' below the HFL.

According to IS:3955-1967, the depth should not be less than 1.33 times the maximum scour depth. The depth of the base of the well below the scour level is kept not less than 2 m for piers and abutments with arches, and 1.2 m for piers and abutments supporting other types of structures.

If inerodible stratum like rock is available at a shallow elevation, the foundation may be taken into it and securely bonded, or anchored to it if necessary.

9.6 Forces Acting on Well Foundations

The following forces should be considered in the design of a well foundation:

(1) *Dead Loads:* The weight of the superstructure and the self-weight of the well foundation constitute the dead loads.

(2) Live Loads: The live loads in the case of highway bridges are specified by IRC Standard specifications and code of practice for Road Bridges-Sec. II (1966). Live loads for railway bridges are specified in the Indian Railway Bridge Rules (1963) given by Research, Design, and Standards Organisation (RDSO), Lucknow of the Ministry of Railways, Govt. of India.

(3) Impact Loads: The live loads cause impact effect and it is considered in the design of pier cap and bridge seat on the abutment. Impact effect may be ignored for the elements of the well.

(4) Wing Loads: Wind loads on the live load, superstructure, and the part of substructure located above the water level are calculated based on IS:875-1964 "Indian Standard Code of Practice for Structural Safety of Buildings-Loading Standards". Wind Loads act on the exposed area laterally.

(5) Water Pressure: Water Pressure is due to the water current acting on the part of the substructure between the water level and the maximum scour level.
The intensity of Water Pressure on piers parallel to the direction of flow is given by

$$p = K.\ v^2$$

where p = Intensity of Water Pressure (N/m2),
v = Velocity of the water current (m/s),
and K = a constant, which depends upon the shape of the well (maximum 788 for square ended piers, and minimum 237 for piers with cut-waters and ease-waters).

v is taken to be the maximum at the free surface of flow and zero at the deepest scour level, the variation being assumed to be linear. The maximum value is taken to be 2 times the average value.

A transverse force of 20% of that parallel to the flow is assumed to allow for occasional obliquity of flow.

(6) Longitudinal Force: Longitudinal force occurs due to tractive and braking forces. These are transmitted to the substructure mainly through fixed bearings and through friction is movable bearings. According to IRC code, a longitudinal force of μW is taken on the free bearing, and the balance on the fixed bearing, where W is the total reaction and μ is the coefficient of friction.

(7) Earth Pressure: The earth pressure is calculated based on one of the classical earthpressure theories of Rankine and Coulomb. Passive earth resistance of the soil is taken into account for the stability of foundations below the scour level. The effect of the live load on the abutment on the earth pressure is considered by taking an equivalent height of surcharge.

(8) Centrifugal Force: A centrifugal force is taken to be transmitted through the bearings if the superstructure is curved in plan.

(9) Buoyancy Force: Buoyancy reduces the effective weight of the well. In masonry or concrete steining, 15% of the weight is taken as the buoyancy force to account for the porousness. When the well is founded on coarse sand, full buoyancy equal to the weight of the displaced volume of water is considered. For semiprevious foundations, appropriate reduction may be made based on the location of water table.

(10) Temperature Stresses: Longitudinal forces are induced owing to temperature changes. The movements due to temperature changes are partially restrained in girder bridges because of friction.

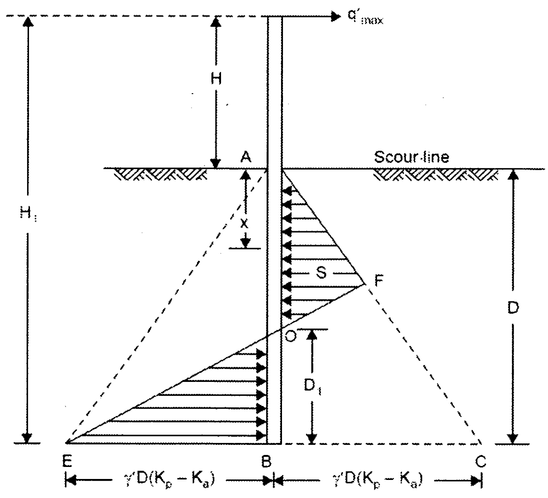
(11) Seismic Forces: These are to be considered in Seismic Zones. The force is taken is αW, where W is the weight of the component, and α is the seismic coefficient. The value of α depends upon the Zone and is given in IS: 1893-1975 "Indian Standard Criteria of Earthquake-Resistant Design of Structures". Its value ranges from 0.01 to 0.08. The Seismic Force acts through the centre of gravity of the component.

