

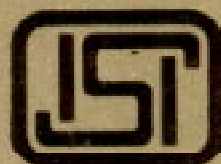
IS : 9527 (Part I) - 1981

*Indian Standard*

CODE OF PRACTICE FOR DESIGN AND  
CONSTRUCTION OF PORT AND  
HARBOUR STRUCTURES  
PART I CONCRETE MONOLITHS

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# Indian Standard

## CODE OF PRACTICE FOR DESIGN AND CONSTRUCTION OF PORT AND HARBOUR STRUCTURES

### PART I CONCRETE MONOLITHS

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## *Indian Standard*

# CODE OF PRACTICE FOR DESIGN AND CONSTRUCTION OF PORT AND HARBOUR STRUCTURES

## PART I CONCRETE MONOLITHS

### 0. FOREWORD

**0.1** This Indian Standard ( Part I ) was adopted by the Indian Standards Institution on 31 July 1981, after the draft finalized by the Ports and Harbours Sectional Committee had been approved by the Civil Engineering Division Council.

**0.2** This standard pertaining to waterfront structures is being issued in the following parts:

- Part I Concrete monoliths
- Part II Caissons
- Part III Sheet piles
- Part IV Cellular sheet pile structures.

**0.3** The methods of design and construction of monoliths for ports and harbours are normally used on the production of evidence of the adequacy of such methods based on analysis, model tests, and past experience. In this code, an attempt has been made to cover common methods of design and construction of concrete monoliths for port and harbour structures.

**0.4** Monolith is a large hollow rectangular or circular foundation sunk as an open caisson. It may have several pockets/wells. On reaching the desired founding strata, the bottom of the pocket/pockets is invariably plugged with concrete and the remaining portion often filled with sand or mass concrete. Monoliths are constructed of concrete, steel, masonry or timber; the most common being concrete. Timber monoliths, though extensively built in the past are now only of academic interest. Monoliths of required shape are built in stages on dry ground and sunk into the ground. The *bottom-most* portion is fixed with the cutting edge and is placed on the surface of the ground where the monolith is desired to be sunk. This code deals with only concrete monoliths which are largely and commonly used for the construction of marine structures such as quaywalls, dolphins and jetties.

**0.5** Monoliths are most suitable for foundation in waterfront structures where the predominating soil consists of soft clay, silt, sand or gravel. These subsoil materials can be readily excavated by grabbing from the pockets and they do not offer high skin friction during sinking. The monoliths may not be suitable where the sinking is through very hard strata, sunken barges, large boulders, tree trunks and other obstacles. By the process of grabbing under water, the soil around the monolith gets loose and tends to flow inside the pocket/pockets and thus cause subsidence of the ground around the monolith. Where damage may be caused by such subsidence to existing structures, the construction of monoliths may not be advisable.

**0.6** The monoliths are subjected to a variety of determinate and indeterminate forces. Moreover the saline waters, tidal variations, and the chemical effects of transhipped and stored goods also severely attack the building materials used in the construction. Therefore, the design of the monolith structure only on the static principles would be inadequate. The design shall be such that the dangers of fatigue, excessive wear and abrasion, corrosion and rusting, cracks, etc, are as minimum as possible.

**0.7** From the view point of basic requirements, the structure should be stable, strong, functionally efficient, and economical. For this purpose, the structural system is first chosen and the loads on it are established. The state of stress is then determined at each of its points under any and all possible loads. The calculated stresses are then compared with stresses that the materials can safely stand.

**0.8** During sinking through soft strata which offers low skin friction, the monolith at times drops down suddenly when the cutting edge is cleared. If the soft strata is overlain by stiff strata, that is when the strata near the top of the monolith offers skin friction greater than the weight of the monolith, the monolith gets suspended from the top and is restrained from the sudden drop. The steining at such occasions is subjected to severe tension and breaks. To safe-guard against such eventualities, adequate reinforcement shall be provided.

**0.9** In the formulation of this standard, due weightage has been given to international coordination among the standards and practices prevailing in different countries in addition to relating it to the practices in the field in this country.

**0.10** For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test, shall be rounded off in accordance with IS : 2-1960\*. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

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\*Rules for rounding off numerical values (*revised*).

## 1. SCOPE

**1.1** This standard ( Part I ) covers the design and construction of concrete monoliths for port and harbour structures.

## 2. TERMINOLOGY

**2.0** For the purpose of this standard, the definitions given in IS : 7314-1974\* and the following shall apply.

NOTE — Various elements of a typical concrete monolith are illustrated in Fig. 1.

**2.1 Bottom Plug** — The open bottom of the monolith is sealed with concrete when it is sunk to the designed founding strata. This sealed base is called the bottom plug, and is meant to evenly transfer the vertical load to the founding strata; it is also termed as bottom seal.

**2.2 Cover Slab** — The slab constructed on the monolith steinings to cover the pocket/pockets.

**2.3 Cutting Edge** — The lowermost portion of the monolith which cuts into the soil during sinking. It is generally made of structural steel.

**2.4 Deck-Slab** — The slab built at the deck level covering the whole monolith in plan.

**2.5 Dewatering** — The removal of water from monolith pocket/pockets by pumping or by any other means.

**2.6 Fascia Wall** — Sea-ward wall of the waterfront structure against which the vessels are berthed.

**2.7 Filling** — The material filled inside the monolith pocket/pockets. This is primarily done to improve the stability of the monolith, but in certain cases done to reduce the stresses in the steining.

**2.8 Kentledge** — The load placed on the monolith to aid sinking. It may be scrap metal, large stones, tanks filled with water, or any other convenient material.

**2.9 Kerb** — The lowermost tapering portion of the steining provided to facilitate sinking. It is heavily reinforced and fitted with cutting edge at the bottom.

**2.10 Monolith** — A large hollow rectangular or circular structure built in stages at the ground level and then sunk to the desired depth by excavation. It may have one or more pockets/wells/dredge holes.

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\*Glossary of terms relating to port and harbour engineering.

