
CHANGE IN RESILIENT MODULUS OF BASE LAYERS IN ASPHALT PAVEMENT STRUCTURES OVER TEXAS

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ABSTRACT

The properties of materials change over time and the same case happens for the HMA pavement. The various components of HMA pavement such as surface, base, sub-base, and sub-grade have time related functions. In particular, the base layer which is the immediate layer below the surface, comprising of various materials such as crush aggregates and HMA also have a time related function. Among the numerous properties of the base layers which are dependent with time is its resilient modulus. Therefore, this paper correlates the effect of the change in resilient modulus with time including the various varying conditions such as rutting, thickness of base layer, precipitation, traffic, temperature, IRI index, wheel path length cracked, cracking percentage, crack length, liquid limit, plastic limit, optimum moisture content, and % fine passing below 200 sieve. Each individual factor has different effects over the resilient modulus of the base layer, but their effects are more severe when they act at once in a pavement structure.

KEYWORDS

HMA pavement, Base layer, Resilient modulus

INTRODUCTION

The construction of flexible pavement involves numerous layers such as surface layer, base layer, and sub base layer over the subgrade. The layer below the surface is known as base layer and is directly responsible for the strength of the pavement structure and as well as, in load spreading and stress reduction [1]. At various instances, base layer has been proven to be the most effective layer for the drainage because of the well graded aggregates which act as a flow-path for water. The properties of base layers have a great importance when talking about the performance of pavement. The base layer comprises of aggregates and if the base layer is purely made of aggregate it is known as unbounded base layer but if the aggregates are treated with some kind of treatment agent it will be referred as bounded base. One of the important properties of the base layer, which is directly related to its strength, is its resilient modulus. The property which is directly related to the stiffness of the flexible pavement is its resilient modulus and requires a lot of analysis. Various researches have been performed for knowing the resilient modulus of the base layer in a flexible pavement structure. Those studies were related to the various independent factors affecting the performance of the base layer in a pavement structure, but numerous factors act on the pavement structure which will decrease the resilient modulus of the pavement and in long term the strength of the pavement. Some of the important factors which play a great role in the changing resilient modulus with time are as rutting, thickness of base layer, precipitation, traffic, temperature, IRI index, wheel path length cracked, cracking percentage, crack length, liquid limit, plastic limit, optimum moisture content, and % fine passing below 200 sieves. These factors are analysed independently as well as in the combination for knowing the resilient modulus of the base layer in a pavement structure and in addition a comparative study of the change in the resilient modulus of base layer with time is presented. These factors may not have direct role with regard to the resilient modulus, but also a simplified model considering the effect of these factors is necessary for understanding the performance of base layer with respect to resilient modulus.

LITERATURE REVIEW

A flexible pavement structure is quite different from other types of monolithic engineering structures and this is due to the presence of a multi-layer system whose properties change when subjected to various external factors over the course of time [1]. These properties are more clearly described when study is done over the material from which it is made. One among those multiple properties is resilient modulus, which is mostly pronounced as modulus. Traffic and environment conditions are more responsible for the complex behaviour of the hot-mix asphalt pavement. Along with traffic and environment, there are numerous factors which play a vital role in the mechanistic design of asphalt pavement.

The resilient modulus also differs from layer to layer, so the modulus at the top of the surface will not be the same in the base and subgrade level. Asphalt surface being the top most layer, its properties can be found easily, but for underlying base layer the same case does not occur. The resilient modulus of the base layer at any time is dependent on the multiple factors including the traffic loading itself.

For this complex nature of pavement, simple method of designs become ineffective, therefore, numerous empirical designs were developed and the observation of pavement performance recorded over various point acts like a strong foundation on the development of this method [2]. The database is provided by various government agencies and one of the noted databases for US and Canada is LTPP (Long Term Pavement Performance) which has a vast database on the hundreds of factor related to pavement [3].

