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Impact of Subgrade and Granular Layer Material Properties on Rutting

Jyoti S.Trivedi[1,*], Dr.Rakesh Kumar[2]

[1]M-Tech(CEM)Faculty of Technology,CEPT University, K.L.Campus Near University Road Navrangpura, Ahmedabad Gujarat, India
[2]Civil Engineering Department, SVNIT Surat, Ichchhanath, SURAT-395 007 Gujarat, India
*Corresponding author: jyoti@cept.ac.i

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Abstract Material properties play avital role to determine the structural and functional performance of pavement layers during its service life. Pavement deformation or rutting is one of the key distress that affects the pavement performance. The strength parameters of subgrade and granular layer are correlated with the permanent deformations characteristics. Theindividualeffect in addition to combined effectof various combinations are considered to estimate rutting using multi linear regression (MLR) and artificial neural network (ANN) techniques. The data was collected in staggered position at every kilometer of a national highway stretch. The characteristic deflection, field dry density, modified liquid limit, California bearing ratio (CBR) were correlated individually with the rutting measurement and sensitivity analysis also performed. The impact of fines and dynamic behavior of soil response are considered in four possible combinations and correlated with rutting. The result shows that characteristic deflection, field dry density, modified liquid limit and modulus of elasticity of subgrade, and granular layer individually consists good relation with rutting except liquid limit. A good correlation was obtained supporting the validity of R^2 values of ANN for subgrade and granular layer 0.84 and 0.86 respectively for combinations of parameters. Likewise, results of R^2 values for MLR models obtained are 0.70 and 0.79, for the given layers subsequently comparing the R^2 values of MLR and ANN it is concluded that ANN models are more efficient than MLR.

Keywords: *material properties, rutting, sub-grade, GSB, characteristic deflection, dry field density, liquid limit, CBR, modified liquid limit, modulus of elasticity*

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1. Introduction

The characteristics of subgrade, granular and base layer material properties have a significant impact on the performance of the flexible pavement. The effects of traffic loading, environment conditions and fluctuations in material behavior cause rutting, fatigue and other forms of deteriorations, which tend to degrade the performance and durability of the pavement layer structure. The width and depth of the rut are widely affected by structural characters of the pavement layers (thickness and material quality), traffic loads, and environmental conditions [13,15,16]. It represents an accumulation of small amounts of unrecoverable deformation that occur whenever the traffic load is applied on the pavement [17,18,23]. The past researchers have proved that permanent deformation i.e. rut can happen in abituminous as well as base, subbase and subgrade layer. The impact of environmental conditions and material behavior during the service life of the pavement is also visible in the form of permanent deformation [19,28].

The main structural function of pavement is to support the wheel loads applied to the carriageway, distribute them to the underlying subgrade and to provide a uniform skid-resistant running surface with adequate service life [8]. A Pavement design is concerned with developing the most economical combination of pavement layers that ensure the stresses and strains transmitted from the carriageway do not exceed the supportive capacity of each layer during the design life of the road [21,23,30]. A selection of layer materials and thicknesses requires evaluation of various design strategies developed by considering various factors. The major variables affecting the design of a pavement are the volume and composition of traffic, the environment, the materials strength characteristics within the pavement layers and the thickness of each layer [20,24,25]. The development of rut in asphalt layers can be generally described through three main stages i.e. initial, secondary and tertiary stages as per the load repetitions. The primary stage develops fast due to the initial densification. The secondary stage is recognized by constant rate rut that develops through most of the pavement life. Flow rutting due to shear stress is the main contributor, although some densification may also remain. The tertiary stage is characterized by accelerating rutting. The three permanent deformation stages may be difficult to observe on the pavement surface due to the effects of wear and tear and structural rutting [9]. The horizontal strain is used to predict and control fatigue cracking in the surface layer. Similarly, the vertical strain at the top of the subgrade is used to predict and control permanent deformation (rutting) of the pavement structure caused by shear deformation in the upper subgrade [7,12,13].

