भारतीय मानक

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Indian Standard

SELECTION OF GROUND IMPROVEMENT TECHNIQUES FOR FOUNDATION IN WEAK SOILS — GUIDELINES

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FOREWORD

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

In poor and weak subsoils, the design of conventional shallow foundation for structures and equipment may present problems with respect to both sizing of foundation as well as control of foundation settlements. Traditionally, pile foundations have been employed often at enormous costs. A more viable alternative in certain situations, developed over the recent years is to improve the subsoil itself to an extent such that the subsoil would develop an adequate bearing capacity and foundations constructed after subsoil improvement would have resultant settlements within acceptable limits. The techniques for ground improvement has developed rapidly and has found large scale application in industrial projects.

Indian Standard

SELECTION OF GROUND IMPROVEMENT TECHNIQUES FOR FOUNDATION IN WEAK SOILS — GUIDELINES

1 SCOPE

1.1 This standard covers the guidelines for selection of ground improvement techniques using one or more methods.

2 REFERENCES

2.1 The following Indian Standards are necessary adjuncts to this standard:

IS No.	*Title*
1892 : 1979	Code of practice for subsurface investigation for foundations (*first revision*)
6403 : 1981	Code of practice for determination of bearing capacity of shallow foundations (*first revision*)
8009 (Part 1) : 1976	Code of practice for calculation of settlement of foundations : Part 1 Shallow foundations subject to symmetrical static vertical loads
8009 (Part 2) : 1980	Code of practice for calculation of settlement of foundations : Part 2 Deep foundations subjected to symmetrical static vertical loading

3 TERMINOLOGY

3.1 For the purpose of this standard, the following definitions shall apply.

3.1.1 *Ground Improvement*

Enhancement of the inplace properties of the ground by controlled application of technique suited to the subsoil conditions.

3.2 Injection

Introduction of a chemical/cementaceous material into a soil mass by application of pressure.

3.2.1 *Preloading*

Application of loads to achieve improvement of soil properties prior to imposition of structural loads.

3.3 Soil Densification

A technique to densify cohesionless soils by imparting shocks or vibrations.

3.4 Soil Reinforcement

Rods, strips or fabrics incorporated within soil-mass to impart resistance to tensile, shear and compressive forces.

4 NECESSARY DATA

4.1 Following information shall be collected to establish the need for ground imporvement at a site, for selection of method to be adopted and for design of scheme selection.

4.1.1 Subsoil profile and soil charatcteristics up to a depth of about twice the width of the loaded area or up to dense/hard strata if encountered earlier. The information shall be acquired by conducting soil investigations as per IS 1892 : 1979.

4.1.2 Engineering properties of subsoil shall include index properties, shear parameters, compressibility characteristics etc.

4.1.3 Boreholes shall be supplemented by conducting a suitable number of static/dynamic cone penetration tests up to the depth to be improved. In conjunction with selected boreholes these tests serve as a economical and rapid method of establishing the state of subsoil before and after treatment.

4.1.4 Information shall be obtained with respect to nature of structure and area covered by it, intensity and nature of loading, permissible distortions, the structure can withstand.

5 CONSIDERATIONS FOR ESTABLISHING NEED FOR GROUND IMPROVEMENT

5.1 Based on subsoil information obtained from site and the loading exerted by the structure, foundation design shall be carried out including sizing and settlement analysis. Ground improvement is indicated if the net loading intensity of the foundation exceeds the allowable pressure computed as per IS 6403 : 1981.

5.2 Ground treatment is also indicated if even for relative low loading intensities, the resultant settlement [computed in accordance with IS 8009 (Part 1) : 1976 and IS 8009 (Part 2) : 1980] exceeds the acceptable limits for the structure both from view point of distortions induced in the structure and from operation angle.

5.3 Loose cohesionless deposits in seismic zones may be prone to liquefaction during earthquakes specially under high water table conditions. In such cases, analysis should be carried out for establishing liquefaction potential of the subsoil. Ground improvement is called for if such analysis establishes that the subsoil is prone to liquefaction.

5.4 Stability of soil in slopes can be enhanced substantially by use of soil reinforcement.

6 METHODS

6.1 Ground improvement is achieved by the following methods.

6.1.1 *Soil Densification*

6.1.1.1 By application of shock and vibration to the subsoil and thereby causing rearrangement of the soil structure from a loose to medium due to dense state. This technique is applicable only to cohensionless soils under high water table conditions.

