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Analysis of Structural Deformation in Flexible Pavement using KENLAYER Programme

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Abstract - *Unbound granular materials are the most commonly used for construction of the base layer of flexible pavement in India and worldwide. Due the minimum thickness of the binder layer, the performance of the compacted unbound aggregate is very much dependent on the properties of the gravel (particles retaining on 4.75mm sieve), sand (particles passing 4.75mm sieve and retaining on 0.075mm sieve) and fines (particles passing 0.075 mm sieve) fraction of the mixture. This paper analyses the plastic deformation of unbound granular material for base and sub-base layer under variable cyclic load repetitions and variable dry densities. In general rut prediction models developed by other researchers proved to be good but in long term, they tends underestimate the plastic deformation. Therefore, in this research first, under KENPAVE software the permanent deformation properties is analyzed using KENLAYER computer programme, which gives pavement responses (stresses, strains and deformation). Second, by varying load repetitions and dry densities the effect on permanent deformation is studied on samples collected from 5 Different categories of roads with Test location 1,2,3,4 and 5. The granular materials did not give satisfactory results to be used in low traffic volume roads. The major concerned is to investigate the effect of load repetitions and density in context of permanent deformation properties of aggregates.*

Key Words: Unbound granular materials. KENLAYER computer Programme. Plastic deformation. Variable Load Repetitions. Density

1. Introduction

Most of the highways in India are usually designed as flexible pavement with available fund for design life. Low traffic roads are mostly having thin bituminous surface and major structural element is unbound granular materials. The two major distresses that affects flexible pavement are Rutting and Fatigue cracking. Rutting is one of the main distresses that causes damage in flexible pavement and it is the result of an accumulation of plastic deformation in the various layers, surface, base, sub-base and subgrade layer both bound and unbound. Accordingly, the structural design of this pavement requires a model that relates plastic deformation behavior of UGM with load repetitions and dry density. The goal is to predict the development of rutting in granular base and sub-base courses. In this research, 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. Therefore number of load repetitions is important factor to consider in the analysis of the long term behavior of granular materials.

In this sense, Perez et al. carried out several analyses related to plastic deformation. In their conclusion they pointed out those mathematical models that predicted plastic deformation as a function of load cycles presented certain deficiencies. The objective was to investigate a relation between the pavement responses and load repetitions.

2. Background

2.1 UGM response Ranges

A pavement is liable to show progressive accumulation of plastic strains (rutting) under traffic loading if the magnitude of the applied load exceeds the limit value. If the applied traffic load is lower than this limit value than due to post compaction, the permanent strains will level off and the pavement will reach at shakedown state, after which only resilient deformation with additional traffic loading. In multilayer system such as in pavements due to load repetitions of various magnitudes pavement deformation results in all layers. For performance prediction, it is of great importance to know whether the selected UGM fails correspond to incremental collapse or the increase of strain leading to stable response (Shakedown state). In this sense, the ideal shakedown concept maintains that there are four regimes of behavior under cyclic loading: Purely elastic, Elastic shakedown, plastic shakedown and Incremental collapse. Werkmeister et al. proposed only three regimes of behavior of UGM under load cycles.

- **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.

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 Ranges:

Range A: εp, 5000-εp, 3000 < $4.5*10^{-5}$

Range B: $4.5*10^{-5}$ < εp, 5000-εp, 3000 < $4.0*10^{-4}$

Range C: εp, 5000-εp, 3000 > $4.0*10^{-4}$

3. Materials and method

The study area for the work consists of all categories of road such as two NH and two 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.

3.1 Data Collection

As discussed above about the study area and test locations, further data collection is required which can be used later for Software inputs and for determining permanent deformation properties. First of all the Field investigation of the study area is important, as it gives the physical appearance of the pavement. Through field visit the Pavement condition is visualized and the core sample of the granular base and sub base layer is taken for laboratory testing. The WMM and GSB sample is further studied so that can be concluded that rutting mainly depends on this layer. The below table describes the specific code guidelines for doing specific field tests.

Table No. 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 measurement	Rutting	ASTM D6433-11
03	FWD	Resilient Modulus	IRC:115-2014
04	Sand Replacement Method	Field Dry Density	IS:2720-PART-28
05	Pavement Thickness	Layer Thickness	

The below table shows the Field test results of different roads i.e. crust thickness, Field dry density by Sand replacement method and Resilient modulus by Falling weight Deflectometer (FWD).