Pavement material properties constantly get the change over time due to load, the influence of climate, as well as the onset of fracture or deformation. Resilient modulus and relative stiffness of various layers are the major indicators of material behavior. The factors that influence material behavior include density, water content, gradation, fine content, and temperature [28].The study reported that low humidity increases the strength of the materials. The effect depends on the content of fines; that is, the resilient modulus decreases when the material reaches saturation [8,11,30]. In addition to this, road construction materials and road surface responses are extremely sensitive to environmental factors, particularly moisture and temperature [10,14,28]. Environmental variations can have a significant impact on pavement materials and the underlying subgrade, which in turn can drastically affect pavement performance. The required thickness of each layer of the flexible pavement varies widely, depending on the materials used, magnitude and number of repetitions traffic load, environmental conditions, and the desired service life of the pavement. The study carried out laboratory tests to assess the compaction, California bearing ratio (CBR) and the unconfined compression strength (UCS) characteristics of the soil samples with varying percent of fines content [4,6,7].

As percentage fines increase, PI of soil increases and ultimately the strength of the soil decreases. In this study, relationship equations between dynamic cone penetration test (DCPT) index to Index and engineering properties of few subgrade with low plasticity characteristics. The tests include determination of DCP index in the field and engineering properties in the lab [1,5]. The pavement subgrade performance is a function of soil type, moisture content and applied stress condition [2,3,27]. The tensile tests were carried out on field cores of asphalt concrete [4,8,16]. The effect of coarse aggregate angularity on rut as interlocking of aggregates may resist to rutting was studied. Finding an alternative with the most cost effective or highest achievable performance parameter (i.e. FDD, Liquid limit (LL), Plasticity limit (PI), characteristic deflection, CBR, modulus of elasticity etc.;) under the given constraints, by maximizing desired factors and minimizing undesired ones is the basic concept of optimization. The stronger the correlation, the closer the score will fall to the regression line and, therefore, more accurate the prediction.

Although there are several attempts which have been made to correlate the HMA layer properties with rutting, the comprehensive effect of material properties of subgrade and subbase layers is yet to be studied. The individual and combined effects of all these material parameters need to be correlated with the rutting. Thus, the current study is limited to formulate impact of the rut on subgrade and granular layer properties of flexible pavement. The study area selected was on national highway of India. The field surveys, as well as laboratory tests, were carried out. In this research the quantity and types of fines which have a significant influence on the performance of an unbound aggregate road base and subgrade properties are considered. Thus, this study is an attempt to establish the correlation between rutting and material properties of sub-grade and granular subbase (GSB) layer which cause progressive accumulation.

2. Data Collection and Analysis

For the purpose of rut depth measurement, a 3.0-meter straight edge was utilized for measuring the rut as per the guidelines narrated in the ASTM E1703M & IRC SP 16:2004. One at the center of wheel path and two observations were made on the either side of the center of the wheel path at a 10cm transverse distance. The center of the wheel path was decided at 1.5 meters from the edge of the road carriageway [IRC: 81-1997]. The rutting measurements were made at an interval of 25 meters longitudinally. Pavement deflection is used to assess the structural adequacy of the pavement. Surface deflection depends on traffic, structural pavement section, temperature and moisture (content)of the pavement structure. For the structural evaluation of the pavement structure, deflection measurement by Benkelman Beam equipment as per the guidelines laid down in the IRC: 81-1997. Trial pits were taken randomly in the middle of each kilometer of chainage on LHS & RHS carriageway, with the help of core cutter machine. The damage to the main carriageway, trial pits of the same thickness of the pavement were taken on the paved shoulder is provided on hard paved side shoulders. The data obtained from the trial pits were field dry density (FDD) of GSB and subgrade by using sand jar method and soil samples were tested in laboratory to obtain LL, PL, PI, CBR, Water absorption test etc. In this study, material properties in terms of strength parameters of subgrade and granular layers are correlated with rutting, independently as well as combined effect of different parameters in various combinations, by using MLR and ANN techniques. This section analyzes the correlation between the different material characteristics and rut measurement. The subgrade and GSB layer data have been considered and co-related with rutting data. Regression analysis, MLR (multi-linear regression analysis) and ANN tools were used with the help of excel and MATLAB (Visual Basic Compiled Programs).