6.1.1.2 Methods under this head include vibroflotation, vibrocompaction, compaction piles, blasting and dynamic consolidation.

6.1.2 *Pre-Consolidation*

6.1.2.1 Expulsion of water from the pores causes consolidation of the soil thereby resulating in build up of shear strength and substantially reduced values of final settlements of foundations. This is achieved by precompression of the subsoil by subjecting the area to a preload. Preload can be of a soil itself or any suitable material. Preloading is generally carried out in stages to allow gradual build up of soil strength enabling it to safely support further stages of preload. For poorly draining soils such as soft clays, precompression is accelerated by provision of vertical drainage channels.

6.1.2.2 This technique is applicable to fine groundsoils such as silts and clays. Subsoils exhibiting high secondary consolidation characteristics may not be amenable to required degree of impovement by the preloading method.

6.1.2.3 Removal of water from pore spaces has also been carried out by application of electric current to subsoil, the process being known as Electro Osmosis.

6.1.3 *Injection and Grouting*

6.1.3.1 Injection of chemicals, lime, cements etc, into subsoils improve subsoil by formation of bonds between soil particles. Mechanical compression of subsoil is also achieved under certain conditions provided grout is pumped in under high pressure.

6.1.3.2 Available methods are suitable for sands as well as fine grained soils.

6.1.4 *Soil Reinforcement*

6.1.4.1 Reinforcement introduced into the soil mass causes marked improvemement in stiffness and consequently load carrying capcity and stability of soil mass.

6.1.4.2 Reinforcements may be in the form of dense granular materials in the form of stone columns. These are used where the primary requirement is increased in capability to carry vertical loads.

6.1.4.3 Reinforcements may also be in the form of horizontal or vertical strips and membranes. These reinforcements serve significantly to increase the capacity of soil to withstand tensile, shear and compression loads and contribute towards improvement of stability of soil mass.

6.1.5 *Miscellaneous Methods*

6.1.5.1 Other methods used successfully include replacement of poor subsoil by competent fill. These methods, however have limitations of depths of application.

6.1.5.2 Improvement of properties of subsoils by heating and drying and by fusion at high temperatures have been employed with success. Soft soil have also temporarily been strengthened by freezing to improve stiffness.

6.1.6 *Choice of Method*

6.1.6.1 Annex A presents various methods of ground improvement alongwith principles, applicabilty to various soil conditions, material requirements, equipments required, results likely to be achieved and limitations. This table may be referred to as guidance for selecting the proper method for a situation.

6.1.6.2 Annex B gives applicable grain size ranges for different treatment methods.

6.1.6.3 For a particular situation more than one method may appear to be suitable. In such cases a relative study should be made for a proper selection. If necessary, a combination of more than one method may be more suitable.

7 EQUIPMENT AND ACCESSORIES

The equipment and accessories will depend upon the method of ground improvement adopted. In practice, the type of equipment employed can vary considerably depending upon the design and resources of the contractor. However, not only it is important that the equipment should be capable of reaching the required depths but also the installation procedure should not adversely affect subsoil properties thereby reducing efficacy of treatment procedure adopted.

8 CONTROL OF GROUND IMPROVEMENT WORKS

8.1 Prior to commencement of ground improvement works, pilot boreholes with relevant field and laboratory tests shall be carried out in locations specific to area to be improved.

8.2 After completion of ground improvement work in a specific area, the field and laboratory tests shall be repeated to assess degree and adequacy of improvement of subsoil.

NOTES

1 For medium and major works it is desirable, to initially earmark a trial area for establishing the pattern and efficiency of the treatment technique employed and optimization of the same.

2 It will also be beneficial to include a programme of instrumentation to monitor the behaviour of subsoil during loading by measurement of pore pressure, soil movements, earth pressures, foundation settlement, etc.

9 RECORDING OF DATA

9.1 A competent inspector shall be present to record the necessary information during execution of the ground improvement work.

9.2 Data to be recorded shall include:

a) Sequence of operation of the work;

b) Sequence and spacing of treatment points;

c) Depth of treatment;

d) Details of equipment employed and installation procedure followed;

e) Records of instrumentation, if any;

f) Results of soil tests before and after treatment; and

g) Settlements during preloading.

