Prediction of Structural Performance of State Highway 1

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Abstract—Performance of pavements includes both structural and functional performance and the accurate prediction of pavement performance is important for efficient management of the transportation infrastructure. Due to the great complexity of road deterioration process, performance models are the best approximate predictors of expected conditions. Pavement performance model is an equation that relates to some extrinsic 'time factor'(age or number of load applications) to a combination of intrinsic factors (structural responses, etc.) and performance indicators which simulate the deterioration process of pavement condition and provide forecasting of pavement condition over a period of time. Structural performance models help to forecast the structural adequacy of flexible pavements.

The study deals with development of structural performance model of State Highway 1, stretching from Thiruvananthapuram to Kottarakkara, incorporating traffic volume plying over the pavement, ageing of pavement, Modified Structural Number and subgrade soil properties of the pavement. Benkelman Beam Deflection measurement was used for the Structural Evaluation of pavement. Multiple Non linear regression analysis was used to develop Structural performance model using SPSS package. It was validated for their better use in field conditions. A structural performance model helps to forecast pavement performance over a period of time.

Keywords—Deflection model; Structural performance; Modeified Structural Number; Subgrade soil properties

I. INTRODUCTION

The structural and functional condition of the pavements changes with passage of time. The failure occurs due to internal damage caused by traffic loads, within an operational environment, over a period of time. The capability to forecast future pavement condition has been a question of common interest for the economic reason for pavement management systems and the need to develop an intelligent prioritization schedule became ever more important for the sake of efficiency. Mathematical models are needed to predict the trend in road condition over time so that reasonable estimates can be made regarding the likely timing and cost of future maintenance on a road and of the resultant quality of the service of the road to the road user.

The primary means of evaluating structural adequacy of flexible pavement is surface deflection measurements because the magnitude and shape of pavement deflection is a function of Traffic load, Age of pavement, pavement layer thickness & composition, pavement surface temperature and subgrade soil properties. Pavement is a very sophisticated structure that responds in a complex manner to all these factors.

II. OBJECTIVES OF STUDY

Objectives of the study included,

- Evaluation of structural performance of the pavement.
- Evaluation of subgrade soil properties and obtaining traffic volume of the pavement.
- Development of structural performance model.
- To quantify the contribution of most relevant variables to the pavement deterioration.
- Validation of the model for their better use in field condition.

III. LITERATURE RIVIEW

In order to achieve a clear knowledge in the field of pavement performance and modeling techniques, different national and international literatures were reviewed. Large numbers of studies have been conducted globally for developing pavement performance models.

Pavement performance models are of three types namely Empirical model, Mechanistic model and Empirical Mechanistic models. Regression can be either linear or non linear. When more than one variable is included in the model, multiple linear or non linear regression is resorted to.

Ankit Gupta et al. (2011) developed an intelligent pavement deterioration model. They considered age of pavement, CBR of subgrade soil, traffic volume and thickness of pavement as input parameters.

Muralikrishnan and Veeraraghavan (2011) developed pavement performance models. Deflection equations were developed in SPSS package.

Reddy and Veeraragavan (1997) developed deterioration models for in-service flexible pavements in India. They modeled future condition as the function of present condition, pavement strength, incremental traffic and age characteristics, and climate.

L Gasper, A veeraraghavan and Bako (2009) presented the theoretical and practical issues of road pavement performance models obtained in India and Hungary.

Sung Hee Kim and Nakseok Kim (2006) developed performance prediction model in flexible pavement using regression analysis method.

Praveen Kumaret al. (2010) developed deterioration prediction models for deflection and roughness.

Different types of techniques were used for the development of pavement performance prediction models. It was seen that many of the models were developed for a particular region or country under specific traffic and climatic conditions.

IV. RESEARCH METHODOLOGY

The research methodology includes review of earlier projects, selection of study area, data collection, data analysis, development of structural performance model and its validation. The study stretches were selected based on the category of the road, terrain and traffic conditions, geographical location etc.

Data collection was done by primary and secondary survey. The data collected were analyzed to determine the performance parameters. The data collected includes characteristic deflection of the pavement, traffic volume, pavement history, and subgrade soil properties of each study road stretches.

The preliminary step for any model development is to identify the highly influenced parameters which affect the model. The best fit structural performance model was developed in IBM SPSS package. The regression model was developed by giving the independent parameters which affects the structural performance of a pavement as the input parameters. And it was found that non linear models best suit to structural performance models due to the complexity in nature and type of the parameters which affect the performance of a flexible pavement.

