BALFOUR BEATTY POWER CONSTRUCTION Ltd.

FOUNDATION DESIGN MANUAL

ISSUE: 1

BY:

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DATE: 15.05.90

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[redacted]

SIDE BEARING FOUNDATIONS

A side bearing foundation is classified as a foundation which safely resists, transfers and spreads the imposed loads (from the overhead catenary system) laterally to the ground. No end bearing or base resistance is considered. A side bearing foundation is normally constructed in concrete. It will have cast-in bolts for a bolted base mast. The hole for the foundation may be hand dug, or machined augured or grabbed.

Side bearing foundations are suitable for the following soils:

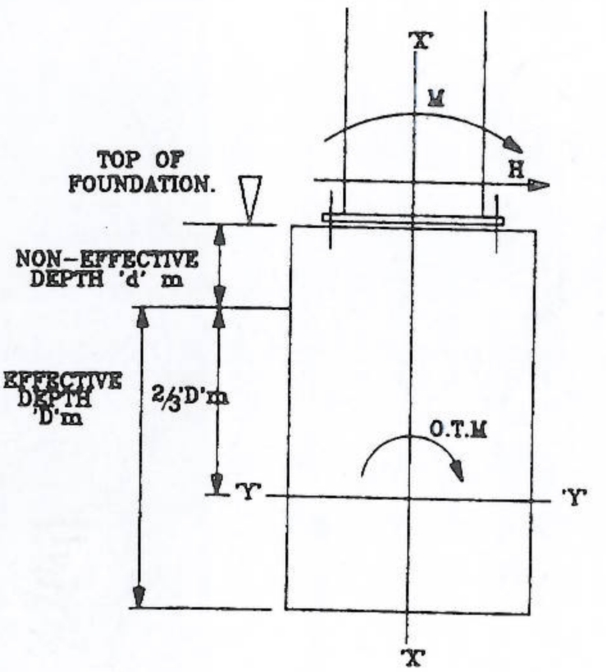
CATEGORY	TYPE OF SOIL	K ($kN/m^2/m$)	P (kN^1/m^2)
Non-cohesive Soils	Dense gravel or dense sand and gravel.	160-200	-
	Dense Sand	160-180	
	Medium dense gravel or medium dense sand and gravel.	80-160	-
	Medium dense sand	80-120	-
Cohesive Soils	Very stiff boulder clays and hard clays	-	30-40
	Stiff Clays	-	20-30
	Firm Clays	-	14-20

Side bearing foundations are not suitable for the following soils:

- Frost susceptible soils
- Peat
- Loose soils
- Filled ground
- Soft clays and silts
- Chalk
- Running sand
- Soils with a very high water table

Where side bearing foundations are not suitable, gravity foundations, rock foundations, or piled foundations will be used.

METHOD OF CALCULATING THE OVERTURNING MOMENT FOR SIDE BEARING FOUNDATIONS.



DEFINITIONS

M – BENDING MOMENT AT TOP OF FOUNDATION DUE TO RADIAL AND WIND LOADS ON CONTACT, MESSENGER AND ANCILLARY WIRES, WIND LOAD ON POLE AND MASSES OF EQUIPMENT AND CANTILEVER (kNm)

H – HORIZONTAL LOAD DUE TO ABOVE LOADS (kN)

d – NON EFFECTIVE DEPTH :– PORTION OF FOUNDATION THAT DOES NOT RESIST O.T.M.

D – EFFECTIVE DEPTH :– PORTION OF FOUNDATION THAT RESISTS O.T.M.
INTERSECTION OF 'X–X' AND 'Y–Y' IS CONSIDERED AS THE POINT AT WHICH THE OVERTURNING MOMENT (O.T.M.) ACTS.

