



KALYANI CHARITABLE TRUST'S
LATE G. N. SAPKAL COLLEGE OF ENGINEERING

Kalyani Hills, Anjaneri-Vadholi, Timbakeswar Road, Dist: Nashik - 422 212 (India)
Tel.: +91 - 2594 - 220168/71, Fax: +91 - 2594 - 220174
Website: www.sapkalknowledgehub.org E-mail: gas_engineering@sapkalknowledgehub.com



Ref No. KCT/ LGNSCOE/Civil/Notice/2024-26/

Date-10/01/2025

Civil Engineering Department
NOTICE

All the SE. Civil. Students are here by informed that submit any one project-topic along with guide name for project based learning(201017) up to 15/01/2025. Group of students should be minimum 4. Presentation will be held on 1st week of march 2025.


Prof. N. R. Nimse
Co-coordinator

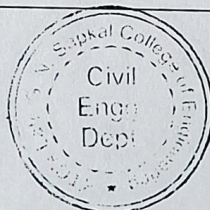

Prof. (Dr.) K. A. Safunke
HOD Civil Engg



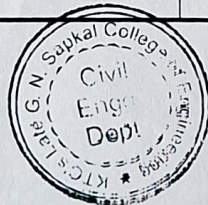
ACAD-DI-01	Project Based Learning Groups and subject of each group	Academic Year: 2024-25
Rev.: 00		Semester: II
SE Civil		

Department of Civil Engineering

Group No	Roll No.	Name of the Student	Email Id	Mob no	Name of Project	Name of Guide
1	1	Andhale Akash Dattu			Sustainable Construction Materials: Developing Eco-friendly Alternatives	Prof. K. A. Salunke
	2	Avhad Akshay Prakash	Akshayavhad2111998@gmail.com	9657575310		
	3	Bagul Krishna Rakesh				
	4	Pagar Yash Bajirao	Yashpagar41@gmail.com	9637336608		
2	5	Singh Shivam Santosh			Smart Infrastructure: Integrating IOT in Civil Engineering Projects	Prof. S. U. Pagar
	6	Navale Vaibhav Santosh				
	7	Aher rushikesh Vilas	aherrushikesh95@gmail.com	9022372959		
	8	Ahire Dipika Parashram				
3	9	Ahire Tejal Sunil	tejuahire296@gmail.com	9309272649	Soil Classification and Testing	Prof. S.H. Tanpure
	10	Bachhav Pranav Rajendra	pranavbachhav2004@gmail.com	9356295214		
	11	Bahiram Dhanshree Kaluram				
	12	Bangar Sudarshan Dyaneshwar	bangarsudarshan620@gmail.com	9373606251		
4	13	Bhamare Bhagyashree Jijabao	bhagybhamare29@gmail.com	8983097056	Slope Stability and Ground Improvement Techniques	Prof. K.M. Deore
	14	Bhamare Gitanjali Jijabao	gitraj.suryawanshi197@gmail.com	7507395347		
	15	Bhasre Harshal Krishna				
	16	Bhojane Nandini Dattatray				
5	17	Chavan Pooja Bhausaheb	pc99227186@gmail.com	8080643673	Innovative Water Management Systems for Urban Areas	Prof. N. R. Nimse
	18	Chavan Tejaswini Arun	chanvantejaswini07@gmail.com	8007407537		
	19	Deore Dipali Nitin	dipalideore9898@gmail.com	8799978755		
	20	Deore Nilesh Rajendra	deorenilesh997@gmail.com	8766405187		
	21	Deore Pranav Sandip	pranavdeore1100@gmail.com	7387883809		



6	22	Dhivar Rohit Bhautal	dhivarrohit251@gmail.com	9322562167	Designing Green Roofs for Sustainable Urban Development	Prof. D. D. Shelke
	23	Gaikwad Gaurav Raosaheb	gauravgaikwad9422@gmail.com	9422563731		
	24	Gaikwad Sanket Devidas	gaikwadsanket74@gmail.com	8446318448		
7	25	Hembade Kiran Samadhan	hembade7177@gmail.com	8432526643	Rain water harvesting Technology	Prof. T. R. Shinde
	26	Ingle Tushar Ravindra	tushh1963@gmail.com	9673089669		
	27	Jagtap Ritesh Santosh	riteshjagtap521@gmail.com	8390551818		
	28	Kalbhile Divya Madhukar	divvakalbhile295@gmail.com	8329627150		
8	29	Kapure Karan Ravindra	karankapure879@gmail.com	8446470249	Green Building Technology	Prof. N. R. Nimse
	30	Kasav Gokul Dinkar	gokulkasav10@gmail.com	7498484779		
	31	Katkade Manas Jagjeet	23manask@gmail.com	7507772918		
	32	Kedar Karan Pramod	kedarkaran01@gmail.com	9503000543		
9	33	Khairnar Adarsh Hemant	adarshkharinaar503@gmail.com	9699358700	Construction site safety	Prof. N. R. Nimse
	34	Khare Vishal Jitesh	vishalkhare09@gmail.com	7219455178		
	35	Khatale Pawan Sharad	khatalepavan7@gmail.com	8767557427		
	36	Khonde Ajay Rangnath	ajaykhonde13@gmail.com	7066438058		
10	37	Kuwar Tejas Satish	tejaskuwar2002@gmail.com	9146263345	Smart Waste Management Solutions for Urban Civil Systems	Prof. A. U. Mankar
	38	Mahale Sachin Suresh		7218503811		
	39	Mali Ashwin Ganpat		8010729932		
	40	Mali Prasad Somnath	maliprasad1209@gmail.com	7447463525		
11	41	More Mukund Dnyaneshwar	mukundmore1804@gmail.com	9588460075	Deterioration and repairs in concrete	Prof. D. D. Shelke
	42	Nevkar Tejas Harish	thnevk@gmail.com	9850412004		
	43	Pagar Darshan Bhausaheb	darshanpagar68@gmail.com	9623347429		
	44	Pagar Dipti Bhausaheb	pagardipty7171@gmail.com	7219367568		
12	45	Pardeshi Jayraj Rajesh	jayrajpardeshi5@gmail.com	9975991277	Remote sensing and GIS technology	Prof. T. R. Shinde
	46	Patil Tejas Jivan	tejaspatil0313@gmail.com	9527948882		
	47	Pavde Chetan Suresh				
	48	Pawar Ganesh Gangaram				

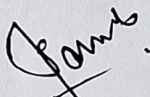


13	49	Pawar Prasad Nitin	prasadpawar7704@gmail.com	8999945655	Town planning and legal aspects:	Prof. R.R. Kuwar
	50	Rajput pranav Sangramsingh				
	51	Sapkal Sahil Kishor	sahilsapkal0@gmail.com	9527550793		
	52	Shaikh Anwar Sardar				
14	53	Shaikh Parvez Saeed	parvezshaikh26891@gmail.com	8983799518	Roles of geological engg in dams and reservoir	Prof. A. U. Mankar
	54	Shendke Shivam Krishna				
	55	Shinde Abhay Bhaskar	shindeabhay2004@gmail.com	9322642690		
	56	Shinde Yash Barku	yashshinde2328@gmail.com	9373740081		

15	57	Shirsat Utkarsha Narendra			Low-Cost Housing Solutions Using Local Materials for Developing Communities	Prof. T. R. Shinde
	58	Shirsath Gayatri Ravindra	gayatriravindrashirsath5@gmail.com	8180972842		
	59	Singh Anis Virbahadur	anissingh2001@gmail.com	9699896738		
	60	Sonkale Mayur Bhagwan	mayursonkale@gmail.com	8793788628		
16	61	Suryawanshi Anagha Rahul			BIM (Building Information Modeling) in Civil Engineering for Improved Project Management	Prof. K. M. Deore
	62	Suryawanshi Vyanktesh Sanjay				
	63	Toshniwal Siddhant Sandeep	siuddhantoshniwal@gmail.com	8010767668		
	64	Wadhvani Piyush Jitendra	wadhvanipiyush060@gmail.com	8668600334		
17	65	Wagh Rushikesh Bharat	rushikesh081@gmail.com	8010183907	Sustainable Urban Planning : Integrating Renewable Energy Systems	Prof. P. K. Bachhav
	66	Zade rudra Raosaheb	rudrazade63@gmail.com	8530416387		


 Prof. N.R. Nimse
 PBL Co-ordinator




 H.O.D. (H/W)



Kalyani Charitable Trust's

Late G. N. Sapkal College of Engineering

Kalyani Hills, Anjaneri, Trimbakeshwar Road, Nashik – 422 213



Project Based Learning (201017) Project Title:

**Slope Stability and Ground Improvement
Techniques**

Submitted by:

1. Bhamare Bhagyashree Jijabrao
2. Bhamare Gitanjali Jijarao
3. Bhasare Harshal Krishna
4. Bhojane Nandini Dattatray

Department: Civil Engineering

Institution: Kalyani Charitable Trust's Late G. N. Sapkal College of Engineering,

Academic Year: 2024-2025

Submitted To: Prof. Prof. K. M. Deore



Kalyani Charitable Trust's

Late G. N. Sapkal College of Engineering

Kalyani Hills, Anjaneri, Trimbakeshwar Road, Nashik – 422 213



Certificate

This is to certify that the project entitled "Slope Stability and Ground improvement Techniques" is a bonafide work carried out by 1.Bhamre Bhagyashree Jijabrao 2.Bhamre Gitanjali Jijarao 3.Bhasre Harashal Krishna 4.Bhojane Nandini Dattaray, students of S.E. Civil Engineering, Kalyani Charitable Trust's Late G. N. Sapkal College of Engineering, during the academic year 2024-2025, in partial fulfillment for the submission of Project Based Learning (201017).

The work has been carried out under my guidance and supervision and is found to be satisfactory.

Prof. K. M. Deore

(Project guide)

Prof. (Dr.) K. A. Salunke

HOD (Civil Engg. Dept)

Prof. (Dr.) S. B. Bagal

(Principal)



Acknowledgement

We would like to express our sincere gratitude to all those who supported and guided us throughout the successful completion of this project on **"Slope stability and ground improvement techniques."**

First and foremost, we are deeply thankful to our project guide, **Prof. K. M. Deore**, for their valuable insights, constant encouragement, and constructive feedback during every stage of this project. Their guidance was instrumental in shaping our understanding of the topic.

We also extend our heartfelt thanks to the faculty and staff of the **Department of Civil Engineering, Kalyani Charitable Trust's Late G. N. Sapkal College of Engineering**, and our HOD, **Prof. (Dr.)**

K. A. Salunke for providing the resources and environment necessary to carry out this research.

Our appreciation goes to all industry professionals, academicians, and fellow students who participated in surveys and interviews, contributing to the practical relevance of our work.

Lastly, we would like to thank our families and friends for their patience, motivation, and unwavering support throughout this academic endeavor.

Synopsis

Slope stability is a fundamental concern in geotechnical engineering, particularly in regions with varied topography and climatic conditions. Unstable slopes can lead to landslides, erosion, and structural failures, posing significant risks to infrastructure and human safety. To mitigate these risks, various ground improvement and slope stabilisation techniques are employed to enhance soil strength, reduce permeability, and increase overall stability.

Ground Improvement Techniques

1. **Compaction:** This method involves mechanically densifying soil to increase its strength and reduce settlement. Techniques such as dynamic compaction are particularly effective for granular soils.
2. **Soil Stabilisation:** Adding stabilising agents like lime, cement, or fly ash to soil improves its load-bearing capacity and reduces permeability. This technique is especially beneficial for cohesive soils.
3. **Grouting:** Injecting cementitious or chemical grouts into soil or rock masses fills voids and binds particles, enhancing strength and reducing permeability. Grouting is effective in stabilising loose or fractured soils.
4. **Geosynthetics:** Materials like geotextiles, geogrids, and geomembranes are used to reinforce soils, improve drainage, and control erosion. They provide additional support, especially in areas with poor load-bearing capacity.

Slope Stabilization Techniques

1. **Grading and Reshaping:** Adjusting the slope angle and geometry through cutting and filling operations reduces driving forces acting on the slope, achieving a more stable configuration.
2. **Drainage Control:** Installing proper drainage systems, such as French drains and culverts, manages surface and subsurface water flow, reducing pore water pressure and increasing stability.
3. **Vegetation and Erosion Control:** Planting vegetation helps stabilise slopes by reinforcing the soil and reducing surface erosion. Techniques like hydroseeding and using erosion control mats provide temporary protection until vegetation becomes established. **Soil Nailing:** This technique involves inserting steel rods into the slope and grouting them into the soil. The rods are then tensioned to reinforce the soil, preventing movement and providing support.
4. **Shotcrete:** Shotcrete is a form of sprayed concrete applied to slope surfaces to reinforce and stabilise the soil. It enhances tensile and shear strength, reducing the chances of slope failure.
5. **Grouting:** Injecting grout into rock fissures and cracks replaces air or water, improving the overall stability of rock masses. This technique is crucial in reinforcing rock structures, particularly in challenging terrains.

Modern Innovations in Slope Stabilisation

- **Bio-mediated Soil Improvement:** Techniques like microbial-induced calcite precipitation (MICP) and plant-root reinforcement enhance soil cohesion and reduce erosion, offering sustainable solutions.
- **Geocells:** Cellular confinement systems provide lateral support to the soil, increasing shear strength and reducing deformation, making them suitable for soft or loose soils.

CONTENTS

Sr. No.	Particulars	Page No.
1.	Introduction	3
2.	Different Slope Stabilization Techniques adopted by Forest Department	6
3.	(A) Traditional methods	7
	(I) Plantation of Slopes	8
	(II) Minor Engineering Works (DRSM & Crates)	11
	(B) New Techniques being adopted	15
	(I) Vetiver Grass Technology	15
	(II) Coir Geotextile	18
	• Geotextile Mat	22
	• Coir Fiber Logs	25
	• Economics of Geo-textile matting and Coir log	27
	(III) Geocell	28
4.	Ground Improvement Techniques UNIT-1	
	1.1 Need for Ground Improvement:	32
	1.2 Objective of Ground Improvement Techniques	32
	1.3 Factors affecting choice of improvement methods	33
	1.4 Classification of Ground Modification Techniques	33
	1.5 Suitability and Feasibility	34
	1.6 Improvement of cohesive soils:	35
	1.7 Improvement of cohesion-less soils:	35
5.	SURFACE/SHALLOW COMPACTION	
	• Sheep foot rollers:	36
	• Pneumatic Tired Rollers:	37
	• Grid Rollers:	38
	• Impact rollers:	39
	• Deep Compaction	39
6.	• Blasting	38
	• Compaction Piles	39
	• Vibroflotation	40
	• Backfill material	42
	• Dynamic Compaction or Dynamic consolidation	42

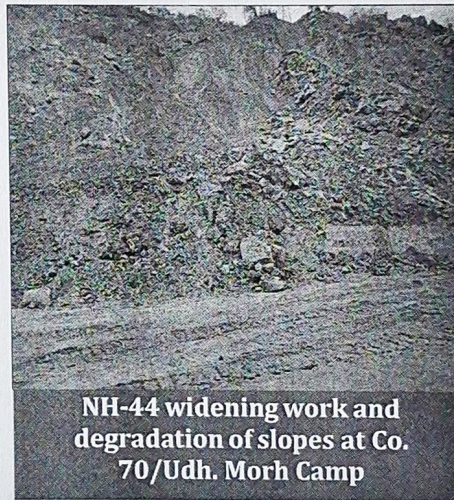
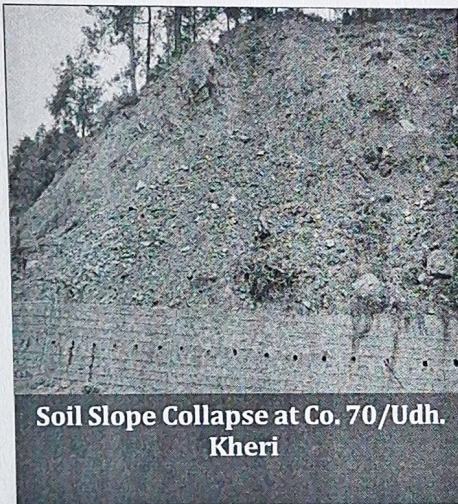
7.	Hydraulic Stabilization UNIT – II - Sumps and sump pumping: 44 - Well point systems: 45 - Advantages of Well point system 45 - Limitations of Well Point systems: 46 - Two Stage Well Point Systems 47 - Dewatering By Electro Osmosis 48 - Vacuum Dewatering 49 - Preloading 49 - Principle 50 - Preloading Methods: 50	
8.	- DRAINS: 50 - Open Drains: 50 - Closed Drains: 50 - Horizontal Drains: 51 - Foundation Drains: 51 - Blanket Drains: 51 - Interceptor Drain: 51 - Vertical Drains: 52 - Types of Vertical Drains: 52 - Sand drains: 52 - DESIGN OF VERTICAL DRAINS: 53	
9.	Physical and Chemical Stabilization UNIT-III - Cement Stabilization 55 - Types of soil cement 55 - Factors affecting cement stabilization 56	
10.	Construction Methods - Mix In Place Methods 57 - Plant Mix Method 57	
11.	Lime Stabilization - Engineering properties of Lime stabilization: 59 - Mechanism/Applications of soil lime: 59 - Uses of Soil Lime: 60 - Factors affecting the properties of soil lime: 60	
12.	Bitumen Stabilization - Types of Soil-Bitumen: 61 - Engineering Properties of Soil Bitumen: 62 - Factors affecting the properties of soil bitumen: 62 - Construction of Bituminous Stabilized layer: 62	
13.	Calcium Chloride Stabilization: - Effects of soil Properties: 64 - Fly Ash Stabilization: 64 - Properties of Fly ash 64 - Engineering Properties 64	

1. INTRODUCTION

The Union Territory of Jammu and Kashmir has a varied topography. The Shivaliks, Pirpanjal and Greater Himalayan ranges of Jammu and Kashmir are highly fragile owing to its geology as they are younger and still growing due to the north-eastern direction of Indo-Australian plate. These ranges are vulnerable/sensitive in nature since they are made up of unconsolidated sediments of gravel and alluvium. They are prone to earthquakes and landslides as they are located at the conversion point of Eurasian and Indo-Australian plates.