Table No. 2 Tests results of different roads

S.NO.	Test Locations	BITUMINOUS LAYER (mm)	CRUST THICKNESS (mm) WMM+ GSB	FIELD DRY DENSITY(γ) KN/M³	RESILIENT MODULUS (E) Mpa
01	TL-1	187	250+200=450	21.50	248.80
02	TL-2	171	250+200=450	22.30	341.20
03	TL-3	118	250+200=450	21.80	251.90
04	TL-4	146	250+200=450	21.20	239.40
05	TL-5	50	250+150=400	21.60	237.30

3.2 DETERMINATION OF PAVEMENT RESPONSES USING KENPAVE SOFTWARE:

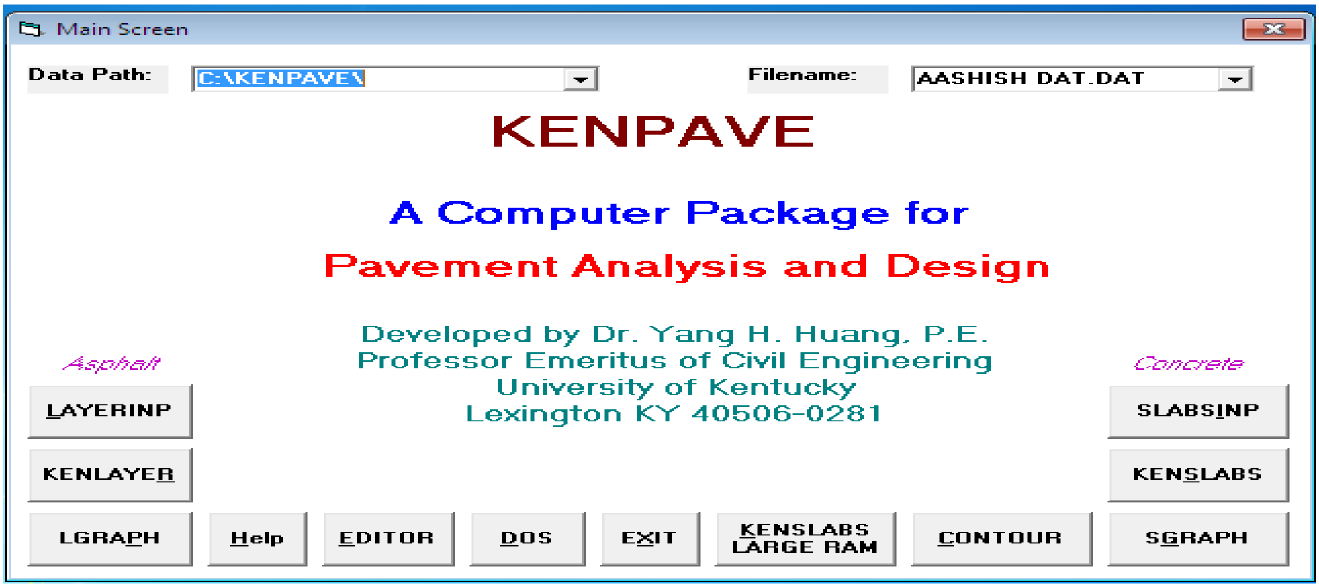

Figure No. 1 Main screen of KENPAVE Software

Pavement responses i.e. (Stresses, Strains and Deformation) are obtained due to application of traffic load, climatic factors and environmental factors which depends as well as on properties of material indirectly. The Pavement responses of unbound granular materials (UGMs) are found at variable dry densities and load repetitions are also variable. The responses are obtained at following dry densities with varying moisture content for each road such as:

For inputs in KENPAVE computer programme, the load repetitions taken 100%, 50%, 20%, 5000, 3000 and 500 and variable densities such as Field dry density(FDD), Maximum dry density(MDD), MDD+5 and MDD-5 . The load repetitions are variable because of the strain needed is recoverable (elastic) as well as irrecoverable (plastic). The strain corresponding to 500 load repetitions is elastic strain that is recoverable while vehicle passes away. Another strain corresponding to 3000-5000 load repetition is plastic strain. Strain corresponding to 100% load repetitions is maximum permanent strain (ε_o). The strain categorization is necessary because of Werkmeister's Criteria which is based on Shakedown concept to define the range in which the UGMs lie after N number of load repetitions.

