Technical Paper

ISSN 1997-1400 Int. J. Pavement Res. Technol. 6(4):269-273

Are Fatigue and Rutting Distress Modes Related?

Ripunjoy Gogoi[1], Animesh Das[1+], and Partha Chakroborty[1]

Abstract: Fatigue (due to traffic repetitions) and rutting are the two distinct modes of failures in asphalt pavements. These two distresses are generally considered separately in pavement design, reliability studies and distress prediction models. It is interesting to study whether occurrence of fatigue cracking and rutting are related to each other; that is, whether a significant level of rutting is expected on a pavement which also shows significant level of fatigue cracking and vice versa. Given that mechanisms of progression of fatigue and rutting are quite complex, the present paper explores the LTPP (Long Term Pavement Performance) database to seek an answer to this question from phenomenological standpoint. A total of 97 data-points have been chosen from 59 LTPP sections with varied levels of fatigue and rutting distresses. The LTPP sections those have not undergone any maintenance or rehabilitation after construction, till the time are considered in the study. Analysis of results shows that rut depth increases with the increase of fatigue cracking up to a fatigue cracking level of about 5%; after that the extent of rutting almost stabilizes and does not show significant increase with the increase in fatigue cracking.

DOI:10.6135/ijprt.org.tw/2013.6(4).269

Key words*: Distress prediction; Distress propagation; Pavement distresses.*

Introduction

Load fatigue and rutting are the two major modes of structural failures in asphalt pavements. Both the failures are caused due to repetitive applications of traffic loading under the prevailing environmental conditions. Fatigue and rutting failures are generally assumed as two independent modes of distresses in reliability analysis [1-3], in distress prediction models [4-7] and in pavement design [8-15].

As per the mechanistic-empirical pavement design framework, the tensile strain at the bottom of the asphalt layer (ε_t) and the vertical strain on the sub-grade (ε_z) are generally considered as indicators of load fatigue and rutting distresses respectively. Fig. 1 shows a plot between ε_t and ε_z for various hypothetical pavement sections where the layer thicknesses and layer moduli values are assigned arbitrarily. The ε_t and ε_z values are calculated using layered elastic analysis scheme. Fig. 1 shows that for higher values of ε_t, the ε_z value is also high and vice versa. Since ε_t and ε_z indicate the fatigue and rutting lives of a given pavement section respectively, it may be inferred that occurrences of fatigue and rutting are related to each other. That is, there is a possibility that the level of rutting and fatigue observed at different points in time of an asphalt pavement may show some characteristic trend. This has motivated the authors to take up this as a research problem, and to explore whether fatigue cracking and rut depth are truly independent during the process of damage progression.

A number of studies have been undertaken to understand the individual mechanisms of progression of fatigue [4, 16-17] and rutting [18-20] distresses in asphalt pavements. From the current understanding on individual mechanisms of fatigue and rutting, it is

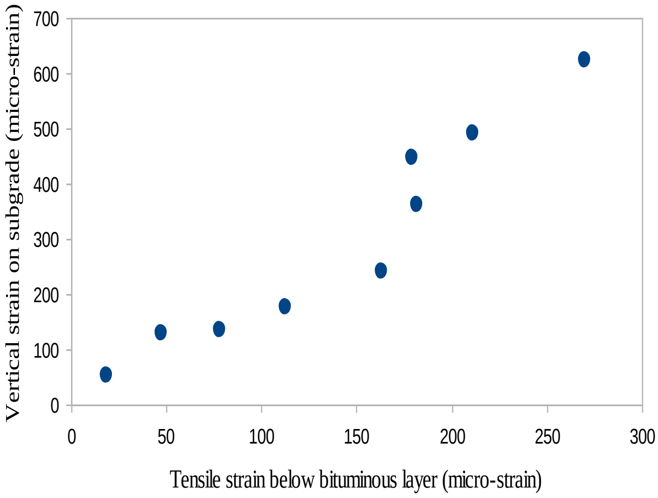


Fig. 1. Vertical Strain on Subgrade Versus Tensile Strain at the Bottom of Bituminous Layer for Hypothetical Pavement Sections.

difficult to assess whether the propagation of two distresses are related to each other. Thus, in the present work, it is decided to study the long term pavement performance database (available from Federal Highway Agency, USA [21]) to find any trend between the extent of fatigue cracking and corresponding level of rutting that may exist.

