Short Term Training Program

Innovative Approaches to Road Safety and Material Engineering (IARSME 2026)

NERIST, Arunachal Pradesh

Mechanistic Behaviour of Soil Subgrade in Post-Mud Pumping Scenario

Dr. Arindam Dey

Associate Professor

Geotechnical Engineering Division

Department of Civil Engineering

Center for Disaster Management and Research (CDMR)

IIT Guwahati

Introduction

Why we need pavement?

General perspective: Infrastructure development of a country and To improve connectivity between different places.

Engineering Perspective: Constructed to distribute the traffic load safely to the subgrade.

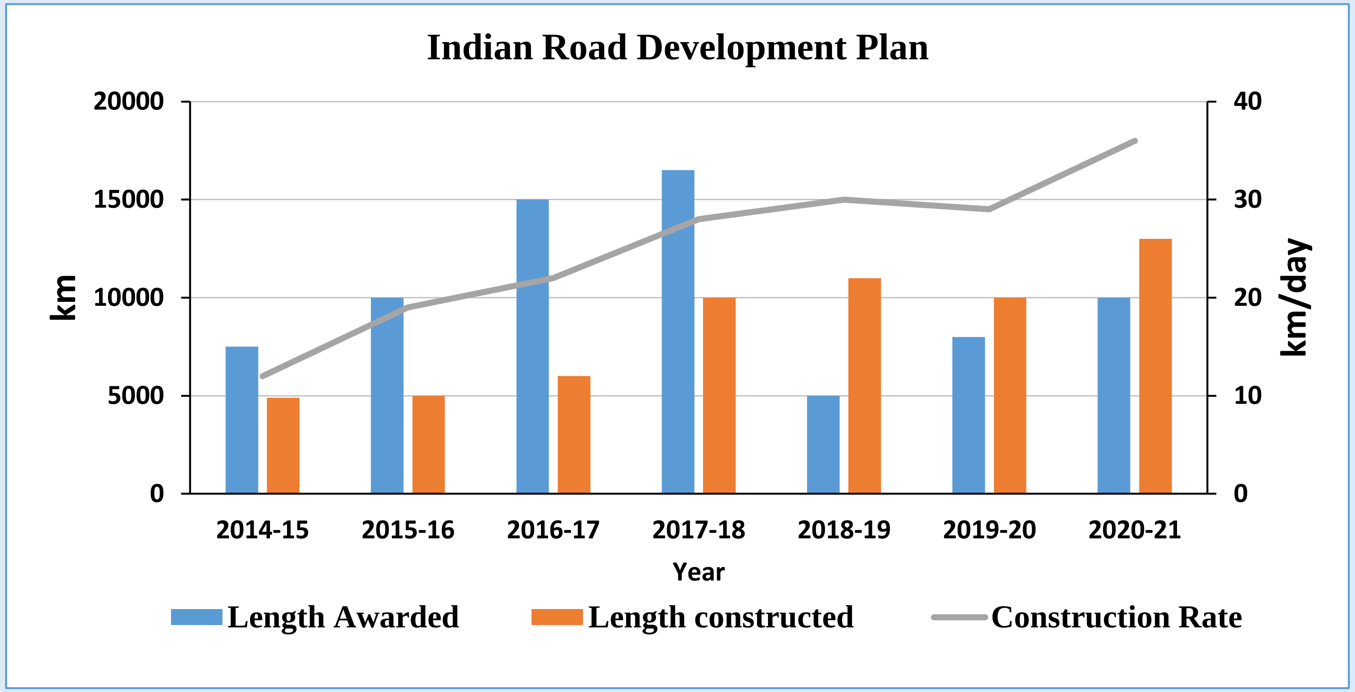
Ref: https://images.app.goo.gl/XrPJFSB1kfdRZmFa6

Ref: https://images.app.goo.gl/EFsvwKdn4Bc2FHWg8

Introduction

Road Pavement Development plans:

The **Ministry of Road Transport and Highways (MORTH)** aims to develop a national highway network of 200,000 km by 2025. The government aims to spend about Rs. 17 trillion on the highways sector in the next five years.



Ref: Road Development India (2021-2022) Report

Introduction

Problems associated with construction of pavement

The one of the major problems involved in pavement construction are the presence of weak subgrade, which leads to different types of pavement failure.

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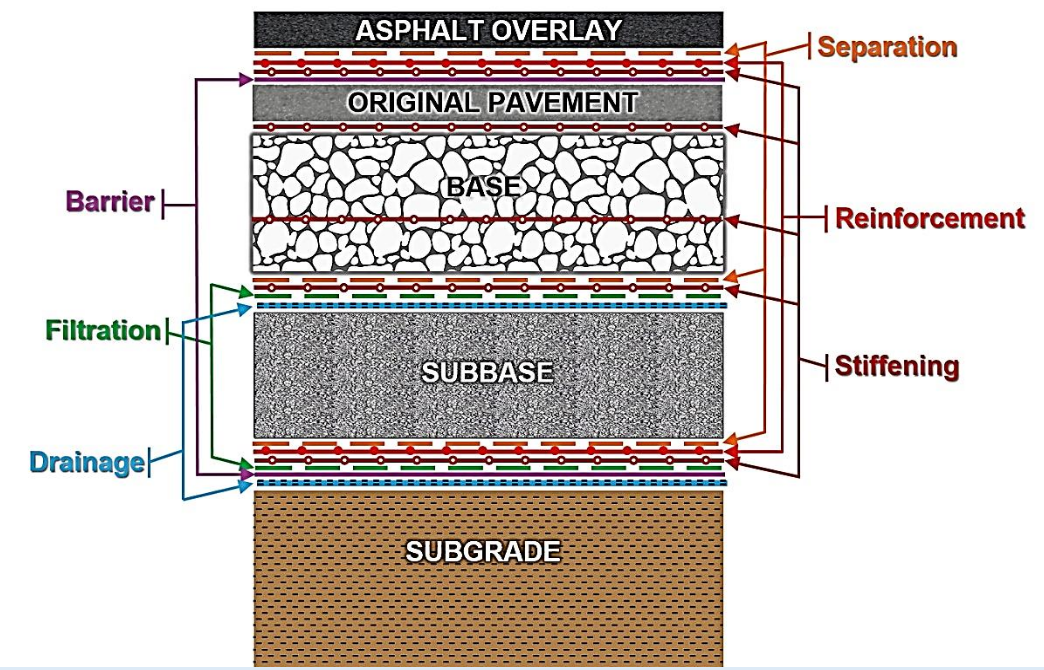
Introduction

Geosynthetic materials and their function in pavement

- Geosynthetic material is generally made up of **High-Density Polyethylene (HDPE)** material.
- The basic functions of the geosynthetic material in the pavement are **separation, filtration, drainage, barrier and reinforcement.**



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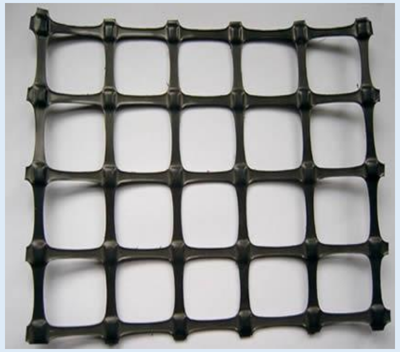
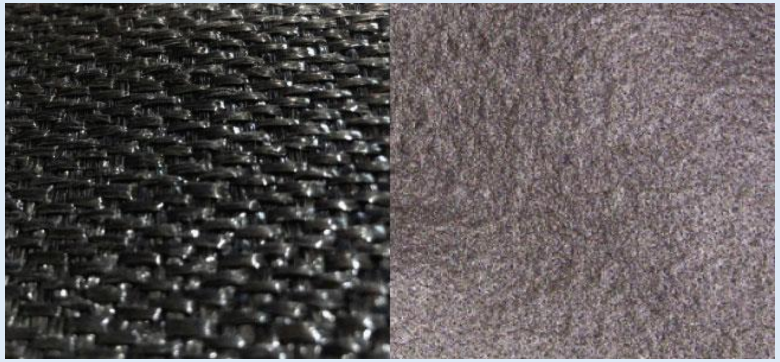


Geogrid



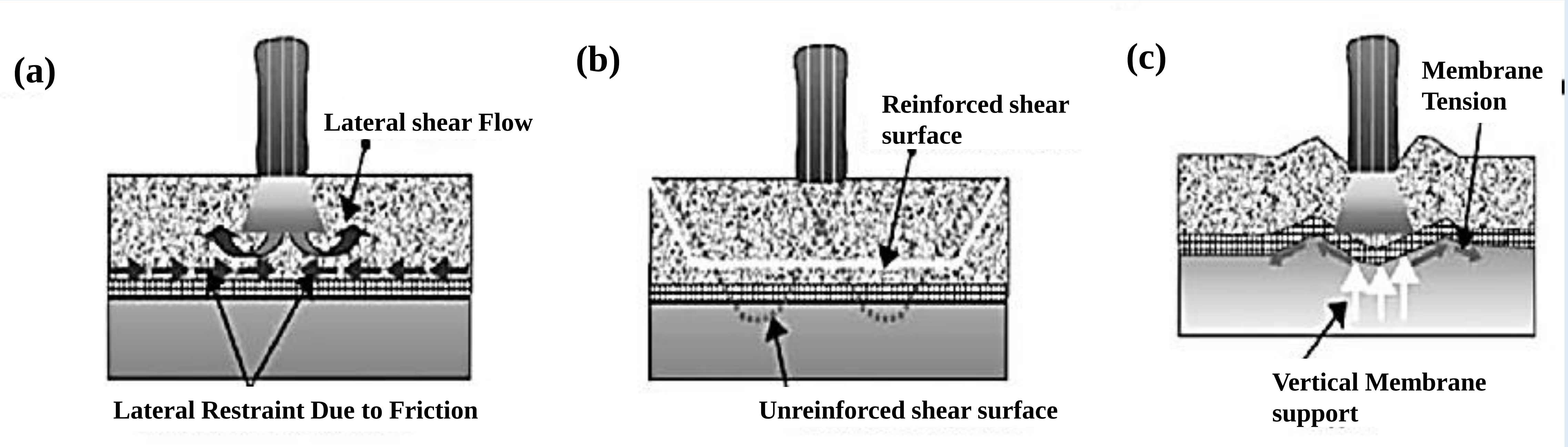
Woven and Non-Woven geotextile

Ref: https://images.app.goo.gl/osSDpYEu3SCk7KkU; https://images.app.goo.gl/cgMAnwykLehqBiNf87

Introduction

Geosynthetic materials and their function in pavement

The basic mechanism of the reinforcement function of geosynthetic in pavement application.



Ref: (Haliburton et al., 1981)

Discussion

Design Practices – Conventional flexible pavement

Layer coefficient approach and Traffic Benefit ratio approach (AASHTO, 1993)

Layer coefficient approach – The strength of the pavement layer is evaluated in terms of structural number, which helps to provide the required thickness of the pavement

$$SN = a_1 \, x \, D_1 + a_2 \, x \, D_2 \, x \, m_2 + a_3 \, x \, D_3 \, x \, m_3$$

Asphalt concrete	Base	Subbase

Where,
a – Layer coefficient; D – Thickness of the layer
m – Drainage coefficient

Traffic Benefit ratio (TBR) - The improvement over the service life of the pavement is represented in terms of TBR

$$TBR = \frac{Cumulative\ number\ of\ load\ cycles\ for\ the\ reinforced\ section}{Cumulative\ number\ of\ load\ cycles\ for\ the\ unreinforced\ section}$$

(at same rut depth)

Design Practices - Conventional flexible pavement

American Association of State Highway and Transportation Officials (AASHTO) – proposed a layer coefficient approach for designing the flexible pavement structure.

$$SN = a_1 \, x \, D_1 + a_2 \, x \, D_2 \, x \, m_2 + a_3 \, x \, D_3 \, x \, m_3$$

Asphalt concrete | Base | Subbase

Where,

SN = Structural number of the pavement

$a_i = i^{th}$ *Layer coefficient*

$D_i = i^{th}$ *Layer thickness*

$m_i = i^{th}$ *Layer Drainage coefficient*

Layer Coefficient:

$a_2 = 0.249 \, M_R - 0.977$ (Base course)

$a_3 = 0.249 \, M_R - 0.839$ (Subbase course)

$* \, M_R =$ *Resilient Modulus*

Discussion

Design Practices - Conventional flexible pavement

American Association of State Highway and Transportation Officials (AASTHO) – proposed a layer coefficient approach for designing the flexible pavement structure.

$$SN = a_1 \, x \, D_1 + a_2 \, x \, D_2 \, x \, m_2 + a_3 \, x \, D_3 \, x \, m_3$$

Asphalt concrete | **Base** | **Subbase**

Where,

SN = **Structural number of the pavement**

$a_i = i^{th}$ *Layer coefficient*

$D_i = i^{th}$ *Layer thickness*

$m_i = i^{th}$ *Layer Drainage coefficient*

Drainage Coefficient:

Calculated based on the permeability of the material and the time of exposure to the moisture levels approaching to saturation.

Discussion

Design Practices - Conventional flexible pavement

American Association of State Highway and Transportation Officials (AASTHO) – proposed a layer coefficient approach for designing the flexible pavement structure.

Recommended drainage coefficient by (AASHTO, 1993)

Quality of drainage		Percentage of time pavement structure is exposed to moisture levels approaching saturation			
Rating	**Water removed within**	**Less than 1%**	**1-5%**	**5-25%**	**Greater than 25%**
Excellent	2 hours	1.40 - 1.35	1.35 - 1.30	1.30 - 1.20	1.20
Good	1 day	1.35 - 1.25	1.25 - 1.15	1.15 - 1.00	1.00
Fair	1 week	1.25-1.15	1.15-1.05	1.00-0.80	0.80
Poor	1 month	1.15-1.05	1.05-0.80	0.80-0.60	0.60
Very poor	Never drain	1.05-0.95	0.95-0.75	0.75-0.40	0.40

Literature Review

Design Practices – Geosynthetic reinforced flexible pavement

Giroud and Han (2013) – Introduced the **Modulus of Improvement factor (MIF)** in the layer coefficient approach to include the benefit of geosynthetic reinforcement in the reinforced flexible pavement design.

Modulus of Improvement Factor:

$$MIF = \frac{E_{bcr}}{E_{bcu}}$$

*E_{bcr} is the elastic modulus of the reinforced section

*E_{bcu} is the elastic modulus of the unreinforced section

Layer Coefficient Ratio:

$$LCR = \frac{0.249 \text{ x } log_{10}\left(MIF \text{ x } \frac{M_{ru}}{0.0069}\right) - 0.977}{0.249 \text{ x } log_{10}\left(\frac{M_{ru}}{0.0069}\right) - 0.977}$$

$$SN = a_1 \text{ x } D_1 + a_2 \text{ x } D_2 \text{ x } m_2 \text{ x } LCR_2 + a_3 \text{ x } D_3 \text{ x } m_3 \text{ x } LCR_3$$

Asphalt concrete | Base | Subbase

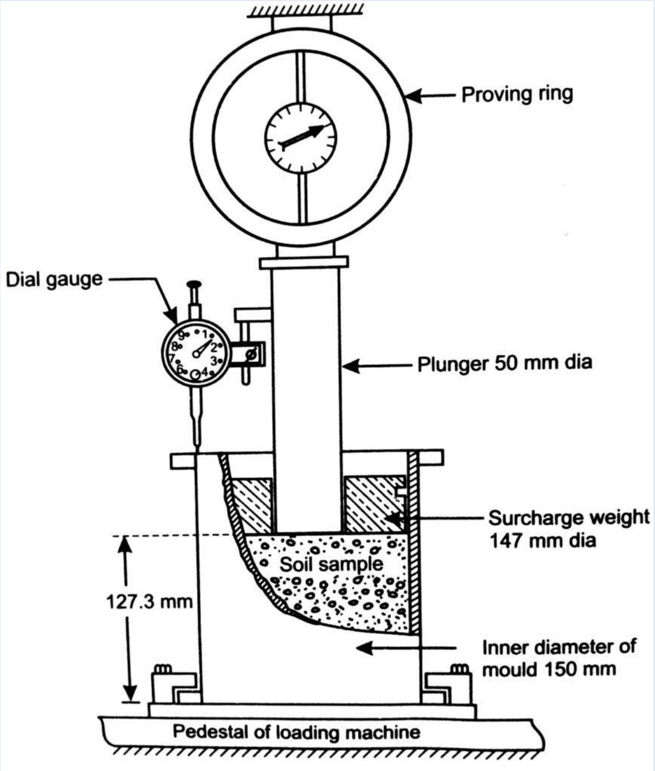
Where,

$$LCR_i = i^{th} Layer\ coefficient\ ratio$$

For all range of CBR

Design Practices – Geosynthetic reinforced flexible pavement

California Bearing Ratio (CBR) – Strength representative test for granular materials.



CBR	Value
3% and less	Poor or weak
3% - 5%	Normal
5% - 15%	Good

From the IRC: 37 -2019 guidelines:

$$M_{Rs} = 10\ x\ CBR \qquad for\ CBR \leq 5\%$$
$$M_{Rs} = 17.6\ x\ (CBR)^{0.64} \qquad for\ CBR > 5\%$$
$$*\ M_R = Resilient\ Modulus$$

Ref: https://images.app.goo.gl/1xtUQ3fBskmnLwww8

Discussion

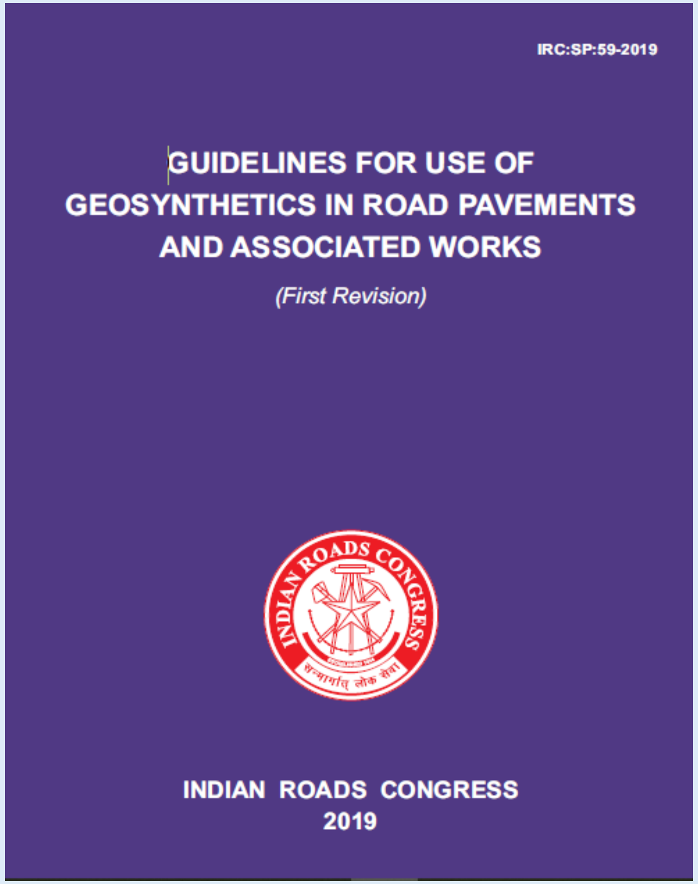
Design Practices - Geosynthetic reinforced flexible pavement

IRC: SP:59 - 2019 – A Guidelines for the Use of Geosynthetics in Road Pavements and Associated Works.

Mechanistic-Empirical Methods: The Mechanistic-Empirical method of design is based on the mechanics of materials that relates an input such, as a wheel load, to an output pavement response such as stress or strain.

LCR&MIF value recommended by IRC (**IRC: SP 59-2019**)

S.No	CBR	Geogrid	
		LCR	MIF
1	<3%	1.2-1.8	1.2-2
2	>3%	1.2-1.6	

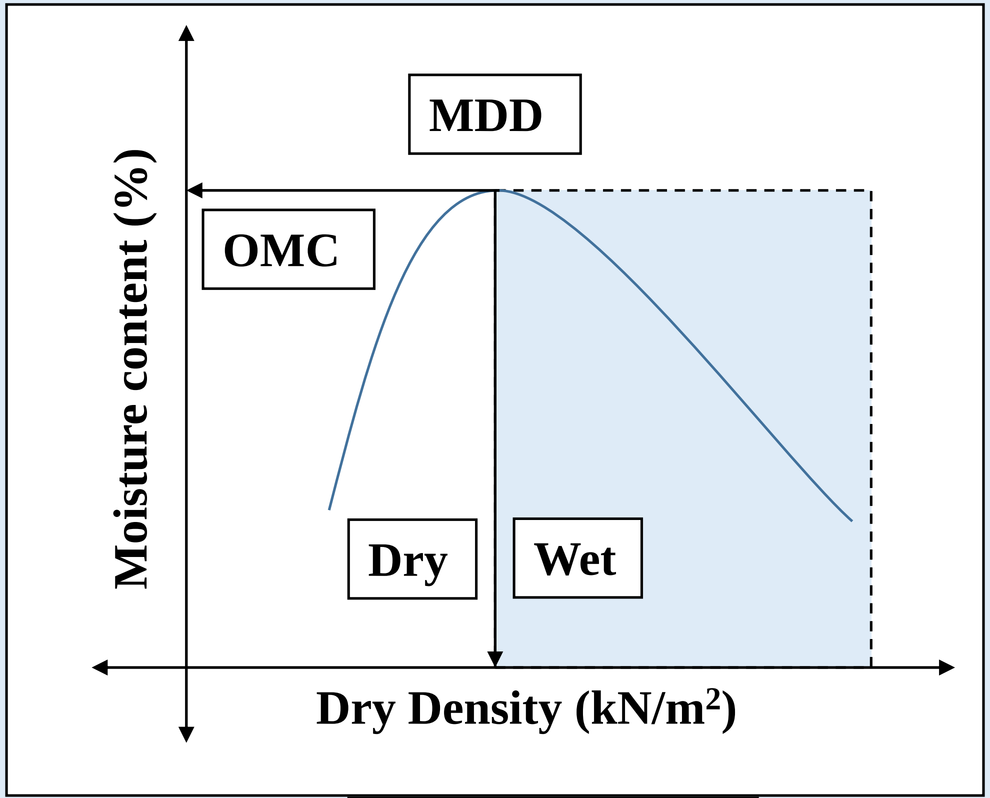


Literature Review

Design Practices - Geosynthetic reinforced flexible pavement

Saride and Baadiga (2021) – Developed a modified Layer coefficient approach for the soft subgrade (CBR – 2-5%)

Soil properties	Value
Specific gravity	2.71
Liquid limit (%)	48
Plasticity index (%)	24
Silt content (%)	23
Clay content (%)	27
Dry density (kN/m^3)	19
Optimum moisture content (%)	14.5

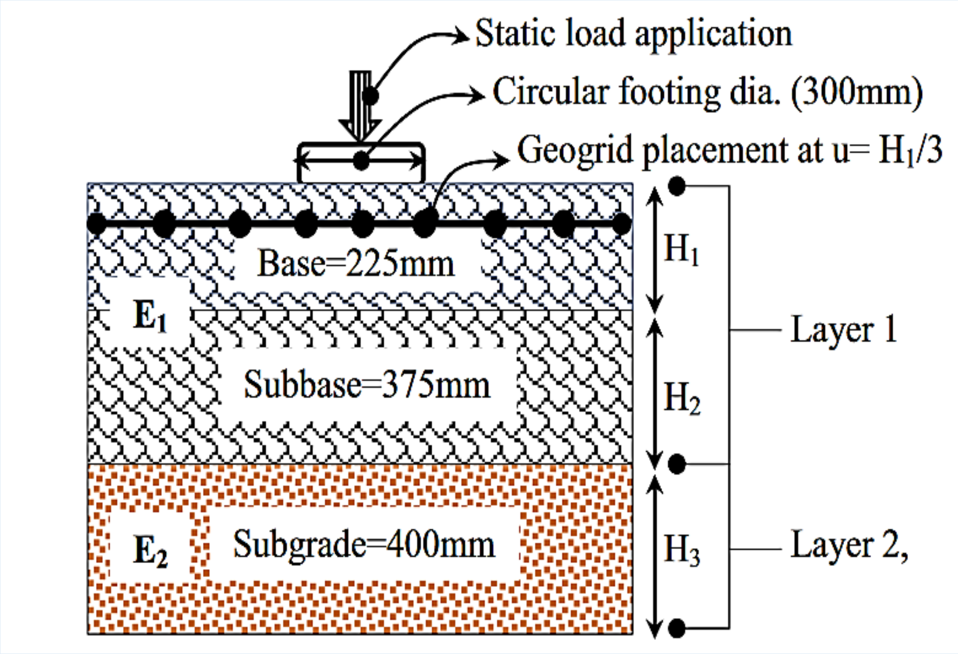


Compaction curve

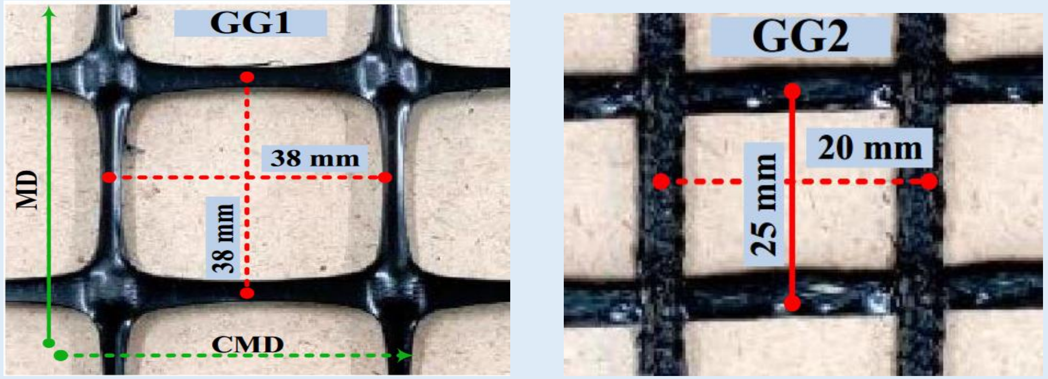
Literature Review

Design Practices - Geosynthetic reinforced flexible pavement

Saride and Baadiga (2021) – Developed a modified Layer coefficient approach for the soft subgrade (CBR – 2-5%)



The thickness of the pavement layer chosen from IRC: 37 – 2018 guidelines w.r.t CBR value of subgrade.