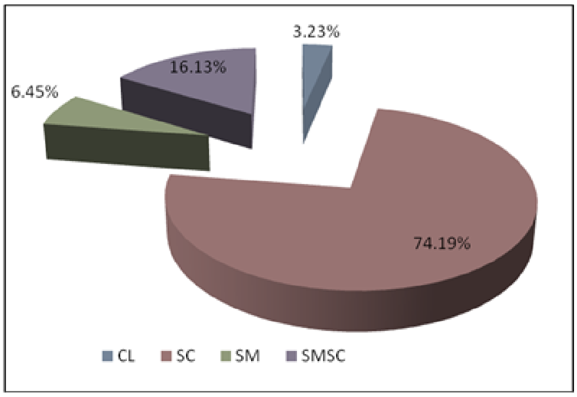

Figure 1. Soil Characteristics

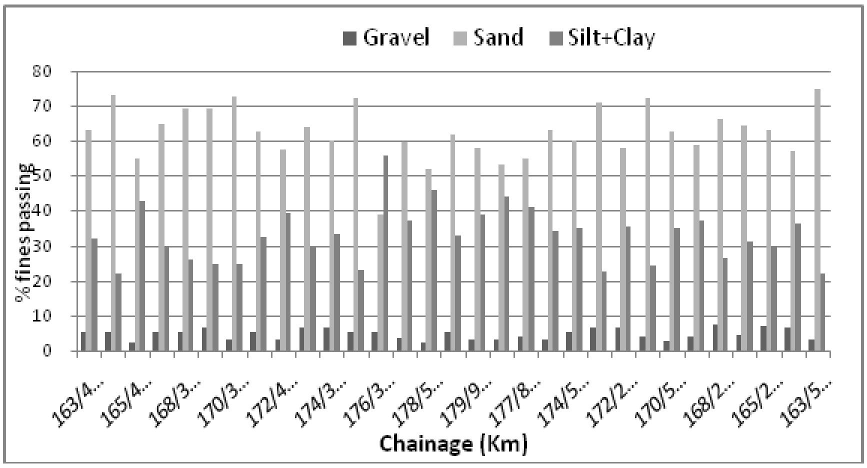

Figure 2. Gradation of subgrade soil

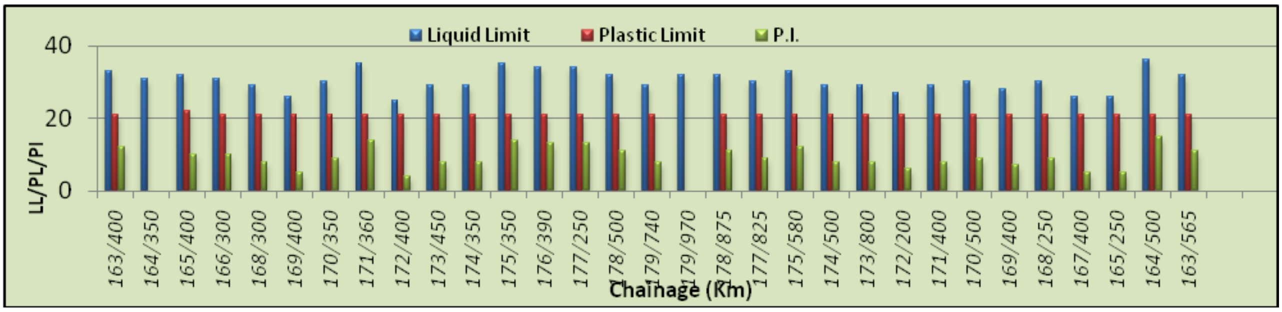

Figure 3. Atterberg's limits of subgrade soil

Soil characteristics play a vital role in pavement deformation. From the trial pit test, it was estimated that study stretch soil is of four type viz. CL (3.23%), SC (74.19%), SM(6.45%) and SMSC (16.13%) classification as shown in Figure 1. The results show that study stretch is having soil of clayey type sand (74.19%).The percentage fines more than the prescribed limit in subgrade soil create 'bathtub' effects and one of the leading cause of subgrade failure as given in Figure 2 at each chainage. The variation of LL, PL, and PI along the project stretch was examined. The results shows that compaction for more than half the study stretch was under 97% compaction level and subgrade CBR was 8% (MORTH, 2013).Liquid limit was estimated in the range of 20-36%, max. MDD 2.05 gm/cc, max. OMC 11.1% and max. CBR as 13.1%. in the subgrade layer. These illustrations will enable a clear effect of that particular parameter on rut measurement. Impact of % of coarser particle in estimating soil index properties was studied. Thus if % fines are more in the subgrade, it lowers the strength, requires more water for compaction and FDD also reduces. Modified Liquid Limit (WL) is defined as % coarse of soil retained on 425 microns sieve, i.e. if coarser particles are higher in subgrade as given in Eq.1. The LL doesn't take the % coarser particle in soil subgrade while estimating LL. That may lead to conservative results of soil properties. That may mislead to consider soil properties as the major cause of structural distress, which may not.It is critical to take percentage fines into the pavement evaluation [4]. Modified Liquid Limit can be estimated as given in Eq.1.

$$WL = LL \times (1 - C/100) \qquad \text{Eq.1.}$$

Where,

WL – Modified Liquid Limit
LL – Liquid Limit
C - % fraction of soil retained on 425 μ sieve.

