Performance Analysis of Overlays for Flexible Pavement

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Abstract. Pavements deteriorate with time in absence of adequate maintenance. The rate of deterioration depends upon a number of factors including traffic loading (magnitude of wheel load and its repetitions), climate, drainage, environmental factors and the initial of pavement structure. The design life of pavement system determines the way in which the surface would deform under the given traffic and environmental conditions. This in turn would establish the longitudinal and transverse profile of the riding surface which has to be maintained within acceptable standards, since it influences passenger comfort, vehicle maintenance, pavement life, etc. In the present study, a number of parameters were considered in developing a model that predicts the design life of flexible pavements. These factors were Characteristic Deflection (Dc), Rut Depth Index (RDI), Cracking Index (CI), Traffic Volume (V), Roughness Index (RI). For this purpose, 4 road test sections were chosen. These five factors have been either measured and observed in the field or computed every 3 months from January 2005 until October 2009. 4 Models were developed for the 4 test sections and R^2(adj) was between 92.1% and 95.3%.

Keywords: Design life · Dc · RDI · CI · V · EASL · R^2

1 Introduction

The basic need is to introduce a design procedure, handling the variability of deflection in a consistent manner so as to eliminate the basic risk of localized early failure or over design initially before strengthen the flexible pavements. Assessment of different lengths of a pavement sub-sections say 100 m, 150 m, and 200 m can be used to work out minimum cost solution which takes into account engineering constraints.

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2 Details of Overlaid Control Road Sections

The field program was established to study the variation of different parameters with time on different type and thicknesses of overlays laid on varied type of existing pavements. Four sections in the region of the Nile Delta have been identified. The details of the identified test sections have been given in Table 1. The above sections have different characteristics in terms of soil subgrades, pavement composition and traffic intensity. On the above sections, continuous measurements were made since 2005. In the present research program, the data has been collected on overlaid flexible pavements and presented chapter 5 for the period of 2005 to 2009.

Table 1. Locational details for road sections under field investigation

Section no.	Road name	Location	Station no.	Sub-sec length
1	Tanta-Quesna	TNT-QSN	6	5 km
2	Benha-Mit Ghamr	BNH-MTG	11	5 km
3	Benha-Quesna	BNH-QSN	111	5 km
4	Kanter Khairia-Bagur	KNK-BGR	115	5 km

3 Field Measurements

For development of suitable methodology, large number of variables such as traffic intensity, pavement composition (four types of subgrade) and road geometrics etc. are required to be incorporated. Four test sections were selected for detailed study during the present study. The final selection was done on the basis of the analysis of deflection data and desirability of having representative test sections for various types of Pavement compositions for long term performance evaluations.

3.1 Deflection Measurements

Structural capacities of flexible pavements can be determined from surface deflection measurements. The most important environmental factor affecting surface deflections of flexible pavements is the temperature of the asphaltic layers (Kim et al. 1995; Shao et al. 1997; Park et al. 2002). All deflection data need to be adjusted to a constant temperature (Chen et al. 2000). BELLS3 and Watson et al. (2004) methods have been used to calculate mid-depth pavement temperature. AASHTO and Chen et al. (2000) approaches have been used to correct pavement deflection to a standard temperature of 30 °C.

The deflection of a pavement surface was measured using the Benkelman beam under vehicle wheels moving at creep speeds (approximately 2 mph). The Benkelman Beam consists of a simple lever arm 3.66 m long supported by 3 legs and pivoted at a distance of 2.44 m from the top (Fig. 1).

The tip of measuring arm was placed between the dual tires of a truck. As the truck moved at the creep speed, the device recorded the rebound deflection of the pavement

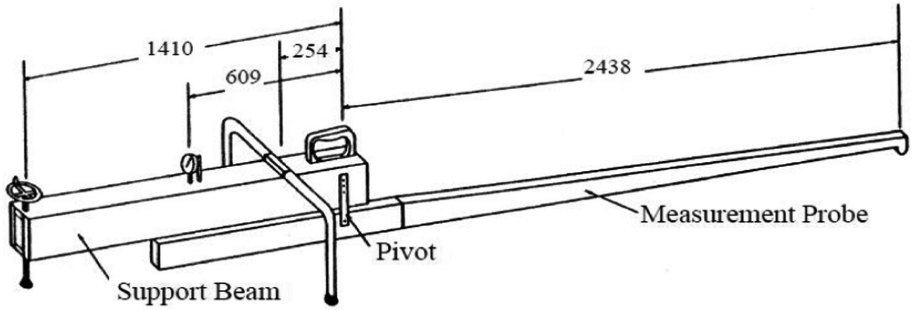

Fig. 1. A Schematic of the Benkelman Beam (all Dimensions in mms).

surface. By suitably placing the probe between the dual wheels of a loaded truck, it is possible to measure the rebound deflection of the pavement structure. While the rebound deflection is related to pavement performance, the residual deflection may be due to non-recoverable deflection of the pavement or because of the influence of the deflection bowl on the front legs of the beam.