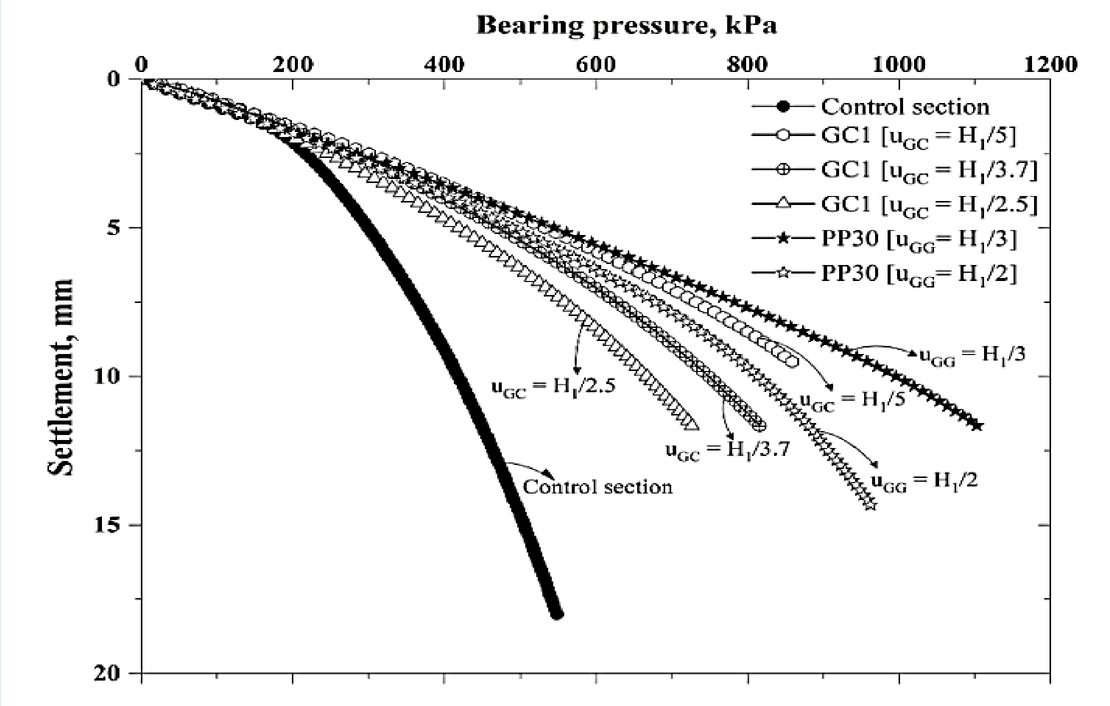
GG 1 = PP30 (Polypropylene Geogrid)
GG 2 = PET60 (Polyester Geogrid)

Polypropylene geogrid has higher rigidity modulus than the Polyester geogrid

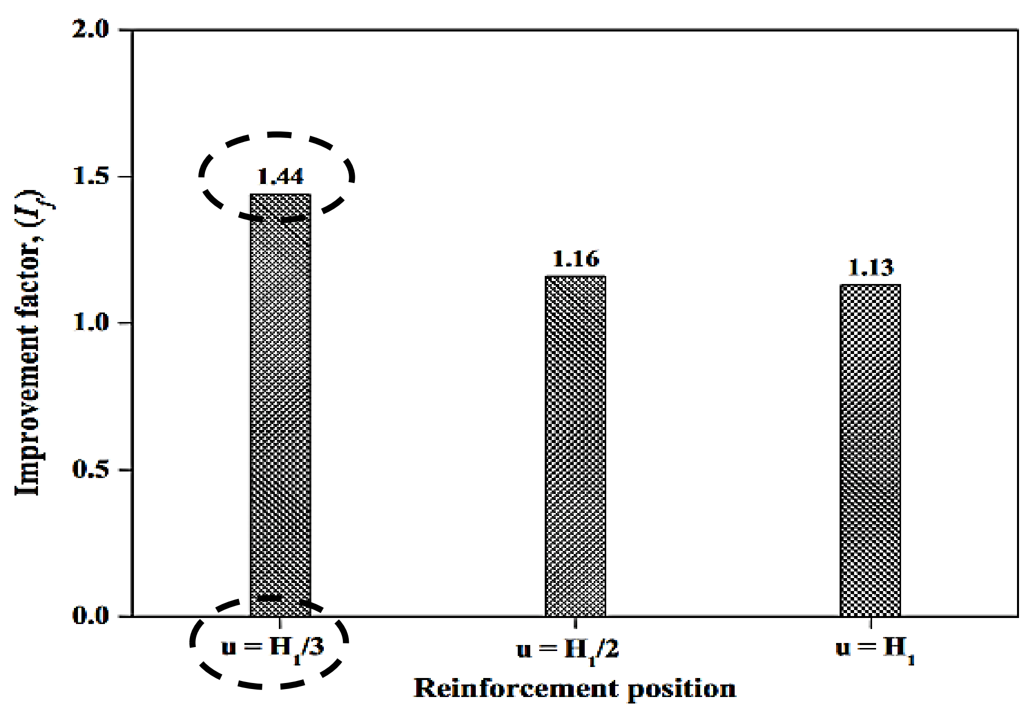
Literature Review

Design Practices - Geosynthetic reinforced flexible pavement

Saride and Baadiga (2021) – Developed a modified Layer coefficient approach for the soft subgrade (CBR – 2-5%)



Pressure verses settlement curve (Saride *et al.*, 2022)



The optimum location of the reinforcement (Saride *et al.*, 2022)

Literature Review

Design Practices - Geosynthetic reinforced flexible pavement

Saride and Baadiga (2021) – Developed a modified Layer coefficient approach for the soft subgrade (CBR – 2-5%)

Modulus of Improvement Factor:

$$MIF = \frac{E_{bcr}}{E_{bcu}}$$

*E_{bcr} is the elastic modulus of the reinforced section
*E_{bcu} is the elastic modulus of the unreinforced section

Layer Coefficient Ratio:

$$LCR = \frac{0.224 \text{ x } log_{10}\left(MIF \text{ x } \frac{M_{ru}}{0.0069}\right) - 0.365}{0.224 \text{ x } log_{10}\left(\frac{M_{ru}}{0.0069}\right) - 0.365}$$

$$SN = a_1 \text{ x } D_1 + a_2 \text{ x } D_2 \text{ x } m_2 \text{ x } LCR_2 + a_3 \text{ x } D_3 \text{ x } m_3 \text{ x } LCR_3$$

Asphalt concrete | Base | Subbase

Where,

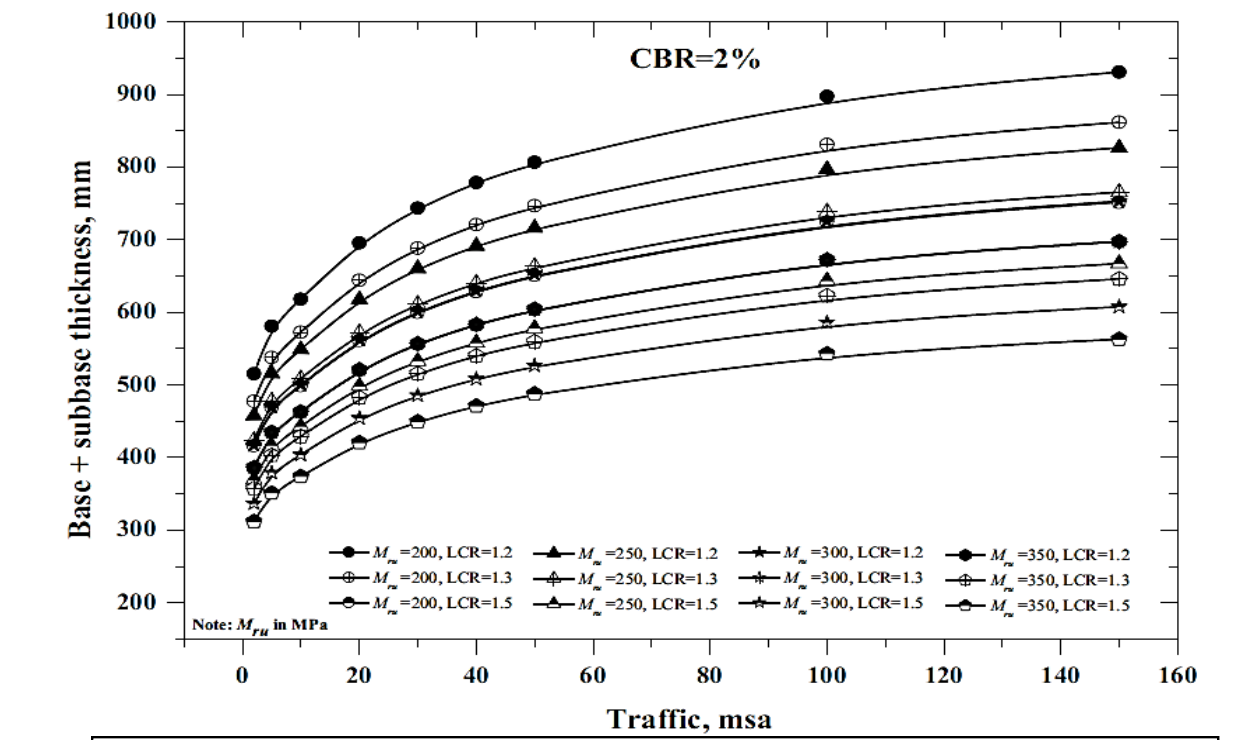
$$LCR_i = i^{th} Layer\ coefficient\ ratio$$

For the CBR range of 2-5%

Literature Review

Design Practices - Geosynthetic reinforced flexible pavement

Saride and Baadiga (2021) - Developed a modified Layer coefficient approach for the soft subgrade (CBR – 2-5%)



Proposed design chart to find the required thickness of the pavement

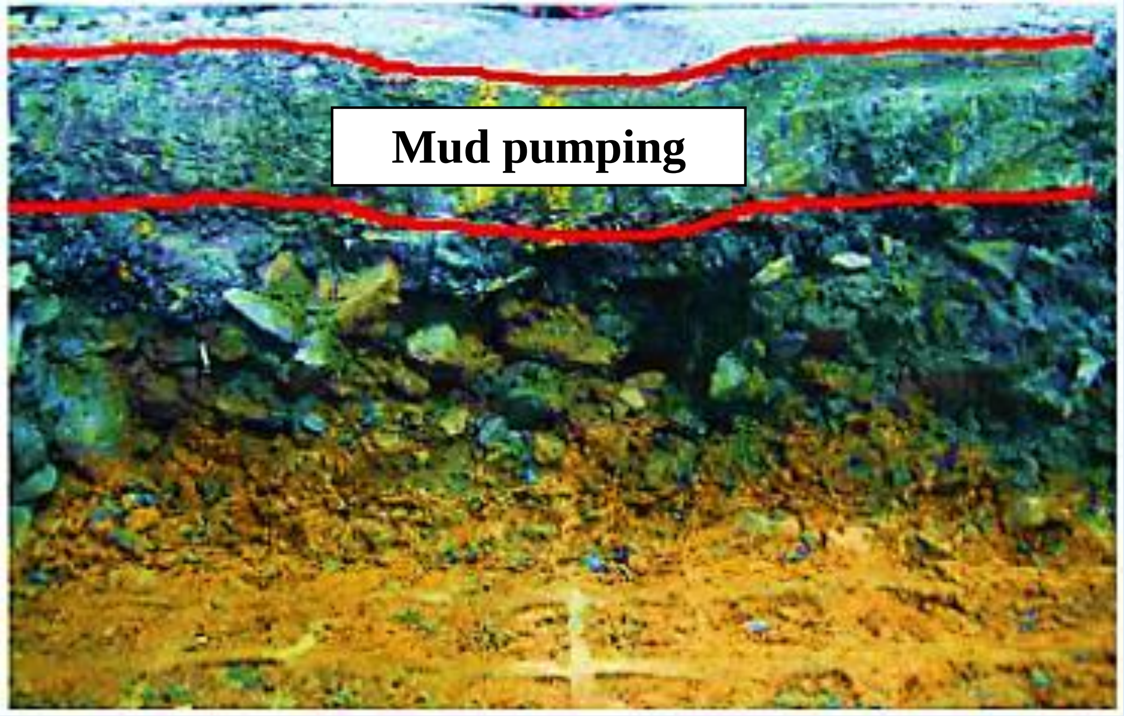
The thickness of the granular layer can be obtained based on:

- LCR of reinforced granular base
- Resilient modulus of granular base (in MPa)
- Expected traffic volume (in msa)

Discussion

Pavement Failure from Accelerated Testing

Tang (2008) – Studied the performance of geogrid reinforced section using scaled accelerated pavement testing machine.



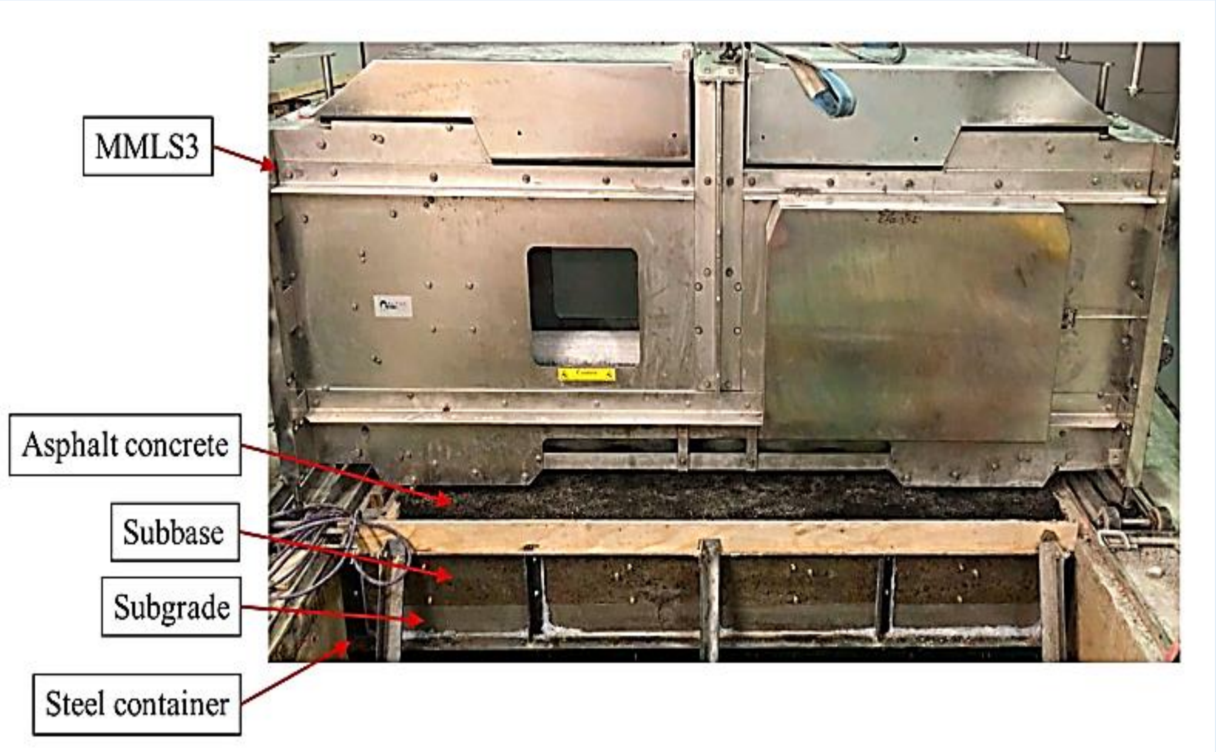
Findings:

- Migration of fine particles observed at the interface of subgrade and subbase layer.
- This phenomenon can affect the strength and drainage properties of the granular layer.

Discussion

Mud Pumping

Kermani et al. (2019) – Studied the amount of fine particle migration into the granular layer.

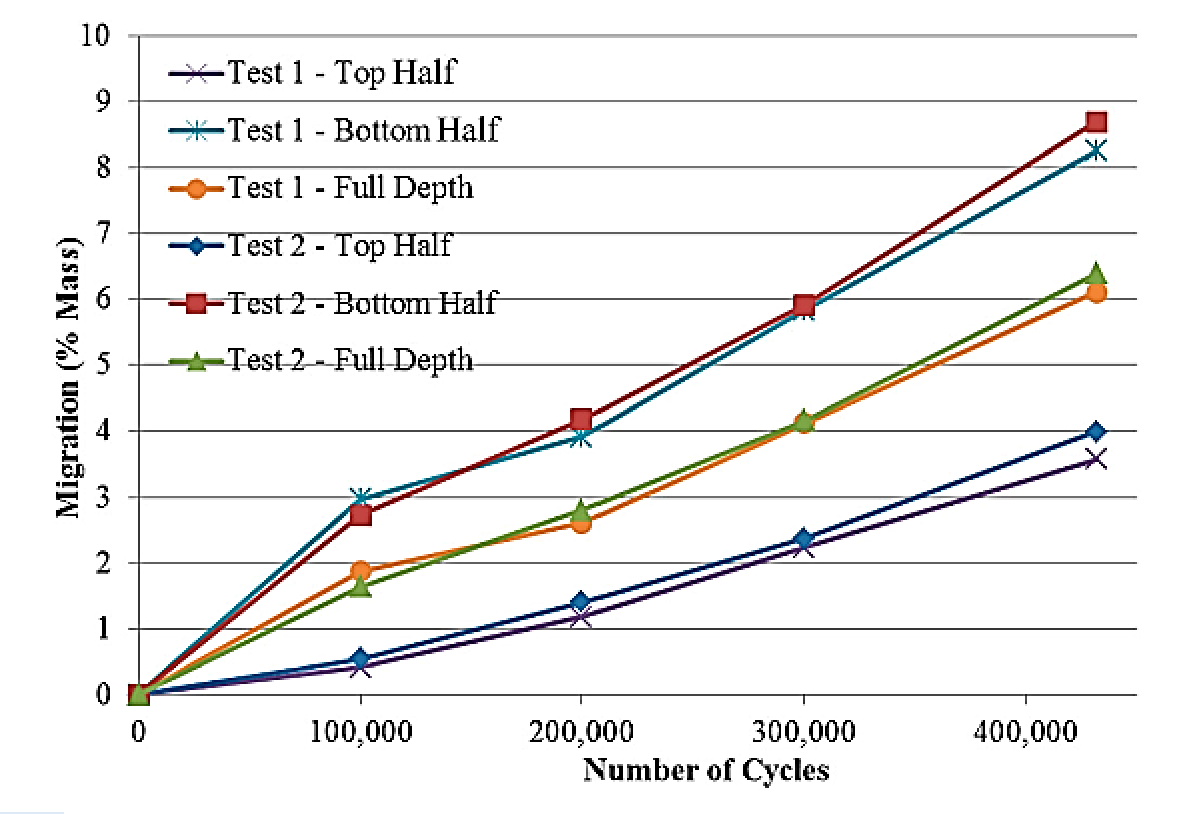


Sampling of granular layer after the test

Discussion

Mud Pumping

Kermani et al. (2019) - Studied the amount of fine particle migration into the granular layer.



Findings:

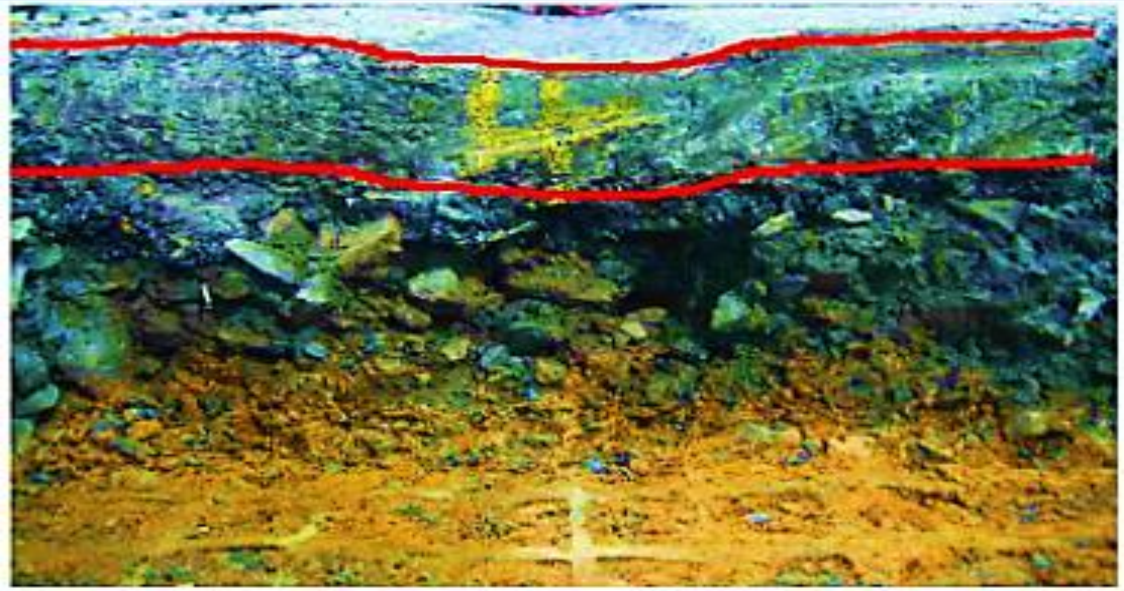
- Amount of fine migrated into the subbase material is high (max 8.9%) at the bottom half of the granular layer.
- The migration of the particle increases with the increase in the loading cycles.