Validation of the generated structural performance model was done to ensure their better use in field condition. Multiple non-linear regression model was validated in terms of goodness of fit and forecasting errors.

V. DATA COLLECTION

A. Study Area

The state Highway 1 stretching from Thiruvananthapuram (Vettu Road near Kazhakoottam) to Kottarakkara (60.9 km), in the state of Kerala was selected as the study road. Six homogeneous stretches (HS) distributed on State Highway 1 was selected for the study purpose. They were designated as HS I, HS II, HS III, HS IV, HS V and HS VI. Representative stretches of 1 km was selected from each homogeneous section and the study was conducted on it. Details of study stretches are shown in table I. Location of study stretch is shown in figure1.

B. Pavement details

The pavement details collected includes pavement history, pavement layer thickness, pavement composition details etc. These data were collected from NATPAC and KSTP (Kerala State Transport Project). The up gradation of road from ordinary 40 mm Chipping Carpet to Bituminous macadam-Bituminous concrete, confirming to the SH standards was done by Public Work Department, Government of Kerala, India under Kerala State Transport Project-1. The study road is two-lane conforming to SH standards. The pavement structural layer composition and thickness is shown in table II.

TABLE I. STUDY STRETCHES

Sl no.	Road section	Section ID	Section name
1	SH 1 (Kerala) Thiruvananthapuram-Kottarakkara (60.9 Km)	HS I	Sainik School-Kinfra
2		HS II	Chanthavila-Kattaikonam
3		HS III	Venjaramoodu-Nilamel
4		HS IV	Nilamel-Chadayamangalam
5		HS V	Vayackal – Policodu Jn
6		HS VI	Lower Karikkom - Kottarakkara

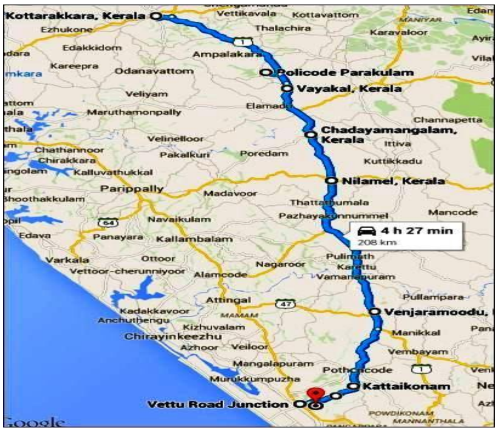

Fig. 1. Location of study stretch

TABLE II. PAVEMENT COMPOSITION AND THICKNESS

Pavement layer composition	Thickness (mm)
AC (Asphalt concrete)	40
DBM (Dense Bituminous Macadam)	75
MSS (Mixed Seal Surfacing)	25
WMM (Wet Mix Macadam)	255
GSB (Granular Sub Base)	150
SG (Sub Grade)	300

C. Subgrade Soil Investigation

Pavement structure eventually rests on soil foundation. Soils are highly heterogeneous and anisotropic in nature and occur in unlimited varieties. Also in any road embankment, the bulk of the material used is soil and if properly designed, should possess stable slopes and should not settle to any appreciable extent. Heavy vehicles are continuously loading our pavements. These loads are transmitted through the pavement to the subgrade. Considering all these aspects, a thorough study of the engineering properties of soil is of vital importance to understand its effects and contributions on the structural performance of pavements which will yield an acceptable level of performance over the design life under the given traffic and climatic conditions.

The subgrade soil samples were collected randomly from the study stretches of SH 1. For that test pits were cut open in pavement shoulder interface and the soil samples were taken to the laboratory in sealed containers. Laboratory tests like Grain size analysis, Atterberg limits, Compaction test and California Bearing Ratio tests were conducted as per the relevant Indian Standard Codes of practice. The soil classification was also done.
The engineering properties of subgrade soil samples are shown in table III.

TABLE III. ENGINEERING PROPERTIES OF SUBGRADE SOIL

Soil sample code	OMC (%)	MDD (g/cm^3)	CBR (%)	LL (%)	PL (%)	PI (%)	Gravel (%)	Sand (%)	Silt& clay (%)	Soil Classification
HS I	21.2	1.57	7.0	37.9	26.9	10.9	1.00	34.2	64.8	SC
HS II	6.41	2.08	17.9	25.0	14.3	11.1	8.00	57.8	34.3	SC
HS III	11.9	1.98	11.7	27.5	21.1	6.39	14.3	59.0	26.7	SM SC
HS IV	11.1	1.93	9.9	44.0	33.3	10.6	16.2	55.1	28.7	SC
HS V	7.80	2.10	36.8	20.5	16.6	3.83	13.9	82.4	3.7[a]	SP
HS VI	11.0	1.79	3.7	35.5	13.3	22.1	9.50	57.5	33	SC

Note: a - conducted in soil fraction passing 425 micron IS Sieve.