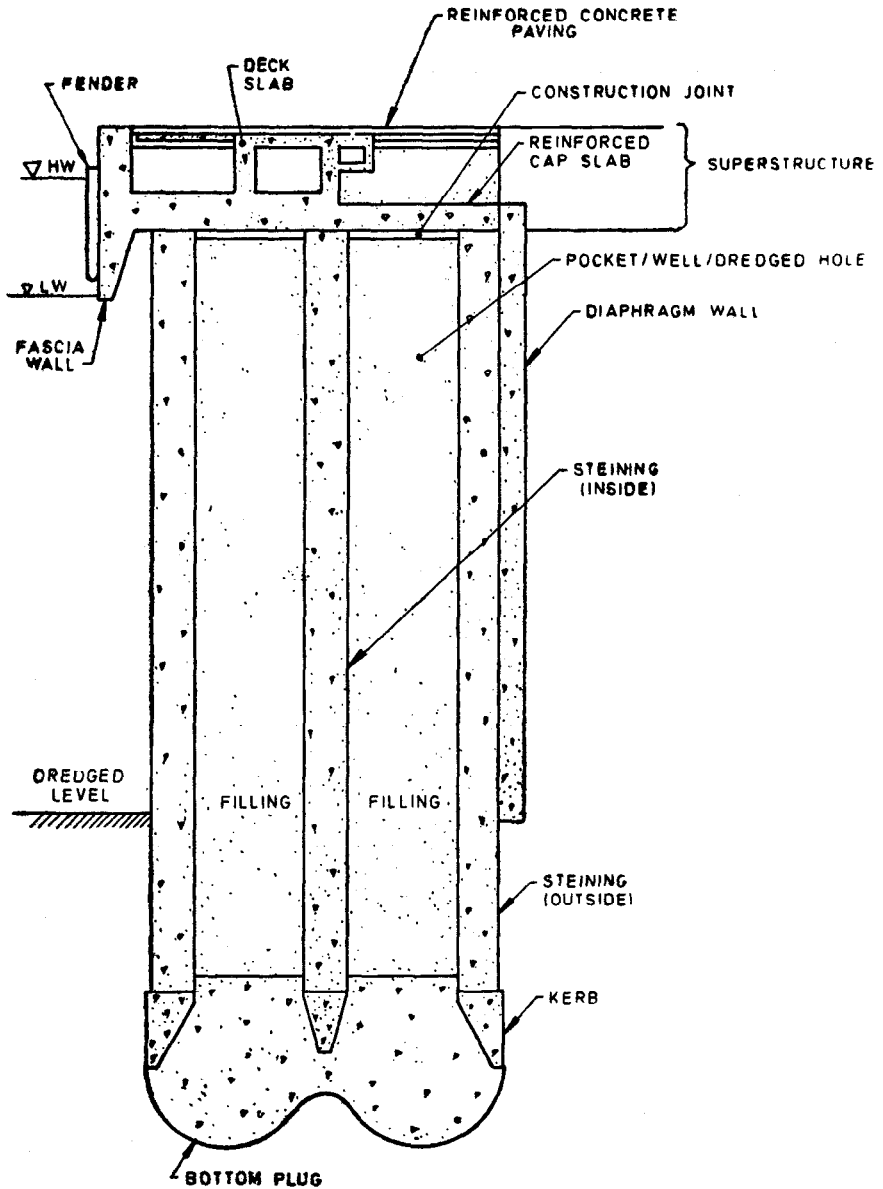


FIG. 1 VARIOUS ELEMENTS OF A MONOLITH

**2.11 Pocket, Well or Dredge Hole** — Vertical shaft between the steining of a monolith through which soil is excavated. The removal of the soil through the pocket/well/dredge hole makes the monolith sink into the ground.

**2.12 Cantilever Relieving Platform** — A cantilever platform sometimes built on the land side of the monolith, at suitable depth, to relieve excessive overturning moments caused by lateral forces.

**2.13 Sand-Blow** — The sudden flow of the soil from the areas adjacent to the steining of the monolith into the dredge hole/pocket.

**2.14 Service Galleries or Ducts** — The ducts constructed between the deck slab and the cover slab. These are meant to install the required services for the vessels berthed alongside.

**2.15 Shift** — The net horizontal movement of the monolith which may be due to tilt during or after construction from its designed position at a given level.

**2.16 Steining** — The load bearing wall of the monolith, external as well as internal, if any.

**2.17 Tilt** — Inclination that the monolith may acquire with respect to the vertical axis expressed as the tangent of the angle measured from the founding level.

### 3. MATERIALS

**3.1** The materials used in the construction should conform to the requirements laid down in IS : 456-1978\*.

**3.2 Plums** — In mass concrete members, stone plums of 160 to 300 mm size or any other reasonable size may be used in plain concrete work up to a maximum limit of 20 percent by volume of concrete when specially permitted.

**3.2.1** All plums shall be hard, durable, clean and free from soft materials or loose pieces or deleterious substances embedded in them and shall not have sharp corners.

**3.3 Storage of Materials** — Storage of materials shall be as per IS : 4082-1977†.

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\*Code of practice for plain and reinforced concrete (*third revision*).

†Recommendations on stacking and storage of construction materials at site (*first revision*).



## 4. STRUCTURAL DESIGN

### 4.1 Dimensions and Shapes

**4.1.1** There is no ideal solution for the design of a monolith and the final design is a compromise of a number of conflicting requirements. The shapes in plan may be round, oblong, oval, rectangular, square, hexagonal, etc and may have one or more cells/pockets ( see Fig. 2 ). The ideal shape of a monolith is circular in plan as this offers minimum surface area to the skin friction due to surrounding soil which opposes the sinking. The shape in most cases is dictated by the following:

- a) Requirements of the superstructure, namely crane tracks; service galleries, and other fixtures on the monoliths;
- b) The magnitude of earth and hydrostatic pressures;
- c) The bearing capacity of the subsoil;
- d) The magnitude of horizontal and vertical loads acting on the monolith;
- e) The requirements of control over tilt and shifts during sinking;
- f) The sinking effort to sink the monolith to its required founding level; and
- g) The dimensions of equipment available for sinking of monoliths.

**4.1.2** The verticality of the monolith, while sinking is better controlled by adopting a shape which comprises multiple pockets/wells. The pockets shall be symmetrically disposed in both sides of the axis to achieve control on tilting in both the directions ( Fig. 2A and 2B ). However, at corners of turnings or restricted locations narrower shape of monoliths may have to be used adopting a row of pockets ( Fig. 2C and 2D ). In such cases care shall be taken to provide pockets of suitable size so that the grab could effectively work for the sinking of monolith. It is advisable to keep the size of the pocket not less than  $3 \times 3$  m as far as possible.

### 4.2 Design Loads

#### 4.2.1 *Permanent Loads*

**4.2.1.1** The permanent loads are the maximum vertical and lateral loads acting on a monolith after it is constructed and sunk in place.

**4.2.1.2** IS : 4651 ( Part III )-1974\* covers the magnitude of the forces and the loads on water front structures which include monoliths.

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\*Code of practice for planning and design of ports and harbours: Part III Loading (first revision).

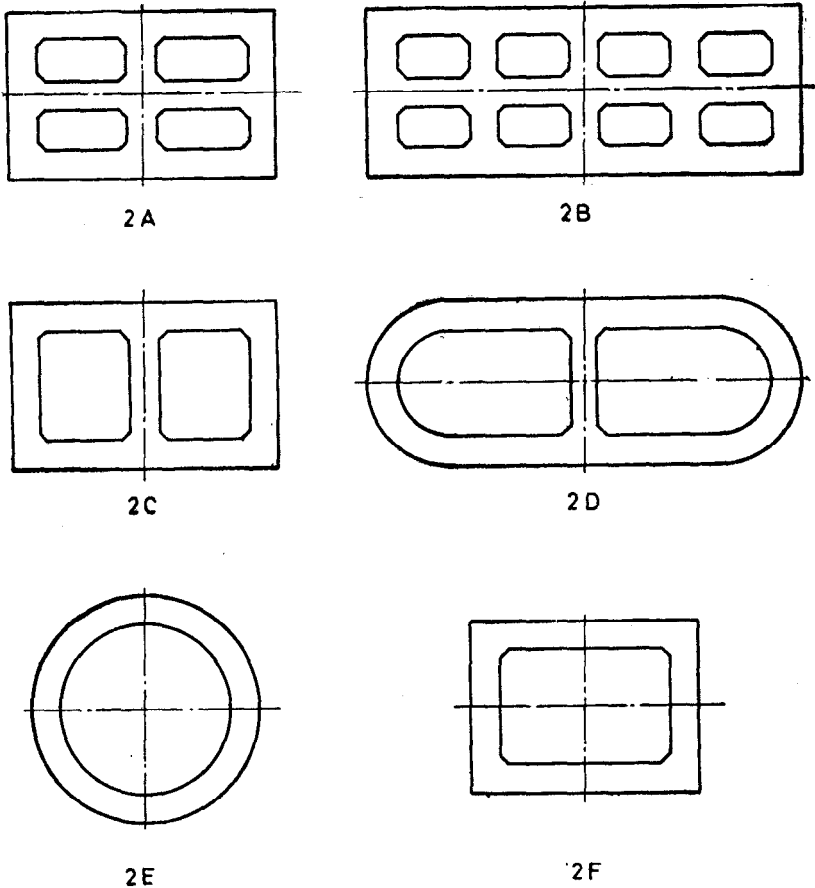


FIG. 2 TYPICAL SHAPES OF MONOLITH

**4.2.1.3** The earth pressure on a monolith shall be computed as stipulated in IS : 4651 ( Part II )-1969\*. Earth pressures and the average soil properties as given in Table 1 may be used for preliminary designs, whereas the final design shall be based on the soil properties obtained from the soil tests.

**4.2.1.4** The wind and seismic forces shall be taken conforming to IS : 875-1964† and IS : 1893-1975‡ respectively.

\*Code of practice for planning and design of ports and harbours: Part II Earth pressures.

†Code of practice for structural safety of buildings: Loading standards ( revised ).

‡Criteria for earthquake resistant design of structures ( third revision ).