Various researches have been performed for the behaviour of resilient modulus of the base layer in the pavement. All of these researches are focused on the pavement material characteristics at various levels of pavement. Vukobratovic et al. [1] had conducted a research focusing over the influence of material characteristics on pavement design. The performance of pavement had changed a lot when the materials‘ characteristics were changed. The primary focus over the research was towards the influences of humidity and temperature on the pavement. Moduli were determined at different moistures and temperature level as material properties were variable on the layer system of pavement. The correct choice of the resilient modulus is the most important thing as it is also the representation of layers of pavement structure over time. Knowing the proper material characterization and development of empirical models can also be very much effective on the cost reduction by decreasing the thickness.

Similarly, Ji et al. [4] conducted a study to evaluate the resilient modulus of subgrade and base materials in Indiana and its implementation in Mechanistic Empirical Pavement Design Guide (MEPDG) as MEPDG itself needs the resilient modulus for the characterization of the layer and their structural design. Resilient Modulus values were correlated with the index of soil and other numerous properties like coefficient followed over layer and California Bearing Ratio, etc. Various procedures and their influences can be very much important for the evaluation of resilient modulus.

Wang et al. [5] conducted a study to know the relationship of resilient modulus with respect to fatigue cracking as well as rutting potential and these factors must be included while judging the mechanical properties of the pavement.

Resilient modulus as presented by Mousa et al. [6] is based on mechanistic pavement design methods that utilized various factors affecting the resilient modulus of the base and subgrade layer. The factors related to soil index properties, stress state, and moisture content and matric suctions were presented in the study. The study demonstrated that the resilient modulus was greatly influenced by the level of applied stresses and amount of moisture content in the material.

Similarly, the study on the effect on the various factors affecting the resilient modulus is not only limited to unbound materials. The research by Li et al. [7] explained the effect of materials and temperatures on the resilient modulus of asphalt treated base layer.

The various studies presented above demonstrated that the resilient modulus in a base layer is affected by numerous factors. Many researchers have provided various numerical models focusing over some factors but a descriptive analysis considering the multiple effects are not presented. Thus, this paper aims on bridging the base layers taking into the factors with actual conditions of the pavement before its construction and after its construction under some time frames.

OBJECTIVE AND SCOPE

The primary objective of this study is to know the influence of various factors in resilient modulus of the base layer in asphalt pavement and determine the empirical model to calculate resilient modulus with respect to these factors. Similarly, as a secondary objective, various sections of the pavement are analysed to know the resilient modulus of those layers with respect to time.

DATA COLLECTION

As we know, hot mixed asphalt pavements are very much susceptible to various environments and mechanical changes over time, hence, the research focuses over the change in the most important property – resilient modulus - of base layer is needed. There also needs to be a look into various conditions such as rutting, thickness of base layer, precipitation, traffic, temperature, IRI index, wheel path length cracked, cracking percentage, crack length, liquid limit, plastic limit, optimum moisture content and % fine passing below 200 sieves. The data with regards to these parameters was collected from Long Term Pavement Performance Database (LTPP) [3]. LTPP has a vast source of the database from the pavement section of United States and Canada. Among the various sections, numerous pavement sections from Texas were taken as the prime purpose of the research. The data from twenty sections were taken along the entirety of Texas. The Figure 1 below shows the sections taken for the analysis.