Where, OMC is the Optimum Moisture Content in percentage (%), MDD is the Maximum Dry Density in gram per cubic centimeter (g/cm^3), CBR is the California Bearing Ratio in %, LL, PL and PI are Liquid Limit, Plastic Limit and Plasticity Index of subgrade soil samples in %, Gravel, Sand and Silt & Clay are the percentage composition of gravel, sand and Silt & Clay in the subgrade soil sample, SC indicates Clayey Sand, SM- SC indicates Silty Sand- Clayey Sand and SP indicates Poorly Graded Sand.

D. Traffic Volume Data

Traffic volume studies are integral part of pavement performance evaluation system since they assess the number of vehicles, particularly number of commercial vehicles plying over the pavement which causes heavy damage to it. Traffic volume studies document the traffic volume trends of different time periods; so that it can be easily understand whether a particular section of the pavement is handling traffic at or above or below its design capacity. Pavement performance models incorporate traffic volume, mainly the number of commercial vehicles as an important factor affecting the structural pavement performance; because generally it is assumed that only vehicles having gross weight 3 tones or more (commercial vehicles) cause significant damage to the pavement structure.

Traffic data in CVPD (Commercial Vehicles per Day) of each study stretches of State Highway 1, collected from NATPAC is given in table IV.

TABLE IV. TRAFFIC DATA OF THE STUDY STRECHES IN CVPD*

Year	HSI&HSII	HS III	HS IV	HS V	HS VI
2012 (October)	688	1268	1108	1276	1299
2013 (March)	754	1327	1160	1335	1385
2013 (November)	802	1368	1197	1376	1446
2014 (June)	846	1405	1229	1413	1501
2015 (March)	906	1453	1271	1461	1574

Note: CVPD*- Commercial Vehicles per Day

E. Modified Structural Number

Structural Number (SN) is a measure of total thickness of the road pavement weighted according to the 'strength' of each layer. The strength coefficients suggested for different pavement materials are given in the Table V (source: Guidelines for maintenance of primary, secondary and urban roads). SN is calculated as follows:

$$SN = \sum a_i . d_i \quad (1)$$

Where i = summation over layers.
a_i = strength coefficient for each layer.
d_i = thickness of each layer measured in inches.

The AASHO Road test was on a single uniform subgrade. Therefore the effect of different subgrades could not be estimated and the structural number could not include a subgrade contribution. Pavements of a particular structural number but built on different subgrades will therefore not carry the same traffic to a given terminal condition. To overcome this problem and to extend the concept to all subgrades, a subgrade contribution was derived and a Modified Structural Number (MSN) defined as follows:

$$MSN = SN+3.51 \log_{10} (CBR_s) -0.85 (\log_{10} CBR_s)^2 -1.43 \quad (2)$$

Where, CBR_s = California Bearing Ratio of the subgrade.

TABLE V. STRENGTH COIFFICIENTS

Layer/Specification	Strength Coefficients
Bituminous Concrete (BC) 40mm	0.3
Bituminous Concrete (BC) 25mm	0.28
Semi Dense Bituminous Concrete (SDBC) 25mm	0.25
Dense Bituminous Macadam(DBM)	0.28
Premix Carpet (PC) 20 mm (only in the case of overlaid pavements which have PMC as original surfacing)	0.18
Bituminous Macadam(BM)	0.18
Water Bound Macadam(WBM Grade I, II or III) Wet mix macadam / (Lime cement) stabilized	0.14
Granular Sub base (GSB)/Quarry Rubish (QR)/Moorum	0.11

MSN was calculated for all the study stretches of SH 1 and incorporated it in the structural pavement performance model.

F. Structural Evaluation Data

The structural condition data collected for the study include road inventory data and deflection measurement using Benkelman Beam. Road inventory details like pavement type, terrain, carriage way width, right of way etc were collected from the NATPAC. The study road is two lane with plain terrain which conforms to SH standards. The road has carriage way width of 7.5 m, right of way of 22 m, paved shoulders of 2.3 to 2.5 m and side drains of 0.9 m.