Need for Slope Stabilization

- Area becomes fragile due to cutting/blasting of slopes for construction/broadening of highways and road.
- Earth work and excavation of mountainous sites cause loosening of soil.



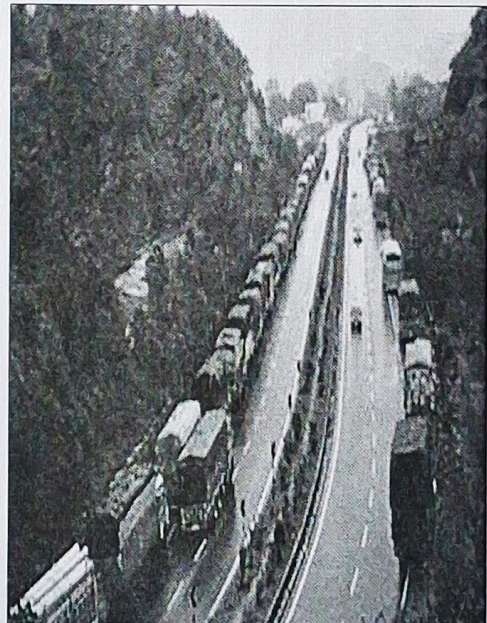
- Weather phenomenon's like Rain and snow increases vulnerability of these areas to landslide & slippage which cause blockage of roads and highways.
- Slope failure requires protection from erosion induced by heavy rain.
- It causes obstruction in vehicular movement which leads to economic loss to the traders of Union Territory of J&K.
- National Highway - 44 is back bone for trade and strategic movement. Its smooth functioning depends on the stable slopes.



Debris Flow on fragile slopes at Co. 70/Udh. Dawal



Rock Slope Collapse at Co. 70/Udh. Kheri

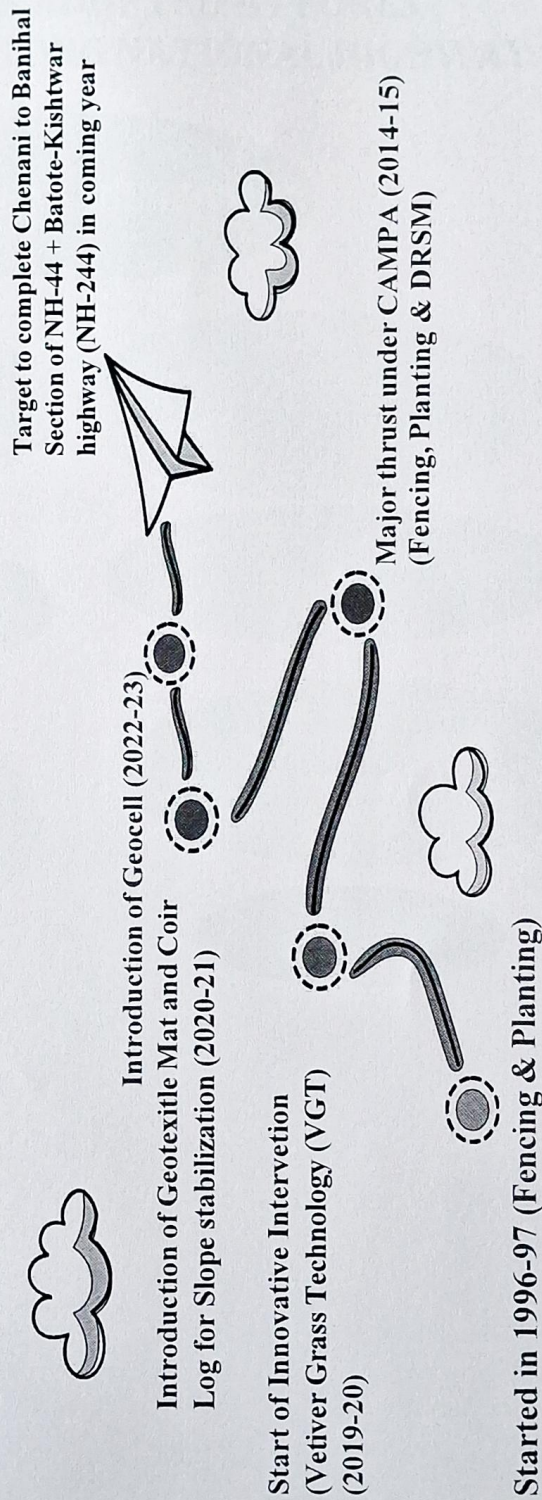


Blockage of NH-44 due to landslide at Co. 70/Udh. Morh Camp

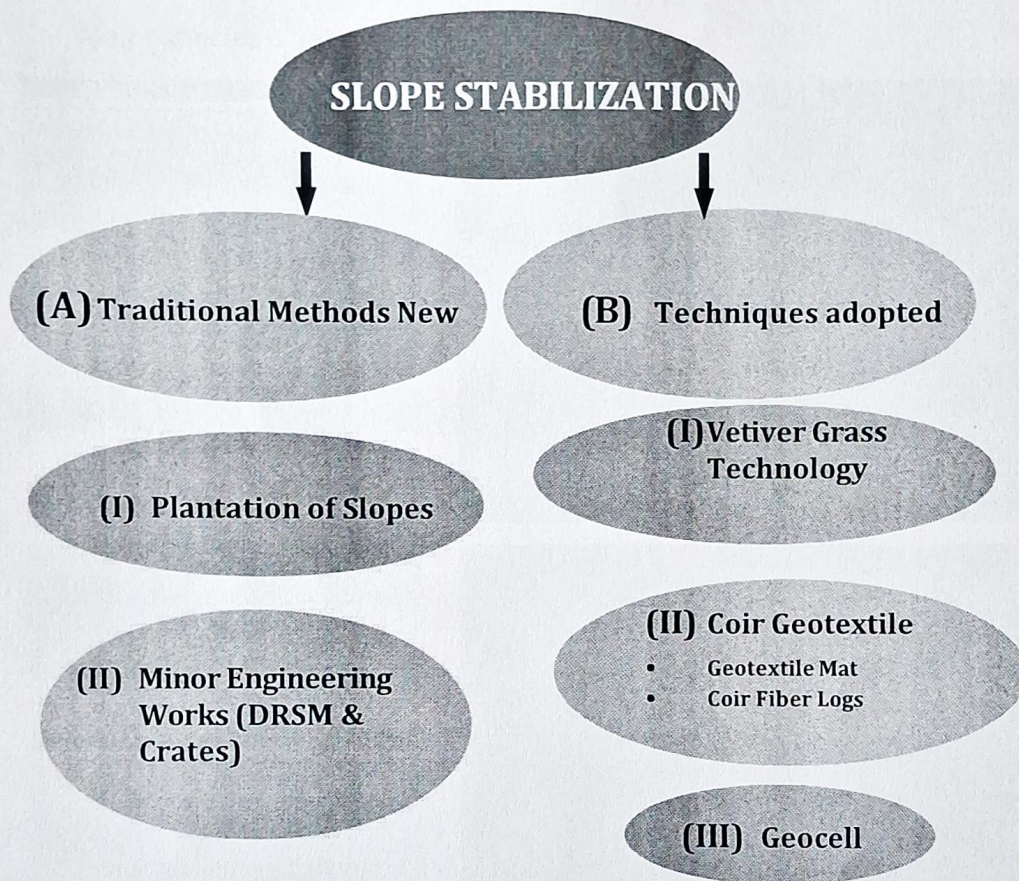
Jammu and Kashmir has a total forest area of 20,194 sq. km accounting for 47.80 % of total geographical area. The Jammu and Kashmir Forest Department supplement the efforts of NHAI in maintaining the good health of slopes and providing them stability through biological measures in combination with minor engineering works.

Chronology

Efforts of Forest Department in slope stabilization along National Highway through window of time...



2. DIFFERENT SLOPE STABILIZATION TECHNIQUES ADOPTED BY FOREST DEPARTMENT ALONG NATIONAL HIGHWAY



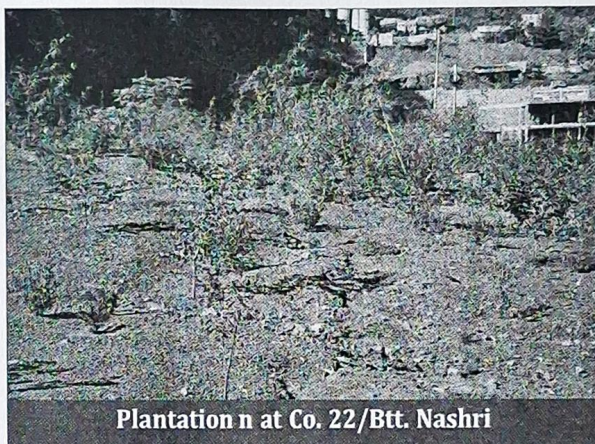
TRADITIONAL METHODS

The traditional method emphasizes on plantation of local species on the slopes. Plantation ensures binding of roots with soil and stabilizes them with the passage of time.

Major species planted on the slopes are: -

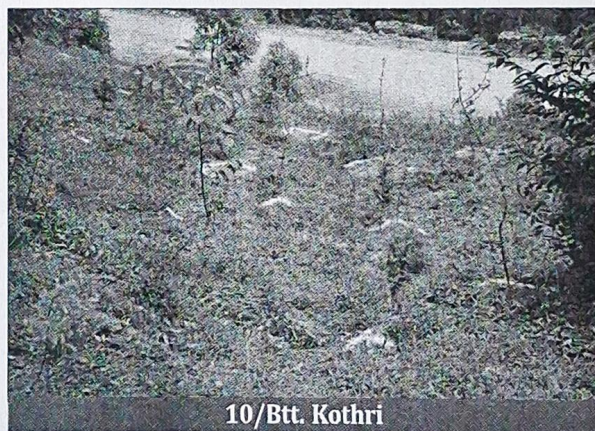
TREES

1. *Ulmus wallichiana*
2. *Quercus spp.*
3. *Grevillia robusta*
4. *Punica granatum*
5. *Callistemon spp.*
6. *Salix spp.*
7. *Sapium sebiferum*
8. *Melia azedarach*



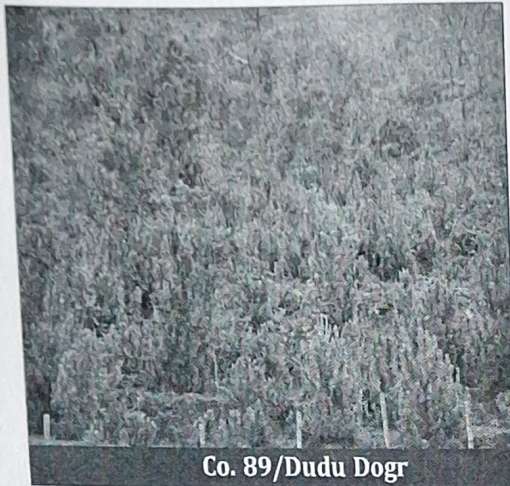
SHRUBS

1. *Nerium spp.*
2. *Dodonaea viscosa*
3. *Bougainvillea spp.*

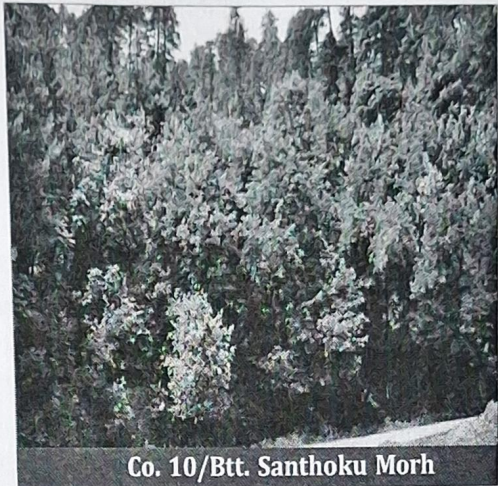


HERBS

1. *Agave spp.*
2. *Vetiver zizanioides*
3. *Dendrocalamus strictus*



Co. 89/Dudu Dogr



Co. 10/Btt. Santhoku Morh

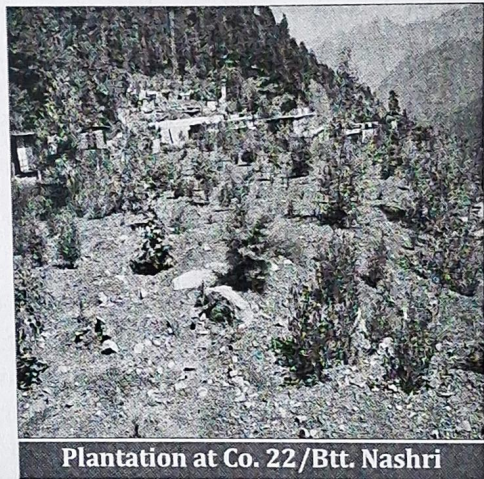
(I) The plantation is done by two methods

- (a) Conventional method
- (b) Innovative method

The Conventional method involves

Transplantation, Dibbling / Broadcasting of

seeds whereas the Innovative method involves **Patch sowing, Seed balls** and planting of **Grass slips**.



Plantation at Co. 22/Btt. Nashri

Role of vegetation in Slope Stabilization

Vegetation helps to stabilize slopes in numerous ways. The traditional method is to plant native species because they provide habitat for wildlife besides being adapted to our native soils, local weather and hydrology. Some major roles of vegetation in slope stability are as follows:

Interception

Erosion occurs when rainfall dislodges soil particles and carries them off a slope, forming rills and gullies that can trigger landslides. Raindrops hitting the soil surface also seal the soil particles and makes a crust preventing infiltration and increasing runoff. Trees and shrubs intercept precipitation before falling on the soil surface. Most of this intercepted precipitation evaporates back into the atmosphere and the moisture that drips off the plants causes little soil damage because of less impact.

It is better to plant evergreen trees for slope stabilization because they intercept more moisture than deciduous trees, especially in the rainy season when deciduous plants shed their leaves. Branches and leaves that fall from the plants shield the soil surface from rain drop impact, slow the movement of water across the soil surface, and encourage rainfall to penetrate into the soil.

Dewatering

Soil saturation can trigger erosion and landslides. Plants improve slope stability by absorbing water from the soil. Plants use water, absorbed through their roots to perform basic metabolic processes such as photosynthesis. Plants release this absorbed water to the atmosphere by transpiration through leaves. Transpiration cools the plant and helps transport minerals up the stems. The rate of transpiration varies greatly depending on the plant species, weather and other factors. A single tree can transpire hundreds of gallons on a hot dry day.

Soil reinforcement

Roots physically reinforce soils, resist erosion and increase infiltration of water into the soil. Roots form physical pathways (little tunnels) that help water to infiltrate into the soil. Deep, woody roots lock the soil layers together and lateral roots connect many plants into an interlocking grid. Fine feeder roots form a network through the upper soil layer preventing surface erosion. Ground covers and grasses which have relatively shallow roots and low biomass prevent surface erosion.

Trees possess deeper roots than shrubs and are essential for slope stabilization. Rainfall saturates the upper soils and then seeps laterally, causing slides. Deep tree roots penetrate into the compacted layer and help tie the layers together, preventing slides. Tree roots occurring at the crest and toe of a slope help in preventing wasting in these susceptible areas where larger slides often start. Selective pruning allow the wind to blow through the trees and reduce load on the soil, improving the tree stability.

Improving ecology of the area

Vegetation actively decompacts soil through the expansion of the root systems and the addition of organic matter. Water penetrates more readily in uncompacted soil. Vegetation also encourages soil fauna to thrive. Soil fauna, such as microorganisms, insects and worms condition the soil as well. The cumulative impacts of these organisms result in healthier soil that is more resilient to storm events.

