Proceedings of 12th IOE Graduate Conference
Peer Reviewed
ISSN: 2350-8914 (Online), 2350-8906 (Print)
Year: 2022 Month: October Volume: 12

Analysis of Premature Cracks in Asphalt Pavement: A Case study of Kathmandu Ringroad

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Abstract
Many of the roads in Nepal have cracks that have appeared at early stage of its design life of the road. Pavement failures were ultimately caused by these cracks. The majority of developed nations employ the Non Destructive Test(NDT) using Falling Weight Deflectometer (FWD) to measure the elastic pavement surface deflections in conjunction with the back calculation of the pavement layer moduli to assess the structural capacity and effectiveness of the pavement. With an emphasis on the freshly built Kathmandu Ring Road portion, the study's goal is to examine the early cracking patterns seen in the asphalt concrete pavements in Kathmandu. Dynatest FWD was used to record field distress surveys and deflection data, which were then utilized to back calculate layer moduli in the ELMOD6.0 program. Using a simple 2D Finite Element Model in the ELMOD6.0 program, a collection of data from FWD at cracked and uncracked areas of the same pavement structure was utilized to assess stress change. According to the deflection results, FWD testing showed that the surface deflection on the cracked section was slightly greater than on the uncracked Section. The Cement Stabilized Gravel Base's Modulus was significantly lower than the design value, and it was also lower in cracked sections than in uncracked sections. Although the horizontal and shear stress regimes on the pavement are considerably impacted, the vertical stress regime is unaffected by the presence of surface cracks.

Keywords
Premature Cracks, NDT, FWD, Back Calculation, Finite Element Analysis

1. Introduction

1.1 Background

Flexible pavements failure has been prevalent in many parts of the world before their design life. These types of failure associated with reduced structural capacity, increased roughness, reduced surface friction, or any other possible number of unforeseen circumstances that don't satisfy the design performance criteria are called premature failure. Pavement failures are caused by many reasons or a combination of reasons and result from one or more of the following pavement distresses: surface unevenness (corrugation), cracking, rutting, shoving, depression, and edge dropping or breaking. Among these, cracks, which appeared as reflective cracks or in other forms, are common signs of pavement failure and do require frequent repair treatment. Cracks are the most important factor for failure and this study aims to analyze the cracks that are seen at an early age. [1, 2]

In Nepal, many roads have developed cracks prematurely before their design life. These cracks ultimately caused pavement failures. In our nation, measuring elastic pavement surface deflections with non-destructive testing utilizing a Benkelman Beam is the norm for pavement evaluation methodologies. The majority of developed nations employ the Falling Weight Deflectometer (FWD) to measure the elastic pavement surface deflections in conjunction with the back calculation of the pavement layer moduli to assess the structural capacity and effectiveness of the pavement. The performance of the pavement and the impact of the existence of cracking can be examined using the layer moduli back-calculated from the falling weight deflectometer (FWD). Additionally, the effects of cracking on the structural and functional performance of the pavement can be determined using the finite element method. To understand the behavior of cracking in bituminous pavements, a simple 2D FEM model can be utilized to model pavement behavior in 2D space. [3]

1.2 Problem Statement

Early pavement cracking makes it possible for moisture to seep into the pavement structure, shortening the pavement section's design life and significantly raising the cost of the life cycle. Taxpayers take a loss when a road's pavement fails before it reaches the design life of the road and more money is needed to rehabilitate, repair, or completely reconstruct the damaged portion of the road. Investigating and determining the reasons for these early pavement cracks is crucial to stop them from happening again by addressing the causes in future design and construction projects.

1.3 Objectives

The purpose of the research is to analyze the early cracking patterns observed in the asphalt concrete pavements in Kathmandu with a focus on the recently constructed Kathmandu Ring Road section. The specific objectives are:

- To evaluate the performance of the road section based on the deflection measurements from the non-destructive testing (Falling Weight Deflectometer).
- To investigate the effect of cracking on the stress regime developed in the bituminous layer using the finite element (FE) model and by comparing the distribution of stresses in similar cracked and uncracked sections.

