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Influence of unbound material properties on rutting potential of low volume roads

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ABSTRACT

More than 80% of roadway mileage in the world carries less than 400 vehicles per day and these roads are classified as low volume roads. India has essentially a rural oriented economy with 72% of its population living in villages. The low volume roads are part of tertiary road system, which consists of other district roads and village roads. The traffic conditions on these roads are distinctly different from the major roads. A variety of vehicles are used for transportation of goods on rural roads, ranging from bullock-carts to the fast moving commercial vehicles. Permanent deformation of the unbound base and sub-base layer is one of the distress types on these roads that require extensive maintenance. The gradation is the most important property that an aggregate can contribute to the performance of pavement. In the present study, an attempt has been made to investigate the rutting potential of low volume roads, taking into account base course gradation, sub-base course gradation, sub-base field density, subgrade field density, subgrade moisture content, subgrade California Bearing Ratio, and traffic volume. The influence of these factors on the rutting potential of in-service pavements has been investigated and a response type model has been developed.

Introduction

In the development of the economy and improvement in the living standards of the people in the rural areas, Low Volume Rural Roads (LVRRs) play a significant role. LVRRs form a major part of the road network in India comprising 80% of the total road length. Considering this fact, they often form the most important link in terms of providing access to education, medical, recreational and commercial facilities in the local or regional areas. A large number of roads are being constructed in India under several national road building projects. Among these projects, Pradhan Mantri Gram Sadak Yojana (PMGSY) is one which focuses directly on the rural connectivity. Low volume roads in India are designed as per IRC:SP:20 (2002) and IRC:SP:72 (2008). A low volume road primarily could be defined as a road which carries less than “X” vehicles per day (vpd) and each road agency must pick its own appropriate number (Oglesby et al., 1976). The low volume roads are generally defined as roads carrying an Average Daily Traffic (ADT) of less than 400 vehicles per day (Smith, 1983; Meyer and Hudson, 1987; Hall and Bettis, 2000; SADC, 2003).

There are several distresses occurring in flexible pavements which may be due to higher magnitude and frequency of loading, climatic condition, improper construction, poor drainage, inappropriate selection of materials or combination of these causes. In order to reduce the environmental impact, emphasis was also given to use of locally available materials appropriately in the low volume roads. However, local materials are often not used, as they do not comply with the conventional specifications for unbound granular materials in pavements.

Rutting is a major mode of failure in flexible pavements. There are various causes of rutting depending on the configuration and structural capacity of various layers and environmental conditions. Dawson et al. (2007) reported that many of the rural roads are distressed due to over loaded local trucks, commercial vehicles and environmental factors.

Objectives of the Study

The objectives of this study are listed below:

- To estimate the influence of base course (WBM grading II and grading III) gradation, sub-base course gradation, sub-base and subgrade moisture contents, sub-base and subgrade field densities on the rutting potential of low volume roads.
- To develop an appropriate rutting prediction model for low volume roads.

Review of Literature

Rutting is a longitudinal depression along the wheel paths in flexible pavements with or without transverse displacement. It is a physical distortion of surface and it also prevents the cross-drainage of water during the rains, leading to accumulation of water in the ruts and causing the potential of hydroplaning related problems (Start et al., 1998). Zakaria and Lees (1995) performed wheel tracking tests and reported that the unbound aggregate gradation influences the rut depth. Ali et al. (1998) developed a mechanistic model to predict rut depth as a function of the vertical compressive elastic strain in all the layers of a pavement cross-section. Ceratti et al. (2000) conducted a study on thin pavements on which weathered basalt was used as base layer and concluded that rutting was found to be the major cause of failure in all tested sections. Archilla and Madanat (2000) developed an empirical rutting progression model using experimental data. Later on Archilla and Madanat (2001) demonstrated the effectiveness of the estimation of rutting models by combining the data from two sources, the AASHO road test and the WesTrack road test. A major advantage of their method is that it allows accounting for the effects of pavement structure, axle load configuration, bituminous mixture properties, freeze-thaw cycles, and hot temperatures in a single

