भारतीय मानक

भूमि सुधार के डिजाइन और संरचना — मार्गदर्शी सिद्धांत

भाग 2 उर्ध्वाधर नालों का उपयोग करते हुए पहले ही संहत करना

Indian Standard

DESIGN AND CONSTRUCTION FOR GROUND IMPROVEMENT — GUIDELINES

PART 2 PRECONSOLIDATION USING VERTICAL DRAINS

ICS 93.020

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

August 2004 **Price Group 3**

Soil and Foundation Engineering Sectional Committee, CED 43

FOREWORD

This Indian Standard (Part 2) was adopted by the Bureau of Indian Standards, after the draft finalized by the Soil and Foundation Engineering Sectional Committee had been approved by the Civil Engineering Division Council.

Whenever soft cohesive soil strata underlying a structure are unable to meet the basic requirements of safe bearing capacity and tolerable settlement, ground improvement is adopted to make it suitable for supporting the proposed structure. Both the design requirements that is shear strength and settlement under loading, can be fulfilled by consolidating the soil by applying a preload, if necessary, before the construction of the foundation. This consolidation of soil is normally accelerated with the use of vertical drains.

This standard or ground improvement has been published in two parts. The other part in this series is:

Part 1 Stone columns

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 or analysis, shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Indian Standard

DESIGN AND CONSTRUCTION FOR GROUND IMPROVEMENT — GUIDELINES

PART 2 PRECONSOLIDATION USING VERTICAL DRAINS

1 SCOPE

This standard (Part 2) covers the guidelines for design and construction of vertical drains used for improving the ground such that the consolidation under preload is accelerated resulting in improvement of ground to carry envisaged loads.

2 REFERENCE

The standard given below contains provisions which, through reference in this text, constitute provision of this standard. At the time of publication the edition indicated was valid. All standards are subject to revision and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent edition of the standard indicated below:

IS No.	*Title*
1892 : 1979	Code of practice for subsurface investigations for foundations (*first revision*)

3 TERMINOLOGY

For the purpose of this standard the following definitions shall apply;

3.1 Displacement/Non-displacement Type of Installation Process — If the soil is laterally pushed or shifted while making the hole (for example, driving tube/casings) it is displacement type of boring. In other case when the soil is taken out during boring to make the hole it is non-displacement type of installation process.

3.2 Ground Improvement — To improve the load bearing capacity and settlement potential of the loose or soft soil lying close to the surface or at depths by some possible and practicable methods.

3.3 Mandrel — The tube (casing) used for installing vertical drains.

3.4 Preconsolidation — Compressor (consolidation) of soft to very soft clay under an imposed load to improve the load carrying capacity.

3.5 Sensitivity of Clay — The ratio of unconfined compressive strength of clay at its natural state to the remoulded condition.

3.6 Smear Zone — The disturbed area radially outside the perimeter of a hole, caused due to driving or boring process.

4 NECESSARY INFORMATION

4.1 For the satisfactory design and installation of vertical drains with or without preloading, the following information is necessary.

4.1.1 Site investigation data as laid down in IS 1892 and/or any other relevant Indian Standard. Sections of trial boring, supplemented where appropriate by penetration test and other *in-situ* tests including soil parameters obtained from laboratory tests sufficiently up to the firm stratum to obtain data/information below the soft soil requiring improvement. The nature of soil should be indicated on the basis of appropriate tests for index properties, shear strengths compressibility and *in-situ* permeability. Ground water level and its conditions (such as artesian condition) should also be incorporated.

4.1.2 The general layout of the structure showing the proposed foundation system.

4.1.3 Loading pattern and intensity as determined from structural analysis.

5 TYPE OF DRAINS

5.1 Sand Drains

These may be installed by any of the following methods:

a) Driven or vibratory closed-end mandrel;
b) Jetting with water; and
c) Continuous flight auger.

The first method is displacement type and the other two are non-displacement type; Comparison of different methods is given in Table 1.