TABLE 1 AVERAGE SOIL PROPERTIES

( Clause 4.2.1.3 )

TYPE OF SOIL  (1)	BULK DENSITY		ANGLE OF INTERNAL FRICTION  (4) <i>degree</i>	COHESIVE STRENGTH  (5) <i>t/m<sup>2</sup></i>	COEFFICIENT OF COMPRESSI- BILITY  (6) <i>t/m<sup>2</sup> × 10<sup>3</sup></i>
	Above Water  (2) <i>t/m<sup>3</sup></i>	Sub- merged  (3) <i>t/m<sup>3</sup></i>			
<i>Non-cohesive Soils</i>					
Loose sand, round	1·8	1·0	30	—	2-5
Loose sand, angular	1·8	1·0	32·5	—	4-8
Medium dense sand, round	1·9	1·1	32·5	—	5-10
Medium dense sand, angular	1·9	1·1	35	—	8-15
Gravel without sand	1·6	1·0	37·5	—	10-15
Coarse gravel, sharp edged	1·8	1·1	40	—	15-20
<i>Cohesive Soils</i>					
Soft clay	1·7	0·7	0-17·5	1·4	0·1-0·25
Medium stiff clay	1·9	0·9	25	2·5	0·5-1·0
Stiff clay	1·8	0·8	20	2	0·25-0·5
Boulder clay, solid	2·2	1·2	30	2·5	3·0-10·0
Loam, semifirm	2·1	1·1	27·5	1	0·5-2
Loam, soft	1·9	0·9	27·5	—	0·4-0·8
Silt	1·8	0·8	27·5	—	0·3-1
Soft, organic, slightly clayey sea silt	1·7	0·7	20	1	0·2-0·5
Peat	1·1	0·1	15	0·5	0·04-0·1

**4.2.1.5** A gap is left between the adjacent monoliths to accommodate for tilts and shifts. This gap shall not be less than two times the thickness of steining. The ultimate closure of gap will result in the transference of the lateral force into the monolith. The computed lateral force on a monolith has to be proportionately increased to account for this transference.

#### 4.2.2 Temporary Loads

**4.2.2.1** A monolith is also likely to be subjected to large stresses during the construction period.

**4.2.2.2** A monolith may be hung up near the top due to skin friction. The lower portion of the monolith is then subjected to tension.

**4.2.2.3** A monolith may get supported on one side only or on two opposite corners only, when it meets with an obstacle/obstacles.

**4.2.2.4** During a sand-blow or during the conditions like sudden drop that may occur at the site during sinking, the monolith is subjected to high earth and hydrostatic pressures.

**4.2.2.5 Monolith**, during sinking, invariably tilts and shifts. The measures adopted for the rectification of the tilts and shifts impose large vertical and raking forces and high earth pressures.

**4.2.3 Skin Friction** — Skin friction is the shearing resistance between the soil and the exterior surface of the monolith encountered during the process of sinking. The skin friction shall be assessed on the basis of soil properties.

### 4.3 Permissible Stresses

**4.3.1** The permissible stresses in concrete and steel reinforcement shall be the same as those given in IS : 456-1978\* unless otherwise specified.

### 4.4 Steining

**4.4.1** The thickness of steining shall be fixed from the following considerations:

- a) The steining should be able to withstand the stresses caused by the temporary loads during sinking besides the permanent loads.
- b) It should normally be possible to sink the monoliths without the use of excessive kentledge.

NOTE — For different thicknesses of steinings and shapes of the monolith, the sinking effort should be evaluated and whichever combination gives the higher value may be adopted for design. The sinking effort is defined as the ratio between the weight of the monolith and its surface area. The use of kentledge cannot be completely avoided in stiffer stratas. However, the designer may decide between the use of thicker steining or application of kentledge.

**4.4.2** For preliminary designs, the thickness of steining may be chosen from the following thumb rule:

$$t = C_1 \left\{ \frac{H}{100} + \frac{L}{C_2} \right\}$$

where

$t$  = thickness of the steining,

$H$  = designed depth of the monolith,

$L$  = maximum unsupported length in case of rectangular monolith and the external diameter in case of circular monolith, and

$C_1$  and  $C_2$  = constants which depend upon the type of strata through which the monolith is expected to be sunk; values of these constants are given in Table 2.

The thickness of the concrete steining shall not be less than 450 mm.

\*Code of practice for plain and reinforced concrete ( *third revision* ).

**TABLE 2 CONSTANTS  $C_1$  AND  $C_2$  FOR CALCULATING THE THICKNESS OF THE STEINING**  
( Clause 4.4.2 )

STRATA	CONSTANTS	
	$C_1$ (2)	$C_2$ (3)
(1)		
Sand	1.0	10
Soft clay	1.1	10
Hard clay	1.25	10
Boulders, Kankar, shale and such hard material	1.25	8

**4.4.3** The exterior walls of a monolith are designed to withstand the flexural stresses caused by the combined maximum lateral pressure and the compressive stress caused by the vertical load including the weight of the monolith. The connections between the interior and exterior walls shall be sufficiently rigid for the mutual transference of the loads coming on them.

**4.4.4** Having chosen the preliminary thickness of the steining the actual stresses which are likely to occur at site shall be worked out to arrive at the final thickness and the reinforcements. The final thickness shall, however, not be less than that stipulated in 4.4.2. The circular monolith is generally subjected to compressive stresses due to vertical loads as well as earth and hydrostatic pressures acting from outside. The behaviour of stresses in the case of rectangular monoliths is different as the steining is under direct compression due to vertical loads and subjected to bending stresses due to external earth and hydrostatic pressures. In the case of rectangular monoliths with multiple wells/pockets, the stresses shall be checked for the following conditions:

- a) The monolith has not reached the desired founding strata but is very close to it; to facilitate sinking at this stage, kentledge is used and the pocket/pockets are dewatered fully or partly.
- b) In the completed state of the monolith where full passive earth pressure and active earth pressure are mobilised on the sea-side steining and the land-side steining respectively.

NOTE — It is, however, advisable to adopt the same thickness of steining throughout the depth, and the reinforcement may be altered to suit the varying stresses.

**4.4.5 Reinforcement** — The vertical and horizontal reinforcement shall be provided according to the stresses worked-out at different depths. Where the computed stresses are within permissible stresses of the concrete, nominal reinforcement as specified in IS : 456-1978\* shall be provided.

\*Code of practice for plain and reinforced concrete ( *third revision* ).

## 4.5 Kerb

**4.5.1** The kerb is made of reinforced concrete. The depth of the kerb is governed by the thickness of the steining and the inclination provided to the inner face of the steining. In general, the requirements of a kerb are as follows:

- a) It should be strong enough to transmit the loads to the bottom of the plug.
- b) The width of the base of the kerb should be such that it affords low resistance when the well is being sunk through hard material and should provide necessary stability in the case of soft material.
- c) The slope of the inner faces of the kerbs should be such as to push forward easily the soil into the dredger hole/pocket. Generally the angle should be decided to suit the dominant factor in sinking. Whether soft soil at the early stages or stiff or bouldering soil at the later stages, the inclination of the inner face with respect to the vertical is recommended between  $30^\circ$  and  $45^\circ$  depending upon the type of strata. In the case of stiff clays, an angle of  $30^\circ$  and in the case of sands or soft clays, an angle of  $45^\circ$  are preferred.
- d) A small offset on the outside is to be provided to ease sinking.

**4.5.2** The kerb shall be designed for the greater of the resultant horizontal forces computed in the following cases:

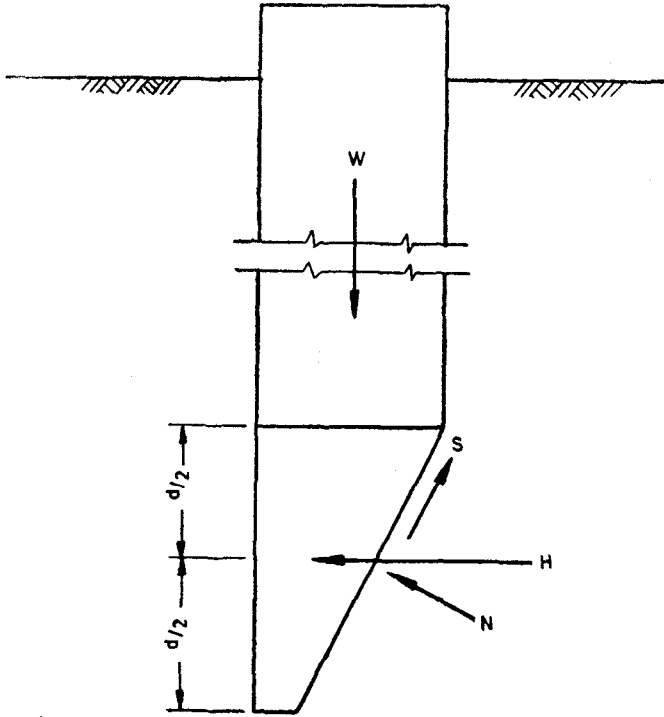
- a) when the monolith is being sunk, and
- b) when the kerb is resting on the bottom plug.

