IS 9527-4 (1980): Code of practice for design and construction of port and harbour structures, Part 4: Cellular sheet pile structures [CED 47: Ports and Harbours]

BLANK PAGE

IS : 9527 (Part IV) - 1980

(Reaffirmed 2012)

“पुनर्पुष्ट १९८०”

“REAFFIRMED 19..”

Indian Standard

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

PART IV CELLULAR SHEET PILE STRUCTURES

UDC 627·21 : 624·04 : 624·154·8 — 405·8 : 006·76

INDIAN STANDARDS INSTITUTION
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

Price Rs 7·00 Gr 4 *August* 1980

Indian Standard

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

PART IV CELLULAR SHEET PILE STRUCTURES

Ports and Harbours Sectional Committee, BDC 66

Chairman	*Representing*
BRIG O. P. NARULA	Ministry of Shipping and Transport
Members	
CAPT P. BALARAM	Marine Department, Madras Port Trust, Madras
CAPT G. A. MANDE (*Alternate*)	
SHRI M. BALASUBRAMANIAM	Mormugao Port Trust, Vasco da Gama, Goa
SHRI U. R. BALASUBRAMANIAM	Engineering Department, Madras Port Trust, Madras
SHRI N. VARDARAJAN (*Alternate*)	
CAPT P. N. BATRA	Marine Department, Calcutta Port Trust, Calcutta
CAPT D. K. DUTTA (*Alternate*)	
SHRI N. P. BHAKTA	Pre-investment Survey of Fishing Harbour, Bangalore
SHRI H. V. RAMASWAMY (*Alternate*)	
SHRI R. K. BUDHBHATTI	Public Works Department, Government of Gujarat, Ahmadabad
SHRI B. P. KUKADIA (*Alternate*)	
CHIEF ENGINEER	Chief Engineers Department, Calcutta Port Trust, Calcutta
CHIEF PORT OFFICER	Maharashtra State Port Authority, Bombay
COASTAL ENGINEER (*Alternate*)	
REAR ADM A. G. DASTIDAR	Indian Navy (Ministry of Defence), Vishakhapatnam
LT-COL V. S. BHANDARI (*Alternate*)	
DIRECTOR	Central Water and Power Research Station, Pune
CHIEF RESEARCH OFFICER I (*Alternate*)	
SHRI A. H. DIVANJI	Asia Foundation & Construction Pvt Ltd, Bombay
SHRI A. N. JANGLE (*Alternate*)	

(*Continued on page* 2)

(*Continued from page* 1)

Members	*Representing*
SHRI K. K. FRAMJI	Consulting Engineering Services India Pvt Ltd, New Delhi
SHRI S. GHOSH (*Alternate*)	
SHRI S. R. GAITONDE	Bombay Port Trust, Bombay
SHRI P. S. RAO JANAMANCHI	Oil and Natural Gas Commission, Bombay
SHRI R. D. KOHLI	Shipping Corporation of India, Bombay
SHRI MANOHAR SINGH	Continental Construction Pvt Ltd, New Delhi
SHRI J. P. AWASTHI (*Alternate*)	
CAPT M. V. K. MENON	Cochin Port Trust, Cochin
SHRI M. K. MATHEW (*Alternate*)	
CAPT SUBIMAL MOOKERJEE	Indian Navy (Operational), Ministry of Defence
CDR P. S. SIVAMANI (*Alternate*)	
DR S. K. NAG	Hydraulic Study Department, Calcutta Port Trust, Calcutta
DR A. N. BISWAS (*Alternate*)	
SHRI H. NANDI	Project & Equipment Corporation of India Limited, New Delhi
PROF S. NARASIMHAN	Indian Institute of Technology, Bombay
DR I. V. NAYAK	Karnataka Regional Engineering College, Suratkal, Srinivasnagar
PROF G. RANGANNA (*Alternate*)	
BRIG OMBIR SINGH	Engineer-in-Chief's Branch, Army Headquarters
SHRI HASMUKH P. OZA	In personal capacity (*Atul, 20 Pathik Society, Ahmadabad*)
SHRI B. K. PANTHAKY	Hindustan Construction Co Ltd, Bombay
SHRI P. V. NAIK (*Alternate*)	
SHRI G. S. RAMAIAH	Andamann Lakshadeep Harbours Works, New Delhi
SHRI T. V. RAMANA RAO	Vishakhapatnam Port Trust, Vishakhapatnam
SHRI P. S. RAO (*Alternate*)	
SHRI S. R. ROESSLER	Howe (India) Pvt Ltd, New Delhi
SHRI C. S. DEBKE (*Alternate*)	
SUPERINTENDING ENGINEER (CENTRAL MECHANICAL CIRCLE)	Public Works Department, Government of Tamil Nadu, Madras
SENIOR DEPUTY CHIEF ENGINEER (BLDG) (*Alternate*)	
SHRI M. C. TANDON	Stup (India) Limited, Bombay
SHRI M. K. CHATTERJEE (*Alternate*)	
DR V. D. TAPASVI	Engineers India Limited, New Delhi
SHRI M. CHOWDHURY (*Alternate*)	
SHRI D. AJITHA SIMHA, Director (Civ Engg)	Director General, ISI (*Ex-officio Member*)