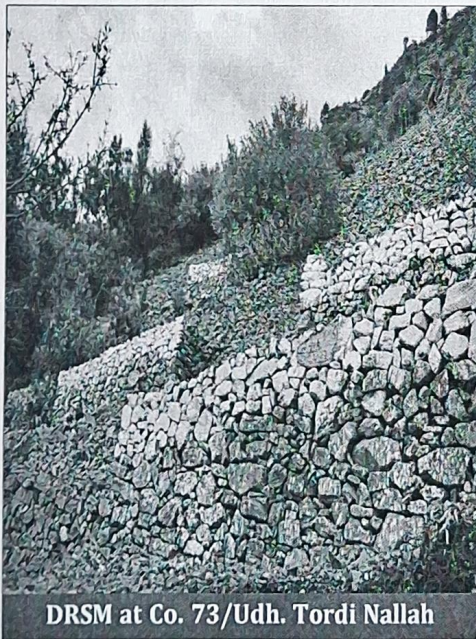
(II) Minor Engineering Works

Following activities have been undertaken:

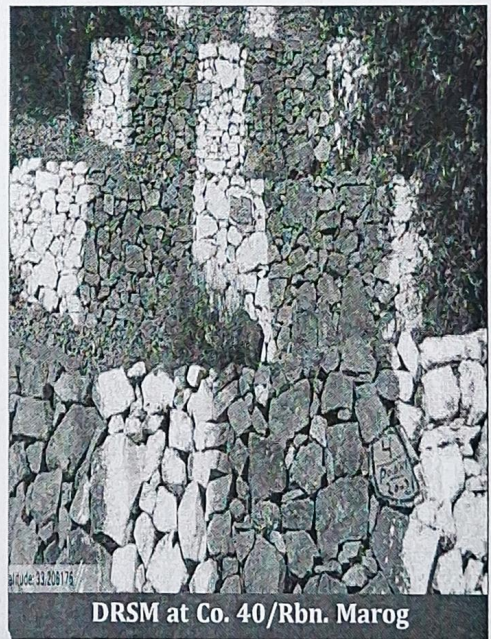
- **DRSM** : Dry Rubble Stone Masonry work is a traditional method of slope stabilization wherein the locally available stones are interlocked to one another for slowing down the movement of water. This prevents the soil erosion and slope degradation. Due to its less cost and ecological compatibility, it is preferred over concrete work.



DRSM at Co. 40/Rbn. Marog

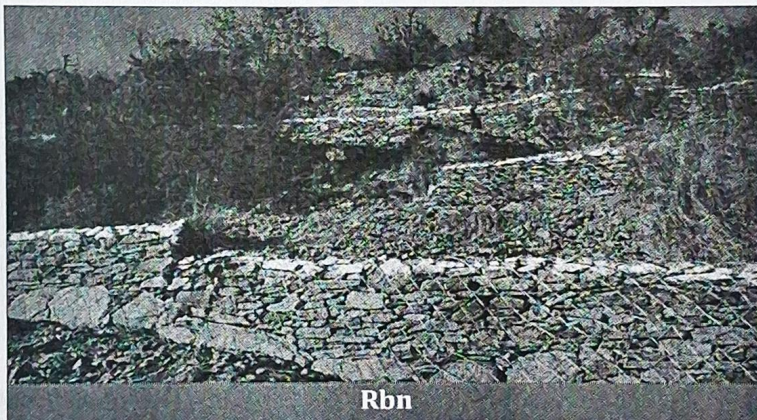
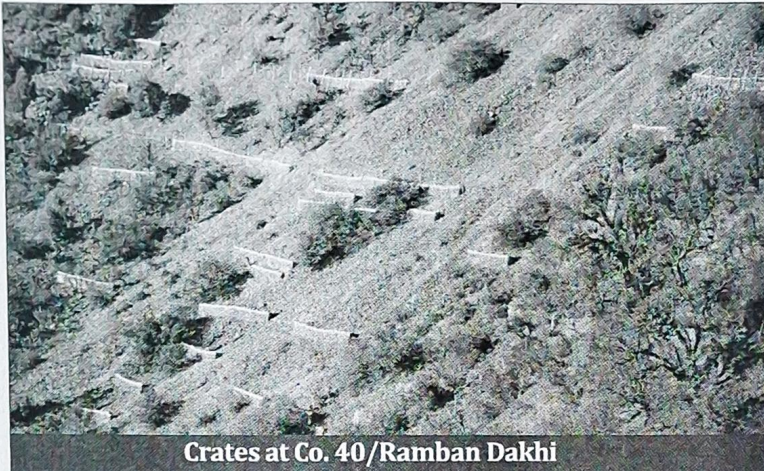


DRSM at Co. 73/Udh. Tordi Nallah



DRSM at Co. 40/Rbn. Marog

- **Crate Work :** Steel mesh wire mounted stone structures are used in slopes where the DRSM structures are less durable due to constant movement of debris. Mesh wire mounted crate provides stability as well as flexibility.



- **Water Harvesting Structures:** The slope check dams are constructed at different locations which prevent the excess flow of water and degeneration.
- **Water Diversion Channel / Drop Structure:** Effect of rain on steep slopes causes flow to become extremely violent, resulting in slope degradation. To prevent this, the diversion channels are made at appropriate locations.



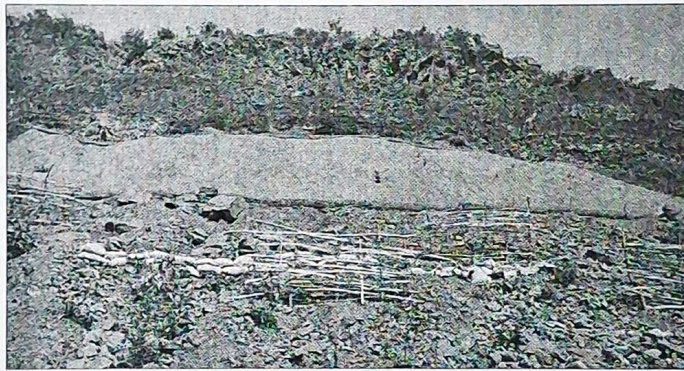
**Water Channel in Marmat Range of Batote
Forest Division**

- **Land Surface Dressing:** It involves leveling, removing of sharp and angular boulders.
- **Supply of Farm Yard Manure (FYM):** To enhance the fertility of the soil Farm Yard Manure is added to the dressed surface.

Sand Bags: Retaining walls of sand bags are created to provide immediate support on the slopes alongwith planting of grass slips behind them. The slopes get stabilized in an ecological way with the passage of time.



Sand bags at Co. 70/Udh. Morh Slip



Sand bags at Co. 70/Udh. Morh Slip

(B) NEW TECHNOLOGIES BEING ADOPTED

(I) Vetiver Grass Technology (VGT)

Vetiver is a grass (*Vetiver zizanioides*) belonging to family poaceae. Due to its fast-growing property, it is used in land stabilization techniques.

The roots of vetiver are stronger and more secure than the roots of trees. Vetiver has a broad and bulky root system which binds to the soil and is hard to remove thereafter. The deep and finely structured root system of the Vetiver extends downward to a length of two to three meters. This makes Vetiver a drought tolerant species.

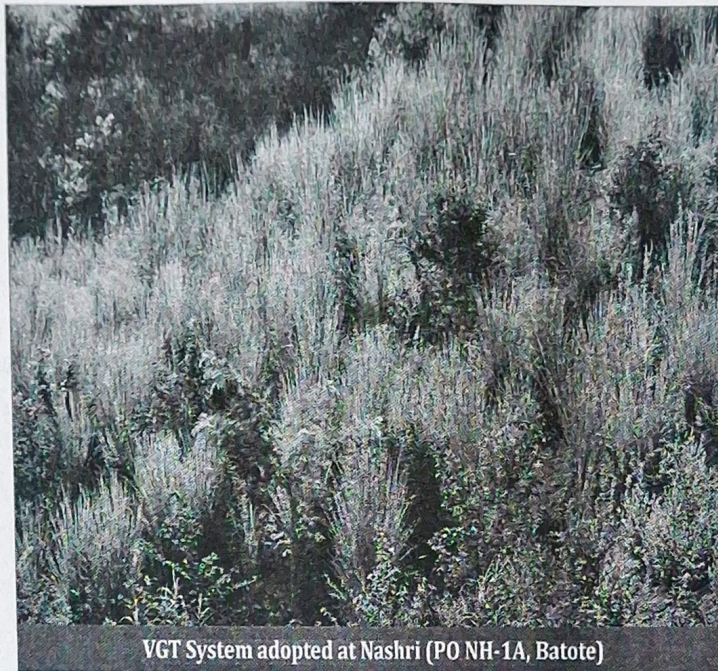
Vetiver is known to be stronger than many hardwood species, as its roots have very high tensile strength, proving its sturdiness in steep slopes.



VGT System adopted along NH-44



VGT System adopted at Nashri (PO NH-



VGT System adopted at Nashri (PO NH-1A, Batote)

The vetiver hedges are able to divert the runoff water and can create a very efficient filter system that has the ability to control erosion. They slow down the flow of water and allow the ground to soak water. Vetiver can tolerate extreme climatic conditions and environmental variations including prolonged floods and drought.

The vetiver can withstand extreme temperatures from a range of -14 to 55 degree celsius. Vetiver has high tolerance and can even grow in a medium which is high in acidity, alkalinity and salinity. It can tolerate high levels of elements like Al, As, Cd, Cr, Zn, Pb and Hg present in the soil. Vetiver is also very efficient in absorbing nitrates and phosphates from polluted water. It is non- invasive and requires very low maintenance.

Methodology

Plantation is done by laying down the trenches separated by 50 cm. The distance between the grass slips is 12-14 cm on each trench. Each trench is about 10-12 cm deeper and is supplied with vermi compost. The grass slips are placed at the centre of the trench.

Maintenance

Watering should be done every day for the first two weeks and then two to three times a week until the plants are fully grown. The Vetiver plants do not require watering after they have grown completely into mature plants. After the first month of planting, all plants that are not able to establish themselves should be removed and replaced with new grass slips.

Some special attributes of Vetiver grass

- ⇒ Densely tufted perennial grass which can grow upto 2 metre height can be established in tropics as well as temperate regions.
- ⇒ Stiff and erect stems, which form dense hedges when planted together has potential to withstand relatively deep-water. It also reduces runoff velocity and traps sediments.
- ⇒ Tolerance to extreme climatic conditions viz; prolonged drought, submergence and flood.
- ⇒ Ability to regrow very quickly despite being effected by adverse conditions.

(II) Coir Geotextile

Coir is a natural fiber extracted from fibrous husk of the coconut shell and is used to make a wide range of products such as ropes, mats, mattresses, fibre baskets, brushes, brooms, etc. India is the largest coir producer in the world accounting for major part of the total world production of coir fiber and coir products. Coir Geotextiles (CGT) are permeable fabrics made from coir fiber extracted from coconut husk by mechanical processes.

Coir Geotextile (CGT) is biodegradable and environment friendly. It has good hygroscopic and hydrophilic properties. Biodegradability, hygroscopic and hydrophilic properties of Geotextiles help in erosion control and in establishing vegetation in varying slopes and environmental conditions. These properties make coir suitable in areas where prevention of a soil surface from erosion is required. The use of CGT in erosion control in embankment construction for roads and railways, dam engineering, canals, etc. is well established. In order to prevent the soil from further degradation, natural Geotextiles are used as soil cover to provide temporary protection for the soil which can effectively control erosion until the soil is stabilized by vegetation.

The CGT, mainly composed of plant fiber, conforms to the green concept which is conducive in reducing environmental pollution. For stabilization of slopes, CGT can replace the traditional methods like stone pitching, bunding, terracing, etc. The water absorption and retention properties help in erosion control. Due to the characteristics of longer durability, low cost, easy to use and availability, the CGT is widely used in soil bioengineering and slope protection works.

Types of Coir Geotextiles

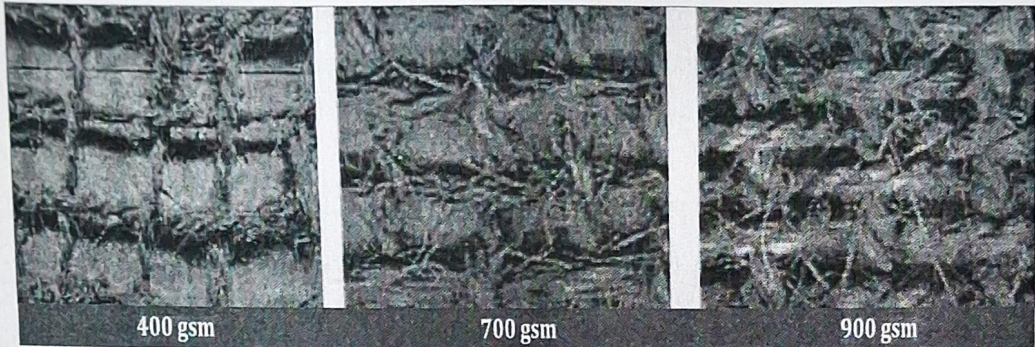
The two main Coir Geotextiles made from coir are:

- ⇒ Woven Coir Geotextiles and
- ⇒ Non-Woven Coir Geotextile

Woven Coir Geotextile (Woven CGT)

Woven Geotextile are manufactured by weaving fibers together on a loom forming one uniform length. Coir mesh mattings of different mesh sizes are most common CGTs. Mesh mattings with

different specifications are available with mesh opening sizes ranging from 4.2 mm to 20mm. These matting of two-treadle weave in construction with the difference that the warp & weft are positioned at a distance to get mesh effect.



Non-Woven Coir Geotextiles (Non-Woven CGT)

The Non-Woven Coir Geotextiles are composed of randomly packed coir fiber needles punched to the desired degree of packing. Non-Woven Geotextiles are manufactured through a process of mechanical interlocking or thermal bonding of fibers. They have excellent moisture absorption and retention characteristics and form an ideal medium for plant growth.

They have a minimum thickness of 2 mm. Non-Woven Coir Geotextiles are available in varying densities from 350 to 1000 gsm.

Role of Geotextiles in Slope Stabilization

General role of Geotextiles in slope stabilization areas:

⇒ The Drainage role or Fluid Transmission

The Geotextile is placed in contact with a material of low permeability wherein it facilitates retention of water and its diversion to exit without causing surface erosion. So the Geotextile has the property of transmissivity.

⇒ Filtration role

A Geotextile acts as a filter as it allows liquid to pass normally to its own plane, while preventing most soil particles from being carried away by the liquid current.

⇒ Protection role

A Geotextile, placed on the soil prevent its surface from being damaged by actions of weather, light, wind, etc.

⇒ Tension Membrane

A Geotextile function as a tensioned membrane when it is placed between two mediums with different pressures, and its tension balances the pressure difference thus strengthening the structure.

⇒ Tensile member

A Geotextile acts as a tensile member when it provides tensile modulus and strength to soil with which it is interacting through interface shear strength, for instance, the interlocking, friction, cohesion and adhesion.

⇒ Conducive medium for germination

The seeds sown underneath the Geotextile mat get the optimum temperature and moisture, with which they get germinated and hence proper vegetation cover develops over a period of time.

Prerequisite conditions for Coir Geotextile

The selection of Coir Geotextiles basically depends on the type of soil, rainfall intensity, average annual rainfall, seepage conditions, type of vegetation etc. For steeper slopes, smaller mesh opening size are required. The maximum intensity of rainfall is more important than the average annual rainfall. It is recommended that the choice of woven Coir Geotextiles shall be 700/900 gsm (gram per square meter) where intensity of rainfall is severe irrespective of the type of soil and slope steeper than 1:1.

Slope is most important factor for considering the type of CGT to be used:

S. No.	Slope	Type of CGT recommended
1	15° – 30°	400 gsm
2	30° – 45°	700 gsm
3	45° – 60°	900 gsm

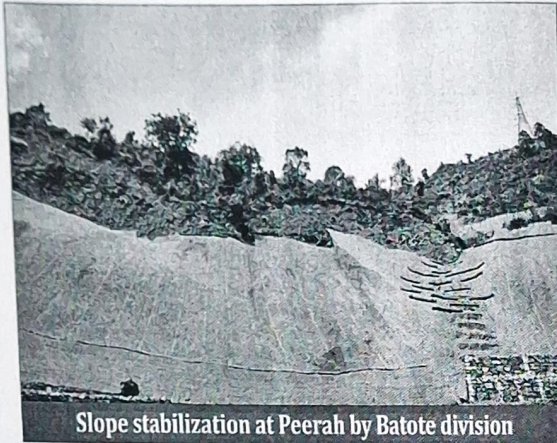
The different grades of Coir Geotextiles require different slope conditions (angle and height), rain fall intensity etc. keeping in mind the topography, accessibility and local conditions of the degraded slope of Jammu and Kashmir, Coir Geotextiles 400 gsm are used. This particular mat has an open weave design with 19 mm X 19 mm opening. These openings allow for seeding after installation as well as allow room for growth of vegetation. This mat is ideal for 1:1 and flatter slopes where annual rainfall is less than 150cm.

Other considerations are:

- ⇒ Soil depth of installation area should be 1.5 feet or more.
- ⇒ For flatter slopes and low intensity rainfall areas 400 gsm can be used.
- ⇒ Ideal slope gradient for Geotextile is 15 - 25 degree.