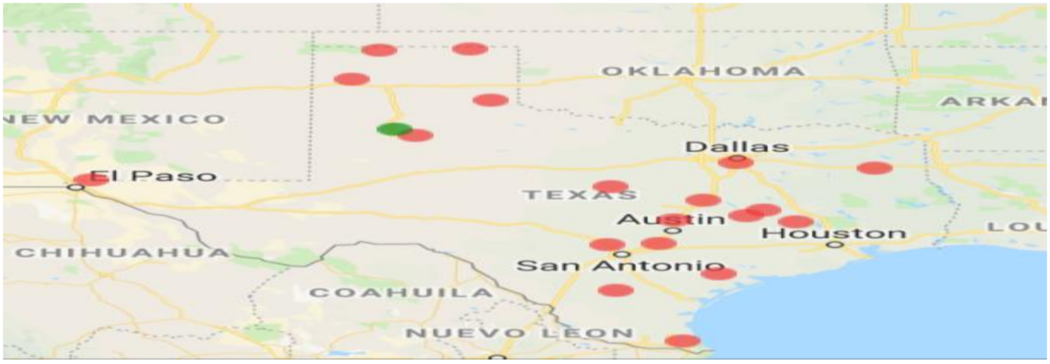

Fig. 1 - Location of sections under study

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With the data from these sections, the relation of these numerous parameters was performed using scatter plots, histograms, and regression analysis. These analyses are described clearly on the preceding contents of this paper.

DATA ANALYSIS

With the collected data, basically three forms of analysis were done. They are described below.

Effect of time on the resilient modulus of the base layer of pavement

The resilient modulus of the base layer of pavement structure is found to have a time dependent property. The resilient modulus decreases with respect to time. All of the section possessed the properties of resilient modulus degradation until and unless any kind of reconstruction and rehabilitation activities were performed on the pavement surface. The Figure 2 below shows 20 sections observed over various times with respect to the resilient modulus and year of data taken.

