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Estimating Flexible Pavements Flood Resilience

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ABSTRACT

Although several studies observed pavement responses after flooding, no detailed quantification has been done to date. This paper has estimated different pavements' performances with flooding to identify flood-resilient roads. This was shown through, new roughness and rutting-based road deterioration (RD) models, the relationship between changes in roughness [International Roughness Index (IRI)] versus time and modulus of resilience (Mr) loss at granular and sub grade layers versus time, CBR of Subgrade, and Flood consequence results. The comparative analysis of different pavement performances shows that a rigid and strong pavement built to a high standard is the most flood-resilient, which may be adopted as a pre-flood strategy. Results obtained using two proposed new gradients of IRI & CBR in Year 1 over the probability of flooding and ΔIRI in Year 1 over the loss in Mr as well as flood consequences provided similar results. Road authorities should consider changing their roads to flood-resilient pavements in the future.

Keyword: *Road Deterioration; Modulus of Resilience; Flooding; Flood-resilient Pavement; CBR*.

1. INTRODUCTION

Pavement performance Shows deterioration of roads with time in it service life, which is dependent on traffic loading, material properties(pavement type, structure, strength, and subgrade strength), climate and environment, drainage, initial road condition, and maintenance activities. It is generally expressed by roughness versus time. Roughness is related to pavement structural and functional conditions, traffic loading, and environmental factors, and it has a direct relationship with vehicle operating costs, accidents, and driver comfort. Therefore, it is the most representative index for evaluating a pavement performance. IRC also uses roughness for pavement design. A pavement shows an abrupt change in road condition, e.g., roughness and rutting, after a disaster such as flooding. As a result, higher pavement deterioration is observed, for example, significant roughness [denoted by International Roughness Index (IRI)] increase is found due to flooding. Studies reveal that the incremental change in IRI (ΔIRI) due to a flood depends on loss of pavement modulus of resilience (Mr) and the probability of flooding.

Several studies have identified that the Mr of granular and subgrade layers are reduced due to moisture intrusion. At Kolhapur to Teraswadi Road found an increase in pavement deflection due to a lower Mr. & CBR and consequently a reduced pavement life. There are no studies that can address pavement performance with flooding. The current paper has aimed to measure pavement performances with flooding in order to obtain strong pavements that can better sustain flooding in their lifecycle, which was determined using the pavement performances with flooding scenarios, that is,

- Performance at different probabilities of flooding,
- Performance at different Mr. loss values in Year 1, and
- Change in CBR due to a flood.

The scope of this research covers flood-damaged pavements that were saturated but for which the embankment and structure have remained intact (not completely damaged or washed away), that are at moderate risk of further flooding and need preventive maintenance and rehabilitation with or without partial reconstruction. These roads need appropriate attention before and after a flood.

2. COLLECTION OF DATA

We have collected all information regarding of that pavement as follows:

- CBR (California Bearing Ratio) Value
- Mr (Modulus of Resilience) Value
- Rutting Model.
- Fatigue Model.

3. METHODOLOGY

3.1 CBR

3.1.1 Procedure

- Take the weight of empty mold.
- Keep the spacer disc on the base plate and a filter paper on the disc and fix the mold to the base plate with the disc inside the mold and the attach the collar over the mold.
- 3. Add water to the specimen and compact it in accordance with Standard Proctor test or modified proctor test.
- 4. After compaction, remove the collar and level the surface using cutting edge.
- 5. Detach the base pate and remove the spacer disc.
- 6. Take the weight of mold + compacted specimen and determine the bulk density of the specimen.
- 7. Take a sample for moisture content determination and hence find the dry density.
- 8. Place filter paper on the perforated base plate.
- 9. Fix the mold upside down to the base plate so that surface of the specimen which was downwards in contact with spacer disc during compaction is now turned upwards on which the penetration test is to be performed (for unsoaked condition).
- 10. For soaked condition, Fix adjustable stem and perforated plate on the compacted soil specimen in the mold along with 2.5kg surcharge load.
- 11. Place the above set up in the soaking tank for four days (ignore this step in case of unsoaked CBR).
- 12. After four days, measure the swell reading and find % swell with the help of dial gauge reading.
- 13. Remove the mold from the tank and allow water to drain.
- 14. Then place the specimen under the penetration piston and place total surcharge load of 4kg (2.5kg during soaking + 1.5 kg during testing).
- 15. The load and deformation gauges shall then be set to zero.
- 16. The load shall be applied to the plunger into the soil at the rate of 1.25 mm per minute.
- 17. Reading of the load shall be taken at penetrations of 0.5, 1.0, 1.5, 2.0, 2.5, 4.0, 5.0, 7.5, 10.0 and 12.5 mm.
- 18. Remove the plunger and determine the water content of the soil.
- 19. Plot load versus deformation curve.

