Study on Impact of Conventional Granular Layer Properties on Rutting Behavior Using KENLAYER Analysis

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Abstract: *The two well-known distresses that occur in flexible pavement are Fatigue and Rutting. These are mainly due to increase in number of load repetitions of high axle loads, environmental conditions, construction and design error and high temperature. As a result the design life of flexible pavement is affected and deteriorates and cause accidents and hydroplaning. Various researchers reported that base and sub-base layer majorly responsible for rutting. The stress strain behavior of unbound granular base and sub-base materials under static and cyclic loading depends on stress acting on aggregates and resilient modulus value is important in context of strength characteristics. Unbound aggregates are the most common type of material used in base and sub-base layers construction in India and worldwide. Due to lack of binder thickness, the performance of the compacted unbound aggregate mostly depends on the properties of the gravel such as its durability, toughness, shape index and fines content. The durability of aggregates is determined by Los Angeles abrasion test, toughness can be determined by impact value test, shape index can be determined by elongation and flakiness index and percent fines content is important in context of plasticity of fine aggregates. The material sample was taken from three categories of road such as two national highways, two state highways and one village road. The accumulated plastic strain is investigated using KENLAYER computer programme. The results obtained after experimental investigation is rounded shape aggregates should be preferred and flaky and elongated aggregates should be avoided in granular layers. The abrasion and impact value should be minimum for high volumes road location for limiting rut depth.*

Keywords: *Unbound aggregate, plastic deformation, KENLAYER computer programme, Abrasion value, Impact value, Shape Index*

I- INTRODUCTION

Rutting is the plastic deformation in pavement usually taking place longitudinally along the wheel path. The rutting may partially 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. Unbound granular base layer is laid between bituminous concrete and sub-grade layer in flexible pavements. Its major purpose is to provide support for bituminous concrete and protect sub-grade from brutal plastic deformation (rutting). Pavements get affected due to rutting when the unbound base layer poorly abides the stresses induced due to repeated traffic loads. Therefore, the plastic deformation behavior of unbound granular materials plays an important role in the evaluation and prediction of the performance of unbound base layer in the field**.** Pavement materials are subjected to cyclic load repetitions over the service life of pavement. In an suitably designed pavement, stress level in pavement materials commonly exceeds elastic limit [Soleiman and Shalaby, 2015]. The occurrence of failure in pavement is a steady process and not a rapid collapse [Sharp, 1985].

In this paper, mechanistic computer program KENLAYER is used. KENLAYER is based on the multi-layer linear elastic Burmister model and depends on its material properties. The KENLAYER was developed by Huang at the University of Kentucky in 1993. KENLAYER is notably different from other available computer programs like MICH-PAVE, ILLI-PAVE, and FPAVE as more materialistic models like linear-elastic, non-linear elastic, viscoelastic and combinations of all models available in it. Different material parameters may be entered for each season variations, there is more detailed characterization of traffic loading with respect to number and speed, up to

19 material layers can be clearly examined, the user can specify the 235 parameters of the critical failure criteria. The program can also be easily calibrated using the practical field failure parameter to set the platform for a given environmental condition. Considering the design parameter and composition of the pavement layers, KENLAYER is suitable for analysis of pavement structure in Indian conditions.

The main mode of failure in unbound granular materials is the plastic deformation. Unbound aggregates are electro-plastic materials which undergoes plastic deformation process under repeating loading [Johson ,1985]. If the elastic limit is not exceeded, which is the case under light loads or thick pavements, an elastic–plastic material undergoes purely elastic behavior with no plastic deformation. When the elastic limit is initially exceeded, the material experiences initial plastic deformation which produces residual stresses. In subsequent load applications, the behavior of the material is dependent on the combined action of the applied load and the residual stresses produced by previous load applications. After a certain number of load repetitions, the residual stresses build up to a value that leads to a steady state with entirely elastic deformation under subsequent load applications (shakedown limit). When the shakedown limit is exceeded, the material experiences incremental plastic deformation under repeated loading.

