GROUND IMPROVEMENT TECHNIQUE
(Subject Code-PCI7J002)

MODULE-I

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Introduction: Ground Improvement Methods and its selection

Civil Engineering Materials: **Steel, concrete, brick stone, timber, glass etc. Many a times we miss one most important material. i., e., soil.**

Soil versus other civil engineering materials:

Steel and concrete: Manufactured, can be produced with desired strength and stiffness, quality can be monitored

Introduction: Ground Improvement Methods and its selection

- **Soil:** Formed Naturally, properties mostly not known or depends on many factors, no control over its quality

Introduction: G I Methods and its selection

- **With the increasing demand on urbanization we need to venture to more challenging sites to built more houses, commercial buildings, high-rise office buildings, highways, railways, tunnels, earth dams etc as suitable site with favorable geotechnical conditions is not abundantly available**

Introduction: G I Methods and its selection

Type of Geo-material	Name	Potential Problems
Natural	Soft Clay	Low strength, high compressibility, large creep deformation, low permeability
	Silt	Low strength, high compressibility, high liquefaction potential, low permeability, high erodibility
	Organic Soil	High Compressibility, Large creep deformation
	Loose sand	Low strength, high compressibility, high liquefaction potential, high permeability, high erodibility
	Expansive soil	Large volume Change
	Loess	Large volume change, high collapsible potential

Introduction: G I Methods and its selection

Problematic Geo-material and potential Problems

Type of Geo-material	Name	Potential Problems
Fill	Uncontrolled fill	Low strength, high compressibility, nonuniformity, high collapsible potential
	Dredged material	High water content, low strength, high compressibility
	Reclaimed fill	High water content, low strength, high compressibility
	Recycled material	Non-uniformity, high variability of properties
	Solid waste	Low strength, high compressibility, nonuniformity and high degradation potential
	Bio-based by-product	Low strength, high compressibility and high degradation potential

Introduction: G I Methods and its selection

Geotechnical problems and possible causes

Problem	Theoretical Basis	Possible Causes
Bearing Failure	Applied pressure is higher than ultimate bearing capacity of soil	High applied pressure, inclined load, small loading area, low strength soil
Large total and differential settlement	Hooke,s law particle re-arrangement	High applied pressure, large loading area, highly compressible soil, non-uniform soil, large creep deformation
Ground heave	Swelling pressure is higher than applied pressure	Water, expansive soil, Frozen soil
Instability	Shear stress is higher than shear strength, driving force is higher than resisting force, driving moment is higher than the resisting moment	High earth structure, steep slope, high water pressure, soft foundation soil, high surcharge, high loading rate

Introduction: G I Methods and its selection

Geotechnical problems and possible causes

Problem	Theoretical Basis	Possible causes
Liquefaction	Effective stress become zero due to increase in excess pore water pressure	Earthquake, loose silt and sand, high ground water table
Erosion	Shear stress induced by water is higher than maximum allowable shear	Running water, high speed of water flow, highly erodible soil (silt and sand)
Seepage	Darcy's law	High water head, permeable soil

Introduction: G I Methods and its selection

Ground Improvement Methods for Transportation Infrastructure

Aggregate Columns	Electro osmosis	Micro-piles
Reuse of waste material	Excavation and replacement	Deep mixing
Bio-treatment for sub-grade	Geo-cell confined in pavement system	PVD
Blasting densification	Geo-synthetic reinforced in pavement	Rapid impact compaction
Chemical grouting/injection	Geo-textile encased column	Reinforced soil slope
Chemical stabilisation of sub-grades and bases	Injected light weight foam fill,	Sand compaction pile
Compaction grouting	Intelligent compaction	Traditional compaction
Deep dynamic compaction	Mechanical stabilisation of subgrades and bases	Vacuum preloading with and without PVD
Drilled/grouted soil nailing	Mechanically stabilised earth wall system	Vibro-compaction

GROUND IMPROVEMENT

GROUND IMPROVEMENT METHODS

Ground Improvement Methods

Classification of Ground Improvement Methods

Reference	Criterion	Categories
Michel (1981)	Construction/Function	1. Insitu deep compaction of cohesionless soil
		2. Pre-compression
		3. Injection and grouting
		4. Admixtures
		5. Thermal
		6. Reinforcement

Ground Improvement Methods

Classification of Ground Improvement Methods

Reference	Criterion	Categories
Haussmann (1990)	Process	1. Mechanical Modification 2. Hydraulic Modification
		3. Physical and Chemical Modification
		4. Modifications by inclusions and confinement

Ground Improvement Methods

Classification of Ground Improvement Methods

Reference	Criterion	categories
Ye et al (1994)	Function	Replacement
		Deep Densification
		Drainage and consolidation
		Reinforcement
		Thermal treatment
		Chemical stabilisation
Chu et al (2009)	Soil type and inclusion	Ground improvement without admixtures in fill materials Ground improvement without admixtures in cohesive soils
		Ground improvement with admixtures or inclusions
		Ground improvement with grouting type admixtures
		Earth reinforcement

Ground Improvement Methods

Classification of Ground Improvement Methods

Reference	Function	Categories
Schaefer and Berg (2012)	Applications	Earthwork construction
		Densification of cohesionless soil
		Embankments over soft soil
		Cutoff walls
		Increased pavement performance
		Sustainability
		Soft ground drainage and consolidation
		Construction of vertical support elements
		Lateral earth support
		Liquefaction mitigation
		Void filling

Ground Improvement Methods

Shallow Replacement

Method and availability	General description	Benefits	Applications
Over excavation and replacement, widely used	Remove problematic geo-material and replace with good quality geo-material	Increase strength, stiffness and reduce deformation, liquefaction, collapsible and ground heave potential	Suitable economic for wide range of geo-materials with limited area and limited depth (typically to 3 m deep and above ground water table

Ground Improvement Methods

Shallow Densification

Method and availability	General Description	Benefits	Applications
Traditional compaction, widely used	Apply static or vibratory load on ground surface in a certain number of passes	Increase density, strength, stiffness and reduce permeability, collapsible potential	Suitable for wide range of fills to a lift thickness of 0.3 m, used to compact fill
High energy impact roller, Occasional use	Apply a lifting and falling motion by a roller with high energy impact on ground surface to densify or crush problematic geo-material	Increase density, strength, stiffness and reduce deformation, permeability, collapsible potential	Suitable for granular geo-materials up 6.0 m deep, used to improve subgrade and foundation soil and compact fill
Intelligent compaction, new and not readily available	Apply and adjust compaction energy based on on-board display from measurements in real time	Increase density, strength, stiffness and reduce deformation, permeability, collapsible potential, maximise productivity	Suitable for granular material, used to improve subgrade and foundation soil and compact fill