ANNEX A

(*Clause* 5.1.6.1)

SOIL IMPROVEMENT METHODS

Summary of Soil Improvement Methods

In-Situ **Deep Compaction of Cohesionless Soils**

Method	Principle	Most Suitable Soil Conditions/Types	Maximum Effective Treatment Depth	Special Materials Required	Special Equipment Required	Properties of Treated Material	Special Adavantages and Limitations	Relative Cost
Blasting	Shock waves and vibrations cause liquefaction and displacement with settlement to higher density	Saturated, clean sands : partly saturated sands and silts (collapsible loess) after flooding	>30 m	Explosives, backfill to plug drill holes, hole casings	Jetting or drilling machine	Can obtain relative densities to 70-80, may get variable density time dependent strength gain	Rapid, inexpensive, can treat any size areas : variable properities, no improvement near surface, dangerous	Low
Vibratory Probe	Densification by vibration; liquefaction induced settlement under overburden	Saturated or dry clean sand	20 m (Ineffective above 3 - 4 m depth)	None	Vibratory pile driver and 750 mm dia, open steel pipe	Can obtain relative densities of up to 80. Ineffective in some sands	Rapid, simple, good underwater, soft underlayers may damp vibrations, difficult to penetrate, stiff overlayers, not good in partly saturated soils	Moderate
Vibro-compaction	Densification by vibration and compaction of backfill material	Cohesionless soils with less than 20 fines	30 m	Granular backfill, water supply	Vibroflot, crane, pumps	Can obtain high relative densities, good uniformity	Useful in saturated and partly saturated soils, uniformity	Moderate
Compaction Piles	Densification by displacement of pile volume and by vibration during driving	Loose sandy soils : partly saturated clayey soils, loess	>20 m	Pile material (often sand or soil plus cement mixture)	Pile driver, special sand pile equipment	Can obtain high densities, good uniformity	Useful in soils with fines, uniform compaction, easy to check results, slow, limited improvement in upper 1-2 m	Moderate to high
Heavy Tamping (Dynamic Consolidation)	Repeated application of high intensity impacts at surface	Cohesionless soils, waste fills, partly saturated soils	30 m	None	Tampers of up to 200 tons, high capacity crane	Can obtain good improvement and reasonable uniformity	Simple, rapid, suitable for some soils with fines; usable above and below water, requires control, must be away from existing structures	Low

Injection and Grouting	Particulate Grouting	Penetration grouting-fill soil pores with soil, cement, and/or clay	Medium to coarse sand and gravel	Unlimited	Grout, water	Mixers, tanks, pumps, hoses	Impervious, high strength with cement grout, eliminate liquefaction danger	Low cost grouts, high strength; limited to coarse-grained soils, hard to evaluate	Lowest of the grout systems
	Chemical Grouting	Solutions of two or more chemicals react in soil pores to form a gel or a solid precipitate	Medium silts and coarser	Unlimited	Grout, water	Mixers, tanks, pumps, hoses	Impervious, low to high strength eliminate liquefaction danger	Low viscosity controllable gel time, good water shut-off; high cost, hard to evaluate	High to very high
	Pressure Injected Lime	Lime slurry injected to shallow depths under high pressure	Expansive clays	Unlimited, but 2-3 m usual	Lime, water surfactant	Slurry tanks, agitators, pumps, hoses	Lime encapsulated zones formed by channels resulting from cracks, root holes, hydraulic fracture	Only effective in narrow range of soil conditions	Competitive with other solutions to expansive soil problems
	Displacement Grout	Highly viscous grout acts as radial hydraulic jack when pumped in under high pressure	Soft, finegrained soils; foundation soils with large voids or cavities	Unlimited, but a few m usual	Soil, cement water	Batching equipment, high pressure pumps, hoses	Grout bulbs within compressed soil matrix	Good for correction of differential settlements, filling large voids; careful control required	Low material high injection
	Electrokinetic Injection	Stabilizing chemicals moved into soil by electroosmosis or colloids into pores by electrophorasis	Saturated silts; silty clays (clean sands in case of colloid injection)	Unknown	Chemical stabilizer colloidal void fillers	DC power supply, anodes, cathodes	Increased strength, reduced compressibility, reduced liquefaction potential	Existing soil and structures not subjected to high pressures; no good in soil with high conductivity	Expensive
	Jet Grouting	High speed jets at depth excavate, inject, and mix stabilizer with soil to form columns or panels	Sands, silts, clays		Water, stabilizing chemicals	Special jet nozzle, pumps, pipes and hoses	Solidified columns and walls	Useful in soils that can't be permeation grouted, precision in locating treated zones	