Discussion

Mud Pumping

Mud pumping phenomenon at different site condition

Mud pumping in heavy-haul track site (Indraratna et al., 2020)

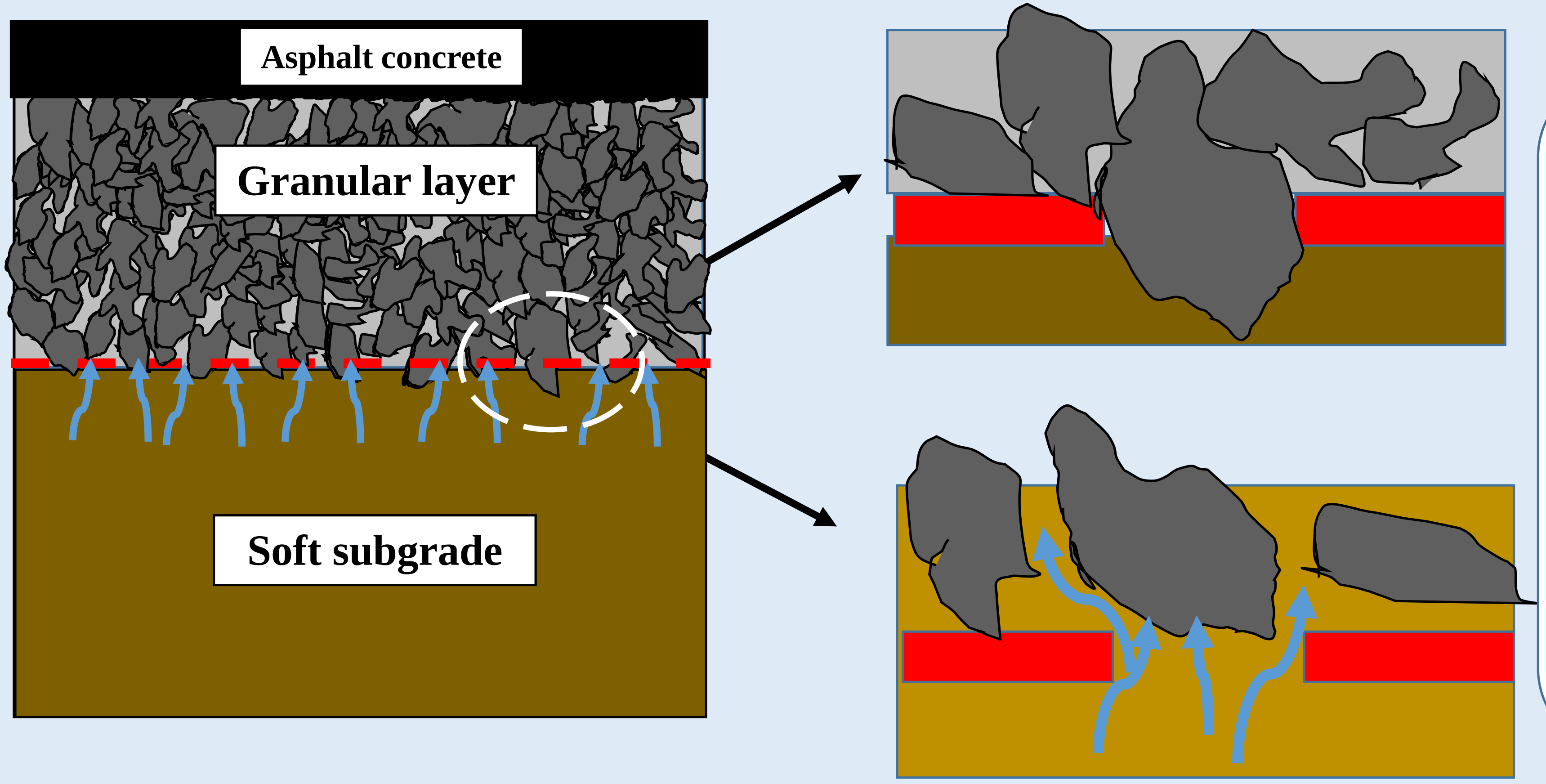


Mud pumping in reinforced flexible pavement (Kermani et al., 2019)

Discussion

How the mud pumping affects the design approach?

The visual representation of stage and effect of mud pumping in reinforced flexible pavement.



Mud pumping reduces the benefit of geogrid and strength and drainage properties of the granular material in geosynthetic reinforced flexible pavement.

Critical Review

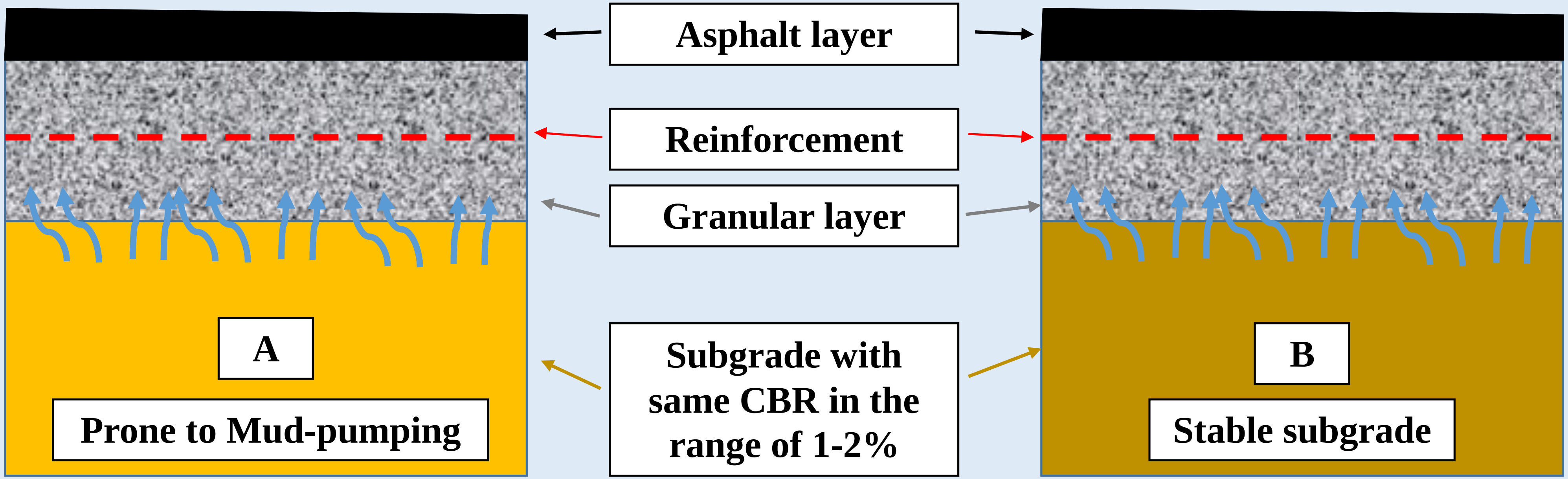
Practical case and Knowledge Gap

The problem arises due to the lack of understanding of subgrade soil in reinforced flexible pavement design

$$\downarrow SN = a_1 \, x \, D_1 + a_2 \, x \, D_2 \, x \, m_2 \, x \, LCR_2 + a_3 \, x \, D_3 \, x \, m_3 \, x \, LCR_3 \downarrow$$

Asphalt | Base | Subbase

Increase in the required thickness of the reinforced flexible pavement



Discussion

Research Gap towards understanding Mud Pumping and Effects

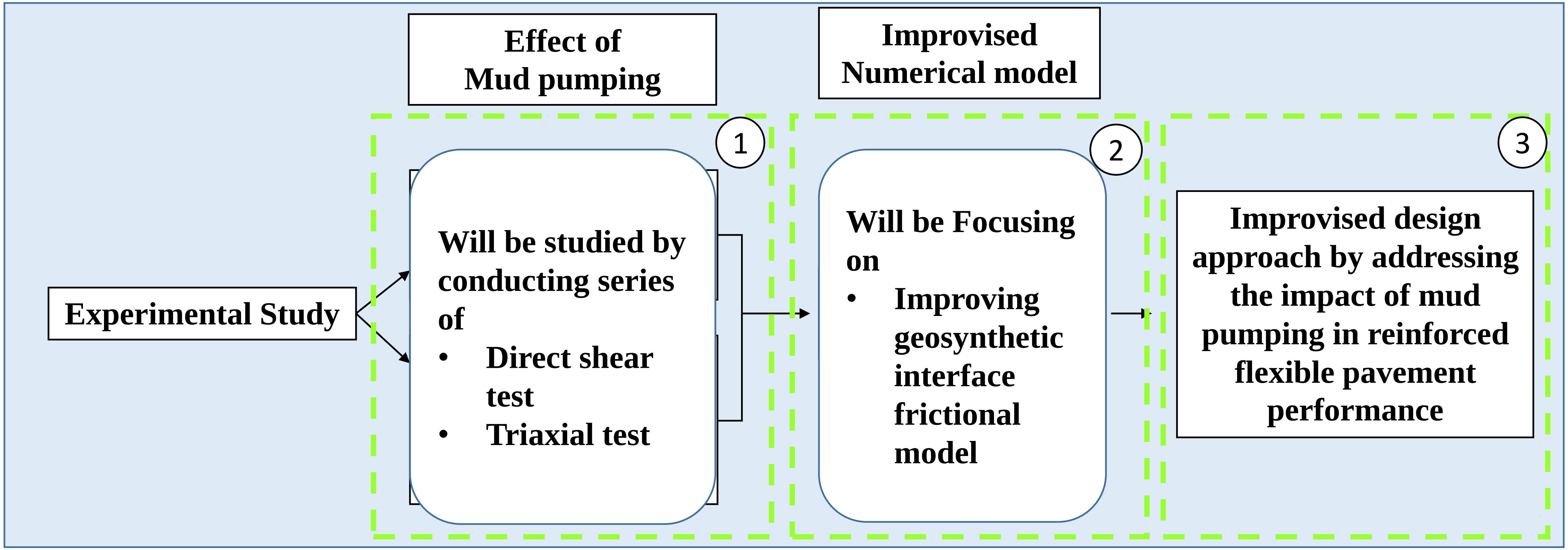
Research gap observed from the critical review of literature survey

- **Limited Exploration of Mud Pumping Effects:** The investigation into the mechanisms and extent of mud pumping influence on reinforced flexible pavement is limited
- **Lack of Comprehensive Design Guidelines:** There is a knowledge gap in developing comprehensive design guidelines that explicitly address the combined effects of mud pumping on both strength and drainage properties.
- **Insufficient Consideration of Climate Variability:** Research in this area is essential to understand how different climatic conditions may mitigate mud pumping effects.
- **Need for Interdisciplinary Approaches:** The complexity of issues related to mud pumping requires interdisciplinary collaboration. A gap exists in integrating geotechnical, pavement material, and environmental considerations in developing better solutions for geosynthetic-reinforced pavement systems over soft subgrade.

Discussion

Methodology

A Tentative methodology for achieving the proposed objectives



Discussion

Expected Outcomes:

The expected outcomes are discussed based on the possible achievement of all the objectives

1. **An improved understanding of the impact of mud pumping** on both the soil-reinforcement interface friction and the alterations in the strength properties of the granular material within reinforced flexible pavement systems.
2. **Validation of experimental** results through finite element-based numerical simulations, providing a cohesive and integrated understanding of the pavement material behaviour under different test conditions.
3. **Development of refined finite element models** based on the experimental data, allowing for a more precise study of the repercussions of mud pumping on pavement material properties.
4. Provision of insights and recommendations for an **improved design approach for geosynthetic-reinforced flexible pavements**, considering the impact of mud pumping on pavement material properties

Discussion

Motivation of the study

A better understanding of geosynthetic reinforced pavement performance and an improved design approach can **help to increase the speed of construction in problematic sites** and also can **reduce the amount of granular material required for pavement construction**

Ref: https://images.app.goo.gl/EAe6PHp4pp9qZmke6

Ref: https://images.app.goo.gl/DKXMVGVkdYz34Uqg8

The phenomenon of mud pumping

Literature review and Methodology

Mud pumping phenomenon

Mud pumping:

- Fluidization of top layer of saturated subgrade material under cyclic repeated loading condition.
- Low to moderate plasticity soils or non plastic fine/medium sand are prone to mud pumping phenomenon. (Indraratna et al., 2020)

Fig. Site image of railway ballast affected by mud pumping **(Indraratna et al., 2020)**

Mud pumping phenomenon

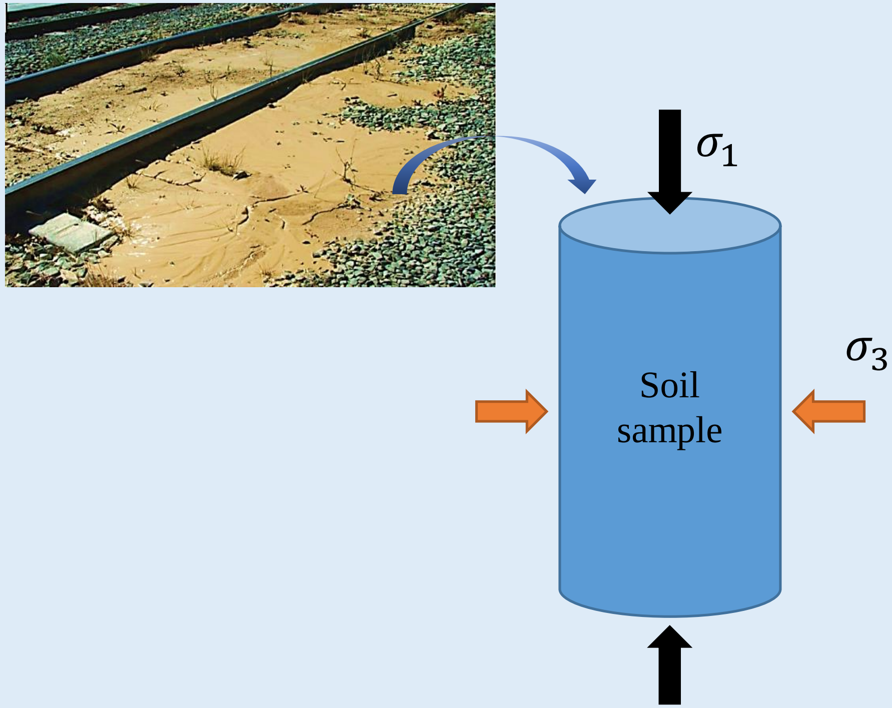


Fig. Triaxial test conducted on the soil sample collected from the mud pumping observed site **(Indraratna et al., 2020)**

Objective of the study (Indraratna et al., 2020):

- The behavior of the soil sample test under varying,
  - loading frequency (i.e., 1-5 Hz)
  - Cyclic stress ratio (i.e., 0.1-1)

Note:

$$CSR = \frac{\sigma_d}{2\sigma_c'}$$

Where, σ_d= applied cyclic stress and σ_c' = effective confining pressure.

Mud pumping phenomenon

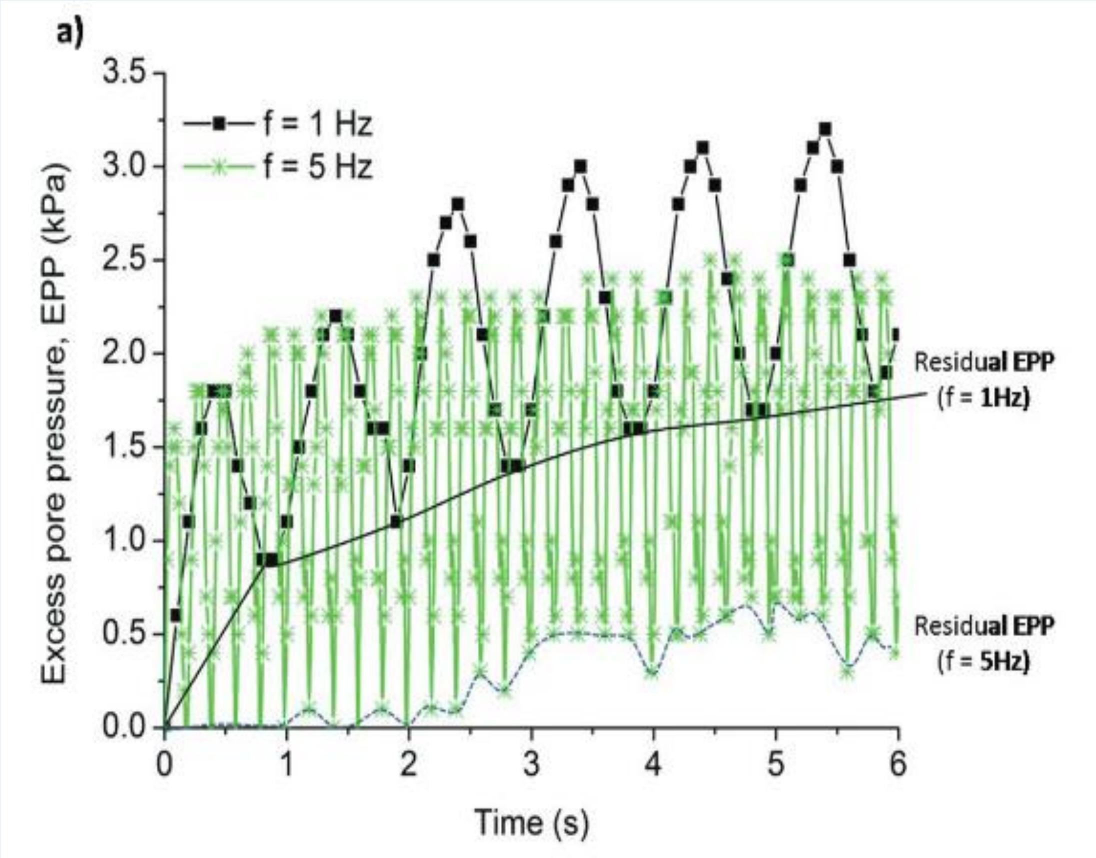


Fig. Effect of loading frequency **(Indraratna et al., 2020)**

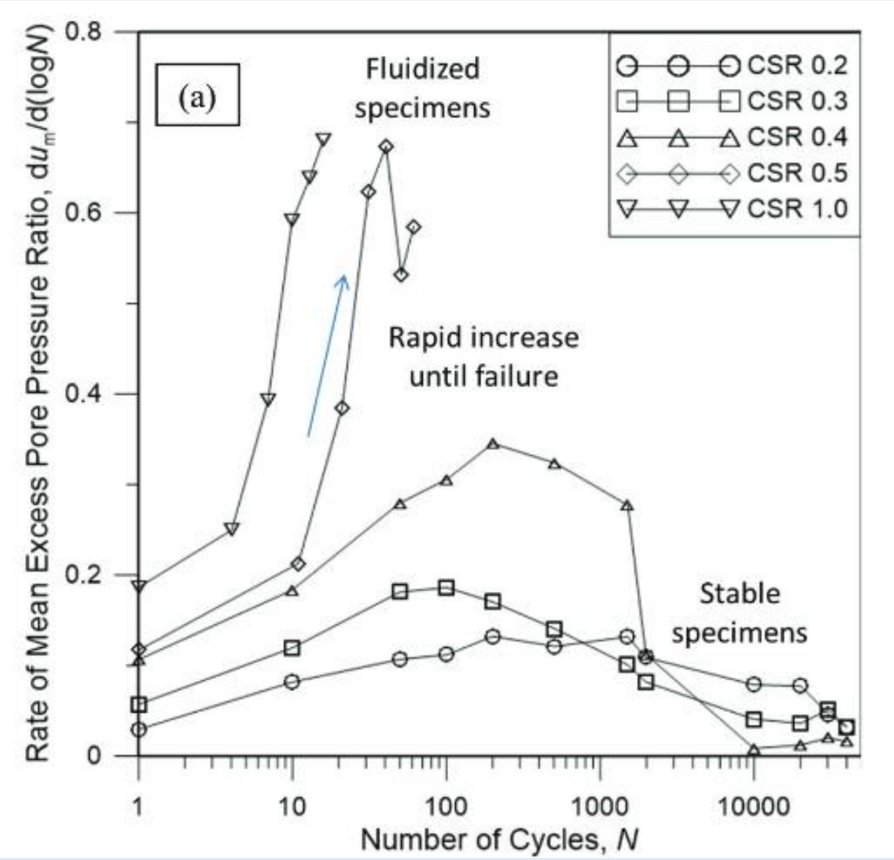


Fig. Effect of loading cyclic stress ratio (CSR) **(Indraratna et al., 2020)**

Mud pumping phenomenon

Fig. Fluidization of top subgrade layer **(Indraratna et al., 2020)**

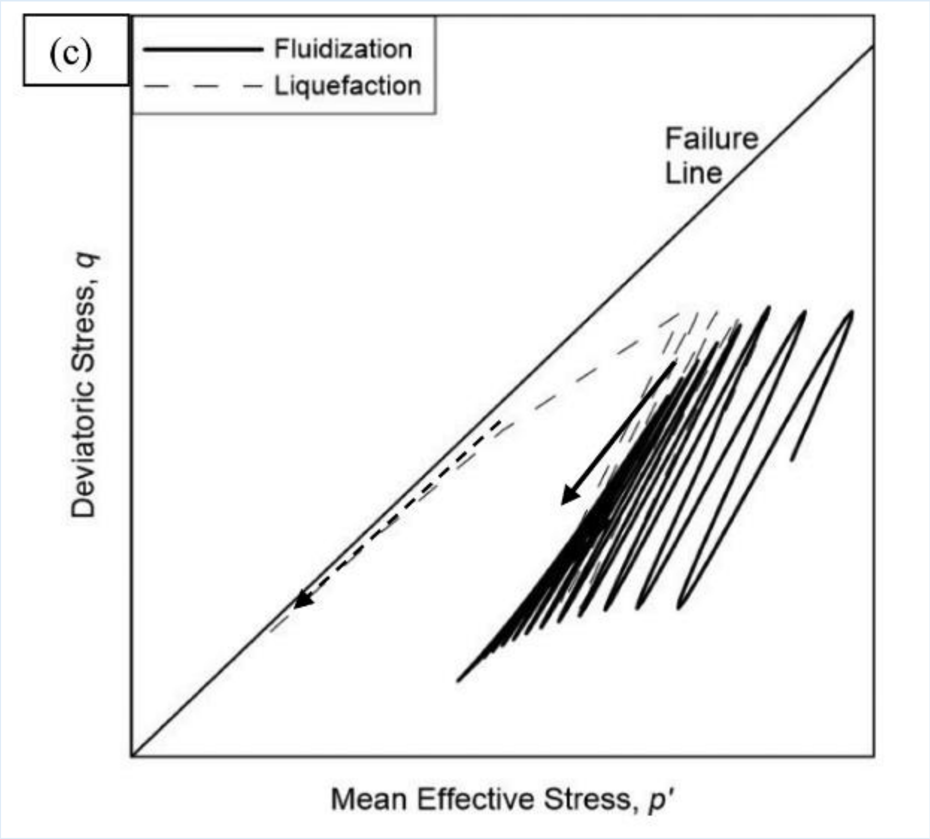


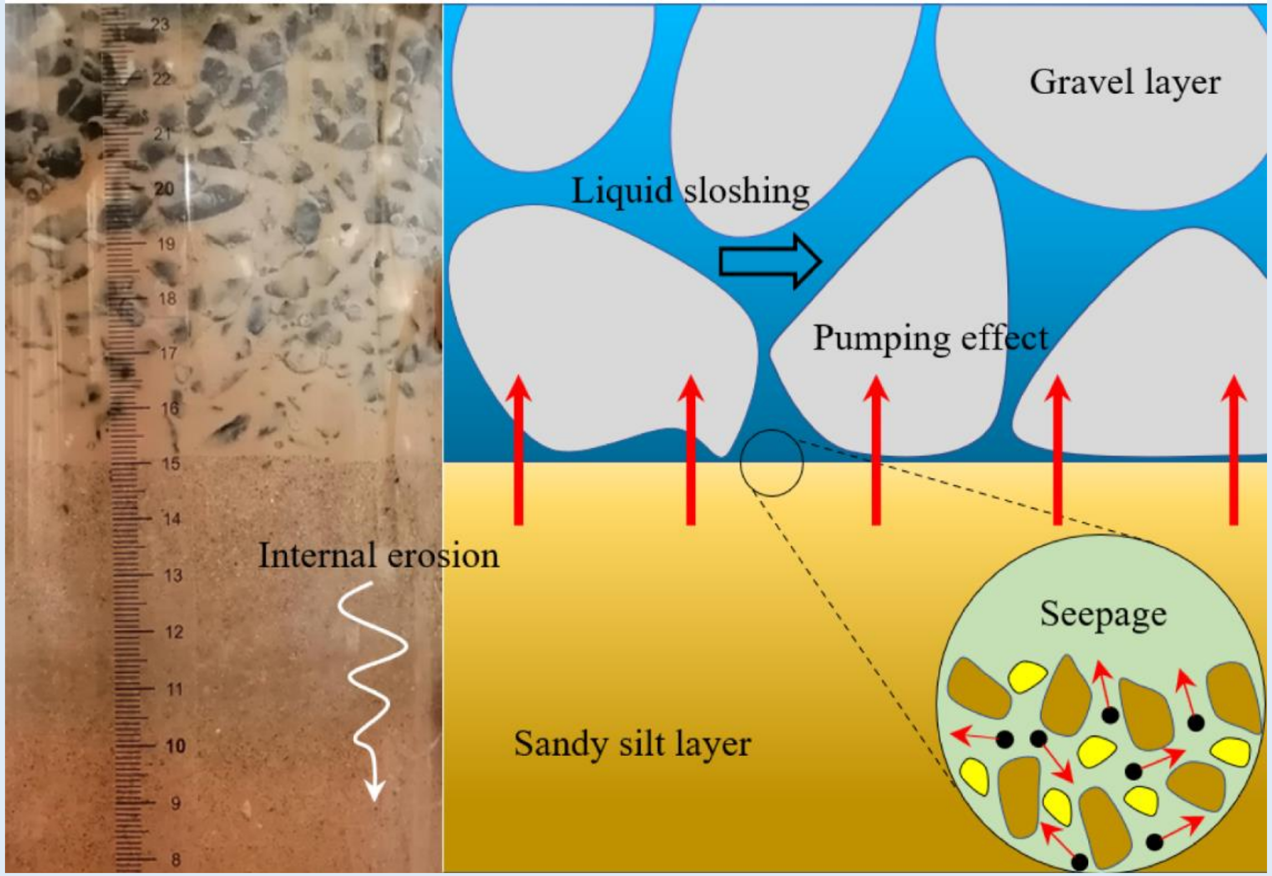
Fig. Fluidization initiated before reaching the failure line **(Indraratna et al., 2020)**

Literature review and Methodology

Difference between Mud Pumping and Liquefaction

Objective of the study (Gao et al., 2021):
The mechanism of mud pumping under combined cyclic loading and effect of rainfall.