In case of (b), it may be reasonable to consider the active earth pressure around the kerb particularly in granular soil while computing the horizontal force.

**4.5.3** The forces acting on a kerb are the following and have been illustrated in Fig. 3:

- a) Weight of the steining and the temporary vertical loads per metre width ( $W$ ),
- b) Reaction acting normal to the bevel face of the kerb per unit width ( $N$ ),
- c) Tangential force acting on the bevel face per unit width ( $S = \mu \times N$ , where  $\mu$  is the coefficient of friction between the soil and the kerb), and
- d) Resultant horizontal force on the kerb per unit width ( $H$ ).

$N$  and  $H$  may be computed as the reactions from the bottom plug by any of the standard methods recommended in the textbooks.



NOTE — The symbols indicated in the figure have been described in 4.5.3 and 4.5.4.

FIG. 3 FORCES ON A KERB

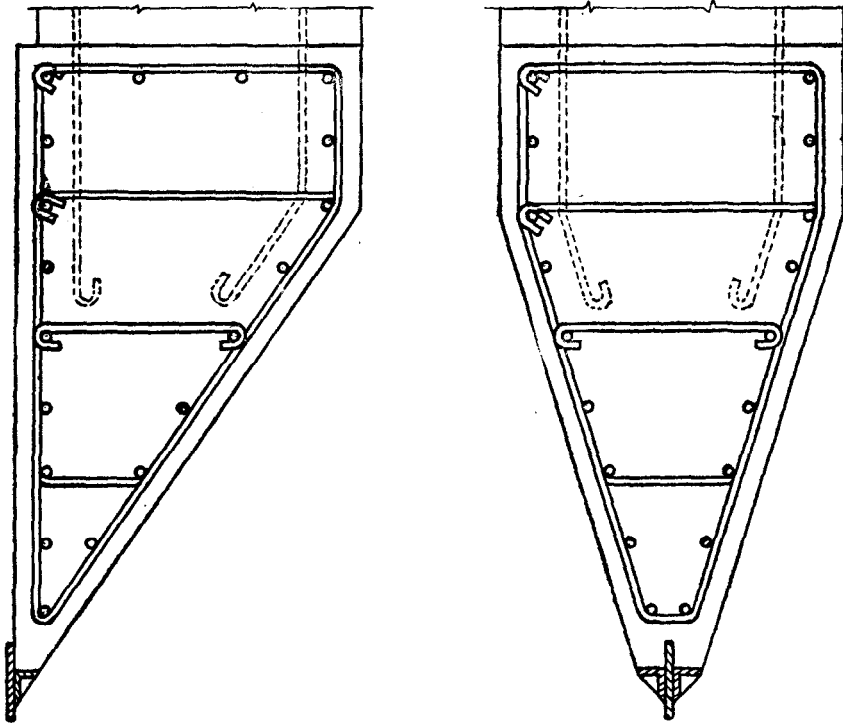
4.5.4 The horizontal thrust,  $H$ , causes:

- a) moment,  $M$ , at the junction of the kerb and the steining,  $M = H \times d/2$ , where  $d/2$  is lever arm as shown in Fig. 3; and
- b) hoop tension in case of circular monolith or tension on the sides of kerb which are parallel to the direction of  $H$  in case of rectangular monolith.

Adequate reinforcement shall be provided to take care of the resultant stresses.

**4.5.5** The reinforcement in the kerb shall be designed to meet the requirements given in **4.5.3**. It is also desirable to make provision for increased stresses due to temporary load such as sudden dropping of the well, by increasing the calculated tension reinforcement by 50 percent and by providing vertical bond rods. The reinforcement may be arranged in the form as shown in Fig. 4.

In case of rectangular monoliths, the reinforcing bars provided to resist the pull, shall be anchored properly round the corners to resist splitting.



4A OUTSIDE KERB

4B INSIDE KERB

FIG. 4 TYPICAL ARRANGEMENT OF REINFORCEMENT IN KERBS

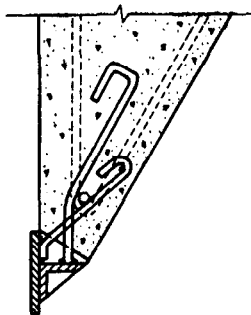
#### 4.6 Cutting Edge

**4.6.1** The cutting edge is made of structural steel plates and angles as it is subjected to concentrated high stresses while sinking; it shall be extremely strong, and rigidly and adequately anchored to the kerb.

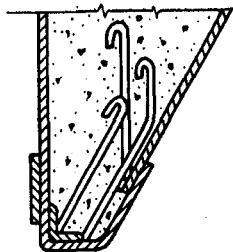


4.6.2 The cutting edge projecting from the kerb face shall be capable of taking the bending stresses caused while correcting the well for any tilt or shift.

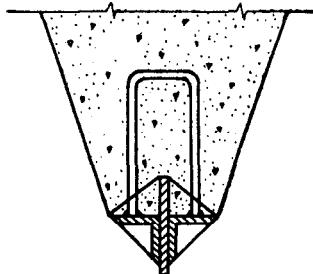
4.6.3 The cutting edges shall be fabricated with a sharp edge or with a stub nose as shown in Fig. 5A stub nose is to be preferred in soft clay and a sharp edge in stiff clay or granular soils.



5A OUTSIDE CUTTING EDGE



5B OUTSIDE CUTTING EDGE



5C INSIDE CUTTING EDGE

FIG. 5 CUTTING EDGES

4.6.4 The cutting edge fixed to the kerb of the inside steining may be kept about 300 mm higher than the cutting edge of the outside steining to avoid rocking of the monoliths during sinking.

## 4.7 Bottom Plug

**4.7.1** The bottom plug is the permanent base transmitting the loads of a monolith on to founding strata and shall, therefore, be designed accordingly. When it is anticipated to dewater the pockets of the monolith after its bottom is plugged, it shall be ensured that the bottom plug is adequately designed, constructed and cured so that it is able to withstand the stresses due to the uplift. It may be designed as a spherical dome or a thick flat slab supported on all sides by the steining and loaded by the subgrade reaction as a uniformly distributed load ( Fig. 6 ). The spherical form is more commonly adopted as compared to flat slab because of being more efficient.

**4.7.2** If the bottom plug is constructed as a flat arch, that is, the rise is very small as compared to the span, the thickness of the plug can be found out using the following expression ( see Fig. 6C ) :

$$t = \frac{ql^2}{8h_f c}$$

where

$t$  = thickness of the bottom plug in m,

$q$  = intensity of contact soil pressure or hydrostatic pressure per unit area in  $\text{N/m}^2$ ,

$l$  = span in m,

$h$  = rise in m, and

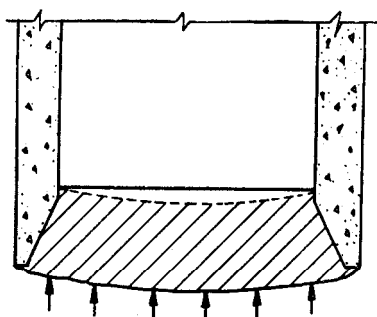
$f_c$  = permissible compressive stress in concrete of the bottom plug in  $\text{N/m}^2$ .

**4.7.3** The thickness of the bottom plug may also be worked out by applying the principles of theory of elasticity. For circular and rectangular monoliths, with different support conditions, the thickness of bottom plug may be worked out from the expressions given in Tables 3 and 4.