Benkelman beam is a device used to measure the rebound deflection of pavement. Deflections were measured at 20 points in each kilometer, staggered at 50 meter interval in both directions with truck having rear axle load of 8.17 tones and tyre pressure of 5.6 kg/cm^2. The measurements are taken as per the procedure given in IRC: 81 (1997). The Benkelman Beam Deflection survey on the study road is shown in figure 2. The deflection progression of the six study stretches of State Highway 1 is shown in figure 3.

Fig. 2. Deflection measurement using Benkelman Beam

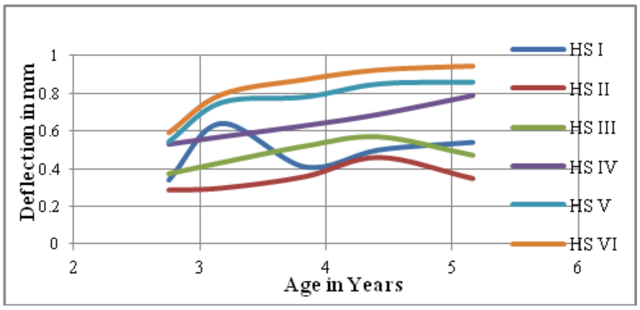

Fig. 3. Deflection progression of study streches of SH 1

VI. DEVELOPMENT OF STRUCTURAL PERFORMANCE MODEL

Statistical models are used to model the structural performance of road sections. Regression analysis is used in this context. The regression model was developed by giving the independent parameters which affects the structural performance of a pavement as the input parameters. And it was found that non linear models best suit to structural performance models due to the complexity in nature and type of the parameters which affect the performance of a flexible pavement. Hence multiple non-linear regression model was developed in SPSS Statistical tool, version 20.

The structural performance model is generated by incorporating Modified Structural Number (MSN) in terms of structural thickness of pavement & California Bearing Ratio (CBR) of subgrade soil, Age of pavement from the year of completion of construction, Traffic volume plying over the pavement in terms of Commercial Vehicles per Day (CVPD) and engineering properties of subgrade. Development of structural performance model produced a statics or mathematical expression between the response variable (dependent variable) and the set of predictors (independent variables). The most common measure of how well a regression model fits the data is its correlation coefficient or coefficient of determination (R^2). The model developed through regression analysis represents how much of the variance in the response variable is explained by the weighed combination of predictors.

Total 30 sets of data have been collected for the model generation. Among that 24 sets data were available from previous studies conducted by NATPAC and 6 set data have been collected from the current field work done in this year. Hence 80% of data (24 sets) were used for model development and 20 % data were used for its validation.

Pavement performance models should be based on correct and legible engineering principles to be reliable and accurate. Useful models should be able to quantify the contribution of most relevant variables to pavement deterioration. Pavement performance models allow the forward prediction of future condition of pavement based on present condition.

The following form of mathematical model was assumed:

$$\log_{10}(\text{Deflection}) = (\beta_1 * \log_{10}(\text{MSN})) + (\beta_2 * \log_{10}(\text{Age})) + (\beta_3 * (\sqrt{\text{Traffic}}) + (\beta_4 * \%\text{Silt \&clay}) + (\beta_5 * \%\text{PL}) + (\beta_6 * \%\text{ Sand}) + (\beta_7 * \%\text{ Gravel}) + (\beta_0) \quad (3)$$

Where,

- $\log_{10}$ (Deflection) = logarithm to the base 10 of the characteristic deflection of each homogeneous section of the study area in mm.
- $\log_{10}$ (MSN) = logarithm to base 10 of Modified Structural number.
- $\log_{10}$ (age) = logarithm to the base 10 of age of the pavement in years, from the year of completion of construction of the study area.
- ($\sqrt{\text{Traffic}}$) = square root of the traffic volume in commercial vehicles per day (CVPD) of each homogeneous sections of the study area in 1000s.
- % Silt & clay = percentage of silt and clay in the subgrade soil of each homogeneous section of the study area.
- % PL = Plastic Limit of the subgrade soil of each homogeneous section of the study area in %.
- % Sand = percentage of sand in the subgrade soil of each homogeneous section of the study area.
- % Gravel = percentage of Gravel in the subgrade soil of each homogeneous section of the study area.
- β_0 = model constant and β_1, β_2, β_3, β_4, β_5, β_6 & β_7 are Coefficients associated with MSN, Age of the pavement (years), Traffic volume (CVPD), % of Silt & clay in subgrade soil, Plastic Limit of subgrade

soil ,% of Sand in subgrade soil and % of Gravel in subgrade soil respectively.