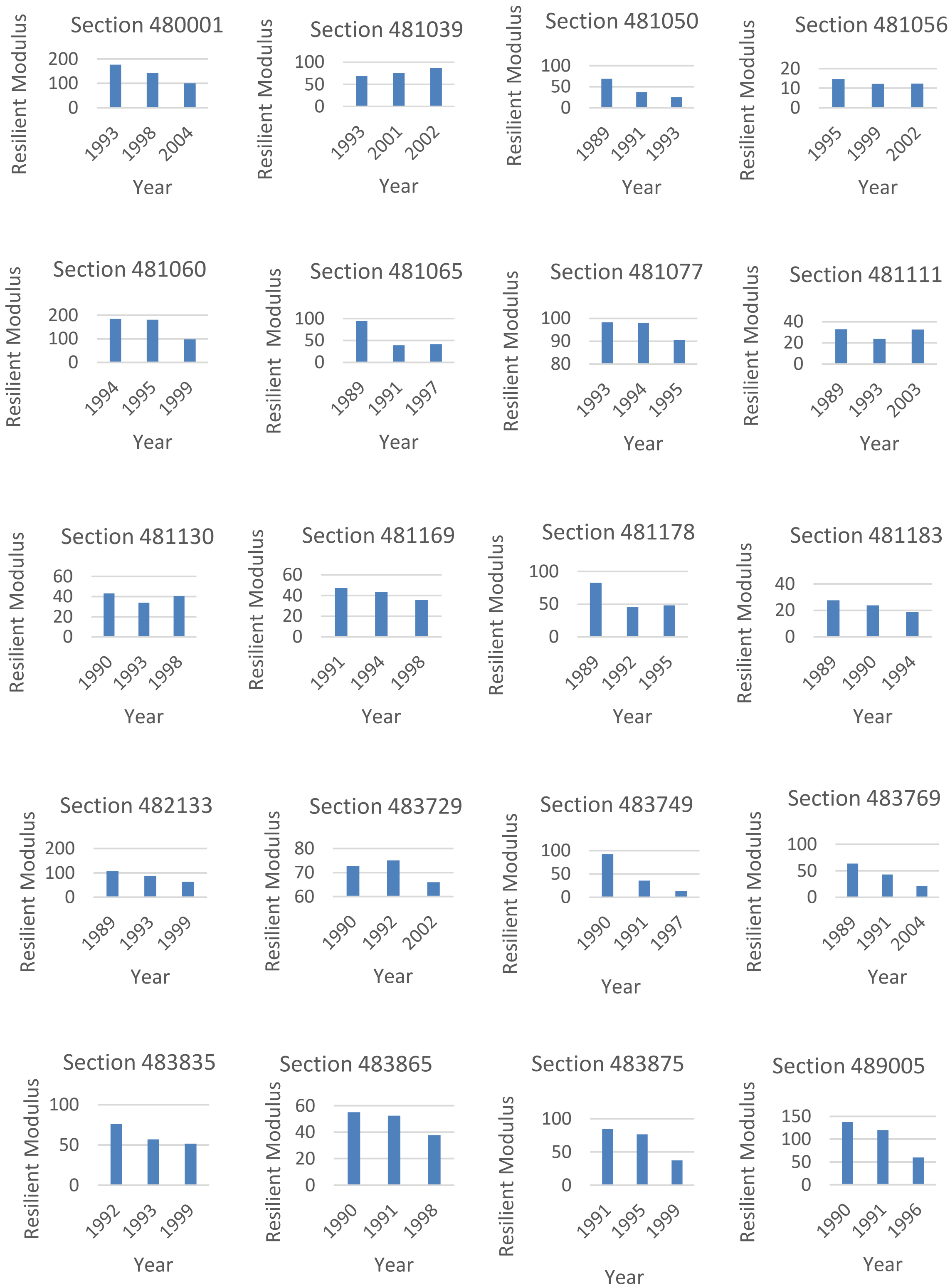

Fig. 2 - Change in resilient modulus (expressed as Ksi) with time

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Effect of singular factor on the resilient modulus of base layer of pavement

In this study, thirteen factors were considered in the analysis of the base layer of the pavement structure. These factors are encountered separately to identify the effect on the pavement. Some factors had shown a great influence on the resilient modulus of base layer but some factors impart a lesser effect.

Traffic loading represented as Annual Average Daily Traffic (AADT) has the most significant effect on the resilient modulus of the base layer of the pavement. The value of R2= 0.20 itself suggests the effect of the AADT on the base layer. Temperature being a surface phenomenon on the HMA pavement has a significant effect on the resilient modulus of the pavement. IRI or International Roughness Index is another factor responsible for the change in the resilient modulus of the pavement. IRI also has a great effect on the resilient modulus of base layer with the value of R2= 0.14. Rutting, referred as surface depression on the wheel path, has a significant effect on entire HMA pavement but in the resilient modulus of the base layer it has a lesser effect. HMA pavement is mostly characterized by its thickness, but thickness of base layer and precipitation had a small effect in the resilient modulus of the base layer of pavement. Similarly, various cracks measured in the pavement showed that the crack in the surface layer does not give any significant effect on base layers, although cracking percentage showed a better relation with resilient modulus than the wheel path length cracked. Various constructions related parameters are also utilized in this study and their relation with resilient modulus of base layer was identified. Liquid limit (LL), plastic limit (PL) ,optimum moisture content (OMC), and percentage passing below 200 mm sieve type aggregate are the detrimental properties needed to be considered during the period of construction, but having the low R2 value suggests that their effects are relatively less when resilient modulus of base layer is considered.

Figure 3 presents the effects of these factors when related to the resilient modulus of the base layer in the pavement structure.

