Journal of Japan Society of Civil Engineers, Ser.
E1 (Pavement Engineering), Vol. 72, No. 2, 54-62, 2016.

STUDY ON PRE-MATURE FAILURE OF FLEXIBLE PAVEMENT STRUCTURES IN DEVELOPING COUNTRIES

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In this study, the damaging influence of excessive axle loading, tire inflation pressure and seasonal variation in climatic condition on the performance of flexible pavement in developing countries was analyzed by using the data from Pakistan as a case study. The Mechanistic-Empirical (M-E) design framework; based on GAMES (General Analysis of Multi-layered Elastic Systems) has been used for the analysis. Results were presented in terms of Relative Damage Factors (RDFs). Based on the analysis of results it was found that the performance of flexible pavements is sensitive to not only axle loading but also significantly to tire inflation pressure; a phenomenon common to many developing countries. The damaging influence of increase in tire pressure keeps on magnifying with each axle load increment. The Design RDF for the legal axle load (118 kN) and the mean observed axle load (145 kN) on single axle with dual tires; with mean observed tire pressure of 896 kPa, was noted to be 5.80 and 11.95, respectively. Consideration of climate regime in the design affects the economy of pavement design. The damage factors derived in this study can be readily used for network level pavement management.

Key Words : *excessive axle load, tire inflation pressure, mechanistic-empirical, GAMES, relative damage factor*

1. INTRODUCTION

A good road transport system is absolutely crucial to the economic as well as social uplift of developing nations. Road transport not only plays a pivotal role in cost effective transportation of freight and passengers, it provide equal opportunities of access to jobs and trade to all segments of society, thus promoting national cohesion and alleviation of poverty, which are the issues faced by almost all the developing nations around the world. Realizing the importance of road transport, a major portion of the national income of such countries is spent on construction and maintenance of roads[1)]. However, in many developing countries the economic and social benefits of an efficient road transport system are negated due to accelerated deterioration and premature pavement failure. Some of the primary causes of premature failure can be attributed to excessive axle loading and over inflation of truck tires coupled with inappropriate design inputs, including climatic consideration, in mostly empirical pavement design methods adopted by these countries.

This study attempts to capture the damaging influence of excessive axle loads, tire inflation pressure and seasonal variation in climatic condition on the performance of flexible pavements, using the data from Pakistan as a case study. The M-E design framework has been used for this purpose. The primary objective is to suggest reasonable values for design inputs for rational design of flexible pavement structures in developing countries.

Road transportation network in Pakistan is not only the lifeline for the country's own economic and social development, it is also an integral part of the greater Asia road network and thus open up enormous prospects for trade, cultural exchange and peace in the entire region. Pakistan's road transport system caters to around 92 percent and 96 percent of nationwide passenger and freight traffic, respectively[2)]. The road network comprises of 259,618 kilometers (kms.), including 179,290 kms. of paved and 80,323 kms. of unpaved roads. An increase of 13 percent in road length has occurred in the last decade alone[3)]. Out of the total road network about 11500 kms. are termed as National Highways and are being administered by an independent federal road agency, the National Highway Authority (NHA). These roads comprise only around 4 percent of Pakistan's total road network however, they carry more than 80 percent of the country's gross commercial traffic. Therefore the analysis parameters in this study primarily relates to the National Highway system of Pakistan.

In one of the latest study[4)] the traffic volume on the country's busiest 1800 kms intercity road from the port city of Karachi in the south to Peshawar in the north-west, bordering Afghanistan and on to the central Asian republics [historically known as grand trunk (GT) road] was found to be ranging between 7000 – 23000 vehicles per day with an annual growth rate of around 4 %. Composition of cars, buses and trucks was found to be 37 %, 24 % and 39 %, respectively. The truck classification study in Pakistan indicated that 2-axle trucks (with single rear axle on dual tires assembly) dominate the truck types with a share of about 70 % in the entire truck fleet in the country[5)].

In recent years the newly constructed as well as rehabilitated pavements have shown accelerated deterioration and premature failure causing not only waste of public money but also safety hazard and inconvenience to the road users. The recent road condition survey conducted by NHA[2)] reveals that more than 60 % of the network exhibit pavement surface cracking, including more than 23 % high severity cracks (crack opening > 10 mm). The survey also indicates that more than 30 % of the network has developed permanent deformation (rutting) of various magnitudes. The Remaining Service Life (RSL) data indicate that nearly 46 % of the entire network has RSL of not more than 2 years. Some of the reasons for this alarming situation are thought to be excessive axle loading, over inflation of truck tires and the use of purely empirical methods for the pavement design, not adapted to the local geo-environmental and loading conditions.