Discussion:
Mud pumping is a phenomenon closer to internal erosion rather than liquefaction.



Ref: (Gao et al., 2021)

Difference between mud pumping and liquefaction

Degree of liquefaction: (McDougal et al., 1989)

$$\lambda = \frac{3\Delta u}{\gamma z(1 + 2K_0)} \times 100\%$$

γ = Unit weight of the soil;
Z = Thickness of the soil;
K_0 = Coefficient of earth pressure at rest
Δu = Excess pore water pressure

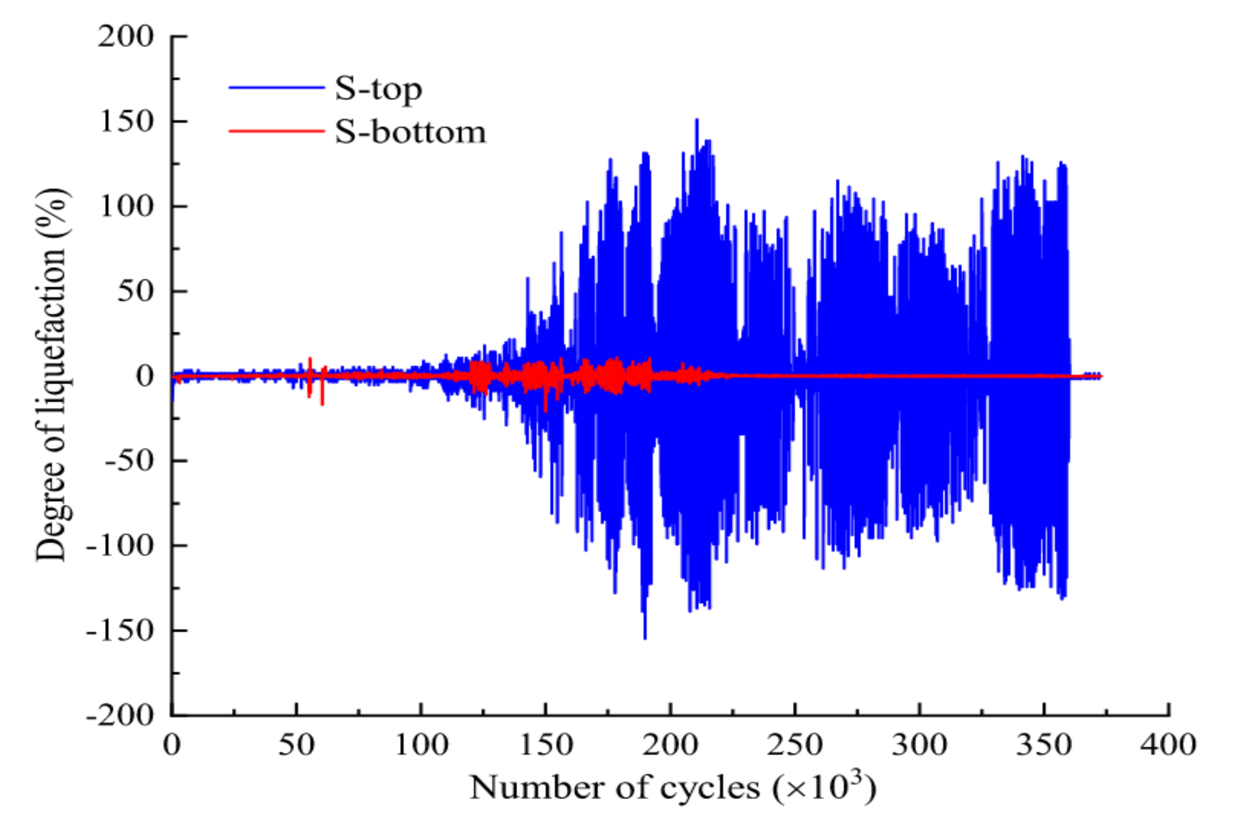


Fig. Measured degree of liquation at top and bottom subgrade **(Gao et al., 2021)**

Effect of mud pumping

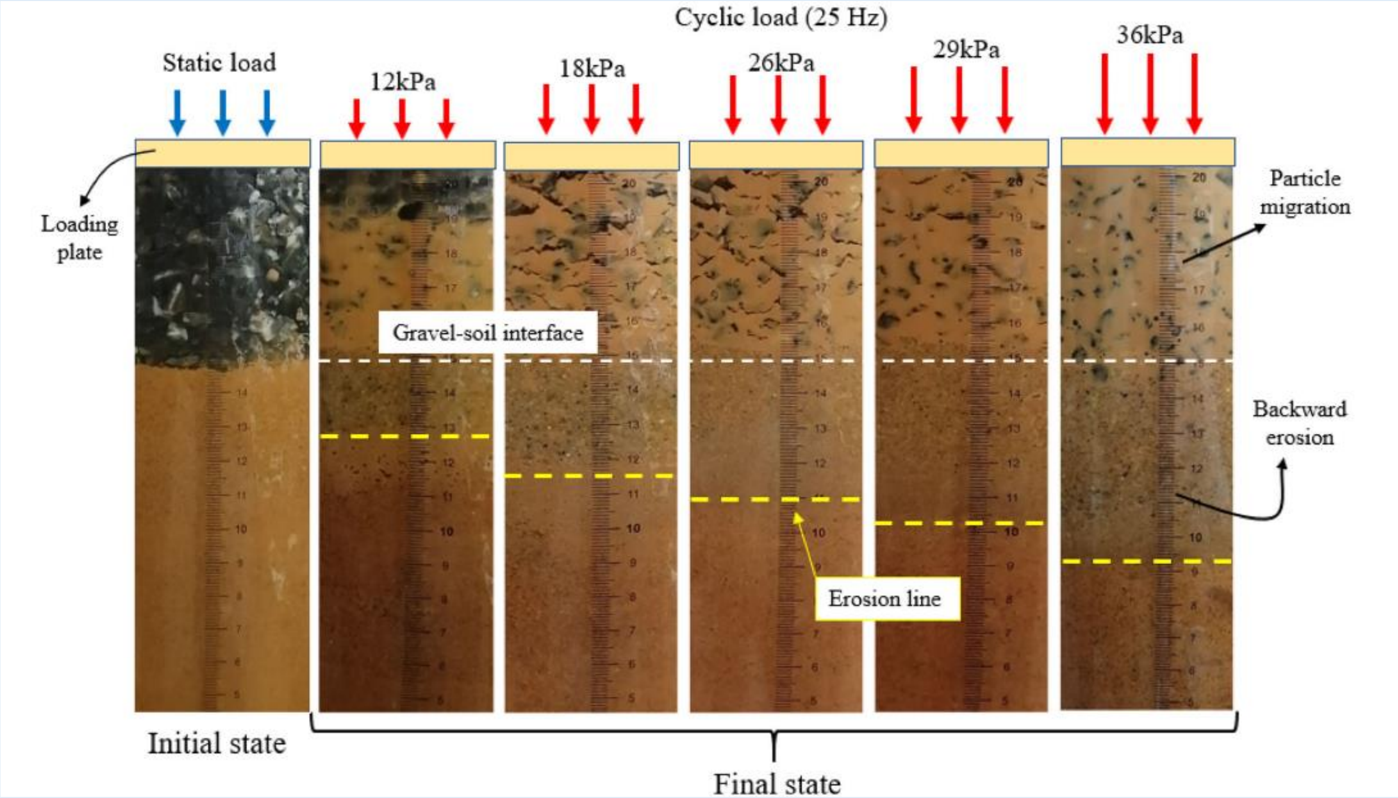


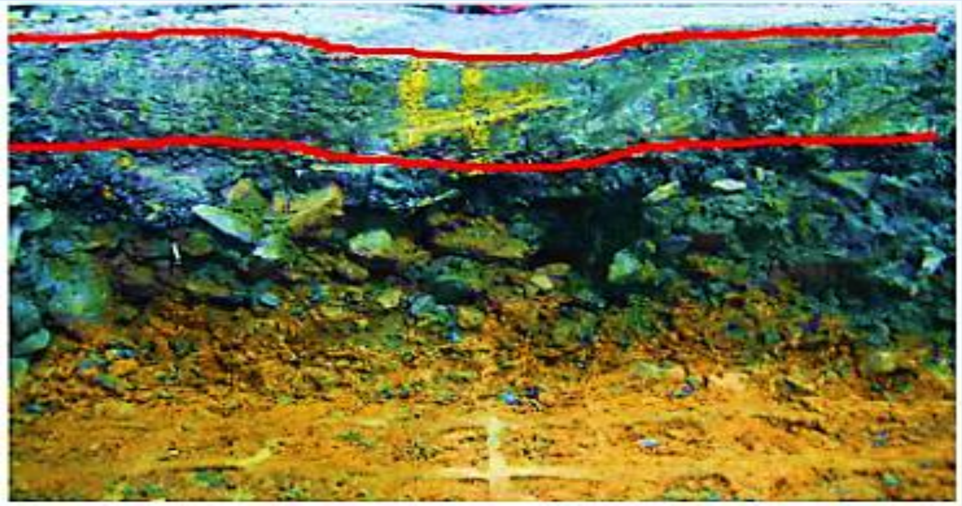
Fig. Intensity of mud pumping under cyclic loading condition **(Zhang et al., 2021)**

Summary:

- The favorable conditions for the mud pumping phenomenon are, high magnitude of repeated loading, fully saturated subgrade, low confining pressure.
- In general low/moderate plasticity soil and non plastic fine/medium sand particles are prone to mud pumping phenomenon.
- The granular layer affected by the mud pumping phenomenon experience a significant loss in frictional and drainage properties.

Focus of the study

Impact of mud pumping in shear strength behavior of the granular layer



Ref: (Tang et al., 2008)

Material characteristics - Gradation

IS sieve	Percent by weight passing the IS sieve					
	1	2	3	4	5	6
75	100	-			100	-
53	80-100	100	100	100	80-100	100
26.5	55-90	70-100	55-75	50-80	55-90	75-100
9.5	35-65	50-80	-	-	35-65	55-75
4.75	25-55	40-65	10.0-30	15-35	25-50	30-55
2.36	20-40	30-50	-	-	10.0-20	10.0-25
0.85	-		-	-	2.0-10	-
0.425	10.0-15.0	10.0-15	-	-	0-5	0-8
0.075	<5	<5	<5	<5	-	0-3

Fig: Suggested gradation for granular subbase Source **(MORTH, 2013)**

Methodology

Material characteristics - Gradation

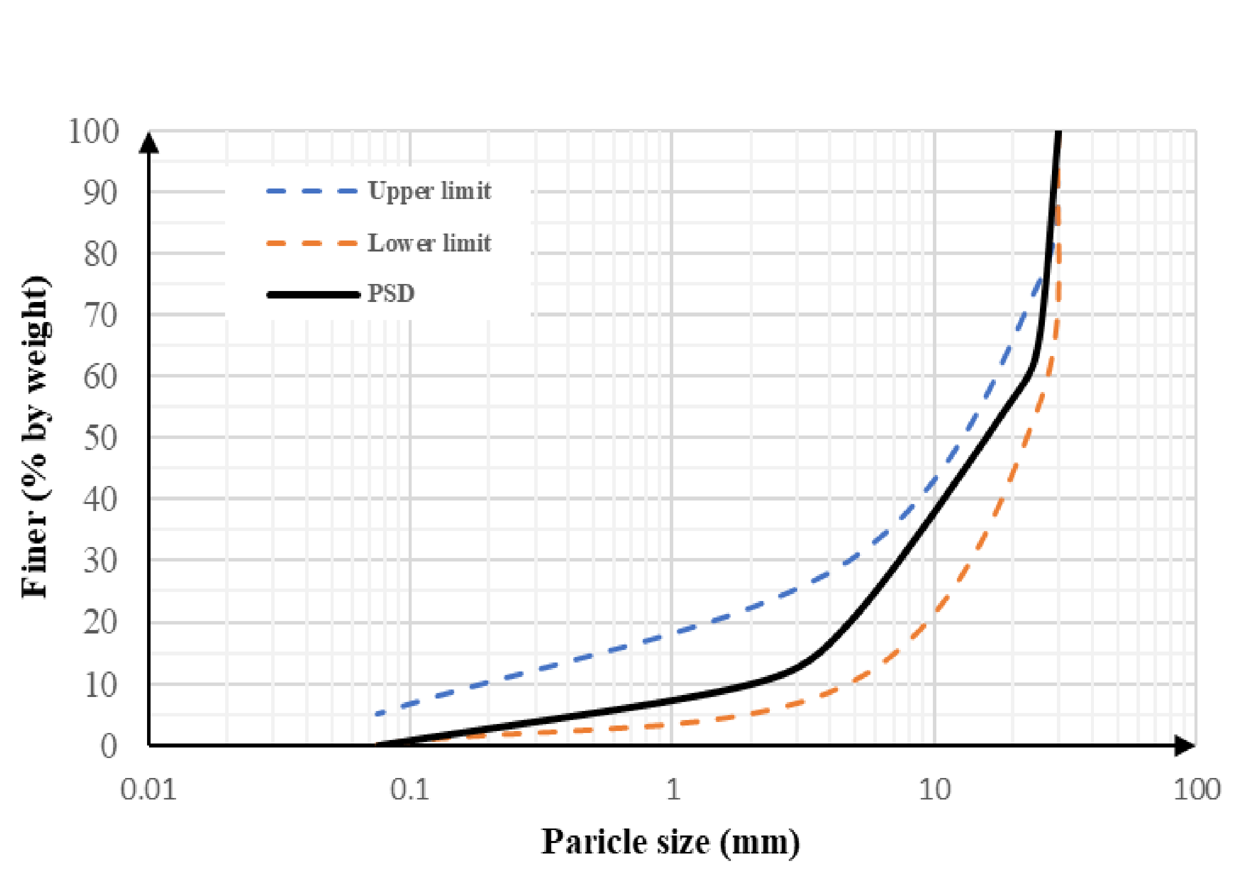


Fig: Gradation curve of the granular mix

Relative compaction test results

Amount of subgrade fines (%)	Max. relative compaction (kg/m^3)
0	1857.24
5	1887.23
10	1989.15
20	2078.77

Methodology

Experimental details – Large direct shear test

Fig. Large direct shear test apparatus (Geotechnical laboratory, IITG)

Test procedures:

- Box size (300*300*200) mm^3
- The maximum size of the granular material is fixed as 30 mm considering the boundary effect.
- Stain rate – 1.25 mm/min
- Maximum displacement = 30mm (H)
  (10% of the box size)

Sample preparation process

Methodology

Modified approach

Fig. Segregation of finer particles in the bottom

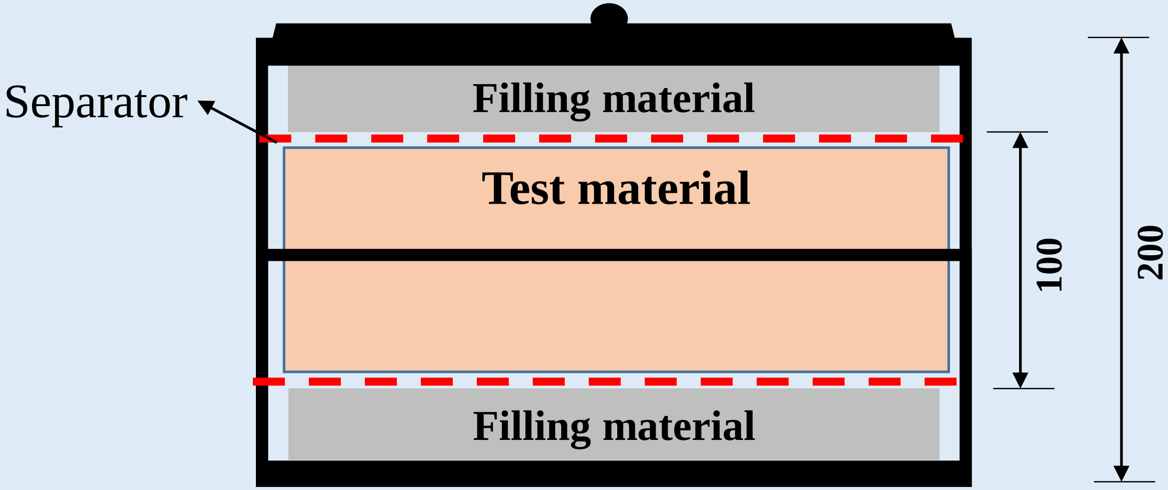


Fig. Schematic representation of the prepared sample for direct shear test

Modified approach - justification

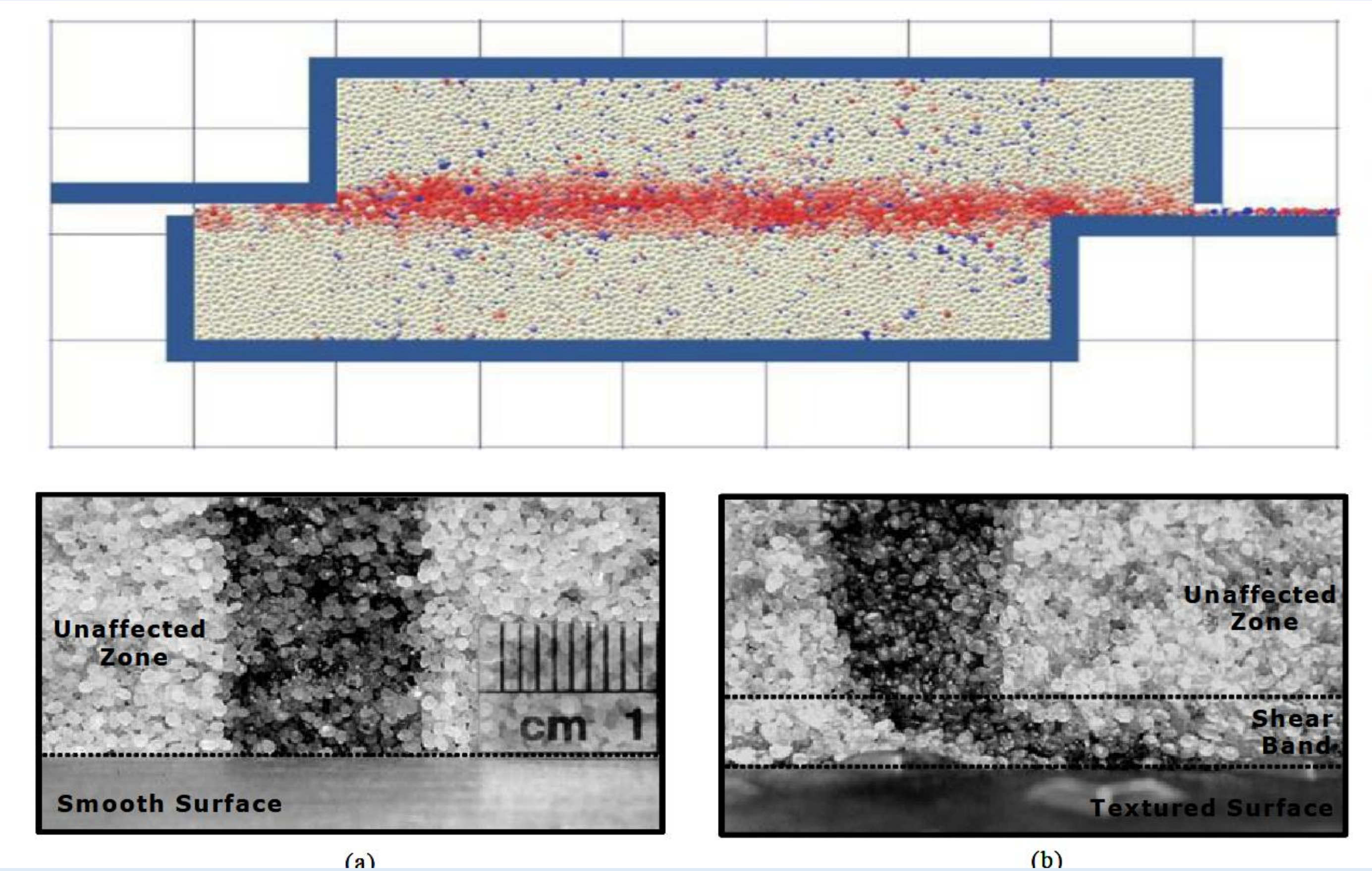


Fig. Observed shear band thickness in direct shear test (Nitaka and Grabowski, 2021; Dejong et al., 2006)

Findings:

- The thickness of the shear band in direct shear test observed as 5 to 7 times of D_{50} **(Dejong et al., 2006; Frost et al., 2004)**
- In the current study,

  $D_{50} \approx 16mm$

  Material layer thickness =100 mm

  (i.e., **6.25 D_{50}**)