(12) Resultant Force: The magnitude, direction, and the point of application of all the applicable forces are found for the worst possible combination. The resultant can be imagined to be replaced by an equivalent vertical force W, and lateral forces, P and Q in the longitudinal and transverse directions of the pier, respectively. The action of Q will be more critical in the consideration of lateral stability of the well.

9.7 LATERAL STABILITY OF WELL FOUNDATIONS:

Terzaghi's (1943) Analysis:

Terzaghi's (Terzaghi, 1943) solution for free rigid bulkheads may be used for the approximate analysis of a well foundation. When a rigid bulkhead embedded in sand moves parallel to its original position, the sand on the front side and rear side are respectively transformed into passive and active states. Assuming that both the active pressure and the passive resistance are fully mobilised, the net pressure at any depth z below the ground surface is given by



$$p = \gamma z(Kp - Ka)$$

A free rigid bulkhead depends for its stability solely on the lateral resistance.

Let q'max be the horizontal force per unit length acting on the structure of total height $H1$ (as given in Fig.). The pressure distribution on both sides of the bulkhead at incipient failure may be represented as shown. The bulkhead rotates about the point 0 at a height of $D1$ above the base. As the soil around the well is usually submerged, the submerged unit weight is used.

Considering unit length, and applying $\Sigma H = 0$,

$$q'_{max} = \text{Area } ABC - \text{Area } FEC$$

$$= \frac{1}{2}\gamma' D^2 (K_p - K_a) - \frac{1}{2}(2\gamma' D)(K_p - K_a).D_1$$

$$= \frac{1}{2}\gamma' D(K_p - K_a)(D - 2D_1)$$

(Note: For convenience, the height to F is also taken as D_1 nearly)

Taking moments about the base,

$$q'_{max} H_1 = \frac{1}{2}\gamma' D^2 (K_p - K_a)\frac{D}{3} - \frac{1}{2}(2\gamma' D)(K_p - K_a)\frac{D_1^2}{3}$$

Substituting for q'_{max} from Eq. 19.27,

$$\frac{1}{2}\gamma' D(K_p - K_a)(D - 2D_1).H_1 = \frac{1}{2}\gamma' D^2(K_p - K_a)\frac{D}{3} - \frac{1}{2}(2\gamma' D)(K_p - K_a)\frac{D_1^2}{3}$$

or
$$(D - 2D_1)H_1 = \frac{D^2}{3} - \frac{2D_1^2}{3}$$

or
$$D_1^2 - 3D_1 H_1 + (1.5DH_1 - 0.5D^2) = 0$$

Solving for D_1,

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

or
$$D_1 = \frac{1}{2}\left[3H_1 \pm \sqrt{9H_1^2 - 2D(3H_1 - D)}\right]$$

. The positive sign yields a value for D_1 greater than D, which is ridiculous.

Hence, rejecting the positive sign,

$$D_1 = \frac{1}{2}\left[3H_1 - \sqrt{9H_1^2 - 2D(3H_1 - D)}\right]$$

Substituting this value in Eq.1, q'_{max} can be computed. For K_p and K_a, Rankine values can be used. (It is interesting to note that K_p and K_a do not appear in the Eqs. of $D1$.

In this simplified analysis, the moments due to side friction and base reaction are neglected; the error is on the safe side, since this results in the under estimating of the stabilizing forces.