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model. Deacon et al (2002) developed an approach for rutting prediction in asphalt concrete pavements using key parameters such as traffic, elastic shear stress and elastic vertical compressive strain at the subgrade surface. Tarefder et al. (2003) reported significant influence of binder grade, temperature, gradation, subgrade moisture and binder content on rutting. Chen et al. (2004) reported that rutting increases with the increase in both the contact pressure and axle load, with a dominant role for the latter. Kim and Tutumluer (2005) reported that actual traffic loading simulated by the multiple path tests could cause greater permanent deformations in the base or sub-base course, when compared with the deformations measured from a dynamic plate loading or a constant confining pressure type laboratory test. Isa et al. (2005) investigated rutting as a function of the mix design parameters, layer thickness, and the pavement strength. Archilla (2006) evaluated rutting as a function of traffic, temperature, and mix characteristics, including voids filled with asphalt, asphalt content, in-place air voids, surface area, and the densification slope. Rodriguez et al. (2006) presented a methodology to estimate rutting of bituminous pavements and to predict the rutting risk considering the bituminous mix rutting resistance characteristics taking into account the traffic and environmental characteristics. Huurman and Molenaar (2006) reported that, for a given confining stress, permanent deformation in granular bases can be controlled by setting threshold values for the ratio between the applied vertical stress and vertical stress at failure. They also observed this ratio to depend on the type of material, gradation, degree of compaction, and the number of load repetitions to be allowed. Dawson et al. (2007) reported that rutting can occur due to a number of reasons like inadequate granular material shear strength in the aggregate, aggregate quality and particle wear. Perez et al. (2010) analyzed the permanent deformation performance of an unbound granular material for base layers of low traffic roads and developed a model which can closely predict the measured permanent deformation. Based on these studies, one can observe that there are several factors contributing to the rutting potential of flexible pavements. In the present study, an attempt has been made to investigate the rutting potential of low volume roads taking into account the base course gradation, the sub-base course gradation, the sub-base field density, the subgrade field density, the subgrade moisture content, the subgrade CBR, and the traffic volume. The influence of these factors on the rutting was investigated on in-service pavements. The analyzed data was taken as input for SPSS statistical tool and a responsive model has been developed for the rutting parameters.

Study Area

In the present study a total number of 15 test stretches were selected in three districts in Andhra Pradesh namely Warangal, Guntur and Kurnool, to represent different geographical and environmental conditions. The selected roads are either newly constructed or upgraded under different phases of PMGSY scheme based on the criteria adopted in Table 1. The traffic volume categories as per IRC:SP:20 (2002) were considered i.e. A, B, C and D corresponding to 0 to 15, 16 to 45, 46 to 150, and 151 to 450 commercial vehicles per day (CVPD) respectively. In all these 15 test stretches, 20 mm thick open graded premix surfacing has been used as the wearing course. The test sections were selected district-wise with four each in Guntur, Kurnool and seven in Warangal district. The following criteria were adopted for selection of the test sections:

- The length of test section selected is 500 m starting from a land mark (in this study), sign board of PMGSY or kilometre stone of the road.
- To represent different subgrade soil types.
- Section is selected on straight reaches avoiding the approaches to bridges and culverts.
- History of the pavement section should be available i.e., the year of construction, crust details and traffic volume counts, etc.

Field Studies

After identifying the test sections, one time inventory data was collected from the primary and secondary sources. Periodical data was collected for a period of 3 years with two sets of data per year; one in the pre-monsoon and the other in post monsoon, for functional and structural evaluation of pavements. In functional evaluation, roughness was measured using low cost equipment, MERLIN. The data obtained was analyzed and converted to International Roughness Index (IRI). In addition to this, visual assessment survey was conducted on the occurrence of rutting, cracking, ravelling, potholes and edge drop. Deflection measurement in structural evaluation was done using Portable Falling Weight Deflect meter (PFWD) called LOADMAN. The traffic data was collected from the study stretches in terms of classified traffic volume counts. Investigations were also made on pavement cross-sectional details and WBM (grading-II and grading-III) gradation through destructive and non-destructive techniques.