The response of an UGM under repeated loading is divided into resilient (elastic) strain and permanent (plastic) strain. The elastic behavior is characterized by the resilient modulus of UGM. The plastic strain accumulated under load repetitions is used to describe the plastic deformation behavior. The shakedown theory has been widely used by the practitioners to evaluate the plastic deformation properties of UGM. According to this theory, the UGMs are categorized as three groups:

• Range A – plastic shakedown: the response is plastic only for a finite number of load repetitions, and becomes resilient after post-compaction;
• Range B – plastic creep: the level of permanent strain rate decreases to a low and nearly constant level during the primary stage; and
• Range C – incremental collapse: the permanent strain rate decreases slowly, and permanent strain accumulation does not cease

In pavement design, the pavement must be able to resist permanent deformation. To ensure that a pavement has desirable rutting resistance, the pavement design guide suggests selecting the base materials from Range A and

Range B, and avoiding using the base materials from Range C. To define the shakedown range boundaries, Werkmeister proposed the following criteria :

• Range A : $\varepsilon p,5000 - \varepsilon p,3000 < 4.5 \times 10^{-5}$
• Range B : $4.5 \times 10^{-5} < \varepsilon p,5000 - \varepsilon p,3000 < 4.0 \times 10^{-4}$
• Range C : $\varepsilon p,5000 - \varepsilon p,3000 > 4.0 \times 10^{-4}$

Where $\varepsilon p, 5000$ is the accumulated plastic strain at the 5000th load cycle, and $\varepsilon p, 3000$ is the accumulated plastic strain at the 3000th load cycle [Werkmeister et al, 2004]

Under repeating loading, unbound granular materials shows resilient and plastic deformation. The former is related to stiffness and lateral is related to plastic deformation.
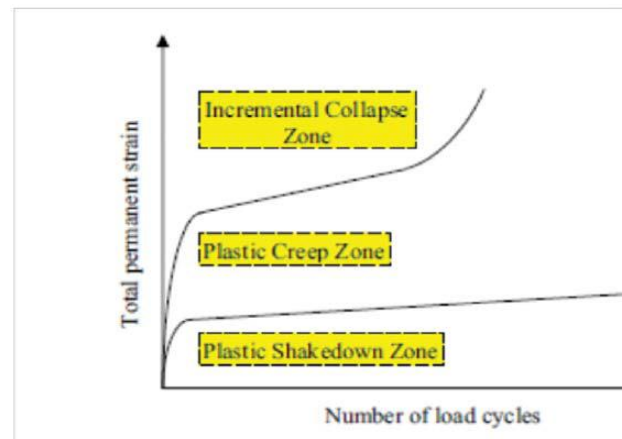

Figure 1.Permanent deformation behavior of unbound granular materials according to shakedown concept [Werkmiester et al. 2004]

II- MATERIALS

The study area for the work consists of all categories of road such as NH, SH and one LVR. This consists of two test location from each road that has severely damaged due to distresses. Majorly the pavement gets damaged due to Fatigue cracking and rutting. But, Major damage is in context of rutting which will cause hydroplaning, shoving which leads to severe accidents sometime. The core sample is taken for laboratory investigation which consists of WMM and GSB layer.

Table 1- Field tests with standard codes

S.NO.	NAME OF TEST	PROPERTY	IS/ASTM/IRC
01	Pavement condition index (PCI)	Distress	ASTM D6433-11
02	Rut Depth	Rutting	ASTM D6433-

	measurement		11
03	FWD	Resilient Modulus	IRC:115-2014
04	Sand Replacement Method	Field Dry Density	IS:2720-PART-28
05	Pavement Thickness	Layer Thickness	

The above field tests are performed to find input parameter that is feed into KENLAYER computer programme for pavement responses (strain, stresses and deformation).

III-EXPERIMENTAL WORKS

After field investigations and taking core sample from pavement, the laboratory investigation is very important to determine the basic properties of the granular materials. It's very important to find the maximum dry density and optimum moisture content. The basic tests related to granular material forming the base and sub base layer of the pavement are abrasion value, impact value, Elongation index, flakiness index (Composition of both is Shape index). After testing, the results can be used as software input to get pavement responses. These will be useful in context of rutting, that how the materials behave when traffic load acts on it. Later, this performance related properties can relate with the pavement responses (strain, stresses & deformation) to develop a rut prediction model. Following tests are performed as mentioned below:

Table 2-Standard codes for Laboratory Investigations

S.NO.	NAME OF TEST	PROPERTY	IS/ASTM/IRC
01	Aggregate Impact value	Toughness	IS:2386 PART-4
02	Aggregate abrasion value	Hardness and Toughness	IS:2386 PART-5
03	Procter Test	Maximum dry Density and Optimum moisture content(OMC)	IS:2720(PART-7-1980)
04	Shape Index	Elongation and Flakiness Index	IS:2386 PART-1

3.1 Aggregate Impact Test

The aggregates impact value indicates a relative measure of resistance of an aggregate to a sudden shock or an impact. This test determines the toughness property of aggregates. As per IS 2386-Part-4 it is carried out. The aggregates should be tough enough to sustain cyclic load repetitions without incremental collapse in granular layers.