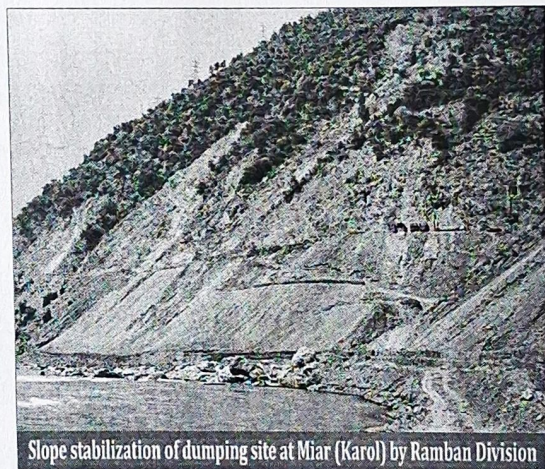
- **Geotextile Mat**

Geotextile Mats are made from woven or non-woven jute, coir, straw etc.



Benefits of Geotextile Mat

- ⇒ Prevents soil erosion.
- ⇒ Air and water permeability promote natural vegetation.
- ⇒ Faster binding of soil.
- ⇒ Biodegradable and environment friendly.
- ⇒ Life span is 4 to 5 years.



Geotextile Mat installation

Step 1: Surface dressing includes leveling, removing of sharp and angular boulders.

Step 2: Making of anchor trench at the top of bund of maximum size 1"-6" X 1".

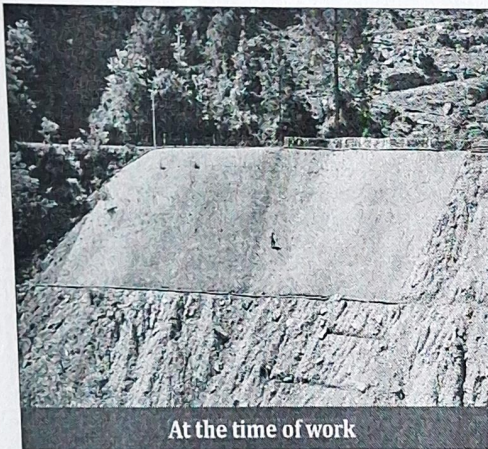
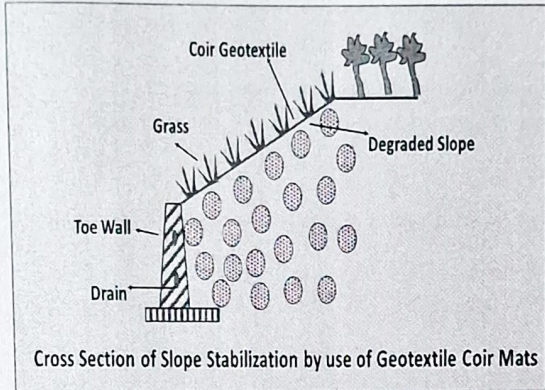
Step 3: Supply and placing of FYM / Humus.

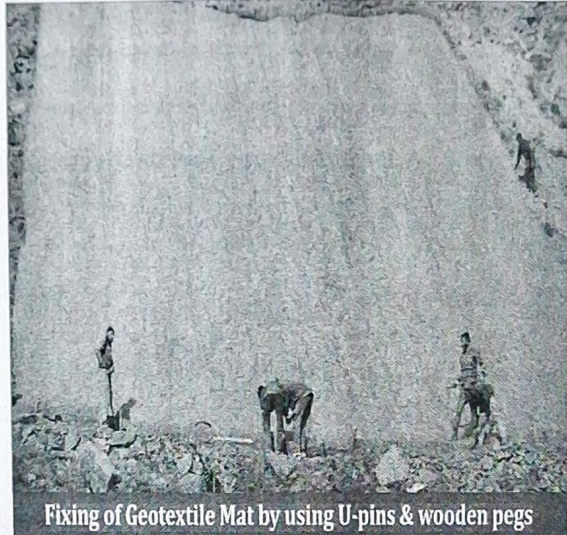
Step 4: Placing of seed of different species (Vetiver grass).

Step 5 : Laying of Geotextile Mat.

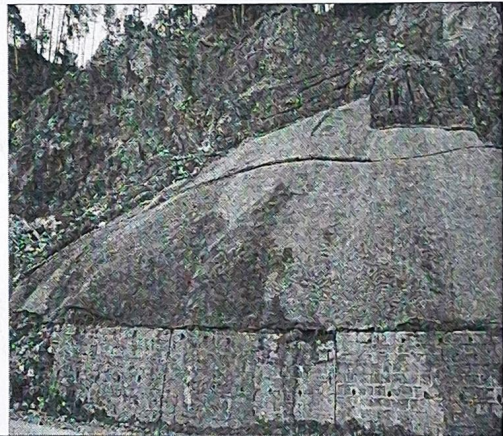
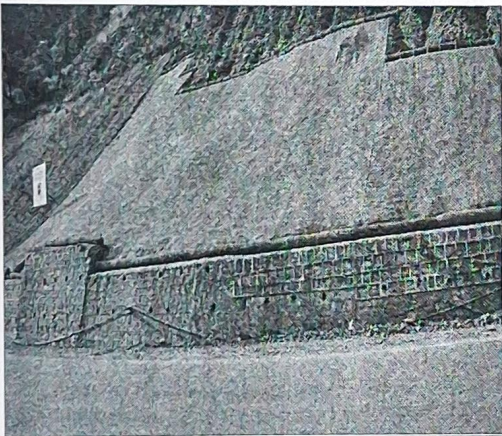
Step 6 : Fixing of Geotextile Mat by using U-pins.

Step 7: Watering of surface to provide moisture to under-soil of already placed Geotextile Mat.





Fixing of Geotextile Mat by using U-pins & wooden pegs



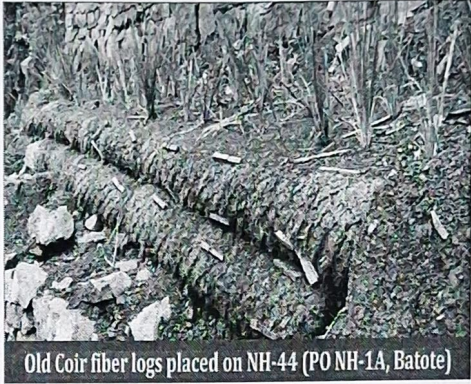
Slope stabilization work along NH-44 (PO NH-1A, Batote)

• **Coir Fiber Logs**

Coir logs are eco friendly and biodegradable. They are made from coconut fiber husk densely packed inside tubular coir twine netting, and are used in sediment control and slope stabilization.



Coir fiber logs placed on NH-44 (PO NH-1A, Batote)



Old Coir fiber logs placed on NH-44 (PO NH-1A, Batote)

Property	Type-1	Type-2	Type-3
Diameter	12 inches	16 inches	20 inches
Weight	8.2 kg/m	14.1 kg/m	22.3 kg/m
Length	10 feet	10 feet	10 feet

Installation of coir logs

Installation requirements and methods may vary depending upon the specifications of locations.

Step 1 : Clear the area of installation for any debris rocks and any other obstructions. It should make contact with the soil underneath.

Step 2: Dig a small trench on the spot where the Coir logs are to be placed as per their size.

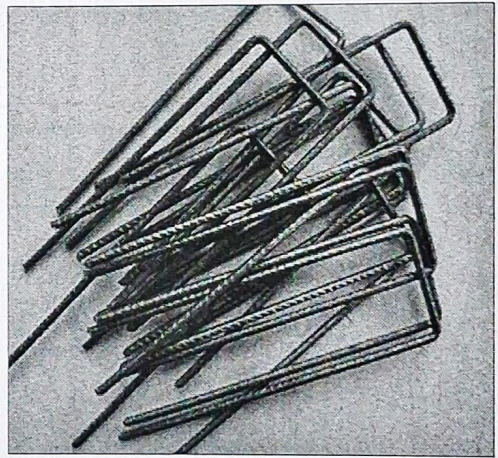
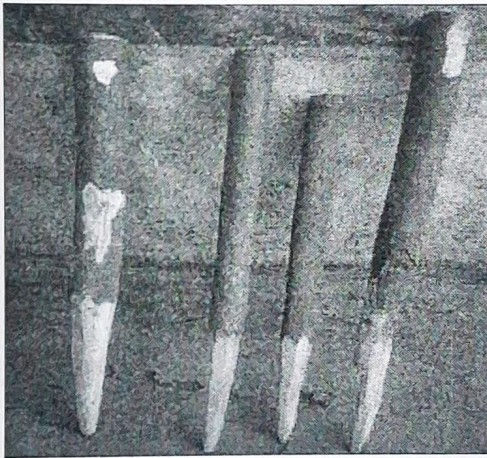
Step 3: Place the Coir log in the trench and back fill the soil so that the logs are tightly packed against the slope. Ends should be joined/secured together with twine or suitable ties. Mattress coir fiber may be used to fill spacing between logs ends.

Dimensions of wooden and iron stakes used to install Coir logs:

- ⇒ 2-2.5 feet for single layer Coir logs.
- ⇒ 3-4 feet for double layer Coir logs.



Coir fiber logs placed on NH-44 near
Chenani-Nashri Tunnel



Economics of Geotextile matting and Coir log

- ⇒ Per Square meter installation charge (Cost of Material, transportation and installation charges)= Rs. 260 to 300 (subject to e-tender/GeM procurement)
Per Hectare Cost= Rs. 26.00 to 30.00 lakhs
- ⇒ Per Coir log installation Charges (Cost of Material, transportation and installation charges)= Rs. 900 per log

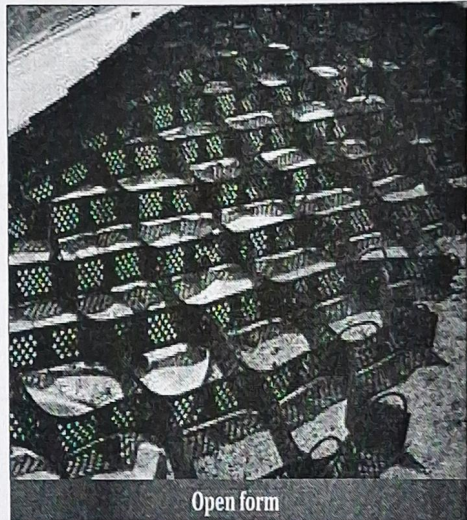
Advantages of Coir Geotextile

Among the natural fibers available, coir is the ideal choice for a Geotextile material.

- ⇒ It is natural and biodegradable.
- ⇒ It lasts for minimum of 4-5 years.
- ⇒ It provides excellent micro climate for plant establishment, growth and provides nutrients.
- ⇒ It is easy to install, economical and has excellent air and water permeability.
- ⇒ It provides excellent check dam effect by reducing runoff velocity and minimizing erosion.
- ⇒ It holds the seeds and saplings of vegetation.
- ⇒ It is eco friendly, non polluting and allows sunlight to pass through.
- ⇒ No chemicals are used during its manufacturing.

(III) Geocell

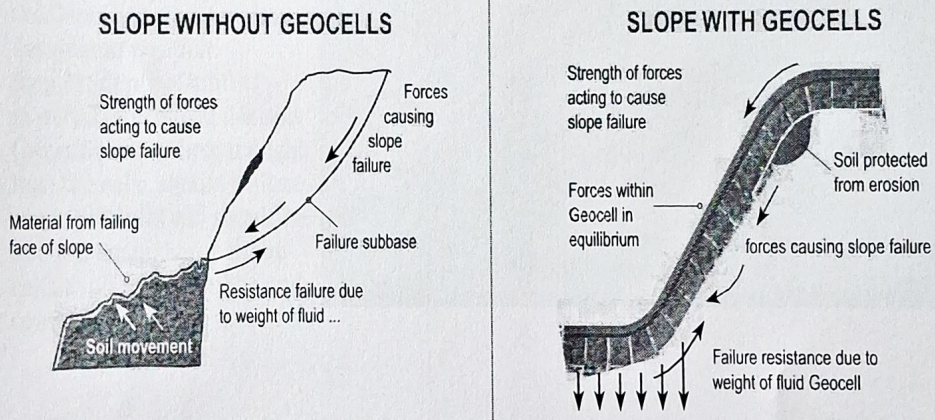
Geocell (also known as Cellular Confinement Systems) are three-dimensional honey combed cellular structures that form a confinement system when in-filled with soil or aggregate. These cellular confinement devices have been developed as simple and long-lasting materials for slope stabilization. Cellular confinement methods successfully preserve the compaction of the soil, resulting in a stronger structure. Its three-dimensional honeycomb shape ensures its strength, durability and establishes a framework for better load distribution.



Geocell panels are expandable three-dimensional panels made up of high-density polyethylene (HDPE). The connecting strips form the walls of a flexible, three-dimensional cellular structure into which specified infill materials are put and compacted. This generates a free-draining system that keeps infill materials in place and prevent mass movement by using tensile reinforcement to constrain them. Soils and aggregate infill materials benefit from cellular confinement systems in terms of structural and functional performance. Ideal slope gradient for Geocell is 25-45 degree.

Role of Geocell in Slope Stabilization

- ⇒ The cell is made of high-density polyethylene (HDPE), which is used to stabilize soil that is weak or unstable. This is due to their capacity to minimize soil particle lateral movement while vertically loading on the enclosed infill.
- ⇒ Cellular confinement system increases the natural resistance to erosive forces, protecting the root zone of vegetated layer. It reinforces vegetation during high flow, directing the flow over the layer rather through inside.
- ⇒ The multi-layered Geocell system features horizontal terraces with exposed outer face of cells, creating a natural environment for selected sustainable vegetation. The vegetated system allows rain water to fall on the exposed horizontal soil terrace, maximizing water collection, and minimizing runoff.
- ⇒ Evaporation of topsoil moisture is controlled through the impervious vertical wall structure creating an environment for healthy vegetation. By maintaining a near vertical profile, the system limits site disruption and reduces valuable land use.



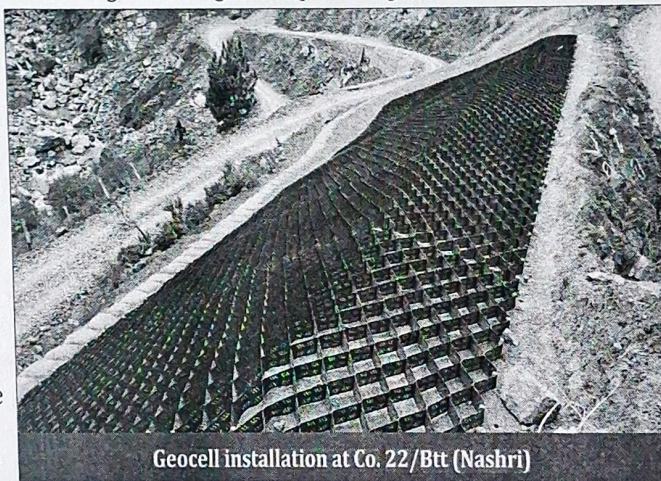
- ⇒ Geocells give a mattress effect and improve the flexibility of the materials in addition to providing stability. The cells have high elastic stiffness and tensile strength, and as a result, they increase the load distribution. Less rutting occurs in the surface materials above due to the weight distribution created by the cells. This also reduces the amount of soil infill required. The design of the cells allows for infill to be imported locally, allowing for the use of marginal soil as an infill.
- ⇒ Geocells increase the modules of adjacent levels by transferring vertical stresses to the Geocell grid via passive resistance. Because of their propensity to expand, these are highly effective for compacting materials inside. This extension creates a free-draining system that prevents mass movements.

Geocell Installation

Step 1: Base Preparation includes leveling, removing of sharp and angular boulders.

Step 2: Position the Geocell section along the slope direction and anchor the upper edge of the Geocell to the top of the slope. Expand the Geocell section into its designated position.

Step 3: Supply of infill material (soil) to fill the cells (excessive drop-height might hurt the cells, should be less than 1m). Infill soil should be about 2 cm higher than the cells to allow for settling and compaction.



Geocell installation at Co. 22/Btt (Nashri)

Step 4: Compact the Geocell system with tools or water may be supplied to achieve the specified compaction.

Step 5: Placing of seed of different species(e.g, Vetiver grass) and supply of Farm Yard Manure (FYM) to improve soil fertility.

Step 6: Watering of surface to provide moisture to the soil.



Salient Features of Geocell

- ⇒ It is a cost-effective alternative for slope stabilization.
- ⇒ It increases overall structural strength.
- ⇒ It has better load bearing capacity and wider stress distribution.
- ⇒ It reduces permanent deformation.
- ⇒ It is quick and easy to install.
- ⇒ It is eco-friendly soil stabilization solution.
- ⇒ It ensures the long-term stability of slopes.