Data Analysis

One of the objectives of this study is to evaluate the effect of selected material parameters on the rutting potential of low volume roads. A sample calculation of one road stretch in the Warangal district, i.e., Tarigoppala to Abdul Nagaram (LVRW-TGAN) has been presented in this paper. Similar calculations have been performed on other road stretches listed in Table 1 and the corresponding data analysis has not been included in this paper. Similar trends as observed in LVRW-TGAN road stretch were also observed in others road stretches. The effect of each material parameter on the measured rut depths has been presented.

Effect of Base Course Gradation

Aggregate samples of WBM grading III and grading II were obtained from all the selected road stretches and detailed sieve analysis was carried out as per MORD (2004) specifications. In order to study the effect of material gradation on the measured rut depths, the entire gradation has been converted into a single point value using the Root Mean Square Error (RMSE). It is required to normalize the data with reference to a specific gradation which can be considered as the datum in the calculation of RMSE. Several trial gradations such as upper limit, lower limit, mid values, half upper – half lower limit, and half lower – half upper limits have been used to prepare slabs using roller compactor. Since granular materials are used in the preparation of the slabs, these slabs have been confined laterally. Wheel tracking tests have been performed on these slabs in an attempt to determine the gradation which can resist permanent deformation to a greater extent. The upper gradation curve resulted in minimum laboratory rut depth for WBM grading III, WBM grading II, and sub-base gradation. Thus, in the calculation of RMSE, the upper limits of the WBM grading III, WBM grading II, and sub-base gradation have been used as the datum or the reference points. The RMSE is a frequently-used measure of the differences between values predicted by a model or an estimator and the values actually observed from these being modelled or estimated.

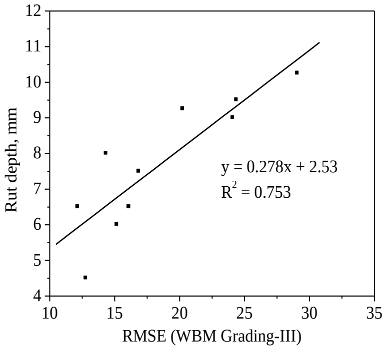

Fig. 1 Variation of measured rut depth with base course (WBM Grading III) gradation

From Figure 1, it can be observed that the rut depth increased as a function of RMSE values of WBM grading III. Thus, as the RMSE increases, the gradation curve deviates from the reference gradation and one can expect higher rut depths. These minimum rut depths may be due to higher density of the material at the reference gradation. As the RMSE increases, the density of the material decreases which inturn can result in higher rut depth. The maximum and minimum rut depths in this test stretch are 10.2 mm and 4.5 mm respectively. Similar trends were also observed in Figure 2 where the observed rut depths were plotted against RMSE of WBM grading II material.

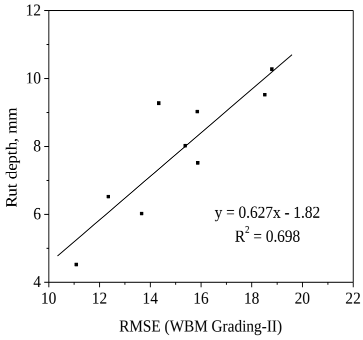

Fig. 2 Variation of measured rut depth with base course (WBM Grading II) gradation