3.2 Aggregate abrasion test

The principle of Los Angeles abrasion test is to find the percentage wear due to relative rubbing action between the aggregate and steel balls. Due to the repetitive load action the surface course mainly affected and wearing of the aggregates occurs due to it. IS: 2386 PART-5 have given guidelines for aggregate abrasion test.

3.3 Shape Index

Flakiness and Elongation Index text is very important for aggregates to be done as per IS: 2386 PART-1.Particles shape is very important for load carrying capacity. For base course construction, the presence of flaky and elongated particles is considered undesirable as they may cause inherent possibilities of breaking down under heavy loads. Combined Index is sum of flakiness and elongation index, which is known as Shape Index

Table 3 -Laboratory tests result for different roads

S.No.	Name of test	Types of Road				
		NH	NH	SH	SH	LVR
01	Impact Value	11.55	12.05	14.00	13.24	17.10
02	Abrasion Value	20.00	22.32	20.50	23.30	28.36
03	Proctor test (MDD) gm/cc	1.99	2.02	1.93	1.93	1.93
04	Shape Index	21.50	27.50	27.86	34.40	33.50

IV-TESTS RESULTS AND DISCUSSION

Table No. 4. Pavement Response (Vertical Compressive Strain) after analysis by KENLAYER software of NH, SH and LVR

Impact Factor Value 4.046   e-ISSN: 2456-3463
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NH AVERAGE STRAIN VALUES						
100%	50%	20%	5000	3000	500	AVERAGE
1.181 E-03	1.179 E-03	1.180 E-03	1.014 E-03	1.014 E-03	1.014 E-03	1.097E-03

NH AVERAGE STRAIN VALUES						
100%	50%	20%	5000	3000	500	AVERAGE
1.181 E-03	1.179 E-03	1.180 E-03	1.014 E-03	1.014 E-03	1.014 E-03	1.097E-03

SH AVERAGE STRAIN VALUES						
100%	50%	20%	5000	3000	500	AVERAGE
1.976 E-03	1.976 E-03	1.976 E-03	1.976 E-03	1.976 E-03	1.976 E-03	1.976E-03

SH AVERAGE STRAIN VALUES						
100%	50%	20%	5000	3000	500	AVERAGE
1.624 E-03	1.624 E-03	1.624 E-03	1.623 E-03	1.625 E-03	1.542 E-03	1.610E-03

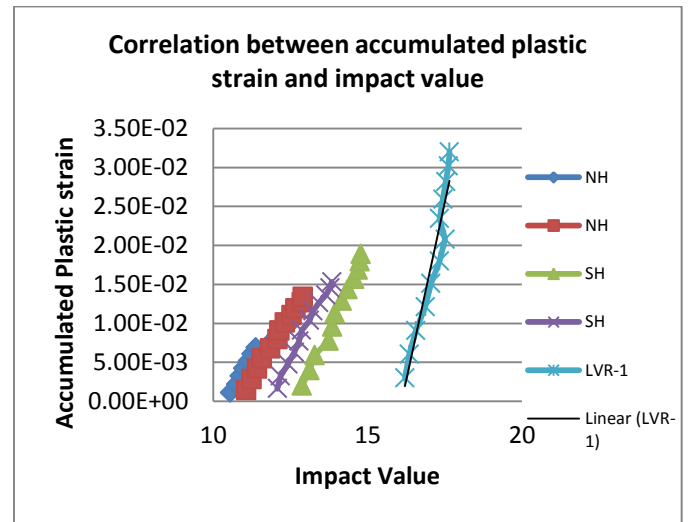| LVR AVERAGE STRAIN VALUES						
100%	50%	20%	5000	3000	500	AVERAGE
2.976 E-03	2.974 E-03	2.974 E-03	2.974 E-03	2.980 E-03	2.974 E-03	2.975E-03

Figure 2 -Correlation between Impact value and Accumulated plastic strain

Figure No. 3- Correlation between Abrasion value and Accumulated plastic strain

The above table gives the compressive vertical strain values that are obtained from KENLAYER analysis, input load repetitions are 100%, 50%,20%,5000,3000 and 500 load repetitions corresponding to variable densities as FDD(Field dry density), MDD(Maximum dry density), MDD+5 and MDD-5 and this accumulated plastic strain defines the structural strength of materials.