Results and Discussion

Direct shear test results

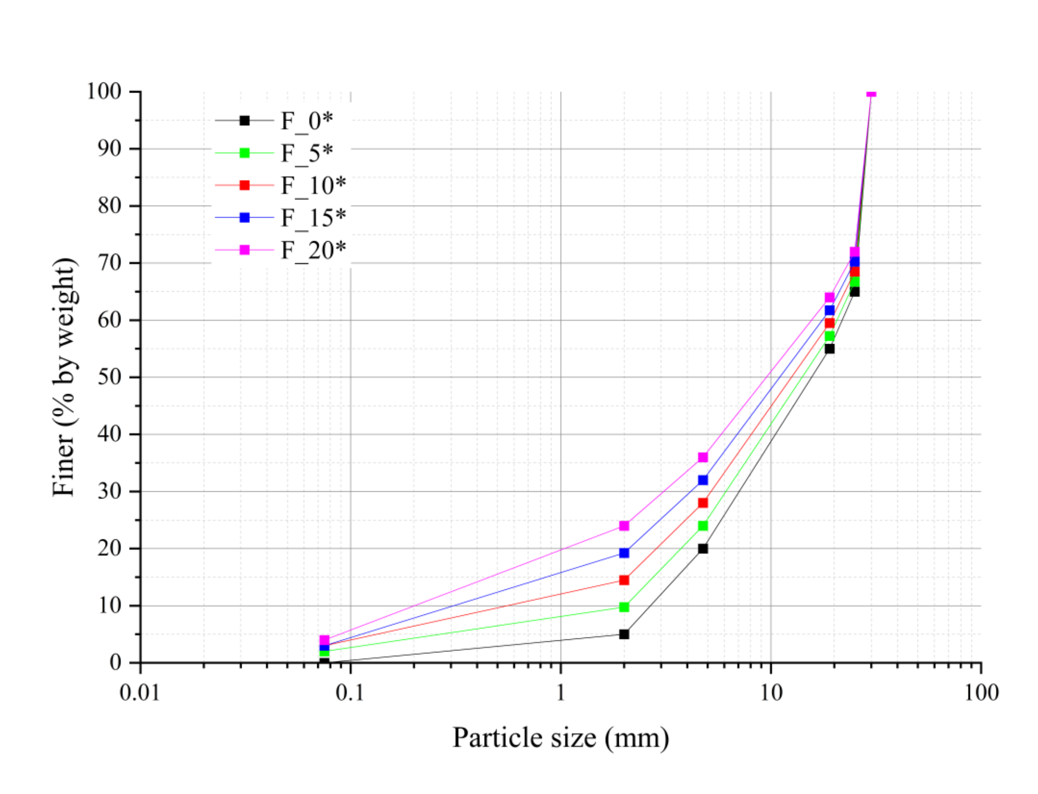


Fig. Change in the gradation with increase in the fine content

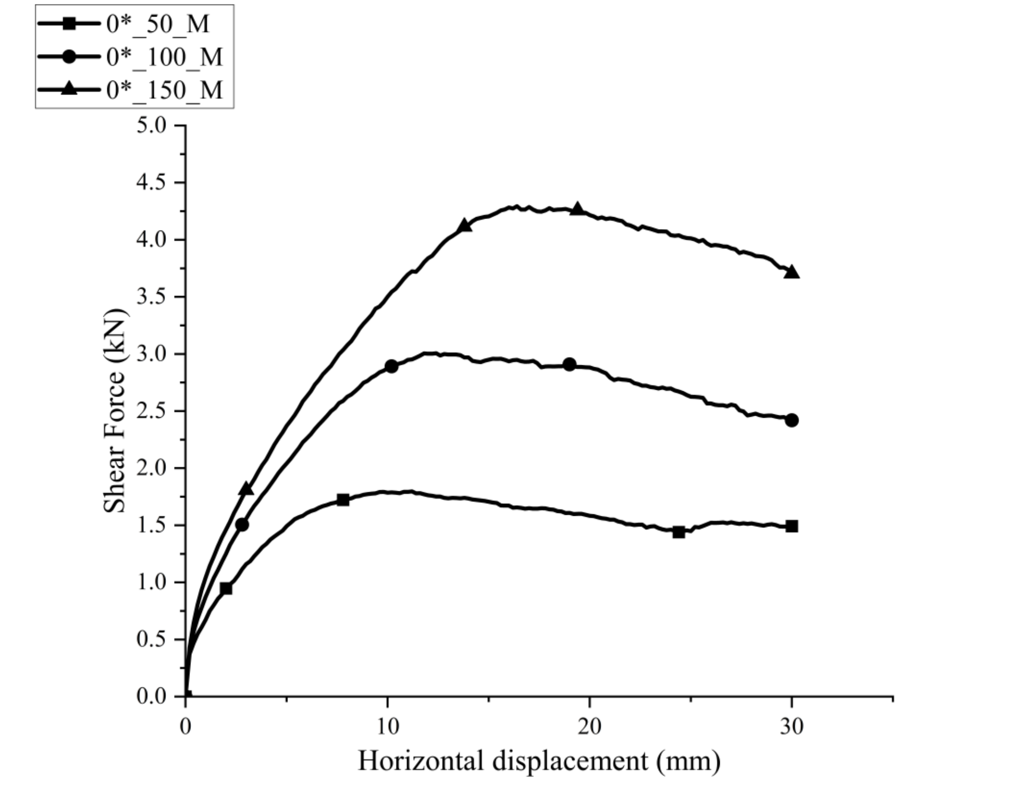


Fig. Shear force (kN) vs Horizontal displacement (mm)

Results and Discussion

Direct shear test results

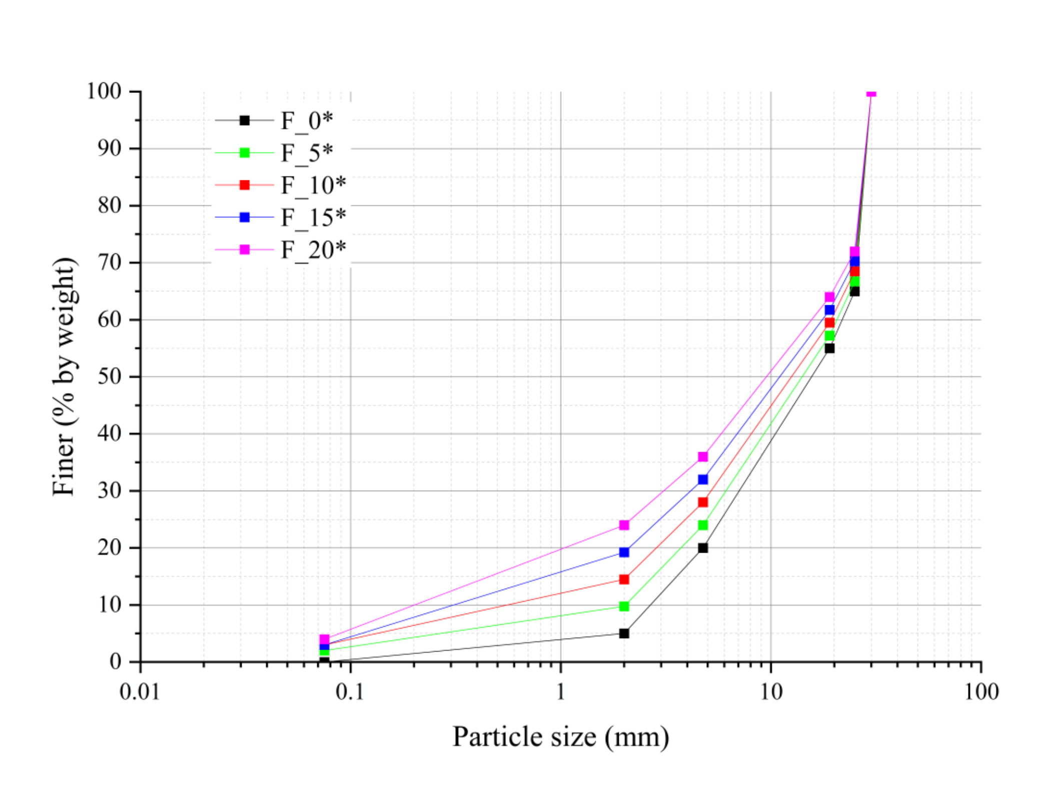


Fig. Change in the gradation with increase in the fine content

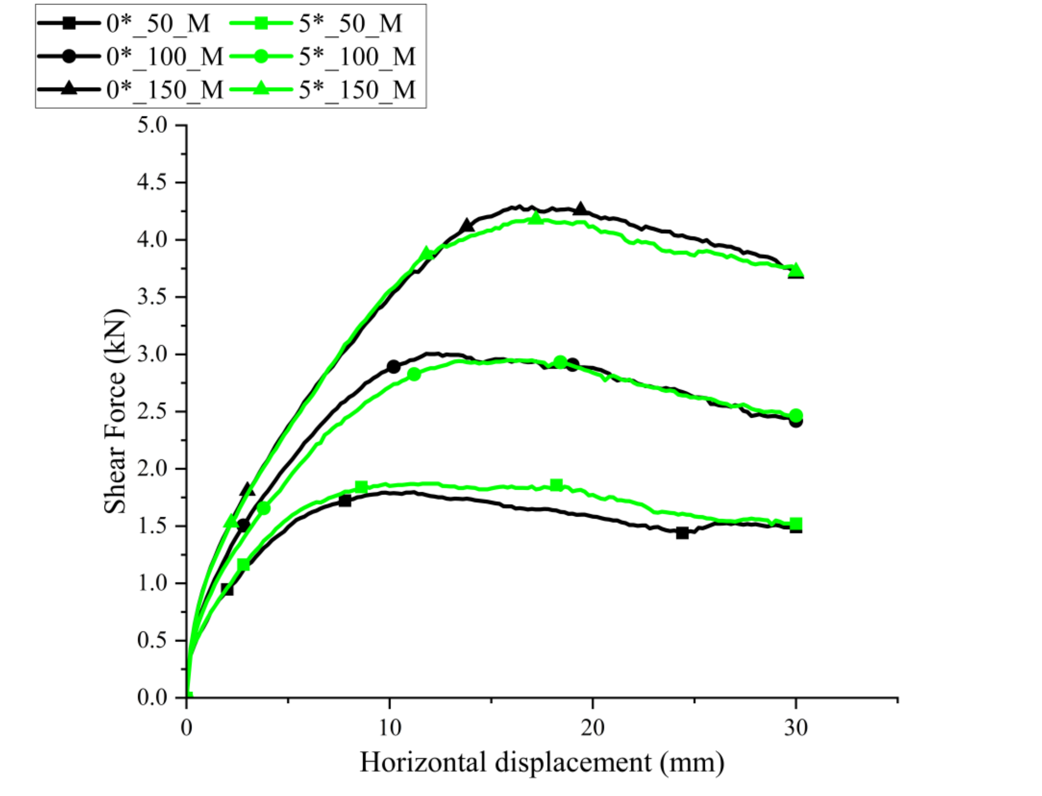


Fig. Shear force (kN) vs Horizontal displacement (mm)

Results and Discussion

Direct shear test results

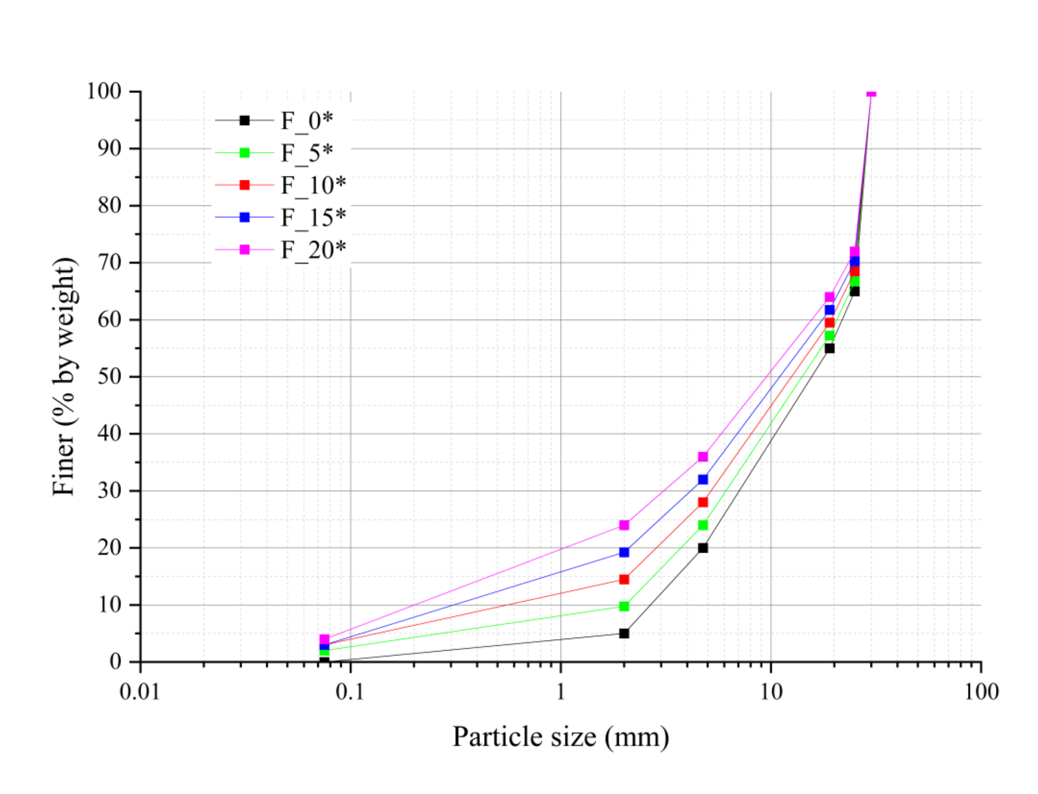


Fig. Change in the gradation with increase in the fine content

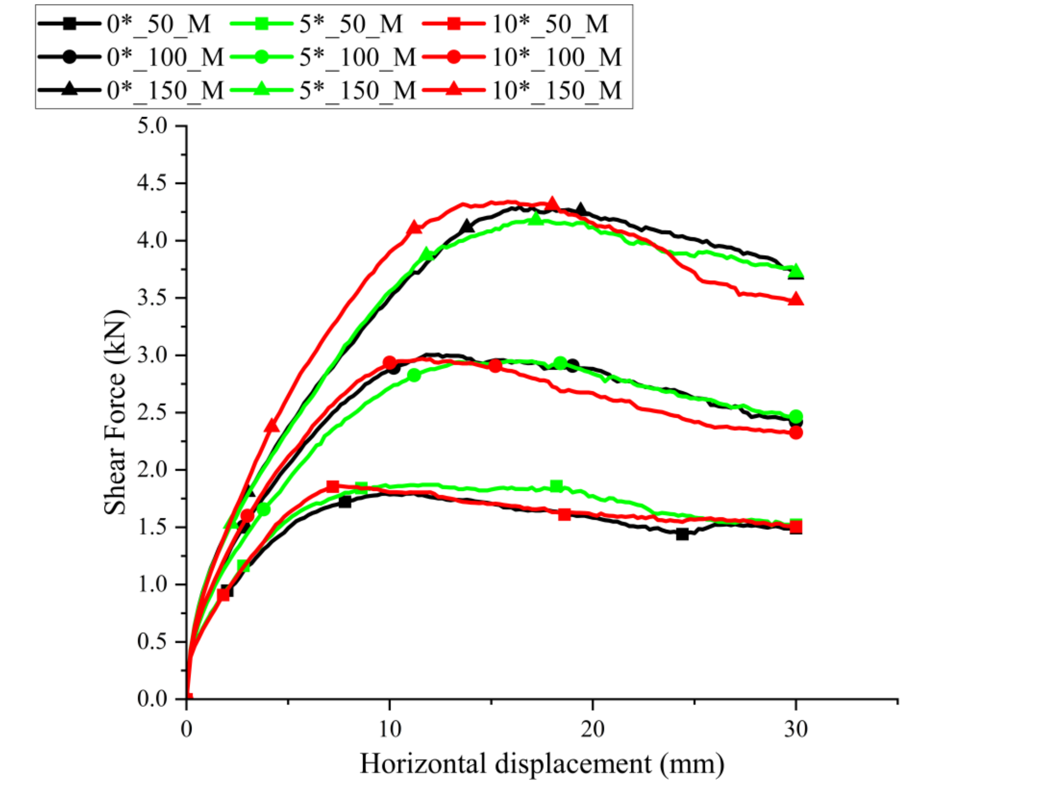


Fig. Shear force (kN) vs Horizontal displacement (mm)

Results and Discussion

Direct shear test results

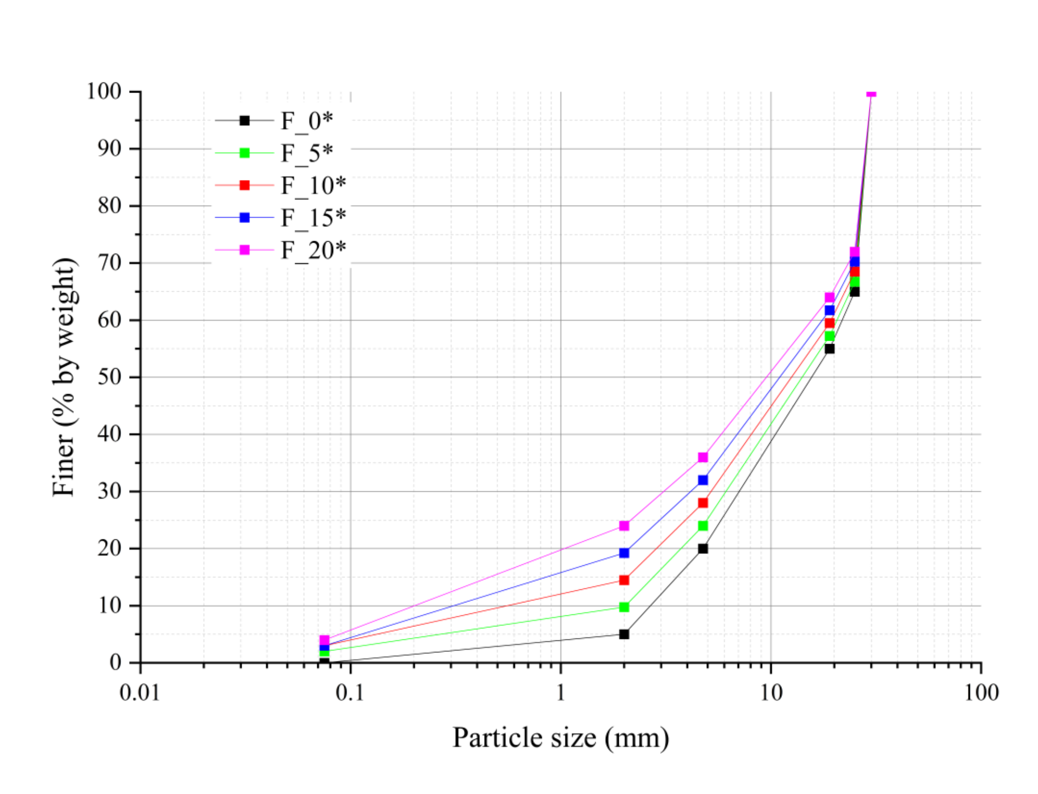


Fig. Change in the gradation with increase in the fine content

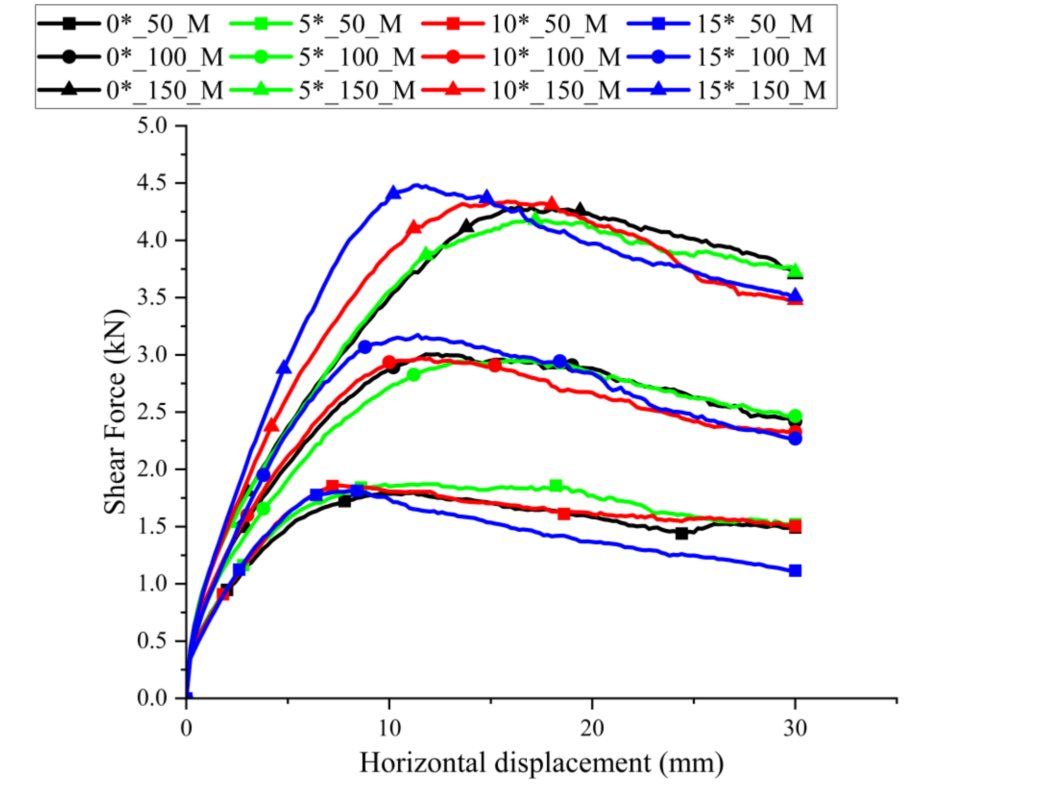


Fig. Shear force (kN) vs Horizontal displacement (mm)

Direct shear test results

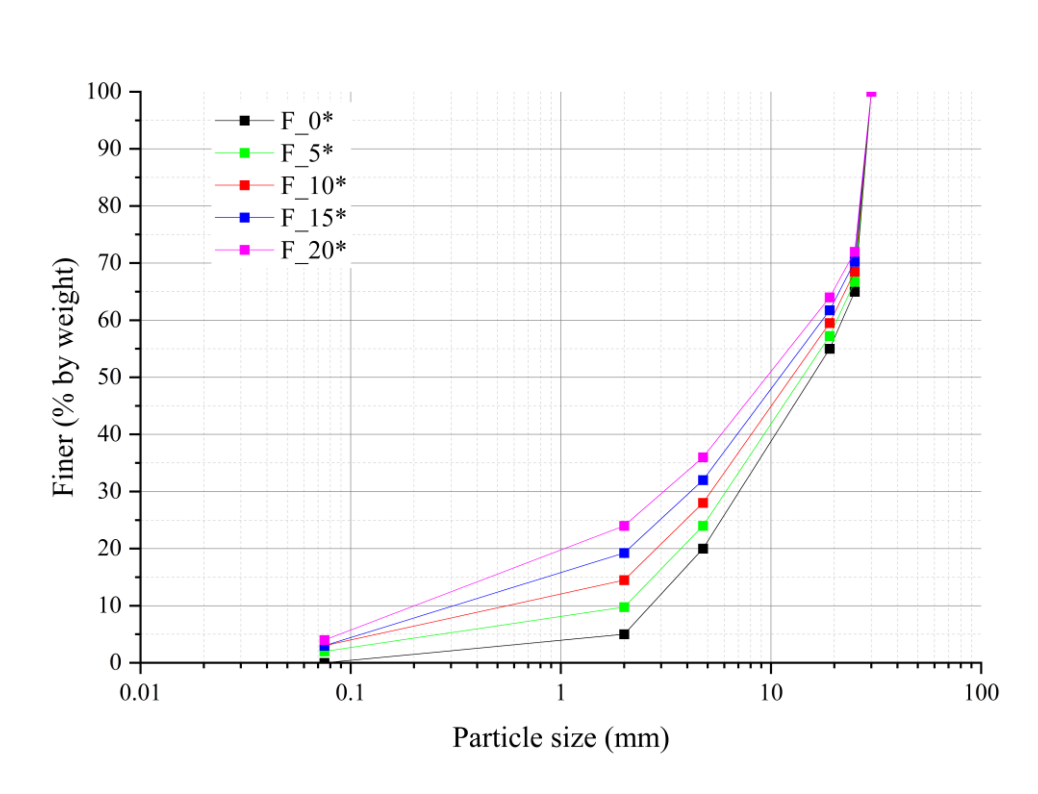


Fig. Change in the gradation with increase in the fine content

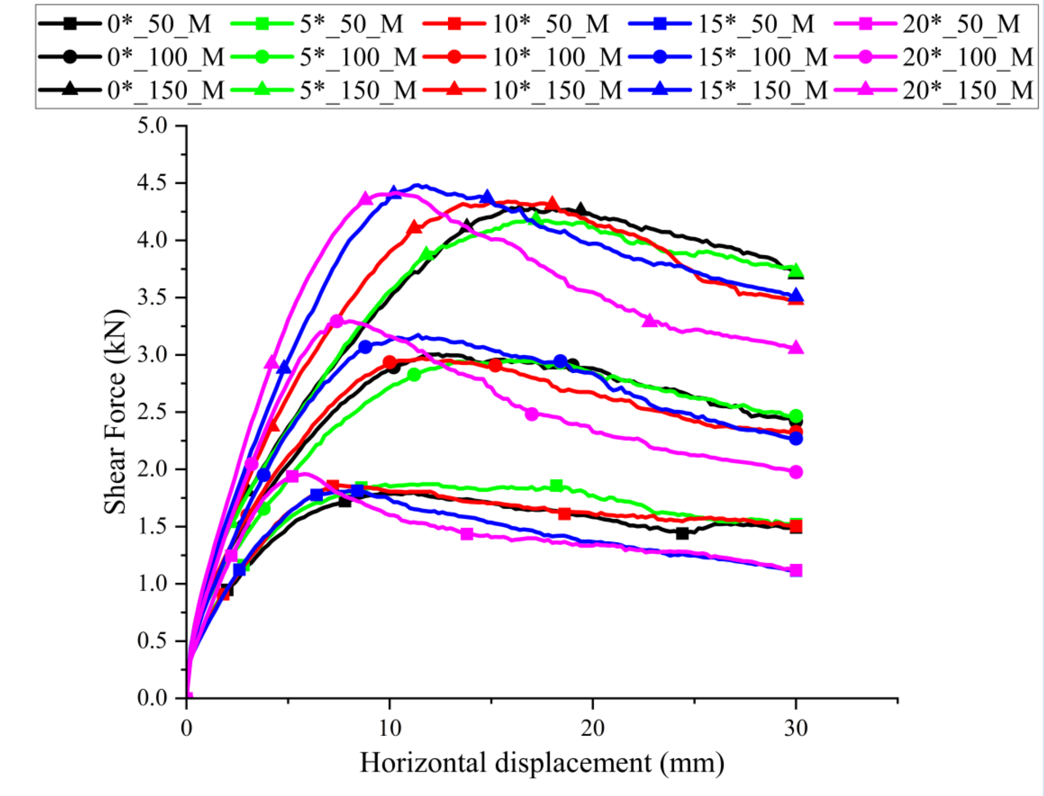


Fig. Shear force (kN) vs Horizontal displacement (mm)