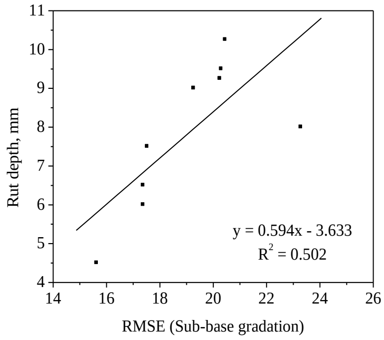

Fig. 3 Variation of rut depth with sub-base course gradation

Effect of Sub-base Course Gradation

In most of the rural roads, layers consisting of a well graded material are laid and compacted in one or more layers over prepared subgrade as sub-base or lower and upper sub-base course (MORD, 2004). The sub-base course materials obtained from the field are tested for gradation in the laboratory. The upper limits of standard gradation of sub-base course material are taken as the reference value in the calculation of sub-base course RMSE. From Figure 3, it can be observed that the rut depth increased as a function of RMSE values of the sub-base course.

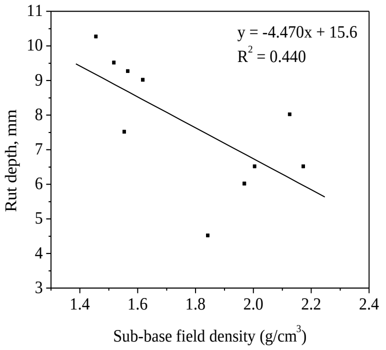

Fig. 4 Variation of rut depth with sub-base course field density

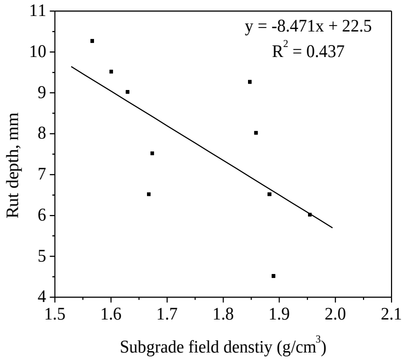

Fig. 5 Variation of rut depth with subgrade field density

Effect of Sub-base Course and Subgrade Field Density

In the present study, sand replacement method has been used to determine the field densities of both the sub-base course and the subgrade materials. From Figure 4, it can be observed that rut depth decreased with increase in the sub-base course field density. That is, rut depth is inversely related to the sub-base field density. With the increase in density of a material, the accumulation vertical compressive strains would reduce and one would expect lower rut depths at higher density of the material. Similar trend was also observed for the subgrade field density which can be seen in Figure 5.

Effect of Subgrade Moisture Content

Subgrade soil strength and/or stiffness are major factors in the design and performance of pavements, particularly in low volume roads due to the variability in soil properties, soil behaviour under repeated traffic loads, environmental factors, geometric factors, and the site conditions. The variation of rut depth with subgrade moisture content is presented in Figure 6. The rut depth increased with the subgrade moisture content. This is due to the fact that, as moisture content increases, the strength of the soil decreases which in turn results in higher accumulation of vertical compressive strains with the movement of vehicles. Higher coefficient of determination could be observed in this case when compared to the previous cases. One can say that subgrade moisture content significantly affects the rut depth.

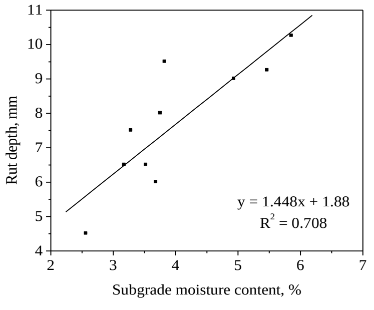

Fig. 6 variation of rut depth with subgrade moisture content

Development of the models

The field data has been analyzed using SPSS statistical package and regression models have been developed by considering the variables for LVRW-TGAN road stretch as shown in Table 2. Initially, the data was consolidated and the model for each test section has been developed. Thereafter, combining all the road stretches data, a single model has been developed for a particular district. Later, on integrating all these models, a comprehensive model was developed. From the extensive statistical analysis, it was observed that different factors considered in this study (base course and sub-base course gradation, sub-base and subgrade field density, subgrade moisture content, traffic volume, and subgrade CBR) showed a significant influence on the rutting parameter. The model developed for LVRW-TGAN road stretch is given by equation (1). Since the traffic volume and the subgrade CBR remained uniform throughout the section, these two variables have not been considered in the development of models for individual road stretches of a particular district.