GROUND IMPROVEMENT TECHNIQUES

UNIT-I

To understand the need of ground improvement techniques

To know about the different techniques involved in densifying the soils

Syllabus: INTRODUCTION

Need and objectives of Ground Improvement techniques, Classification of ground modification techniques, Suitability and feasibility

Methods of compaction-Shallow Compaction, Deep Compaction

Shallow Compaction: Smooth wheeled Rollers, Sheep foot rollers, Pneumatic tired rollers Deep

Compaction: Vibroflotation, Blasting, Dynamic consolidation, Precompression and Compaction Piles

Learning Outcomes:

After completion of this unit the student will be able to

- Explain the need and objective of ground improvement techniques
- List the different techniques that are available for improvement
- Choose the suitable technique depending upon the condition of soil and requirements
- Know different methods that are available for Compaction or densifying the soils
- Identify the type of techniques required for various soils

LEARNING MATERIAL

1.1Need for Ground Improvement:

Generally Engineers design Foundation and other structures basing on soil investigation. If soil good at lesser depth shallow foundation can be laid, if hard stratum available at higher depth, Deep foundation can be laid.

In some cases, Deep foundation becomes uneconomical, it becomes a problem practically. So there need arises to improve the ground conditions by ground improvement. However, it is also costly but proved to be cost effective many times.

Ground improvement is rapidly developing filed because good sites for construction are limited day by day. So improving characteristics of soil at site, that consists of increasing shear strength, decreasing compressibility of soil. So that Bearing capacity increases which reduces settlements.

As more and more land becomes subject to urban or industrial development, good construction sites and borrow areas are difficult to find and the soil improvement alternatives becomes the best option, technically and economically.

Where a project encounters difficult foundation conditions, possible alternative solutions are:

1. Avoid the particular site: Relocate a planned highway or development site.
2. Design the planned structure accordingly: Some of the many possible approaches are to:
 - Use a raft foundation supported by piles,
 - Design a very stiff structure which is not damaged by settlement,
 - Or choose a very flexible construction which accommodates differential movement or allows for compensation.
3. Remove and replace unsuitable soils: Remove organic topsoil, which is soft, compressible, and volumetrically unstable. This is a standard precaution in road or foundation construction.
4. Attempt to modify the existing ground

1.2 Objective of Ground Improvement Techniques

The most common traditional objectives include improvement of the soil and ground for use as a foundation or construction material.

The typical Engineering objectives have been:

- 1) Increasing shear strength, durability, stiffness and stability
- 2) Reducing undesirable properties (eg. Shrink/ swell potential, compressibility, liquefability)
- 3) Modifying permeability, the rate of fluid to flow through a medium; and
- 4) Improving efficiency and productivity by using methods that save time and expense

The engineer must take a determination on how best to achieve the desired goals required by providing a workable solution for each project encountered. Ground improvement methods have provided adverse choice of approaches to solving these challenges.

1.3 Factors affecting choice of improvement methods

5. **Soil type:** This is one of the most important parameters that will control what approach or materials will be applicable to only certain types of soil types and grain sizes
6. **Depth and location of treatment required-** many ground improvement methods have depth limitations that render them unsuitable for applications for deeper soil horizons.
7. **Desired/required soil properties-** obviously, different methods are use to achieve different engineering properties, and certain methods will provide various levels of uniformity to improved sites.
8. **Availability of materials-** Depending on the location of the project and materials required for each feasible ground improvements approach.
9. **Availability of skills, local experience, and local preferences-** While the engineer may possess the knowledge and understanding of a preferred method.
10. **Environmental concerns-** With a better understanding and a greater awareness of effects on the natural environment, more attention have been placed on methods that assure less

environmental impacts.

11. **Economics**- when all else has been considered, the final decision on choice of improvement method will often come down to the ultimate cost of a proposed method, or cost will be the deciding factor in choosing between two or more otherwise suitable methods.

1.4 Classification of Ground Modification Techniques

Four groups of ground improvement Techniques are distinguished:

12. Mechanical modification
13. Hydraulic modification
14. Physical and chemical modification
15. Modification by inclusion and Confinement

a. Mechanical modification

Soil density is increased by the application of short-term external mechanical forces, including Compaction of surface layers by:

- Static,
- Vibratory,
- Impact rollers,
- Plate vibrators.

Deep compaction by heavy tamping at the surface or vibration at depth

b. Hydraulic modification

Free –pore water is forced out of the soil via (by means of) drains or wells. - In coarse grained soils, this is achieved by lowering the ground water level through pumping from boreholes or trenches. - In fine-grained soils, the long term application of external loads (preloading) or electrical forces (electro kinetic stabilization) is required.

c. Physical and chemical modification

Additives include: - natural soils - industrial by-products or waste materials (fly ash, slag), - Cementations and other chemicals (lime, cement) which react with each other and the ground.

When additives are injected via boreholes under pressure into the voids within the ground or between it and a structure, the process is called GROUTING. Rigs with multiple injectors deliver the stabilizing fluid into the soil. The fluid will prefer to travel into cracks and fissures.

Soil stabilization by heating the ground and by freezing the ground come under, Thermal Methods of Modification.

- Heating evaporates water and causes permanent changes in the mineral structure of soils.
- Freezing solidifies part or all of the water and bonds individual particles together.

d. Modification by inclusion and Confinement Reinforcement by:

- Fibers, Strips, Bars, Meshes and Fabrics.

In-situ reinforcement is achieved by nails and anchors.

1.5 Suitability and Feasibility

The choice of a method of ground improvement depends on many factors including:

- Type and degree of improvement required
- Type of soil, geological structure,
- Seepage conditions,
- Cost (the size of the project may be Decisive),
- Availability of equipment and materials and the quantity of work required,
- Construction time available,
- Possible damage to adjacent structures or Pollution of ground water resources,
- Durability of the materials involved,
- Toxicity or corrosively of any chemical Additives

The feasibility of a particular method is strongly related to the type of problem in hand:

- A foundation,
- An embankment on soft ground,
- An unstable slope,
- An excavation,
- An earth-retaining structure,
- A leaking dam or reservoir.

1.6 Improvement of cohesive soils:

Cohesive soils such as soft clay with large void ratio and higher water content have a necessity to improve their characteristics. To reduce void ratio and water content, to increase strength for which increases bearing capacity of soil.

Generally following methods are in practice:

- 1.6.1 Precompression or Preloading
- 1.6.2 Sand Drains
- 1.6.3 Wick Drains
- 1.6.4 Stone columns

1.7 Improvement of cohesion-less soils:

Cohesion-less soils with $N < 10$ value has low shear strength, and hence the bearing capacity is quite low. If a deposit of loose sand exists at site of construction the ground improvement can be achieved by strong vibration in ground. Such that relative density increases, consequently N - Value and Bearing capacity increases.

Some of the adopted methods are:

- 1.7.1 Vibrofloatation
- 1.7.2 Terra Probe
- 1.7.3 Dynamic Impact
- 1.7.4 Compaction by Blasts
- 1.7.5 Compaction Piles

Mechanical stabilization covers two methods of changing soil properties,

- i) The rearrangement of soil particles and
- ii) The improvement of soil gradation.

There are several examples of particle rearrangement i.e., the blending of the layers of a stratified soil, the remoulding of an undisturbed soil, and of most importance, the densification of soil. Methods of densification of soils are of two types.

1. Surface/shallow Compaction
2. Deep Compaction

SURFACE/SHALLOW COMPACTION

Shallow compaction is achieved either by static pressure or dynamic pressure is caused by impact or vibration. The rollers used for static pressure and the impact on the surface can be caused by various equipments are as follows:

Static Rollers: Smooth Wheeled Rollers, Pneumatic tired rollers, Sheep foot rollers and Grid Rollers

Impact or vibratory Equipment: Heavy Tampers and impact rollers.

Smooth wheel rollers:

These are two types. One with two large wheels in rear and smaller single drum in front and the other type has large single drum in the front and the rear.

These might be static and Vibratory type. Static type:

- Gives limited pressure because of their relatively large contact area.
- Effective depth of Compaction is limited to shallow.
- Compaction is restricted only for thin layers
- Compaction is done in separate layers. Eg. Base, Sub-base, Sub-grade layers.

Some rollers are equipped with electronic devices named by compaction meters, which receives continuous signals from accelerometer mounted on drums, measures deformation modulus and moisture content of soil through correlation.

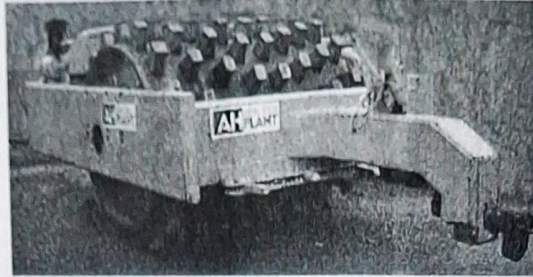
Vibratory type:

These have a light impact effect on the ground. The vibrating amplitude of this roller varies in the order of 1-2mm. Heavy vibrating drums are fixed to the rollers to add the impact on the ground. Compaction mainly depends on static weight, frequency and amplitude, speed of roller, Drum diameter.

- Effective in compacting clean granular soils in fills or subgrades.
- Maximum compaction effort in soils is achieved at frequency between 25 and 50Hz with amplitude in the range of 1.5 to 2.0mm.
- Normal rollers speed ranges between 3 and 6 km/hr.

Sheep foot rollers:

Well suited for compacting clay and silty-clay soils. Sheep foot rollers are also called as tamping foot rollers, have projecting studs or feet on the surface of the rollers and compact by a combination of tamping and kneading action. The kneading action of the feet causes successive layers to be fused and thus increases the stability.



These compactors consist of steel drums which can be filled with water or sand to increase the weight. As rolling proceeds, most of the roller weight is imposed through the projecting studs and results in fairly high contact pressure.

When a loose soil layer is initially rolled, the projections sink into the layer and compact the soil near the lowest portion of the layers. In subsequent passes, the zone being compacted already continuously rises until the surface is reached.

These rollers are available in drum width ranging from 120 to 180cm and drum diameter ranging from 100 to 180cm and load per drum ranges from 2950 to 13600 kg. The area of foot ranges from 36 to 50 sq cm and length range from 18 to 25.5 cm.

Rollers are available in two types. 1. Self propelled. 2. Only rollers (A tractor is required to tow the rollers where self propelled rollers attain speed of 9km/hr).

Advantages:

- More suitable for cohesive soils.
- Feet or stud produces kneading action.
- Possible soil compaction over a wide range of moisture content.
- Effective in breaking large pieces of soft rock. Disadvantages:
- Relatively slow operation
- Lower compacted density
- Large entrapped air

Pneumatic Tired Rollers:

These rollers are more effective for low cohesive soils and cohesionless soils like Gravels, Sands, Clayey soils, silty sands and even sandy clays.

- In this technique compaction is due to kneading action.
- These rollers are outfitted with a weight box between two axles so that the compaction load can be easily varied. Light rubber tired roller have 7 to 13 wheels which are mounted in two rows.
- The wheels fitted on the rear row are such that fitted in the tracks of the spaces between of the front row wheels.
- These rollers are available in wide range of loads, of which the heaviest is 1800kN. However 450kN is in common use.
- Roller speeds generally vary between 6 to 12 Km/hr. Heavier weight rollers requires less number of passes and gives smooth finishing compared to smooth wheeled rollers
- Light rollers (20000Kg) compacts 15cm thick with few passes where as in heavy rollers (40000kg to 50000kg) compacts 30cm thick layer with 3-5 passes only.

- ✓ Wheel load
- ✓ Tire Sizes
- ✓ Inflation Pressure
- ✓ No. of passes
- ✓ Loose Lift thickness

} depends upon the soil type and equipment available

Grid Rollers:

- These are intermediate of smooth wheeled and sheep foot rollers. With their rotating wheels made of a network of steel bars forming a grid with square holes.
- These rollers provide less kneading action but high contact pressure.
- Mostly suitable for coarse grained soils.

Impact rollers: These consist of a non circular mass, which can be pulled on the ground. It results in high impact effect i.e., heavy compaction is carried out as its center rises and falls and leaves an uneven surface.

DEEP COMPACTION

The following are the techniques applied in densification of deep soil deposits.

1. Pre-compression: In this technique, the site is preloaded or precompressed by the application of surcharge load on the surface. This technique is adopted for cohesive soils.
2. Explosion or Blasting: In this technique a certain amount of explosive charge is buried at a certain depth of cohesionless soil required to be compacted and then detonated.
3. Heavy tamping: This technique is also called as dynamic consolidation. This technique basically utilizes the vibration and shocks caused by dropping an heavy weight and then densification takes place by displacement of soil grains.
4. Vibration: Soil Densification in this technique is obtained by vibrating the piles or the needles inserted in to the ground surface.
5. Compaction Grouting: This technique is applied with very stiff mortar and is injected to loose soils where there is a possibility to form a grout bulb. Grout bulb makes the surrounding soil densified and displaces without any penetration in to the soil pores.

BLASTING:

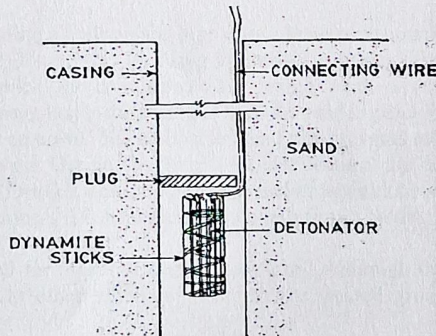
In this technique a certain amount of explosive charge is buried at a certain depth of cohesionless soil required to be compacted and then detonated.

A Borehole is made and a pipe of 7.5 to 10cm is driven to the required depth of the soil.

Then the sticks of dynamite and a electric detonator are wrapped in the water proof bundles and lowered down through the casing. The casing is withdrawn and a wad of paper or wood is placed against the charge of explosives to protect it from misfire.

The hole is backfilled with sand in order to obtain the full force of blast. The electric circuit is closed to fire the charge.

In this manner a series of holes are made ready. Each hole is detonated in succession and the resulting



large diameter holes are formed by lateral displacement and are back filled.

Usually Explosions are arranged in the form of horizontal grid of which spacing is depended on the depth of strata to be densified, the size of the charge and the overlapping of the charges. Generally a spacing of 3-8m is used and should not be less than 3m. Weight of charge required can be computed from the following relationship,

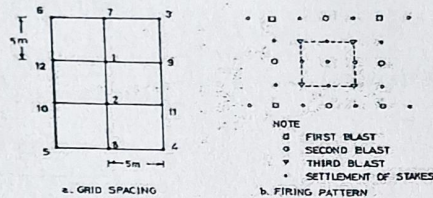
$$W = 164 C R^3$$

Where W = weight of the explosive (N)

C = Coefficient (0.0025 for 60% detonator) R = Radius of influence (m).

Generally, a charge mass of 2kg to 30kg are to be used. A typical pattern of firing the explosions are as follows

However, adequate data regarding to the following are to be collected before planning this kind of



technique.

- Type of soil
- Depth of compaction
- Degree of saturation
- Degree of densification

Sometimes some preliminary tests are required to ascertain spacing, depth, sequence of operation.

Advantages:

- ✓ This technique requires less time, less labour, less expensive
- ✓ More successful for greater depth
- ✓ Large volume compaction.

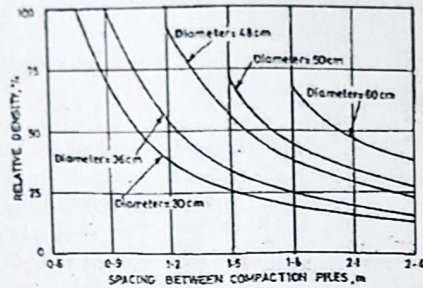
Disadvantages:

- ✓ It requires experienced person and special supervision
- ✓ Non uniformity
- ✓ Adverse affects on adjacent structures.
- ✓ Only suitable when the soil is in dry or completely saturated.
- ✓ Very fine grained soils with cohesion cannot be compacted.

COMPACTION PILES

This method consists of driving a hollow steel pipe with a detachable bottom plate down to the desired depth. The driving can be done either by using an impact hammer or a vibratory driver. Sand is introduced in lifts with each lift compacted concurrently with a withdrawal of the pipe pile. Compressed air is blown down inside the casing to hold the sand in place. The in-situ soil is densified while the pipe is being driven down. The compacted sand pile prevents collapsing of the surrounding soil as the pipe is withdrawn. During the process of compaction, the compacted column expands laterally below the pipe tip forming a caisson pile. This technique is also referred to as vibro-composer method. The installation process is schematically shown in figure below.

This method is economical for moderate depths upto 15m. Although this technique is costlier for deeper depths compared to other vibration methods, the treated ground generally has uniform properties.



If the initial void ratio is e_0 , at which after compaction the final void ratio is given by e and the pile spacing S may be obtained from

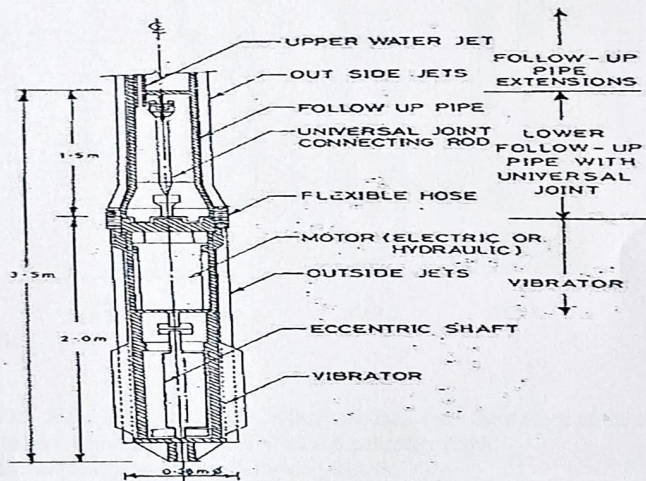
$$S = \left\{ \frac{\pi(1 + e_0)}{e_0 - e} \right\}^{1/2} d \dots \dots \dots \text{for square pattern}$$

$$S = 1.08 \left\{ \frac{\pi(1 + e_0)}{e_0 - e} \right\}^{1/2} d \dots \dots \dots \text{for triangular pattern}$$

Where d is diameter of the pile.