ANNEX A (*continued*)

Summary of Soil Improvement Methods

	Method	Principle	Most Suitable Soil Conditions/Types	Maximum Effective Treatment Depth	Special Materials Required	Special Equipment Required	Properties of Treated Material	Special Advantages and Limitations	Relative Cost
Precompression	Preloading with/without Drain	Load is applied sufficiently in advance of construction so that compression of soft soils is completed prior to development of the site	Normally consolidated soft clays, silts, organic deposits, completed sanitary landfills	—	Earth fill or other material for loading the site; sand or gravel for drainage blanket	Earth moving equipment, large water tanks or vacuum drainage systems sometimes used; settlement markers, piezometers	Reduced water content and void ratio, increased strength	Easy, theory well developed, uniformity; requires long time (vertical drains can be used to reduce consolidation time)	Low (Moderate if vertical drains are required)
	Surcharge Fills	Fill in excess of that required permanently is applied to achieve a given amount of settlement in a shorter time; excess fill then removed	Normally consolidated soft clays, silts, organic deposits, completed sanitary landfills	—	Earth fill or other material for loading the site; sand or gravel for drainage blanket	Earth moving equipment; settlement markers, piezometers	Reduced water content, void ratio and compressibility; increased strength	Faster than preloading without surcharge, theory well developed extra material handling; can use vertical drains to reduce consolidation time	Moderate
	Electro-osmosis	DC current causes water flow from anode towards cathode where it is removed	Normally consolidated silts and silty clays	—	Anodes (usually rebars or aluminium) cathodes (well points or rebars)	DC power supply, wiring, metering systems	Reduced water content and compressibility, increased strength, electrochemical hardening	No fill loading required, be used in confined area, relatively fast; non-uniform properties between electrodes; no good in highly conductive soils	High

Admixtures	Remove and Replace	Foundation soil excavated, improved by drying or admixture, and recompacted	Inorganic soils	10 m	Admixture stabilizers	Excavating, mixing, and compaction equipment dewatering system	Increased strength and stiffness, reduced compressibility	Uniform, controlled foundation soil when replaced; may require large area dewatering	High
	Structural Fills	Structural fill distributes loads to underlying soft soils	Use over soft clays or organic soils, marsh deposits	—	Sand, gravel fly ash, bottom ash, slag, expanded aggregate, clam shell or oyster shell, incinerator ash	Mixing and compaction equipment	Soft subgrade protected by structural load-bearing fill	High strength, good load distribution to underlying soft soils	Low to high
	Mix-in-Place Piles and Walls	Lime, cement, or asphalt introduced through rotating auger or special in-place mixer	All soft or loose inorganic soils	> 20 m	Cement, lime asphalt, or chemical stabilizer	Drill rig, rotary cutting and mixing head, additive proportioning equipment	Solidified soil piles or walls of relatively high strength	Uses native soil, reduced lateral support requirements during excavation; difficult quality control	Moderate to high
Thermal	Heating	Drying at low temperatures; alteration of clays at intermediate temperatures (400–600°C); fusion at high temperatures (>1 000°C)	Fine-grained soils, especially partly saturated clays and silts, loess	15 m	Fuel	Fuel tanks, burners, blowers	Reduced water content, plasticity, water sensitivity; increased strength	Can obtain irreversible improvements in properties; can introduce stabilizers with hot gases	High
	Freezing	Freeze soft, wet ground to increase its strength and stiffness	All soils	Several m	Refrigerant	Refrigeration system	Increased strength and stiffness, reduced permeability	No good in flowing ground water, temporary	High

ANNEX A (*concluded*)

