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Indian national report on codes, regulations and practices of 'braced excavations in soft ground'

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SYNOPSIS: In this National Report from India, the authors have summarised the current practice and experience of design and construction of underground excavations, particularly using lateral supports in the form of bracing and anchors. Soft/loose soils are found at various places along the vast coast of the Indian sub-continent. Accordingly widely different practices are followed. With the recent construction of a very large project at Calmetro, there is now a better documentation.

1. OCCURENCE OF SOFT/LOOSE SOILS IN INDIA

1.1 Soft/loose soils are present at various locations along the long coast line of the Indian sub-continent. These are predominant almost all over the Eastern Coast (starting from Calcutta to Haldia, Paradip, Vizag, Kakinada, Madras). On the Western Coast such soils occur at isolated river-mouth locations starting from Kochi in the south to Mangalore, Goa, Bombay, Surat and Kandla in the north (See Fig.1).

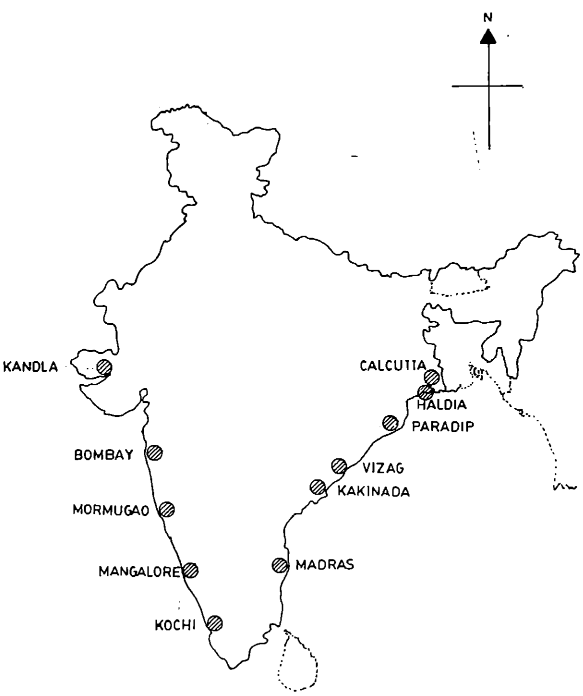


FIG.1. MAJOR MARINE CLAY LOCATIONS IN INDIA

1.2 Published data and other evidence suggest that the soil deposits of Calcutta and Haldia are of recent origin formed mainly by flood deposits of river. Deposits of Mangalore, Kochi, Bombay, etc. are of marine origin formed at the mouths of the depositing rivers. Soils in Kandla region are formed in Back swamp conditions. Typical subsoil profiles are given in Fig. 2.

2. USE OF BRACED EXCAVATIONS FOR UNDERGROUND CONSTRUCTION

2.1 Braced excavations with concrete diaphragm walls/sheet-piles/contiguous-pile-walls are being regularly used in India for structures such as Calmetro - Underground tube railway, drydocks, dumper-house at Madras, underground basements/tanks at Bombay and Calcutta, etc.

2.2 At Calcutta Metro-rail, about 13 Km length was constructed using braced RCC diaphragm walls for the cut-and-cover construction method. For a typical excavation depth of 14.0 M, 4 struts were used to support 600mm thick RCC diaphragm walls 16 M apart. These D. Walls were cast in 3 M long panels and normally penetrated 4 M below the excavation floor. In the earlier phases of Calmetro, soldier piles and timber lagging were used for about 0.5 Km route and steel sheet piles for another 0.5 Km. But due to subsidence-control problems, these methods were replaced by RCC D.Walls. During this work, more than 170 struts were instrumented for load measurements. (Ref. 16).

2.3 At Vizag, a building dock was constructed using 800mm thick and 8-12 M deep RCC diaphragm walls with 140T capacity cable anchors as lateral supports. For control of uplift pressures on the Dock floor, a system of filter-fabric and relief-wells was installed alongwith a pumping arrangement. (Ref. 8).