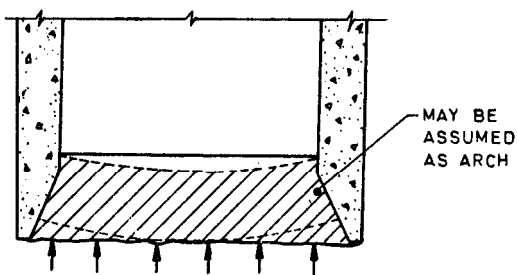
**4.7.4** Alternatively, the thickness of the bottom plug may be provided empirically as 0.3 m more than the thickness of the kerb.

## 4.8 Cover Slab

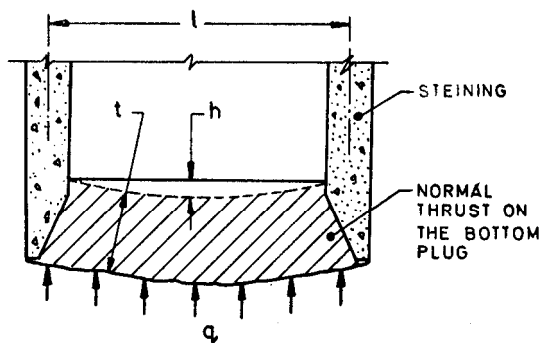
**4.8.1** The cover slab is designed to span the pockets/wells of the monolith. The slab is supported by the steinings on all the four sides, and is loaded by the superstructure and surcharge acting on the monolith structure. The support, if any offered by the sand filling in the pockets is ignored in



6A ARCH/DOME SHAPED BOTTOM PLUG



6B FLAT BOTTOM PLUG



6C DESIGN OF BOTTOM PLUG AS A FLAT ARCH

NOTE — The symbols indicated in Fig. 6C are described in 4.7.2.

FIG. 6 BOTTOM PLUGS AND THEIR DESIGN

TABLE 3 THICKNESS OF BOTTOM PLUG

( Clause 4.7.3 )

SUPPORT CONDITION	THICKNESS	
	Circular Monolith (2) m	Rectangular Monolith (3) m
(1) Edges simply supported	$\sqrt{\frac{3q R^2 (3 + \mu)}{8 f_c}}$	$\sqrt{\frac{6 \beta q l^2}{f_c}}$
Edges fixed	$\sqrt{\frac{6 q R^2}{8 f_c}}$	$\frac{6 \alpha q l^2}{f_c}$

NOTE 1 — In the expressions given in the table,  $q$ ,  $f_c$  and  $l$  are same as in 4.7.2;  $R$  is the radius of the monolith in m;  $\mu$  is Poisson's ratio; and  $\alpha$  and  $\beta$  are coefficients given in Table 4.

NOTE 2 — The permissible stress in the bottom plug concrete may be taken lesser than what is permissible as per IS : 456-1978\* because the bottom plug involves mass concreting which is done under-water. It may be taken from 1/6 to 1/10 of the ultimate crushing strength of the concrete used for the bottom plug.

\*Code of practice for plain and reinforced concrete ( *third revision* ).

TABLE 4 VALUES OF  $\alpha$  AND  $\beta$ 

( Clause 4.7.3 and Note 1 in Table 3 )

Length/Breadth Ratio of Mono- lith's Pocket	1	1.2	1.4	1.6	1.8	2	3	$\infty$
$\alpha$	0.051	0.064	0.073	0.078	0.081	0.083	0.083	0.083
$\beta$	0.048	0.063	0.075	0.086	0.095	0.102	0.119	0.125

the design of the cover slab. It shall be designed as a conventional slab, in accordance with IS : 456-1978\*.

**4.8.2** The level of the cover slab is decided on the basis of the depth required for the service galleries and the superstructure construction. It is normally kept just above the low water level.

\*Code of practice for plain and reinforced concrete ( *third revision* ).

**4.9 Superstructure**— The design of the superstructure involves the design of all components which are constructed above the cover slab. The superstructure may consist of fascia wall, service galleries, bollard blocks, gap slabs between adjacent monoliths, arrangements for mooring rings and fenders, ladders, crane beams, pavements, and any other special features as required over a particular monolith.

These shall be designed as per the recognised design practices. The structural soundness and the stability of individual elements, as well as of the whole system with the monolith, shall be ensured while designing the superstructure.

#### **4.10 Monolith with Cantilever Relieving Platform**

**4.10.1** The cantilever relieving platform is used when there are excessive overturning moments due to deep layer of soft soils and heavy surcharges. A cantilever, as shown in Fig. 7 is built on the landside of the monolith at a designed depth. This shadows the earth pressure on the monolith and also exerts moment opposite in direction to the overturning moment caused by the earth pressure and mooring forces. Since it relieves the pressure on the monolith structure, it is called relieving platform.

**4.10.2** The depth at which the cantilever should be built, and its span depends upon the amount of relief required on the structure. The cantilever may be designed as a reinforced concrete structure conforming to IS : 456-1978\*. However, wherever relieving platform is adopted in design special attention shall be given by the designer to the sequence of construction such that it is constructed monolithic with the monolith.

### **5. STABILITY**

**5.1 General**— The monoliths are invariably designed for heavy lateral loads in addition to the vertical loads, which are caused due to the earth pressure, hydrostatic pressure, and the mooring forces ( *see* Fig. 8 ). The conditions described in 5.2 to 5.5 in respect of overturning, sliding, bearing pressure and slip are required to be satisfied to ensure the stability of the structure.

In case the monoliths are part of a composite structure, rotation of monolith and its effect may also be examined.

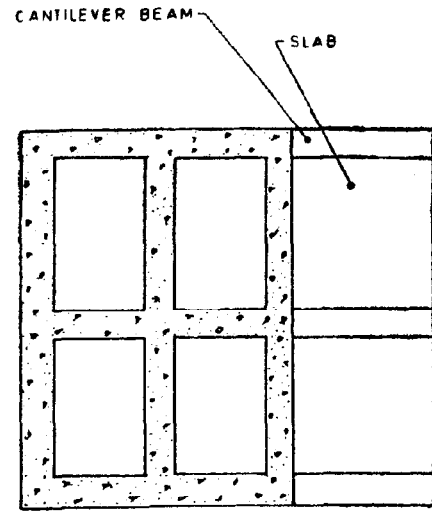
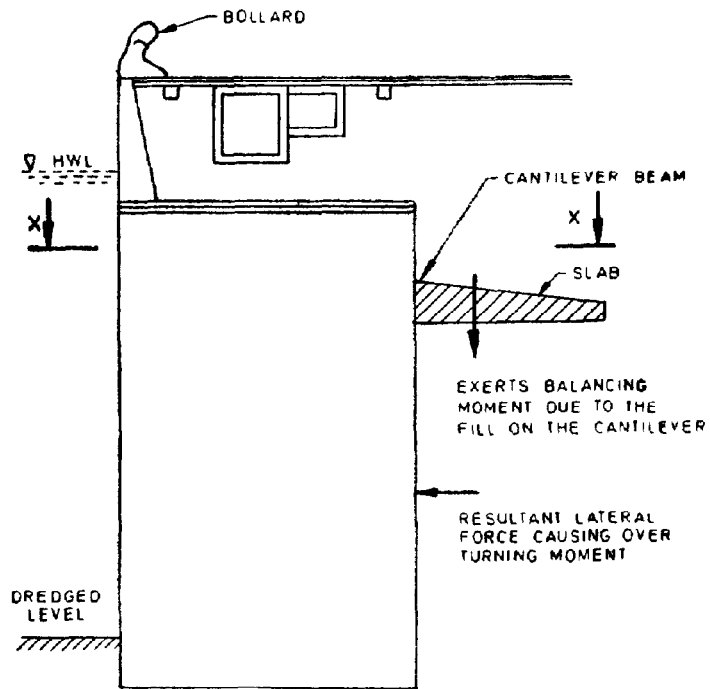
#### **5.2 Overturning**

**5.2.1** The horizontal forces on the monolith create overturning above the base. This is resisted by the restoring moment offered by the dead

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\*Code of practice for plain and reinforced concrete ( *third revision* ).