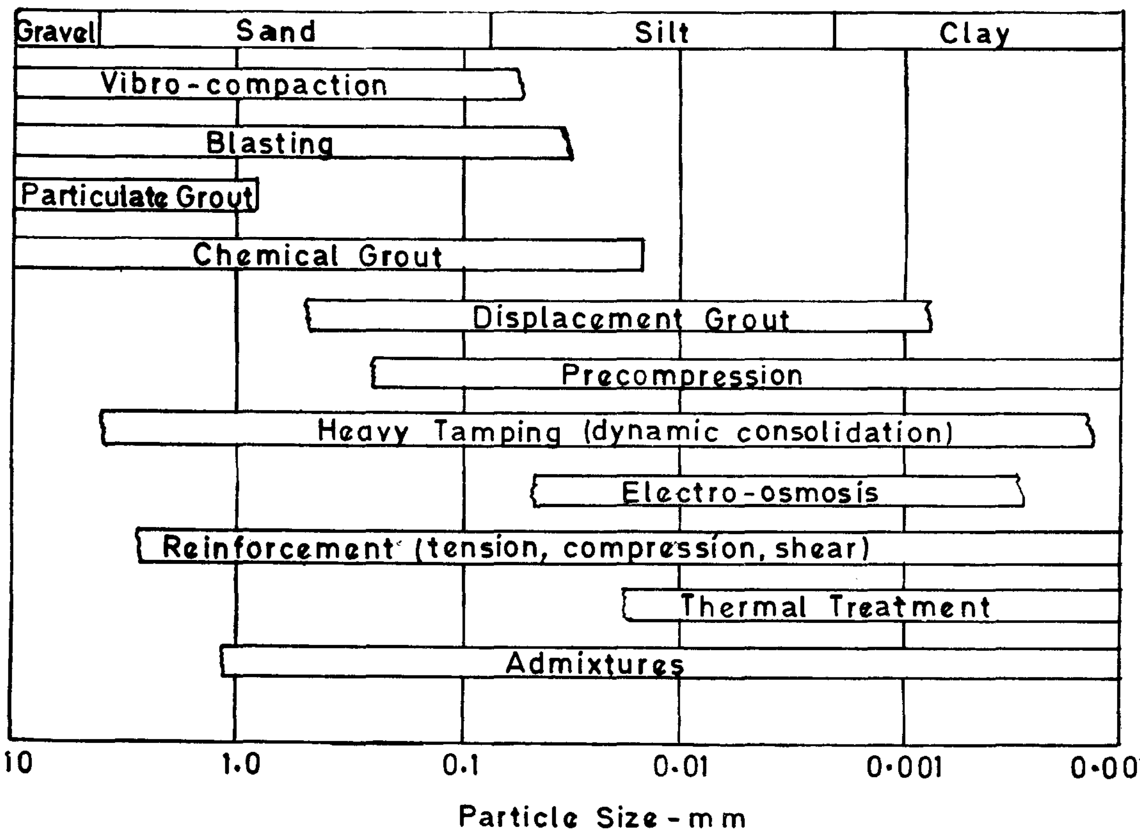
Summary of Soil Improvement Methods

	Method	Principle	Most Suitable Soil Conditions/Types	Maximum Effective Treatment Depth	Special Materials Required	Special Equipment Required	Properties of Treated Material	Special Advantages and Limitations	Relative Cost
Reinforcement	Vibro Replacement Stone and Sand Columns	Hole jetted into soft, fine-grained soil and backfilled with densely compacted gravel or sand	Soft clays and alluvial deposits	20 m	Gravel or crushed rock backfill	Vibroflot, crane or vibrocat, water	Increased bearing capacity, reduced settlements	Faster than precompression, avoids dewatering required for remove and replace; limited bearing capacity	Moderate to high
	Root Piles, Soils Nailing	Inclusions used to carry tension, shear, compression	All soils		Reinforcing bars, cement grout	Drilling and grouting equipment	Reinforced zone behaves as a coherent mass	*In-situ* reinforcement for soils that can't be grouted or mixed-in-place with admixtures	Moderate to high
	Strips and Membranes	Horizontal tensile strips, membranes buried in soil under embankments, gravel base courses and footings	Cohesionless soils	Can construct earth structures to heights of several tons of m	Metal or plastic strips, geotextiles	Excavating, earth handling, and compaction equipment	Self-supporting earth structures, increased bearing capacity, reduced deformations	Economical, earth structures coherent, can tolerate deformations; increased allowable bearing pressure	Low to moderate

ANNEX B

(*Clause* 6.1.6.2)

GRAIN SIZE RANGES FOR DIFFERENT TREATMENT METHODS



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