Secretary

SHRI K. M. MATHUR
Deputy Director (Civ Engg), ISI

Indian Standard

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

PART IV CELLULAR SHEET PILE STRUCTURES

0. FOREWORD

0.1 This Indian Standard (Part IV) was adopted by the Indian Standards Institution on 8 February 1980, 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 water front structures is being issued in the following parts:

Part I Monoliths

Part II Caissons

Part III Sheet Piles

Part IV Cellular Sheet Pile Structures

0.3 Cellular sheet pile structures are commonly used both on land and as water-front structures such as retaining walls, cofferdams, docks, locks, breakwaters, piers, etc. There are many types of cellular structures like circular, diaphragm, clover-leaf, modified circular and separate circular. This standard (Part IV) covers circular and diaphragm types, which are generally used in this country.

0.4 In the formulation of this standard due weightage has been given to international co-ordination among the standards and practices prevailing in different countries in addition to relating it to the practices in the field in this country.

0.5 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.

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

1. SCOPE

1.1 This standard (Part IV) covers the design and construction of cellular sheet pile structures of circular and diaphragm types which are constructed with straight web steel sheet piles as the perimeter sheet with soil fill inside.

2. DESCRIPTION

2.1 Circular Type — Each cell can be constructed independently and forms a stable unit by itself. Hence this type provides high safety during construction and high structural stability. But the wall width is limited by interlock tension of the steel sheet piling. Circular type cell is the most commonly preferred one as each cell forms a stable unit and failures if any are localized into a cell.

2.2 Diaphragm Type — In this type wall width can be enlarged without increasing the interlock tension of the steel sheet piling. Unlike circular type, each cell is not independent and failure of one cell affects the others. This type is sensitive to differential filling in adjacent cells.

3. MATERIAL

3.1 Steel Sheet Piles — Only straight web steel sheet piles conforming to ISPS 100 F of IS : 2314-1963* are suitable for this type of construction. Other sections, namely, Z or U type, are not suitable. It is recommended that steel should contain 0·2 to 0·35 percent copper for imparting corrosion resistance to sea water.

3.2 Soil Fill — Freely draining non-cohesive soil fill is generally used. Fine sand which may flow out with seepage water, is avoided. Other type of soils may be used with caution.

3.3 Paint — One coat of primer shall be applied on the clean surfaces of steel piles. These should, then, be painted with at least two coats of special marine paint before pitching and driving (*see* IS : 1419-1959†).