The developed structural performance model is:

$\log_{10}$ (deflection) = - (2.332* $\log_{10}$ (MSN)) + (0.559* $\log_{10}$ (Age)) + (0.281*(√Traffic)) – (0.007* %Silt &clay) + (0.016* %PL) + (0.012* % Sand) – (0.028* % Gravel) – 0.004

Correlation coefficient, $R^2 = 0.968$.

VII. DISCUSSIONS AND FINDINGS FROM THE MODEL

The developed model emphasize that, Modified Structural Number (MSN) is the most important parameter for the structural response of flexible pavement followed by age of pavement, traffic volume plying over the pavement and engineering properties of subgrade.

MSN has a high inverse relation to deflection of pavement which indicates that the strength of a pavement is inversely related to maximum deflection under a known dynamic load. So it could be inferred that the most important parameter which the strength of a pavement depends is, the structural thickness of pavement and the strength of subgrade.

Age of pavement has great influence in deflection progression. Also the traffic plying over the selected study stretches (Commercial Vehicles per Day) appears to have a significant effect on the structural performance of a pavement. As the traffic volume increases, the deflection of the surfaces also increases and hence the structural performance of the pavement may get affected.

As per the model, the percentage composition of subgrade soil like percentage of gravel, sand, silt and clay clearly contributes to the strength of the subgrade and hence to the structural performance of a pavement. An increase in the content of sand in the subgrade beyond a limit reduces its strength, which in turn explains that that in damped state an increase in sand content leads to the development of cohesion between the subgrade soil particles due to capillary water, which leads to bulking. It prevents the soil particles from taking a stable position. As per the model, the effect of type of soil is also significant which affects the structural performance of a pavement. If the clay content in the subgrade soil increases, shrinkage and swelling happens depending on the seasonal variations. The contribution of gravel in providing the strength of subgrade is noticeable. So the percentage composition of gravel, sand, silt and clay should be in acceptable limits in accordance with the pavement recommendations to provide an increased bearing capacity and strength to the subgrade.

The model also reveals that, the subgrade soil should attain its plastic limit at the earliest due to the reason that at this water content, the soil loses its plasticity and passes in to a more stable state.

VIII. VALIDATION OF THE GENERATED MODEL

To check for real field applications, the generated model's validity should be checked necessarily. The generated structural performance model was validated in terms of goodness of fit and forecasting errors. The goodness of fit of the model was checked by comparing observed and predicted deflection, which gives model performance. The goodness of fit of the model is shown in figure 4 and it indicates that the model is significant.

In determining the forecasting errors, Mean Absolute Error (MAE) and Mean average percentage error (MAPE) were computed which is shown in table VI. They indicate how close the predicted values of deflection are to the observed values. The value of MAE is very low. So the developed model is significant. MAPE expressed in percentage. If MAPE value is less the model is highly significant. Hence it is proved that the generated model is highly significant. But it can be seen that the MAPE values of HS II and HS III is slightly higher due to a slightly higher variation between observed and predicted deflection of that stretches.

F- Test was conducted to check the reliability of the model. It helps to test the hypothesis about the model programming. The F-test evaluates the null hypothesis (H_0) that all regression coefficients are equal to zero versus the alternative (H_1) that at least one does not. Rejection of H_0 implies that at least one of the independent variable contributes significantly to the model and hence the model is valid. Rejection of H_0 is possible if ($F_{0\ model}$) exceeds ($F_{0\ statistical\ table}$).

$F_{0\ model}$ = 289 (For α = 0.05)

$F_{0\ statistical\ table}$= 2.64 (For degrees of freedom, df = 7 & α = 0.05)

Since $F_{calculated\ model}$ >> $F_{Statistical\ table}$; we can reject the null hypothesis (H_0) which indicates that the model is valid.

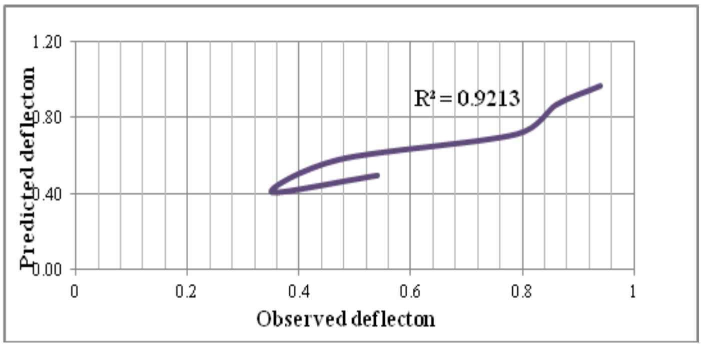

Fig. 4. Goodness of fit of the model

TABLE VI. CALCULATED MAE AND RMSE OF MODELS

Study Stretch	MAE	MAPE (%)
HS I	0.04	7.4
HS II	0.06	17.14
HS III	0.11	23.40
HS IV	0.07	8.86
HS V	0.01	1.16
HS VI	0.03	3.19

