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Evaluation of Subgrade Soil on Premature Failure of Flexible Pavement in Hilly Area of Mizoram, India

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Abstract

Objectives: Subgrade soil has played an important role in the premature failure of, especially flexible pavement in a hilly area where rainfall intensity is very high. Even a slight failure in subgrade will reflect on the structure of the pavement in terms of cracks, undulations and rutting. An attempt has been made to find the influence of subgrade soil on the premature failure of the road along the State Highway which connects the lifeline between North and South of Mizoram, India. **Methods:** The locations where early deteriorations took place were located and testing was performed to assess the value of atterberg limits, permeability, bearing capacity, free swell index and hydrophilic coefficient. **Findings:** Premature failures of pavement are highly influenced by the emanation of groundwater in the form of spring along the hilly side of the road. The deep cutting of the road is not suggested due to the possibility of encountering water seepage. The studies reveal that the value of permeability, CBR value, type of soil, water saturation level and geometry of the pavement has contributed an important role in the performance of the pavement. **Novelty:** Road cutting at a differential level on sloping terrain results in non-uniform soil strength across the transverse section.

Keywords: Permeability; soil strength; groundwater; premature failure; hill road

1 Introduction

When the pavement below gets saturated as a result of the migration of water by capillarity it results in a gradual loss of bearing capacity, which may eventually lead to pavement failure[(1)]. Increased moisture content reduces the resilient modulus of granular materials, their frictional strength and resistance to deformation[(2)]. Fine grained soils have a relatively smaller capacity in bearing a load than the coarser grained soils[(3)]. Once the moisture content reached or went over an optimum value the permanent deformation increased dramatically and the material collapsed[(4)]. The pavement structure loses significant structural capacity when the unbound material layers are saturated. The pavement structure rapidly regains strength once the subsurface water level drops below the base course layer[(5)]. Failures may be due to either traffic (load associated) or environmental (non-load associated) influences. Destructive actions in the flexible pavement are quickly increased when surplus water is retained in the flexible pavement void spaces and increased moisture content in the soil can lead to increased pavement deflection [6–9].

1.1 Study area

The state highway was constructed in 2000 and completed in March 2010 under the Mizoram State Road Project funded by World Bank with a length of 164 km. This SH has the shortest route link to the southern side of Mizoram as shown in the Figure 1. It is considered as 'Priority Road' as it is the shortest route to connect the north and south of Mizoram.

The road has been divided into four sections as shown in Table 1. 'Section I' pavement condition is good except for the few locations which are addressed in this study. The 'Section II' condition of the pavement is good and structurally sound and performs after 10 years of construction. 'Section III' is not included in this study due to the choice of thin bituminous pavement layer. 'Section IV' is the worst section where failure occurs repeatedly even after every repair and overlay. The pavement composition along the state highway (ATL Road) is as below:

Table 1. Pavement Composition of State-Highway (ATL) Road

Pavement Composition	Section I (0.57 -28.50 km)	Section II (28.50 - 52 km)	Section III (52-98 km)	Section IV (98-164 km)
Wearing Course	20 mm MSS	30 mm BC	20 mm MSS	30 mm BC
Binder Course	50 mm BM	-	-	-
Base Course	150 mm WMM	225mmWMM	225mmWMM	225mmWMM
Sub-base Course	150 mm GSB	150 mm GSB	150 mm GSB	200 mm GSB
Pavement Thickness	370 mm	405 mm	395 mm	455 mm
Avg IRI (mm/km)	7.7	8	8.5	9