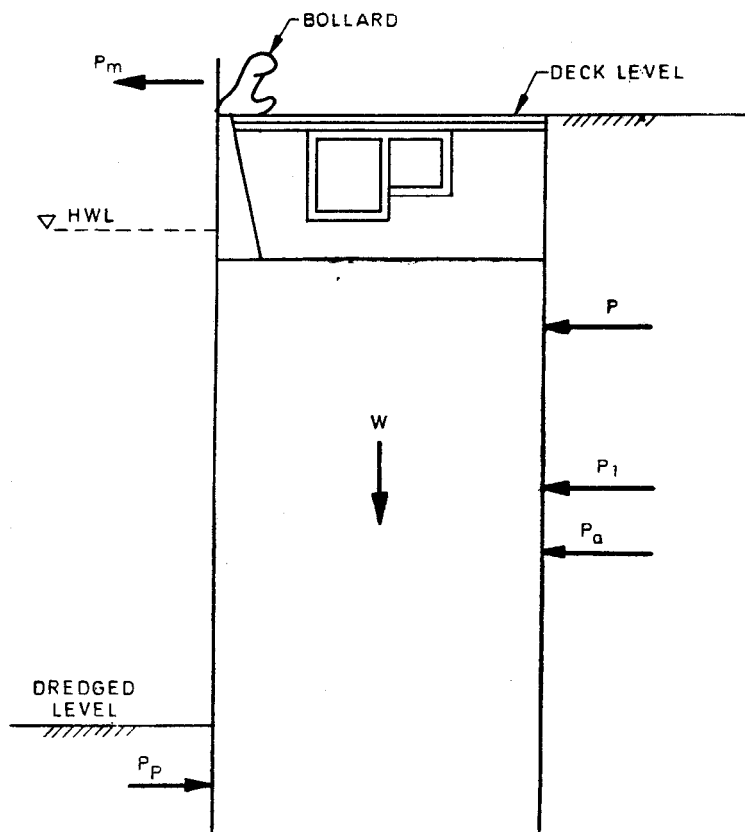
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SECTION XX

FIG. 7 CANTILEVER RELIEVING PLATFORM

weight of the monolith, the super-imposed load acting over it, and the passive earth pressure developed by the soil on the sea-side of the monolith ( see Fig. 8 ).



- $P$  = Hydrostatic force
- $W$  = Resultant vertical force
- $P_1$  = Resultant horizontal force
- $P_a$  = Resultant active earth pressure
- $P_p$  = Resultant passive earth pressure
- $P_m$  = Bollard pull

FIG. 8 FORCES ON A MONOLITH FOR CALCULATION OF STABILITY AGAINST OVERTURNING

**5.2.2** The factor of safety against overturning shall be not less than 1.5 when dead load, live load and earth pressures are considered together with seismic forces. When dead load, live load and earth pressure only are considered, the factor of safety shall be not less than 2.

NOTE 1 — Due allowance shall be made for buoyancy of the submerged portion of the monolith and the filling.

NOTE 2 — The exact evaluation of passive earth pressure is still an indeterminate feature. It develops to the full extent only after the monolith has moved considerably. It has been noticed by experiments that to develop the full passive pressure, the bulkhead had to deflect by about 2 degree. It has been observed that half the maximum passive earth pressure is developed even when the movement is insignificant. Monoliths are invariably very rigid and massive and are not likely to deflect to mobilise full passive earth pressure; therefore, a reduction factor 0.5 may be adopted in computing the passive earth pressure.

### 5.3 Sliding

**5.3.1** The unbalanced horizontal forces on the monolith tend to slide it on the founding strata. It shall be ensured that the structure is sufficiently safe against slidings. Resistance to sliding is offered by friction at the bottom of the monolith and the passive resistance of the soil on the sea-side of the monolith. While calculating the lateral forces causing slide, the hawser-pull shall also be taken into account.

**5.3.2** The factor of safety against sliding shall not be less than 1.5, that is

$$\frac{F_r}{F_a} \geq 1.5$$

where

$F_r$  = resultant lateral force resisting in slide, and

$F_a$  = resultant lateral force tending to slide the monolith.

**5.3.3** If the monolith is founded on a sloping rock, it shall be suitably anchored at founding level to avoid any sliding, by means of dowels, benching or any other suitable means.

### 5.4 Bearing Pressure

**5.4.1** Design shall be based on permissible bearing pressures established by detailed soil investigation and tests and previous experience. In deciding the permissible bearing pressure, the following shall be considered:

- a) The safety factor against shear failure shall be not less than 2.5.
- b) Settlements under allowable bearing pressure shall not exceed the tolerable limits.
- c) The effect of the skin friction on the monolith shall not be taken into consideration while working out the bearing stresses on the founding strata.



5.4.2 The maximum and minimum pressure at the base of the monolith ( see Fig. 9 ) shall be worked out as:

$$P = \frac{R}{A} \pm \frac{M_x}{Z_x} \pm \frac{M_y}{Z_y}$$

where

- $P$  = permissible bearing pressure,
- $R$  = resultant vertical load,
- $A$  = area of the base of the monolith,
- $M_x, M_y$  = resultant moment in  $x$  and  $y$  directions, and
- $Z_x, Z_y$  = section modulus of the monolith in  $x$  and  $y$  directions.

For a rectangular monolith, the above expression works out to the following:

$$P = \frac{R}{A} \left( 1 \pm \frac{6 e_x}{L} \pm \frac{6 e_y}{D} \right)$$

where

- $P, R$  and  $A$  are same as described above;
- $e_x, e_y$  = eccentricity of the resultant force  $R$  in  $x$  and  $y$  directions; and
- $L, D$  = dimensions of the monolith in plan,  $L$  being the width and  $D$ , the depth ( see Fig. 9 ).

5.4.3 The maximum bearing pressure exerted on the foundation soil beneath the wall base, which will be usually at the toe, shall not exceed the safe bearing capacity appropriate to the foundation soil. A factor of safety of 2 is adequate to determine safe bearing capacity.

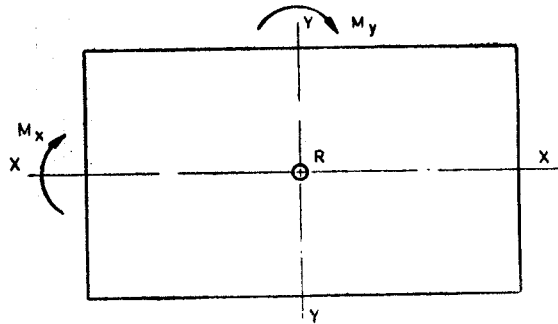
**5.5 Stability Against Slip**— In some cases, the monolith is founded on stiff clay. In such cases, if the soil on the back of the monolith is predominantly soft clay which is deficient in cohesion and internal friction, it is probable that the monolith, the back side soil, and the underlying strata may slip as a unit. The stability against such slip shall be checked and a factor of safety of not less than 1.5 be maintained. For temporary loading conditions or where the stability reaches a minimum during construction or for extreme combinations of loading, safety factor may be reduced to 1.2.