4. LAYOUT

4.1 Circular Type

4.1.1 Circular cell construction requires accurate pitching and driving to ensure closing of a cell with the required number of standard piles. Cell diameter, spacing, connecting arc radius, number of piles, etc, may be adopted from Table 1 read with Fig. 1. A plan may be drawn with the dimensions so obtained and minor adjustments made in geometry, if required.

---

*Specification for steel sheet piling sections.

†Specification for anti-fouling paint, brushing, for ships' bottoms and hulls, red, chocolate or black, as required.

TABLE 1 DETAILS OF LAYOUT OF CIRCULAR CELL TYPE OF CELLULAR SHEET PILE

(*Clause* 4.1.1, and *Fig.* 1)

No. of Piles in Cell	*D*	2*L*	No. of *M* Pile	*R*	No. of *N* Pile	*X*	*C*	*B*	Area	
									Within Circle	Between Circle
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	m	m		m		m	m	m	m²	m²
60	7·64	9·01	14	2·55	9	0·90	1·36	6·40	45·87	14·83
64	8·15	9·37	15	2·55	9	1·08	1·21	6·81	52·19	14·98
68	8·66	9·73	16	2·55	9	1·26	1·06	7·23	58·93	15·06
72	9·17	10·09	17	2·55	9	1·44	0·91	7·64	66·04	15·06
76	9·68	10·81	18	2·80	10	1·44	1·13	8·07	73·59	18·22
80	10·19	11·53	19	3·06	11	1·44	1·34	8·51	81·55	21·67
84	10·70	11·89	20	3·06	11	1·62	1·19	8·92	89·92	21·70
88	11·21	12·61	21	3·31	12	1·62	1·40	9·35	98·70	25·46
92	11·71	12·97	22	3·31	12	1·80	1·25	9·76	107·77	25·48
96	12·23	13·69	23	3·57	13	1·80	1·46	10·20	117·44	29·53
100	12·74	14·05	24	3·57	13	1·98	1·31	10·61	127·44	29·53
104	13·25	14·77	25	3·82	14	1·98	1·52	11·05	137·84	33·91
108	13·76	15·13	26	3·82	14	2·16	1·37	11·46	148·62	33·89
112	14·27	15·85	27	4·08	15	2·16	1·59	11·89	159·84	38·59
116	14·74	16·18	28	4·08	15	2·33	1·45	12·27	170·55	38·56
120	15·29	16·57	29	4·08	15	2·52	1·29	12·72	183·52	38·45
124	15·80	17·29	30	4·33	16	2·52	1·50	13·15	195·97	43·51
128	16·30	17·65	31	4·33	16	2·70	1·35	13·57	208·77	43·39
132	16·81	18·37	32	4·59	17	2·70	1·56	14·00	222·04	48·75
136	17·32	18·73	33	4·59	17	2·88	1·41	14·42	235·71	48·60
140	17·83	19·46	34	4·84	18	2·88	1·62	14·85	249·80	54·30
144	18·34	19·81	35	4·84	18	3·06	1·47	15·26	264·23	54·14
148	18·85	20·18	36	4·84	18	3·24	1·32	15·68	279·13	53·90
152	19·36	20·90	37	5·10	19	3·24	1·53	16·11	294·44	59·97
156	19·87	21·26	38	5·10	19	3·42	1·39	16·53	310·15	59·71
160	20·38	21·98	39	5·35	20	3·42	1·60	16·96	326·27	66·10
164	20·89	22·34	40	5·35	20	3·60	1·45	17·38	342·74	65·83
168	21·40	22·70	41	5·35	20	3·78	1 30	17·79	359·68	65·48
172	21·91	23·42	42	5·61	21	3·78	1 51	18·22	377·03	72·24
176	22·42	23·78	43	5·61	21	3·96	1·36	18·64	394·79	71·87
180	22·93	24·14	44	5·61	21	4·14	1·21	19·06	412·88	41·43
184	23·42	24·85	45	5·86	22	4·14	1·42	19·48	430·94	78·48
188	23·95	25·22	46	5·86	22	4·33	1·27	19·91	450·43	78·01

Note 1 — The smallest circular cell that can be built using flat-type sheet piles is about 3 m in radius, but construction can be expedited by making the radius larger than 3 m.