Ground Improvement Methods

Deep Densification

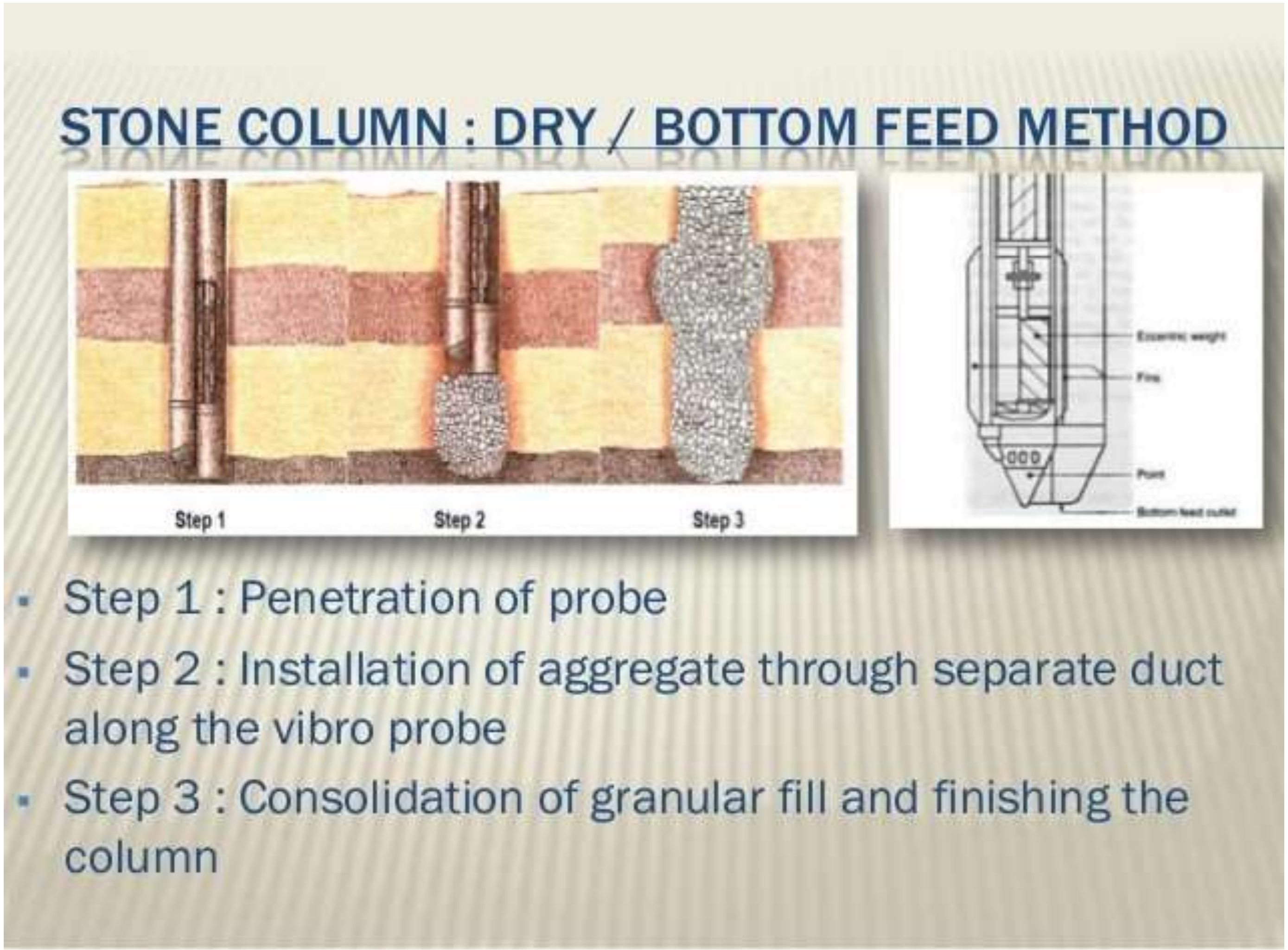
Method and availability	General description	Benefits	Applications
Dynamic Compaction, widely used	Drop a heavy weight from a high distance to apply high energy on ground surface, causing liquefaction of saturated problematic geo-material and densification of unsaturated problematic geo-material	Increase density, strength, stiffness and reduce deformation, liquefaction, collapsible potential to a greater depth	Suitable for granular geo-materials, collapsible soils and waste material with less than 15% fine to a depth of 10 m, used to improve foundations
Vibro-compaction Widely used	Apply a vibratory force and/or water by a probe on surrounding problematic geo-materials , causing liquefaction and densification	Increase density, strength, stiffness and reduce deformation, liquefaction, collapsible potential to a greater depth	Suitable for clean sands with less than 15%silt or less than 2%clay to a typical depth of 5-15 m, used to improve foundations

Ground Improvements methods and classification

Deep Densification

Method and availability	General description	Benefits	Applications
Sand compaction columns, widely used	Displace problematic geo-material by driving a casing into the ground backfill the hole with sand	Increase bearing capacity and stability, reduce settlement and liquefaction potential, accelerate consolidation	Suitable for a wide range of geo-materials to a typical depth of 5-15m, used to improve foundations
Stone columns, widely used	Jet water or air to remove or displace problematic geo-material by a probe and backfill the hole with stone to form a densified columns by vibration	Increase bearing capacity and stability, reduce settlement and liquefaction potential, accelerate consolidation	Suitable for a wide range of geo-materials to a typical depth of 5-10m (u to 30 m), used to improve foundations

Ground Improvements methods and classification



Ground Improvements methods and classification

Deep Replacement

Method and availability	General description	Benefits	Applications
Rammed aggregate column, quite popular	Pre-drill a backfilled with aggregate, densified by ramming	Increase bearing capacity and stability, reduce settlement and liquefaction potential, accelerate consolidation	Suitable for a wide range of geo-materials to a typical depth of 5-10m with a deep ground water table, used to improve foundations
Geo-synthetic encased columns, occasional use	Drive a steel casing to the ground to displace problematic geo-material replace with a geo-synthetic casing and fill	Increase bearing capacity and stability, reduce settlement, accelerate consolidation	Suitable and economic for very soft soil to typical depth of 5-10 m, used to improve foundations

Ground Improvements methods and classification

Drainage

Method and availability	General description	Benefits	Applications
Fill drains, widely used	Place a layer of permeable fill inside a roadway or earth structure	Reduce water pressure and collapsible and ground heave potential, accelerate consolidation, increase strength, stiffness and stability	Suitable for low permeability geo-material, used for roads, retaining walls, slopes and landfills
Drainage geo-synthetics, quite popular	Place a layer of nonwoven geotextile or geocomposite in ground or inside a roadway or earth structure	Reduce water pressure and collapsible and ground heave potential, accelerate consolidation, increase strength, stiffness and stability	Suitable for low permeability geo-material, used for roads, retaining walls, slopes and landfill