In order to check and prevent pre-mature failures, the Government of Pakistan has fixed a legal limit of 118 kN on a single axle with dual tires. A limit of 828 kPa tire inflation pressure has also been fixed accordingly. However, it has been observed in various studies that even these upper limits beyond the standard axle load of 80 kN and 551 kPa tire pressure are rarely being followed[4)-6)]. These studies reveal that in practice the load on this axle ranges from 98 kN to as high as 195 kN. In one of the recent study the mean axle load has been observed to be 145 kN[4)]. Similarly, the mean tire inflation pressure has been observed to be 896 kPa[6)].

Like many other developing countries, in Pakistan the American Association of State Highway and Transportation Official (AASHTO) design guide is being followed for design of new and rehabilitated flexible pavements structures. The AASHTO design equation estimates pavement life in terms of the numbers of equivalent standard axle loads (80 kN on single axle with dual tires)[7)]. The AASHTO design method is based on the empirical analysis of data from an accelerated pavement test (AASHO Road Test) conducted in Ottawa, Illinois during the late 1950s[8)]. Since the said test was conducted in a specific geo-environment with limited loading conditions and local material properties, the design equation may not produce reliable results when either the load (traffic & environment) or the materials are changed from those used in the pavement test. However, with the enormous research and development in the last few decades towards the Mechanistic-Empirical (M-E) pavement design systems with better pavement material characterization, response analysis and damage prediction models, it is now possible to investigate not only the impact of changing loading conditions but also changing the materials and environment can also be investigated with much precision and greater reliability[9)-12)].

2. RESEARCH APPROACH

Damage impact analysis due to increasing axle load, tire inflation pressure and seasonal variation in ambient temperature on pavement structure, typically constructed by NHA for the traffic conditions corresponding to National Highways with 10 years design life, has been conducted using the M-E design framework in this study.

In the M-E approach flexible pavements are modeled as layered elastic systems with infinite lateral dimensions, resting on an elastic subgrade layer of infinite depth. Elastic theory implies that each of the pavement layers and the subgrade can be described by their corresponding elastic modulus "E" and Poisson's ratio "μ". Each layer is assumed to be homogeneous and isotropic. Tire loads are commonly assumed as circular loads of uniformly distributed vertical stress, equal to tire inflation pressure. The radius of the circular load is given by the following equation[11]:

$$a = \sqrt{p/(i\pi)} \qquad (1)$$

where a is contact radius in meter (m), p is the vertical load in kN and i is the tire inflation pressure in kN/m^2.

Critical pavement responses e.g., stress, strains and deflections are calculated using theory of elasticity. Analyzing these responses is the mechanistic element of the M-E design system. The empirical component of M-E design constitute relating these critical responses to observable and measurable pavement distresses e.g. pavement surface cracking, permanent deformation or rutting, roughness etc., using distress functions calibrated to local conditions. The analysis parameters employed in this study are discussed in more detail here bellow.

(1) Pavement response model

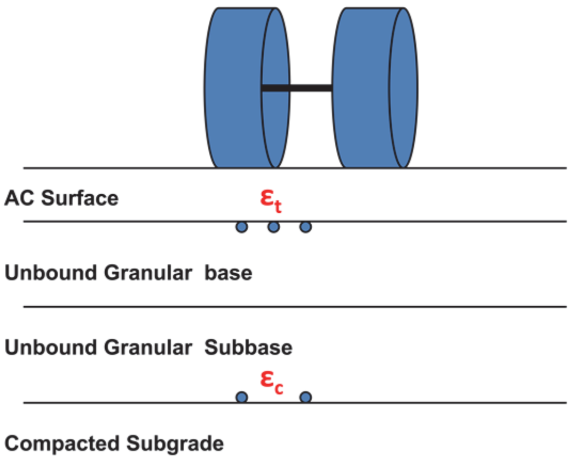
A recently developed analysis tool, for layered elastic system to assist in M-E design of pavement structures in Japan has been used for this study. The tool named as General Analysis of Multi-layered Elastic System (GAMES) provide an excellent combination of analysis features and computation speed for linear elastic layer system and has been found to produce comparable results with a range of other analysis softwares which are used worldwide[13),14)]. The graphical presentation of results makes it rather more user friendly[15)].