Table 1 Comparison of Different Sand Drain Installation Techniques
(*Clause* 5.1)

Sl No.	Technique	Range	Limitations	Remark
(1)	(2)	(3)	(4)	(5)
i)	Driven or vibratory closed end mandrel	Diameter 15 to 60 cm Spacing 2 to 8 m times diameter, maximum length 30 m	Shear strength of subsoil is reduced temporarily. A highly disturbed smear zone is formed	Should not be used where clay sensitivity is more than 4 to 6
ii)	Continuous flight auger	Diameter 30 to 50 cm, Spacing 2 to 8 m, maximum length 35 m	Disturbance and smearing of the surrounding clay is intermediate between full displacement and jetted sand drains	—
iii)	Jetted	Diameter 20 to 30 cm	Installation technique is quite complex and requires close supervision	—

5.2 Prefabricated Drains

The prefabricated drains can be of two types;

a) Sand wicks, and
b) Band shaped drains.

5.2.1 Sand wicks are made by filling preformed pipes of HDPE or other woven permeable fabric, including natural fabric with sand and stitching along the sides and the ends. The material to be used for vertical drains should be well graded coarse to medium sand or any other suitably graded material with permeability in the range of 10^{-3} to 10^{-1} cm/s. The prepared sand wick shall be saturated by keeping it in a water vat. After driving the mandrel to the specified depth the flexible sand wick is inserted in the tube and the tube is withdrawn.

5.2.2 A mandrel is often pushed into the soil along with the prefabricated drain with the help of a hydraulic power and pulley system. Anchor plates are generally used for installation of band-shaped drains. The strip drain is made with a central core having typical groves, studs or channels for water transport. During installation, the anchor plate ensures that the bottom of the band-shaped drain is taken up to desired depth.

6 DESIGN

6.1 The design of vertical drain for preloading consists of the following:

a) Determination of the depth and spacing for a given drain size based on the soil properties and stratification. Normally the drains are arranged in equilateral triangular or square grids, and
b) Determination of the rate of loading, stages and pause period of preload without causing plastic flow or any detrimental effect on the ground based on the soil properties, stratification and topography of adjoining ground.

6.2 The depth of vertical drains for a given soil profile are so determined that the drains extend through the most significant compressible strata that account for the major consolidation settlement during preloading.

6.3 In general, preloading is done by an applied pressure, which is nearly equal to the foundation loading. However, depending on the soil strength and the magnitude of required load, preloading may be done in stages allowing at least 90 percent consolidation under each stage of loading.

6.4 At each stage of preload the degree consolidation achieved by radial and vertical dr is determined. Improvement of shear streng evaluated and considered to determine the of the next stage of preload. The stabilit of loading is examined by finding th against possible slip or bearing factor of safety of 1.25 is consid preload stage.

6.5 As per theory of thre

$U = 1-(1-U_z)$

where

U = deg d

U_z =

U_r

U_z and U_r for vertical an

6.5.1 The time fac r vertical flow:

$$T_v = \frac{C_v t}{H^2}$$

where

C_v = coefficient of consolidation for vertical flow,

t = time elapsed since application of a preload, and

H = thickness of consolidating layer depending on one way or two way drainage (this depends on presence of drainage layer if any at bottom of treated soil since drainage blanket is essential at ground level).

For given value of C_v, t and H, T_v can be computed, and corresponding U_z can be obtained (*see* Fig. 1 and Table 2).

6.5.2 The time factor for radial flow:

$$T_r = \frac{C_r t}{(2R)^2}$$

where

C_r = coefficient of consolidation for radial flow, and

$2R$ = well spacing, (*see* Fig. 2).

For given value of C_r, t and R, T_r can be calculated.

Now $U_r = 1 - e^{-A}$

where

$$A = \frac{8\,T_r}{F_n}$$

where

$$F_n = \frac{n^2}{n^2-1}\log_e n - \frac{3n^2-1}{4n^2}$$

$n = \frac{R}{r_w}$, r_w being the radius of drain

The relationship between U_r and T_v for different values on n is given in the Table 3.