Note 2 — The number of sheet piles required to form a cell is always even because of the shape of the joint. If an odd number of sheet piles is required, one special-shaped pile shall be used.

As in the Original Standard, this Page is Intentionally Left Blank

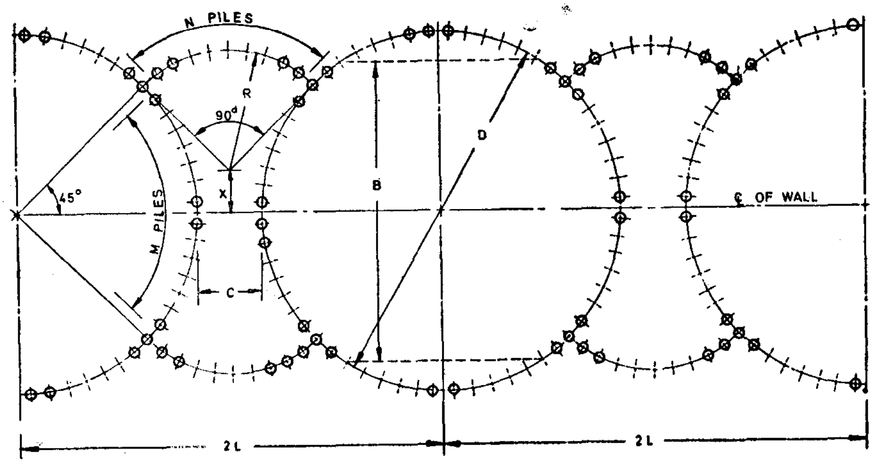

FIG. 1 DETAILS FOR LAYOUT OF CIRCULAR SHEET PILE CELL

4.1.2 The front part of the connecting arc tends to be pushed forward under the pressure of the filling material. Therefore, the front part of the arc is placed behind the tangent to the front of the cell.

4.1.3 The whole wall may yield or deflect on full loading. It is recommended that the front wall of the cell be placed in such a manner that its tangent runs about 30 cm inside the planned normal face.

4.2 Diaphragm Type — The various details are given in Table 2 read with Fig. 2.

5. DESIGN CONSIDERATIONS

5.1 The following forces should be considered in the design of the cellular structures:

a) Active lateral earth pressure at the backside of the wall,
b) Passive lateral earth pressure at front of the wall,
c) Lateral earth pressure of the fill,
d) Residual water pressure,
e) Seismic force (which has influence on the fill) and its effect on fill and back fill,

f) Mass of the fill,
g) Impact of vessel,
h) Bollard pull,
j) Wave force, and
k) Any other force peculiar to a particular situation.

5.2 Earth pressures and loading should be calculated in accordance with IS : 4651 (Part II)-1969* and IS : 4651 (Part III)-1974†.

TABLE 2 DETAILS OF LAYOUT OF DIAPHRAGM TYPE CELLULAR SHEET PILE STRUCTURE

(*Clause* 4.2, and *Fig.* 2)

No. of N Piles	$R = C$	H	Y
(1)	(2)	(3)	(4)
	m	m	m
10	4·20	0·56	0·76
11	4·58	0·61	0·83
12	4·96	0·66	0·90
13	5·35	0·72	0·97
14	5·73	0·76	1·04
15	6·11	0·82	1·10
16	6·49	0·87	1·17
17	6·87	0·92	1·24
18	7·26	0·97	1·31
19	7·64	1·02	1·38
20	8·02	1·07	1·45
21	8·40	1·12	1·52
22	8·78	1·18	1·59
23	9·16	1·23	1·66
24	9·55	1·28	1·73
25	9·93	1·33	1·80
26	10·31	1·38	1·87
27	10·70	1·44	1·94
28	11·08	1·48	2·00
29	11·46	1·54	2·08
30	11·84	1·59	2·14