Critical responses analyzed in this study were horizontal tensile strain (ε_t) at the bottom of the asphalt concrete layer and vertical compressive strain (ε_c) at the top of the subgrade layer as shown in **Fig.1**. These responses were computed for various loading conditions using GAMES. Strains at each point (dots) in the figure were computed and the maximum strain responses were later used as inputs in the distress models, also known as transfer functions for damage analysis.

(2) Pavement distress models

Number of load repetition to failure (N_f) due to maximum ε_t corresponding to fatigue fracture or bottom up cracking failure and ε_c corresponding to permanent deformation or rutting failure were computed for a range of loading conditions, using the distress functions proposed by Japan Road Association (JRA). The JRA distress models are basically modified and calibrated version of Asphalt Institute (AI) models[10)]. Many different versions of (AI) models were extensively used in the past for the pavement performance studies. However, capitalizing on the recent advancement in the field of flexible pavement engineering in Japan, the current models suggested by JRA have been used for this study. The JRA distress model for asphalt concrete (AC) fatigue life also considers the AC mix properties and layer thickness thus producing realistic results. Prior to using the models for extensive study, they were initially tested for the standard loading conditions with the material and climatic conditions of Pakistan and the results were found to be comparable to earlier studies[12)]. Moreover, the overall results shown in the later part of this paper were also found to be in conformity with the actual pavement deterioration trends in Pakistan as highlighted in the introduction above, which suggest that the models are generally fit to be used for the Pakistani conditions.

In the M-E design system proposed by JRA, a pavement section is considered to be failed when either 20% of lane area is cracked and/or the pavement structure exhibit 15 mm of rut depth[10), 17)].



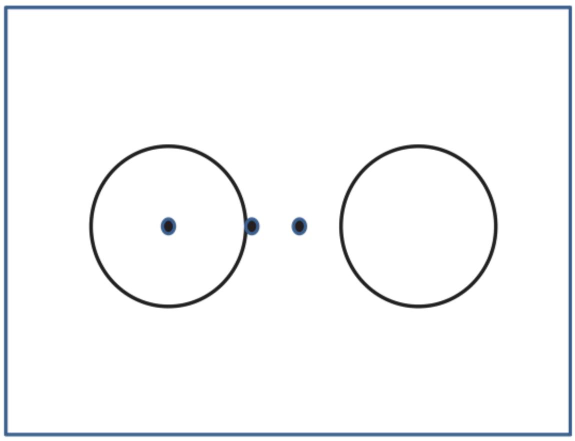


Fig.1 Locations of critical strains under one wheel (with dual tires) of a single axle.

Table 1 Pavement layer properties.

Layer	Thickness (cm)	Modulus (MPa)	Poisson Ratio
AC Surface	5	225 – 6850 (depending on pavement temperature)	0.35
AC Base	10		0.35
Granular Base	25	193	0.40
Granular Sub Base	35	117	0.40
Subgrade	-	72	0.45

The model to predict the allowable number of load repetition to fatigue cracking (N_{ff}) is a function of tensile strain (ε_t) and asphalt concrete mix stiffness (modulus) "E" and is presented here bellow:

$$N_{ff} = \beta a1 \cdot C \cdot 6.617 \cdot 10^{-5} \cdot \left(\frac{1}{\varepsilon_t}\right)^{3.291 \cdot \beta a2} \left(\frac{1}{E}\right)^{0.854 \cdot \beta a3} \quad (2)$$

where, $$C = 10^M \quad (3)$$

$$M = 4.84\left[\frac{VFA}{100} - 0.69\right] \quad (4)$$

where, VFA is volume of voids filled with asphalt binder (%).

A typical VFA value of 73 %, as suggested by NHA General Specifications 1998 has been used in this analysis[18].
$\beta a1$, $\beta a2$, $\beta a3$ are calibration constants.

$$\beta a1 = Ka \cdot \beta a1' \quad (5)$$

Ka is a correction coefficient for asphalt concrete layer thicknesses (h_{ac}) and is expressed as:

$$Ka \frac{1}{8.27 \times 10^{-0.11} + 7.83 \cdot e^{-0.11(h_{ac})}} \quad (6)$$

The values of $\beta a1'$, $\beta a2$, $\beta a3$ are given as 5.229×10^4, 1.344 and 3.018, respectively.

The model to predict the allowable number of load repetition to permanent deformation or rutting (N_{fd}) is a function of vertical compressive strain (ε_c) at the top of the subgrade and is expressed as:

Table 2 load and tire pressure conditions.