The above figure shows the correlation between the accumulated plastic strain and Impact value as seen from graph the aggregate sample from Test location 1 of NH have higher lower impact value therefore the aggregates are tough enough to carry the cyclic load and overloading. The resilient modulus value is also high for such materials. But for LVR due to the heavy load repetitions and minimum surface thickness the plastic deformation is high. The surface thickness is also important for plastic deformation phenomenon with impact value.

The above figure shows the correlation between the accumulated plastic strain and Abrasion value as seen from graph the aggregate sample from Test location 1 of NH shows minimum plastic deformation because of lower abrasion value. LVR sample from test location 1 shows maximum plastic deformation due to higher abrasion value. This resembles that most aggregates are weak and gradation of aggregates should be improved
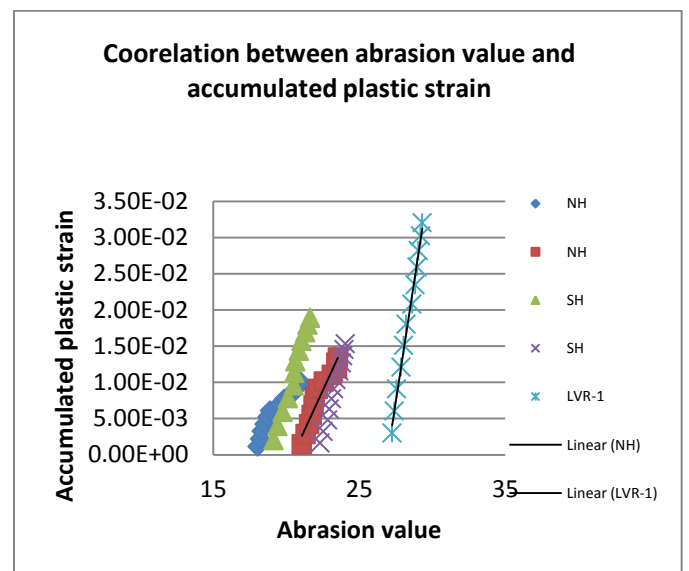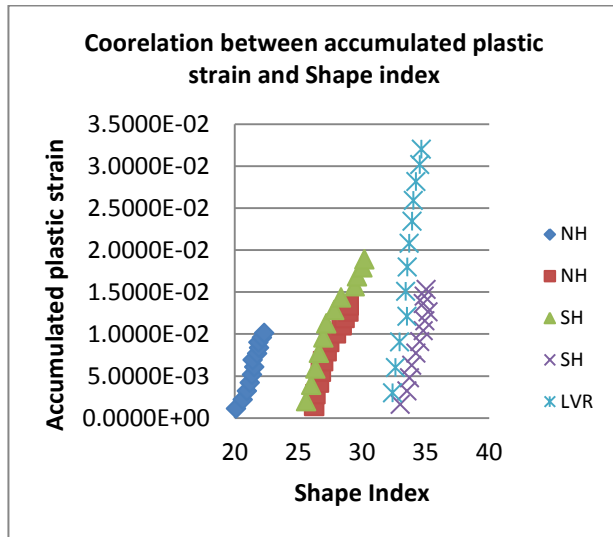
Figure No. 4 Correlation between Shape Index and Accumulated plastic strain

The above figure shows the correlation between the accumulated plastic strain and Shape Index value as seen from graph the aggregate sample from Test location 1 of NH shows minimum plastic deformation because of lower shape index value. LVR sample from test location 1 shows maximum plastic deformation due to higher shape index value. This resembles that most of the aggregates are Flaky and elongated in shape. The curve shows incremental collapse of particles and is in Range C as per Werkmeister's criteria.

V-CONCLUSION

- As per Werkmeister criteria the aggregate structural deformation response (i.e. Strain) should be in range A and B as per shakedown concept and range C material should be ignored as fails due to incremental collapse.

- As seen from Figure 2 the LVR road sample shows incremental collapse stage as compared to NH and SH road are in Plastic creep zone. Impact value should be low to sustain the structural deformation.

- As seen from Figure 3 sample collected from the roads are severely damaged in incremental collapse Range C, abrasion value of aggregate should be low to bear the stresses induced due to cyclic loading.

- As seen from Figure 4 the aggregate shape is very important as core sample collected from test locations have more flaky and elongated shape aggregate that have low strength and get crushed during post compaction stage, inducing large accumulated plastic strain in base and sub-base layers.

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