Approach and Methodology

Long Term Pavement Performance (LTPP) data have been studied in the present work. The sections are so chosen that,

- The information on fatigue and rutting levels are available for the same month of any given year.
- The pavement sections should not have undergone any maintenance activity (such as crack sealing, patching,

[1] Department of Civil Engineering, Indian Institute of Technology Kanpur, Kanpur, Uttar Pradesh, India 208016.

[+] Corresponding Author: E-mail adas@iitk.ac.in
Note: Submitted February 27, 2013; Revised June 5, 2013; Accepted June 6, 2013.

rehabilitation etc) during the period considered in the present study. (If there is any maintenance work on a pavement, this will change the existing levels of fatigue and the rutting. Hence, such data have not been included in the present study.)

A total of 97 data points from 59 test sections are used from LTPP data base [21]on the roads of various US and Canadian States. The data considered is presented in Table 1. In the table the Section codes, State names, State codes, the time at which data were taken

Table 1. The Sections Used in the Study.

State Code	State	Section	Year	Number of Data Points
1	Alabama	4155	3/1993, 7/1995	2
1	Alabama	1001	1/1993	1
1	Alabama	4125	8/1994	1
5	Arkansas	3048	9/1991	1
17	Illinois	A340	3/2001	1
18	Indiana	A 310	11/1990	1
19	Iowa	A 340	11/1990, 10/1992, 9/1993	3
19	Iowa	6150	9/1993	1
20	Kansas	1005	11/1990	1
20	Kansas	1010	11/1990	1
20	Kansas	B 340	4/1993, 4/1995, 3/1997	3
21	Kentucky	A 340	3/1993	1
24	Maryland	1634	5/1992	1
24	Maryland	A 340	5/1992	1
24	Maryland	509	5/1990	1
24	Maryland	504	5/1990	1
24	Maryland	507	5/1990	1
24	Maryland	560	2/1992	1
26	Michigan	C 340	10/1990, 9/1992, 5/1993, 5/1995,	4
26	Michigan	1001	9/1992	1
26	Michigan	B 340	9/1992, 6/1993	2
26	Michigan	1012	9/1992	1
27	Minnesota	B 340	6/1992, 7/1993	2
27	Minnesota	6251	6/1992	1
27	Minnesota	C 340	11/ 1990, 7/1993, 8/1995	3
28	Mississippi	3090	11/1995	1
28	Mississippi	1802	12/1990, 1/1993, 7/1995	3
28	Mississippi	3087	11/1995	1
29	Missouri	1002	5/1992	1
29	Missouri	1005	5/1992	1
29	Missouri	A 340	11/ 1990, 4/ 1991, 5/1992, 5/1993, 7/1995, 3/2000	6
36	New York	B 340	10/1990, 5/1992	2
36	New York	B 350	5/1989	1
36	New York	A 310	5/1990	1
36	New York	A 320	5/1990	1
42	Pennsylvania	B 340	5/1995	1
42	Pennsylvania	1605	5/1992	1
48	Texas	A 340	3/1991, 10/1991, 8/1991, 6/1997 6/1998	5
48	Texas	F 340	12/1992, 7/1994, 7/1995	3
48	Texas	A 320	8/1989	1
48	Texas	M 340	4/1991, 8/1991	2
48	Texas	L 340	6/1997, 10/2001, 7/1999	3
48	Texas	M 330	3/1995	1
48	Texas	H 340	11/1996	1
48	Texas	Q 340	7/1995, 4/1998, 6/1997, 7/1999	4
48	Texas	B 340	7/1999, 6/1998	2
48	Texas	N 340	3/1992	1
48	Texas	N 330	12/1990	1
49	Utah	1008	5/1990	1
51	Virginia	A 320	11/1989	1