IT FOLLOWS THAT:–

O.T.M. = M + H(d +2/3D) kNm

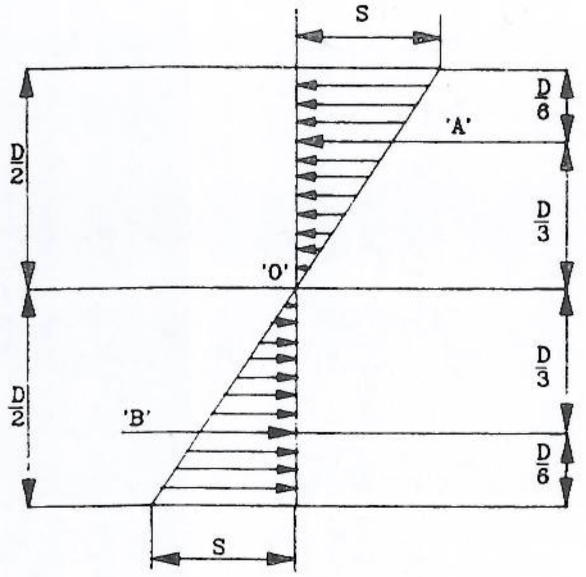
THE RESISTANCE MOMENT OF THE PARTICULAR FOUNDATION MUST NOT BE LESS THAN ITS OVERTURNING MOMENT.

SLOPE ADJUSTMENT

FOR SLOPES UP TO 10 DEGREES, TREAT AS LEVEL GROUND.
FOR SLOPES BETWEEN 10 AND 20 DEGREES INCREASE 'D' BY 10%
FOR SLOPES BETWEEN 20 AND 30 DEGREES INCREASE 'D' BY 25%
FOR SLOPES BETWEEN 30 AND 45 DEGREES INCREASE 'D' BY 43%

FORMULAE FOR SIDE BEARING FOUNDATION

COHESIVE SOILS



THE ASSUMPTIONS MADE IN DERIVING THE FORMULA ARE:-

1. THE CENTRE OF OVERTURNING 'O' OF FOUNDATION IS 1/2 DEPTH OF FOUNDATION BELOW EFFECTIVE GROUND LEVEL.
2. THE STRESS DIAGRAM IS BOUNDED BY A STRAIGHT LINE.
3. THE PERMISSIBLE GROUND PRESSURE IS A CONSTANT RELATED TO THE ULTIMATE SHEAR VALUE OF THE SOILS 'S'.
4. THE LINE OF FAILURE OF THE SOIL IS NOT PARALLEL TO THE SIDES OF THE FOUNDATION. A CONSTANT 'C' SHOULD BE ADDED TO THE ACTUAL LENGTH OF FOUNDATION FACE 'L' RESISTING THE LOADS THEREFORE THE EFFECTIVE LENGTH OF FOUNDATION = L+C. ASSUME C = 0.4m FOR L > 1.0m, FOR L < 1.0m L+C = 1.4 X L

FORCE 'A' = FORCE 'B' $= \frac{D}{2} \times \frac{S}{2} \times (L+C)$

$$= \frac{DS(L+C)}{4}$$

RESISTANCE MOMENT ABOUT 'O' $= \frac{DS(L+C)}{4} \times \left[\frac{D}{3} + \frac{D}{3}\right]$