$$\begin{aligned}\mathrm{RD} &= 0.5992 + 0.15192^{*}(\text{Base Gr. III}) + 0.02273^{*}(\text{Base Gr. II}) \\ &+ 0.3767^{*}(\text{SBG}) - 1.3459^{*}(\text{SBFD}) - 1.0957^{*}(\text{SGFD}) + 0.3265^{*}(\text{SGMC}) \rightarrow (1)\end{aligned}$$

Where,

RD = rut depth (mm),

Base Gr. III = base course (WBM grading III) gradation (RMSE),

Base Gr. II = base course (WBM grading II) gradation (RMSE),

SBG = sub-base gradation (RMSE),

SBFD = sub-base field density (g/cm^3),

SGFD = subgrade field density (g/cm^3),

SGMC = subgrade moisture content (%).

For equation (1), R^2 = 0.96, F-test = 4.072, and standard error = 0.585. This equation has been checked for logical errors. The base course (WBM Grading III and Grading II) gradation, sub-base course gradation, and subgrade moisture content resulted in a positive sign indicating a direct proportionality between these three independent variables and the dependent variable, rut depth. The sub-base field density and the subgrade field density resulted in a negative sign indicating an inverse relation between these two independent variables and the dependent variable, rut depth. Similar equations have been developed for all the fifteen road stretches considered in this study.

Warangal District Model

The Warangal district model has been developed by considering all the seven road stretches of the district shown in Table 1. Apart form the six dependent variables that are considered in equation (1), the traffic volume and subgrade CBR were also considered in the development of the Warangal district model given by equation (2).

$$\begin{aligned}\text{Rut depth} &= 44.201 + 0.3465^{*}(\text{Base Gr. III}) + 0.55549^{*}(\text{Base Gr. II}) \\ &+ 0.1955^{*}(\text{SBG}) - 11.212^{*}(\text{SBFD}) - 8.987^{*}(\text{SGFD}) \\ &+ 1.508^{*}(\text{SGMC}) - 152.856^{*}(\text{N}) - 1.42^{*}(\text{CBR}) \rightarrow (2)\end{aligned}$$

Where,

N = traffic volume (msa),

CBR = subgrade California bearing ratio (%).

For equation (2), R^2 = 0.84, F-test = 41.44, and standard error = 3.63. This equation has been checked for logical errors. The base course (WBM Grading III and Grading II) gradation, sub-base course gradation, and subgrade moisture content resulted in a positive sign indicating a direct proportionality between these three independent variables and the dependent variable, rut depth. The sub-base field density, the subgrade field density, traffic volume, and the subgrade CBR resulted in a negative sign indicating an inverse relation between these independent variables and the dependent variable, rut depth. With increase in traffic volume, one would expect an increase in the rut depth. However, an inverse relationship between the traffic volume and the rut depth has been observed in the Warangal district model.

Guntur District Model

The Guntur district model has been developed by considering all the four road stretches of the district shown in Table 1. All the independent variables considered in the development of the Warangal district model were also considered in the development of the Guntur district model given by equation (3).

$$\begin{aligned}\text{Rut depth} &= 9.061 + 0.5002^{*}(\text{Base Gr. III}) + 0.4059^{*}(\text{Base Gr. II}) \\ &+ 0.1166^{*}(\text{SBG}) - 15.082^{*}(\text{SBFD}) - 2.922^{*}(\text{SGFD}) \\ &+ 0.8557^{*}(\text{SGMC}) + 57.062^{*}(\text{N}) + 1.694^{*}(\text{CBR}) \rightarrow (3)\end{aligned}$$

For equation (3), R^2 = 0.92, F-test = 49.98, and standard error = 2.77. This equation has been checked for logical errors. The base course (WBM Grading III and Grading II) gradation, sub-base course gradation, subgrade moisture content, traffic volume, and the subgrade CBR resulted in a positive sign indicating a direct proportionality between these independent variables and the dependent variable, rut depth. The sub-base field density, and the subgrade field density resulted in a negative sign indicating an inverse relation between these independent variables and the dependent variable, rut depth. With increase in subgrade CBR, one would expect a decrease in the rut depth. However, a direct proportionality between the subgrade CBR and the rut depth has been observed in the Guntur district model.