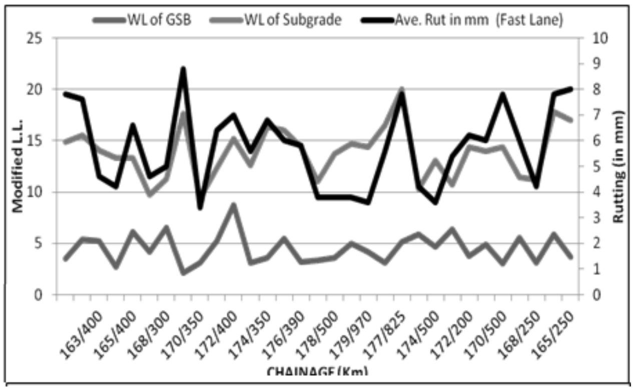

Figure 4. Modified Liquid Limit and Rutting

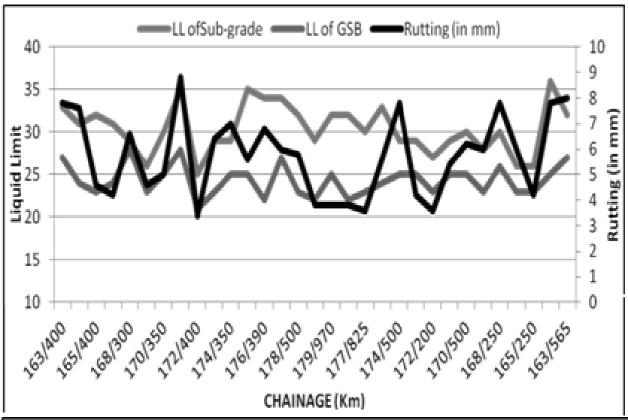

Figure 5. Liquid Limit and Rutting

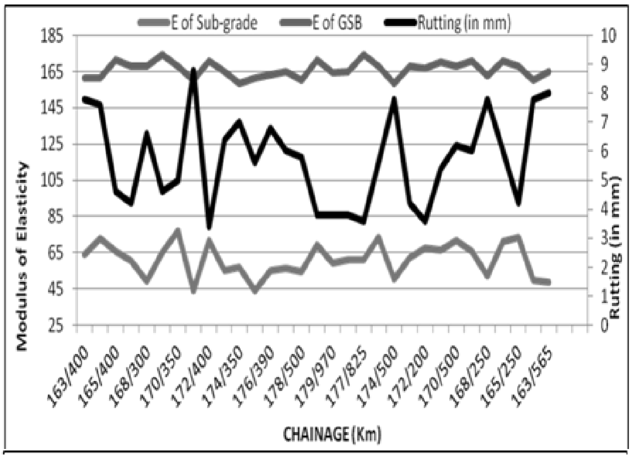

Figure 6. Modulus of Elasticity and rutting

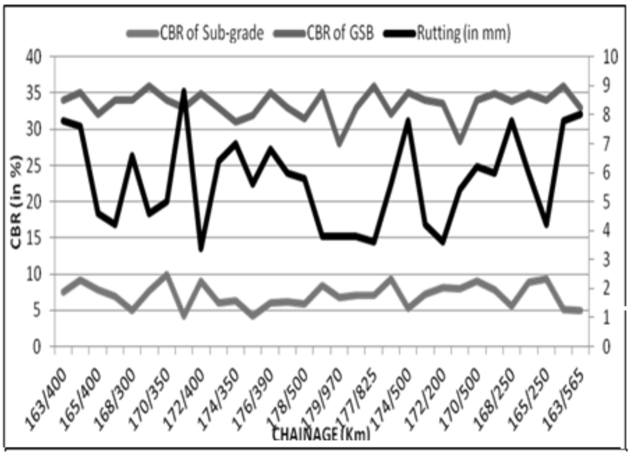

Figure 7. CBR and rutting

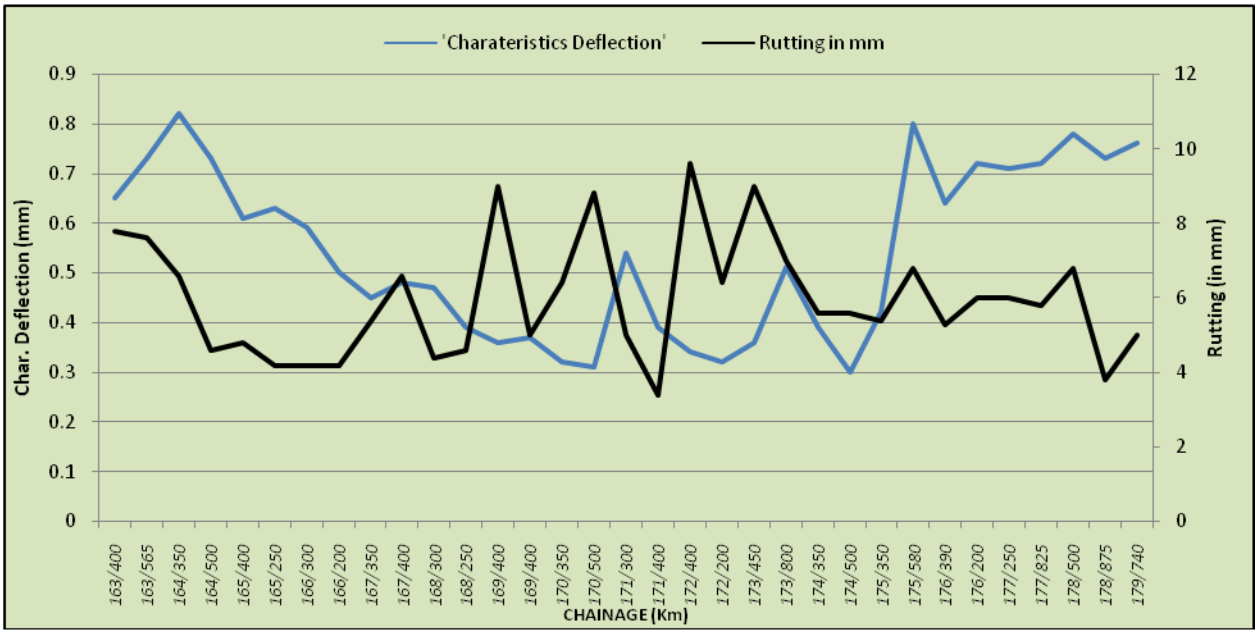

Figure 8. Deflection versus rutting measurement

The nature of measured rutting is corresponding with modified LL more than LL as given in Figure 4 and Figure 5. The resilient modulus can be estimated from acceptable equation (IRC-37-2012). The strength properties such as modulus of elasticity and CBR was also estimated for GSB and subgrade layer as given in Figure 6 and Figure 7. The behavior of the subgrade 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 the design and the performance of a pavement.

Figure 8 the total measured rutting in this study ranges from 4 to 8 mm. Besides characteristics deflection of GSB and subgrade, this amount of variation impacts the surface rutting and also been contributed to the variation of asphalt concrete(AC) layer construction.

3. Result and Discussion