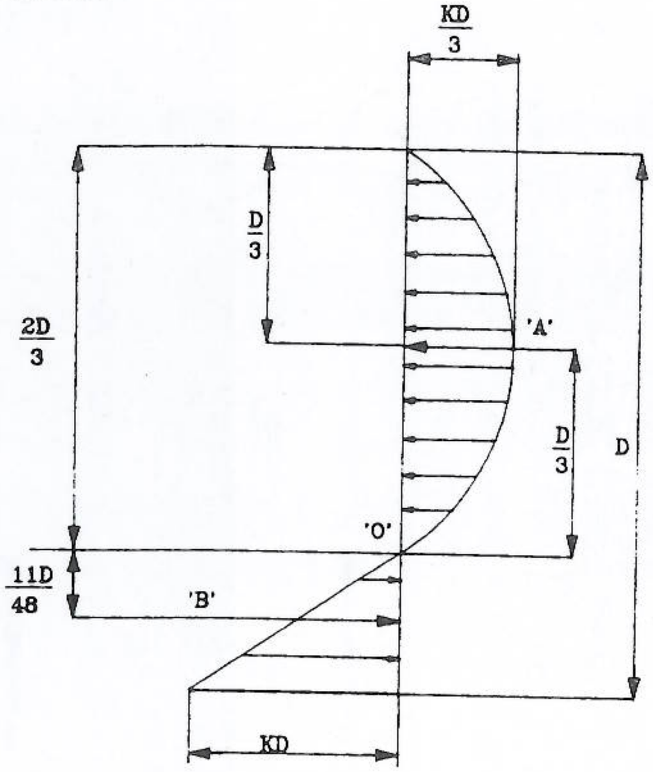
$$= \frac{D^2 S(L+C)}{6}$$

LET $\frac{S}{6}$ = CONSTANT 'P'

RESISTANCE MOMENT = $PD^2(L+C)$

FORMULAE FOR SIDE BEARING FOUNDATIONS

NON-COHESIVE SOILS



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2. THE STRESS DIAGRAM FROM EFFECTIVE GROUND LEVEL IS BOUNDED BY A PARABOLA.
3. THE MAXIMUM PERMISSIBLE GROUND PRESSURE ON EITHER SIDE OF THE FOUNDATION DOES NOT EXCEED K TIMES DEPTH.

IF K = ALLOWABLE PRESSURE/UNIT DEPTH
IF L = LENGTH OF FOUNDATION FACE IN PLANE PERPENDICULAR TO FORCE 'A'.

FORCE 'A' = FORCE 'B' = $\frac{4D^2KL}{27}$

RESISTANCE MOMENT ABOUT 'O' = $\frac{4D^2KL}{27} \times \frac{D}{3} + \frac{4D^2KL}{27} \times \frac{11D}{48} = \frac{4D^2KL}{27}\left[\frac{D}{3} + \frac{11D}{48}\right]$

RESISTANCE MOMENT $= \frac{D^3KL}{12}$

TYPICAL BATTERS OF EMBANKMENT SLOPES

MATERIAL	TYPICAL SLOPE BATTERS (VERTICAL : HORIZONTAL)
Hard Rock Fill	1:1.5 (34°) to 1:1 (45°)
Weak Rock Fill	1:2 (27°) to 1:1.25 (39°)
Gravel	1:2 (27°) to 1:1.25 (39°)
Sand	1:2.5 (22°) to 1:1.5 (34°)
Clay	1:4 (14°) to 1:1.5 (34°)

It should be noted that the properties of an embankment fill may alter with time, together with the stability of the embankment.

There may be settlement of the embankment due to settlement of the embankment fill and/or the foundation strata. Potential seasonal variations and potential for local deterioration of soil properties must be noted.

Consideration must be given to both the theoretical Effective Depth required to resist applied forces due to the overhead catenary system, and the actual condition of the embankment.

TYPICAL BATTERS OF CUTTING SLOPES

MATERIAL	TYPICAL SLOPE BATTERS (VERTICAL : HORIZONTAL)
Massive Rock	1:5:1 (56°) to Vertical (90°)
Well Jointed/ Bedded Rock	1:2 (27°) to 2:1 (63°)
Gravel	1:2 (27°) to 1:1 (45°)
Sand	1:2.5 (22°) to 1:1.5 (34°)
Clay	1:6 (9.5°) to 1:2 (27°)

It should be noted that the properties and stability of slopes in cuttings may alter with time.

The stability of natural and cut slopes is a complex interaction between the soil materials that form the slopes, the ground water conditions or pore water pressures, seasonal variations, external and/or surcharge loadings and weathering of the cutting slopes.

Consideration must be given to both the theoretical Effective Depth required to resist applied forces due to the overhead catenary system, location of the foundation and the actual condition of the cutting slope.