Analysis Conditions	Range
Axle load	58 kN – 176 kN
Tire inflation pressure	551 kPa – 965 kPa

$$N_{fd} = \beta s1 \cdot \left(1.365 \times 10^{-9} \cdot \varepsilon_c^{-4.477 \cdot \beta s2}\right) \quad (7)$$

Where, $\beta s1$, $\beta s2$, are calibration constants, their values are 2.134×10^4 and 0.819, respectively.

(3) Pavement layer properties

Table 1 shows the properties of each layer, assumed for this analysis. The pavement section represents typical design thicknesses and material properties utilized in Pakistan for the National Highway design traffic of about 25 million Equivalent Standard Axle Loads (ESALs) over a design life of 10 years, in accordance with AASHTO pavement design method. The elastic moduli of pavement materials have been worked out from the typical California Bearing Ratio (CBR) test values, which is the common test being performed in the laboratories as well as in the field extensively in Pakistan. The correlations proposed by AASHTO design guide have been used for this purpose.

(4) Axle load and tire inflation pressure

The primary focus of this study was to assess the damaging impact of legal axle load and the observed excess axle load, as highlighted in section 2 above. However, in order to make this study more useful for pavement designers and road administration agencies for rational and economical design of flexible pavements, the analysis variables were enhanced to include a wide range of load and tire pressures as shown in **Table 2**.

Table 3 AC stiffness (moduli) corresponding to mean monthly temperatures in Pakistan.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean Monthly air Temp(^{o}C)	10	13	17	23	28	31	30	29	27	23	12	10
Mean Monthly Pavement Temp(^{o}C)	15	18	22	29	35	38	37	36	34	29	17	15
Modulus of AC Layer (MPa)	6850	5290	3560	1450	480	225	300	380	660	1450	5790	6850

(5) Seasonal variations in climate

One of the major advantages of the M-E design approach is the consideration of climatic condition directly into the design process. The interaction of climatic factors with pavement materials significantly affects the performance of flexible pavements. Particularly, the sensitivity of asphalt concrete mix stiffness (modulus) to temperature variations has been well recognized[9), 12)]. Mean monthly air temperatures data, derived from the 60 years' (1931-1990) historical climate data of Pakistan; established in a recent study [19)], has been used in this analysis. The mean monthly pavement temperatures were obtained using the following relation which was originally presented by AI and also adopted by JRA[12), 17)]:

$$M_p = M_a\left[1+\frac{2.54}{z+10.16}\right]-\left[\frac{25.4}{9(z+10.16)}\right]+\frac{10}{3} \qquad (8)$$

where,

M_p: Mean monthly Pavement Temperature (^{o}C)

M_a: Mean monthly air Temperature (^{o}C)

z : Depth below the surface (cm).

The temperature at the upper third point of the AC base layer has been used in this analysis[12)].

A number of AC temperature-stiffness (moduli) correlation are available in literature[20)-22)]. For this study the stiffness values were worked out using the correlation established by Scott Wilson pavement engineering, Nottingham, UK[20)]. **Table 3** shows the mean monthly air and mean monthly pavement temperatures and their corresponding AC moduli.

3. ANALYSIS OF RESULTS

The impacts of variation in axle loading, tire inflation pressure and climate analyzed in this study have been presented in terms of Relative Damage Factors (RDFs). RDF can be expressed as the damage caused to a pavement structure by a set of input conditions (i.e. axle loading, tire inflation pressure, material properties and climate) relative to the damage produced by standard conditions. In this case the standard load and tire pressure was assumed to be the same as suggested by AASHTO guide (i.e. 80 kN load on single axle with a set of dual tires, inflated to 551 kPa each).

The RDFs corresponding to fatigue cracking and permanent deformation or rutting can be expressed as:

$$\mathrm{RDF}_f = \frac{N_{ffs}}{N_{ffi}} \qquad (9)$$

and,

$$\mathrm{RDF}_d = \frac{N_{fds}}{N_{fdi}} \qquad (10)$$

where, RDF_f : Relative damage factor for fatigue cracking, RDF_d : Relative damage factor for rutting. N_{ffs} and N_{fds} are number of repetition for fatigue cracking and rutting under standard axle loading conditions, respectively. N_{ffi} and N_{fdi} are allowable numbers of repetition for fatigue cracking and rutting under any arbitrary loading conditions, respectively. The RDF resulting in larger value among the two is selected as Design RDF.