IX. CONCLUSIONS

Based on theoretical, statistical and field works conducted in this study, a multiple nonlinear regression model is developed to predict the structural performance of State Highway 1, which helps in forecasting of structural performance of pavement over a period of time. Hence the structural adequacy of pavement at any time could be analyzed. The developed models were validated to ensure their better use in field conditions. The model performance was evaluated in terms of goodness of fit and forecasting errors and the model was found to be significant. F-test was also carried out for the validation purpose.

The developed structural performance model emphasize that, Modified Structural Number (MSN) in terms of thickness of layers of pavement and CBR of soil subgrade is the most important parameter for the structural response of flexible pavement followed by age of pavement, traffic volume plying over the pavement and engineering properties of subgrade.

From the study it is understood that the traffic volume plying over the selected study stretches reaches 1600 CVPD in the current year 2015, conforming to heavy traffic in most of the stretches. As the age of pavement increases and as there is a fast pace in increase of traffic volume, deterioration of pavement happens.

The periodic conduction of Benkelman Beam Deflection surveys on the selected study stretches of State Highway 1 revealed that, the characteristic deflection values are comparatively lower in homogeneous stretches, HS I, HS II and HS III indicating a stronger pavement. But in remaining stretches, slightly higher values of deflection are observed. The characteristic deflection of HS VI reached above 0.9 mm. Based on the referred research studies conducted elsewhere in the country, it can be inferred that for deflection values up to 1 mm, the pavement structure can be referred to be reasonably strong category [6]. According to IRC 37: (2001), the present pavement thickness was found to be sufficient for the current year. But considering the increase in both aging of pavement and traffic volume for the upcoming years, an overlay is recommended to increase the pavement thickness for better serviceability.

REFERENCES

[1] Ankit Gupta, Praveen Kumar and Rajat Rastogi, "A Critical Review of Flexible Pavement Performance Models Developed for Indian Perspective", Indian Highways, Indian Road Congress, New Delhi , september 2011,Vol. 40 (3), pp 41-60.

[2] Ankit Gupta, Praveen Kumar and Rajat Rastogi, "Pavement Deterioration and Maintenance Model for Low Volume Roads", International Journal of Pavement Research and Technology, 2011, Vol.4 (4), pp 195-202.

[3] Muralikrishna P and Veeraragavan, "Decision support system for performance based maintenance management of highway pavements", J. Transp. Research Board, 2011, Vol.2205, pp 155-167.

[4] Praveen, Kumar., Satish, Chandra., and M. D. A. Sajid., (2010), "Performance Study of PMGSY Roads", Indian Highways.

[5] Gaspar L. Veeraragavan A. and Bako, A, "Comparison of Road Pavement Performance Modeling of India and Hungary", Acta Technical Jaurinensis, 2009, Vol. 2(1) pp. 35-53.

[6] B. Sengupta, "Performance evaluation of polymer coated bitumen built roads", Project Report by Central Pollution Control Board, Delhi, August 2008, pp 25-26.

[7] K. R. Arora, "Soil Mechanics and Foundation engineering", 7th Edition, 2008, pp 89.

[8] Sung Hee Kim and Nakseok Kim, "Development of Performance Prediction Models in Flexible Pavement Using Regression Analysis Method", KSCE Journal of civil engineering, 2006, Vol. 10(2) , pp. 91-96.

[9] IRC: 37, Guidelines for the design of flexible pavements, second revision, 2001, *Indian Road Congress.*

[10] IRC: 81, "Guidelines for Strengthening of Flexible Road Pavements Using Benkelman Beam Deflection Technique", 1997, *Indian Roads Congress.*

[11] A El-Desouky, "Statistical Based Models for Behavior of Flexible Pavements", 13th international conference on Aerospace Science and Aviation technology, 2009, Military Technical College, Kobry Elkobbah, Cairo, Egypt

[12] Reddy B. B. and Veeraragavan A, "Structural Performance of In Service Flexible Pavements", Journal of Transportation Engineering, ASCE, 1997, Vol.123 (2), pp. 156-166.