## 6. CONSTRUCTION

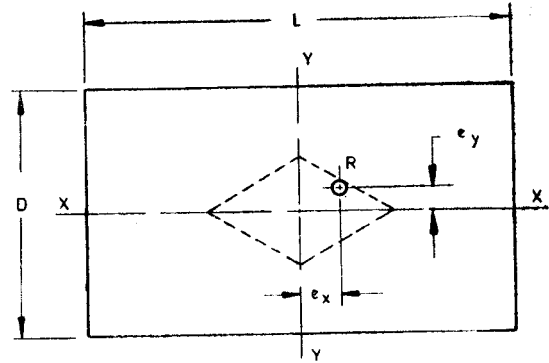
### 6.1 Zones of Monolith

6.1.1 The monolith is differentiated into three zones as described below ( see Fig. 10 ):

- a) Zone I above high water level ( HW ) or above the mean high water springs ( MHWS );



9A AXIAL LOAD AND MOMENT



9B EQUIVALENT AXIL LOAD AND MOMENT

FIG. 9 CALCULATION OF BEARING PRESSURE

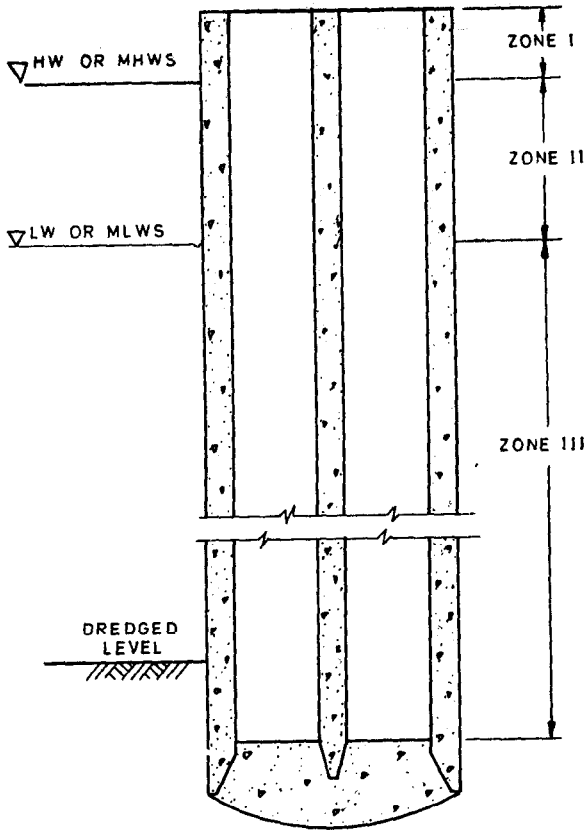


FIG. 10 CONSTRUCTION ZONES OF A MONOLITH

- b) Zone II between HW or MHWS and low water ( LW ) or mean low water springs ( MLWS ), in other words, between high and low tide spring tidal range; and
- c) Zone III below the low water ( LW ) or mean low water springs ( MLWS ).

In these three zones, varying requirements should be established as to the quality of concrete and reinforcement. The design and location of construction joints also need special attention depending upon the special local conditions.

**6.1.2** In Zone II, the minimum grade of concrete shall be M200, with a minimum cement content of 370 kg/m<sup>3</sup>. No construction joints shall be allowed in the zone from 600 mm below LW ( MLWS ), to 600 mm above the HW ( MHWS ). Where usually severe conditions of abrasion are anticipated, such parts of the work shall be protected by suitable coatings or stone facings.

## **6.2 Spacing**

**6.2.1** Monoliths shall be constructed as isolated units, separated by some distance from adjacent monolith. The sinking and grabbing inevitably cause tilt and shift; therefore, adjacent monoliths shall be so spaced that there is no adverse influence on either of them due to tilt and shift. If the monoliths are spaced very close, the soil confined in between the gap of the monoliths may get compacted and make the sinking difficult. On the other hand if the spacing is too large then the closure of this gap with the construction of diaphragm wall may work out to be very uneconomical. A compromise between these conflicting factors is, therefore, required while deciding the spacing. It is recommended that the monoliths are spaced not closer than twice the thickness of the outside steining.

**6.2.2** Sometimes notches are left in the side walls of the monoliths to accommodate diaphragm walls to close the gaps between them. This system would invariably be unworkable as the monoliths go out of position due to tilt and shift.

## **6.3 Placing of Kerb**

**6.3.1** The kerb of the monolith may be cast slightly away from the final location of the monolith to take care of anticipated tilt and shift. The extent of this displacement depends upon the actual site conditions and experience. Generally, it is cast landwards of the actual location to obviate the necessity of shifting the fascia-line seaward in case of sea-ward tilt/shift. In case of land-ward tilt/shift the superstructure can always be built up to the designed fascia-line.

**6.3.2** At sites where the ground level is higher than the designed cut-off level of the steining, it shall be excavated to avoid excessive skin friction. The excavation may be done up to 150 mm above the subsoil water table. If the existing soil is weak, a layer of murrum may be spread and compacted over it such that the kerb can be laid.

**6.3.3** If the site of construction is submerged under water, but the depth of the water is not more than 5 m or so, sand-island may be formed at the site by dumping sand. The sides of the island should be at least three-times the sides of the monolith for ease of construction. When the depth of water and large tidal variations make the formation of sand-island uneconomical, the use of floating caissons is resorted to.

## **6.4 Sinking of Monolith**

**6.4.1** The monolith is sunk as a single unit by dredging the bed material below the cutting edge. The dredging may be done manually or mechanically but is usually done by grabs operated from derricks or cranes. In hard strata, straight chisels may be used to break the material, which is then taken out with the help of grab. The divers may also be employed to sink the monolith through hard and difficult strata. They may use water jets or pneumatic tools to do the excavation and clear the cutting edges. Whether the sinking should be done by divers or grabs, depends upon the following factors:

- a) Initial cost of equipment,
- b) Availability of divers,
- c) Overall cost of sinking,
- d) Required speed of sinking, and
- e) Safety during sinking.

**6.4.2** The kerb of the monolith shall be allowed to set for at least a week before the sinking is commenced. In the early stages of sinking, the monolith is very unstable because it has very little grip in the surrounding strata. The chances of tilting increase considerably if the monolith is made top heavy by raising the steining too high in early stages. In the beginning it is advisable to let the kerb sink without raising the steining above it. The steining may then be raised by about 1.0 to 1.5 m at a time and sinking continued by allowing it to set for at least 24 hours. The setting time should be increased to 3 days if the surrounding soil and the sub-soil water contain deleterious materials which are likely to attack the fresh concrete. Once the monolith has acquired a firm grip in stiff strata, the steining may be raised more than 1.5 m at a time as it assists sinking.

When the monolith is in the vicinity of founding stratum, the raising of steining should be restricted so that any variation in the founding level due to site conditions is taken care of without breaking the already cast steining.

**6.4.3** To ensure the verticality of the monolith, it is essential that the steining is constructed as straight as possible. During the course of sinking the monolith tilts and the steining does not remain in plumb. If each lift of concrete is raised vertically, the final shape of the steining will come out zig-zag due to which the sinking may become impossible at some stage. It shall, therefore, be ensured that plumb bobs are not used for raising the steining.

**6.4.4** The main equipment required for the sinking of the monolith includes grabs, chisels, sand pumps, dredgers, clay and stone cutter, helmets for divers, cranes, derricks and shearlegs. In the hard strata, heaviest possible grab and chisel which can be operated in the pocket of the monolith,

is recommended to be used. Special rock cutting teeth may be added to the grab while sinking through very hard strata.

**6.4.5** The monolith sinks by its own weight when the soil below the cutting edge is removed. Kentledge will have to be added to achieve sinking when the skin friction due to the external soil is so large that the monolith is unable to sink under its own weight. Dewatering of the monolith may also be done where the sinking is not possible even with the help of the kentledge. Sometimes, this activates sand-blow resulting in sudden drop of the monolith. This sudden drop cannot be controlled and invariably causes excessive tilt/shift. Care shall therefore be exercised not to depress the water level excessively.

**6.4.6** If the addition of kentledge and dewatering does not produce the desired results, air and water jets are used to reduce the friction on the sides. If such problems are envisaged at the time of designing the monolith, suitable passages for water, air or mud (bentonite) may be left in the steining and nozzles permanently fitted at suitable locations.

**6.4.7** If all other methods fail, restricted blasting may be permitted. A very controlled blasting, with appropriate explosive, may be allowed ensuring that no damage is caused to the existing structures. No divers should be allowed to work in the nearby monoliths when the blasting is done. In case of monoliths with two or more pockets, all pockets shall be subjected to simultaneous explosion so that the monolith does not sink unevenly.

**6.4.8** To achieve sinking in stiff soils, invariably the cutting edge has to be undercut. This loosens and disturbs the soil around the monolith.