3.1.2 Collected CBR value before flooding from PWD office.

a. CBR value before flooding = 5.84 and
b. CBR value after flooding as follows:

Table - 1: CBR TEST

(a) Before Flooding

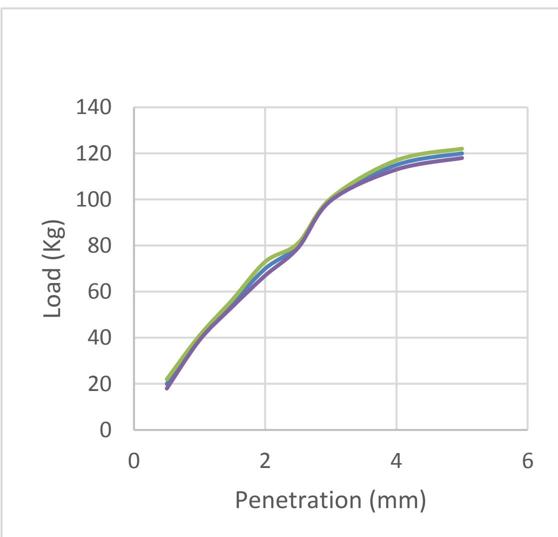
Penetration (mm)	Load(Kg)		
	Average	Trial 1	Trial 2
0.5	20	22	18
1	40	41	39
1.5	55	56.5	53.5
2	70	73	67
2.5	80	81	79
3	100	100.5	99.5
4	115	117	113
5	120	122	118

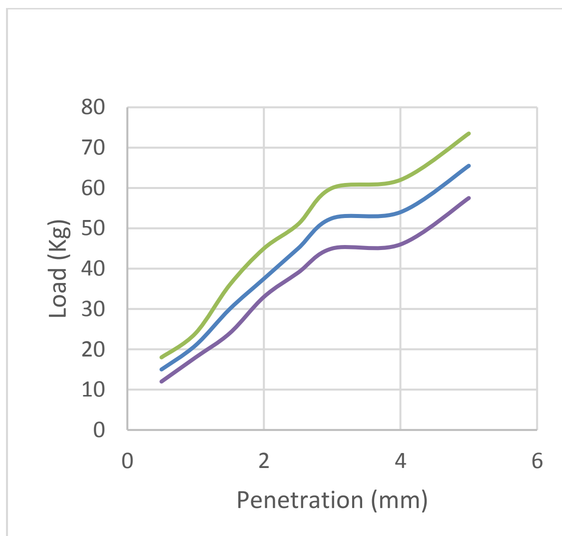
(b) After Flooding

Penetration(mm)	Load(kg)		
	Trial 1	Trial 2	Average
0.5	18	12	15
1	24	18	21
1.5	36	24	30
2	45	30	37.5
2.5	51	39	45
3	60	45	52.5
4	62	46	54
5	73.5	57.5	65.5

Chart No. 1: CBR Graph

(a) Before flooding
(b) After flooding





CBR value after flooding for 2.5 mm penetration: 3.43

CBR value for 5 mm penetration: 3.18
As per the result of CBR before and after flooding the performance of road is goes on decreasing by 41%.

Requirements of CBR for Sub Grade

The sub grade is the top 500 mm of the embankment immediately below the bottom of the pavement, and is made up of in-situ material, selects soil, or stabilized soil that forms the foundation of a pavement. It should be well compacted to limit the scope of rutting in pavement due to additional densification during the service life of the pavement.

The select soil forming the sub grade should have a minimum CBR of 8 per cent for roads having the traffic of 450 commercial vehicles per day or higher.