Results and Discussion

Direct shear test results

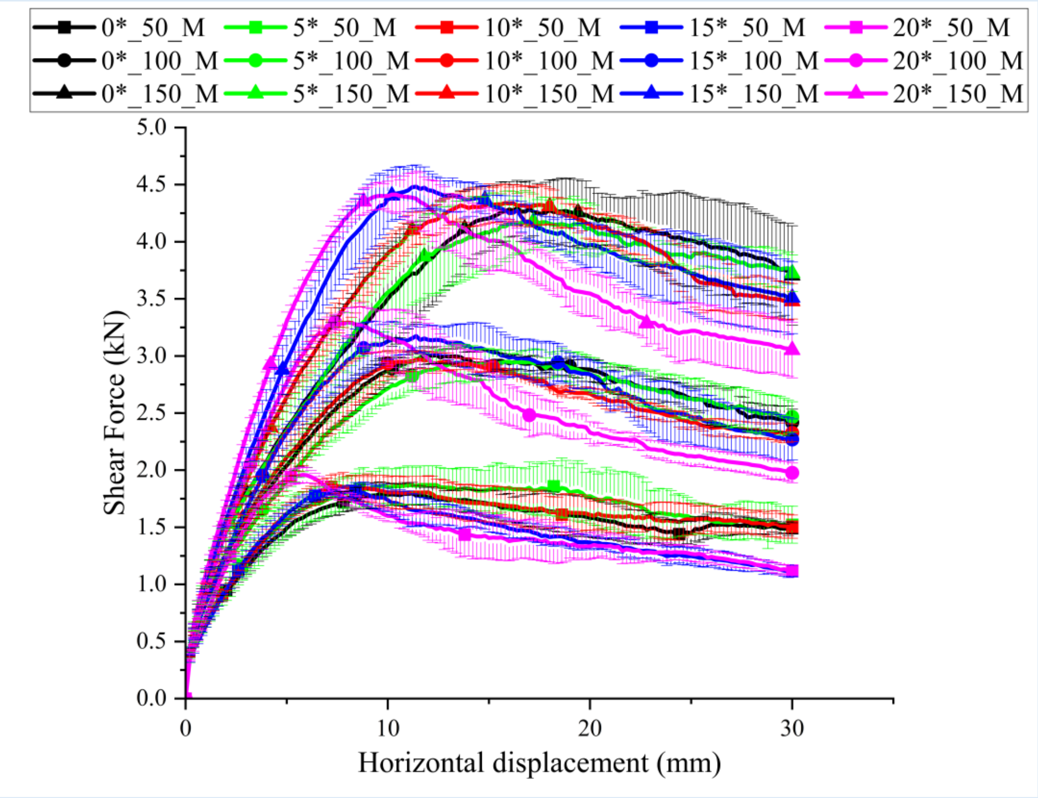


Fig. Cumulative SF vs HD graph with error bar

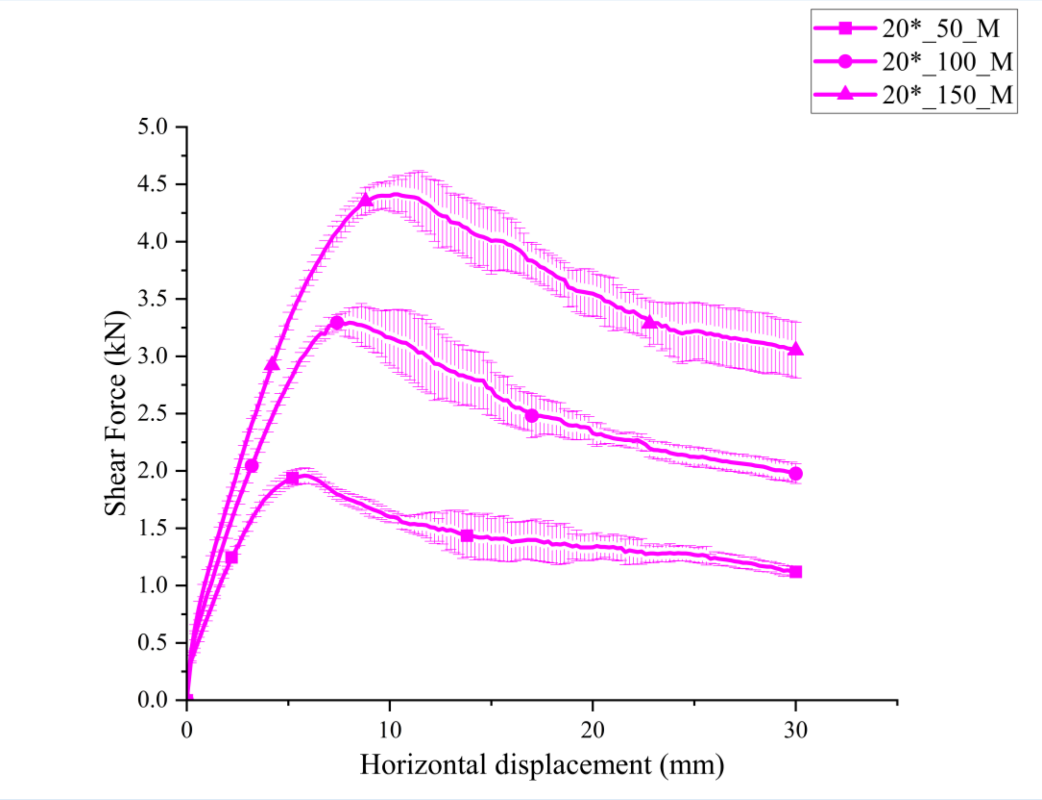


Fig. Typical observation of variation in the errors

Results and Discussion

Direct shear test results

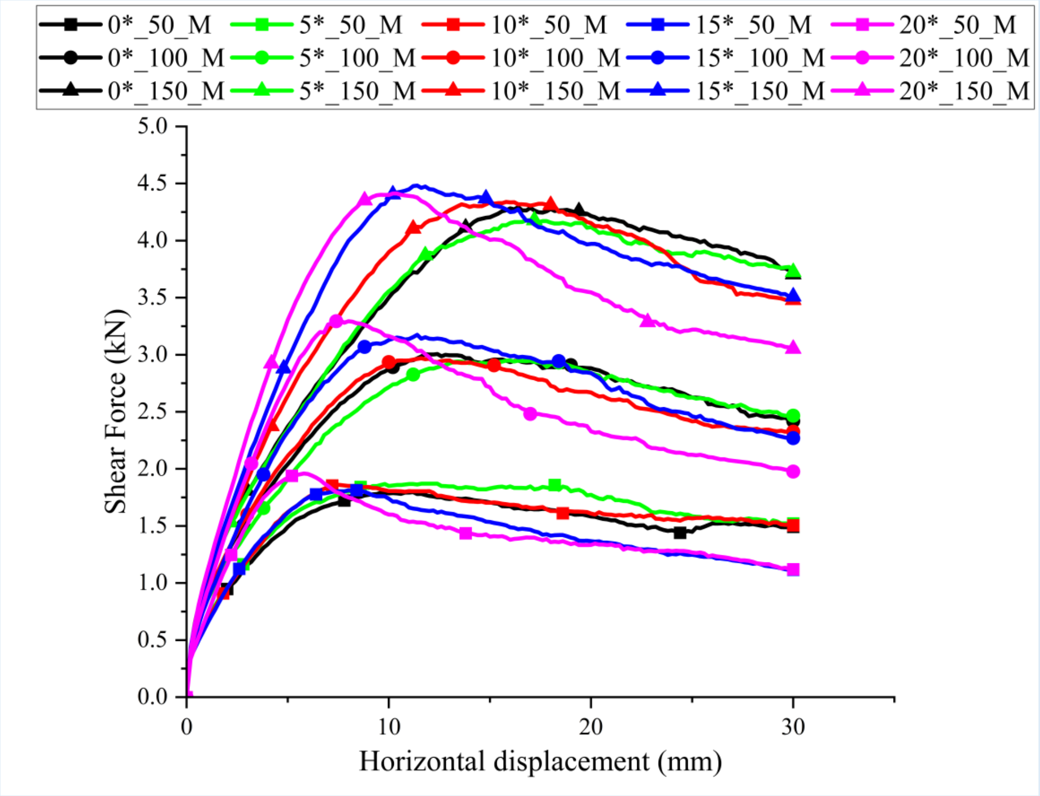


Fig. Cumulative SF vs HD graph from the mean value

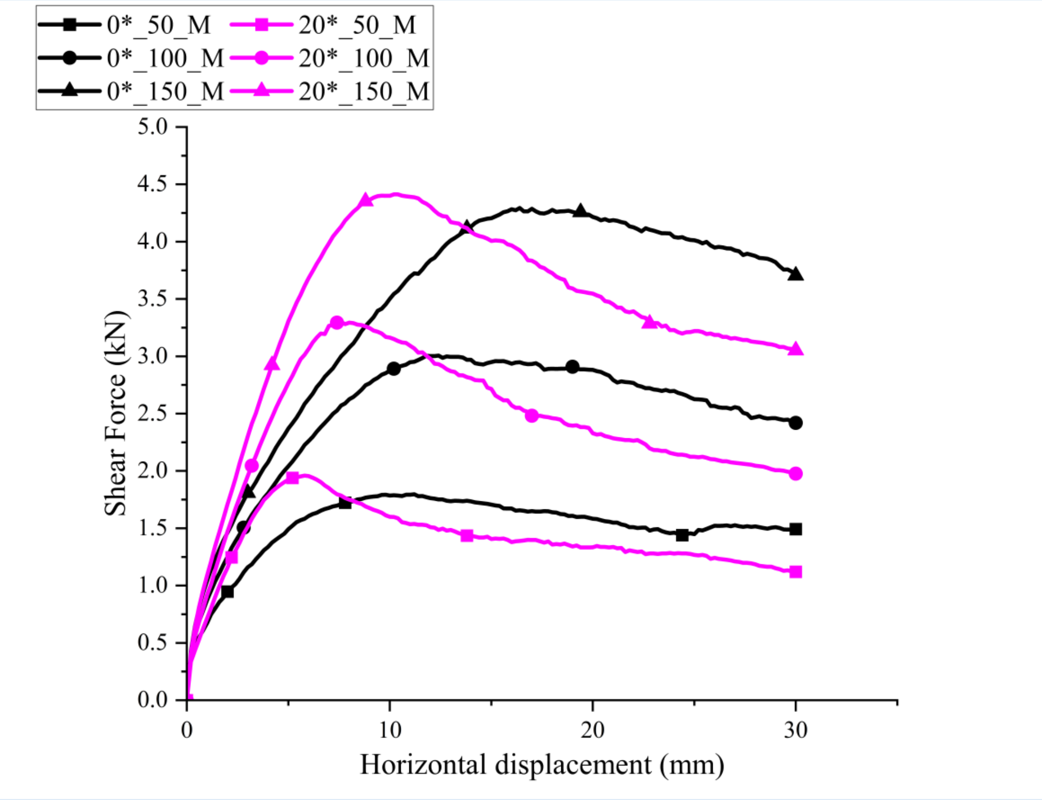
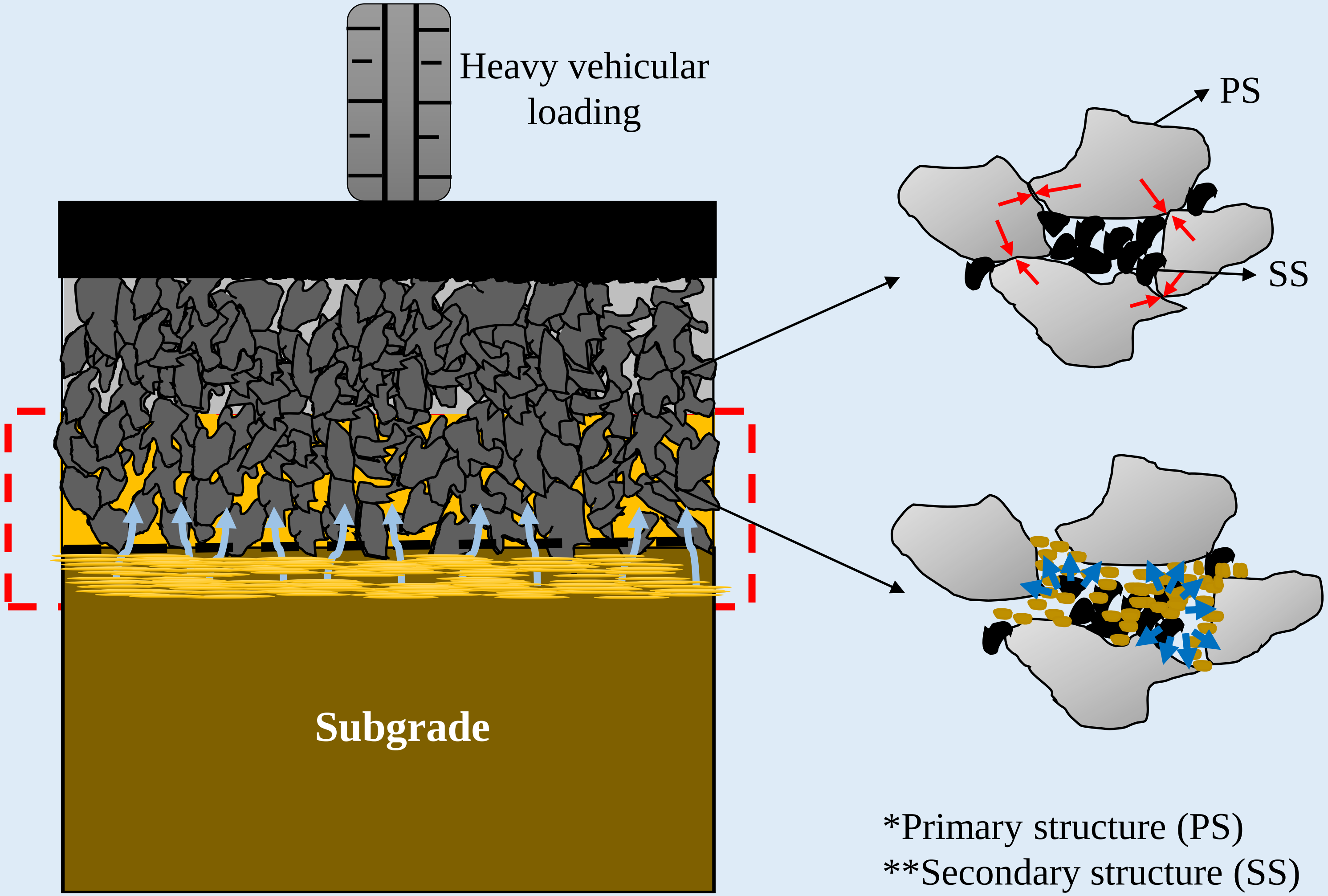
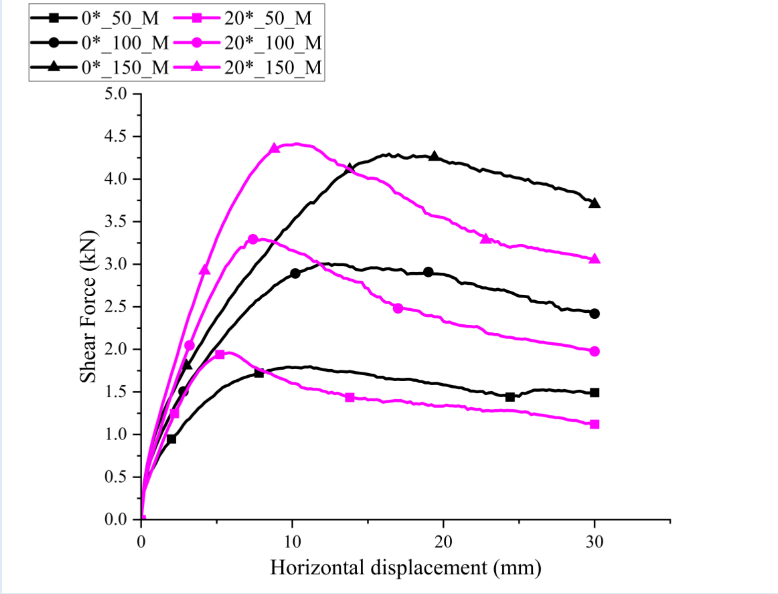


Fig. Comparing the granular sample without fine and with 20% of fine

Results and Discussion

Discussion based on granular packing theory





*Primary structure (PS)
**Secondary structure (SS)

Note:

DP < 0.5 - Unstable
0.5 < DP < 1 - Stable
DP > 1 - Dispersive

Summary

Major observation from the experimental study conducted

Summary:

- With the increase in the fine content, the material stiffness increases.
- The resistance to the particle rotation or readjustment in the granular matrix is lowered due to the mud pumping phenomenon.

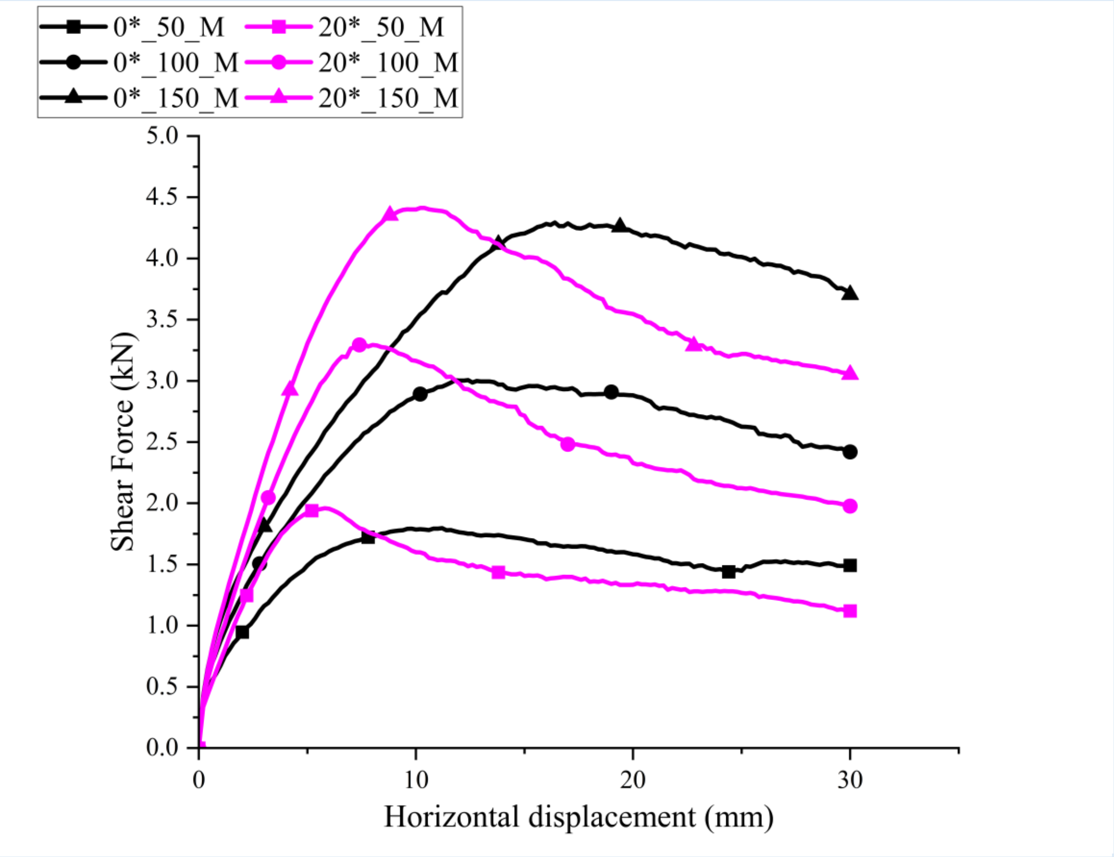
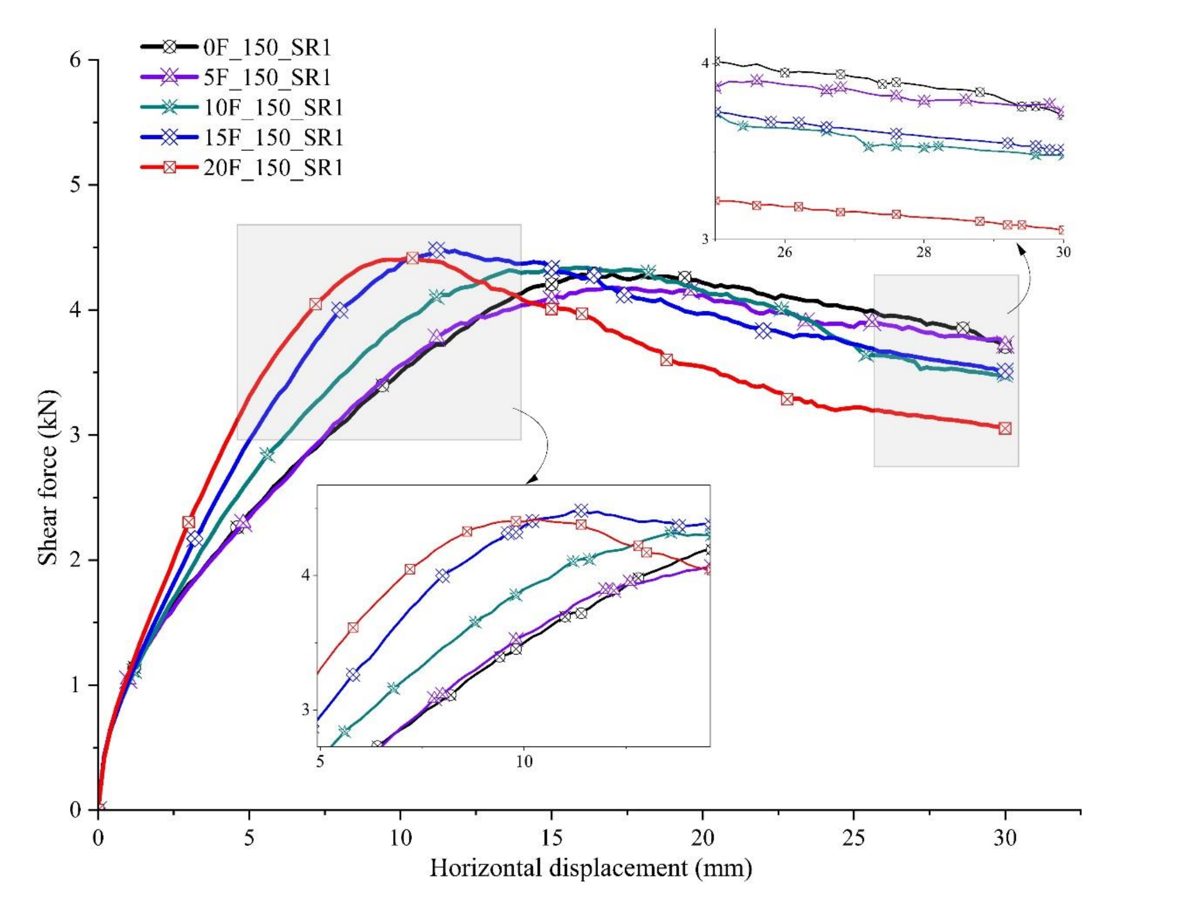