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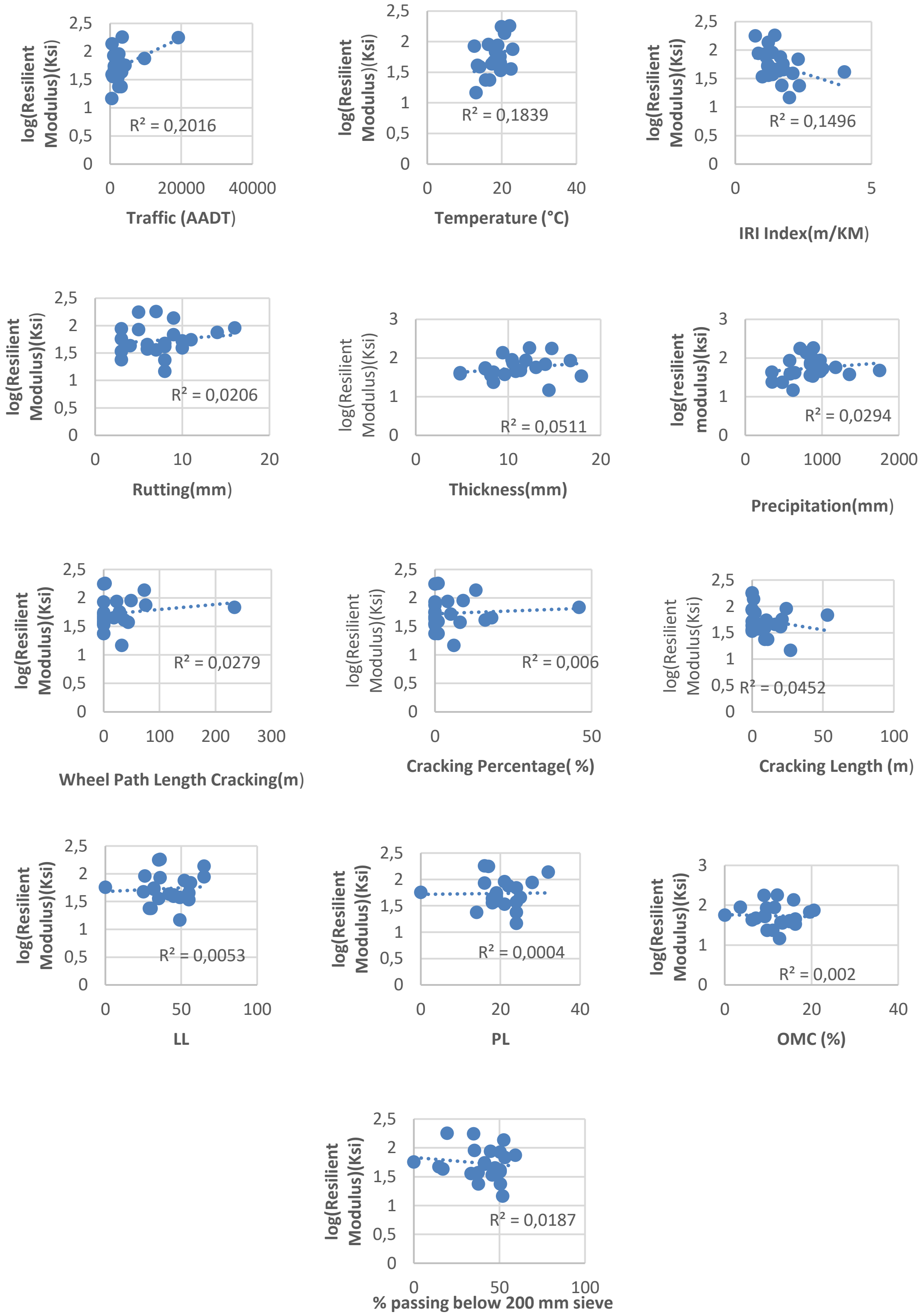

Fig. 3 - Effects of various factors in resilient modulus

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Effect of multiple factors on the resilient modulus of base layer of pavement

The study of effect of individual factors on the pavement was performed before, but the pavement is exposed to diverse conditions. For example, precipitation, wheel loading, and cracking of the pavement can occur at the same instant. Structures exposed to this kind of multiple factors do not rely solely on one factor. In this section of the analyses, all the factors are considered so that the actual condition of the pavement is simulated. Multiple regression analysis was applied as a tool to analyse this data. The following Table 1 shows the regression statistics obtained from the multiple regression analyses using excel.