The permanent deflection observation points (PDOP) have been established on each road section and marked with paint along 0.90 m from either edge of the lane. Eleven points of the subject road were marked at equal distance of 20 m in each kilometer (to be tested) of the road sub section in both directions, in a homogenous section of about 200 m of the kilometer. Figure 2 illustrates the deflection measurement pavement sub section. Twenty series of deflection measurements were conducted in the present research program. The first series started at January 2005 and the measurements were repeated every three months.

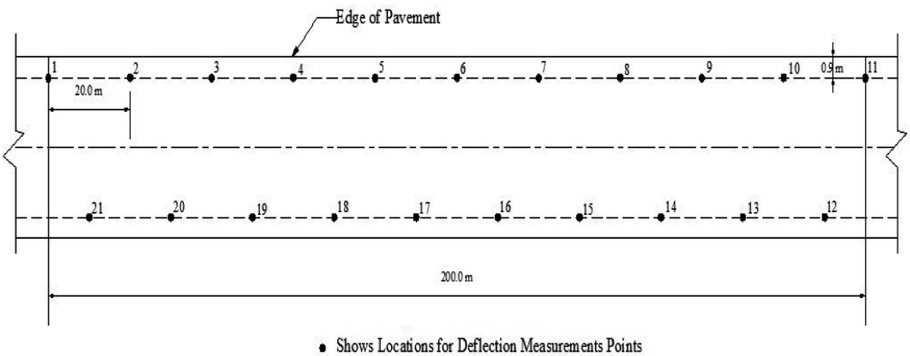

Fig. 2. Deflection observation points for a sub section length of 200 m at 20 m intervals

3.1.1 Determination of Characteristic Deflection

Overlay design for a given section is based not on individual deflection values but on a statistical analysis of all the measurements in the section, corrected for temperature and seasonal variation. This involves calculation of mean deflection, standard deviation and characteristic deflection as given below.

$$\text{Mean deflection}\,\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \quad (1)$$

$$\text{Standard deviation, } \sigma = \frac{\sqrt{(x - \bar{x}}}{n - 1} \quad (2)$$

Characteristic deflection is given by

$$D_c = \bar{x} + \sigma, \text{ for all other roads}$$

Where, x = individual deflection values (mm)
$\bar{x}$ = mean deflection (mm)
n = number of deflection measurements
σ = standard deviation (mm), and
D_c = characteristic deflection (mm)

Temperature Correction Factor
The stiffness of bituminous layers changes with temperature of the binder and consequently the surface deflections of a given pavement will vary depending upon the temperature of the layers. For the purpose of design, it is necessary that the measured temperature be corrected to a common standard temperature. The standard temperature for Egyptian conditions in plain areas is recommended as 30 °C.

Moisture Correction Factor
Since the pavement deflection is dependent upon the change in the climatic season of the year, it is always desirable to take deflection measurements during the season when the pavement is in its weakest condition (i.e. just after the rainy season) when the subgrade moisture condition is maximum or near saturation. When deflections are measured during other periods of the year, they require a correction factor, which is defined as the ratio of the maximum deflection immediately after rain season to that of the minimum deflection in the dry months. The moisture correction factor is estimated using the values of Plasticity Index and moisture content of the subgrade soil.

Corrected Values of Characteristic Deflection
The ideal time of Benkelman Beam deflection studies is after the rain season. Since the deflection measurements were made in several months of the year, the characteristic deflection was corrected for temperature and moisture as explained above.

3.2 Measurement of Roughness

In order to address specifics of roughness measurement, or issues of accuracy, it is necessary to firstly define the roughness scale. In the interest of encouraging use of a common roughness measure in all significant projects throughout the world, an International Roughness Index (IRI) has been selected. The IRI is so-named because it was a product of the International Road Roughness Experiment (IRRE), conducted by research teams from Brazil, England, France, the United States, and Belgium for the purpose of identifying such an index. The IRRE was held in Brasilia, Brazil in 1982 (Sayers et al. 1986) and involved the controlled measurement of road roughness for a number of roads under a variety of conditions and by a variety of instruments and methods. The roughness scale selected as the IRI was the one that best satisfied the criteria of being time-stable, transportable, and relevant, while also being readily measurable by all practitioners.