Heavy Wells

Wells are in general, heavy compared to bulkheads, with low ratios of length to lateral dimension. A heavy well is expected to rotate about its base, as observed in model experiments by several investigators; the force per unit length may be obtained by taking moments about the base.

$$q'_{max} H_1 = (1/2)\gamma' (K_p - K_a) D^2 \times \frac{D_1}{3}$$

or
$$q'_{max} = (1/6)\gamma'(K_p - K_a)\frac{D^3}{H_1}$$

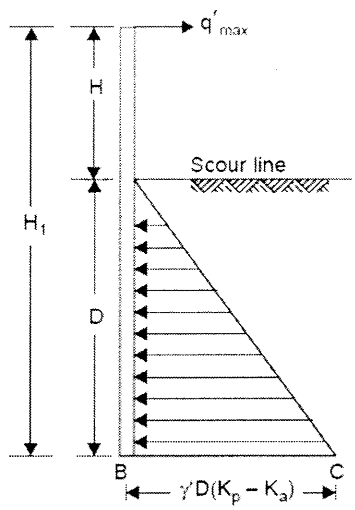


Fig. Heavy well

Effect of Surcharge

The effect of surcharge due to the weight of soil above the scour line can be considered in the analysis. The soil below the maximum scour line is subjected to a surcharge Z of the unscoured soil (Fig. below). The height Z may be taken as half the normal depth of scouring case it is not possible to ascertain it by actual measurement.

The pressure distribution is shown in the figure. The maximum pressure at the base is equal to $\gamma'(K_p - K_a)(D + Z)$.

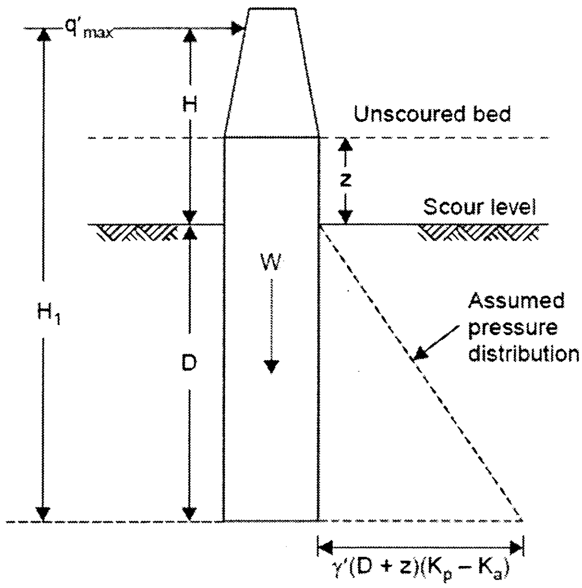


Fig. Effect of surcharge on wells

In this case q'_{max} is given by

$$q'_{max} = (1/6)\gamma'(K_p - K_a).\frac{D^2(D + z)}{H_1}$$

Total Safe Lateral Load on a Well

Since the equations for q'_{max} by Terzaghi's analysis, Heavy wells and effect of surcharge give only the lateral load per unit length of well, this value should be multiplied by the length of the well, L, parallel to the water flow in order to obtain the total lateral load on the well. Since the bulkhead equations are derived based on the assumption that the length is very much larger than the width, in practice, the error is considered to be not appreciable if wells are rectangular in shape. A multiplying factor, less than unity, called the 'Shape Factor', has to be applied for circular wells. This factor is taken to be $\frac{\pi}{4}$.

However, the shape factor for circular wells with a diameter larger than 4.5m, is taken to be unity, as for rectangular wells. The safe later load, Qa, for the well would be got by applying K_p' in place of K_p in the relevant equation for q'_{max}. and multiplying by the length and the shape factor as applicable.