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

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

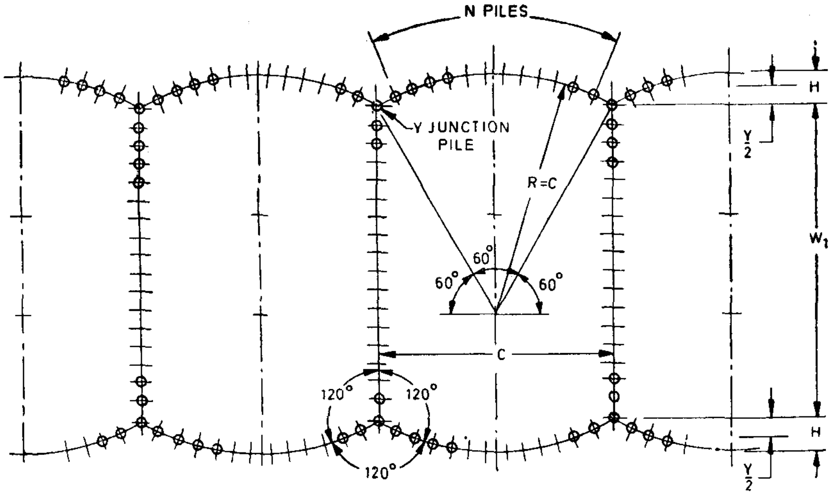

FIG. 2 DETAILS OF LAYOUT OF DIAPHRAGM TYPE SHEET PILE CELL

5.3 Where one side of cell head is dewatered, water saturation line could be assumed to take a slope of 1 : 2 for common free draining fill and 1 : 1 for specially designed fill materials. Dry bulk density of soil fill is assumed above this saturation line for computation.

5.4 Cellular structures shall be designed as gravity structures resting and not embedded on a founding stratum. Penetration of sheet piles through common soils up to founding stratum is possible, but not through very stiff clays, boulder clay or weathered rock which, however, are suitable as founding strata.

5.4.1 Cellular structures founded in clays should be examined for slip circle failure and also checked for effects of consolidation of the clay.

5.5 The effect of scour on the founding level of the structure should be taken into account.

5.6 The effect of exit gradients in sandy materials and other special materials used as fill inside the cells should be considered.

5.7 The stability of the structure during construction should also be taken care of. The heavy live load or dead loads may be transferred to founding strata through piles.

5.8 It would often become necessary to transfer live or dead load through load-bearing piles to founding stratum where such structures are to be used as wharves or dockwalls.

6. STABILITY REQUIREMENTS

6.0 Notations

B = Effective width

$= \dfrac{\text{Area of one cell + area between arc}}{D + C}$ for circular type and

$= \dfrac{\text{Area of one cell}}{C} = W_1 + y$ for diaphragm type;

D = Diameter of main circular cell;

C = Clear spacing between main cells for circular type

= Width of one cell for diaphragm type;

W_1 = Length of straight portion of diaphragm type cell;

γ = Equivalent length of curved portion of diaphragm type cell;

M = Resultant overturning moment = $M_a - M_p$;

r = Unit weight of fill;

K = Krynine constant = $\dfrac{\cos^2 \phi}{2 - \cos^2 \phi}$

ϕ = Angle of internal friction of fill;

H = Height of cell above bed/dredge line;

f = Interlock friction of sheet piles (to be taken as 0·3);

P_a = Total active horizontal pressure due to soil and water;

M_a = Total active moment due to soil and water;

P_p = Total passive horizontal pressure due to soil and water; and

M_p = Total passive moment due to soil and water.