An optimization procedure is used by first calculating the effect of all strength parameters values for subgrade and GSB layers, then choosing the solution identifying root-mean-square error between the results. The method was used on pavement sections with known layer thicknesses and chainages(points 1-33) as given in Figure 4 & Figure 5. Later, the individual and combined effects of parameters for optimization are validated through MLR and ANN techniques. The result shows the relationship between subgrade individual parameters and rutting is given in Table 1. The analysis shows that FDD have a strong impact on rutting and characteristic deflection, whereas modified liquid limit consists less relationship with rutting, CBR, and Modulus of elasticity are moderately related with the rutting, and there is no connection between liquid limit of subgrade and rutting. Table 2 is the summary of results of correlation between different parameters of GSB and rutting. FDD, Liquid Limit, Characteristic deflection and modulus of elasticity are moderately correlated with the rutting. Among these parameters, FDD affects fairly more than the others. Modified Liquid Limit and CBR not related to rutting.

Combined effect of parameters on rutting (MLR).The parameters of different combinations are related with the rutting by MLR. The results are as shown in Table 4. Relations of all combinations are good, as R^2 is right. For combination 3 in GSB, R^2 is right, but it shows that as modulus of elasticity increased rutting also increases. As per Table 4, there is a moderate relationship between these two parameters. So these two contradictory results are objectionable.