Fig. Shear force (kN) vs Horizontal displacement (mm)

Summary



Shear force (kN) vs Horizontal displacement plot

xF_y_SRz

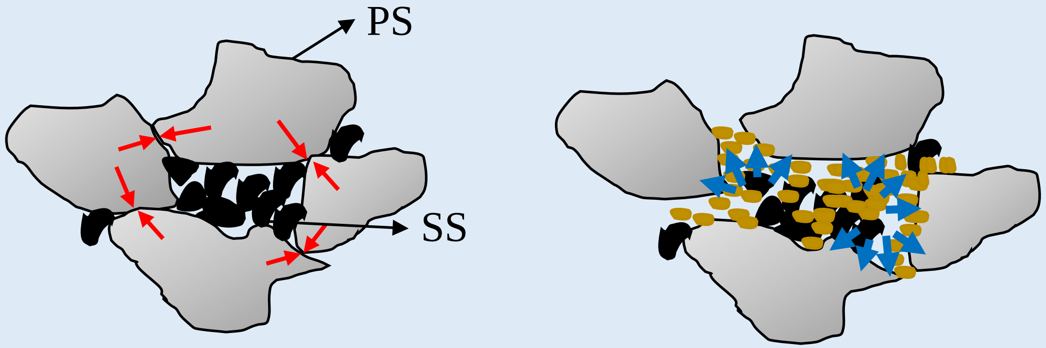
x – amount of fine sand added (%)

y- applied Normal stress (kPa)

z – Shearing rate SR1 – 1.25 mm/min

Conclusion:

- Increasing the fine sand content in the subgrade-granular mix (0% to 20%) **increases the initial stiffness** of the materials and changes the failure pattern from residual type to **peak failure type** by reducing the failure displacement.
- Post-peak stress reduction is **more pronounced at relatively higher fine sand contents.**



*Primary structure (PS)

**Secondary structure (SS)

Granular packing theory

Evaluation of granular packing theory

Kim et al. (2006)

Kim et al. (2009)

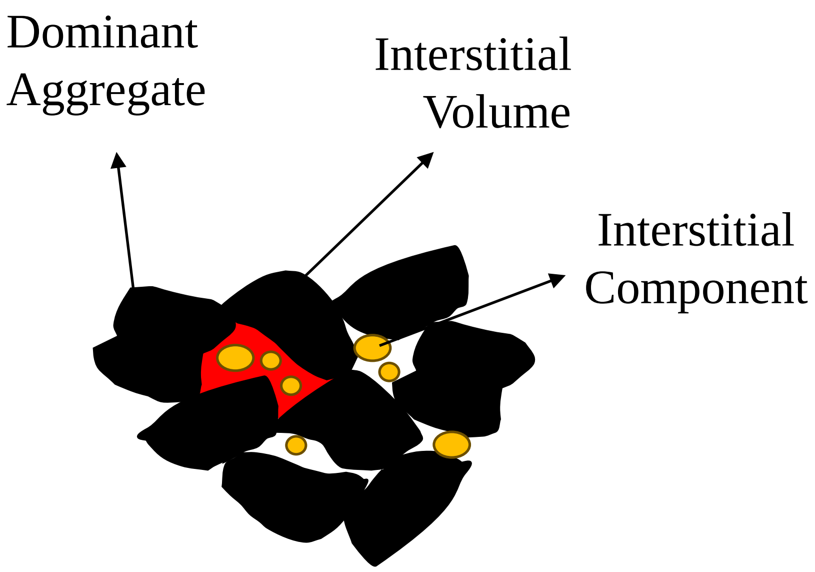
Gurain et al. (2013)

Lira et al. (2013)

Yideti et al. (2013)

Discussion:

- Improvement over bailey technique, defined the terms such as DASR, IC, IV.
- Recommended 70/30 rule between the consecutive sieve size
- Granular mix porosity should be less than 50%



Evaluation of granular packing theory

Kim et al. (2006)

Kim et al. (2009)

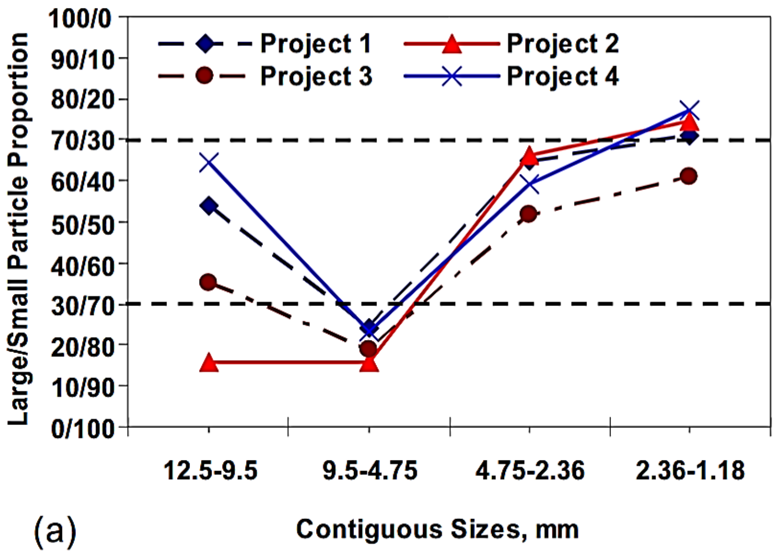
Gurain et al. (2013)

Lira et al. (2013)

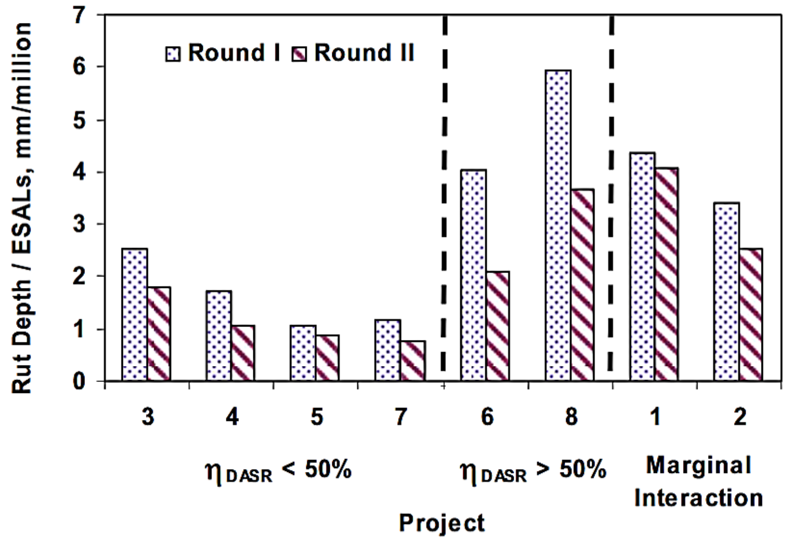
Yideti et al. (2013)

Discussion:

- Proved the framework developed by Kim et al. (2006)
- The sample mix with porosity more than 50% showed higher rut depth under wheel load testing.
- The consecutive sieve size with minimum porosity will be considered as the DASR components



(a)



Evaluation of granular packing theory

Kim et al. (2006)

Kim et al. (2009)

Gurain et al. (2013)

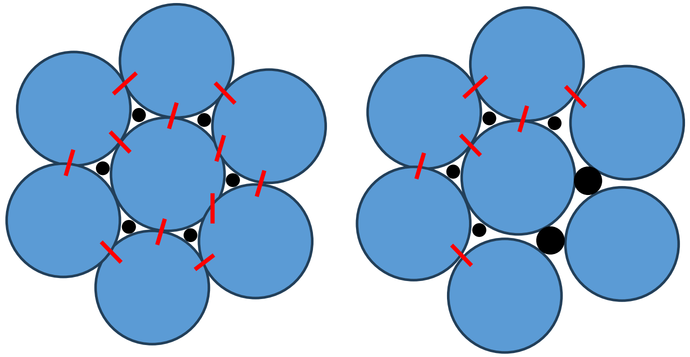
Lira et al. (2013)

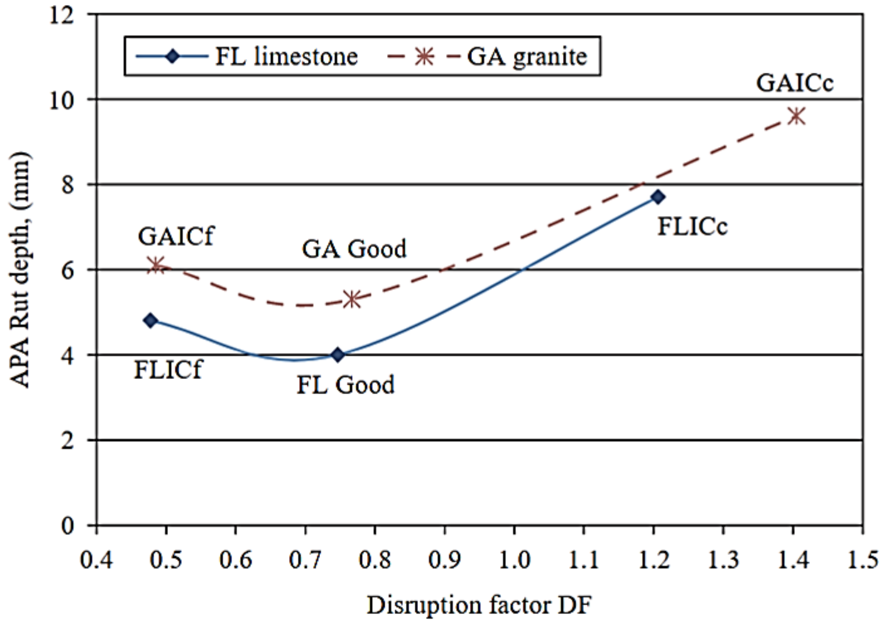
Yideti et al. (2013)

Discussion:

- Introduced the spherical particle concept.
- The optimum range of DF value observed in the range of 0.65-0.85
- Suggested the potential disruptive range of IC particle size as 0.732D to 0.225D
- Limited to the consecutive sieve system with size ratio of 1:2/1.5 (AASTHO-M 147, 1965)

$$DF = \frac{Volume\ of\ potentially\ diruptive\ IC\ particles}{Volume\ of\ DASR\ voids}$$





Evaluation of granular packing theory

Kim et al. (2006)

Kim et al. (2009)

Gurain et al. (2013)

Lira et al. (2013)

Yideti et al. (2013)

Discussion:

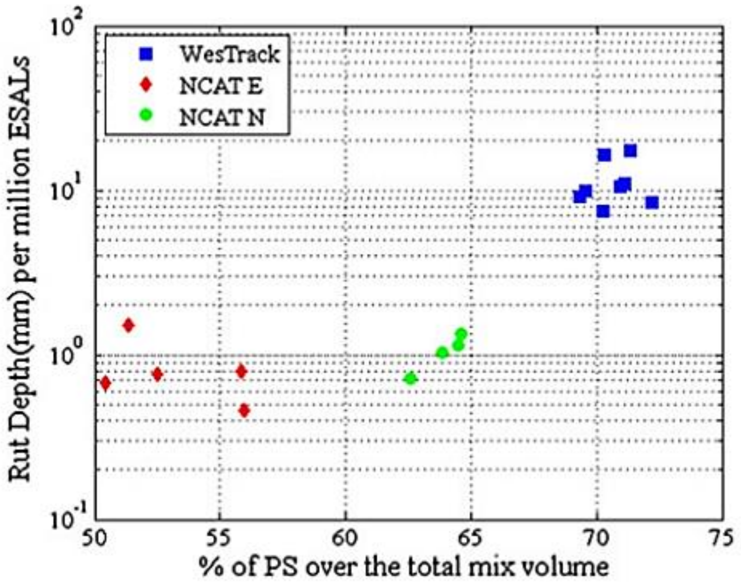
- The higher number of PS will create lesser air voids and higher coordination number; this will lead to local disruption.
- Removes the structured sieve system (AASTHO D 147) (2:1/1.5:1) limitation

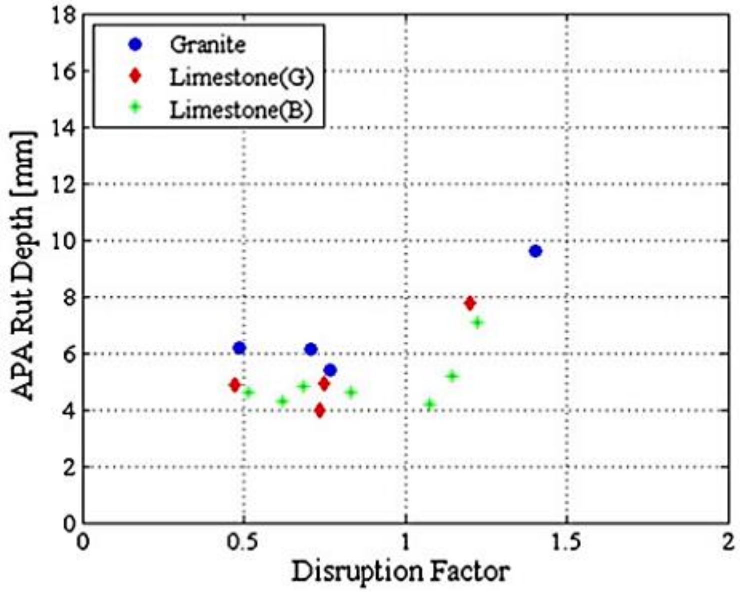
$$0.311\overline{D}_n + 0.689\overline{D}_{n+1} \leq D_{avg} \leq 0.703\overline{D}_n + 0.297\overline{D}_{n+1}$$

Where,

$\overline{D}_n$- mean diameter of the sieve size

$\overline{D}_n > \overline{D}_{n+1}$





Evaluation of granular packing theory

Kim et al. (2006)

Kim et al. (2009)

Gurain et al. (2013)

Lira et al. (2013)

Yideti et al. (2013)

Discussion:

- Introduced the granular packing theory
- Defined the min size of the potential disruption material as 0.225 $D_{PS,min}$

$$\frac{1.1 \times D_1 D_2}{\sqrt[3]{D_2^3 + 2.36 \times D_1^3}} \leq d_{w,avg} \leq \frac{1.1 \times D_1 D_2}{\sqrt[3]{2.36 \times D_2^3 + D_1^3}}$$

Where, D1 and D2 are the consecutive sieve size (D1>D2)

$d_{w,avg}$ – Weighted average void diameter (i.e., 0.732 $D_{w,avg}$)

$$\text{Disruption potential}(DP) = \frac{V_{DM}^{SS}}{V_{free}^{PS}}$$

V_{DM}^{SS}- Volume of potential disruptive material

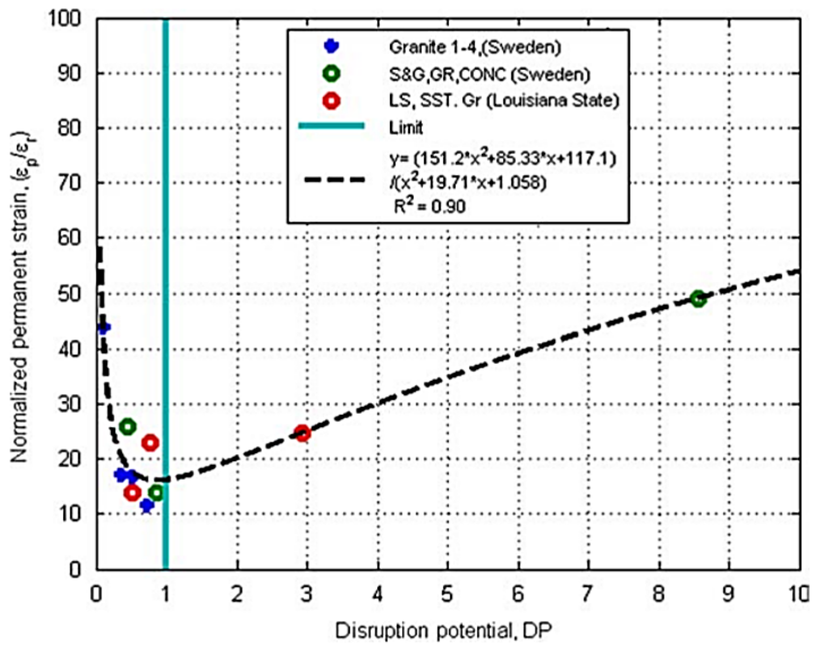
V_{free}^{PS}- Volume of free voids between the PS particles

Note:

DP < 0.5 - Unstable

0.5 < DP < 1 - Stable

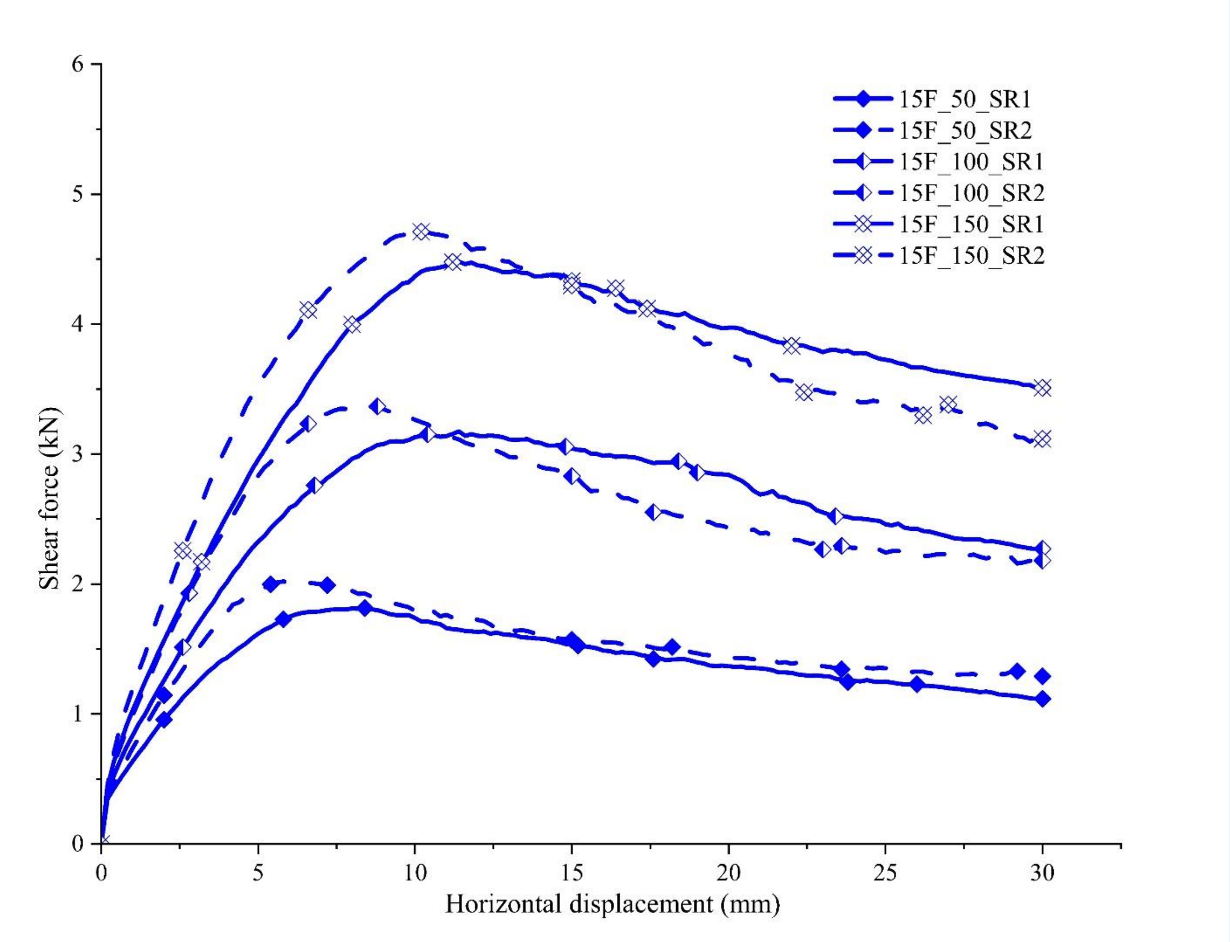
DP > 1 - Dispersive



Under higher shearing rate

Shearing behaviour of subbase-subgrade samples under higher shearing rate (3.25 mm/min)

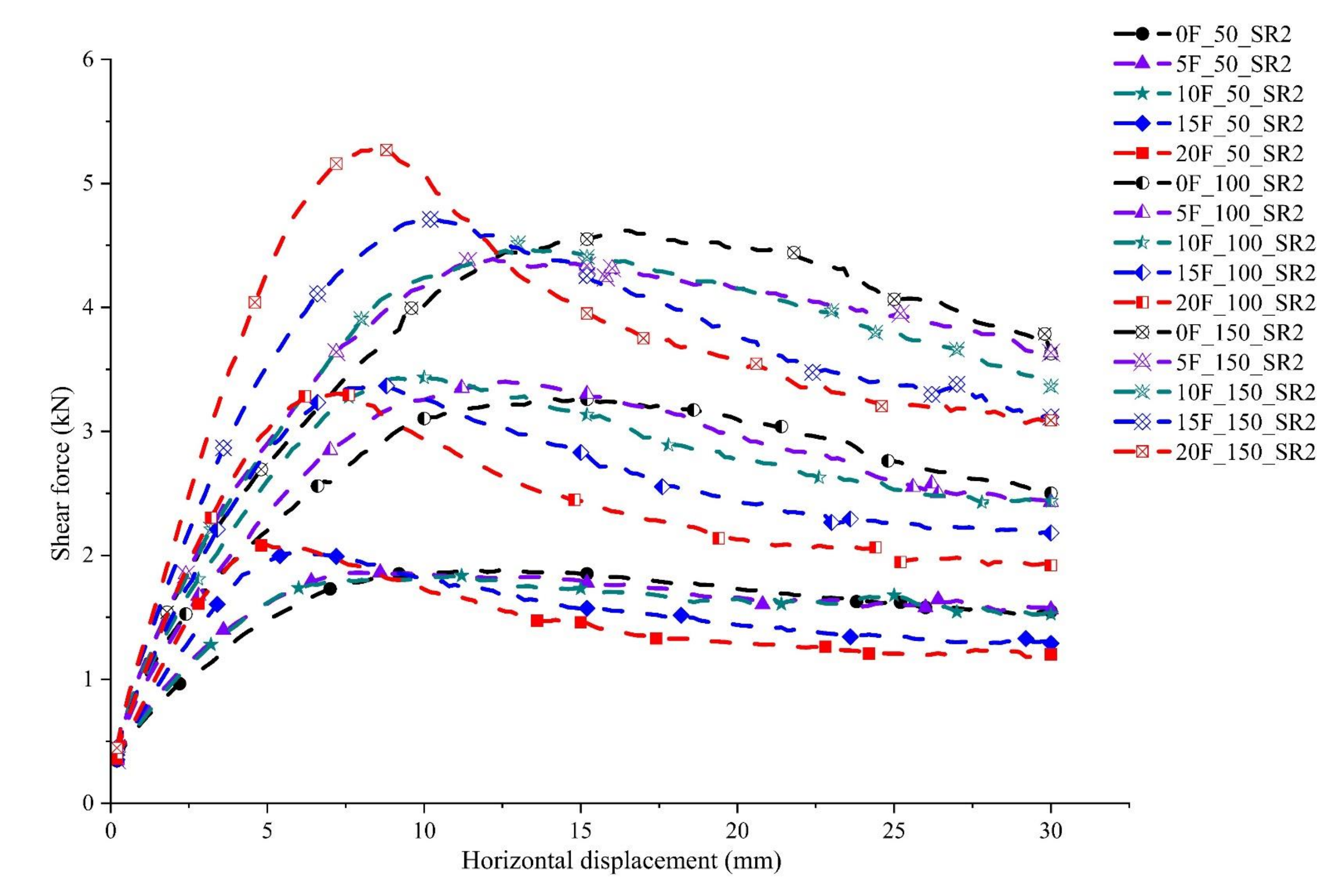
Sample ID	15_F	15_F
	SR 1	SR 2
Applied normal stress	100	100
Peak shear force (kN)	3.18	3.37
Residual shear force (kN)	2.36	2.21
Post peak shear reduction (%)	25.79	34.42
Failure displacement (mm)	11.4	8.4