6.0.1 The cellular structures shall be checked for the conditions given in **6.1** to **6.6**.

6.1 Cell Shear — The safety against vertical shear failure at midsection of cell shall be examined as follows:

Vertical shear force (V) = $1{\cdot}5 \dfrac{M}{B}$

Soil shear strength (S) = $\frac{1}{2} \gamma K H^2 (\tan \phi + f)$

Factor of safety against cell shear failure $\left(= \dfrac{S}{V} \right)$ should not be less than 1·25.

NOTE — Contribution of interlock friction should not be taken more than that due to fill ($f \leqslant \tan \phi$).

6.2 Sliding — The safety against failure due to sliding of cell shall be examined as for a gravity structure. The factor of safety against sliding shall not be less than 1·25.

6.3 Tilting — The safety against failure due to overturning of the cell shall be examined according to Cumming's method outlined in Appendix A. The factor of safety against tilting shall not be less than 1·2.

6.4 Bursting of Cell — The safety against failure of interlocking joints due to hoop tension developed due to active pressure of fill shall be examined at a critical height equal to 0·75 H. The hoop tension developed shall not be greater than the allowable interlock tension, which can be considered as 150 t/m.

6.5 Soil Support — The safety against failure due to piping, caving of excavation and so on, shall also be checked as in conventional retaining walls or footings.

NOTE — Bulkheads founded on hard soils or rock and filled with well drained soil will generally be safe if B is equal to 0·8 to 0·9 H.

7. CONSTRUCTION

7.1 It should be necessary to use a template as shown in Fig. 3 to pitch the piles. The height of template should be about one-third the length of piles to be pitched. A tensioned rope is put outside to keep the piles conforming to the ring.

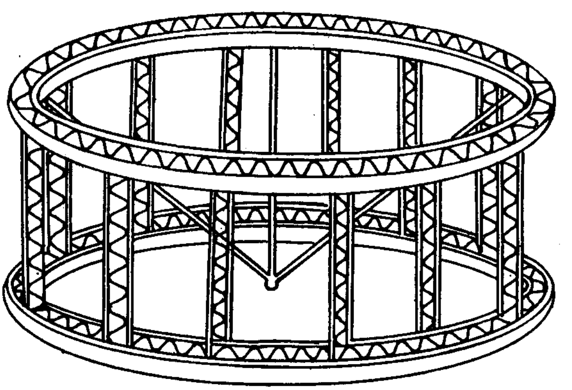

FIG. 3 TYPICAL TEMPLATE

7.2 The first pile should be put very accurately ensuring plumb in both planes and driven a few metres only. Subsequent piles should be pitched on either side. Clutching is done according to instructions. The piles are pitched with alternative faces appearing on either side. After pitching 7 to 8 piles, next one is driven again to some extent taking into account the corrections. Ring should thus be completed before driving down to design level.

7.3 'Tee' piles should not be put till the ring is completed. These should be pitched after the closure of ring when the ordinary piles are withdrawn and 'Tee' piles are inserted in their places.

7.4 Piles are best driven by wire suspended double acting hammers operated by steam, compressed air or diesel combustion. For sandy soils, vibrating hammers are very efficient.

7.5 Cellular structures are provided with a RCC or steel ring on top and at least alternate piles are bolted to it. This helps in retention of shape on deflection. Welding of piles to each other on top for a distance of about 30 cm helps in rigidity of cell and helps in its stability.

7.6 Where used as permanent structure, sheet piles in tidal zone are recommended to be encased in concrete or provided with cathodic protection against corrosion.

7.7 Main cells should be filled first and then the area enclosed by connecting arcs.

7.8 Cellular structures can be straight or form an arc to cover an opening. Where there is change of direction, it should be ensured that 'Tee' piles are not closer than one-twelfth of the circumference.

8. DEVIATIONS

8.1 Closing of cells may be permitted with one additional or less pile from the design number by using a special closure pile since only even number of piles give proper clutch joint.