CATEGORY	TYPE OF SOIL	FIELD INDICATIONS	VISUAL	K kN/m²/m
Rocks	Not inferior to Sandstone or limestone	Requires at least a pneumatic or other mechanically operated pick for excavation. See section on Rock Foundations.	-	>200
Non-cohesive Soils	Dense gravel, dense sand and gravel	Requires mechanical excavation	Very stable sides during excavation. Teeth marks of excavator visible.	160
	Dense sand	Requires pick for excavation	Very stable sides during excavation.	160
	Medium dense gravel or medium dense sand and gravel	Requires pick for excavation	Stable sides during excavation.	120
	Medium dense sand	Can be excavated with a spade with strong force	Firm sides during excavation. Some soil falling from sides.	80
	Loose gravel, loose sand and gravel, loose sand	Can be easily excavated with a spade	Loose sides during excavation. Do not remain vertical and may collapse.	N/A (40-60)

The above table is dependent on the ground water table assumed to be a depth not less than below the base of the foundation.

CATEGORY	TYPE OF SOIL	FIELD INDICATIONS	VISUAL	P kN/m²
Cohesive Soils	Very stiff boulder clays and hard clays	Brittle or very tough. Requires mechanical excavation.	Very stable sides during excavation. Vertical teeth marks of excavator visible.	30
	Stiff clays	Cannot be moulded in the fingers. Requires a pick for excavation.	Stable sides during excavation.	20
	Firm clays	Can be moulded in the fingers by strong pressure. Can be excavated by graft with a spade.	Firm sides during excavation.	14
	Soft clays	Easily moulded in the fingers, sticks to the hand.	-	N/A
	Very soft clays	Exudes between the fingers when squeezed in the fist.	-	N/A

The above table may be affected by seasonal variations i.e., a hot summer might affect the field indications of a soft clay or a very soft clay.

THE UPLIFT RESISTANCE OF DRILLED-IN ROCK ANCHORS

The resistance to pull out of anchors drilled and grouted into rock depends on five factors:

1. The safe working stress on the steel anchor itself.

2. The allowable bond stress between the anchor and the grout.

3. The allowable bond stress between the grout and the rock.

4. The dead weight of the mass of rock and any overlying soil which is lifted by the anchor.

5. The dead weight of the mass of rock and any soil overburden which is lifted by a group of closely spaced anchors.

The bar anchor will usually be manufactured in high tensile steel. Working stresses vary from $250 N/mm^2$ for reinforcement bar to over $500 N/mm^2$ for very high strength alloy steels (Macalloy etc).

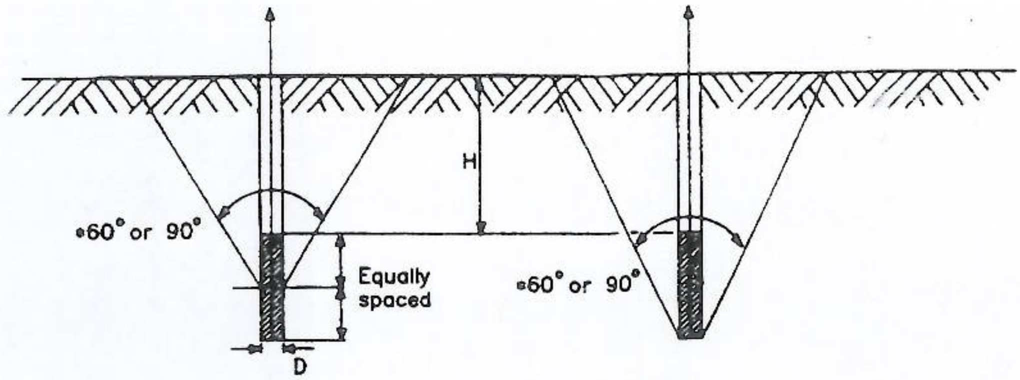
The allowable bond stress between the anchor and the grout depends on the compressive strength of the grout, the amount of deformity in the bar and the diameter of the bar. As a guide allowable values of $0.3-0.7 N/mm^2$ can be used for bars up to 150mm.