Pavement roughness is an important characteristic monitored by many road agencies. It is used as an indicator of road performance and also for feasibility studies. Road roughness is a characteristic of a road surface that is experienced by the operator and passengers of any vehicle travelling over that pavement surface. Surface roughness is a function of the road surface profile and certain parameters of the vehicle including tires, suspension, body mounts, etc. as well as sensibilities of the passenger to acceleration and speed. All of these factors affect the phenomenon of roughness. The road roughness shows the distortion of the pavement surface which contributes to an undesirable or an uncomfortable ride.

3.2.1 Roughness Measurement Methodology

The riding quality (roughness) measurement was carried out using a vehicle mounted bump integrator (VMBI), which records the cumulative vertical displacement of the rear axle relative to the body of the vehicle, while the vehicle is in motion.

The Vehicle Mounted Bump Integrator (VMBI) is a device of the Road Measurement Data Acquisition System (ROMDAS) which is a response-type road roughness meter (RTRRM) mounted in a vehicle to monitor pavement unevenness. It records the vertical displacement of the vehicle chassis relative to the rear axle per unit distance travelled, usually in terms of counts/km or m/km. Since each vehicle responds differently to unevenness due to its own unique springs and shocks, as these changes over time with wear and tear, it is necessary to calibrate each vehicle against a standard unevenness-measuring device. It is also necessary to follow prescribed principles in conducting the measurement to ensure the validity and accuracy of the results. For the present research program, the Roughness was measured using Vehicle Mounted Bump Integrator linked to ROMDAS software controlled by the operator from a laptop computer in the measurement vehicle.

3.3 Rut Depth Measurement

Rutting is a surface depression in the wheel paths caused by inelastic or plastic deformations in any or all of the pavement layers and subgrade. The plastic deformations are typically the result of: (1) densification or one-dimensional compression and consolidation and (2) lateral movements or plastic flow of materials (HMA, aggregate base, and subgrade soils) from wheel loads. The more severe premature distortions or rutting failures are related to lateral flow and/or inadequate shear strength any pavement layer, rather than one-dimensional densification.

Ruts are permanent deformations of the pavement structure. They are an important indicator of the structural integrity of the pavement as well as having an impact on road user safety. A rut is a surface depression in the wheel paths. Pavement uplift may occur along the sides of the rut. However, in many instance ruts are noticeable only after the rains have occurred and the wheel paths are affected by the storage of water. Development of rutting from the permanent deformation in any of the pavement layers or subgrade, usually caused by consolidation or lateral movement of the materials due to traffic loads. Rutting may be caused by elastic movement in the mix in hot weather or inadequate compaction during construction. Significant rutting can lead to major structural failure of flexible pavements.

3.3.1 Procedure

Rut depth in a pavement section is a permanent deformation along the wheel path and it indicates the poor camber profile. The rut depth has been measured in mm by placing a 2.0 m straight edge across the pavement at each PDOP. The above data has been collected as per the procedure shown in Fig. 3 and has been recorded in this chapter.

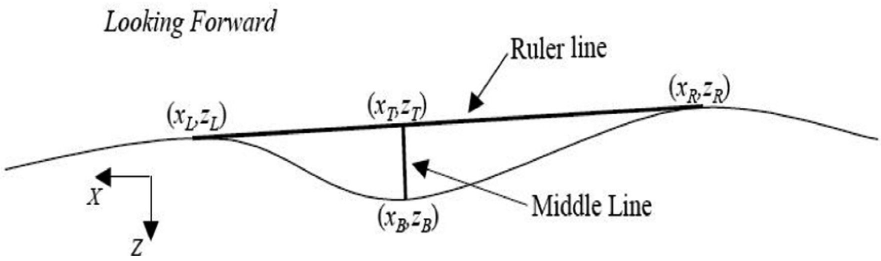

Fig. 3. Rut exteraction description

The rut analysis can be performed in after all the road profile data have been gathered. The rut depth/width is computed according to ASTM 1703 standard (see Fig. 3).

According to this figure, rut depth and rut width are given by:

$$\text{Depth} = \text{sqrt}\left\{(X_B - X_T)^2 - (Z_B - Z_T)^2\right\}$$

$$\text{Width} = \text{sqrt}\left\{(X_R - X_L)^2 - (Z_R - Z_L)^2\right\}$$

3.4 Measurement of Cracks and Cracking Pattern

Cracking is measured in square meters of surface area. The major difficulty in measuring is that two or three levels of severity often exist within one distressed area. If these portions can be easily distinguished from each other, they should be measured and recorded separately. However, if the different levels of severity cannot be divided easily, the entire area should be rated at the highest severity present. If rutting occurs in the same area, it is recorded separately as its respective severity level.