VIBROFLOTATION

- Efficient technique for densifying the cohesionless soils.



This technique was originated in Russia and was applied in Germany in 1939 for improvement of building foundation soil.

Equipment of comprises of

- Vibrofloat Probe
- Accompanying power supply
- Water supply
- Crane
- Front end loader (used for backfilling soil)

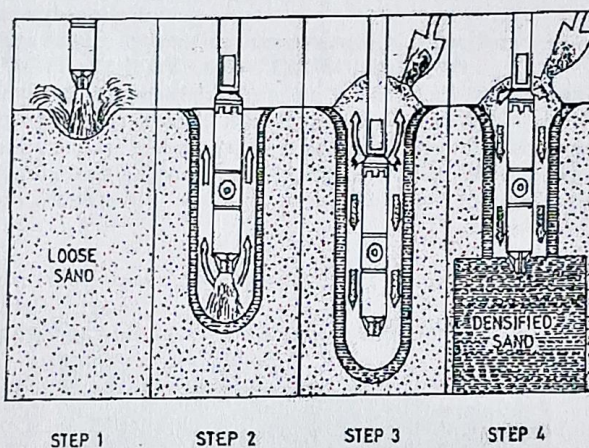
Vibrofloat Probe: It consists of cylinder with 400mm dia and 2m long, with a motor and a eccentric shaft to create centrifugal forces of 100kN at 1800rpm.

The equipment primarily is of two parts

- i. Lower part which is an horizontal vibrating unit which connects to the upper part
- ii. Upper part, it is a followup pipe in which length can be varied depending up on compaction depth.

Once the equipment is dropped or freely suspended to the compaction required depth. It has four basic steps to complete a compaction sequence as follows

- Vibro float is positioned over the spot to be compacted and its lower jet is then fully opened.
- Water is pumped in faster than it can be drained in to sub soil. This creates momentary quick condition beneath the jet.
- Water is switched from the lower to the top jets and the pressure is reduced to allow water to return back to the surface and facilitating continuous feed of backfill.
- Compaction takes place during 0.3m per minute lift on which the vibro float returns to the surface.



Liquefaction occurs at a radial distance of 300 – 500mm distance from the surface of the vibro float. In each filling of backfill it consumes 0.5 to 1.5m³ of soil per meter depth.

Application of this technique depends on the following factors:

- Equipment capacity
- Probe spacing and pattern
- Type of soil to be compacted
- Backfill material
- Vibro float withdrawal procedure (Generally 0.3 – 0.6m/minute is a customary)
- Workman ship



Backfill material:

Generally depends upon the gradation of soil. Brown (1976) had given a rating system to assess the suitability of backfill material.

$$\text{Suitability Number} = 1.7 \sqrt{\frac{1}{D_{10}^2} + \frac{1}{D_{20}^2} + \frac{3}{D_{50}^2}} \text{ where } D_{20}, D_{50} \text{ are particle sizes}$$

D_{10}

corresponding to 10%, 20% and 50% finer from the gradation curve.

Suitability Number	Description of rating
0 to 10	Excellent Good Fair Poor
10 to 20	Unsuitable
20 to 30	
30 to 50	
> 50	

This technique claims its *merits* based on the following:

- ✓ No Material cost except backfill material
- ✓ Complete uniformity in density therefore better control of settlements
- ✓ Gives high bearing capacity (250 – 400 kPa)
- ✓ Faster than pile driving
- ✓ Much quicker in operation than conventional impact hammer

DYNAMIC COMPACTION OR DYNAMIC CONSOLIDATION

Dynamic compaction is also known as heavy tamping. A technique which uses an heavy hammer of weight up to 45000kg and will be dropped freely from a height of 15 to 20m to the ground surface.

The heavy impact causes its mark on the ground surface and creates vibrations in adjacent soils. This process is repeated at same location over the subsequent parts of the area with spacing 5 to 10m.

Usual energy per blow is $135 \times 10^3 - 450 \times 10^3$ kg-m. Generally 2 to 3 blows per square meter is used.

When the weight strikes the ground surface vibrations pass through the adjacent soil layers in the form of P, S and R waves.

Considering effective depth as a function of impact energy the depth of penetration is within the



following range

$$1.26\sqrt{Wh} < D < 3.16\sqrt{Wh}$$

D is effective depth (m) W is weight of drop (kg) h is height of drop (m) Merits:

- One of the simplest methods for compacting loose soils
- Depth of compaction can reach upto 20m
- Any type of soil can be compacted
- Produces equal settlements throughout the area This method depends upon the following
 - i. Magnitude of the weight
 - ii. Size of the weight
 - iii. Height of the drop
 - iv. No. of drops
 - v. Distribution of drops throughout the site
 - vi. Homogeneity of soil throughout the site
 - vii. Strength & permeability of soil
 - viii. Degree of saturation (Water Content)

HYDRAULIC STABILIZATION

UNIT – II

Objective: To know about the different techniques involved in dewatering to make an strengthen for constructions and other works.

Syllabus: **Methods of dewatering-** Open sumps and ditches, well point system Electro- osmosis, Vacuum dewatering wells, Preloading with sand drains, Strip drains, Design of vertical drains

Outcomes:

Student will be able to

- Know different methods that are available for dewatering
- Idealize the working procedure involved in the methods
- Know about different kinds of drains that are able to make the site free from water logging

LEARNING MATERIAL

Construction of buildings, powerhouses, dams, locks and many other structures requires excavation below the water table into water-bearing soils. Such excavations require lowering the water table below the slopes and bottom of the excavation to prevent ravelling or sloughing of the slope and to ensure dry, firm working conditions for construction operations.

Groundwater can be controlled by means of one or more types of dewatering systems appropriate to the size and depth of the excavation, geological conditions, and characteristics of the soil.

Construction sites are dewatered for the following purposes:

- To provide suitable working surface of the bottom of the excavation
- To stabilize the banks of the excavation thus avoiding the hazards of slides and sloughing
- To prevent disturbance of the soil at the bottom of excavation caused by boils or piping, such disturbances may reduce the bearing power of the soil.

A number of methods are available for controlling the inflow of water into an excavation; the choice of method will depend on the nature and permeability of the ground, the extent of the area to be dewatered, the depth of the water table below ground level and the amount by which it has to be lowered, the proposed methods of excavation and ground support, the proximity of existing structures, the proximity of water courses etc.

The available methods of groundwater control fall into the following basic groups:

1. Surface water control like ditches, training walls, open excavations, embankments.
2. Gravity drainage. Relatively impermeable soils.
3. Sump pumping
4. Well-point systems with suction pumps.
5. Shallow (bored) wells with pumps.
6. Deep (bored) wells with pumps.
7. Eductor system
8. Drainage galleries. Removal of large quantities of water for dam abutments, cut-offs, landslides etc. Large quantities of water can be drained into gallery (small diameter tunnel) and disposed of by conventional large – scale pumps.
9. Electro-osmosis. Used in low permeability soils (silts, silty clays, some peats) when no other method is suitable. Direct current electricity is applied from anodes (steel rods) to cathodes (well-points, i.e. small diameter filter wells)

Sumps and sump pumping:

A sump is merely a hole in the ground from which water is being pumped for the purpose of removing water from the adjoining area. They are used with ditches leading to them in large excavations. Up to maximum of 8m below pump installation level; for greater depths a submersible pump is required. Shallow slopes may be required for unsupported excavations in silts and fine sands. Gravels and coarse sands are more suitable. Fines may be easily removed from ground and soils containing large percent of fines are not suitable. If there are existing foundations in the vicinity pumping may cause settlement of these foundations. Subsidence of adjacent ground and sloughing of the lower part of a

slope (sloped pits) may occur. The sump should be preferably lined with a filter material which has grain size gradations in compatible with the filter rules. For prolonged pumping the sump should be prepared by first driving sheeting around the sump area for the full depth of the sump and installing a cage inside the sump made of wire mesh with internal strutting or a perforating pipe filling the filter material in the space outside the cage and at the bottom of the cage and withdrawing the sheeting.

Well point systems:

A well-point is 5.0-7.5 cm diameter metal or plastic pipe 60 cm – 120 cm long which is perforated and covered with a screen. The lower end of the pipe has a driving head with water holes for jetting. Well-points are connected to 5.0-7.5 cm diameter pipes known as riser pipes and are inserted into the ground by driving or jetting. The upper ends of the riser pipes lead to a header pipe which, in turn, connected to a pump. The ground water is drawn by the pump into the well-points through the header pipe and discharged. The well-points are usually

installed with 0.75m – 3m spacing (See Table 1). This type of dewatering system is effective in soils constituted primarily of sand fraction or other soil containing seams of such materials. In gravels spacing required may be too close and impracticable. In clays it is also not used because it is too slow. In silts and silt – clay mixtures the use of well points are aided by upper (0.60m – 0.90m long) compacted clay seals and sand-filtered boreholes (20cm – 60cm diameter). Upper clay seals help to maintain higher suction (vacuum) pressures and sand filters increase the amount of discharge. Filtered boreholes are also functional in layered soil profiles.

The header pipe (15-30 cm diameter, connecting all well-points) is connected to a vacuum (Suction assisted self – priming centrifugal or piston) pump. The well-points can lower a water level to a maximum of 5.5 m below the center line of the header pipe. In silty fine sands this limit is 3 – 4m. Multiple stage system of well-points are used for lowering water level to a greater depth. Two or more tiers (stages) are used. More pumps are needed and due to the berms required the excavation width becomes wider. A single well-point handles between 4 and 0.6m³/hr depending on the soil type. For a 120 m length (40 at 3 m centres) flow is therefore between 160 and 24 m³/hr.

Horizontal well-points are used mainly for pipeline water. They consist of perforated pipes laid horizontally in a trench and connected to a suitable pump.

Following is the list of factors to be collected:

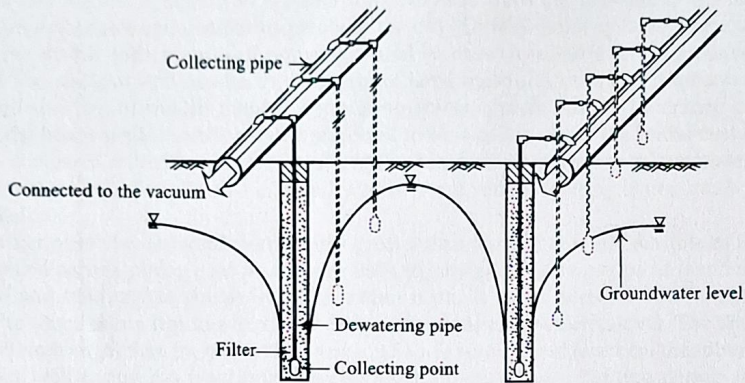
1. The physical Layout
2. Adjacent areas
3. Soil conditions
4. Permeability of soil
5. The amount of water to be pumped
6. Depth to imperviousness
7. Stratification

Advantages of Well point system

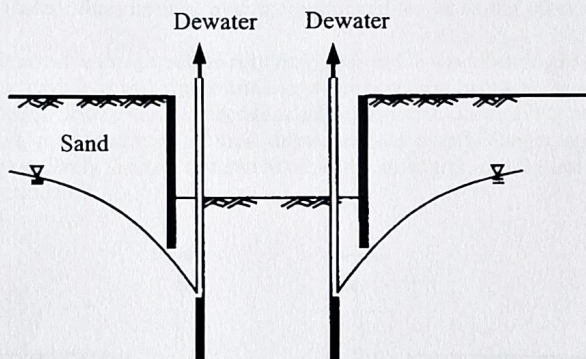
- a) Installation is very rapid
- b) Requires reasonably simple and less costly equipment

Limitations of Well Point systems:

1. A Lowering of about 6m (20ft) below pump level is generally possible beyond which excessive air shall be drawn into the system through the joints in the joints, pipes, valves etc., resulting in the loss of pumping efficiency.
2. If the ground is consisting mainly of large gravel, stiff clay or soil containing cobbles or boulders it is not possible to install well points.



General View of Well Point System



Single Stage Well Point System

Two Stage Well Point Systems

Shallow Wells:

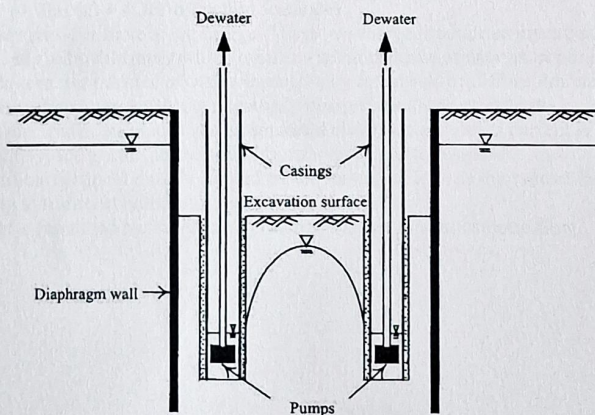
Shallow wells comprise surface pumps which draw water through suction pipes installed in bored wells drilled by the most appropriate well drilling and or bored piling equipment. The limiting depth to which this method is employed is about 8 m. Because wells are pre-bored, this method is used when hard or variable soil conditions preclude the use of a well-point system. These wells are used in very permeable soils when well-pointing would be expensive and often at inconveniently close centres. The shallow well can be used to extract large quantities of water from a single hole. On congested sites use of smaller number dewatering points is preferred (no hindrance to construction operations) hence shallow wells may be preferred to well-points. Since the initial cost of installation is more compared to well-points it is preferred in cases where dewatering lasts several months or more. Another field of application is the silty soils where correct filtering is important.

Deep Wells:

When water has to be extracted from depths greater than 8 m and it is not feasible to lower the type of pump and suction piping used in shallow wells to gain a few extra meters of depth the deep wells are such and submersible pumps installed within them. A cased borehole can be sunk using well drilling or bored piling rigs to a depth lower than the required dewatered level. The diameter will be 150 – 200 mm larger than the well inner casing, which in turn is sized to accept the submersible pump. The inner well casing has a perforated screen over the depth requiring dewatering and terminates below in 1 m of un-perforated pipe which may serve as a sump for any material which passes the filter. After the slotted PVC or metal well screen (casing) has been installed it is surrounded by backfill over the un-perforated pipe.

length and with graded filter material over the perforated length as the outer casing progressively withdrawn.

Deep well systems are of use in gravels to silty fine sands and in water bearing rocks. They are priority or use with deep excavations and where artesian water is present below an impermeable stratum. If this type of installation is to be designed economically the ground permeability must be assessed from full scale pumping tests. Because of their depth and the usually longer pumping period these installations are more likely to cause settlement of nearby structures, and the use of recharge methods may have to be considered.



Deep Well System

HORIZONTAL WELL POINTS: These are used for drainage which is on hill side. The diameter of the wells is 5cm to 8cm. A perforated casing is installed in the well to collect and discharge the water. These are installed at an upward slope for horizontal length of 60m.

DEWATERING BY ELECTRO OSMOSIS

When an external electro motive force is applied across a solid liquid interface the movable diffuse double layer is displaced tangentially with respect to the fixed layer. This is electro osmosis. As the surface of fine grained soil particles causes negative charge, the positive ions in solution are attracted towards the soil particles and concentrate near the surfaces. Upon application of the electro motive force between two electrodes in a soil medium the positive ions adjacent to the soil particles and the water molecules attached to the ions are attracted to the cathode and are repelled by the anode. The free water in the interior

of the void spaces is carried along to the cathode by viscous flow. By making the cathode a well, water can be collected in the well and then pumped out.

Electro osmotic flow is given by $Q_e = K_{ele}A$

- Electro osmotic consolidation means the consolidation of soft clays by the application of electric current.
- It was studied and applied for the first time by Casagrande.
- It is inherent that fine grained clay particles with large interfacial surface will consolidate and generate significant settlement when loaded.
- The settlement creates problem in the foundation engineering.
- Electro osmosis was originally developed as a means of dewatering fine grained soils for the consolidation and strengthening of soft saturated clayey soils.
- Electro osmotic dewatering essentially involves applying a small electric potential across the sediment layer.
- It is the process where in positively charged ions move from anode to cathode. ie. Water moves from anode to cathode where it can be collected and pumped out of soil
- Electro osmotic flow depends on soil nature, water content, pH and on ionic type concentration in the pore water.
- Due to the applied electric potential the electrolysis of water occurs at the electrodes $2H_2O \rightarrow O_2(g) + 4H^+ + 4e^-$ oxidation (anode)

$4H_2O + 4e^- \rightarrow 2H_2(g) + 4OH^-$ reduction (cathode)

- The clay particles have a -ve charge. These -ve charge produce an electro static surface property known as the double layer which creates a net abundance of cations in pore space.
- Electro osmotic transfer of water through clay is a result of diffuse double layer cations in the clay pores being attracted to a negatively charged electrode or cathode.
- When electrodes are placed across saturated clay mass and direct current is applied, water in the clay pore space is transported towards cathode by electro osmosis.
- In addition frictional drag is created by the motion of ions as they move through the clay pores helping to transport additional water.
- The flow generated by the electric gradient is called electro osmotic flow.