(1) BOMBAY

DEPTH M.	STRATA	WL	WP	Cu kg/cm²
3.0	FILL			
11.0	MARINE CLAY	90	36	0.15
14.0	YELLOW CLAY	65	20	1.25
	ROCK			

(2) KANDLA

DEPTH M.	STRATA	WL	WP	Cu kg/cm²
1.0	FILL			
15.0	MARINE CLAY	65	25	0.08
17.0	SAND			
	STIFF CLAY			

(3) COCHIN

DEPTH M	STRATA	WL	WP	Cu kg/cm²
2.0	SAND			
20.0	SOFT CLAY	88	45	0.1
21.0	LATERITIC SOIL			
39.0	STIFF CLAY	62	34	0.75

(4) MADRS

DEPTH M	STRATA	WL	WP	Cu kg/cm²
1.7	SANDY CLAY	31	8	1.4
8.4	SILTY CLAY	50	12	0.4
11.20	SAND	-	-	-
	SANDY CLAY	27	10	0.8

(5) VIZAG

DEPTH M	STRATA	WL	WP	Cu kg/cm²
1.6	FILL			
13.6	SILTY CLAY	84	21	0.1
17.0	SANDY CLAY	-	-	-
	WEATHERED ROCK			

(6) CALCUTTA

DEPTH M	STRATA	WL	WP	Cu kg/cm²
3.0	SILTY CLAY	46	27	0.4
13.0	SILTY CLAY	62	25	0.25
21.0	SANDY SILT	-	-	-
	SILTY CLAY	70	20	1.1

FIG-2: TYPICAL SUBSOIL PROFILES

2.4 Top-down method of construction was adopted at Mormugao Port for a 12 M deep dumper house. For the associated conveyor-tunnel, 80 M long, two parallel diaphragm walls with struts were used. (Ref. 3).

2.5 A combination of continuous piles and D.Walls was adopted for 6 M deep basement construction in Calcutta. (Ref.21). These walls were supported by struts bearing against the central permanent structure which was constructed in phases.

3. DESIGN PRACTICES/PROCEDURES

3.1 For Calmetro, semi-empirical design procedure (Terzaghi-Peck) was adopted.

3.2 For Dumper House at Mormugao Port, a simplified method was developed by the consulting engineer. This method considered the stiffness of the wall, subgrade soil modulus and redistribution of moments considering elasticity of the strut-system. The entire calculations were repeated for a 'range of values' for soil modulus and elasticity of concrete and different dimensions and positions of the supporting system to arrive at 'optimum' values of stresses in D.Walls and the supports.

3.3 A graphical method using polygon of forces is also used. In this method, depth of fixity of the D.Wall is found out by trial method. For this purpose, the active and the passive pressures acting on the wall are replaced by discrete forces acting at discrete points. The polygon of forces and funicular polygon are drawn for this system of vectorial forces. This funicular polygon represents the deflected shape of the wall. These deflections have to be zero at 'the point of fixity' and the 'tie levels'. If this condition is not satisfied, the whole process is repeated by changing the depth of fixity, till congruence is obtained.

3.4 Finite Element Method (FEM) was used for design of port structures at Kakinada and Surat (Hazira). But it was observed that the moments were too large. Hence, a method was developed to reduce the moments depending on the fixity in sand or clay.

4. OUTLINE OF THE DESIGN PROCEDURES

4.1 Bottom Heave

4.1.1 In cohesive soils, the following method was used at Calmetro:

The depth of penetration of supporting wall below the bottom of the cut shall be determined from the consideration of stability against heaving of the bottom excavation. The supporting wall has to extend sufficiently deep to provide a factor of safety greater than 1.5. Preferably the wall has to be taken into a stiff stratum below. Otherwise, the wall penetration is arrived at from the following :(Ref.11).

$$F = \frac{C.N_c + \gamma.D_f.N_q}{\gamma(H+D_f) + \frac{C'(H+D_f)}{D_1} - \frac{C(H+D_f-2C\div\gamma)}{D_1} + q} \geq 1.5$$

Where, C' is skin friction between soil and the wall,

C is soil cohesion

q is surcharge pressure

Df is depth of wall penetration below excavation floor

D1 is depth to stiff stratum below the wall tip
Nc, Nq are bearing capacity factors.