Table 1. Summary of results of relation between rutting and individual parameters of Subgrade

Parameter “X”(independent variable)	Parameter “Y.”(dependent variable)	Equation	R2
Char. Deflection (in mm)	Rutting (in mm)	y = 30.48 x2 – 27.95 x + 11.05	0.47
FDD	Rutting (in mm)	y = -24.56x + 52.67	0.69
Liquid Limit (LL)	Rutting (in mm)	y = 0.784x + 25.92	0.19
Modified LL (WL)	Rutting (in mm)	y = 1.078x + 7.707	0.45
CBR	Rutting (in mm)	y = -0.490x + 9.208	0.25
Mod. Of Elasticity (E)	Rutting (in mm)	y = -3.004x + 78.44	0.27

Table 2. Summary of results of relation between rutting and individual parameters of GSB

For GSB			
Parameter “X”(independent variable)	Parameter “Y” .(dependent variable)	Equation	R2
Char. Deflection (in mm)	Rutting (in mm)	y = 30.48 x2 – 27.95 x + 11.05	0.47
FDD	Rutting (in mm)	y = -26.72x + 61.53	0.49
Liquid Limit (LL)	Rutting (in mm)	y = 0.549x - 7.622	0.39
Modified LL (WL)	Rutting (in mm)	y = 0.086x + 5.347	0.006
CBR	Rutting (in mm)	y = 0.071x + 3.344	0.007
Mod. Of Elasticity (E)	Rutting (in mm)	y = -0.230x + 44.02	0.45

Table 3. Combinations of parameters for MLR and ANN

Combination	Parameters
1	Char. Deflection, FDD, LL, CBR
2	Char. Deflection, FDD, LL, E
3	Char. Deflection, FDD, WL, CBR
4	Char. Deflection, FDD, WL, E