The allowable bond stress between the grout and the surrounding rock depends on the compressive strength of the intact rock, the size and spacing of joints, the amount of keying given to the anchor pole by the drilling bit and the cleanness of the rock surface which can be achieved by the drilling water flush. Observed bond stresses at failure range from $0.15-0.3 N/mm^2$ in weak weathered chalk, mudstone and shale to $1.0-2.0 N/mm^2$ in strong relatively unweathered but jointed rocks.

The pull-out resistance of the mass of rock depends on the shape of the mass of rock lifted which itself depends on the degree of jointing and fissuring of the rock and the inclination of the bedding planes. A cone with a half angle of 30° gives a conservative value for the pull out shape and represents a heavily jointed rock. A cone with a half angle of 45° could be used for most sound rocks. Take a safety factor of unity where the rock is bedded horizontally or at moderate angles as the shear strength of the rock has been ignored.

Where a number of anchors are grouped relatively closely together the cones of uplift overlap. The anchorages of the group should be deep enough to ensure that there is sufficient weight in the cone of rock encompassing the whole group.

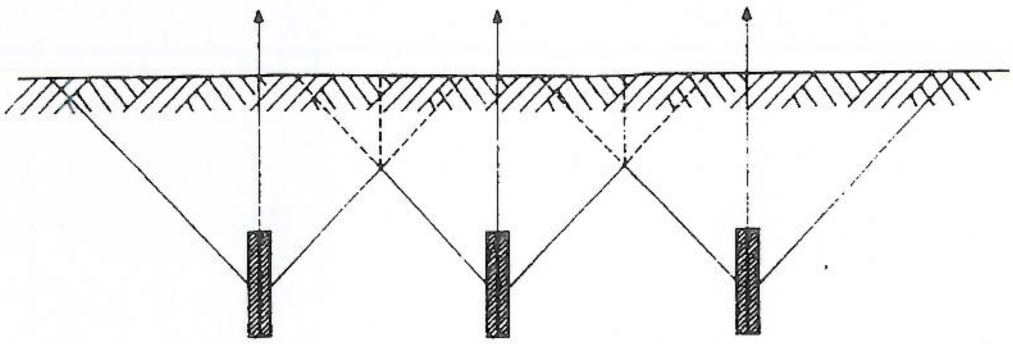
C2:ANCHORS.SB



(1) Load transferred to bond (2) Load transferred by end plate.

*60° used when rock mass is soft, heavily fused or weathered.
90° used in all other rock conditions.

(a) Geometry of cone



(b) Interaction of cones for overall stability analysis.

Transient loading in rock (after Littlejohn & Bruce 1977)

BALFOUR BEATTY POWER CONSTRUCTION LIMITED
SIDE BEARING FOUNDATION DESIGN METHOD
(Version 1.0 24/06/90)

DESIGN TABLES FOR USE WITH LIMITED
SITE INVESTIGATION

Side Bearing Length/Diameter		0.3 m
Non-Side Bearing Length (Rectangular Fdns)		0.3 m
Minimum Depth		1.3 m

VALUES	P1=	30.0 kN/m^2	K1=	160.0 kN/m^2/m
	P2=	20.0 kN/m^2	K2=	120.0 kN/m^2/m
	P3=	14.0 kN/m^2	K3=	80.0 kN/m^2/m