Base Pressures

If Q is the actual applied transverse (horizontal) load and Q_a is the allowable equivalent resisting force, the unbalanced force $(Q - Q_a)$ acting at a height H above the scour level would produce an overturning moment M_B about the base.

$$M_B = (Q - Q_a)(H + D)$$

The maximum and minimum pressures at the base will then be

$$q_{\max} = \frac{W}{A_b} + \frac{M_B}{Z_b}$$

and

$$q_{\min} = \frac{W}{A_b} - \frac{M_B}{Z_b}$$

where W = net vertical load on the base of the well, after making allowance for buoyancy and skin friction,

A_b = Area of the base of the well,

and Z_b = Section modulus of the base cross-section of the well.

The maximum pressure should not exceed the allowable soil pressure. The minimum pressure should not be negative, that is to say, it should not be tensile. It is the general practice not to give any relief due to skin friction while calculating the maximum pressure at the base in clays, but to consider it for calculating the minimum pressure, so that the worst conditions are taken into account in either case.

Maximum Moment in Steining

The maximum moment in the steining occurs at the point of zero shear. Referring Terzaghi's analysis the depth χ to the point of zero shear, S, is such that the applied force and force due to the mobilised earth pressure balance each other. With a factor of safety η, $K_p' = K_p/\eta$.

$$[1/2\gamma'(K_p' - K_a).\chi^2.L] = Q$$

or

$$x = \left[\frac{2Q}{\gamma'(K_p' - K_a).L}\right]^{1/2}$$

Taking moments about S,

$$M_{\max} = Q(H + \chi) - (\text{Force due to pressure}).\chi/3$$

Taking the force due to pressure as being equal to Q,

$$M_{\max} = Q(H + \chi) - Q(\chi/3)$$

or

$$M_{\max} = Q.H + (2/3)Q.\chi$$

If the well rests on rock or on unyielding stratum, no rotation need be expected, and the moment developed is transmitted to the foundation bed, which withstands it.

9.8 Construction and sinking of well foundation:

(1) Construction of the Well Curb
If the river bed is dry, the cutting edge over which the well curb is to be built is placed at the correct position after excavating the bed for about 150 mm for seating. If there is water, with a depth upto 5 m, a sand island is created before placing the curb. The size of the island should be large enough to accommodate the well with adequate working space all round (Fig. 19.22). In case the depth of water is more than 5 m, it is more economical to build the curb on the bank and float it to the site.

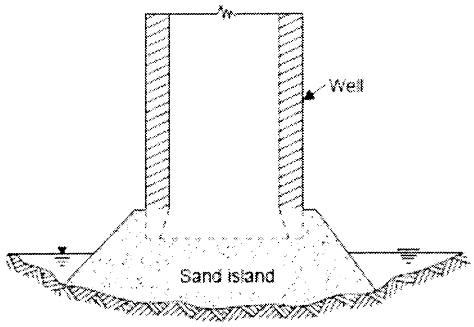


Fig. 19.22 Sand island for sinking a well

Wooden sleepers are usually inserted below the cutting edge at regular intervals to distribute the load evenly on the soil. The shuttering of the well curb is erected—the outer one with steel or wood and inner with brick masonry. The reinforcements for the curb are then placed in position, the vertical bars projecting about 2 m above the top of the curb. Concreting of the curb is done in continuous operation. After the curb is cured and allowed to cure for at least seven days, the shuttering may be removed as also the sleepers.

(2) Construction of Well Steining
The Steining is constructed with a height of 1.5 m at a time and sinking done after allowing at least 24 hours for setting. Once the well has acquired a grip of about 6 m into the ground, the steining can be raised 3 m at a time. The height of any lift is restricted such that the well does not lose stability.

(3) Sinking Process
The sinking process is commenced after the curb is cast and the first stage of steining is ready after curing. The material is excavated from inside manually or mechanically. Manual dredging is feasible when the depth of water inside the well is not more than 1 m. An automatic grab operated by diesel winches is used when the depth of water is more. Blasting with explosives is used when weak rock is encountered.