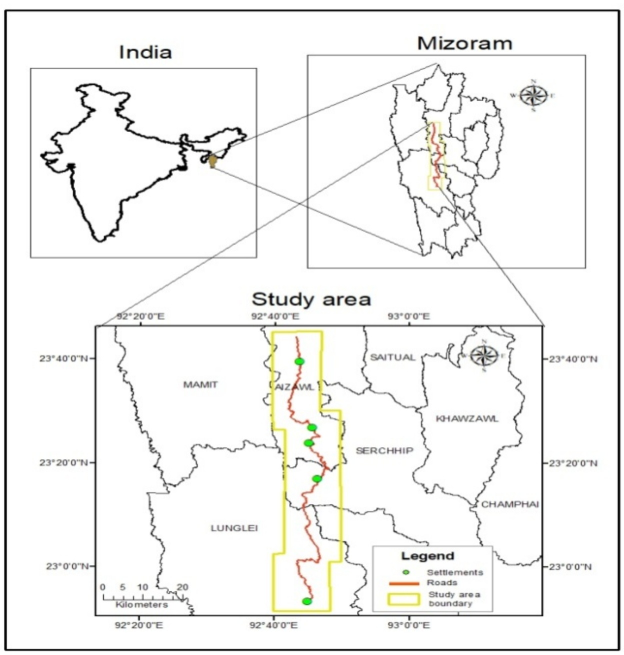

Fig 1. Study Location

The section locations selected in this study are as follows:

1. Chainage 15-16 km (Muallungthu Area)
2. Chainage 14-15 km (Falkawn Area)
3. Chainage 150 -164 km (Pukpui Area)

Details of the different locations considered under study area including location coordinates, section condition, and type of distressis tabulated in Table 2.

Table 2. Sample Location Details

Sl No	Name of the sample	Location coordinates		Section Condition	Distress Type
		N	E		
1	Falkawn (1H&1V)	N23^{0}37'12.67"	E92^{0}43'22"	Very Poor	Rutting, Crack, Pothole
2	Falkawn (2H&2V)	N23^{0}37'02.04"	E92^{0}43'08.17"	Very Poor	Rutting, Crack, Pothole
3	Muallungthu (3H)	N23^{0}36'03.81"	E92^{0}43'07.46"	Very Poor	Rutting, Crack, Pothole
4	Mel 5(Good Section)	N23^{0}40'9.94"	E92^{0}43'31.41"	Good	-
5	Kelsih (Moderate Section)	N23^{0}38'06.66"	E92^{0}43'24.37"	Moderate	Crack
6	Hualngo	N23^{0}39'23.81"	E92^{0}43'39.28"	Very Poor	Rutting, Crack, Pothole
7	Pukpui 5	N22^{0}57'48.45"	E92^{0}44'14.14"	Very Poor	Rutting, Crack, Pothole
8	Pukpui 6	N22^{0}57'59.27"	E92^{0}43'52.18"	Very Poor	Rutting, Crack, Pothole

1.2 Condition of the pavement

A pavement functional condition test was conducted in 2020 after 10 years of construction. It was observed that IRI values were more than 4 exceeding the permissible limit at different sections using Hawkeye 1000 Laser Profiler as shown in table 1. Based on a traffic volume count, it was found that Cumulative Standard Axle (CSA) is 3 msa (million standard axles). FWD (Falling Weight Deflectometer) was used to assess the structural strength of the pavement by measuring deflection, layer thickness, and material properties. The average Deflection value obtained along the state highway is 0.77 mm. An axle-load survey is carried out to estimate the axle-load distribution of commercial vehicles using the road. Vehicle damage factor (VDF) or equivalent standard axle load is calculated from axle load survey data and found to be 0.64 which is lower than the indicative value of VDF 1.7 for hilly terrain as per IRC 37-2018. Due to the low VDF, wheel load is not a factor causing premature pavement failure. The state highway was designed with Cumulative Standard Axle (CSA) 3 msa (million standard axles) and CBR 6% at the time of construction. There were numerous shady and damp stretches along the road length that received little or no sunlight at all. This posed a huge problem for the construction of pavement as sub-grade would remain damp even well into the working season.

In this study, the subgrade soil is examined to determine the causes of premature failure of the pavement as the pavement condition along the highway is in bad condition at a few stretches despite using the same road construction materials. The premature failure occurred frequently at some locations even after many repairs. Since all sections of the pavement are constructed from the same material, except for the foundation soil, the subgrade soil has been focused on. The cause of the premature failure is most likely a soil-related problem. Since the foundation soil differs from the subgrade soil in different sections of pavement, the subgrade soil was targeted.