Table 1. (Continued)

State Code	State	Section	Year	Number of Data Points
51	Virginia	A 321	11/1989	1
51	Virginia	1423	8/1989	1
53	Washington	1005	6/1989	1
83	Manitoba	A 340	6/1993, 6/1995	2
87	Ontario	B 340	5/1991	1
87	Ontario	A 340	5/1991, 4/1992	2
87	Ontario	1620	4/1992	1
89	Quebec	1021	5/1992	1
89	Quebec	A 340	5/1991, 5/1992	2
90	Saskatchewan	B 340	7/1992	1
90	Saskatchewan	6405	7/1992	1

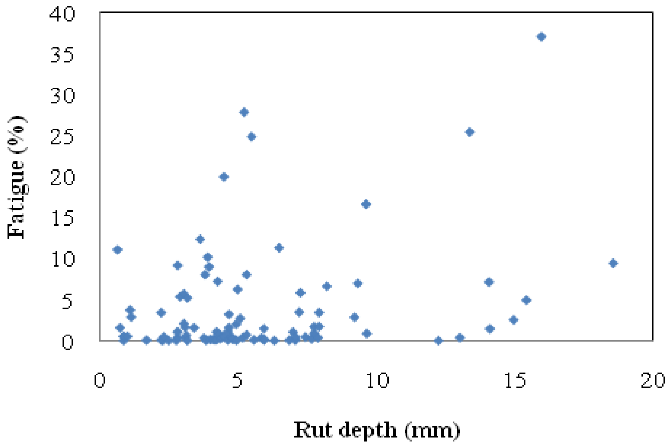


Fig. 2. Fatigue Versus Rut Depth for the 97 Data-points.

and the number of data points available are mentioned.

The total fatigue distress of a pavement is expressed in square meters and rut depth is expressed in millimeters. In LTPP database, the fatigue distress area are categorized as low, medium and high and therefore to find out the total fatigue area, the above mentioned categories are summed up (that is, no relative weightage factor is used for the different types of cracks). Total fatigue cracked area of a pavement section is divided by the area of the section (length of the section × number of lanes × lane width) and is expressed as percentage. Rut depth is calculated by taking the overall average [22, 23] of the right and left wheel rut depth.

The average rut depth of the sections studied varies between 1 mm to 19 mm, whereas percentage fatigue area observed to vary between 1% to 38%. Fig. 2 shows a plot of fatigue and rut depth of all these 97 data points. The plot shows considerable scatter. The scatter may be attributed to various effects such as different layer thicknesses of pavement, environmental effects, different construction practices and so on.

To investigate this issue further, the progression of fatigue and rutting distresses are plotted individually against year. It is observed that the extent of fatigue cracking monotonically increased for the LTPP sections considered in the present study. However, for rutting, similar trend has not been observed for some sections (refer Fig. 3). Thus, it is decided to group the fatigue and rutting data into some data ranges.

Thus, the data is further organized (refer Table 2), where for a given fatigue range, the respective rut depths are obtained. The data are organized in 5 different fatigue categories as 0 to 1 %, 1 to 3 %, 3 to 6 %, and 6 to 10 % and greater than 10 %. The average rut depths for each fatigue category are mentioned in Table 2. The standard deviation (σ) of rut depth (in each category of fatigue cracking) is observed to be varying between 2 mm to 5 mm.