Additional loading, known as 'Kentledge' is used, if necessary. Kentledge is generally in the form of sand bags placed on a suitable platform on top of the well. Water jetting on the exterior face is applied in conjunction with kentledge. Pumping water from inside the well is also effective in sinking a well. But this should be resorted to only when the well has gone sufficiently deep into the ground, so as to avoid tilts and shifts. Also dewatering is not used after the well has sunk to about 10 m. 'Blow of sand' may occur if dewatering is resorted to in the early stage of sinking, inducing sudden tilting, and posing hazards to the workmen. Scrap gunny bags and grass boundles are placed round the periphery of the well to prevent sand blow.

Shifts and Tilts

The well should be sunk straight and vertical at the correct position. It is not an easy task to The well should be sunk straight and vertical at the correct position. It is not an easy task to achieve this objective in the field. Sometimes the well tilts onto one side or it shifts away from the desired position.

The following precautions may be taken to avoid tilts and shifts:

(*i*) The outer surface of the well curb and steining should be smooth.

(*ii*) The curb diameter should be kept 40 to 80 mm larger than the outer diameter of the steining, and the well should be symmetrically placed.

(*iii*) The cutting edge should be uniformly thick and sharp.

(*iv*) Dredging should be done uniformly on all sides and in all the pockets.

Tilts and shifts must be carefully noted and recorded. Correct measurement of tilt is an important observation in well sinking. It is difficult to specify permissible values for tilts and shifts. IS:3955-1967 recommends that tilt should be generally limited to 1 in 60. The shift should be restricted to one percent of the depth sunk. In case these limits are exceeded, suitable remedial measures are to be taken for rectification.

Remedial Measures for Rectification of Tilts and Shifts:

The following remedial measures may be taken to rectify tilts and shifts:

(1) *Regulation of Excavation:* The higher side is grabbed more be regulating the dredging. In the initial stages this may be all right. Otherwise, the well may be dewatered if possible, and open excavation may be carried out on the higher side [Fig. 19.23 (*a*)].

(2) *Eccentric Loading*: Eccentric placing of the kentledge may be resorted to provide greater sinking effort on the higher side. If necessary a platform with greater projection on the higher side may be constructed and used for this purpose. As the depth of sinking increases, heavier kentledge with greater eccentricity would be required to rectify tilt [Fig. 19.23 (b)].

(3) *Water Jetting*: If water jets are applied on the outer face of the well on the higher side, the friction is reduced on that side, and the tilt may get rectified [Fig. 19.23 (c)].

(4) *Excavation under the Cutting Edge*: If hard clay is encountered, open excavation is done under the cutting edge, if dewatering is possible; if not, divers may be employed to loosen the strata.

(5) *Insertion of Wood Sleeper under the Cutting Edge*: Wood sleepers may be inserted temporarily below the cutting edge on the lower side to avoid further tilt.

(6) *Pulling the Well*: In the early stages of sinking, pulling the well to the higher side by placing one or more steel ropes round the well, with vertical sleepers packed in between to distribute pressure over larger areas of well steining, is effective [Fig. 19.23 (d)].

(7) *Strutting the Well*: The well is strutted on its tilted side with suitable logs of wood to prevent further tilt. The well steining is provided with sleepers to distribute the load from the strut. The other end of the logs rest against a firm base having driven piles [Fig. 19.23 (e)].

(8) *Pushing the Well with Jacks*: Tilt can be rectified by pushing the well by suitably arranging mechanical or hydraulic jacks. In actual practice, a combination of two or more of these approaches may be applied successfully [Fig. 19.23 (f)].