Design traffic volume is calculated in below using formula:

$$N = \frac{365 * [(1 + r)^n - 1]}{r} * A * D * F$$

Where,
N= Cumulative number of standard axles in million standard axles (msa), A= It is the initial traffic in the year of completion of construction in terms of CVPD (Commercial Vehicle Per Day), D= Lane distribution factor, F= Vehicle damage factor, N=Design life in years
R= Annual growth rate of commercial vehicles

Table No. 3 Traffic survey Data

Design parameters	National Highway		State Highway		Low Volume Road
	NH	NH	SH	SH	LVR
Design Life	10	10	10	10	10
LDF	75%	75%	50%	50%	100%
VDF	5.5	5.0	4.5	5.0	3.0
CVPD	6870	5277	1858	3428	234
Traffic Growth Rate	7.5	7.5	5	5.5	5
Design Traffic	146.332	102.183	19.192	40.275	3.223
E-value	1250	1250	700	1250	700

The Traffic survey data of different roads are given in above Table, which is used in KENLAYER computer programme to obtained pavement responses. The vertical compressive strain is noted which on accumulation produce rutting.

4. Results and Discussion:

The below Figure shows relation between Plastic strain to number of load repetitions, as the strain path of selected UGMs have similar curve that in initial stage a large plastic strain observed due to post compaction or densification of material after that the strain is elastic then after few load repetitions the plastic strain increases drastically leads to incremental collapse or produces a large rut depth before its design life gets over. In LVR strain curve the strain rate is high in initial cyclic load repetition as leads to Range C of Werkmeister's criteria.