2 Methodology

2.1 Materials

A total of 10 soil samples were collected from 8 different places on State Highway (ATL Road) of Mizoram. Eight samples out of 10 were taken from 'poor section' where premature failure frequently occurs. The locations are Falkawn (1V, 1H, 2V, 2H), Muallungthu (3H), Hualngo, Pukpui 5 and Pukpui 6. Two soil samples were taken from 'moderate section' at Kelsih and 'good section (pavement failure not observed for a long period time)' at Mel 5. Subgrade soil sample was collected not only in a failed section; it was also taken from the 'moderate' and 'good section' also to make a comparison.

A CBR test was conducted on the soil samples that were collected from the Melnga site of the World Bank road to assess the effect of moisture content on the strength of the soil under different duration of soaking.

2.2 Methods

Samples of soil collected from the site were tested by Atterberg limits, Wet sieve analysis, Permeability test, Compaction test and California Bearing Ratio Test (CBR) to determine the physical properties, compaction characteristics and strength of the soil. A soil swell test was conducted using the free swell index and hydrophilic coefficient measurements.

3 Results and Discussion

3.1 Classification and physical properties of soil

Soil classification is conducted to find out the type of soil using the Highway Research Board, Unified Soil Classification and Group Index Method as shown in Table 3. It is found that the soil types in the 'Poor section' of the road are considered not suitable for subgrade. The soil quality in terms of drainage, volume change characteristics is poor as seen from the table below. The Good section (Mel5) and Moderate sections (i.e Kelsih) are found as suitable for subgrade material. The soil is silt based on a soil classification system.

Table 3. Classification of Soil

Name of the Sample	Soil Classification			Type of Soil	Suitability as a subgrade	Drainage	Volume Change
	HRB	USC	GI				
1V	A-7	CL	11.63	Clay	Poor	Very poor	High
1H	A-4	ML	5.34	Silt	Fair	Poor	Medium to High
2V	A-7	CH	13.42	Clay	Poor	Very poor	Very High
2H	A-5	ML	3.63	Silt	Fair	Poor	Medium to High
3H	A-4	CL	8.00	Silty clay	Fair	Very poor	Medium
Kelsih	A-4	ML	4.09	Silt	Fair	Poor	Slight to Medium
Hualngo	A-6	CL	3.17	Plastic Clay	Very Poor	Very poor	Medium
Pukpui 5	A-4	CL	2.72	Silt	Poor	Very poor	Medium
Pukpui 6	A-6	CL	9.94	Clay	Very Poor	Very poor	Medium
Mel 5	A-4	ML	3.29	Silt	Good	Fair to Poor	Slight to Medium

Table 4. Physical Properties of Soil

Name of the Sample	Specific Gravity	Permeability (cm/sec)	Liquid Limit %	Plastic Limit %	Plasticity Index %	CBR %	MDD	OMC
1V	2.34	8.05x10-7	44	26.93	17.07	4.68	1.44	25
1H	2.55	5.6x10-6	25.6	20.95	4.65	5.12	1.75	18
2V	2.59	7.34x10-6	53	34.01	18.99	5.53	1.53	18
2H	2.52	9.5x10-6	40	30.73	9.27	5.84	1.74	16
3H	2.57	1.69 x10-6	34.7	26.43	8.27	5.58	1.69	19
Kelsih	2.57	1.34 x10-6	29	19.34	9.66	6.57	1.73	16
Hualngo	2.6	3.52x10-6	35	21.8	13.2	3.51	1.89	13
Pukpui 5	2.53	2.35x10-6	35	27.1	7.9	5.2	1.73	16
Pukpui 6	2.53	3.6 x10-7	40	22.98	17.02	4.2	1.8	17
Mel 5	2.484	4.31 x10-5	30	25.98	4.02	7.88	1.76	14

As shown in Table 4, the good section (Mel 5) soil is selected to compare the soil condition with the poor section of the road. The good section of soil is having a low PI value of 4.02%, a high MDD of 1.76 kg/cm^3, a high CBR value of 6.88%, and lesser silt and clay content (46.95%). The poor section of the road soil samples are having high plasticity, low CBR (CBR <5.5%), MDD value less than 1.75 kg/cm^3 and a high value of silt and clay content (>70%). Pavement sections such as Hualngo, Pukpui 5 and Pukpui 6 have a bottom-up failure as a result of high groundwater levels during rainy season, which lead to the failure of the subgrade.