Cracks are caused by the fatigue failure of the bituminous wearing surface under repeated traffic loading. The cracking initiates at the bottom of the asphalt surface where tensile stress and strength is highest under a wheel load. The cracks propagate on the surface initially as one or more longitudinal parallel cracks. After repeated traffic loading the cracks connect, forming many sided, sharp angled pieces that develop a pattern resembling the skin of an alligator. Alligator cracking occurs only in areas which are subjected to repeated traffic loading. Therefore, it would not occur over an entire area unless it is subjected to traffic loading. Cracking is measured in square meters of surface area.

Typical Cracking Pattern for Traffic Loaded Pavements

3.4.1 Procedure

The crack length have been measured in an area of 1.0 sq.m (1.0 m $\times$ 1.0 m) with the PDOP as the center of this square after classifying the cracks into the following three classes:

i. Fine cracks for width less than 3.0 mm
ii. Medium cracks of width 3.0 to 6.0 mm
iii. Wide cracks of width greater than 6.0 mm

Cracking is generally regarded as a structural failure, though it greatly affects the riding quality of a pavement which tells us about its functional condition.

3.4.2 Studies for Traffic Volume Counts and Axle Loads

3.4.2.1 Traffic Volume Count Studies

The traffic characteristics are determined in terms of the number of repetitions of an 18.000 Ib (80 kilonewtons (kN)) single-axle loads applied to the pavement on two sets of dual tires. This is usually referred to as the Equivalent Single Axle Load (ESAL). The total ESAL applied on the highway during its design period can be determined only after the design period and the traffic growth factors are known.

The traffic volume data were collected for 24 h. Directional classified volume count was recorded on working day. The volume count stations were fixed by the General Authority for Roads, Bridges and Land Transport (GARBLT) at least 100 m away from an intersection and close to the overlaid test sections.

3.4.2.2 Axle Load Data

As per Asphalt Institute, the traffic characteristics are determined in terms of the number of repetitions of an 18,000 Ib (80 kilonewtons (kN)) single-axle load applied to the pavement on two sets of dual tires. This is usually referred to as the Equivalent Single Axle Load (EASL). The dual tires are represented as two circular plates, each 4.51 in. radius. spaced 13.57 in. apart. This representation corresponds to a contact pressure of 70 Ib/in. The use of an 18,000-Ib axle load is based on the results of experiments that have shown that the effect of any load on the performance of a pavement can be represented in terms of the number of single applications of an 18,000 Ib single axle. Axle load based pavement design methods should be followed for all important roads. The traffic on the roads in developing countries mostly consists of trucks and buses which are normally overloaded. The damaging power of any load with reference to a standard load increment increases approximately by a power of 4. Thus, if the damaging power of an 8 ton single axle truck is 1, the damaging power of a 16 ton single axle load increases to 16 (Kathmandu 1999). By the same way with increasing axle load the surface deflection also will increase.

For highways the maximum legal axle load as specified by the ECP is 8170 kg, with a maximum equivalent single axle load of 4085 kg. The California Bearing Ratio (CBR) method has been modified by the ECP considering the cumulative number of standard axle load repetitions instead of number of commercial vehicles per day. The equivalent single axle loads have been calculated using the following from and from the basic traffic count obtained from the General Authority for Roads, Bridges and Land Transport (GARBLT) traffic count stations on the selected test roads.

3.4.3 Overlay Life Prediction Models

The model has been developed using the field data collected from all the test sections. The following equation is used for developing the general model utilizing the data of test sections located in the Nile Delta.

$$\textbf{\textit{Life of overlay}}\ (\textbf{\textit{months}}) = \boldsymbol{a_o} + \boldsymbol{a_1}(\boldsymbol{Dc}) + \boldsymbol{a_2}(\boldsymbol{RDI}) + \boldsymbol{a_3}(\boldsymbol{V}) + \boldsymbol{a_4}(\boldsymbol{CI}) + \boldsymbol{a_5}(\boldsymbol{RI})$$

The characteristic deflection ($Dc = X + \sigma$) is found out by measuring the deflection at defined points by Benkelman beam deflection method. The mean deflection (X) and the standard deviation (σ) is calculated from the measured deflection at defined points. The details of the commercial vehicles per day [V] have been obtained from the traffic count survey.

The following overlay life prediction models have been developed.