Fig. 4 shows a plot between the mean fatigue and the mean rut depth. Such a representation indicates that the rut depth increases with fatigue cracking. It is further observed that beyond fatigue cracking of around 5%, rut depth does not increase appreciably. The following general logarithmic model (refer Eq. (1)) is proposed as a representation of the trend in Fig. 4.

$$R = a \log_{10} F + b \tag{1}$$

where, F is the percentage fatigue and R is the rut depth. A linear regression method is used to find the parameters a and b of the model in Eq. (1). The estimated regression parameters are found to be a = 0.5653 and b = 5.37. For the 95% confidence interval for a is [0.3077, 0.8229] and for b is [4.915, 5.825]. Table 3 shows the parameters related to the goodness of fit. The Sum of Square of Error (SSE) and the R^2 value imply that the logarithmic fit is good. The adjusted R^2 value and the Root Mean Square Error (RMSE) values are also satisfactory.

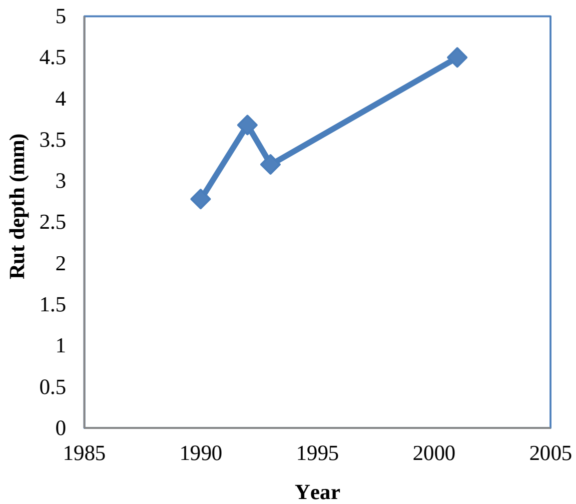
Therefore, the final model is

$$R = 0.5653 \log_{10} F + 5.37 \tag{2}$$

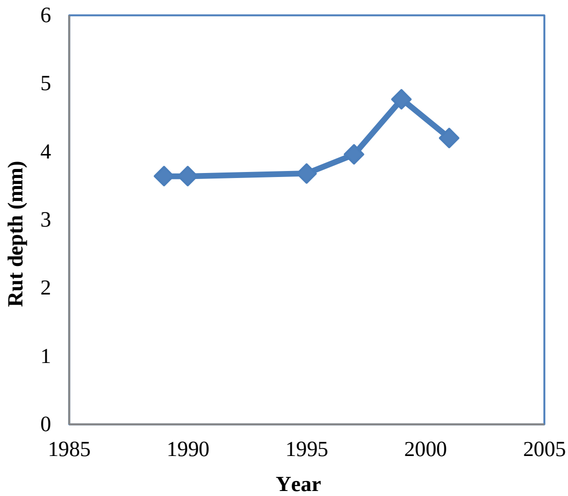
Summary

An attempt has been made, in this paper, to study whether there is any interdependency between the progression of fatigue and rutting distresses in asphalt pavement. The LTPP database has been explored and a total of 97 data-points, where both fatigue and rutting distress data are available from around the same time (that is at least in the same month). These selected sections also have not undergone any maintenance activity after construction.

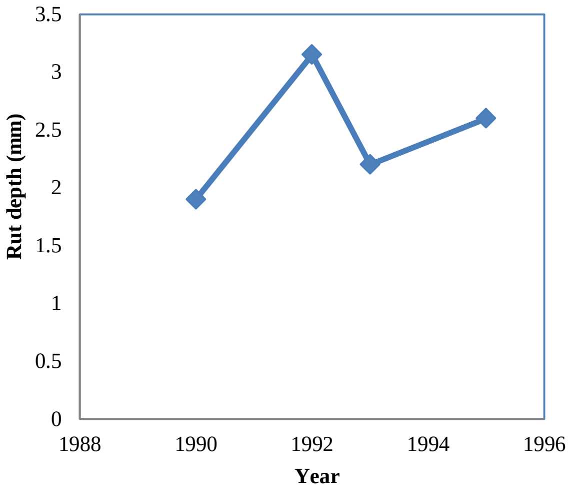
It is observed that, during the initial stages, both fatigue and rutting increases. After the fatigue cracking level reaches about 5%, the progression of rutting does increase appreciably. The entire behaviour has been captured as a logarithmic trend, presented as Eq. (2). It may be pointed out that the proposed regression equation does not establish any cause-and-effect relationship, rather it suggests that progression of fatigue and rutting distresses at