4.1.2 In non-cohesive soils, the depth of wall penetration is to be worked out from the consideration that the moment due to passive pressure is 1.2 times the moment due to active pressure, about the point of lowermost strut.

4.1.3 For rocky strata, the walls are preferably taken down 0.5 to 1.0 M into the rock.

4.2 Spacing of struts

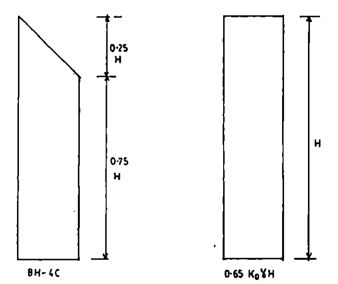
4.2.1 At Calmetro, the longitudinal spacing of the struts was 3 M. Vertically the struts were placed at 3.2, 7.1, 9.5 and 11.5 M depth below the ground-level (for an excavation depth of 13.6 M).

4.2.2 Forces in the struts are normally worked out from the 'trapezoidal' contributory areas of the 'Earth-pressure diagrams'. These force-values were verified from the initial instrumented struts at Calmetro, because this project was in populated urban areas and also covered more than 13 Km length of construction.

4.3 Earth pressure distribution above the floor of the excavation

4.3.1 The pressure above cut line is taken as active soil pressure together with full ground water pressure. Theoretically, the pressure distribution is taken as triangular - linearly increasing with depth.

4.3.2 At Calmetro, the ground-water level was assumed at ground level and the earth-pressure diagrams for cohesive and cohesionless soils were taken as shown below (Ref.11) (Peck's diagrams) for strut loads.



(i) COHESIVE SOIL (ii) COHESIONLESS SOIL

FIG:3 - EARTH PRESSURE DIAGRAMS

4.3.3 For calculating the moments in the walls, a triangular pressure distribution was used for sandy soils. For clay soils, 33% reduction can be allowed on Peck's diagram for normally consolidated clays, but for the over-consolidated clays, triangular distribution was used (Ref.13).

4.3.4 Lateral pressures due to adjacent buildings were adopted at 5.5 Tons/sq.m. starting from the building line and at 1.5 M below the ground level. These were assumed to act continuously along the building lines (Ref. 11).

4.4 Earth-pressure distribution below the floor of the excavation

4.4.1 Earth-pressure below the cut line is taken as active on the soil-side and passive on the excavation side. Water pressure is taken based on the respective ground water levels and the flow net.

4.4.2 At Calmetro, the wall was assumed as cantilevering from bottom-most strut for embeded portion. In the earth-pressure diagram, relief due to passive pressure for the embeded portion was taken into account. For clay soil, the passive pressure was taken as 2C, where C is the cohesion of soil below the cut level.

4.5 Strut loads

4.5.1 Peck's trapezoidal pressure-distribution is used to estimate the strut loads. These strut loads are worked out for each strut for each stage of excavation and the maximum value is taken in the design considerations. Similarly, moments in the wall are calculated and various moment distribution diagrams are super imposed. If required, the number, spacing and elevations of the struts are varied to obtain safe strut-loads and moments in the wall.

4.5.2 At Calmetro, the observed strut loads and the estimated loads were fairly in good agreement.

4.6 Ground movement adjacent to the braced excavations

Ideally there should be a direct relationship between the volume of soil displaced by the wall movement (Vw) and the volume of subsided ground (Vg) near the ground level. This will be valid for truly elastic soil deformations.
Many times the designs are based on Peck's normalised plot for braced-cuts, where different zones of settlement (I, II and III) are proposed by plotting "distance away from the cut/depth of cut" along x-axis and "% settlement/Depth of cut" along y-axis (Ref.20).

Table 1 by Appolonia (Ref.1) correlating surface settlement with Ncb (bearing capacity number depending on ratio H/B) and Nb is used.

$\left(\frac{\text{Settlement}}{\text{Depth of cut}}\right)$ %	Ncb ÷ Nb
1.0 - 2.5	Less than 1
0.7 - 1.5	1.0 to 1.3
0.5 - 1.5	greater than 1.3

As a prudent practice, relatively rigid RCC Diaphragm Walls are used for cuts in the vicinity of urban populated areas. This was a case at Calmetro along most of the alignment. Observed ground settlements here were much less than those predicted by Peck's diagram.