Kurnool District Model

The Kurnool district model has been developed by considering all the four road stretches of the district shown in Table 1. All the independent variables considered in the development of both the Warangal and Guntur district models were also considered in the development of the Kurnool district model given by equation (4).

$$\begin{aligned}\text{Rut depth} &= -6.181 + 0.383^{*}(\text{Base Gr. III}) + 1.202^{*}(\text{Base Gr. II}) \\ &+ 0.1677^{*}(\text{SBG}) - 2.492^{*}(\text{SBFD}) - 13.071^{*}(\text{SGFD}) \\ &+ 0.264^{*}(\text{SGMC}) + 295.154^{*}(\text{N}) - 3.495^{*}(\text{CBR}) \rightarrow (4)\end{aligned}$$

For equation (4), R^2 = 0.83, F-test = 49.71, and standard error = 3.64. This equation has been checked for logical errors. The base course (WBM Grading III and Grading II) gradation, sub-base course gradation, subgrade moisture content, and the traffic volume resulted in a positive sign indicating a direct proportionality between these independent variables and the dependent variable, rut depth. The sub-base field density, the subgrade field density, and the subgrade CBR resulted in a negative sign indicating an inverse relation between these independent variables and the dependent variable, rut depth.

Comprehensive Model for Andhra Pradesh

The comprehensive model for Andhra Pradesh has been developed by considering all the districts such as Warangal, Guntur, and Kurnool. All the independent variables considered in the development of the district wise models were also considered in the development of the comprehensive model given by equation (5).

$$\begin{aligned}\text{Rut depth} &= 12.694 + 0.557^{*}(\text{Base Gr. III}) + 0.807^{*}(\text{Base Gr. II}) \\ &+ 0.0057^{*}(\text{SBG}) - 10.198^{*}(\text{SBFD}) - 2.390^{*}(\text{SGFD}) \\ &+ 1.677^{*}(\text{SGMC}) - 49.598^{*}(\text{N}) - 0.873^{*}(\text{CBR}) \rightarrow (5)\end{aligned}$$

For equation (2), $R^2 = 0.83$, F-test = 86.11, and standard error = 4.62. This equation has been checked for logical errors. The base course (WBM Grading III and Grading II) gradation, sub-base course gradation, and subgrade moisture content resulted in a positive sign indicating a direct proportionality between these three independent variables and the dependent variable, rut depth. The sub-base field density, the subgrade field density, traffic volume, and the subgrade CBR resulted in a negative sign indicating an inverse relation between these independent variables and the dependent variable, rut depth. As explained in the Warangal district model, with increase in traffic volume, one would expect an increase in the rut depth. However, an inverse relationship between the traffic volume and the rut depth has been observed in the comprehensive model. Even though only three districts (Warangal, Guntur, and Kurnool) have been considered in the development of the comprehensive model for Andhra Pradesh, these three districts distinctly represents the three Geographic regions of the state such as Telangana, Coastal Andhra, and Rayalaseema, respectively.

Conclusions

Based on the extensive field studies and critical analysis of the data, the following conclusions are drawn from this study:

(i) The gradation of the materials (base course and sub-base course) significantly affected the observed rut depths of the test sections. The gradation has been converted into a single point using the RMSE with upper limit as the datum. The rut depth was found to be minimum when upper limits of the standard gradation were considered. As the gradation curve deviates from the upper limit of the standard gradation curve, that is, with the increase in RMSE value, one could observe an increase in the rut depth.