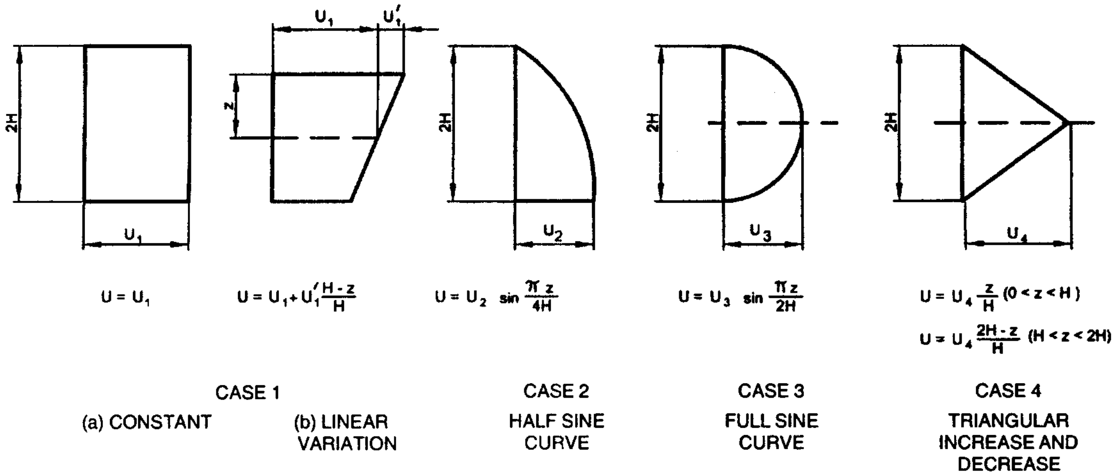
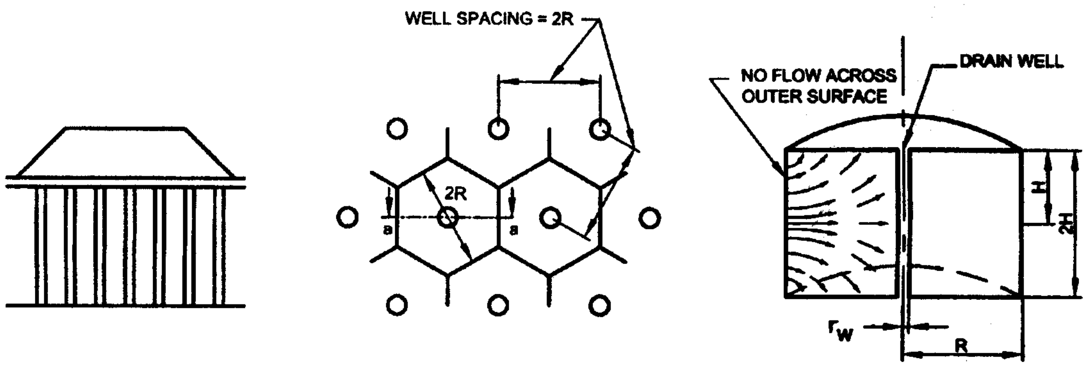


FIG. 1 FOUR CASES OF INITIAL EXCESS PORE PRESSURE DISTRIBUTION WITH DOUBLE DRAINAGE

Table 2 Values of U_z for Various Values of T_v
(*Clause* 6.5.1)