Comparison of Shear force (kN) vs Horizontal displacement response under low and higher shearing rate

Under higher shearing rate

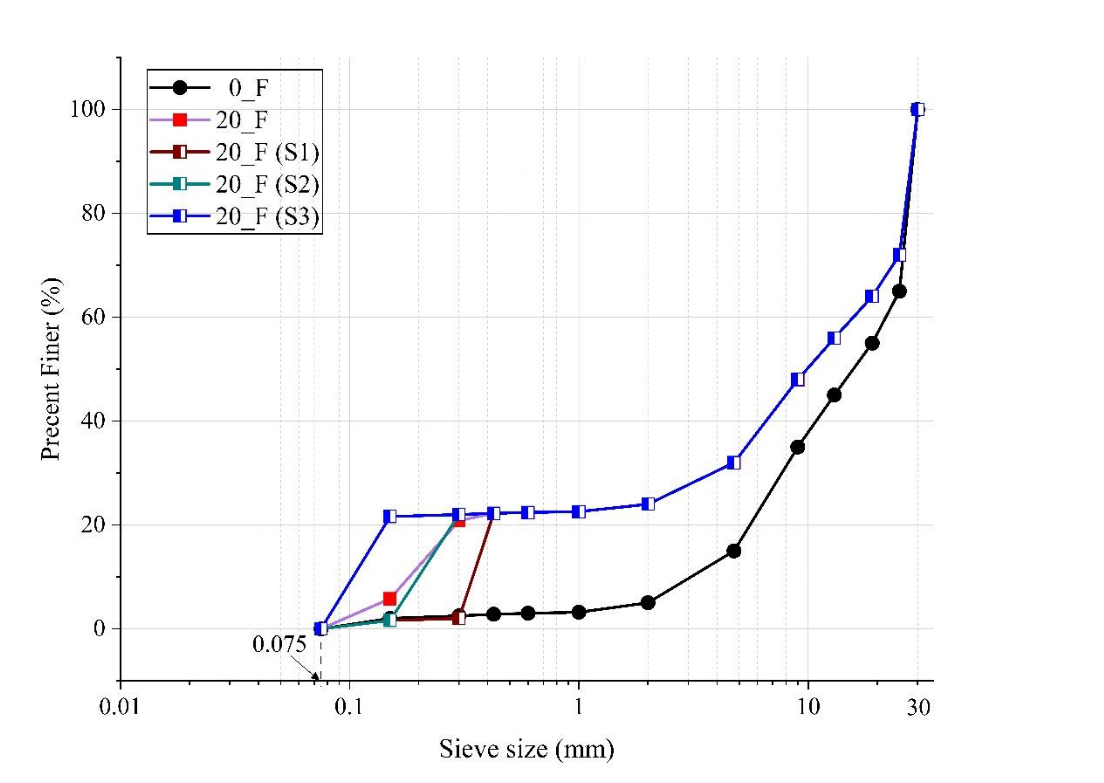
Shearing behaviour of subbase-subgrade samples under higher shearing rate (3.25 mm/min)

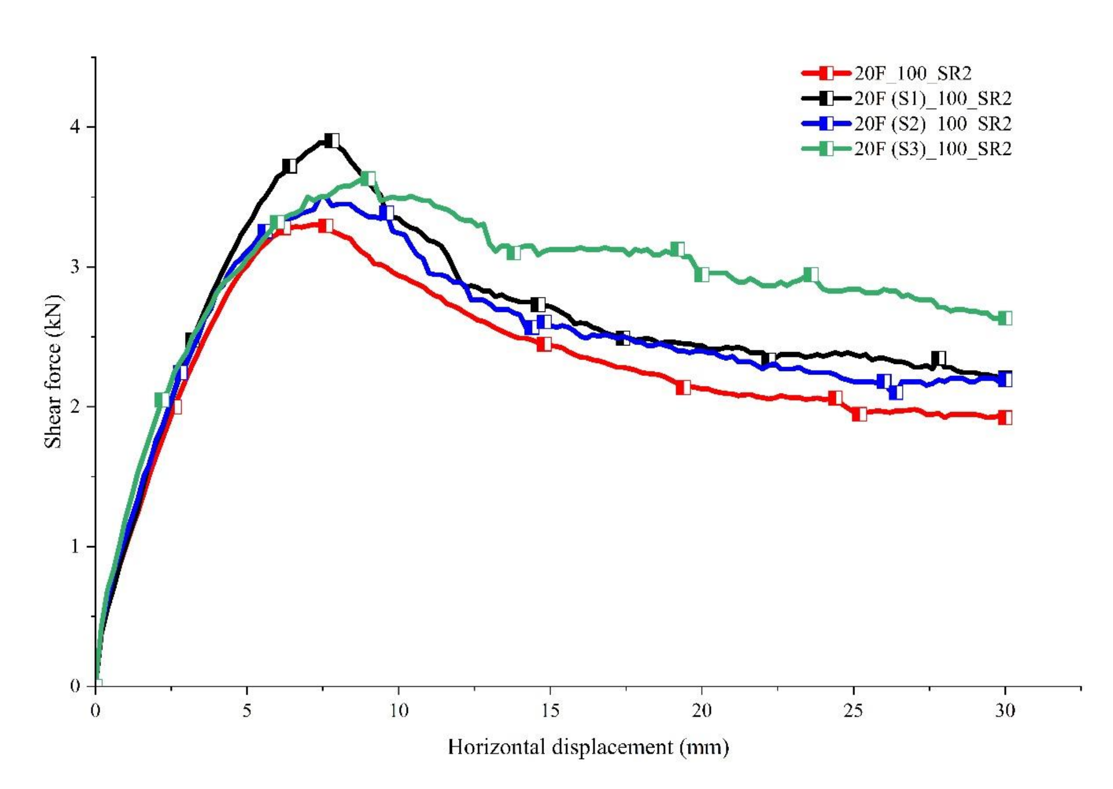


Shear force (kN) vs Horizontal displacement response under higher shearing rate

- As per the granular packing theory framework, the minimum size of potential disruption material **(i.e., 0.225 $D_{ps,min}$) is 0.45 mm (=0.225×2mm**)
- The size range of added fine sand particle is **0.425-0.075 mm**

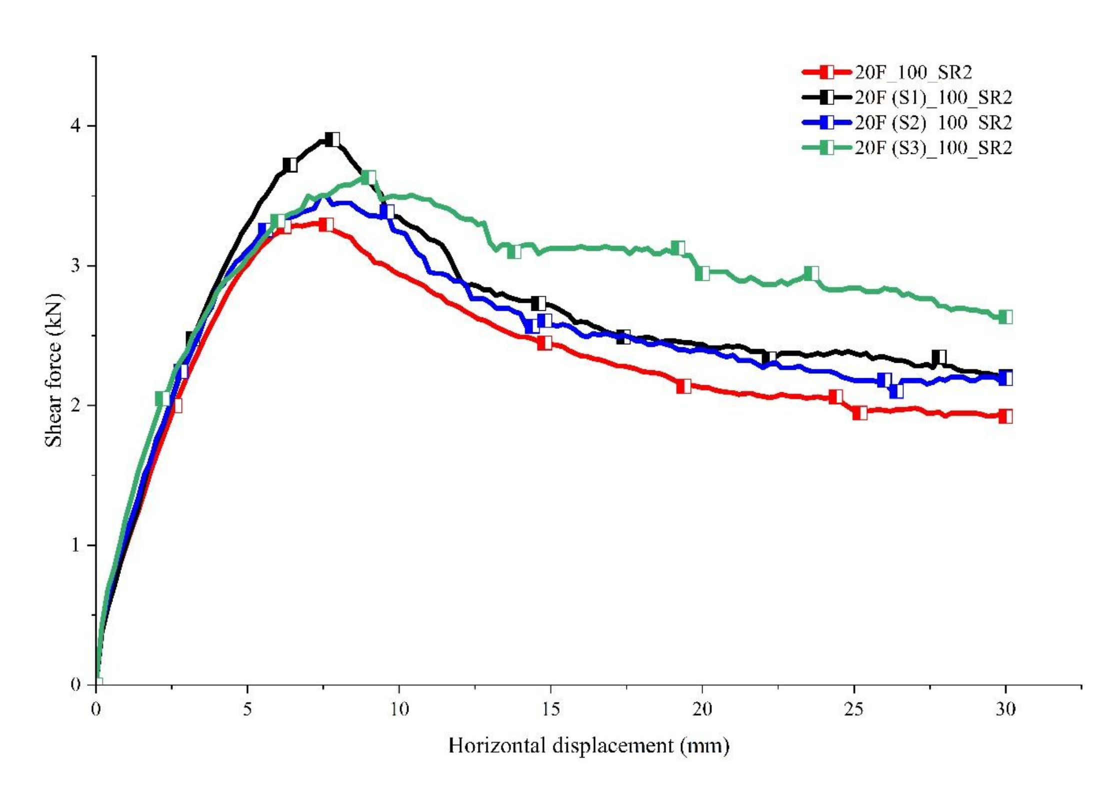
Shearing test of sample with mono size particles

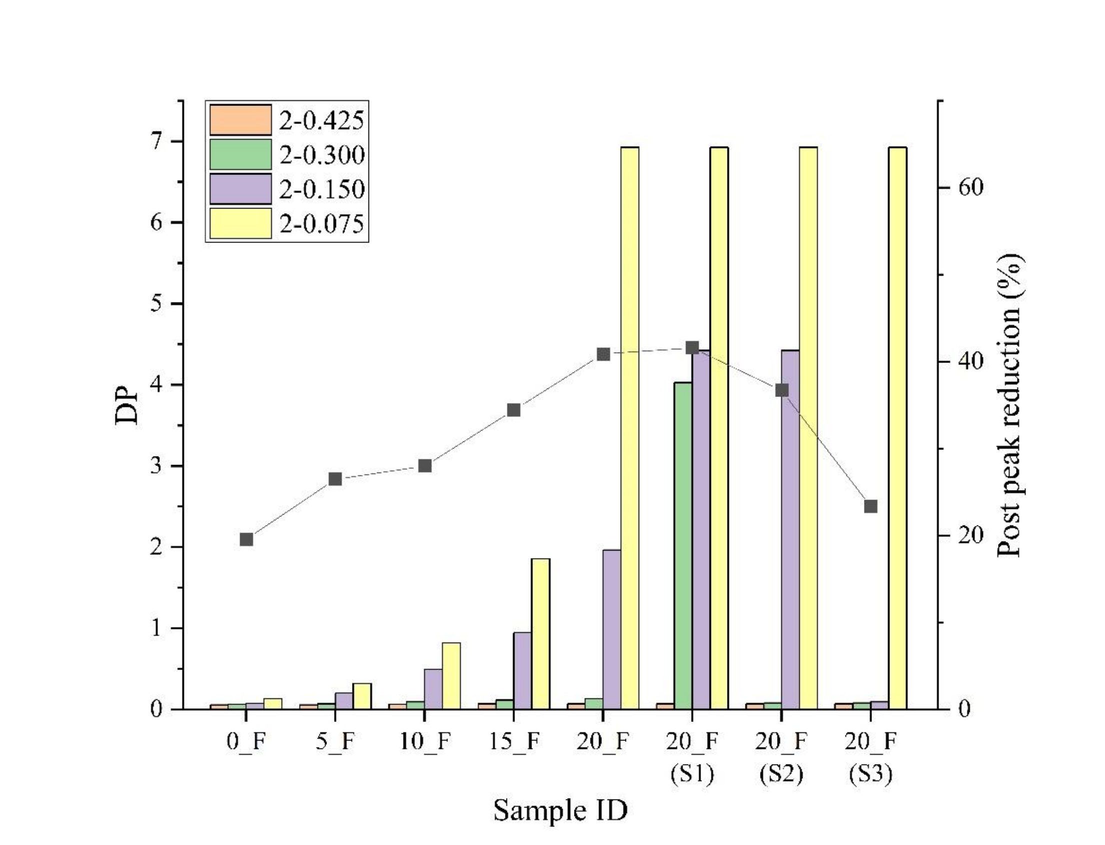


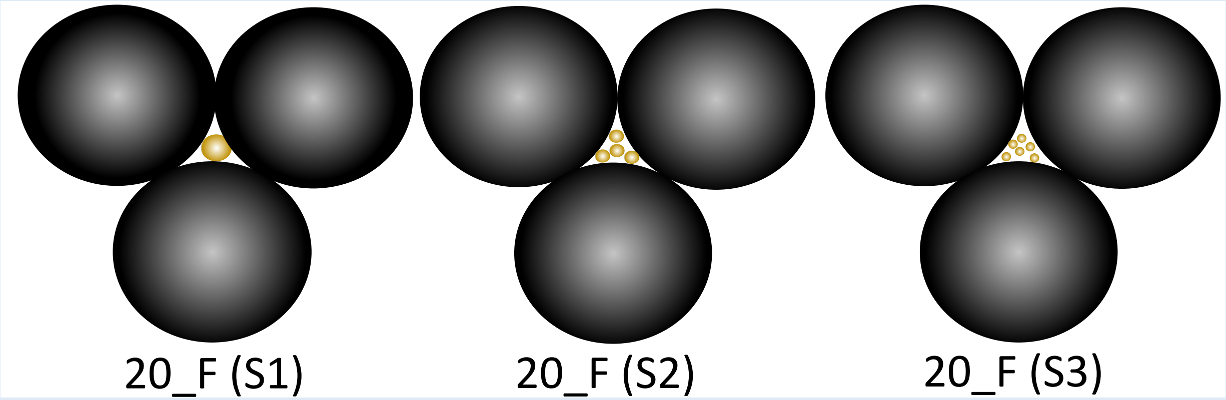


Sample ID	20_F (0.425-0.075 mm)	20_F S1 (0.425-0.300 mm)	20_F S2 (0.300-0.15 mm)	20_F S3 (0.150-0.075 mm)
Applied normal stress	100	100	100	100
Peak shear force (kN)	3.3	3.92	3.44	3.58
Residual shear force (kN)	1.95	2.29	2.178	2.745
Post peak shear reduction (%)	40.091	41.58	36.69	23.32
Failure displacement (mm)	7.2	7.8	7.4	8.8

Analytical framework

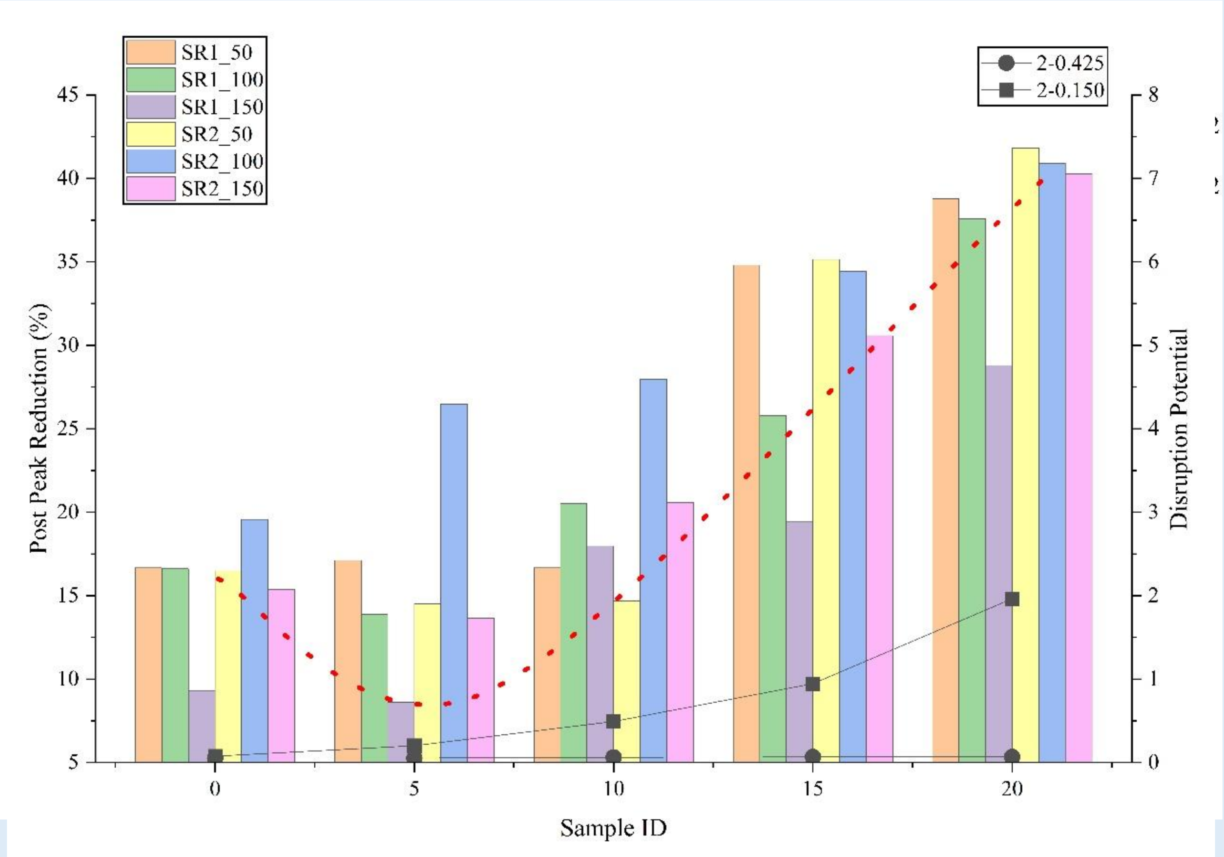


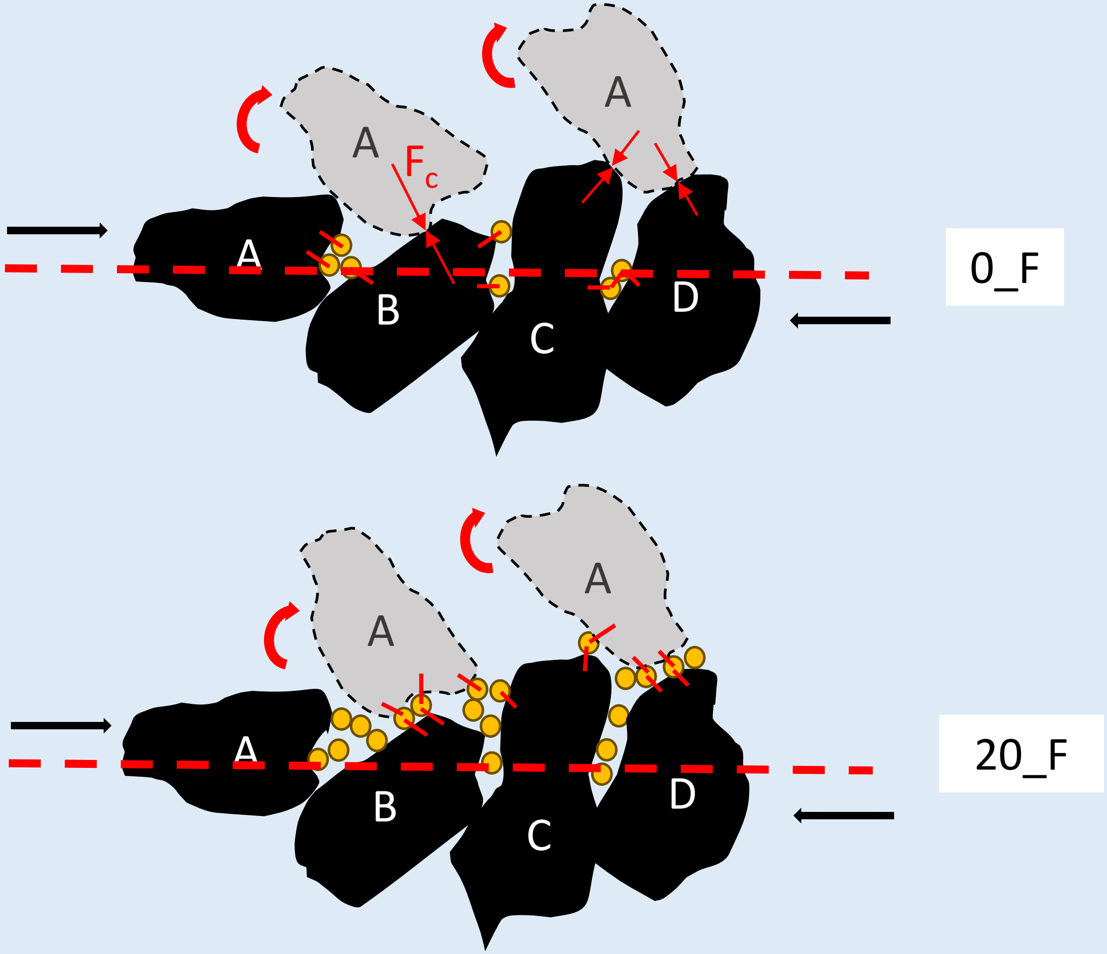




- As per the granular packing theory framework, the minimum size of potential disruption material **(i.e., 0.225 $D_{ps,min}$) is 0.45 mm (=0.225×2mm)**
- The size range of added fine sand particle is **0.425-0.075 mm**

Analytical framework





- Disruption phenomenon takes place when the amount of potential disruptive material exceeds the available voids space between the primary structure particle

Key Understandings

1. In general, a residual stress state is attained for a lower shearing rate (1.25 mm/min), while a higher shearing rate (3.25 mm/min) exhibits a peak stress state with substantially lower failure displacement.
2. Post-peak stress reduction is more pronounced at relatively higher fine sand content sample (i.e., 20_F) and at higher shearing rates (3.25mm/min).
3. While previous studies identified **$0.225 \times D_{PS,\ min}$ (0.225×2=0.45 mm for the present study)** as the lower limit for SS particles that act as DM. However, the present study reveals that the particles smaller than 0.45 mm (0.075-0.425 mm for present study) can also significantly contribute to disruption.
4. The degree of disruption potential reduces with decrease in the diameter of the SS particles.
5. From the study observation particle size above **0.15mm (i.e., $0.075 \times D_{PS,min}$),** can cause disruption effect in the load carrying matrix.

Future work

Triaxial testing (In progress)

Fig. Triaxial sample preparation and sample after the testing

<u>Work in progress:</u>

The future work will be focusing on the effect of:

- Moisture content
- Drainage condition

Acknowledgement

- **Organizers of the Event (NERIST and Organizing Team)**
    - **A platform to discuss interesting issues related to the Innovative Approaches to Road Safety and Material Engineering (IARSME 2026)**

- **A special appreciation to the contributors**
    - **The workforce to bring out the intricate findings**

- **All those researchers who laid the foundation of present day discussions**

Thank You for Patient Hearing

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