## **6.5 Tilt and Shift**

**6.5.1** The tilt and shift occur in every conceivable direction. Up to certain limits, the tilts and shifts are always permitted and their influence on the stability of the monolith is taken care of in the design. The limit is decided by the designer on the basis of his experience and the soil conditions. Whenever, a monolith has tilted beyond the permissible limit, its stability shall be rechecked and suitable remedial measures, if required, should be taken before the bottom is plugged. The cumulative effect of tilts and shifts on a number of monoliths forming a waterfront structure, invariably alters the originally decided wharf line. This affects the span between the adjacent monoliths, shifts the position of the fixtures and necessitates the redesign of the superstructure.

**6.5.2** Usually the combined effect of tilt and shift should not be more than  $\pm 300$  mm at top of the monolith. Shifts up to  $\pm 300$  mm and tilts up to 1 : 60 depending upon the soil conditions and the size and depth of the monolith, are permitted. These limits may however be taken as a guide and be decided as per site conditions.

**6.5.3** The tilts and shifts usually do not occur suddenly. The movement may be observed when the monolith is about a metre above the level of a comparatively harder strata. This is the time for taking effective measures to prevent its occurrence. If adequate precautions are not taken to rectify the tilt and shift at the time it starts, it gets aggravated.

**6.5.4** The tilt/shift may occur due to various reasons, a few of which are described below:

- a) Efforts to rush the work in early stages when the monolith has not even obtained the desired grip in the stiff strata.
- b) When too radical steps are taken to correct minor tilts and shifts.
- c) Due to the unequal grabbing from the pockets of the monolith—simultaneous and equal grabbing should be carried from the pockets symmetrical about the axes of the monolith.
- d) When the monolith enters a harder strata from a comparatively softer strata—tilting gets further aggravated if the harder strata happens to be sloping.
- e) Occurrence of sand-blow.
- f) When the strata being penetrated is having uneven bearing capacity.
- g) Due to the presence of underground obstruction falling under a part of the cutting edge.

**6.5.5 Methods of Rectification** — The methods to rectify the tilt depend upon the magnitude of tilt, type and depth of soil surrounding the monolith, the size of the monolith, the availability of resources and the time, and the most important the ingenuity of the site engineer. Some of the methods which are commonly used, individually or in combination with each other, are listed below:

- a) *Eccentric loading* — The higher side of the monolith is provided with a cantilever platform and loaded with kentledge; this is accompanied with eccentric grabbing, that is removing the material from the higher side only.
- b) Eccentric grabbing.
- c) By pulling or pushing the monolith.
- d) By arresting the movement of the lower kerb of the monolith—this can be achieved by packing the lower portion of the monolith with sand-bags or hard wooden-blocks, and then continuing the grabbing operation on the higher side. The sand-bags/wooden-blocks are removed once the monolith attains the desired verticality.
- e) By jetting water under pressure through the pipes provided in the steining during its casting — jetting will loosen the dense sands at the cutting edge and will reduce skin friction on the exterior wall.

- f) By chiselling or blasting the stone/boulder which might be obstructing the edge by sending a diver.

## 6.6 Construction of Bottom Plug

**6.6.1** The bottom of a monolith is plugged with concrete using tremie process or skip boxes, or by colloidal concrete. Any of the methods may be adopted ensuring that sound concrete is obtained, and in no case the concrete is dropped from a height. If the concreting is done using skip-boxes, adequate arrangements should be made such that they distribute the concrete evenly at the base.

**6.6.2** The bottom of the monolith shall be thoroughly cleaned of sand and other loose materials before the commencement of plugging. Accurate sounding shall be taken and recorded to ascertain the depth of various points in the pocket/pockets. Founding of the monolith is always difficult on sloping or uneven rocky bed. Under such circumstances, it may become necessary to blast the rock or do underpinning to support the steining adequately. Sufficient soil/rock samples obtained at the founding level shall be kept for inspection and record.

**6.6.3** The water in the pockets of the monolith shall be still and up to its normal level before the plugging is commenced.

**6.6.4** The plugging shall be done in one continuous operation till completed. If there are two or more pockets, the plugging shall be done simultaneously and to equal heights in all the pockets.

**6.6.5** It has been observed that the concrete used for the bottom plug takes longer time to set and considerable proportion of cement gets washed resulting in weak concrete; therefore, 10 percent extra cement shall be mixed in the concrete.

**6.6.6** There shall be no flow of water through the concrete till it is set.

**6.6.7** *Testing of Bottom Plug* — The soundness of the bottom plug may be tested by dewatering the monolith by 5 m below the surrounding ground water-level, and checking the rise of water. The rate of rise shall be less than 100 mm per hour and in case it is higher, suitable remedial measures shall be taken. The test shall not be done earlier than 21 days after concreting of bottom plug.

## 6.7 Filling

**6.7.1** The pockets of the completed monoliths are generally backfilled with approved sand. The sand filling cannot be relied upon for transmitting the weight of the superstructure to the bottom plug. The main contribution of the filling is to improve the stability of the monolith, and eliminate the



development of tension at the base which may be caused due to overturning moment. The stresses in the steining due to outside earth and hydrostatic pressures are partly reduced by the filling.

**6.7.2** The filling, though helps in the stability of the monolith increases the bearing pressure on the founding strata. If the bearing pressure is likely to increase beyond the acceptable limits, the monolith may not be back-filled provided the monolith is stable otherwise.

### **6.8 Expansion Joints**

**6.8.1** The quay wall solidly built with monoliths should be provided with expansion joints so that they can absorb the movements arising from shrinkage, temperature changes and yielding of the foundation. The normal length of the sections between the expansion joints is 30 m; however, it is left to the discretion of the designer in view of the large number of factors involved in deciding the location.

**6.8.2** The expansion joints in the sections are keyed for mutual horizontal support. These shall be so provided that the necessary movement occurs with a minimum resistance at the joint. Reinforcement shall not extend across the expansion joint and the break between the sections shall be complete. These shall also be covered vertically in such a way that the backfill is prevented from being washed out.

### **6.9 Construction Joints**

**6.9.1** There shall be no construction joints in the tidal zone ( *see 6.1.2* ). The construction joints shall be so placed in the outer walls that no shrinkage cracks may possibly occur. The steel reinforcement shall also be so designed that it prevents the occurrence of shrinkage and temperature cracks; but making a special mesh for the purpose is unnecessary. For guidance on providing the construction joint, requirements of IS : 456-1978\* shall be followed.

### **6.10 Facing and Nosing**

**6.10.1** Facing of the concrete may be omitted if the steining and the superstructure is well designed and satisfactory concrete is used. If a facing is required as a protection against unusual mechanical wear, the use of basalt, granite or equivalent is recommended. A hard concrete coating about 50 mm thick is also considered suitable as a wearing surface along the coping of the water front structure, but is only required if there is going to be heavy traffic and the vessels are moored with steel hawsers.

**6.10.2** The fascia wall is constructed vertically and is generally given a chamfer of about 150 mm at the upper edge or is correspondingly rounded off when a special nosing is not used. When nosing is installed for the protection of the wall, and as a safety against slipping of the line handlers, it shall be so constructed that the surface water easily drains off.

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\*Code of practice for plain and reinforced concrete ( *third revision* ).

**6.11 Precast Structural Elements**—Precast concrete structural elements may be used with advantage for various components of superstructure. Care shall however be taken for joining them securely with cast-in-situ concrete for proper transmission of forces. The unavoidable construction joints often occur at such locations where the stresses are high. In such cases the joints shall be carefully designed and constructed.

**INDIAN STANDARDS**  
**ON**  
**PORTS AND HARBOURS**

IS:

- 4651 ( Part I )-1974 Code of practice for planning and design of ports and harbours:  
Part I Site investigation (*first revision*)
- 4651 ( Part II )-1969 Code of practice for planning and design of ports and harbours:  
Part II Earth pressures
- 4651 ( Part III )-1974 Code of practice for planning and design of ports and harbours:  
Part III Loading (*first revision*)
- 4651 ( Part IV )-1979 Code of practice for planning and design of ports and harbours:  
Part IV General design considerations (*first revision*)
- 4651 ( Part V )-1980 Code of practice for planning and design of ports and harbours:  
Part V Layout and functional requirements
- 7314 - 1974 Glossary of terms relating to port and harbour engineering
- 9527 ( Part IV )-1980 Code of practice for design and construction of port and harbour  
structures: Part IV Cellular sheet pile structures