There is low permeability in the entire stretches at the level of subgrade as shown in the table 4. Most of the pavement section fails on the hilly side first in the study area, maybe due to the slow rate of water dissipation in the downward and transverse directions. A significant amount of rainfall infiltrates into the subgrade through the shoulder on both sides of the pavement. As the valley side has an open slope terrain, it can easily drain water out horizontally, while the hilly side has a massive and denser soil, which makes it hard to drain water fast horizontal and downward direction. In fact, the hill side does not have an open surface to drain out water.

Based on the properties of the soil, soil by itself is not the primary reason for pavement failure; rather, failure happens when the soil becomes significantly saturated with water over an extended period of time.

3.2 Influence of silt and clay in the subgrade soil

Wet Sieve Analysis test is conducted to find out the particle size of the soil. Silt and clay are soil particles passing 75microns sieve. From Table 5, we observed that soil from locations 1H, 2V, 3H, and Pukpui 6 are having silt and clay content of more than 70%. A higher percentage of silt & clay content leads to low permeability and infiltration which results in poor drainage. Poor drainage causes early pavement distress such as rutting, cracking and shoving.

Table 5. Particle Size Distribution

Name of the Sample	Particle Size Distribution		
	Gravel%	Sand %	Silt & Clay %
1V	1.3	19.49	79.21
1H	0.073	38.205	61.712
2V	3.2	24.733	72.067
2H	6.5	41.2	52.3
3H	3.1	19.329	77.571
Kelsih	8.71	35.825	55.465
Hualngo	18.767	35.342	45.891
Pukpui 5	10.6	40.8	48.604
Pukpui 6	5.2	24.129	70.671
Mel 5	13.3	39.75	46.95

3.3 Influence of the road design level from original ground level

As the depth of the pavement level differs from the original ground level (OGL), soil samples were taken from the hill and valley sides of the pavement (sections 1 and 2) to determine the differences in their physical properties. Soils are able to hold more loads with increasing depth. Due to the gradient of the slope terrain; the level of the road cutting varies from hilly to flat terrain. The depth of cutting depends on the degree of terrain. Steep terrain has resulted in a higher cutting height and vice versa.

Table 6. Comparison between Hillside and Valley Side of Subgrade Soil

Name of the Sample	Permeability (cm/sec)	Plasticity Index %	CBR %	MDD in kg/cm^2	OMC %	Silt & Clay %	Avg. Height of cutting in m
1(Valley)	$8.05x10^{-7}$	17.07	4.68	1.44	25	79.21	1.7
1(Hill)	$5.6x10^{-6}$	4.65	5.12	1.75	18	61.712	4.5
2(Valley)	$7.34x10^{-6}$	18.99	5.53	1.53	18	72.067	1.2
2(Hill)	$9.5x10^{-6}$	9.27	5.84	1.74	16	52.3	3.9

The valley side of the pavement section has a lower plasticity index, CBR, and MDD than the hillside as shown in Table 6. The pavement fails to start normally from the hillside may be caused by delayed drainage of water entering in the subgrade from the shoulder. There is inconsistency in the density of soil on the cross section of the road due to varying depths of pavement levels from the original ground surface. In other words, uniformity of soil strength does not exist on the transverse section of the road.

3.4 Influence of moisture level in pavement subgrade

3.4.1 ***Effect of groundwater level***

Even during the dry season (March), there is still water seepage on the surface of the pavement at Pukpui, Hualngo as shown in Figure 2. Since the pavement is fully saturated even during the dry season, it will weaken the pavement structure as soil tends to lose strength when fully saturated with water. It is necessary to lower the water table in this section and to provide good drainage so that the water can drain off quickly.