Ground Improvements methods and classification

Dewatering

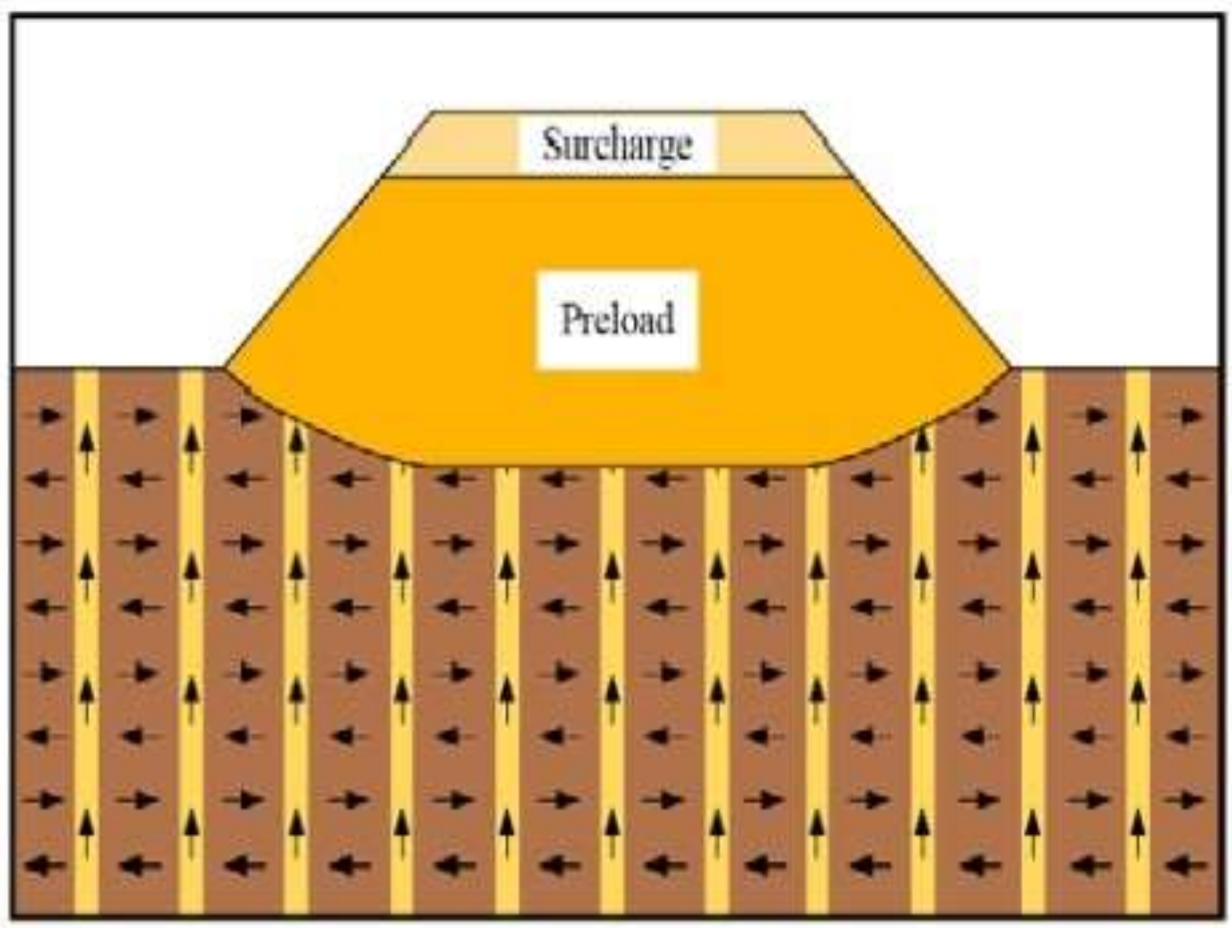
Method and availability	General description	Benefits	Applications
Open pumping, widely used	Use sumps, trenches, and umps to remove a small amount of water inflow in open excavation	Remove water to ease construction	Suitable for a small area, relatively impermeable soil, and lowering of the ground water table by a limited depth in open excavation
Well system, quite popular	Use well point and/or deep wells to remove a large amount of water inflow in open excavation	Remove water to ease construction increase stability of excavation	Suitable for large area, relatively permeable soil, and lowering of the ground water table by a large depth for excavation

Ground Improvements methods and classification

Consolidation

Method and availability	General description	Benefits	Applications
Fill Preloading, widely used	Apply temporary surcharge on ground surface for a duration and then remove the surcharge for construction	Increase soil strength, reduce settlement	Suitable for saturated inorganic clay and silt, used to reduce settlement for foundation soil
Vacuum preloading, moderately available	Apply vacuum pressure on ground surface and/or through drains into the ground for a desired duration and then remove the pressure for construction	Increase soil strength, reduce settlement	Suitable for saturated inorganic clay and silt, used to reduce settlement for foundation soil

Ground Improvements methods and classification



Ground Improvements methods and classification

Shallow Chemical Stabilization

Method and availability	General description	Benefits	Applications
Chemical stabilisation of sub-grade and base, widely used	Mix lime, cement and/or fly ash with sub-grade and base course in field and then compact the mixture, have chemical reaction with soil particles to form a cementitious matrix	Increase strength and stiffness, reduce ground heave potential	Suitable for unsaturated clay and silt, mainly used for roadway construction with a typical lift thickness of 0.3 m.

Ground Improvements methods and classification

Deep Chemical stabilization

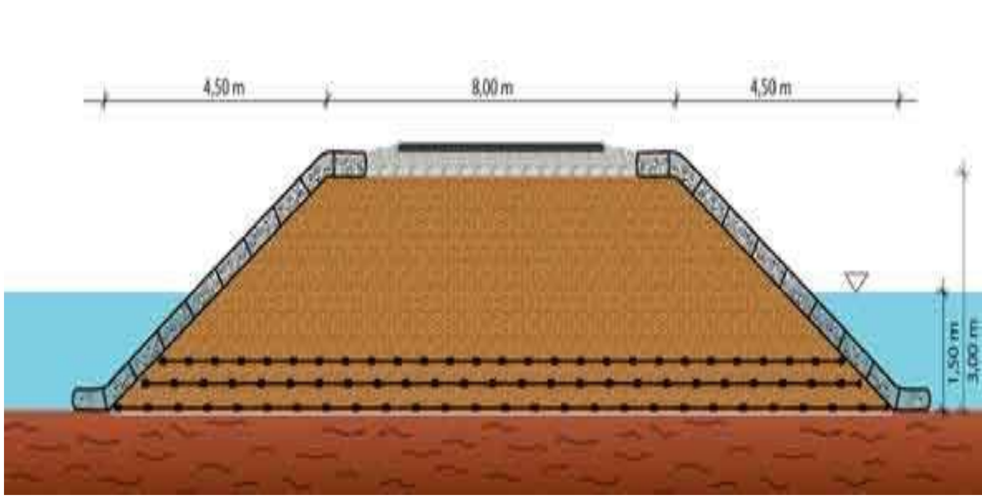
Method and availability	General description	Benefits	Applications
Grouting, quite popular	Inject grout into ground to fill voids, densify soil and have chemical reaction with soil particles to form a hardened mass	Increase strength, reduce permeability, liquefaction, and ground heave potential	Different grout suitable for different geo-material, mainly used for remedying measures or protective projects
Deep mixing, quite popular	Mix cement or lime from surface to depth with geo-material by mechanical blade to have chemical reaction with soil particles after mixed to form a cemetitious matrix	Increase strength, stiffness and stability, reduce permeability, liquefaction and ground heave potential	Suitable for wide range of geo-materials, mainly used for foundation support, earth retaining during excavation and liquefaction mitigation

Ground Improvement Classification

Fill Reinforcement

Method and availability	General description	Benefits	Applications
Geo-synthetic reinforced slopes, widely used	Place geo-synthetic in slope at different elevation during fill placement to provide tensile resistance	Increase stability	Suitable for low plasticity fill, mainly used for slope stability
Geo-synthetic reinforced embank-ments, widely used	Place high strength geo-synthetics at base of embankments to provide tensile resistance	Increase bearing capacity and stability	Suitable for embankments over soft soil, mainly used for enhancing embankment stability