Table 4. Combined effects of parameters on rutting

Layer	Combination	Equation of MLR	R^2
Sub-grade	1	y = 1.951 x1 – 19.091 x2 + 0.001 x3 – 0.189 x4 + 42.379	0.719
	2	y = 1.998 x1 – 18.878 x2 + 0.0002 x3 – 0.034 x4 + 42.750	0.720
	3	y = o.676 x1 – 18.120 x2 + 0.147 x3 – 0.109 x4 + 38.704	0.743
	4	y = 0.711 x1 – 17.993 x2 + 0.146 x3 – 0.020 x4 + 38.902	0.743
GSB	1	y = 4.441 x1 – 15.419 x2 + 0.336 x3 – 0.103 x4 + 23.734	0.785
	2	y = 4.080 x1 – 13.033 x2 + 0.266 x3 – 0.071 x4 + 35.851	0.797
	3	y = 5.425 x1 – 20.582 x2 + 0.180 x3 + 0.038 x4 + 43.488	0.700
	4	y = 4.515 x1 – 16.363 x2 + 0.149 x3 – 0.092 x4 + 51.955	0.744

As per the analysis, It is clear that there is strong, moderate and poor relation between rutting and other parameters. It also signifies that there is an enormous difference of relationship between the parameters for subgrade and GSB. The liquidlimit of the subgrade is poorly related with the rutting, but the relation is moderate for GSB. CBR and modified liquid limit of GSB layer have no impact on rutting, during the same parameters of the subgrade show relationship with the rutting. Therefore, it is acomplex decision, which parameters should be taken for combined effect on rutting. The solution to this problem is the *sensistivity of* different combinations of variables have been done. In these 4-combinations of Table 3, characteristic deflection and field dry density have astrong relationship with the rutting and not correlated or derived from any other parameters in the study. Hence, these two variables remain constant, and the other parameters are varied as they are dependent on other parameters in the study which is explained before. The different combinations are made as shown in Table 3, and MLR and ANN techniques are applied for the model development and optimized it for the same. Table 5

Table 5. Statistical table obtained by MLR

Combination	Subgrade		GSB	
	t-stat	P-value	t-stat	P-value
1	4.785	0.000	2.374	0.025
	1.421	0.167	3.842	0.001
	-4.624	0.000	-3.871	0.001
	0.020	0.984	3.679	0.001
	-1.530	0.138	1.308	0.202
2	4.837	0.000	3.532	0.002
	1.455	0.158	3.519	0.002
	-4.540	0.000	-3.175	0.004
	0.003	0.998	3.013	0.006
	-1.552	0.133	-1.825	0.080
3	4.858	0.000	4.447	0.000
	0.437	0.665	4.030	0.000
	-4.608	0.000	-4.652	0.000
	1.547	0.134	1.510	0.143
	-0.917	0.367	0.422	0.676
4	4.899	0.000	5.498	0.000
	0.458	0.651	3.444	0.002
	-4.539	0.000	-3.652	0.001
	1.534	0.137	1.351	0.188
	-0.932	0.360	-2.175	0.039

ANN technique is used to find the relation of combined parameters of different combinations and rutting by using MATLAB tool. Table 6 shows the relative importance of parameters and R^2 results for various combinations of thesubgrade. All the combinations are strongly correlated with the rutting. The relative importance is highest for characteristic deflection, modulus of elasticity, modified liquid limit and themodified liquid limit for the combinations 1, 2, 3 & 4 respectively. Similarly for GSB, all the combinations are strongly correlated with the rutting. The relative importance is highest for FDD, modulus of elasticity, FDD and FDD for the combinations 1, 2, 3 & 4 respectively which indicates they are highly significant parameters towards rutting.