Effective Side Bearing Length = 0.4 m

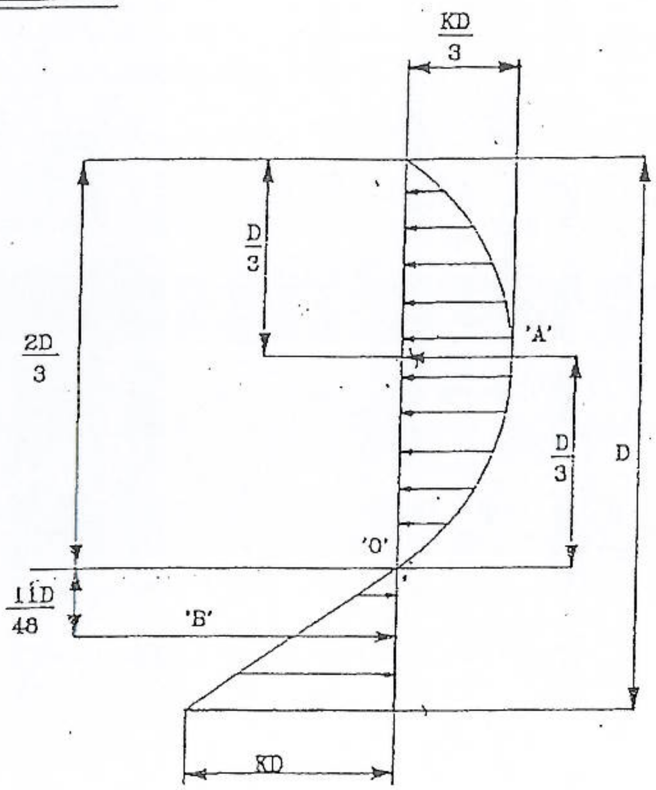
Resistance Moment for

Depth (m)	K1 160.0 Non-Coh (kNm)	P1 30.0 Cohesive (kNm)	Allowable (kNm)	K2 120.0 Non-Coh (kNm)	P2 20.0 Cohesive (kNm)	Allowable (kNm)	K3 80.0 Non-Coh (kNm)	P3 14.0 Cohesive (kNm)	Allowable (kNm)	Volume (m^3)
1.3	8.79	21.29	8.79	6.59	14.20	6.59	4.39	9.9	4.39	0.12
1.4	10.98	24.70	10.98	8.23	16.46	8.23	5.49	11.5	5.49	0.13
1.5	13.50	28.35	13.50	10.13	18.90	10.13	6.75	13.2	6.75	0.14
1.6	16.38	32.26	16.38	12.29	21.50	12.29	8.19	15.1	8.19	0.14
1.7	19.65	36.41	19.65	14.74	24.28	14.74	9.83	17.0	9.83	0.15
1.8	23.33	40.82	23.33	17.50	27.22	17.50	11.66	19.1	11.66	0.16
1.9	27.44	45.49	27.44	20.58	30.32	20.58	13.72	21.2	13.72	0.17
2.0	32.00	50.40	32.00	24.00	33.60	24.00	16.00	23.5	16.00	0.18
2.1	37.04	55.57	37.04	27.78	37.04	27.78	18.52	25.9	18.52	0.19
2.2	42.59	60.98	42.59	31.94	40.66	31.94	21.30	28.5	21.30	0.20
2.3	48.67	66.65	48.67	36.50	44.44	36.50	24.33	31.1	24.33	0.21
2.4	55.30	72.58	55.30	41.47	48.38	41.47	27.65	33.9	27.65	0.22
2.5	62.50	78.75	62.50	46.88	52.50	46.88	31.25	36.8	31.25	0.23
2.6	70.30	85.18	70.30	52.73	56.78	52.73	35.15	39.7	35.15	0.23
2.7	78.73	91.85	78.73	59.05	61.24	59.05	39.37	42.9	39.37	0.24
2.8	87.81	98.78	87.81	65.86	65.86	65.86	43.90	46.1	43.90	0.25
2.9	97.56	105.97	97.56	73.17	70.64	70.64	48.78	49.5	48.78	0.26
3.0	108.00	113.40	108.00	81.00	75.60	75.60	54.00	52.9	52.92	0.27
3.1	119.16	121.09	119.16	89.37	80.72	80.72	59.58	56.5	56.51	0.28
3.2	131.07	129.02	129.02	98.30	86.02	86.02	65.54	60.2	60.21	0.29
3.3	143.75	137.21	137.21	107.81	91.48	91.48	71.87	64.0	64.03	0.30
3.4	157.22	145.66	145.66	117.91	97.10	97.10	78.61	68.0	67.97	0.31
3.5	171.50	154.35	154.35	128.63	102.90	102.90	85.75	72.0	72.03	0.32
3.6	186.62	163.30	163.30	139.97	108.86	108.86	93.31	76.2	76.20	0.32
3.7	202.61	172.49	172.49	151.96	115.00	115.00	101.31	80.5	80.50	0.33
3.8	219.49	181.94	181.94	164.62	121.30	121.30	109.74	84.9	84.91	0.34
3.9	237.28	191.65	191.65	177.96	127.76	127.76	118.64	89.4	89.43	0.35
4.0	256.00	201.60	201.60	192.00	134.40	134.40	128.00	94.1	94.08	0.36
4.1	275.68	211.81	211.81	206.76	141.20	141.20	137.84	98.8	98.84	0.37
4.2	296.35	222.26	222.26	222.26	148.18	148.18	148.18	103.7	103.72	0.38
4.3	318.03	232.97	232.97	238.52	155.32	155.32	159.01	108.7	108.72	0.39
4.4	340.74	243.94	243.94	255.55	162.62	162.62	170.37	113.8	113.84	0.40
4.5	364.50	255.15	255.15	273.38	170.10	170.10	182.25	119.1	119.07	0.41