Ground Improvement Classification

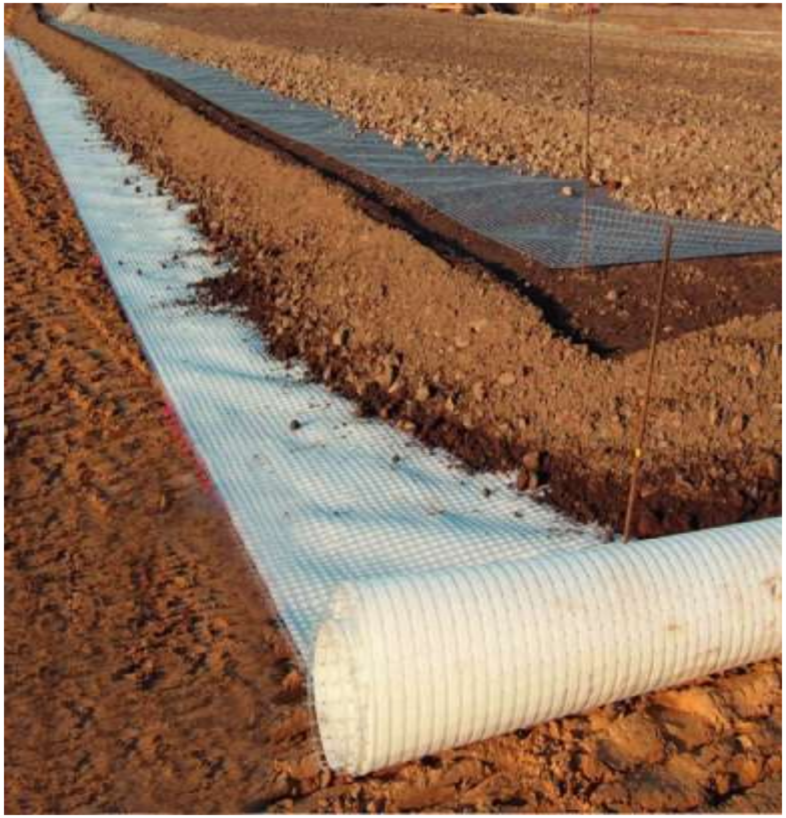


Ground Improvement Classification

Fill Reinforcement....contd

Method and availability	General description	Benefits	Applications
Mechanically stabilised earth wall, widely used	Place geo-synthetic or metallic reinforcement in wall at different elevations during fill placement to provide tensile resistance	Increase stability	Suitable for low plasticity free draining fill
Geo-synthetic reinforced roads, quite popular	Place geo-synthetic reinforcement on to of sub-grade or within base course to provide lateral constraint	Increase bearing capacity & roadway life, reduce deformation & base thickness requirement	Suitable for granular bases over soft sub-grade

Ground Improvement Classification

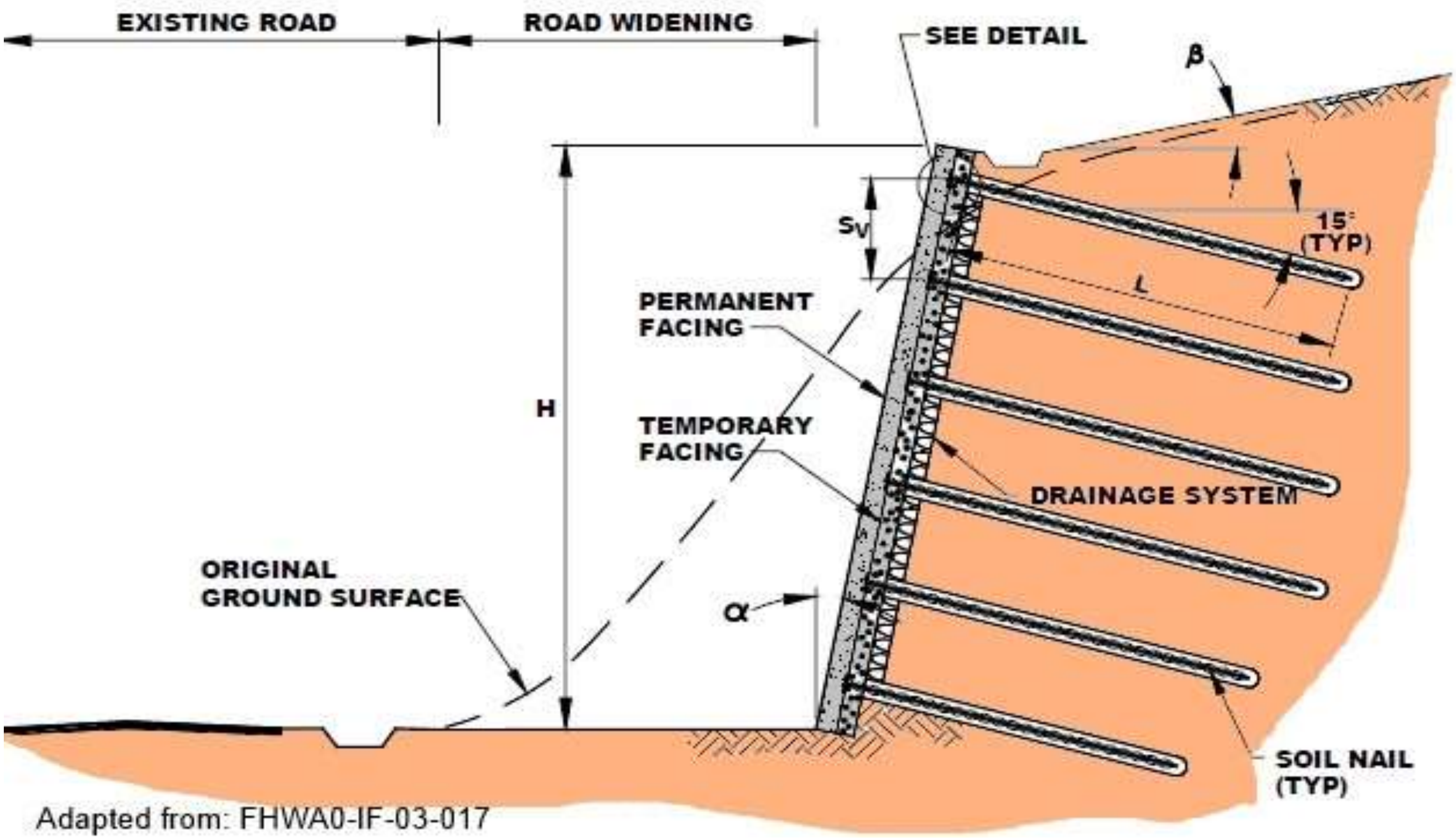


Ground Improvement Classification

In-situ Reinforcement

Method and availability	General description	Benefits	Applications
Soil nails, quite popular	Insert a steel bar with grout throughout the whole nail in existing ground to provide tensile resistance and prevent ground movement	Increase stability	Suitable for low plasticity stiff to hard clay, dense granular soil and rock, mainly used for temporary and permanent slopes and walls during excavation
Micro-piles, quite popular	Insert a steel reinforcing bar in a bored hole, grout in place to form a small diameter pile(<0.3m) and provide vertical and lateral load capacities	Increase stability, protect existing structures during ground movement	Suitable for variety of geo-materials, used for slopes, walls and underpinning of existing foundations