Table 6. Results of ANN technique for Subgrade:

Combination	Parameters(independent variables)	Sub-grade		GSB	
		Relative Importance	R2	Relative Importance	R2
1	Deflection	35.81%	0.8172	28.41%	0.859
	FDD	15.38%		32.23%	
	Liquid Limit	18.60%		16.03%	
	CBR	30.21%		23.33%	
2	Deflection	14.42%	0.7586	17.29%	0.828
	FDD	24.04%		21.02%	
	Liquid Limit	30.64%		28.22%	
	Mod. Of Elasticity	30.91%		33.47%	
3	Deflection	18.88%	0.8446	13.16%	0.757
	FDD	26.89%		37.95%	
	Modified LL	30.91%		30.39%	
	CBR	23.32%		18.50%	
4	Deflection	22.76%	0.7225	27.97%	0.792
	FDD	27.68%		29.09%	
	Modified LL	28.04%		22.18%	
	Mod. Of Elasticity	21.52%		20.75%	

4. Conclusion

The objective of the paper is to examine the strength parameters of subgrade and GSB layer which impact on rutting. Its sensitivity analysis is carried out by considering strength parameter effect individually and in each combination of its effects towards rutting. Results are optimized through regression correlation and an effective combined result identified of strength parameter is validated through MLR and ANN technique.

This study attempts to accomplish majorly: a) to analyse the effect of different parameters of sub-grade and GSB on rutting, individually, b) to formulate and distinguish the combined effect of various combinations of variables by using MLR and ANN, and c) To calculate the relative importance of variables in each combination. From the results obtained, the following conclusions were drawn:

1. From the results of regression of individual parameters, the optimization concluded that FDD, characteristic deflection and modified liquid limit consist right relation as compared to liquid limit, CBR and elasticity modulus of subgrade, and relation of characteristic deflection, FDD, Liquid limit, modulus of elasticity is much better than modified liquid limit and CBR for GSB layer.

2. Sensitivity analysis of gradation percentage fines is the major impact towards rutting which is covered by this study as effect of modified liquid limit which results 0.45 R^2 for subgrade layer when taken as individual parameter and gives good resultin combined effect parameters for combination 3 & 4. Thus, it states that theeffect of modified liquid limit is an important parameter to be considered which has not yet considered its impact towards rutting.

3. Optimization of MLR results shows that the good fit between the parameters of all the combinations and rutting for both the layers with R^2 is more than 0.70. The comparison of R^2, t-stat and P-value shows the combination-4 having parameters Characteristic deflection, FDD, Modified LL and elasticity modulus of subgrade gives strong relation with rutting and the combination-2 containing parameters deflection, FDD, Liquid Limit and elasticity modulus of GSB have more influence on rutting having R^2 value 0.79.

4. The results of ANN models describes that the parameters characteristic deflection, FDD, Modified LL and CBR in combination-3 have a greater influence on rutting which is recognized by the highest R^2 value of 0.84 among all combinations; while for GSB layer, characteristic deflection, FDD, liquid limit and CBR of combination-1 effects on rutting considerably, which is proved by R^2 is equal to 0.86.

5. Comparison of MLR and ANN models concludes that characteristic deflection, FDD and modified liquid limit are the most influencing parameters of subgrade that affect rutting, but the elasticity modulus have more influence on rutting than CBR in MLR model and vice-versa for ANN model. For GSB layer, characteristic deflection, Liquid limit are the significant factors that effects on rutting, furthermore elasticity modulus gives

satisfactory results than CBR values in MLR model and vice-versa for ANN model.

6. For the subgrade, the relative significance of parameters for the selected model in descending order of significance is FDD, modified liquid limit, elasticity modulus and deflection for MLR, while for ANN model it is modified liquid limit, FDD, CBR and characteristic deflection. The descending order of significance of GSB parameters of MLR model is atypical deflection, FDD, liquid limit, elasticity modulus and for ANN model it is FDD, CBR, characteristic deflection and liquid limit.

Based on field measured data rut prediction model was developed for this study which offers promising potential for accurately predicting the permanent deformation behavior of subgrade and granular layer. This methodological approach can be extended to other subgrade layer soil properties and validate it for different field data set.

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