3.4.3.1 General Model to Predict Life of Overlays

(a) **General Model**

The following general model has been developed utilizing the data of all the test section located in the region of Nile Delta.

Life of overlay (months) = −16.0 + 0.233 Dc + 0.586 RDI + 30.9 ESAL + 1.05 CI + 0.00203 RI

Predictor	Coef.	SE Coef.	T	P
Constant	−16.005	2.483	−6.45	0.000
Dc	0.2333	0.1243	1.88	0.082
RDI	0.5864	0.4158	1.461	0.180
ESAL	30.874	1.667	18.52	0.000
CI	1.0466	0.2926	3.58	0.003
RI	0.002029	0.001233	1.64	0.122

S = 0.0841626 R-Sq = 95.6% R-Sq(adj) = 94.7%

(i) **Model for Benha-Quesna Test section**

Life of overlay (months) = −12.8 + 0.206 Dc + 1.43 RDI + 19.3 ESAL + 0.361 CI + 0.00178 RI

Predictor	Coef.	SE Coef.	T	P
Constant	−12.7797	0.5646	−22.64	0.000
Dc	0.2062	0.1644	1.25	0.230
RDI	1.4264	0.7776	1.83	0.088
ESAL	19.346	1.046	18.50	0.000
CI	0.3609	0.2190	1.65	0.122
RI	0.0017767	0.0005981	2.97	0.010

S = 0.142319 R-Sq = 96.1% R-Sq(adj) = 95.3%

(ii) **Model for Benha-Mit Ghamr Test section**

Life of overlay (months) = −25.4 + 0.438 Dc + 0.911 RDI + 29.5 ESAL + 0.902 CI + 0.00627 RI

Predictor	Coef.	SE Coef.	T	P
Constant	−25.393	8.289	−3.06	0.008
Dc	0.4376	0.3253	1.35	0.100
RDI	0.9105	0.4314	2.11	0.053
ESAL	29.521	6.088	4.85	0.000
CI	0.9019	0.4267	2.11	0.053
RI	0.006266	0.003747	1.67	0.117

S = 0.141967 R-Sq = 93.2% R-Sq(adj) = 92.1%

(iii) **Model for Tanta-Quesna Test section**

Life of overlay (months) = −39.6 + 0.342 Dc + 0.403 RDI + 15.6 ESAL + 0.597 CI + 0.0105 RI

Predictor	Coef.	SE Coef.	T	P
Constant	−39.633	9.587	−4.13	0.001
Dc	0.3423	0.2364	1.45	0.170
RDI	0.4026	0.2341	1.72	0.107
ESAL	15.579	3.715	4.19	0.001
CI	0.5972	0.2525	2.36	0.033
RI	0.010484	0.003732	2.81	0.014

S = 0.116810 R-Sq = 96.8% R-Sq(adj) = 95.3%

(iv) **Model for Kanater Khyriya Bagour Test section**

Life of overlay (months) = −24.9 + 0.134 Dc + 0.461 RDI + 90.0 ESAL + 0.889 CI + 0.00522 RI

Predictor	Coef.	SE Coef.	T	P
Constant	−24.949	4.432	−5.63	0.000
Dc	0.13404	0.08608	1.56	0.142
RDI	0.4613	0.3464	1.33	0.204
ESAL	90.021	7.033	12.80	0.000
CI	0.88860	0.09996	8.89	0.000
RI	0.005222	0.001685	3.10	0.008

S = 0.0861060 R-Sq = 94.3% R-Sq(adj) = 93.1%

Interpretation of Model to Predict Life of Overlays

As it can be seen through previous Models, the probability of error P is least in most models for equivalent single axle load and that means that the ESALs are the most correlated thing with the age of the overlay, the next is crack index and sometimes roughness index while rut depth index and characteristic deflection is next in correlation with the age of overlay.

From the analysis of variance we can see that we took most of the factors that affect the age of pavement and this is seen through the large value of R-Sq and R-Sq(adj).

It should be reported that for all test sections the program made the analysis of variance which classifies all of the independent variables according to their influence on the dependant variable (age of overlay) and this was characterstic deflection (DC) then rut depth index (RDI), then equivalent single axle load (EASL), then crack index and finally roughness index.