2. Literature Review

2.1 Understanding the Pavement Structure

Pavements can be viewed of as multi-course, layered structures made of processed materials. Each material has distinct mechanical characteristics of its own. The vehicle loads are supported by and transmitted to the subgrade below this layered system. It has been stated that for bituminous materials the resilient modulus may be more appropriate than other moduli types in analyzing the FWD deflection bowl using multi-layer elastic programs if the stress regime within the pavement layers is taken under consideration. In addition, the moduli predicted from the dynamic nondestructive testing of pavements are more representative of the in situ resilient moduli of the materials. [4, 5]

The presence of microcracks in an uncracked cement-bound material may be the reason for the layer to behave like material with a modulus as low as 500 MPa. Furthermore, weakly-cemented layers tend to crack quite rapidly. This can occur even under construction traffic. Thus, with time the material behaves as a granular material. [6]

2.2 Falling Weight Deflectometer (FWD) and Back Calculation

Modern methods for assessing the structural strength of existing pavements are based on the examination of a pavement's deflected shape under a non-destructive device using a program designed for this purpose. Different NDT devices were tested to assess the relative performance of field-testing apparatus, and it was found that they all tend to produce similar deflection basins. But they claimed that the FWD is the most dependable tool for layer moduli back computation. When a load is applied to the surface of pavement the consequent vertical stress regime and deflection basin may be considered. [4, 7]

In this study, the Falling Weight Deflectometer machine from Dynatest is used for loading and ELMOD6.0 Software from Dynatest is used for the Back calculation of Moduli of Layers as shown in Figure 3. Using ELMOD we can analyze much information regarding pavement like deflections caused by load, Pavement Structure, Moduli of Layers, Remaining Life of pavement, and Overlay design. In ELMOD6.0 we can back-calculate the moduli in three different methods namely: [8]

- Linear Elastic Theory
- Method of Equivalent Thickness
- Finite Element Method

In a recent study, the causes of cracks on a recently built flexible pavement in Kenya were investigated using the Falling Weight Deflectometer and several lab experiments. The study's findings indicated that several variables contributed to the development of cracks, including the following: the sub-grade does not adequately support the pavement because of its high base and sub-base strengths; the varying strengths of the pavement layers and the collapse of some cores during the soaking process indicate instances of inadequacy; and the variance in the strength. [2]

The Research for Oregon Department of Transportation and Federal Highway Administration by R. Christopher Williams, Iowa State University in 2015 studied the behavior of Premature Cracking in Asphalt Concrete Pavement and gives numerous conclusions: [9]

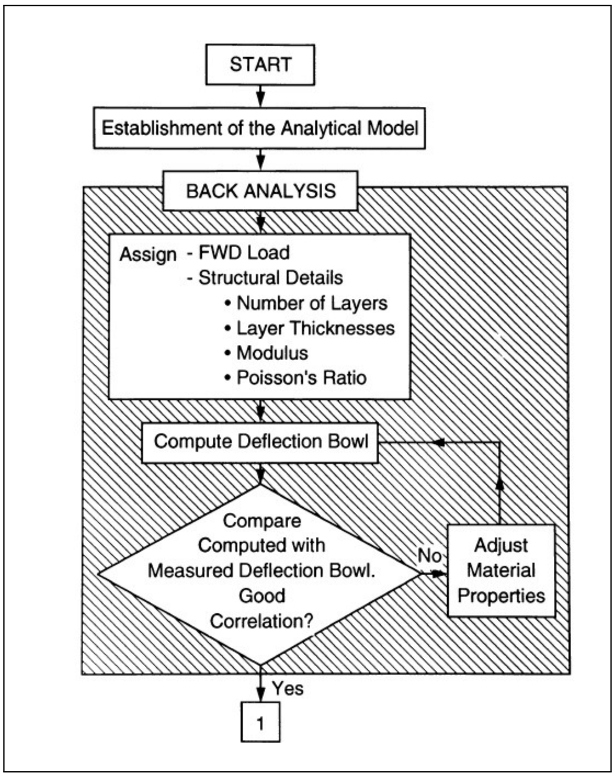

Figure 1: Typical Back Calculation Process

- Most of the premature cracks were top-down/surface-initiated cracks. FWD tests indicated that top-down cracked pavements were structurally sound, even some of the sections with top-down cracking showed better structural capacity compared to non-cracked sections.
- Top-down cracking initiation and propagation were found to be independent of pavement cross-section or the AC thickness.
- Top-down cracking can be caused by several contributors such as stiffer AC mixtures, mixture segregation, binder aging, low AC tensile strength, stiffness differentials between pavement layers, and poor bond under the wearing course or by a combination of any. [9]

3. Research Methodology

3.1 Study Road Section

The road section selected for the study is a recently constructed asphalt pavement in Kathmandu Ring Road (NH39) [10]. Irregular pattern cracks with 1-10 mm crack width in transverse and longitudinal directions have been seen on pavement surface after some months of project completion. The section of the ring road is from Kalanki to Koteshwor which is 10.5 Km in length. Among this section, the road from Balkumari (Manohara Bridge) to Balkhu (Bagmati Bridge) is selected as the study section which is 6.6 Km in length. Cracks are mostly seen in this section on both the outer lanes of the inner main carriageway.