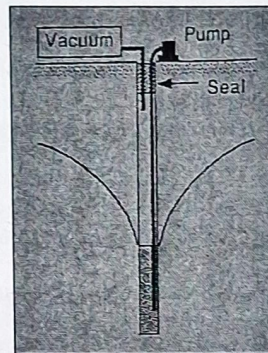
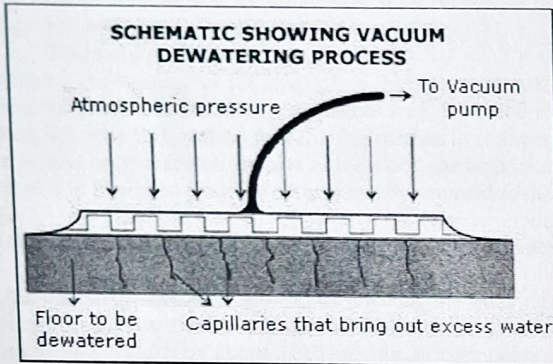
Vacuum Dewatering

- In fine sands and silts, with permeabilities of 10^{-4} to 10^{-6} m/sec, water does not flow freely under the influence of gravity, due to capillary tension. To make dewatering and stabilizing of these soils possible, a vacuum may be applied to the sealed off filter section of well. Seepage into the well is then increased due to the influence of atmospheric pressure. Water inflow is generally low and wells may only require intermittent pumping out.

Vacuum action is also present in well point systems which use a combined vacuum and centrifugal pump, the net vacuum applied at the well point is however only equivalent to the vacuum in the header pipe less the lift in the riser pipe. Care has to be taken that all the connections in the pipe system are alright and an effective seal is formed around the riser pipe in its upper section.

To be effective, vacuum wells have to be spaced very closely say 1 to 2.5m apart. The distance between rows of wells should not be more than 15 to 20m.

Submersible pumps in combination with vacuum pumps could provide dewatering to great depth.



PRELOADING:

Preloading or precompression increases the bearing capacity and reduces the compressibility of weak ground by forcing loose cohesionless soils to densify the clayey, silty soils to consolidate. It is achieved by placing a temporary surcharge on the ground prior to the construction of the planned structure.

Preloading with or without vertical drains is only effective in causing substantial settlement if the total applied load significantly exceeds the preconsolidation pressure of the foundation material.

Several advantages compared to the other ground improvement methods are as follows:

1. The cost involved is comparatively less and vary between 10 to 20% without using vertical drains and 20 to 40 % with the use of vertical drains.
2. Very attractive method when fill is used back as fill material in the site preparation for construction.
3. Simple conventional construction equipment needed for earth moving job is sufficient for the preloading works.
4. Cost of monitoring instruments are cheap
5. Effect of preloading can be observed periodically from the field instrumentation.
6. Provide uniform improved properties of ground.

The reason to adopt this technique depends upon the following:

1. There should not be any base failure during preloading or during the operation of final structure.
2. The duration of preloading should be within the time allotted by the construction schedule.
3. There will be no damage to adjoining structure.
4. There will be no undue disturbance to nearby communities.
5. Settlements after construction will be within range of tolerance.
6. Cost is less compared to other methods.

➤ **Principle:**

Preloading increases the pore pressure in soil and then consolidation occurs, where effective stress increases accompanied by surface settlement. The time required for attainment of full consolidation varies directly as the square of the layer thickness and inversely as the permeability.

The ratio of weight used for preloading to the weight of the final structure to be constructed on the improved soil is called **coefficient of surcharge**

➤ **Preloading Methods:**

Heaping or Dumping of fill materials is the most common method of preloading. In some cases, the material is left and the removed material may be reused in the same project. There is a danger of a base failure in this method, but still this method is commonly used as it is less costly for all types of structures and locations. In most of the cases, the embankment loading is used for preloading which takes 3 to 8 months from the embankment placement to the end of removal of loading. The height of preload in most cases is 3 to 8m above the original grade and where the maximum and minimum heights are 1.5m and 18m respectively with usual settlement ranges between 0.3 to 1m.

Another method of preloading is by lowering the water table. In highly permeable soil effect will be more. As the water table is lowered the effect of buoyancy is lost and the soil above the water table gains unit weight by about 10kN/m^3 . As an approximation, every meter lowering of water table produces settlement that caused by half meter depth of loading by fill. The rate of settlement may be substantially increased by combining the method of lowering the water table and heaping fill.

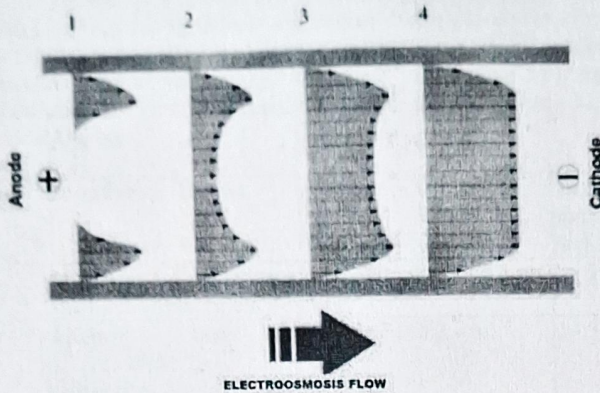
Another method of preloading is inundating or preponding. Lowering of water table is applicable when the water table is high. But when water table is low, a load can be applied to some soil by opposite action, by inundating or preponding the surface. The effect of preponding is breaking loose bonds between particles, increasing surface tension forces and weight of water. The combined effect depending on the type of soil cause adequate densification of soil. This technique is also referred to as hydrocompaction.

Another method was proposed by Kjellman (1952) named as Vacuum Preloading method. In this a 150mm layer of sand is placed on the surface of soft clay, the layer is covered with an impervious membrane. An application of a vacuum of 60 to 80 kPa is induced in the sand which acts as an equivalent overload. In its simplest form the method of vacuum consolidation consists of a system of vertical drains and a drainage layer (sand) on top. It is sealed from atmosphere by an impervious membrane. Horizontal drains are installed in the drainage layer and connected to a vacuum pump. To maintain air tightness, the ends of the membrane are placed at the bottom of a peripheral trench filled e. g. with bentonite. Negative pressure is created in the drainage layer by means of the vacuum pump. The applied negative pressure generates negative pore water pressures, resulting in an increase in effective stress in the soil, which in turn is leading to an accelerated consolidation.

DRAINS:

- **Open Drains:** This method is very old in draining excavations, roads using a ditch or a sump. A sump is said to be a shot ditch which can be constructed even with the unskilled labour.
- **Closed Drains:** When a piping or seepage erosion is creating trouble or where there is desire of permanent drain, the laying of perforated pipe is carried out at a suitable depth in ditches and the ditch is backfilled with suitable filter material. The laying of pipes should be straight. For every

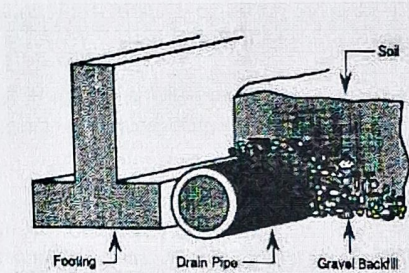
- 30 to 50m there must be openings to flush out the pipe. At 100m to 150m intervals, the manholes must be provided at changes in direction along straight section



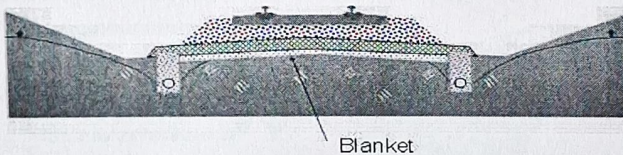
ELECTROOSMOSIS FLOW IN SOIL PORES

Horizontal Drains: If adequate submergence is not available in the situation of field warrant to avoid open-cut work, lowering of ground water can be done with a rainy drainage system. Reinforced concrete shaft or wells are present in this system from which a number of horizontal perforated pipes are fixed. The extension of these pipes may be carried out to a required length in any direction. By using turbine pump, the water collected in the well is pumped out.

- **Foundation Drains:** Used to prevent foundation leaks and building water entry



- **Blanket Drains:** A blanket drain is a drainage structure used to accommodate seepage zones on the road cut. The objective is to disperse low-velocity flows over the hill-slope rather than concentrating them in cross-ditches.



- **Interceptor Drain:** An interceptor drain is a gravel trench that is excavated into a relatively impermeable soil layer and installed to collect and remove groundwater as it flows across the impermeable

Vertical Drains:

Vertical drains are installed to accelerate settlement and gain in strength of soft cohesive soil. Without installing vertical drains, bearing failures may occur during placement of the fill and settlement of clay soils may extend over many years. Because highly efficient drain installation methods have been developed, preloading combined with vertical drains has become an economic alternative to the installation of deep foundation or other method of ground improvement.

Types of Vertical Drains:

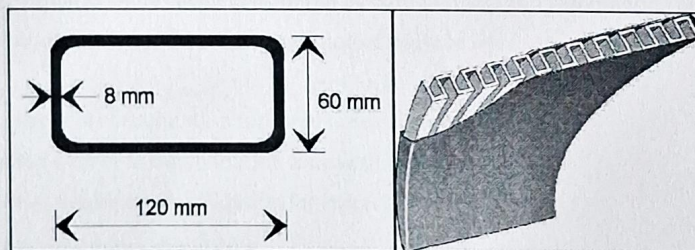
Drain type	Installation method	Drain diameter [m]	Typical spacing [m]	Maximum length [m]
Sand drain	Driven or vibratory closed-end mandrel(displacement type)	0.15 – 0.6	1 - 5	≤ 30
Sand drain	Hollow stem continuous flight auger (low displacement)	0.3 – 0.5	2 - 5	≤ 35
Sand drain	Jetted (non-displacement)	0.2 – 0.3	2 - 5	≤ 30
Prefabricated sand drains (sand-wicks)	Driven or vibratory closed-end mandrel; flight auger; rotary wash boring (displacement or non-displacement)	0.06 – 0.15	1.2 - 4	≤ 30
Prefabricated band-shaped drains	Driven or vibratory closed-end mandrel(displacement or low displacement)	0.05 – 0.1	1.2 – 3.5	≤ 60

➤ Sand drains:

Sand drains simply consisted of boreholes filled with sand. The holes may have been formed by boring or drilling or augering and would have diameters of 200 to 450mm with spacing 1.5 to 6m apart.

A large diameter sand, or gravel drain, in a fine grained soil not only enables consolidation of surrounding material but also provide vertical compressive reinforcement that could transfer surface loads to strong bearing stratum at depths. The higher the reinforcing effect, lower will be the consolidation stresses in the foundation soil. So large diameter gravel drains, therefore would not serve the purpose of preloading.

➤ Prefabricated or Geosynthetic Drains:



DESIGN OF VERTICAL DRAINS:

Many theories have been proposed over the years based upon various assumptions about the homogeneity of the soil, the variations with time of the permeability and coefficient of consolidation, the appropriate hydraulic flow law, drain effects loading rate and creep effects. A review on vertical drains was made by Richart (1959) and Johnson (1970). The basic theory of vertical drains which has been in use till today is Reudulic (1935) and Barron (1948). In this analysis of theories two conditions prevail;

- i. Free-Strain Conditions: Applications of a flexible surcharge load will cause an uneven settlement at the surface and this condition is referred to as free strain condition.
- ii. Equal-Strain Condition: Applications of a rigid surcharge load will cause an equal settlement at the surface and this condition is referred to an equal strain condition.

The theoretical design of vertical drain is based upon the independent behaviour of each drain in the center of a cylindrical soil mass. Considering a element of soil with vertical and radial flow and developing the governing equations similar to one dimensional theory, we have

$$c_v \frac{\partial^2 u_w}{\partial z^2} + c_h \left[\frac{\partial^2 u_w}{\partial r^2} + \frac{1}{r} \frac{\partial u_w}{\partial r} \right] = \frac{\partial u_w}{\partial t} \dots \dots \dots A$$

Where $c_v = \left(\frac{k_v(1+e_0)}{\gamma_w a_v} \right)$ is the coefficient of vertical consolidation and $c_h = \left(\frac{k_h(1+e_0)}{h} \right)$ is the

coefficient of radial or horizontal consolidation, where k_v and k_h are referred to as vertical and horizontal permeabilities.

Equation A is the governing differential equation for three dimensional consolidation and may be considered to consist of two parts:

One dimensional flow:

$$c_v \frac{\partial^2 u_w}{\partial z^2} = \frac{\partial u_w}{\partial t} \dots \dots \dots B$$

Radial Flow:

$$c_h \left[\frac{\partial^2 u_w}{\partial r^2} + \frac{1}{r} \frac{\partial u_w}{\partial r} \right] = \frac{\partial u_w}{\partial t} \dots \dots \dots C$$

A solution of Equation A has been considered by Carilo (1942) as a combination of solutions of equation B and Equation C and accordingly we have

$$1 - U = (1 - U_z)(1 - U_r)$$

Where U = degree of consolidation for three dimensional

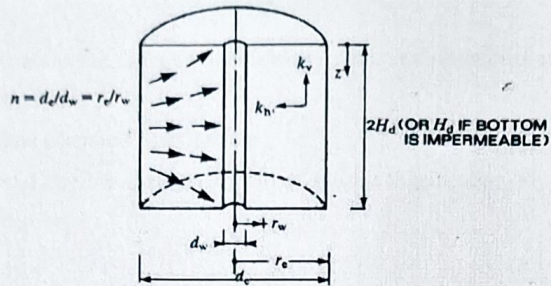
flow U_z = degree of consolidation for one dimensional

flow U_r = degree of consolidation for radial flow

Time factor for one dimensional flow $T_v = \frac{c_v t}{d^2}$

Time factor for radial flow $T_r = \frac{c_v t}{(2r_e)^2}$

Where r_e is radius of influence



Solutions for the equation B was given by Rendulic (1935) for free Strain Condition and by Barron (1948) for equal strain condition. It has been reported by Richart (1959) for values of $n (= r_e/r_w)$ greater than five, both the solutions give almost the same value.

Efficiency of vertical drains: The efficiency of system of vertical drains is assessed with reference to the primary consolidation attained with and without installation of vertical drains has been expressed by Bjerrum (1972)

PHYSICAL AND CHEMICAL STABILISATION

UNIT-III

Objective: To know about the different stabilisation techniques available to strengthen the soil for constructions and other works.

Syllabus: Physical and Chemical Stabilization

Cement Stabilization, Lime Stabilization, Calcium Chloride Stabilization, Fly ash Stabilization and Bitumen Stabilization.

Outcomes:

Student will be able to

- Know different methods of stabilisations
- Idealize the working procedure involved in each method
- Know about different functions and suitability of each stabilising process

LEARNING MATERIAL

CEMENT STABILISATION:

Cement stabilization is done by mixing pulverised soil and Portland cement with water and compacting the mix to attain a strong material. The material obtained thus obtained is called soil-cement.

Types of soil cement:

1. **Normal soil cement:** It consists of 5 to 14% cement by volume. The quantity of cement mixed with soil is sufficient to produce a hard and durable construction material. The amount of water used should be just sufficient to satisfy hydration requirements of the cement to make workable.
2. **Plastic soil cement:** This type of soil cement also contains cement 5 to 14% by volume, but it has more quantity of water to have wet consistency similar to that of plastering mortar at the time of placement. The plastic soil cement can be placed on steep or irregular slopes where it is difficult to use normal road making equipment. The plastic soil cement can be used for protection of steep slopes against erosive action of water.

3. **Cement Modified Soil:** It is a type of soil cement that contains less than 5% of cement by volume. As quantity of cement is small, it is not able to bind all the soil particles but it reduces the swelling and shrinkage properties of the soil.

The important factors affecting the soil-cement are nature of soil content, conditions of mixing, compaction, curing and admixtures used.

Factors affecting cement stabilization:

- a) **Type of soil:** Granular soils with sufficient fines are ideally suited for cement stabilization. Such soils can be easily pulverized and mixed. They require least amount of cement.

Granular soils with deficient fines can be stabilized but require more cement. Whereas, silty and clayey soils can produce soil cement but with high clay content in soil is difficult to pulverize. Moreover, the quantity of cement required is more for high clay content is more.

- b) **Quantity of Cement:** A well graded soil requires about 5% cement, whereas poorly graded; uniform sand may require about 9% cement. Non plastic silts require about 10% cement, whereas plastic clays may need about 13% cement.

The actual quantity of cement required for a particular soil is ascertained by laboratory tests. To determine quantity of cement durability tests are conducted which consists of 12 cycles of wetting and drying with a volume change of 2% that is permitted.