(ii) The subgrade moisture content showed good correlation with rut depth in all the fifteen stretches of the roads considered in this study. With the increase in subgrade moisture content there is an increase in the rut depth. Because of increase in the moisture content, the subgrade gets weaker and one would expect an increase in the rut depth.

(iii) The field density of sub-base course and subgrade also exhibited an influence on the rut depth. It was observed in all the selected stretches that, with the increase in field density, there is a decrease in the rut depth. With increase in density, the material offers more resistance to rut formation.

(iv) For the selected road stretch in the Warangal district, the coefficient of determination is 0.96. That is, the variables considered in the development of the LVRW-TGAN road stretch model could explain 96% of the observed rut depth. Consideration of other variables probably would have explained the remaining 4%.

(v) District wise models have been developed for Warangal, Guntur, and Kurnool. Even though the gradation, density and moisture content could significantly explain the observed rut depth, there seems to be a slight ambiguity when traffic volume and subgrade CBR were included in the model. The Kurnool district model seems to be logically correct when compared to Warangal and Guntur district models.

(vi) A comprehensive rutting model has been developed by considering 15 road stretches in the three districts of the state representing three geographical regions. Even though the traffic volume shows a negative sign, the coefficient of determination was found to be 0.83. The unexplained 17% could probably be explained with the inclusion of more independent variables and with increased data points.

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Table 1 Road stretches identified for field investigation

S.No.	Road identity	District	Subgrade soil type	Rainfall intensity, mm/year	Traffic volume curve
1	LVRG-LPYZPT	Guntur	Silty/mixed red earth	500-1000	C
2	LVRG-CHDL	Guntur	BC soil	>1000	B
3	LVRG-YPDI	Guntur	BC/silt mixed	>1000	C
4	LVRG-PMKM	Guntur	BC soil	>1000	C
5	LVRK-JGPK	Kurnool	Gravel/BC	500-1000	A
6	LVRK-MDKP	Kurnool	BC soil/ HG soil	500-1000	B
7	LVRK-ASHG	Kurnool	BC soil	500-1000	A
8	LVRK-NH-18GT	Kurnool	BC soil	500-1000	B
9	LVRW-TGAN	Warangal	Gravel	500-1000	B
10	LVRW-VDAP	Warangal	Gravel	500-1000	B
11	LVRW-SGSP	Warangal	Gravel	>1000	B
12	LVRW-EPKG	Warangal	Gravel	>1000	B
13	LVRW-PWD	Warangal	BC soil	500-1000	B
14	LVRW-SDSP	Warangal	BC soil	500-1000	C
15	LVRW-HPNM	Warangal	BC soil	500-1000	B

Table 2 Summary of variables for LVRW-TGAN road stretch

Chainage, km	Avg. Rut depth, Mm	RMSE			Subgrade moisture content, %	Field density, g/cm^3	
		WBM Grading III	WBM Grading II	Sub-base gradation		Sub-base	Subgrade
2.9-2.95	9	24.112	15.88	19.27	4.94	1.971	1.631
2.95-3.0	6.5	16.115	12.377	17.375	3.53	2.175	1.884
3.0-3.05	9.25	20.248	14.359	20.254	5.47	1.877	1.849
3.05-3.1	4.5	12.798	11.111	15.631	2.57	1.845	1.891
3.1-3.15	10.25	29.089	18.82	20.457	5.86	1.961	1.568
3.15-3.2	7.5	16.87	15.895	17.531	3.29	1.556	1.675
3.2-3.25	8	14.352	15.403	23.288	3.76	2.128	1.86
3.25-3.3	6	15.192	13.685	17.38	3.69	1.971	1.956
3.3-3.35	9.5	24.392	18.541	20.308	3.83	1.994	1.602
3.35-3.4	6.5	12.165	15.588	19.072	3.18	2.007	1.669