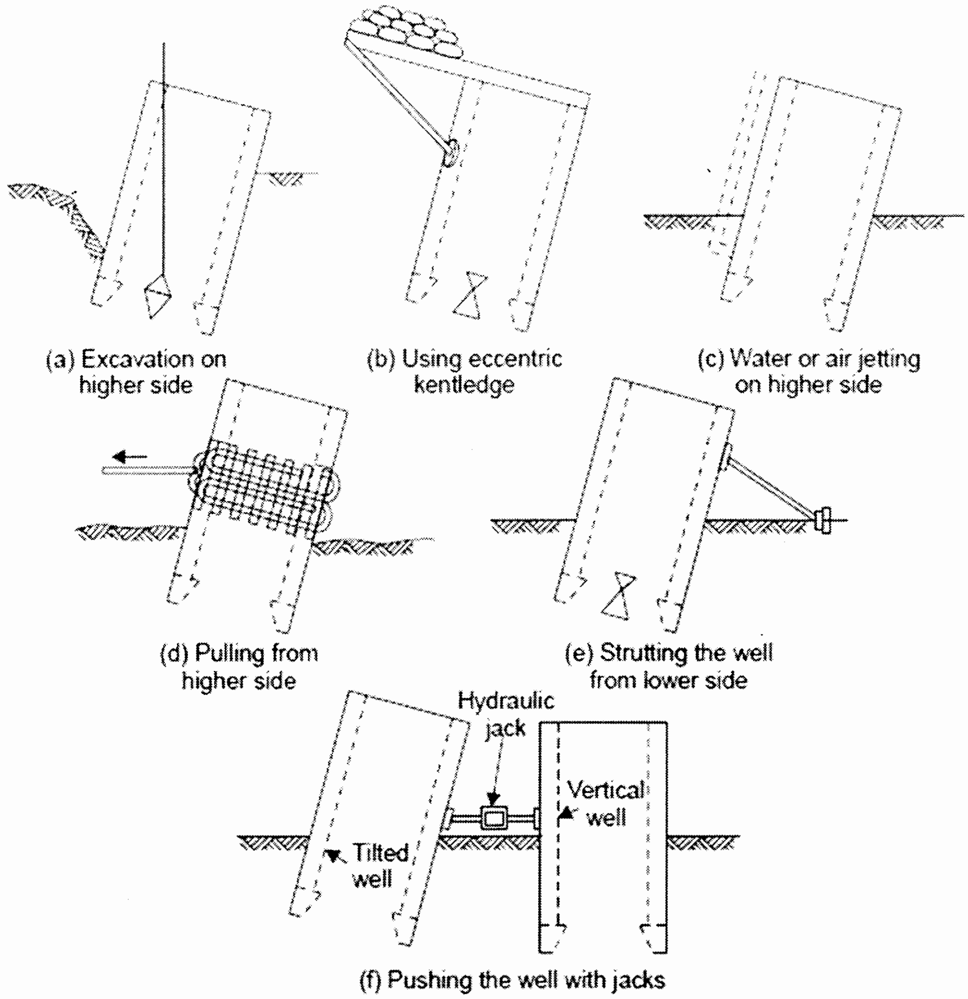


Fig. 19.23 Remedial measures for correction of tilt of wells

ILLUSTRATIVE EXAMPLES:

1. A cylindrical well of external diameter 6 m and internal diameter 4 m is sunk to a depth 16 m below the maximum scour level in a sand deposit. The well is subjected to a horizontal force of 1000 kN acting at a height of 8 m above the scour level. Determine the total allowable equivalent resisting force due to earth pressure, assuming that (*a*) the well rotates about a point above the base, and (*b*) the well rotates about the base. Assume $\gamma' = 10$ kN/m3, $\varphi = 30°$, and factor of safety against passive resistance = 2. Use Terzaghi's Approach:

2. A circular well has an external diameter of 7.5 m and is sunk into a sandy soilto a depth of 20 m below the maximum scour level. The resultant horizontal force is 1800 kN.The well is subjected to a moment of 36,000 kN.m about the maximum scour level due to thelateral force. Determine whether the well is safe against lateral forces, assuming the well torotate (*a*) about a point above the base, and (*b*) about the base, Assume $\gamma' = 10$ kN/m3, and $\varphi = 36°$.
Use Terzaghi's analysis, and a factor of safety of 2 against passive resistance.