(1) Effect of axle load and tire inflation pressure

The results show that the performance of flexible pavement is sensitive to not only axle load but also to tire inflation pressure as presented in **Figs. 2** to **4**. **Fig.2** shows the effect of increasing axle loading and tire inflation pressure (Tp) on asphalt concrete (AC) fatigue life with mean monthly pavement temperature (M.M.T). It was observed that the RDF_f 's for axle loads between 60 – 90 kN, under all Tp range remained under 2.5. However, the RDF_f sharply increases beyond the 90 kN axle loads.

This figure also shows that for any fixed axle load, increasing the Tp resulted in increased RDF_f s. This

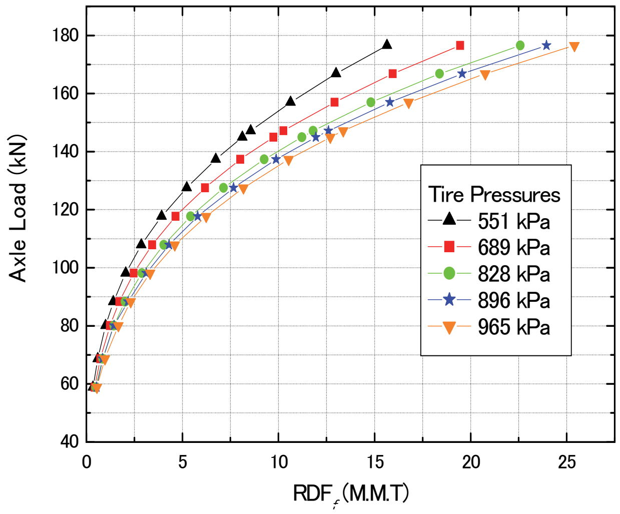


Fig.2 Relative damage factors for fatigue failure (RDF$_f$).

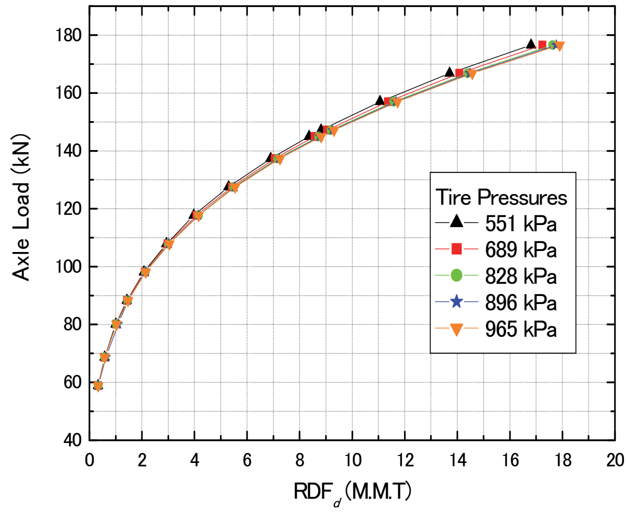


Fig.3 Relative damage factors for rutting failure (RDF$_d$).

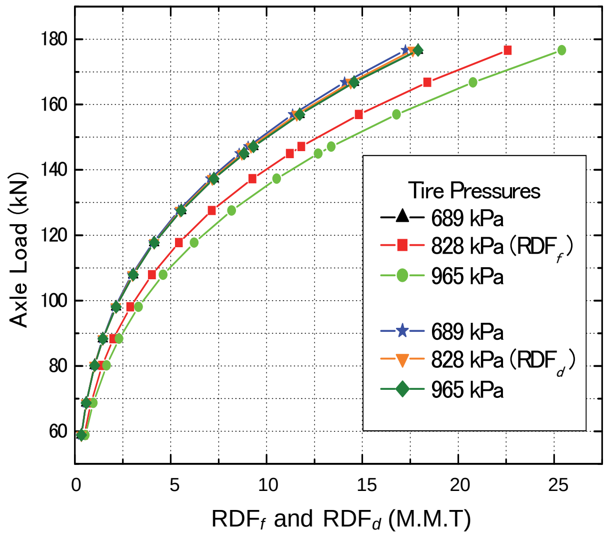


Fig.4 Comparison of RDF$_{(f\,\&\,d)}$ at three identical tire pressures.