8.2 **Verticality of Piles** — Deviation in verticality to the extent that the cell diameter does not vary more than 1·5 percent at any point may be permitted.

APPENDIX A
(*Clause* 6.3)

DETERMINATION OF RESISTANCE TO TILTING (CUMMING'S METHOD)

A-1. Let *abgh* be the cross section of a cell of effective width B. Cell is filled with ϕ solid up to line *cd* and below is existing ϕ_2 soil (*see* Fig. 4).

A-2. Soil line is drawn from dredged level as shown by *ek* and *kl*. Soil is divided into a number of prisms such as *ajkd*, *amnp*, *abef*, etc.

Resistance due to prism *ajkd* (T_1) = weight of soil in prism × tan ϕ_2

Resistance due to prism *amnp* (T_2) = weight of soil in prism × tan $\phi_2 - T_1$

Resistance due to prism *abef* (T_3) = weight of soil in prism × tan $\phi_2 - (T_1 + T_2)$, etc

Resistance moment due to weight of fill $M_R = T_1 Y_1 + T_2 Y_2 + T_3 Y_3$, etc

Resisting moment due to interlocking friction $M_f = P \times f \times B$, where

P is interlocking friction which may be determined from appropriate formula

$$\text{Factor of safety} = \frac{M_p + M_R + M_f}{M_a}$$

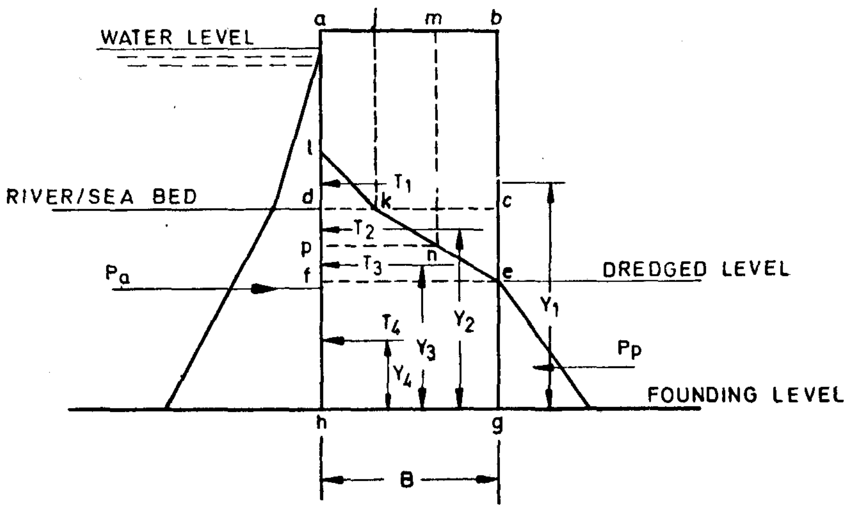

FIG. 4 RESISTANCE OF SOIL FILL TO TILTING

INTERNATIONAL SYSTEM OF UNITS (SI UNITS)

Base Units

Quantity	*Unit*	*Symbol*
Length	metre	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin	K
Luminous intensity	candela	cd
Amount of substance	mole	mol

Supplementary Units

Quantity	*Unit*	*Symbol*
Plane angle	radian	rad
Solid angle	steradian	sr

Derived Units

Quantity	*Unit*	*Symbol*	*Definition*
Force	newton	N	1 N = 1 kg. m/s^2
Energy	joule	J	1 J = 1 N.m
Power	watt	W	1 W = 1 J/s
Flux	weber	Wb	1 Wb = 1 V.s
Flux density	tesla	T	1 T = 1 Wb/m^2
Frequency	hertz	Hz	1 Hz = 1 c/s (s^{-1})
Electric conductance	siemens	S	1 S = 1 A/V
Electromotive force	volt	V	1 V = 1 W/A
Pressure, stress	pascal	Pa	1 Pa = 1 N/m^2