Ground Improvement Classification



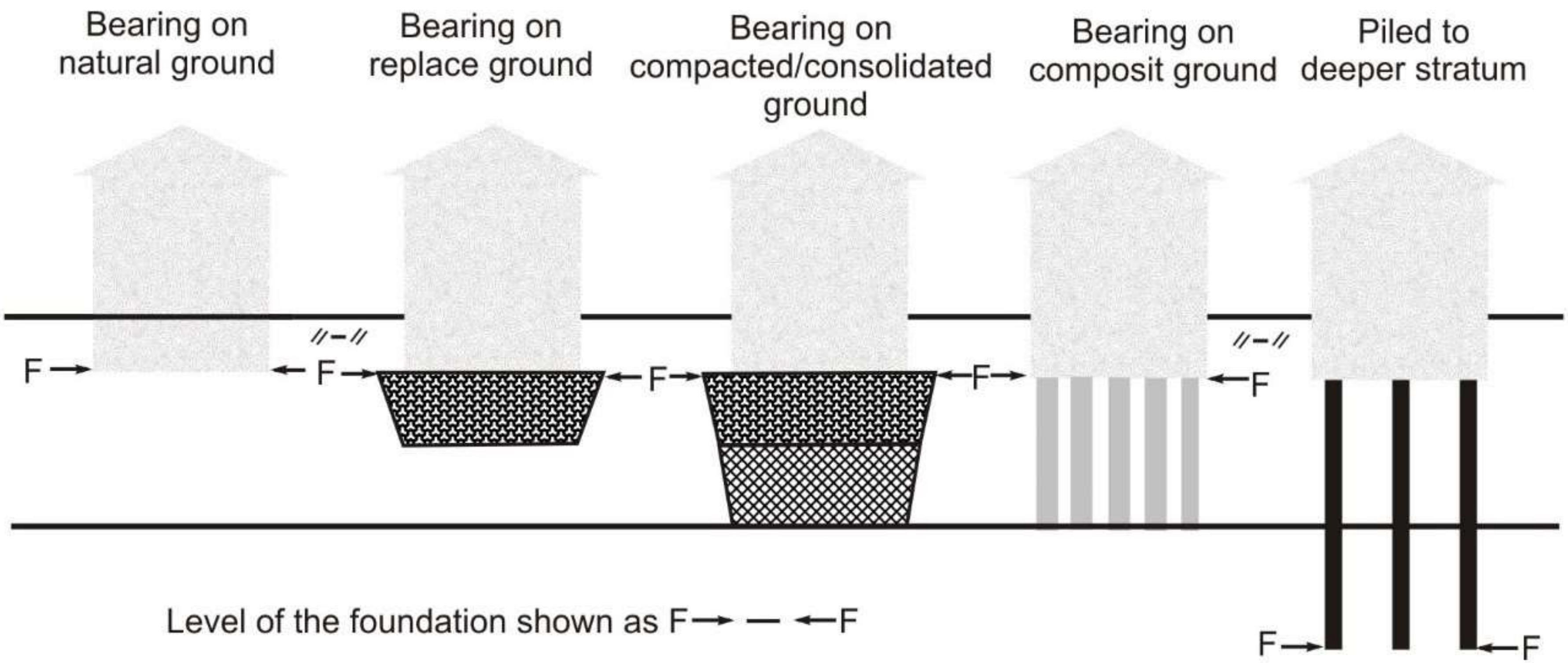
Adapted from: FHWA0-IF-03-017

Ground Improvement Classification

Thermal and biological treatment

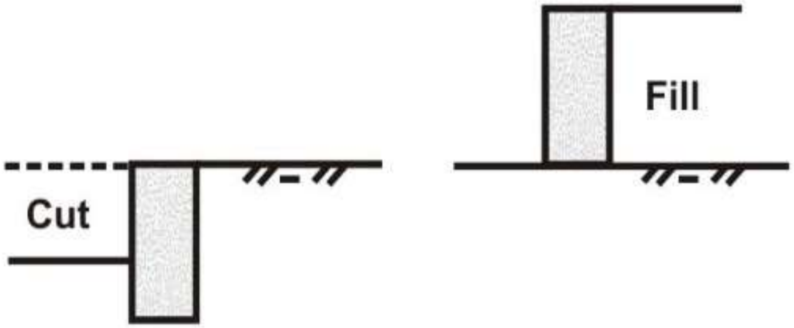
Method and availability	General description	Benefits	Applications
Ground Freezing, occasional use	Remove heat from ground to reduce soil temperature below freezing point and turn geo-material into solid	Increase strength, reduce water flow and ground movement	Suitable for saturated clay and sand, used for temporary protection during excavation
Biological treatment, rare use	Utilise vegetation and roots to increase shear strength of soil or change soil properties by bio-mediated geochemical process	Increase strength and stiffness , reduce erodibility and liquefaction potential	Suitable for cohesive and cohesionless geo-materials, requires more research and field trail before it is adopted in practice