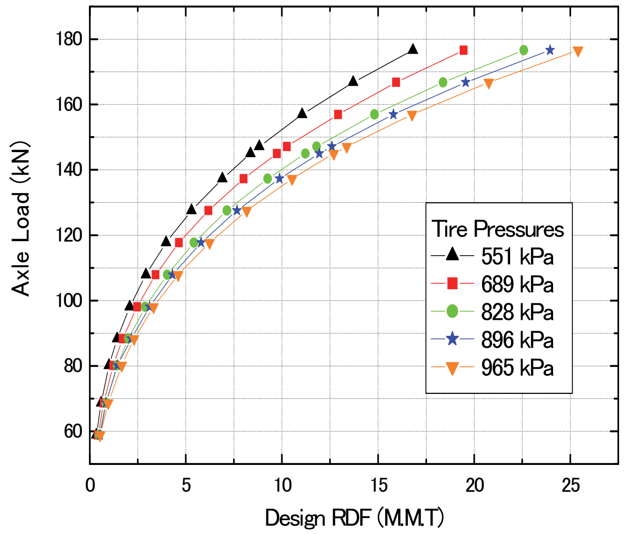


Fig.5 Representative design RDFs for all loads and Tp ranges.

shows that fatigue performance is highly sensitive to Tp. The phenomenon can be observed even at the standard axle load (80 kN), where the RDF$_f$ increases from 1.0 to 1.66. However, the damaging impact widens for higher axle loads, e.g. at the legal axle load (118 kN) and the observed axle load (145 kN) the RDF$_f$ increases by 2.3 and 4.6 points, respectively (for Tp ranging from 551 kPa – 965 kPa).

Fig.3 shows that while the Tp increase has minimal effect on rutting performance, the axle load increase has significant effect. This figure also indicates that for the axle load ranging between 60 – 98 kN, the RDF$_d$ remained around 2.0. However, it keeps on increasing until a maximum value of 17.0 at the axle load of 176 kN. The difference in RDF$_d$'s for each individual load increment remained under 1.0 for all Tp's, which substantiate the observation that Tp has minimal impact on the rutting performance. A comparison of RDF$_f$'s and RDF$_d$'s at three identical Tps is presented in **Fig.4**. This figure reveals that the impact of increased Tp is more damaging to flexible pavement fatigue performance compared to rutting performance.

Fig.5 shows the Design RDFs for all loads and Tp ranges. The Design RDFs reveal that pavement performance in Pakistan is more sensitive to fatigue failure compared to rutting failure. This result, rather substantiate the actual in-service condition of pavements in Pakistan, as revealed by the pavement condition surveys conducted by NHA observed in section 1, above. **Fig.6** summarizes the effect of axle load and Tp on the design life of the pavement structure. The expected pavement life for each axle load increment is calculated as:

$$\text{Expected Pavement life} = \frac{\text{Design Life (Years)}}{\text{Design RDF}} \quad (11)$$

The design life in this study was assumed to be 10

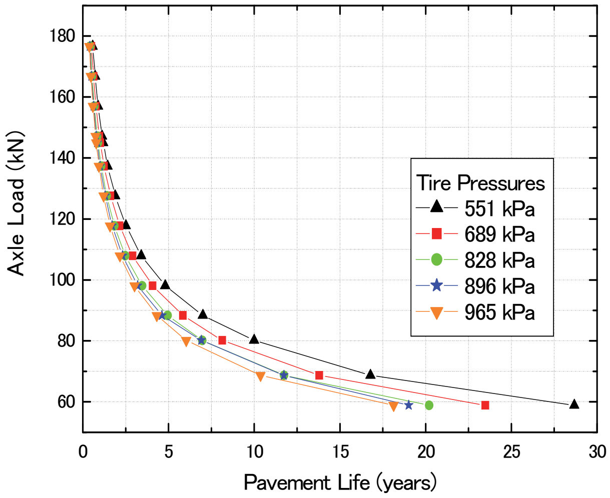


Fig.6 Effect of axle load and tire pressure on design life.

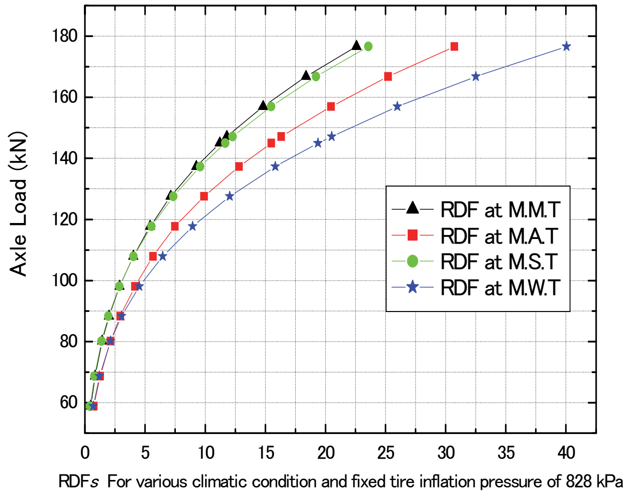


Fig.7 Effect of climate on pavement performance.

years. The effect on pavement life expectancy due to tire pressure can be observed even at the standard axle load of 80 kN, where the pavement life drops from 10 to 6 years when the Tp was increased from 551 kPa – 965 kPa. At the legal and observed axle loads, the pavement life may be expected to be between 1.5 to 3 years and between 0.8 to 1.2 years, respectively; depending on Tp.