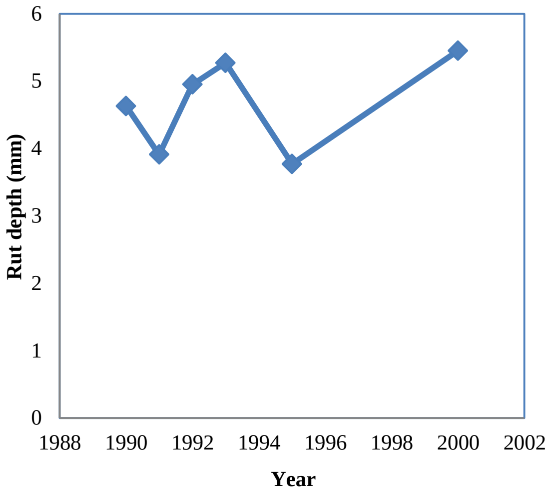
(a) A 340, Illinois section



(b) L 340, Texas section



(c) B 340, Minnesota section



(d) A 340, Missouri section

Fig. 3. Rutting Progression in Various Sections.

Table 2. Mean Rut Depths Corresponding to Fatigue Range.

Fatigue Range (%)	Average Rut Depth (mm)
0 - 1	4.57
1 - 3	5.49
3 - 6	6.38
6 - 10	6.52
> 10	6.85

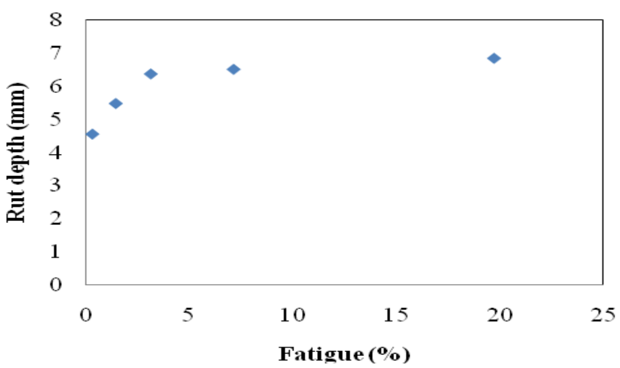


Fig. 4. Fatigue Range Versus Mean Rut Depth.

Table 3. Statistics for the Proposed Relation.

SSE	0.1991
R^2	0.9421
Adjusted R^2	0.9227
RMSE	0.2567

various points in time show some correlation between them, indicating that their mechanisms may be related. This inference is drawn from an empirical study on limited data. Thus, there is a need to investigate further as to whether the mechanisms of fatigue and rutting are related at any stage. Such research may find useful application in pavement design, reliability studies and distress progression models.

References

1. Lytton, R. L., and Zollinger, D. (1993). Modeling reliability in pavement. *Proc., 72nd Annual Meeting, Transportation Research Board*, National Research Council, Washington, DC, USA.