Ground Improvement: Selection of Method



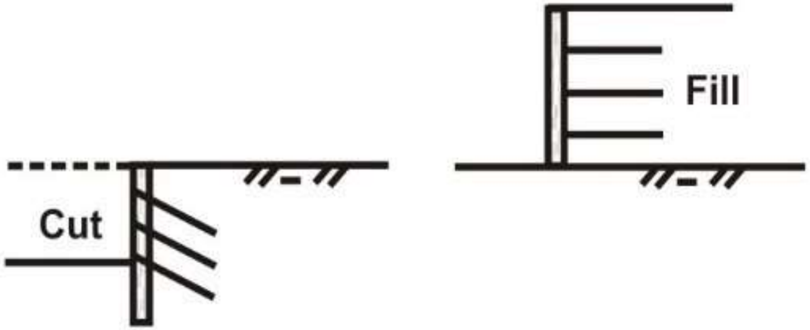
Ground Improvement: Selection of Method

(a) Unreinforced cut and fill slops



(b) Unreinforced cut and fill earth walls

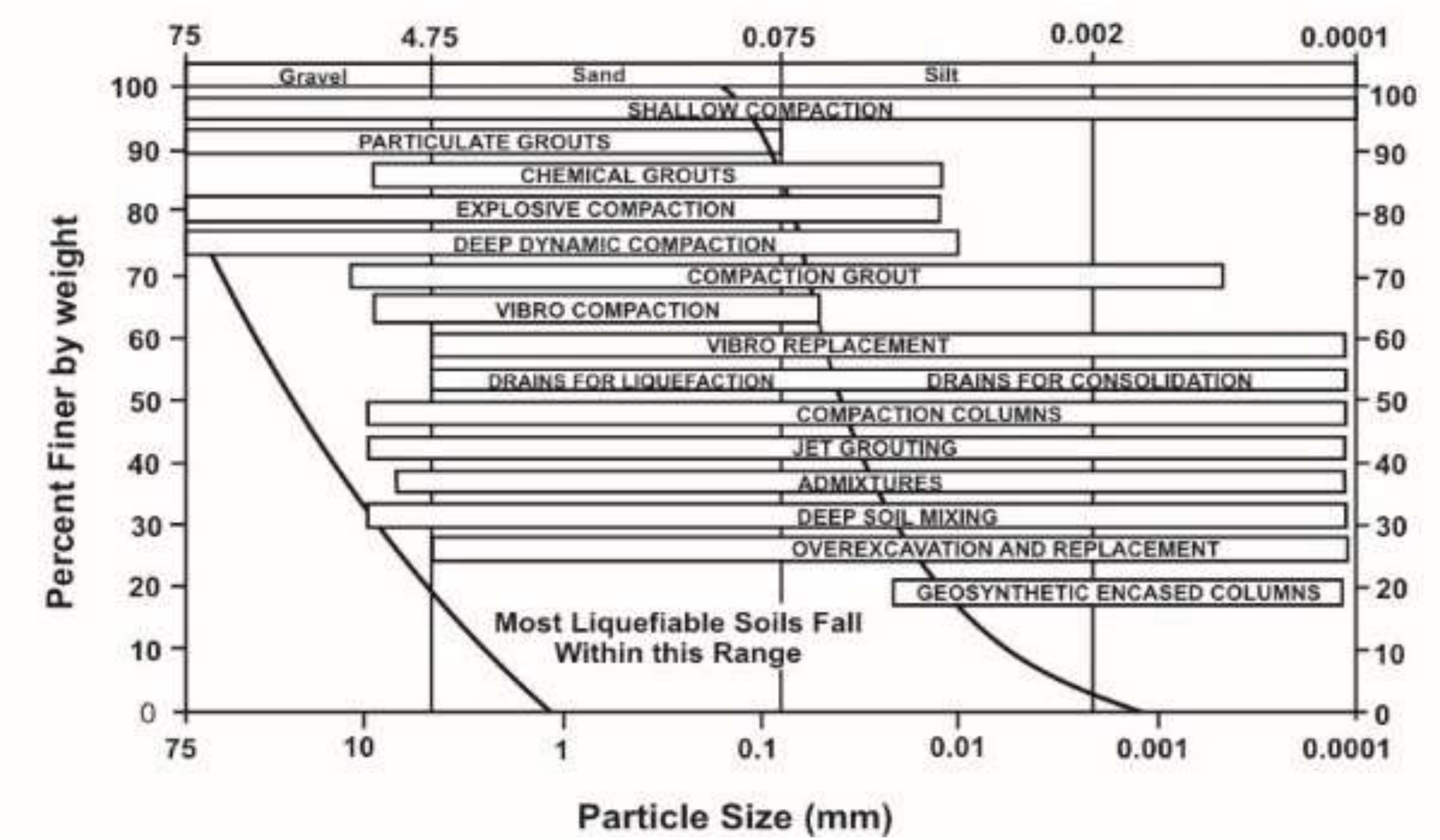
(c) Reinforced cut and fill slops



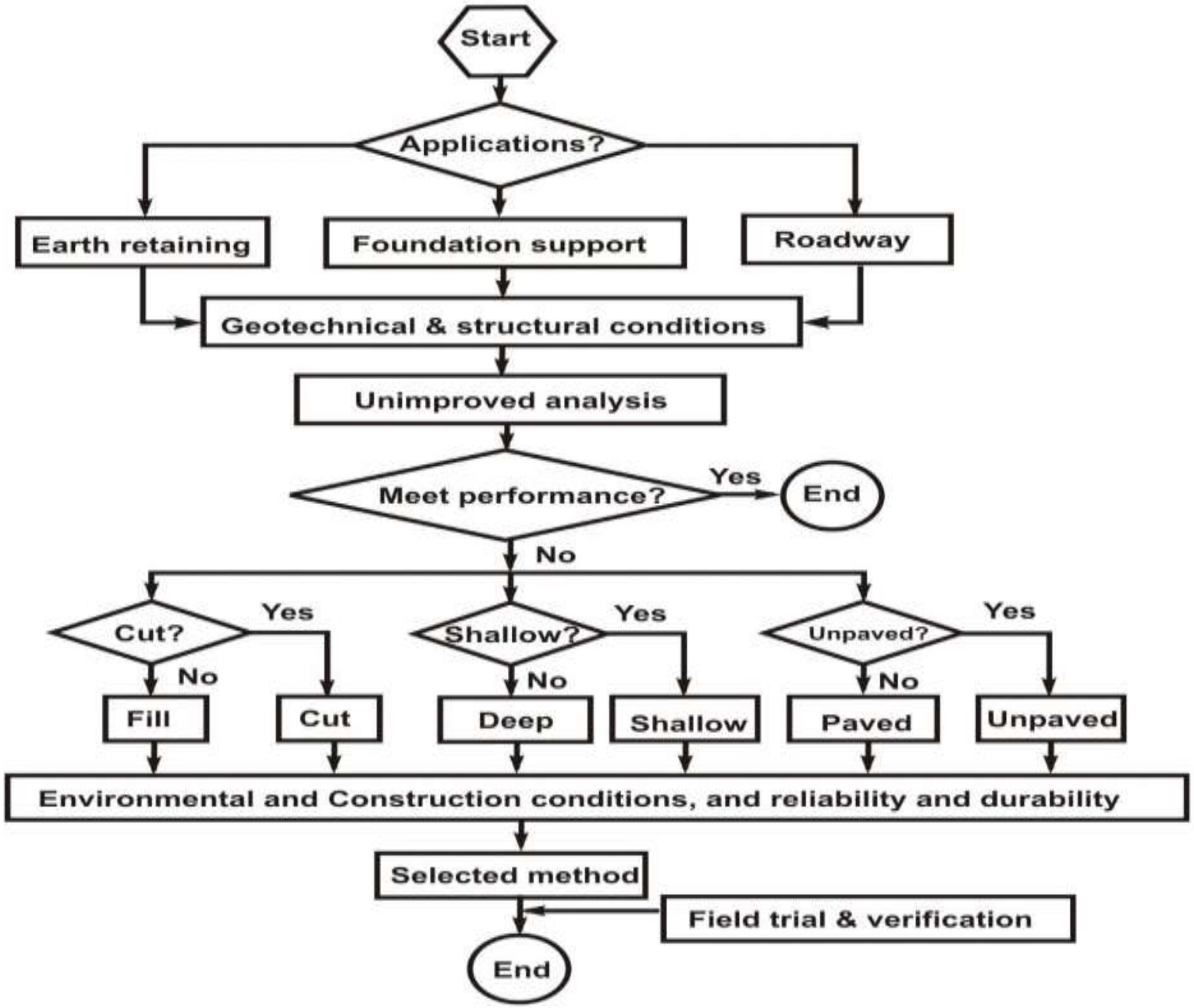
(d) Reinforced cut and fill earth walls

Ground Improvement: Selection of Method

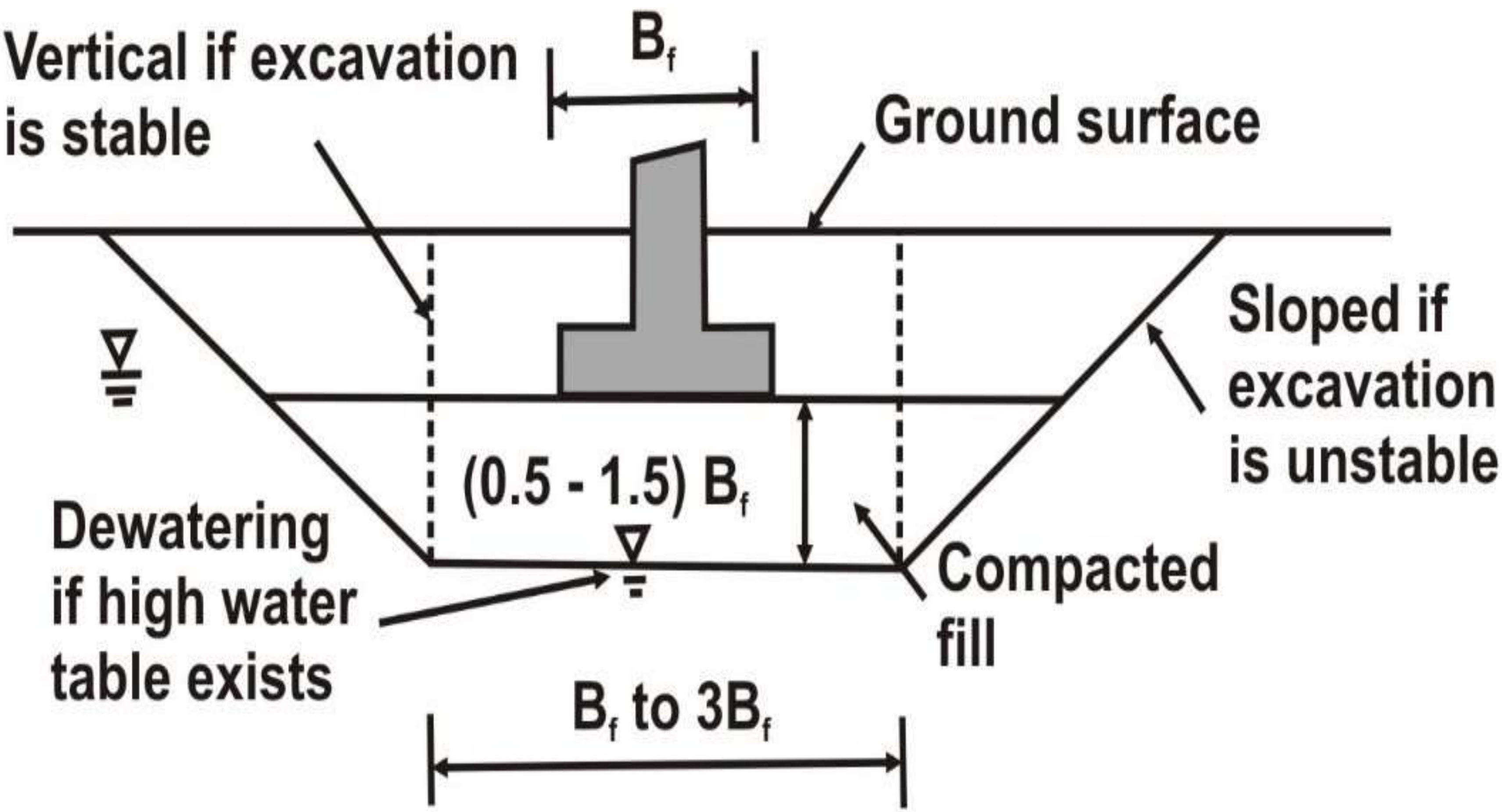
Factors for Selection of Ground Improvement Methods:
Structural, Geotechnical, Environmental, construction constraints and reliability and durability



Ground Improvement: Selection of Method



Excavation and Replacement



Excavation and replacement
Application

Improving shallow problematic geo-materials. It includes uncontrolled fill, loose sand and silt, soft soil, expansive soil liquefiable soil and frozen soil. Excessive deformation and/or potential bearing failure occurs due to low strength during service. In the following event it is frequently used:

- ❑ **The area of over excavation is limited**
- ❑ **The depth of excavation is less than 3m**
- ❑ **No or limited temporary shoring and dewatering are required**
- ❑ **No existing structure is close to the over excavation area**
- ❑ **Removed soil can be easily disposed or reused**
- ❑ **Fill material is readily available**

Excavation and replacement

The method can be used for:

- **Increase bearing capacity**
- **Reduce settlement**
- **Eliminate expansion/shrinkage of expansive soil**
- **Eliminate the freeze-thaw of frozen soil**

Commonly used to improve geo-materials under continuous and isolated footings. It is also used for highways and railways construction when problematic geo-materials are encountered within limited areas and depth

Excavation and replacement

Advantages:

- **Often cost effective when area and depth are limited**

- **Fill material is readily available**

- **Simple, reliable and well established**

- **Does not required specialty contractors and special equipment except excavators and rollers**

EXCAVATION AND REPLACEMENT

Disadvantages

- **Method is unsuitable when deep excavation is required**
- **Method is unsuitable when high ground water table**
- **Method is unsuitable in presence of onsite or nearby existing structures and utility lines**
- **Method is unsuitable when limited truck access to the site**
- **Method is unsuitable when the distance is long for hauling fill material and disposing of excavated soil**
- **Method is unsuitable when time is limited**

EXCAVATION AND REPLACEMENT

Principle

- Partly or fully replacing problematic soil by good soil
- Complete replacement is preferred
- Partial replacement is acceptable and more economical as long as performance of the structure satisfactory on partially replaced zone
- For expansive soil, and frozen soil depth of excavation should be greater than the active depth of problematic soil
- For uncontrolled fill, loose sand and silt, and soft soil, the depth of excavation should be greater than or equal to the width of the foundation on replaced ground to meet bearing capacity and settlement requirement

EXCAVATION AND REPLACEMENT

Design Consideration

In addition to the bearing capacity and settlement other requirements namely, swelling, liquefaction etc should be considered while designing the replaced zone. The parameters to be designed:

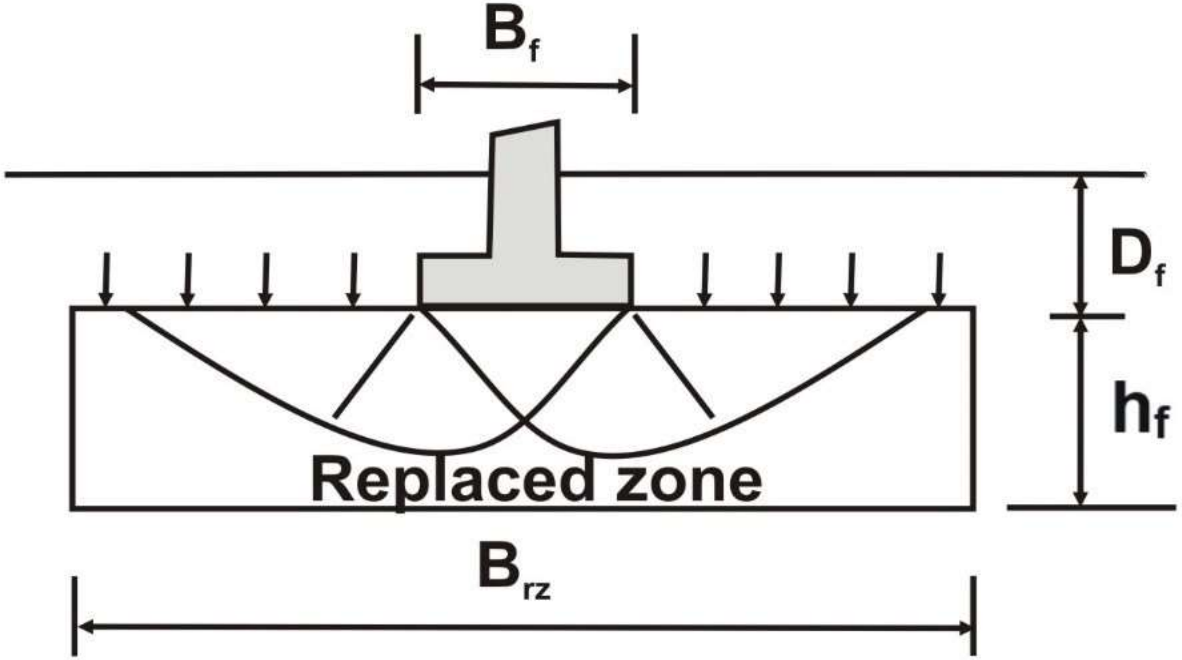
- **Depth of replaced zone**
- **Length and width of replaced zone**
- **Fill quality including strength and modulus of fill**

Also in addition to the above one should examine the all possible modes of failure