The Pukpui stretches have a layer of shale rock that is considered impermeable. A layer of impermeable material prevented the water from further propagating downward. Impermeable layers prevent water from flowing further downward, making an unconfined aquifer that leads to pavement collapse.

Fig 2. High water table

3.4.2 ***Effect of water saturation level***

Saturation level of any soil with water can be understood by the total amount of void in the soil that has been filled up by water. The success or failure of a pavement is more often dependent upon the underlying subgrade. Saturation mainly affects the subgrade layer of the pavement. The amount of rainfall is relatively high in Mizoram. Under the influence of the southwest monsoon, the study area experiences significant rainfall from June to September, with an average annual rainfall of 2,794 mm. The high intensity of rainfall leads to the saturation of subgrade soil if proper geometric design is not incorporated.

The CBR tests were performed at different water saturation levels to investigate the variation of CBR value with respect to different duration of soaking. The saturation period of soil in water is divided into number of days such as unsoaked, 4,7, 14,21,61, 90, 102 and 150 days. The soil classified as is silt based on the value of A-4 (HRB), 3.29 (Group Index) and ML as per USC.

It is observed that the CBR value of the soil sample prepared at a particular density decreases rapidly after 4 days of soaking. The rate of decrease of CBR value beyond 4 days soaking is minimal. It is also observed that there are not much significant variations in CBR values from 90th day of soaking. The soil strength reduces as the water saturation period of soil increases as shown in the Figure 3. Subsurface moisture reaches lower layers of pavement from different sources like pavement surface, seepage from shoulders and seepage from adjoining hills and capillary rise of moisture from the ground. If water is able to enter the pavement, there must be a way for it to depart. Soil resistance to compression may drop substantially if its moisture content increases. Increased moisture content reduces the load-carrying capacity of the road and causes premature pavement failure, resulting in shorter pavement life.

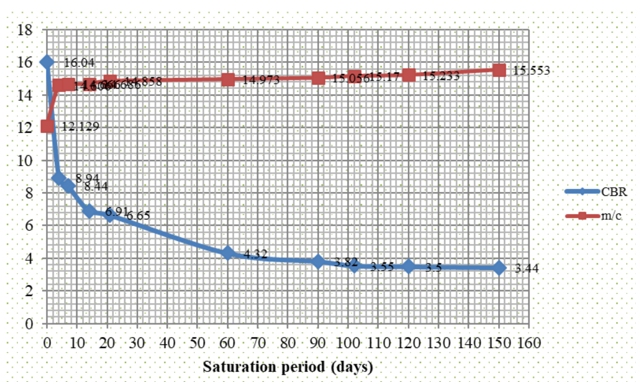

Fig 3. Effect of moisture in soil strength

It was conceivable that the build-up of moisture in the subgrade would ultimately lead to its degradation under vehicular load and this was evident from the localized appearance of rutting and depressions at several locations. In a few cases, substantial accumulation of water had led to the puncturing through of the sub-base layer and complete failure of the subgrade.

3.5 Soil hydrophilic coefficient and Free swell index

Surface wettability plays a significant role in how fluids interact with materials. Water has a strong affinity for hydrophilic surfaces; while hydrophobic surfaces have a weaker affinity for water. The hydrophilic coefficient is the ratio of volumes after 72 hours of sedimentation of equal dry-volumes of dry and high specific surfaced soil in water and paraffin. The hydrophilic coefficient can be defined as follows:

$\eta = V_{water}/V_{paraffin}$

η : hydrophilic coefficient

Vwate r : volume of soil in water after 72 hours sedimentation

Vparaffi n : volume of soil in paraffin after 72 hours sedimentation

The hydrophilic soils have a higher volume in water than they do in paraffin; therefore, their hydrophilic coefficient will be high. If the coefficient is greater than 1, the soil has a hydrophilic property. If it is under 1, the soil has a hydrophobic property.