Solution of Q.No. 1 is given below. And solve no. 2yourself.

$D = 16$ m $\quad\quad H = 8$ m $\quad\quad \phi = 30°$

$$\therefore \quad K_a = \frac{(1-\sin 30°)}{(1+\sin 30°)} = \frac{1}{3}$$

$$K_p = \frac{(1+\sin 30°)}{(1-\sin 30°)} = 3$$

Total height above base + $H_1 = 16 + 8 = 24$

Modified passive pressure coefficient,

$$K_p' = \frac{K_p}{F.S} = \frac{3}{2} = 1.50$$

(a) Rotation about a point above the base:

From Eq. 19.30:

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

$$= 3 \times 24 \pm \sqrt{9 \times 24^2 - 2 \times 16(3 \times 24 - 16)}$$

$$= 72 \pm \sqrt{5184 - 1792}$$

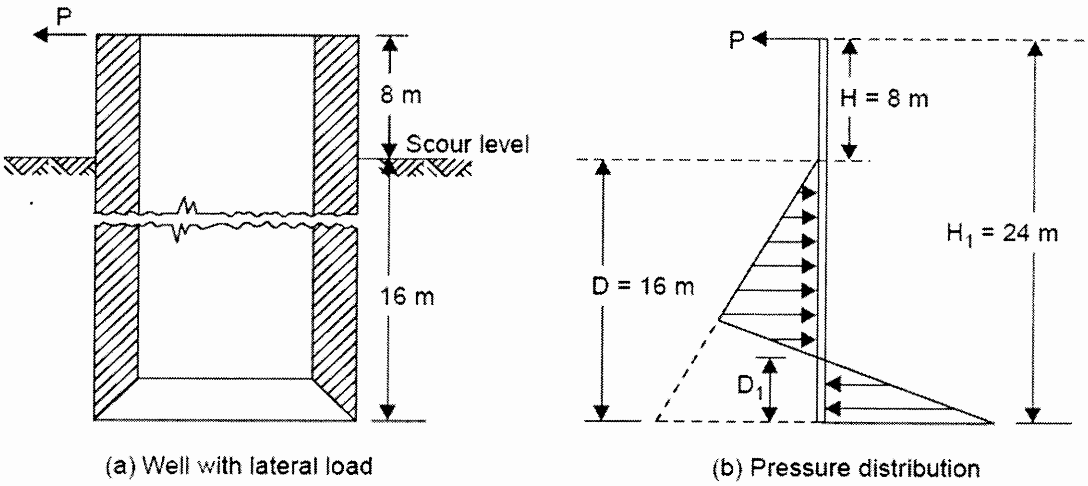


Fig. Cylindrical well with lateral load (Ex.)

$2D_1 = 72 - 58.24$ (rejecting the +ve sign, as it leads to a value for $D_1 > D$)

$= 13.76$

$D_1 = 6.88$ m

From Eq. 19.28,

$$q'_{max} = \frac{1}{2}\gamma' D(K_p' - K_a).(D - 2D_1)$$

$$= (1/2) \times 10 \times 16\{(3/2) - (1/3)\}(16 - 13.76)$$

$$= 209.1 \text{ kN/m}$$

Allowable Transverse load,

$$Q_a = q'_{max} \times L = 209 \times 6 = 1254 \text{ kN}$$

(The shape factor may be taken as unity since $D_e > 6$ m)

(*b*) Rotation about the base:

From Eq. 19.32,

$$q'_{max} = \frac{1}{6}\gamma'(K_p' - K_a)\frac{D^3}{H_1}$$

$$= (1/6) \times 10\{(3/2) - 1/3)\}.\frac{16^3}{24}$$

$$= 332 \text{ kN/m}$$

Hence the allowable lateral load

$$Q_a = q'_{max} \times L = 332 \times 6 = 1992 \text{ kN}$$

Since the actual horizontal load is given as 1000 kN, the well is safe against lateral load.