Generally it is advisable to control/prevent damage to adjacent structures and hence, more emphasis is placed on observing such distress and on controlling it immediately by additional struts/by preloading of the struts - i.e. the design approach is based on 'observational method'.

5. INSTRUMENTATION AND PERFORMANCE STUDIES

5.1 Instrumentation, though on a restricted scale, is adopted on major projects. At Calmetro, the instrumentation was used both for initial design-checks and for subsequent test-checks. At Mormugao, Dumper House excavation, strut load measurements were used to monitor the performance.

5.2 Commonly employed instrumentation includes jacks for strut-loads, settlement-stakes for ground movement, inclinometers for lateral movements and piezometers for ground water/pore-pressures. At major projects, e.g. Calmetro, additional instruments such as soil pressure cells to measure active/passive soil pressures, strain-guages to measure strut-loads and wall stresses, magnetic-extensometers to monitor soil heave,survey lines etc. were also used. (Ref. 7, 13, 25).

6. MONITORING PROGRAMS

Surface/ground settlements are recorded along the braced excavations over a typical horizontal distance equal to the depth of the cut.

For structures adjacent to the braced-excavations, visual observations is the first step. If any cracks are seen, movements of the cracks is monitored by fixing glass-plates and/or extensometers. This helps in studying the effect on the cracks of distance and time of the excavation/dewatering and helps to take decisions regarding the remedial measures, such as propping-up of the affected structures or under-pinning or for increasing the struted supports to the excavation. For tall structures, tilting is also measured by plumb-bobs and/or theodolite.

At Calmetro, there is also a provision for compensaation for such damages, as determined by a judicial officer (called a Competent Authority) appointed as per this Metro Act.

7. CODES OF PRACTICE RELATED TO DESIGN AND CONSTRUCTION OF BRACED-EXCAVATIONS IN INDIA

7.1 IS:4651 (Part II) - 1971: Code of Practice for Design and Construction of Dock and Harbour Structures - Earth Pressures (for braced cuts refer Clause 6.6 and Fig.5).

7.2 IS:4651 (Part IV) - 1969 : Code of Practice for Design and Construction of Dock and Harbour Structures - Sheet Pile Retaining Walls.

8. REPORTS/MANUALS GIVING RECOMMENDATIONS ON BRACED-EXCAVATIONS

There are specifications and guidelines given for design of anchored or braced Diaphragm Walls (for construction of Dry Docks, Building Docks, open trenches, etc.) by reputed Consultants or Owners in India, such as: Ministry of Surface Transport (including Ports), Calcutta Metro Rail Authority, Howe India Limited, Consulting Engineering Services Limited, Hindustan Shipyards Limited, various Port Trust Authorities, etc.

Detailed observations at Calmetro are being published from time to time at National and International forums. Such published data from Calmetro, various Ports and other projects has become a useful data bank for guidance of designers and construction engineers.