3.4.3.2 General Model to Predict Roughness Index

General Model

Following type of model to predict roughness in terms of characteristic deflection (Dc), rut depth index (RDI), and crack index (CI) has been developed.
RI = 1962 + 37.5 Dc + 535 RDI − 132 CI

Predictor	Coef.	SE Coef.	T	P
Constant	1961.77	54.24	36.17	0.000
Dc	37.54	52.95	0.71	0.489
RDI	534.73	87.31	6.12	0.000
CI	−131.67	77.04	−1.71	0.107

S = 36.5121 R-Sq = 92.7% R-Sq(adj) = 91.8%

(i) **Model for Benha-Quesna Test section**

RI = 872 + 121 Dc + 705 RDI − 144 CI

Predictor	Coef.	SE Coef.	T	P
Constant	871.78	83.75	10.41	0.000
Dc	121.30	64.84	1.87	0.080
RDI	705.13	83.24	8.47	0.000
CI	−144.14	70.75	−2.04	0.059

S = 63.0326 R-Sq = 93.7% R-Sq(adj) = 92.6%

(ii) **Model for Benha-Mit Ghamr Test section**

RI = 1963 + 203 Dc − 31 RDI + 286 CI

Predictor	Coef.	SE Coef.	T	P
Constant	1962.88	47.11	41.67	0.000
Dc	203.3	106.0	1.92	0.073
RDI	−31.0	155.1	0.20	0.844
CI	285.8	130.8	2.19	0.044

S = 51.3467 R-Sq = 94.5% R-Sq(adj) = 93.4%

(iii) **Model for Tanta-Quesna Test section**

RI = 2163 + 225 Dc + 167 RDI + 99 CI

Predictor	Coef.	SE Coef.	T	P
Constant	2163.3	137.6	15.72	0.000
Dc	225.5	107.9	2.09	0.053
RDI	167.3	123.8	1.35	0.195
CI	99.5	131.0	0.76	0.459

S = 68.6483 R-Sq = 95.1% R-Sq(adj) = 94.9%

(iv) **Model for Kanater Khyriya Bagour Test section**

RI = 2493 − 11.9 Dc + 350 RDI + 28.9 CI

Predictor	Coef.	SE Coef.	T	P
Constant	2493.24	28.48	87.53	0.000
Dc	−11.90	22.81	−0.52	0.609
RDI	350.44	21.22	16.52	0.000
CI	28.91	16.64	1.74	0.102

S = 23.2210 R-Sq = 96.9% R-Sq(adj) = 95.9%

Interpretation of Model to Predict Roughness Index

As can be observed from previous Models, the probability of error P is least in most models for rut depth index and that means that the RDI is the most correlated distress with the roughness index, and that is practically obvious not only statistically cause when ruts increase the overlay surface will increase in roughness, the next is crack index and sometimes characteristic deflection is next in correlation with roughness.

From the analysis of variance we can see that we took many of the factors that affect the roughness and this is seen through the large value of R-Sq and R-Sq(adj).

And in all test sections the program made the analysis of variance which categorizes all of the independent variables according to their influence on the dependant variable (roughness) and this was characteristic deflection (DC) then rut depth index (RDI), and finally crack index.

3.4.3.3 Model of Correlation Between EASLs and Roughness

General Model

Following type of model to predict roughness in terms of Equivalent Single Axle load has been developed using all the data obtained from field measurements.

RI = 2158 + 1766 ESAL

Predictor	Coef.	SE Coef.	T	P
Constant	2157.79	19.59	110.13	0.000
ESAL	1766.40	19.84	89.02	0.000

S = 35.9972 R-Sq = 94.8% R-Sq(adj) = 94.3%

(i) Model for Benha-Quesna Test section

RI = 1027 + 1513 ESAL

Predictor	Coef.	SE Coef.	T	P
Constant	1027.07	55.58	18.48	0.000
ESAL	1513.09	35.95	42.09	0.000

S = 102.111 R-Sq = 95.0% R-Sq(adj) = 94.9%

(ii) Model for Benha-Mit Ghamr Test section

RI = 2250 + 1909 ESAL

Predictor	Coef.	SE Coef.	T	P
Constant	2249.91	7.43	302.92	0.000
ESAL	1908.77	9.31	205.12	0.000

S = 13.6464 R-Sq = 96.5% R-Sq(adj) = 95.9%

(iii) Model for Tanta-Quesna Test section

RI = 2671 + 1215 ESAL

Predictor	Coef.	SE Coef.	T	P
Constant	2670.99	9.11	293.28	0.000
ESAL	1215.30	7.02	173.18	0.000

S = 16.7333 R-Sq = 96.9% R-Sq(adj) = 96.4%

(iv) Model for Kanater Khyriya Bagour Test section

RI = 2683 + 4995 ESAL

Predictor	Coef.	SE Coef.	T	P
Constant	2683.19	12.26	218.93	0.000
ESAL	4994.95	39.84	125.37	0.000

S = 22.5180 R-Sq = 95.9% R-Sq(adj) = 95.3%

Interpretation of Model to Predict Roughness Index

As can be observed from previous Models, the probability of error P is almost zero in most models and that means that the correlation between roughness index and EASLs is very strong.