3.2 Modulus of Resilience

The behavior of the sub grade is essentially elastic under the transient traffic loading with negligible permanent deformation in a single pass. Resilient modulus is the measure of its elastic behavior determined from recoverable deformation in the laboratory tests. The modulus is an important parameter for design and the performance of a pavement. The relation between resilient modulus and the effective CBR is given as:

$$\mathrm{Mr} = 10 \times \mathrm{CBR}\ , \quad \text{For CBR} \leq 5$$

$$\mathrm{Mr} = 17.6 \times \mathrm{CBR}^{0.64}\ , \ \text{For CBR} > 5$$

Where Mr = Resilient Modulus of Sub grade soil.

$$\mathrm{Mr} = 17.6 \times 5.84^{0.64}$$

MR before flooding= 54.45 N/mm^2

$$\mathrm{Mr} = 10 \times 3.43$$

MR after flooding= 34.3 N/mm^2

As per the result of the modulus of resilience before and after flooding the performance of road is goes on decreasing by 37% after flooding.

3.3 Rutting Model

Rutting is the permanent deformation in pavement usually occurring longitudinally along the wheel path. The rutting may partly be caused by deformation in the sub grade and other non-bituminous layers which would reflect to the overlying layers to take a deformed shape.

For 80% Reliability

$$N = 4.1656 \times 10^{-8} \times \left[\frac{1}{\varepsilon v}\right]^{4.5337}$$

Where, ε_v = Allowable vertical strain in sub grade layer

$$= 291\mathrm{x}10^{-6}$$

$$N = 448.049 \times 10^{6} = 44.8\ \mathrm{msa}$$

Limiting value of rutting

- 20 mm to 20% length for up to 30 msa
- 20 mm in 10% length for > 30 msa

3.4 Fatigue Model

Two fatigue equations were fitted, one in which the computed strains in 80 per cent of the actual data in the scatter plot were higher than the limiting strains predicted by the model (and termed as 80 per cent reliability level in these guidelines) and the other corresponding to 90 per cent reliability level. The two equations for the conventional bituminous mixes designed by Marshall Method are given below:

$$\mathrm{Nf} = 2.21 \times 10^{-4} \times \left(\frac{1}{\varepsilon t}\right)^{3.89} \times \left(\frac{1}{\mathrm{Mr}}\right)^{0.854} \quad , \quad \text{For 80\% Reliability}$$

$$\mathrm{Nf} = 0.711 \times 10^{-4} \times \left(\frac{1}{\varepsilon t}\right)^{3.89} \times \left(\frac{1}{\mathrm{Mr}}\right)^{0.854} \quad , \quad \text{For 90\% Reliability}$$

Where,

Nf = fatigue life in number of standard axles,

ε_t = Maximum Tensile strain at the bottom of the bituminous layer

$=153 \times 10^{-6}$

Mr = resilient modulus of the bituminous layer.

For Mr = 34.3 N/mm^2

Before flooding

$$\mathrm{Nf} = 2.21 \times 10^{-4} \times \left(\frac{1}{153 \times 10^{-6}}\right)^{3.89} \times \left(\frac{1}{54.4}\right)^{0.845}$$

$$\mathrm{Nf} = 5.24 \times 10^{9}$$

After flooding

$$\mathrm{Nf} = 2.21 \times 10^{-4} \times \left(\frac{1}{153 \times 10^{-6}}\right)^{3.89} \times \left(\frac{1}{34.3}\right)^{0.845}$$

$$\mathrm{Nf} = 7.49\mathrm{X}10^{9}$$

As per calculation of Fatigue model before and after flooding the value goes on increasing by 30%.

As per the prevailing practice, the mixes used in the pavements under study sections were generally designed for 4.5 per cent air voids and bitumen content of 4.5 per cent by weight of the mix (which in terms of volume would come to 11.5 per cent).

4. CONCLUSION

The study of before and after flooding situation indicates that performance of flexible pavement goes on decreasing. It concludes that CBR value of sub grade reduced by 41% after flooding, means sub grade value of pavement is poor under flooding condition. Also, it effects on the modulus of resilience value and goes on decreasing by 37%, due to a decrease in Modulus of resilience permanent deformation may occur. The value of rutting model indicates that, rutting in pavement occur 20 mm for 10% length of traffic more than 30 msa. Fatigue model indicates air voids percentage in road pavement, as per results fatigue value increased by 30% which shows an increase in air voids percentage which causes deformation of pavement.

From above results, it indicates that pavement performance after flooding gets reduced to more extent than before flooding situation.

5. REFERENCE

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