Tab. 1 - Statistics result from multiple regression analysis

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	1.891E+00	1.04658	1.807	0.108
Rutting	4.354E-02	0.02389	1.823	0.106
Thickness	2.051E-02	0.02767	0.741	0.480
Precipitation	-1.513E-04	0.00023	0.663	0.526
Traffic	2.008E-05	0.00002	1.268	0.240
Temperature	-4.531E-04	0.03569	0.013	0.990
IRI index	-2.922E-02	0.17719	0.165	0.873
WP length cracked	8.748E-04	0.00276	0.317	0.759
Cracking %	2.788E-02	0.01479	1.885	0.096
Crack Length	-2.412E-02	0.01105	2.183	0.061
LL	6.681E-03	0.01046	0.639	0.541
PL	-1.666E-02	0.02144	0.777	0.459
OMC	-2.220E-02	0.02942	0.754	0.472
Passing no. below 200	-5.487E-03	0.00875	0.627	0.548

DEVELOPMENT OF PREDICTION MODEL

With the above multiple regression analyses and statistics value, a model is developed to incorporate all the factors affecting the resilient modulus of the base layer in the hot mixed asphalt pavement structure. The equation is valid for the correlation value as high as 0.70. The equation (A) is the predicted model and the Figure 4 is the regression analysis on the predicted versus measure value.

$$\text{Log (Resilient Modulus)} = 1.891 + 4.354E-02 * \text{Ruting} + 2.051E-02 * \text{thickness} - 1.513E-04 * \text{Precipitation} + 2.008E-05 * \text{Traffic} - 4.531E-04 * \text{Temperature} - 2.922E-02 * \text{IRI} + 8.748E-04 * \text{WP lengthcracked} + 2.788E-02 * \text{Cracking\%} - 2.412E-02 * \text{CrackLength} + 6.681E-03 * \text{LL} - 1.666E-02 * \text{PL} - 2.220E-02 * \text{OMC} - 5.487E-03 * \text{Passing no. below 200}$$

------------(A)

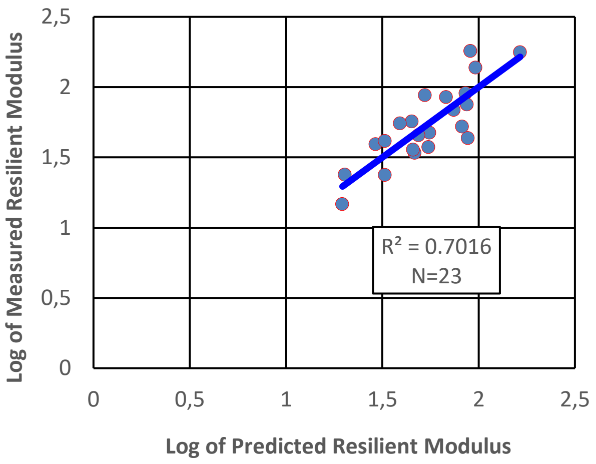

Fig. 4 - Measured VS predicted log of resilient modulus

RESULTS AND CONCLUSION

It is found that HMA pavement is influenced by multiple factors and for actually predicting the resilient modulus of the base layer in HMA pavement, multiple factors are needed to be taken into account. A real pavement structure is acted by numerous distresses, loading, and environment conditions at time and judging a pavement structure with only one factor can be a wrong practice to be followed. The independent factors presented in this study influence the performance of pavement structure. Similarly, a pavement must be rehabilitated and maintained time and again because this will increase overall performance of the pavement, thus, increasing the resilient modulus of the base layer of pavement. Therefore, the model developed in this study utilized all thirteen different factors to predict the resilient modulus of the base layer at that instant, and the model having a coefficient of determination equals to the value of 70 % indicates a good prediction capacity.

RECOMMENDATIONS

The data presented in this study resembles climatic conditions in the state of Texas, and the model also features the conditions resembling those climatic conditions. Therefore, the expansion of the study to the diverse area along with the field verification can be very beneficial.

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