3.4.3.4 Estimation of Remaining Service Life Using Prediction Models

Remaining service life (RSL) has been defined as the anticipated number of years that a pavement will be functionally and structurally acceptable with only routine maintenance. The present thesis aimed to use the life prediction models to calculate the remaining service life of a pavement. The following prediction models have been developed in terms of pavement distresses.

General Model
Life of overlay (months) = −56.9 + 0.064 Dc + 4.17 RDI − 3.02 CI + 0.0222 RI

Predictor	Coef.	SE Coef.	T	P
Constant	−56.882	5.550	−10.25	0.000
Dc	0.0636	0.6048	0.11	0.918
RDI	4.171	1.796	2.32	0.035
CI	−3.0244	0.9423	−3.21	0.006
RI	0.02226	0.002812	7.90	0.000

S = 0.410674 R-Sq = 94.3% R-Sq(adj) = 92.9%

(i) **Model for Benha-Quesna Test section**

Life of overlay (months) = −9.04 − 0.346 Dc + 13.3 RDI − 1.97 CI − 0.00188 RI

Predictor	Coef.	SE Coef.	T	P
Constant	−9.042	2.569	−3.52	0.003
Dc	−0.3462	0.7876	−0.44	0.666
RDI	13.284	2.145	6.19	0.000
CI	−1.9671	0.8735	−2.25	0.040
RI	−0.0019	0.00275	−0.68	0.505

S = 0.693466 R-Sq = 96.9% R-Sq(adj) = 95.8%

(ii) **Model for Benha-Mit Ghamr Test section**

Life of overlay (months) = −65.0 + 0.707 RDI + 0.365 CI + 0.0241 RI + 0.491 Dc

Predictor	Coef.	SE Coef.	T	P
Constant	−65.039	2.155	−30.17	0.000
Dc	0.4906	0.5141	0.95	0.355
RDI	0.7071	0.6790	1.04	0.314
CI	0.3653	0.6516	0.56	0.583
RI	0.024122	0.001093	22.07	0.000

S = 0.224508 R-Sq = 97.1.0% R-Sq(adj) = 96.7%

(iii) **Model for Tanta-Quesna Test section**

Life of overlay (months) = −79.6 − 0.135 Dc + 0.096 RDI + 0.131 CI + 0.0260 RI

Predictor	Coef.	SE Coef.	T	P
Constant	−79.636	1.378	−57.79	0.000
Dc	−0.1355	0.3005	−0.45	0.659
RDI	0.0961	0.3227	0.30	0.770
CI	0.1315	0.3291	0.40	0.695
RI	0.0260324	0.0006173	42.17	0.000

S = 0.169501 R-Sq = 94.7% R-Sq(adj) = 93.8%

(iv) **Model for Kanater Khyriya Bagour Test section**

Life of overlay (months) = −73.3 + 0.283 Dc + 1.63 RDI − 0.058 CI + 0.0232 RI

Predictor	Coef.	SE Coef.	T	P
Constant	−73.331	7.966	−9.21	0.000
Dc	0.2832	0.2937	0.96	0.350
RDI	1.627	1.151	1.41	0.178
CI	−0.0576	0.2316	−0.25	0.807
RI	0.023227	0.003192	7.28	0.000

S = 0.296466 R-Sq = 100.0% R-Sq(adj) = 100.0%

With respect to the developed models to predict life of overlay in months in terms of the pavement distresses, the remaining service life of an existing overlay can be estimated. Since, the constants are known in each developed equation as well as the values of each distress as they are determined from field measurement, the current life or age of overlay in terms of distresses can be determined. Then, if the current life is subtracted from the design life we can get the remaining service life.

In view of the advantages of the adopted tool, it is a simple technique for estimation of the remaining service life of an overlay. Since, it takes into account the existing actual conditions of the pavement which may be named as the structural life of the pavement. In terms of time, the life here means the actual time spent since the first openings of the road for traffic after constructions. If the design assumptions are completely valid, both lives will be compatible. However, in actual practice traffic growth is more than expectations and hence the structural life will be more than the time life. For clarification, if design life of a pavement was 10 years, but deterioration takes place after 5 years i., e before that time. This means that the total design traffic passage used that pavement within 5 years not as expected by the designer within 10 years.