2. Kim, H.B. and Buch, N. (2003). Reliability-based pavement design model accounting for inherent variability of design parameters, *Proc., 82nd Annual Meeting, Transportation Research Board*, National Research Council, Washington, DC, USA.
3. Maji, A. and Das, A., (2008). Reliability considerations of bituminous pavement design by Mechanistic-Empirical approach, *The International Journal of Pavement Engineering*, 9(1), pp.19-31.
4. Baburamani, P. (1999). Asphalt fatigue life prediction models-a literature review, ARRB Transport Research Ltd. ARR 334, National Interest Service Program (NIS), Vermont South, Australia.
5. SHRP: Strategic Highway Research Program (1994). Permanent deformation response of asphalt aggregate mixes, *SHRP-A-415*, Asphalt Research Program, Institute of Transportation Studies, University of California, Berkeley, National Research Council, Washington, DC, USA.
6. Von Quintus, H. L., Mallela, J., Bonaquist, R., Schwartz, C. W., and Carvalho, R. L. (2012). Calibration of rutting models for structural and mix design, *NCHRP Report No. 719*, Transportation Research Board, National Research Council, Washington, DC, USA.
7. White, T. D., Haddock, J. E., Hand, A. J. T., and Fang, H. (2002). Contributions of pavement structural layers to rutting of hot mix asphalt pavements, *NCHRP Report No. 468*, Transportation Research Board, National Research Council, Washington, DC, USA.
8. AASHTO 1993. Guide for design of pavement structure, Washington, DC, USA.
9. Asphalt Institute (AI) (1999). Thickness design—Asphalt pavements for highways and streets, 9th Ed., *Manual Series No.1*, Lexington, KY, USA.
10. Austroads (2004). *Pavement design*, Sydney, Australia.
11. French design manual for pavement structures (1997). Guide Technique, LCPC and SETRA, Union Des Synducates, De L'industrie Routiere, France.
12. Shell International Petroleum Company Limited (1978). Shell pavement design manual—Asphalt pavement and overlays for road traffic, London, UK.
13. Indian Roads Congress (IRC) (2012). Guidelines for the design of flexible pavements, IRC:37-2012, 2nd Revision, New Delhi, India.
14. Theyse, H.L., Beer, M., and Rust, F.C. (1996). Overview of the South African mechanistic pavement design analysis method. *Transportation Research Record*, No. 1539, pp. 6–17.
15. NCHRP: National Cooperative Highway Research Program (2004). Mechanistic empirical design of new and rehabilitated pavement structures. NCHRP Project 1-37A, Washington, DC, USA. (http://onlinepubs.trb.org/onlinepubs/archive/mepdg) (December 2012).
16. SHRP: Strategic Highway Research Program (2004). Fatigue response of asphalt-aggregate mixture. *SHRP A 404*, Asphalt Research Program, Institute of Transportation Studies, University of California, Berkeley., National Research Council, Washington, DC, USA.
17. Harvey, J.T., Deacon, J.A., Tsai, B.W. and Monismith C.L. (1995). Fatigue performance of asphalt concrete mixes and its relationship to asphalt concrete pavement performance in California. *Report No. RTA-65W485-2*, Institute of Transportation Studies, University of California at Berkeley, USA.
18. NCHRP: National Cooperative Highway Research Program (2012). Calibration of Rutting Models for Structural and Mix Design. *NCHRP Report No. 719*, Transportation Research Board of the National Academics, Washington, DC, USA.
19. Dawson, A. and Kolisoja, P. (2004). Permanent deformation, Report on task 2.1, Rodex II Lead partner, The Higland Council, Transport, Environmental and Community Service HQ, Scotland, UK.
20. Uzan, J. (2004). Permanent deformation in flexible pavements, *Journal of Transportation Engineering*, 130(1), pp. 6-13
21. Long Term Pavement Performance (2012). US department of transportation, Federal highway administration, Standard Data Release 26.0. (http://www.ltpp-products.com).
22. Agarwal, P. K., Das, A., and Chakroborty, P. (2006). Simple model for structural evaluation of asphalt concrete pavements at the network level", Journal of Infrastructure Systems, 12(1), pp.41–49.
23. Hoegh, K., Khazanovich, L., and Jensen, M. (2010). Local calibration of mechanistic–empirical pavement design guide rutting model Minnesota road research project test sections, Transportation Research Record: Journal of the Transportation Research Board, No. 2180, Transportation Research Board of the National Academies, Washington, D.C., pp.130–141.