Sl No.	T_v	*U* %(Percentage Consolidation)			
		Case 1	Case 2	Case 3	Case 4
(1)	(2)	(3)	(4)	(5)	(6)
i)	0.004	07.35	6.49	0.98	0.85
ii)	0.008	10.38	8.62	1.95	1.62
iii)	0.012	12.48	10.49	2.92	2.41
iv)	0.020	15.98	13.67	4.81	4.00
v)	0.028	18.89	16.38	6.67	5.60
vi)	0.036	21.41	18.76	8.50	7.20
vii)	0.048	24.64	21.96	11.17	9.50
viii)	0.060	27.64	24.81	13.76	11.98
ix)	0.072	30.28	27.43	16.28	14.36
x)	0.083	32.33	29.67	18.52	16.46
xi)	0.100	35.62	32.88	21.87	19.76
xii)	0.125	39.89	36.54	26.54	24.42
xiii)	0.150	43.70	41.12	30.93	28.86
xiv)	0.175	47.18	44.73	35.07	33.06
xv)	0.200	50.41	48.09	38.95	37.04
xvi)	0.250	56.22	54.17	46.03	44.32
xvii)	0.300	61.32	59.50	52.30	50.32
xviii)	0.350	65.82	64.21	57.83	56.49
ixx)	0.40	69.73	68.36	62.73	61.54
xx)	0.50	76.40	76.28	70.88	69.94
xxi)	0.60	81.56	80.69	77.25	76.52
xxii)	0.70	85.59	84.91	82.22	81.65
xxiii)	0.80	88.74	88.21	86.11	85.66
xxiv)	0.90	91.19	90.79	89.15	88.80
xxv)	1.00	93.13	92.80	91.52	91.25
xxvi)	2.00	99.42	—	—	—



(a) SECTION OF DRAIN-WELL PATTERN (b) PLAN OF DRAIN-WELL PATTERN (c) SECTION a-a

FIG. 2 SCHEMATIC DIAGRAM OF DRAIN-WELL INSTALLATION

Table 3 Solution of Radial-Flow Equation Equal Vertical-Strain Condition
(*Clause* 6.5.2)

Sl No.	Degree of Consolidation, U_r	Time Factor T for Value of R/r_w										
		5	10	15	20	25	30	40	50	60	80	100
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
i)	5	0.006	0.010	0.013	0.014	0.016	0.017	0.019	0.020	0.021	0.023	0.025
ii)	10	0.012	0.021	0.026	0.030	0.032	0.035	0.039	0.042	0.044	0.048	0.051
iii)	15	0.019	0.032	0.040	0.046	0.050	0.054	0.060	0.064	0.068	0.074	0.079
iv)	20	0.026	0.044	0.055	0.063	0.069	0.074	0.082	0.088	0.092	0.101	0.107
v)	25	0.034	0.057	0.071	0.081	0.089	0.096	0.106	0.114	0.120	0.131	0.139
vi)	30	0.042	0.070	0.088	0.101	0.110	0.118	0.131	0.141	0.149	0.162	0.172
vii)	35	0.050	0.085	0.106	0.121	0.133	0.143	0.158	0.170	0.180	0.196	0.208
viii)	40	0.060	0.101	0.125	0.144	0.158	0.170	0.188	0.202	0.214	0.232	0.246
ix)	45	0.070	0.118	0.147	0.169	0.185	0.198	0.220	0.236	0.250	0.291	0.288
x)	50	0.081	0.137	0.170	0.195	0.214	0.230	0.255	0.274	0.290	0.315	0.334
xi)	55	0.094	0.157	0.197	0.225	0.247	0.265	0.294	0.316	0.334	0.363	0.385
xii)	60	0.107	0.180	0.226	0.258	0.283	0.304	0.337	0.362	0.383	0.416	0.441
xiii)	65	0.123	0.207	0.259	0.296	0.325	0.348	0.386	0.415	0.439	0.477	0.506
xiv)	70	0.137	0.231	0.289	0.330	0.362	0.389	0.431	0.463	0.490	0.532	0.564
xv)	75	0.162	0.273	0.342	0.391	0.429	0.460	0.510	0.548	0.579	0.629	0.668
xvi)	80	0.188	0.317	0.397	0.453	0.498	0.534	0.592	0.636	0.673	0.730	0.775
xvii)	85	0.222	0.373	0.467	0.534	0.587	0.629	0.697	0.750	0.793	0.861	0.914
xviii)	90	0.270	0.455	0.567	0.649	0.712	0.764	0.847	0.911	0.963	1.048	1.110
ixx)	95	0.351	0.590	0.738	0.844	0.926	0.994	1.102	1.185	1.253	1.360	1.444
xx)	99	0.539	0.907	1.135	1.298	1.423	1.528	1.693	1.821	1.925	2.091	2.219

6.6 The degree of consolidation, U can be calculated using U_z and U_r. Generally, where vertical drains are provided, U_z is small and U may be considered same as U_r.