9. LIST OF IMPORTANT PROJECT INVOLVING BRACED EXCAVATIONS

9.1 Underground Rail System at Calcutta.

9.2 Dumper House and Approach Ducts at Mormugao and Vizag.

9.3 Entrance Dock at Haldia Port.

9.4 Underground Water Tanks at Bombay and Calcutta.

9.5 Building Dock at Vizag.

9.6 Basement construction at Bombay.

9.7 Underground Market at Calcutta.

9.8 Construction of a Track Hopper in West Bengal.

9.9 Underground Sewage Pumping Stations at Bombay.

10. DOCUMENTED EXPERIENCES AT PROJECTS IN INDIA

10.1 Calmetro Construction Method and Problems are vividly described in Ref.11,13,16,17,18,20,22,23,25.

10.2 Experiences at Mormugao Dumper House and Track Hopper construction are given in Ref. 3 and 5 respectively.

11. ACKNOWLEDGEMENTS

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REFERENCES

1. Appolonia, D.J. (1971). Effects of Foundation Construction on Nearby Structures, 4th Pan Am Conf., San Juan, Puerto Rico.
2. Banerjee, P. (1968). Geology of Bengal Basin, Proc. Symp., on Application of SMFE in West Bengal, Calcutta.
3. Dabke, C.S. and Sridhara, S. (1980). Design and Construction Aspects of Dumper House, Proc. Indian Geotechnical Conference, Bombay.
4. Gangopadhyay, C.R. and Bhattacharya, U. (1968). Geotechnical Properties of the subsoil at Joypur Beel, W. Bengal, Proc. Symp. on Application of SMFE in W.Bengal, Calcutta.
5. Ghosh, Dhiman Kr. and Batavyal, H.N. (1984). Dewatering and Ground Subsidence Check during construction of a Track Hopper, Proc. IGC, Calcutta.
6. Ghosh, P.K. and Gupta, S. (1972). Subsoil Character of Calcutta Region, Proc. of Symposium on Application of Soil Mechanics and Foundation Engineering in Eastern India, Calcutta.
7. Kapur, O.P. (1978). Instruments for Measuring Stresses and Movements for Underground Structures, Proc. Geocon - India, IIT Delhi.
8. Karunakar Rao, Dr.P. - Personal Communication (Unpublished).
9. Ketkar, D.J. (1970). Subsurface conditions - Bombay Island. Proc. IGC, Bombay.
10. Majumdar, M. and Ghosh, A. - (1976). Construction of a large Underground Water Reservoir in Calcutta, Proc. Symp. on Foundations and Excavations in weak soils, Calcutta.
11. Metro Railway, Calcutta - Specifications including Design Criteria for Construction of Diaphragm Walls (unpublished).
12. Narasimha Rao, S. and Kodandaramaswamy, K. (1984). Geotechnical Properties of Indian Marine Clays, Proc. IGC, Calcutta.
13. Palit, B.K. and Kapur, O.P. (1976). Pressure Distribution in Braced Cuts - Instrumentation in MTP, Calcutta, Proc. of Sym. on Foundations and Excavations in Weak Soils, Calcutta.
14. Paradip Port Trust - Specifications for Anchored Diaphragm Wall for General Cargo Berth (unpublished).
15. Peck, R.B. (1969). State of the Art Report on 'Deep Excavation and Tunnelling' - Proc. 7th Int. Conf. on SMFE, Mexico.
16. Phadke, G.N. (1985). Constraints and Problems in the Construction of Metro Railway, Calcutta with Special Emphasis on Civil Engineering Aspects, Int. Seminar on Metro Railway, Calcutta.
17. Sengupta, A. (1985). Geotechnical Problems of Metro Construction at Calcutta, Intl. Seminar on Metro Railway, Calcutta.
18. Sengupta, A.K. and Ghosh, S. (1985). Diaphragm Wall Construction for Calcutta Metro, Intl. Seminar on Metro Railway, Calcutta.
19. Sengupta, P.S. and Varadarajulu, G.H. (1984). Study of Geotechnical Properties of Two thick Clay Deposits in South India, Proc. IGC, Calcutta.
20. Som, N.N. (1991). Panelist's Remarks on 'Embankments, Excavations and Buried Structures', Asian Conference on SMFE, Bangkok.
21. Som, Dr. N. and Chowdhury, A.B. (1988). Construction of Underground Market in Soft Clay at Satyanarayan Park, Calcutta, Proc. IGC, Allahabad.
22. Som, Dr. N. and Ghosh, S. (1985). Performance of Braced Excavation in Cut-and-Cover stretches of Calcutta Metro Construction, International Seminar on Metro Railway Problems and Prospects, Calcutta.
23. Som, Dr. N. and Narayan, V. (1984). Ground Settlement in Cut-and-Cover Construction for Calcutta Metro, Indian Geotechnical Conference, Calcutta.
24. Sridharan, A., Rao, S.M. and Chandrakaran, S. (1989). Engineering Properties of Cochin and Mangalore Marine Clays, Proc. IGC, Vizag.
25. Varma, R.N. (1978). Soil Instrumentation in Braced Cuts MTP Calcutta - Proc. Geocon India, IIT Delhi.