EXCAVATION AND REPLACEMENT

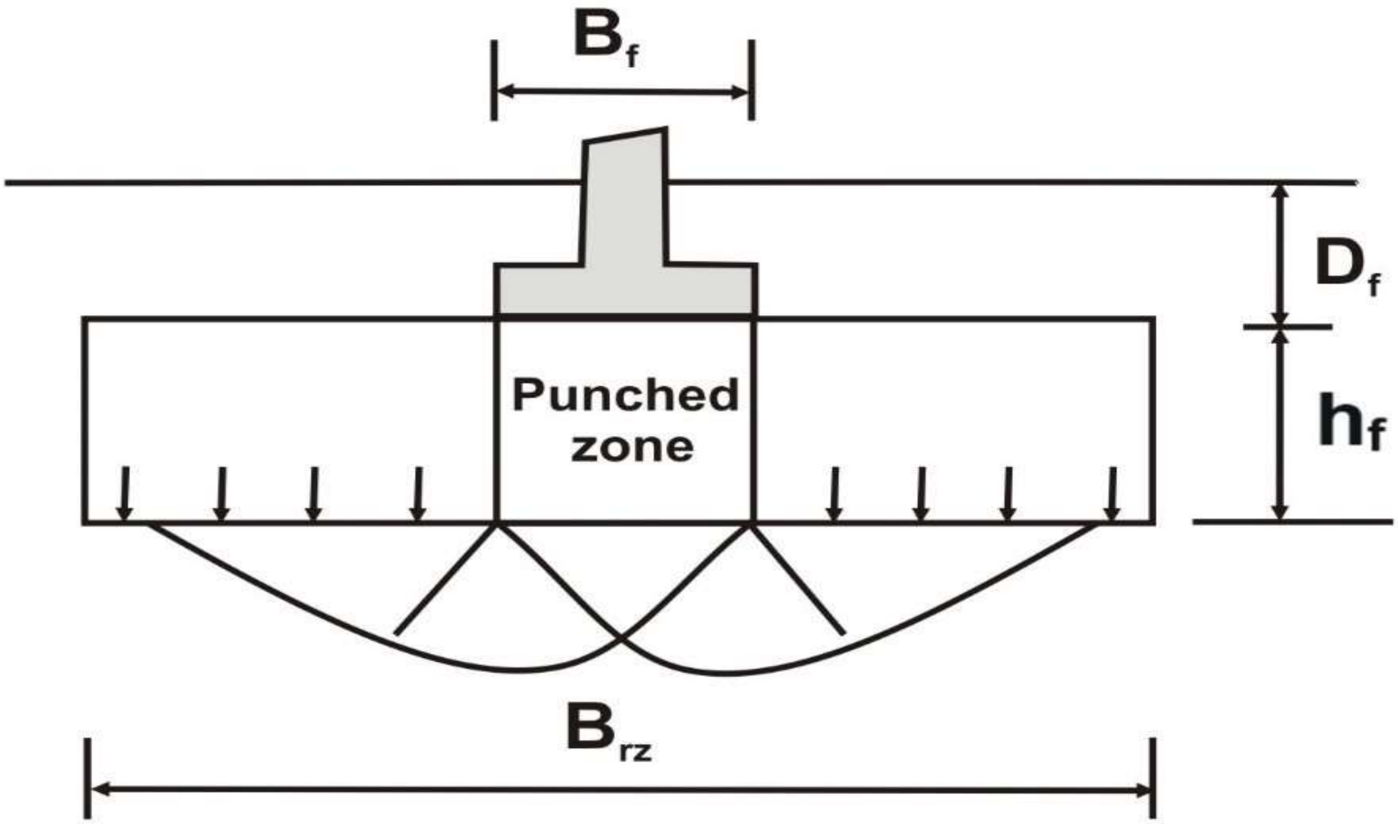
Failure modes:

- General failure within the replaced zone



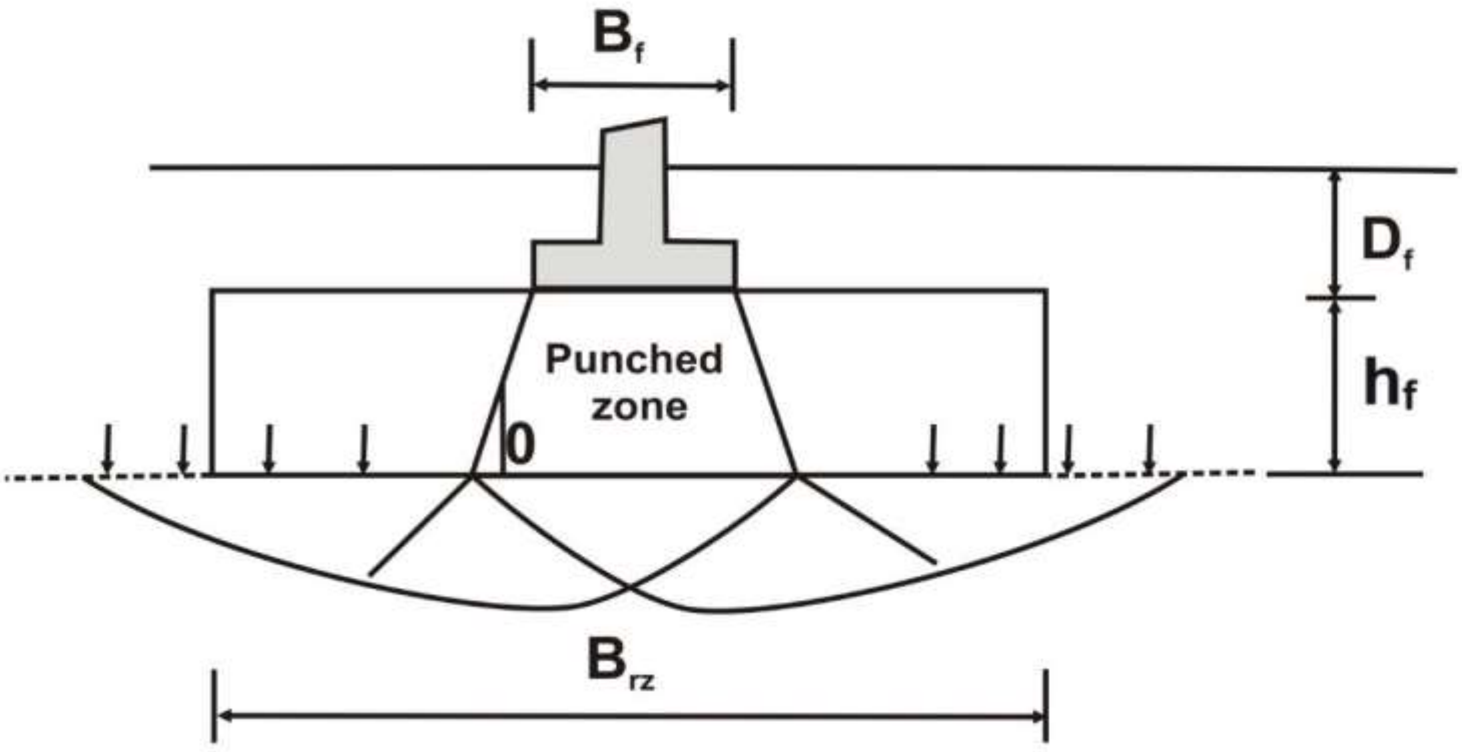
EXCAVATION AND REPLACEMENT

- **Punching failure within the replaced zone**



EXCAVATION AND REPLACEMENT

- The distributed failure through a replaced zone



Excavation and replacement

- **Punching failure of replaced zone into the underlying weak soil**