If the U percent so obtained for a time '*t*' for the assumed spacing is not sufficient /suitable then the spacing is adjusted to get the most suitable U percent with respect to '*t*'. Experiences with preloading in the field suggest that 90 percent consolidation can be achieved in about 4 to 12 weeks with normal sand wick spacing of 1.0-2.0 m.

6.7 In case of soft soil and specially where the final load is high, preloading is done in stages. At each load stage similar calculation as given in **6.4** above is done to check, if the desired percentage consolidation is complete or not.

6.8 Depending on the percentage consolidation at each stage, the shear strength of the soil will be improved proportionally. The gain in shear strength can be considered while checking the safety against failure under the next stage of preload.

7 SPECIAL REQUIREMENT

7.1 The treatment area, that is, vertical drains and preloaded area should be sufficiently extended beyond the outer edge of loaded area/foundation area depending on the size of the loaded area.

7.2 At top, the vertical drains are to be connected to a permeable layer to allow the pore water to flow out to the atmosphere. For this purpose a sand blanket of minimum thickness 400 mm is to be provided at ground level and sufficient length of prefabricated drain (at least 150 mm) shall be embedded in the sand-blanket.

7.3 Depending on the installation process there will be a disturbed zone (smear zone) extending to some distance away from the bored/driven holes. The extent of smear zone will depend upon the sensitivity of soil and method of installation of drains. This aspect is to be considered in design and effective radius of the drains should be considered as a fraction of actual hole size.

7.4 The C_r value is generally different from C_v because of anisotropy and the nature of soil deposition. It is preferable to conduct laboratory consolidation test on samples cut in horizontal direction to get direct measurement of C_r otherwise, C_r may be estimated from a realistic evaluation of the ratio of horizontal to vertical permeability. In varved clay *in-situ* permeability tests may be done.

8 CONTROL OF PRELOADING IN FIELD

Suitable instrumentation to measure the settlement of the ground and the dissipation of pore water pressure under each stage of loading should be done to ensure that settlement is essentially over under a preload. The pause period for consolidation under subsequent loading stages may be suitably controlled based on these observations. An instrumentation scheme for measuring the settlement and pore water pressure may be worked out.

This Indian Standard has been developed from Doc : No. **CED 43 (5716).**

Amendments Issued Since Publication

Amend No.	Date of Issue	Text Affected

BUREAU OF INDIAN STANDARDS

Headquarters :

Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi 110 002
Telephones : 2323 0131, 2323 33 75, 2323 9402

Telegrams : Manaksanstha
(Common to all offices)

Regional Offices :		Telephone
Central	: Manak Bhavan, 9 Bahadur Shah Zafar Marg NEW DELHI 110 002	2323 7617 2323 3841
Eastern	: 1/14 C.I.T. Scheme VII M, V. I. P. Road, Kankurgachi KOLKATA 700 054	2337 8499, 2337 8561 2337 8626, 2337 9120
Northern	: SCO 335-336, Sector 34-A, CHANDIGARH 160 022	60 3843 60 9285
Southern	: C.I.T. Campus, IV Cross Road, CHENNAI 600 113	2254 1216, 2254 1442 2254 2519, 2254 2315
Western	: Manakalaya, E9 MIDC, Marol, Andheri (East) MUMBAI 400 093	2832 9295, 2832 7858 2832 7891, 2832 7892

Branches : AHMEDABAD. BANGALORE. BHOPAL. BHUBANESHWAR. COIMBATORE. FARIDABAD. GHAZIABAD. GUWAHATI. HYDERABAD. JAIPUR. KANPUR. LUCKNOW. NAGPUR. NALAGARH. PATNA. PUNE. RAJKOT. THIRUVANANTHAPURAM. VISAKHAPATNAM.

Printed at Prabhat Offset Press, New Delhi-2