(2) Climatic consideration

Fig.7 shows the sensitivity of flexible pavement performance to climatic considerations. This figure shows the effects on Design RDFs due to changes in pavement temperature regime. The results show that the RDFs are much conservative when the mean monthly pavement temperatures (M.M.T) and corresponding layer properties are considered in the design. Conversely, the results could be misleading when a single annual temperature (e.g. mean annual temperature (M.A.T)) is selected for the design purpose; as in the case of purely empirical design methods, resulting into overdesign and hence unnecessary waste of public money.

Fig.7 also shows the damaging impact of the two extreme seasons i.e. summer and winter, analyzed in this study by considering mean summer monthly temperature (M.S.T) and mean winter monthly temperature (M.W.T), respectively. It shows that the damage impact is much more during the winter season compared to summer. This is however, now understandable in light of the observation noted in section **3.(1)** above, that the pavement performance in Pakistan is governed by the AC fatigue failure. In the winter months, the combined effect of increased AC stiffness (making it brittle) and the repeated application of excessive axle loading coupled with increased Tp enhance its susceptibility to damage, resulting in to increased surface cracking. Conversely, during the summer months, damage phenomenon shifts to rutting failure and all the rutting occurs during this season. It was also observed that the MST curve runs very close to M.M.T curve (which was earlier shown to be representing the AC fatigue failure as a general failure mode in Pakistan, refer **Fig.5**). This shows that while the pavements in Pakistan are generally susceptible to AC fatigue failure, they are also potentially exposed to rutting failure (during summer) due to excessive axle loading.

(3) Design RDFs

Fig.8 presents the suggested RDF curve for the representative climatic conditions (M.M.T) and the legally allowed tire pressure in Pakistan, arrived at as a result of this study.

Fig.9 shows the damage ratio (*Dr*) for each axle load corresponding to the suggested RDF. Dr is defined as the damage caused by a single application of load[12]. These curves can be readily used with confidence for the network level pavement management purposes, when the detail axle load data is not available or is cost intensive.

(4) Practical implications

As mentioned in the introduction, currently many developing countries including Pakistan are using the AASHTO design guide for design of flexible pavements. The empirical relationships suggested in the guide for estimating the expected traffic in terms of ESALs is based on the AASHO road test conducted about 50 years ago in a specific geo-environment with limited loading conditions and fixed tire pressure of 551 kPa. The relationship is expressed as:

$$ESAL = \sum_{i=1}^{m} F_i n_i \tag{12}$$

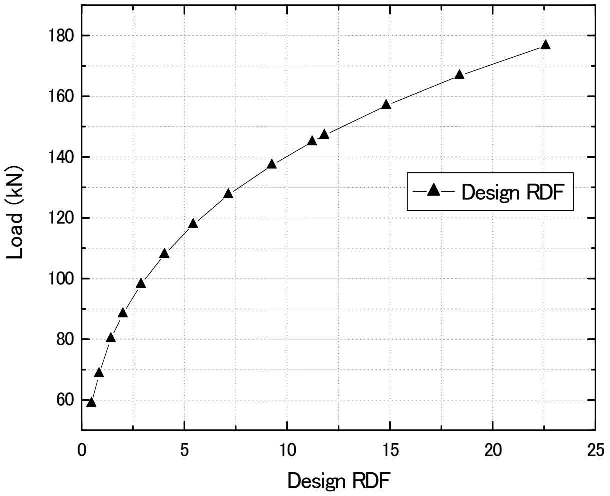


Fig.8 Suggested RDFs (Tp-828 kPa and MMT).