The Free-swell index is the increase in the volume of soil, without any external constraints, upon submersion in water. The possibility of damage to structures due to swelling of expansive clays needs to be identified. All the soils are hydrophobic having non reactivity with water as shown in Table 7.

Table 7. Swelling Properties of Soil

Name of the Sample	Free Swell Index %	Hydrophilic coefficient
1V	0	1.01
1H	0	1.06
2V	0	0.98
2H	0	1.01
3H	0	1
Kelsih	0.56	1.01
Hualngo	1.69	1.12
Pukpui 5	1.35	1
Pukpui 6	0.75	1.03
Melnga	0	1.01

The soil is non-reactive with water since they do not change in volume when in contact with water. Moreover, a small change in volume of soil is observed at Hualngo, Pukpui 5 & 6.

3.6 Geometry of the pavement

Pavement geometry includes carriage width, alignment, sight distance, shoulder, side drain, curve, camber, and gradient. The 35-year average rainfall of Mizoram is over 2000 mm which has a significant impact on subgrade softening if surface and sub-surface drainage is poor. The rainy season (monsoon) lasts for at least four months (June-September) and contributes about 70 percentage of total annual rainfall. The road with a high shoulder delays the surface runoff of water due to poor surface drainage as shown in Figure 4. Delay water saturates the subgrade by entering the shoulder from the edge of the pavement.

Fig 4. Raised shoulder & tall grass blocking surface drainage

The performance of embankment sections is good and there is no pavement distress found along the road till today. With the pavement raised above the ground, an embankment provides the advantage of preventing groundwater and allowing for improved drainage.

4 Conclusion

The soil samples were found not reactive to water and did not swell. It is found that pavement failures occur due to over saturation of soil caused by poor drainage at Hualngo and Pukpui stretches. Pavement stretches in Hualngo and Pukpui have a layer of shale rock that prevents water from penetrating further downward, causing unconfined aquifers and pavement failure.

The varying amount of saturation level of the soil increases (i.e. the degree of exposure of the soil to water/moisture), the overall load bearing strength of the soil decreases considerably. Based on the properties of the soil, soil by itself is not the primary reason for pavement failure; rather, failure happens when the soil becomes significantly saturated with water over an extended period of time. Due to better drainage and being free of groundwater, the embankment sections along the state highway tend to last longer.

The hillside section of the pavement structure becomes cracked quite quickly due to water ingress with poor drainage which saturated and softens the subgrade soil. One of the major causes of premature failures is due to the emanation of groundwater in the form of springs along the hilly side of the road.

Road cutting at a differential level on sloping terrain results in non-uniform soil strength across the transverse section. The deep cutting of the road is not suggested due to the possibility of encountering water seepage. Replacement of weak subgrade with granular material was found to be ineffective as the new material would get saturated in a short period of time. Although not ideal, the technique of applying a layer of stone soling was determined to be the most effective.

5 Declaration

Presented in 4th Mizoram Science Congress (MSC 2022) during 20th & 21st October 2022, organized by Mizoram Science, Technology and Innovation Council (MISTIC), Directorate of Science and Technology (DST) Mizoram, Govt. of Mizoram in collaboration with science NGOs in Mizoram such as Mizo Academy of Sciences (MAS), Mizoram Science Society (MSS), Science Teachers' Association, Mizoram (STAM), Geological Society of Mizoram (GSM), Mizoram Mathematics Society (MMS), Biodiversity and Nature Conservation Network (BIOCONE) and Mizoram Information & Technology Society (MITS). The Organizers claim the peer review responsibility.

Availability of data and material

We give consent for the availability of our data and material.

Authors' Contribution

H Laldintluanga: Investigation, Conceptualization, Methodology, Writing - original draft. **Rebecca Ramhmachhuani:** Visualization, Supervision, Editing. **Lalramtiami:** Investigation, formal analysis.

Ethics Approval

This research article is not submitted to any other journal or any type of publication forms. This research is an original work and is not split in any kind to increase the number of submissions.

Consent to participate

We give our consent for any kind of participation require in the process of our article publication.

Consent to publish

We give our full consent to the concerned authority/party to publish our article.

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