Sometimes quantity of cement is determined according to minimum unconfined compressive strength which is generally considered as 1500kN/m^2 for clayey soils and 5500kN/m^2 for sandy soils. High strength is obtained by decreasing the water cement ratio. As a rough guide, 6% of cement for sandy soils and 15% for clayey soils is considered.

- c) **Quantity of water:** The quantity of water used must be sufficient for hydration of cement and silt clay cement. Water used should be clean and free from harmful salts, alkalies, acids or organic matter.
- d) **Mixing, Compaction and Curing:** The mixture of soil, cement and water should be thoroughly mixed, as the success of cement stabilisation depends mainly on thorough mixing. If it is not mixed properly, it may results in non-homogeneous weak product.

Soil cement should be properly compacted. For good results, fine grained soils compacted at wet of optimum and coarse grained soils compacted at dry of optimum.

- e) **Admixture:** To increase the effectiveness of cement as stabilizer, admixtures are sometimes added to soil cement as a replacement of cement in the mix which reduces cement content. Lime and calcium chloride used for harmful organic matter to make them more responsive to cement. Likewise Flyash for dune sand, and many more like sodium carbonates and sodium sulphates.

Construction Methods:

MIX IN PLACE METHODS: In this method of construction, mixing of soil cement is done at the place where it would be finally placed.

The subgrade is cleared of all undesirable material and levelled and the material on subgrade is pulverized till at 80% of soil passes 4.75mm IS sieve which can be done manually or mechanically with help of machine. The pulverized material is spread uniformly and required quantity of water is sprinkled over the surface and wet mixing is done till the mixture is uniform. Compaction should be done by suitable machines. The compacted soil- cement is moist cured for at least 7 days by providing a bituminous primary coat.

PLANT MIX METHOD:

Stationary plant: In this method, the excavated soil is transported to a stationary plant located at a suitable place. Then required quantity of cement is added to the soil in the plant with proper mixing is done after applying water into the plant. The mixed material is then discharged into dumpers, trucks and transported back to the area subgrade to be made ready. Uniform mix can be obtained in this method.

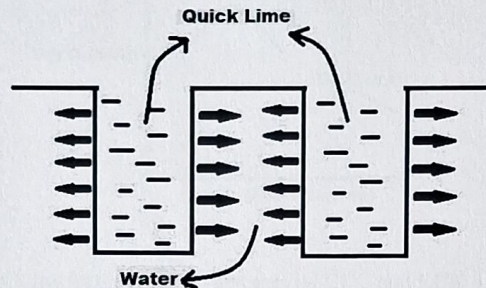
Quite expensive method compared to mix in place method.

Travelling Plant: A travelling plant can move along the road under construction. The soil after placement of cement is lifted up by an elevator and discharged into the hopper of the mixer of the travelling plant. Water is added and proper mixing is done. The mix is then discharged on the subgrade and spread by a grader. It is then properly compacted.

LIME STABILISATION

Soil lime reactions:

1. **Hydration:** Quick lime will absorb moisture from the soil and reacts instantly. This reaction is known as slaking of lime, which will increase its volume by 2.25 times of its volume, thus exerting large lateral thrust on the sides of bore holes. The process of removal of water from soft soil completely with the lateral pressure causes consolidation of the clay bed.

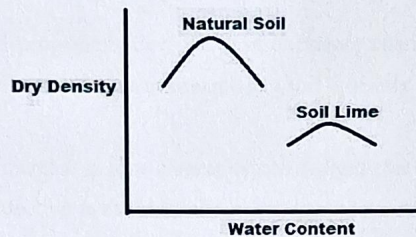


2. **Flocculation:** Replacement of monovalent cations like sodium, lithium, etc by divalent cations from lime decreases the thickness of double layer water around the clay mineral particles, thus increasing the attracting forces between the soil particles. This helps soil particles to flocculate together, thus reducing their specific surface area which brings down the activity of clay.
3. **Cementation:** When lime is added to clay, its pH value increases beyond 12 where the silica and alumina from the clay particles will be liberated due to high alkalinity. Calcium from lime reacts with the silica and alumina in the presence of water, thus forming hydrated calcium silicate and calcium alumino silicate hydrates which are cementing compounds. However requires large time period for reactions.
4. **Carbonation:** It involves absorption of CO_2 from the atmosphere and the formation of CaCO_3 and MgCO_3 . The contribution of carbonation is generally negligible.



Engineering properties of Lime stabilisation:

1. **Plasticity:** Upon addition of lime, the plasticity of clayey soils will be thoroughly modified by the cation exchange. The soil becomes workable and friable thus making compaction possible.
2. **Dry density:** The OMC of lime stabilized soil increases with the corresponding reduction in the dry density. However, the compaction curve becomes flatter making soil irresponsive to moisture changes.



3. **Strength:** The addition of lime to soil increases its UCC and CBR upto an optimum lime content and thereafter decreases due to the presence of free lime.
4. **Permeability:** The permeability of lime stabilized soils increases due to the flocculated structure with the larger size of pores. The increased value of k helps to relieve the developed pore water pressures quickly.
5. **Swelling and Shrinkage:** Treatment of expansive clays by lime helps to reduce the degree of volume change.

Mechanism/Applications of soil lime:

It is used to modify the clayey soils or used as binder. Clayey soils of high plasticity are treated with lime and the plasticity is decreased, the soil becomes friable and easy to pulverize, have less affinity with water. Lime imparts binding action in granular soils.

In fine grained soils, due to pozzolonic action, with the addition of cement, the strength will be increasing.

When clay is treated with lime, the various possible reactions are:

1. Base Exchange
2. Coagulation or flocculation
3. Reduction in the thickness of water film around the clay particles.
4. Cementing action
5. Carbonation

Uses of Soil Lime:

- Quite suitable as sub base courses for pavements
- Used as a base course for pavements with low traffic.
- Soil lime cannot be used as surface course even for light traffic in view of its very poor resistance to abrasion and impact.
- Soil lime is quite suitable in warm regions but not suitable for freezing temperatures.

Factors affecting the properties of soil lime:

1. **Soil type:** The soil properties affect the base exchange characteristics and puzzolonic action. The proportion of increase in strength in a soil lime mix depends on the puzzolone in the soil.
2. **Lime content:** An increase in lime content causes a slight change in liquid limit and also in plastic limit. Reduction in the plasticity index, increase in the compressive strength is also observed with the curing time.
3. **Compaction:** It is done at OMC and MDD. The maximum dry density can be obtained at the optimum of lime content.
4. **Curing:** The strength of soil lime increases with the curing period of several years. The rate of increase in strength is rapid during the initial period of curing which also depends on temperature.

At low temperature the rate of strength gain decreases considerably and below freezing point, practically there is no gain in strength. The humidity of the surrounding during curing also affects the strength.

5. **Additives:** Addition of lime alone with soil often does not increase the strength of the mix as desired. Portland cement, Puzzolonic materials like fly ash, steel slag, and surkhi are used at the desired percentages. Chemical additives like sodium metasilicate, sodium hydroxide and sodium sulphate are useful to stabilize lime soil for desirable strength.

Construction of soil lime base course:

Materials: The soil to be stabilized is scarified. Even high plastic soils can also be suitably modified by lime for OMC and MDD. Fresh stock of hydrated lime or quick lime can be used. It is desirable that the lime available is made of fine powder.

Plants and Equipment: The equipment needed is for scarifying, mixing and compaction

Construction Steps:

- Preparation of subgrade
- Pulverization of soil to be stabilized
- Addition of part of lime as dry powder or as slurry with water and mixing
- Allowing the mixture to age for about a day, thus remixing becomes easy.
- Adding the rest of the lime and water, if necessary and remixing
- Spreading to the desired rate and compaction
- The soil lime is protected from drying out and it allows moist curing.
- Field control tests include checking moisture content at the time of compaction and checking dry density soon after the compaction.

BITUMINOUS STABILISATION

Bitumen a petroleum product obtained by the destructive distillation of crude petroleum. Tar is obtained by the destructive distillation of coal. Asphalt consists of inert mineral particles cemented by bitumen. The use of all three minerals in soil stabilisation is collectively called as bituminous stabilization. It can be adopted for clay and sands provided they can be mixed with bitumen. In clays it helps to repel water making it insensitive to moisture changes. In cohesionless soils, bitumen binds the particles.

Types of Soil-Bitumen:

1. **Soil Bitumen:** It is a water proofed cohesive soil system. It consists of 4-7% bitumen.
2. **Sand Bitumen:** Sand Particles are cemented together with bitumen. It consists of 4-10% bitumen.
3. **Water Proofed Granular soils:** Granular soils with low plastic fines can be stabilized using a small percentage of bitumen (1-2%).
4. **Oiled Earth:** A Bituminous emulsion or cut back is sprayed on the soil surface to make it water proof. It requires 4-5 litres of bitumen per m³. Normally bitumen is applied in the form of emulsion.

Engineering Properties of Soil Bitumen:

1. **Optimum Moisture Content:** Stabilisation of soil with bitumen results in the reduced dry density and also reduced OMC. The reduction in OMC is attributed to the additional lubrication effect of bitumen.
2. **Strength:** The UCC of soil bitumen increases upto an optimum content and thereafter decreases.
3. The performance of the soil bitumen in practise depends on the % fines in the soil. Higher % fines increases the dry density but softens the material under wet condition.

Principle of Soil Bitumen:

The principle involved in soil bitumen is its water proofing and binding characteristics. By water proofing, the inherent strength and other properties of the soil could be retained. For soils, both binding and water proofing action are provided. In granular soils, the coarser grains may be individually coated and struck together by a thin film of bituminous material. In fine grained soils, bituminous material plugs up the voids between the small soil clogs and thus water proofing the compacted soil bitumen. Most commonly used materials are cut back or emulsions.

Factors affecting the properties of soil bitumen:

1. **Soil type:** Depends on the particle size, shape and gradation. Small portion of fines in the soil is preferable. High clay content is not desirable.
2. **Proportion of bituminous material:**
 - i. **Type of bituminous material:** Cut back of different grades give different stability values of soil. Higher grade and type of cut back is preferred. Emulsions generally give slightly inferior results than cut-back.
 - ii. **Amount of Bitumen:** Increasing percentage of bitumen causes a decrease in the maximum dry density of soil bitumen. Stability increases upto an optimum of bituminous content and then decreases with the increase in the percentage of bitumen content.
3. **Mixing:** Low mixing period and uniform mixing is required. Mix the soil first and then add the cut back.
4. **Compaction:** Better the compaction, higher will be the stability and resistance to absorb water. Also depends on the compaction moisture content and the temperature.
5. **Curing:** Air curing or curing with the open atmosphere. The water and the volatiles are evaporated and the bitumen to be effective to impart the binding and water proofing action. Depends on the curing temperature, humidity and soil type.
6. **Additives:** Anti-stripping and reactive chemical additives have been tried to improve the properties of the mix with varying degree of success. Portland cement is also sometimes used along with soil bitumen to increase the stability of the mix.

Construction of Bituminous Stabilized layer:

1. **Materials:** Soil is pulverized and stacked. Properties of soil to be preferred are as follows:

Passing through 4.75mm sieve	<50%
Passing through 0.425mm Sieve	35 – 100%
Passing through 0.075mm Sieve	10 – 50%
Liquid Limit	< 40%
Plastic Limit	< 18%

2. **Plants and Equipment:** Plants and equipment are needed for scarifying, pulverising, mixing and compaction.

3. **Construction Steps:**

- The soil to be stabilized is pulverised.
- Water is added to the soil and then mixed.
- Cut back or emulsion is added.
- The mix is spread, graded and compacted.
- The compacted layer is allowed to cure, where the moisture and volatiles of the solvent evaporate from the soil mass.

Field control tests include the following:

- i. Checking of pulverization of wet mixed soil.
- ii. Checking of moisture content and bitumen before compaction.
- iii. Checking of dry density of compaction.

CALCIUM CHLORIDE STABILIZATION:

Calcium Chloride has been used in highway construction & maintenance. It is generally a by- product in making sodium carbonate or from other chemical processes. In Australia, it is available as PACWET, obtained by reacting lime or limestone with hydrochloric acid (HCl) ie., by-product in manufacture of fluorocarbons.

Physical Properties:

It is an inorganic salt with a number of physical properties which makes advantageous to Geotechnical Engineering.

- **Hygroscopicity:** Calcium chloride is hygroscopic, which attracts and absorbs moisture content from atmosphere ie., a function of relative humidity and temperature.
- **Deliquescence:** A deliquescent substance is one that liquefies in moisture of its own absorption. (Becoming liquid or having a tendency to become liquid).
- **Solubility:** Calcium chloride is highly soluble (59.5g/ 100ml of water). According to Slessor(1943), solubility of substance in water is a major factor that determine the extent of which vapour pressure, density, freezing point of water can be altered by addition.
- **Vapour Pressure:** Tendency of a substance to pass from liquid/solid to gaseous state. Vapour pressure of a calcium chloride solution is always lower than that of water.
- **Surface tension:** Calcium chloride has higher surface tension than water.
- **Freezing point:** Calcium chloride has lower freezing point than water completing freezing of calcium chloride occurs at -51°C .

Effects of soil Properties:

- **Soil Structure:** Calcium chloride has several physico-chemical effects on fine grained component of soil. If sodium ions (Na^+) are present around negatively charged clay surface, They will be replaced with calcium (Ca^{++}), which reduces the thickness of double layer, upon lowers plasticity and increases strength by strengthening molecular bonds between particles.
- **Compaction properties:** In Gravelly clay soils, if calcium chloride is added it attributes to increased surface tension of moisture and increased density of pore water. However, calcium chloride reduces evapourative water losses from soil that facilitates moisture content during construction and controls of dust generation on unpaved roads.

Uses:

- The most appreciated use of calcium chloride is as adust palliative on highly trafficked unpaved roads where causes problems of poor visibility, increased vehicle wear and adversely effects the environment. So keeping the road surface moist, less dust will be created where addition of calcium chloride helps keeping the moisture content for a longer period.
- As a secondary additive also bring benefits in cement or lime stabilization by increasing early strength values with a minimum of 0.5 to 1.5% of calcium chloride addition.
- Many uses of Calcium chloride can be found in electro-kinetic stabilization & grouting.

Construction Steps: The same process as if in lime stabilization can be done.

FLY ASH STABILIZATION:

Fly ash is a solid waste product created by the combustion of coal. It is carried out of the boiler by the flue gasses and extracted by electrostatic precipitators or cyclone separators and filter bags. Its appearance is generally that of a light to dark gray powder of predominantly silt size.

Making more productive use of fly ash would have considerable environmental benefits with reduced land, air and water pollution. Increased use as a partial cement or lime replacement would also represent a savings in energy (Fly ash has been called a high energy waste material).

Besides using fly ash alone as a structural fill material, scope exists for employing techniques of ground modification to find more medium to high volume applications in the following ways:

- Add cement or lime to stabilize the fly ash.
- Stabilize soils with cement lime fly ash mixes.
- Use fly ash in the containment of toxic wastes.

Properties of fly ash:

- Chemical composition and reactivity: A microscopic view of fly ash reveals mainly glassy spheres with some crystalline and carbonaceous matter. The principal chemical constituents are silica(SiO_2), Alumina(Al_2O_3), ferric oxide (Fe_2O_3) and calcium oxide (CaO). Other components are magnesium Oxide (MgO), Titanium Oxide (TiO_2), Alkalies (Na_2O and K_2O), Sulphur trioxide (SO_3), Phosphorous Oxide (P_2O_5).
- Water added to fly ash usually creates an alkaline solution, with a pH ranging from 6 to 11.
- Fly ash is a heterogeneous material.
- Factors affecting the physical, chemical, and engineering properties of fly ash include:
 - Coal type and purity
 - Degree of pulverization
 - Boiler type and operation
 - Collection and stockpiling methods
- In this process, Cementitious calcium silicate and calcium aluminosilicate hydrates are formed when glassy components of the fly ash react with water and lime.
- Critical to the pozzolanicity of the fly ash are conditions such as
 - Amount of silica and alumina in the fly ash
 - Presence of moisture and lime
 - Fineness of the fly ash
 - Low carbon content
- The degree of self hardening of ash is also highly dependent on the ash's density, temperature and age.

Engineering Properties:

- The specific gravity of the ash particle ranges from 1.9 to 2.5, which is below that of soil solids.
- The average grain size D_{50} of fly ash is likely to be in the range of 0.02 to 0.06mm. Fly ash is non plastic and in dry state it is cohesionless. The lack of cohesion makes non hardening fly ash highly erodible. In moist state, surface tension of the pore water gives fly ash an apparent cohesion and when pozzolanic reaction occurs, unconfined compression strength is increased with age.
- Compacted ash may have a dry density between 1.2 and 1.9 t/m^3 with a corresponding optimum moisture content from 30 to 15% respectively.
- Compression index of fly ash can range from 0.05 to 0.37 for initial loading. In recompression, these values are much lower of 0.006 to 0.04.

Effect of other material with fly ash for stabilization:

- For cohesionless soils or soils with low plasticity, cement will be more effective than lime, either alone or combined with fly ash.
- For more plastic soils, either cement or lime may be added with fly ash.