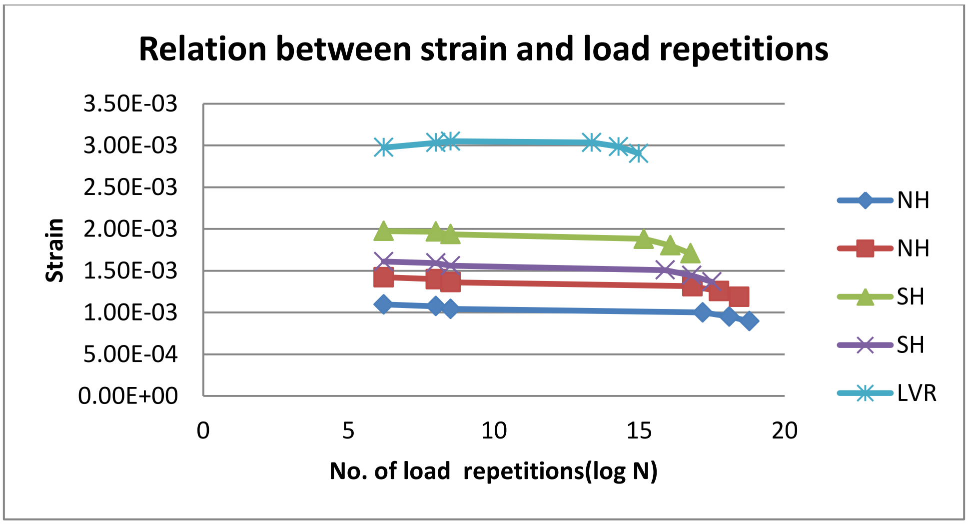

Chart-1 Permanent Deformation versus Load cycles

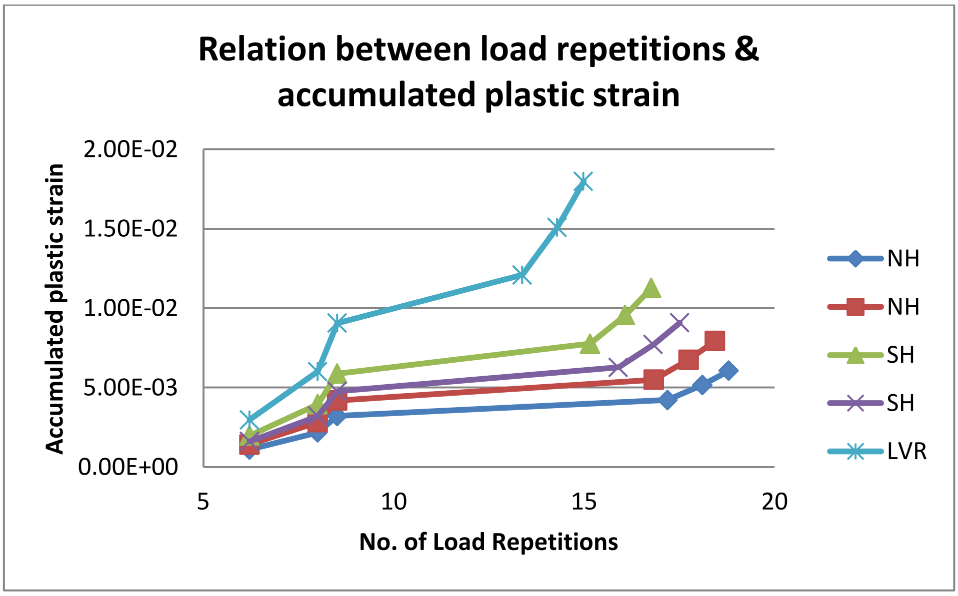

Chart-2 KENPAVE Results of Selected Unbound Granular Materials

The above Figure shows the relation between the accumulated Plastic Strain (**εp**) and No. of Load Repetitions (N). As seen from above figure as the load repetitions increases the accumulated plastic strain also increases simultaneously. The primary stage has a high initial permanent deformation, with a decreasing rate of change of plastic strain, as per Werkmeister's criteria Range A and B plastic strain curve material should be used, as seen here for LVR strain curve there is high permanent strain and it comes under Range C which indicates Incremental collapse case so material properties lying in this Range should be ignored because it produces large rut depth before its design life.

5. Conclusions:

- The material selected for base material should be from Range A and B as per Werkmeister's criteria and Range C material is of low strength fails due to incremental collapse.
- The plastic deformation of aggregates increases as cyclic load repetitions magnitude is increased.
- The angularity, texture and shape index is also important morphological property that affects permanent deformation properties in some manner.
- The overloading, temperature, moisture and other climatic and environmental factors have adverse effect on pavement.
- The aggregate sample should be avoided to be used in base and sub-base layers in low traffic road pavement.
- Density is inversely proportional to plastic strain as maximum dry density is high the accumulated plastic strain is low.

References:

1. AASHTO, Standard method of test for resilient modulus of subgrade soils and untreated base/subbase materials, AASHTO T307-99, American Association of State Highway and Transportation Officials (AASHTO), Washington, DC, 2003
2. Arnold, G.: Rutting of Granular Pavement. Ph.D. Thesis. University Of Nottingham, UK (2004)
3. Collop A C, Cebon D, Hardy M S A,: Viscoelastic Approach to Rutting in Flexible Pavements. J. Transp. Eng., 1995, 121(1): 82-93
4. E. Tutumluer, T. Pan, Aggregate morphology affecting strength and permanent deformation behavior of unbound aggregate materials, J. Mater. Civil Eng. 20 (9) (2008) 617–627

5. F. Lekarp, I.R. Richardson, A. Dawson, Influence on permanent deformation behavior of unbound granular materials, Transp. Res. Rec. 1547 (1) (1996) 68– 75
6. F. Lekarp, U. Isacsson, A. Dawson, Permanent strain response of unbound aggregates, J. Transp. Eng. 126 (1) (2000) 76–83
7. Huang, Y.H. (2004), "Pavement Analysis and Design", 2nd Edition, New Jersey, Prentice Hall.
8. J. Kwon, S. Kim, E. Tutumluer, M. Wayne, Characterization of unbound aggregate materials considering physical and morphological properties, Int. J. Pavement Eng. 18 (4) (2017) 303–308
9. Perez I, Medina L, Gallego J.: Plastic deformation behaviour of pavement granular materials under low traffic loading. Granular Matter (2010) 12:57–68
10. Pérez, I.,Medina, L.,Romana, M.G.: Permanent deformation models for a granular material used in road pavements. Constr. Build. Mater. **20**, 790–800 (2006)
11. Saberian Mohammad, Li Jie, Nguyen Bao, Wang George. : Permanent deformation behaviour of pavement base and subbase containing recycle concrete aggregate, coarse and fine crumb rubber. Construction and Building Materials 178 (2018) 51–58
12. Taherkhani H, Valizadeh M: An Investigation on the Effects of Aggregates Properties on the Performance of Unbound Aggregate Base Layer, International Journal of Transportation Engineering, Vol 3/ No. 2/ Autumn (2015)
13. Theyse, H.L.: Mechanistic-empirical modelling of the permanent deformation of unbound pavement layers. In: ISAP 8th International Conference on Asphalt Pavement. Seattle (USA) (1997)
14. Werkmeister, S.: Permanent deformation behaviour of unbound granular materials in pavement construction. Ph.D. Thesis. Dresden University of Technology, Germany (2003)
15. Werkmeister, S., Dawson, A., Wellner, F.: Permanent deformation behavior of granular materials and the shakedown concept. Transp. Res. Record **1757**, 75–81 (2001