Oppositely, for its limitations it is an empirical model. Also, it assumes that the rate of cracks propagation is constant while this rate should not be so. As the cracks initiated and with more traffic passage over such cracked area, the rate of deterioration is accelerated. Furthermore, the developed models through such technique are based upon only four roads which in turn means low data points for regression. The investigated roads were monitored for five years with regular measurements every 3 months. These models can be easily modified if a data base created through the General Authority for Roads, Bridges and Land Transport (GARBLT),. Once, the actual service life determined, the remaining service life can be easily determined. This can be helpful for optimization the maintenance works in the whole Egyptian roads network.

3.4.3.5 Significance of Variable Distresses in the Life Prediction Model

Each distress has a certain effect on the design life of overlay. In order to find out the most significant distress on the overlay design life, a number of plots have been drawn for each test section representing the relationship between the design life of overlay. These plots were tried with constant values of all distresses except the distress type under consideration.

As can be seen from Figs. 4 and 5 and the statistical model, rutting was found to be the basic parameter affecting design life of overlay. It has the most significant influence as rutting constant in the prediction model is the largest in most of the developed models, so if rutting increases the total life of the pavement increases greatly. The next significant distress is pavement characterstic deflection. It influences the life prediction model in general model, Beha Quesna, Benha Mit Ghamr, and Kanater El-Khayria El-Bagur test sections.

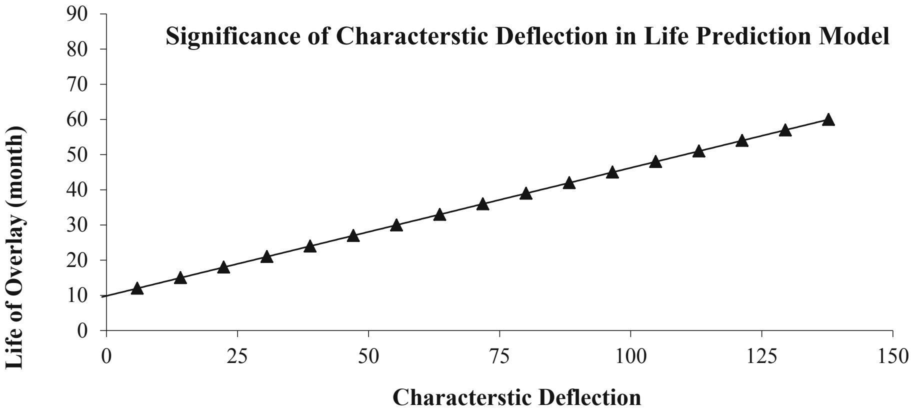

Fig. 4. Significance of Characteristic Deflection in life prediction Model

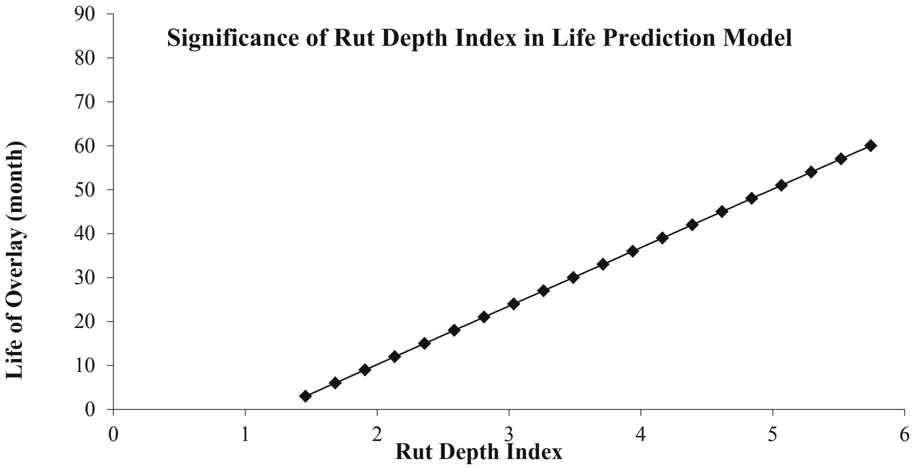

Fig. 5. Significance of Rut Depth Index in life prediction Model

4 Conclusions

1. Rutting was found to be the basic parameter affecting design life of overlay. It has the most significant influence as if rutting increases the total life of the pavement increases.
2. Rutting data can be used to report about pavement condition at network level. It can be used to select the optimum maintenance and rehabilitation option to improve the existing functional characteristics.
3. Remaining service life of an existing pavement can be easily estimated as the actual service life determined by the developed life prediction models.

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