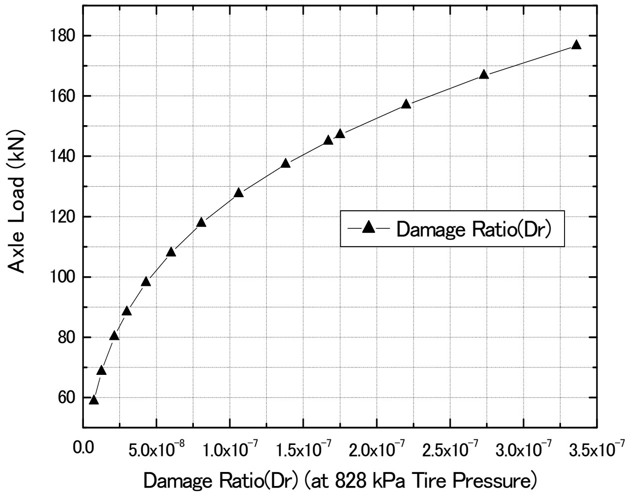


Fig.9 Damage ratios (Tp-828 kPa and MMT).

Table 4 Comparison of RDFs with AASHTO load factors.

Load (kN)	AASHTO Range (SN:5, Pt:2.5 & Tp 551 kPa)	RDF at Tp 551 kPa	RDF at Tp 689 kPa	RDF at Tp 828 kPa (***Allowed***)	RDF at Tp 896 kPa	RDF at Tp 965 kPa (***Observed***)
58.86	0.26	0.35	0.43	0.49	0.53	0.79
68.67	0.48	0.60	0.72	0.85	0.85	1.37
80.11	1.00	1.00	1.23	1.43	1.44	2.31
88.29	1.51	1.43	1.71	2.01	2.16	3.20
98.10	2.18	2.08	2.46	2.89	3.12	4.55
107.91	3.03	2.93	3.43	4.03	4.31	6.17
117.72	4.09	3.97	4.64	5.43	5.80	8.12
127.53	5.39	5.30	6.17	7.14	7.66	10.58
137.34	6.97	6.90	8.01	9.26	9.88	13.71
147.15	9.98	8.82	10.26	11.81	12.60	17.48
156.96	12.50	11.06	12.92	14.82	15.80	21.92
166.77	15.50	13.71	15.95	18.39	19.56	27.03
176.58	20.41	16.81	19.45	22.58	23.95	32.99

Where, m is the number of axle load groups, F_i is equivalent load factor (Design RDF in this study) for the i^{th} axle load group, and n_i is the number of passes of the i^{th} axle load group during the design period duly estimated from traffic count surveys with adequate growth factor.

The equivalent load factors derived in the said test are still being used without the consideration of the current axle loading, tire pressure, climatic conditions, geomaterials and subgrade soils much different from those encountered in the road test. Since the load factors, which are identified in this study as RDFs are based on representative conditions and are derived using the rational M-E design approach, these factors will result into economical and reliable pavement structures.

These factors can be used even with the current empirical design methods, until the economies of the developing countries in general and Pakistan in particular permit to invest in more sophisticated and cost intensive data accumulation and analysis techniques related to traffic; for example using axle load spectra instead of ESALs, developing enhanced integrated climatic models and improved laboratory characterization of geomaterials etc. A comparison of the damage factors derived in this study and those estimated using AASHTO equations is shown in **Table 4**. It can be noted that using the AASHTO factors (which is the general case in Pakistan) for estimating the expected numbers of ESALs will result in an under designed pavement structure susceptible to premature failure when exposed to actual in-service conditions explained earlier. The highlighted rows from top to bottom in the table show comparative factors under standard, legal and observed axle loads in Pakistan, respectively.

4. CONCLUSIONS

In this study, the damaging influence of excessive axle loading, tire inflation pressure and seasonal variation in climatic condition on the performance of flexible pavement was analyzed; using the M-E design framework. Results were presented in terms of Relative Damage Factors (RDF). Conclusions drawn from this study may be summarized as follows:

1) The Mechanistic-Empirical (M-E) Pavement design approach, realistically capture the variations in all variables that influence the pavement performance, resulting in rational pavement design.
2) The performance of flexible pavement is sensitive to not only axle loading but also significantly to tire inflation pressure. The damaging influence of increase in tire pressure keeps on magnifying with each axle load increment.
3) The Design RDF for the legal axle load (118 kN) and the mean observed axle load (145kN) on single axle with dual tires; with mean observed tire pressure of 896 kPa, was noted to be 5.80 and 11.95, respectively.
4) Consideration of climate regime in the design affects the economy of pavement design. Considering a single value for air/pavement temperature, e.g. mean annual temperature or extreme temperature condition, may result in extravagant pavement design.
5) The damage factors derived in this study can be readily used for network level pavement management when the detail axle load data is time and/or cost intensive.

ACKNOWLEDGEMENTS: The authors respectfully acknowledge the guidance of Professor Kunihito Matsui in the understanding and appropriate usage of GAMES software for this study.

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(Received March 25, 2011)