FORMULAE FOR SIDE BEARING FOUNDATIONS

BALFOUR PREFERENCE:

NON-COHESIVE SOILS



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2. THE STRESS DIAGRAM FROM EFFECTIVE GROUND LEVEL IS BOUNDED BY A PARABOLA.
3. THE MAXIMUM PERMISSIBLE GROUND PRESSURE ON EITHER SIDE OF THE FOUNDATION DOES NOT EXCEED K TIMES DEPTH.

IF K = ALLOWABLE PRESSURE/UNIT DEPTH
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RESISTANCE MOMENT ABOUT 'O' = $\frac{4D^2KL}{27} \times \frac{D}{3} + \frac{4D^2KL}{27} \times \frac{11D}{48} = \frac{4D^2KL}{27}\left[\frac{D}{3} + \frac{11D}{48}\right]$

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K = 80.

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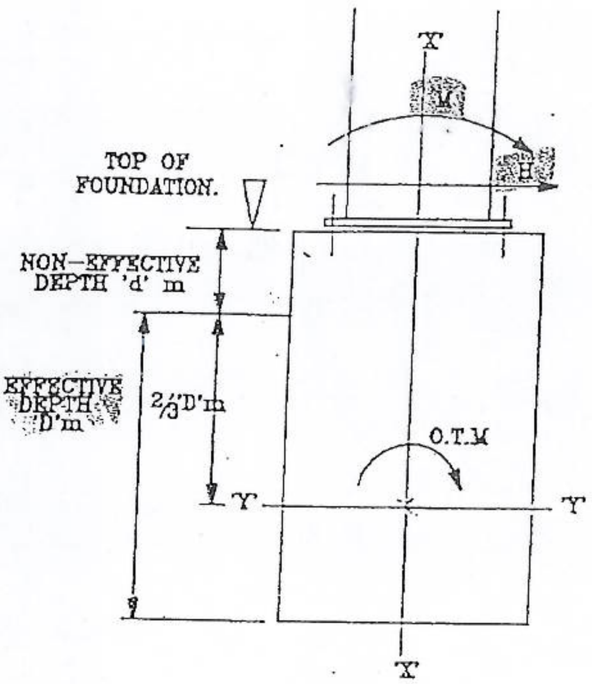

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	Firm Clays	-	14-20

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- Filled ground
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- Chalk
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- Soils with a very high water table

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	Loose gravel, loose sand and gravel, loose sand	Can be easily excavated with a spade	Loose sides during excavation. Do not remain vertical and may collapse.	N/A (40-60

The above table is dependent on the ground water table assumed to be a depth not than below the base of the foundation.