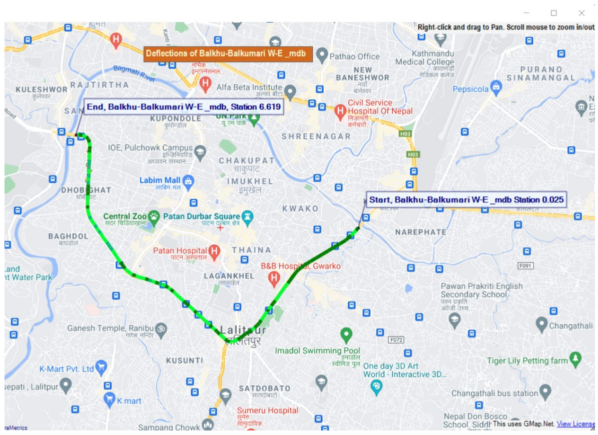

Figure 2: Study Area, Kathmandu Ringroad (Balkhu-Balkumari Section)

3.2 Review of Project Documentation

Relevant documents related to the project were reviewed. The road within the scope of the project was asphalt concrete pavement, including the overlay design and new-built pavement design for broadening the existing road on both sides. The road was designed according to the Design Code of Highway Asphalt Pavement (JTG D50-2006).

The pavement structure designed for the road was composed of 4cm Fine Grained Asphalt Concrete AC-13C over 6cm Medium Grained asphalt concrete AC-20C Lower Surface/Bonding layer. The base layer was constructed with 32cm Cement Stabilized macadam and Subbase layer with 18cm graded broken stone (i.e., granular). The Class of road according to the code was found to be High Class pavement/Secondary Highway with design life of 12 years. The design traffic was 8 million cumulative standard axles of 100 KN standard axle load which is equivalent to 19.6 million cumulative standard axles of 80KN standard axle load.

3.3 Distress Survey and Designation of Test Section

The study section was the National Highway of Nepal designated as NH39 from Balkumari, Manohara Bridge (0+000) to Balkhu, Bagmati Bridge (6+640). The total length of the test section was 6.6 Km. The pavement was divided into sections as below based on the pavement condition. [9]

Table 1: Designation of the Test Sections in the Study

Traffic	Cracking	Designation Used In Study
Balkumari-Gwarko (E-W)	No	NH3901EW -UC
Gwarko-Balkumari (W-E)	Yes	NH3901WE -C
Gwarko-Sanepa (E-W)	Yes	NH3902EW -C
Sanepa-Gwarko (W-E)	Yes	NH3902WE -C
Sanepa-Balkhu (E-W)	No	NH3903EW -UC
Balkhu-Sanepa (W-E)	Yes	NH3903WE -C

3.4 Non-Destructive Test Using Falling Weight Deflectometer

The Falling Weight Deflectometer (FWD) is a fully automatic impulse loading device that applies a transient weight to the pavement and measures how the surface has been deflected at various radial distances. Calibration of Equipment for Distance Calibration (DMI Calibration) and Relative Deflector Calibration was done in Field according to the DYNATEST FWD/HWD TEST SYSTEMS OWNER'S MANUAL Version 2.8.17. [8]

At the flexible pavement section, the deflections were measured at ten geophonic sensors situated at radial distances of 0, 200, 300, 450, 600, 900, 1200, 1500, 1800, and 2100 micron respectively. The peak load that is applied to the pavement is 50 KN (+/- KN), which is equal to the loads placed on one dual-wheel set with a standard axle load of 100 KN. [11]

3.5 Traffic Data

The traffic counts were obtained from the Department of roads, Statistics of Strategic Road Network (SSRN). The average daily traffic (ADT) count based on the vehicle volumes was arrived at by computing the weighted average for all the days in the week. [10] Vehicle Damage factors for commercial vehicles for the design were obtained from Flexible Pavement Design Guideline 2021 for roads classified under Guideline. Similarly, Lane Distribution factors were obtained from guidelines to incorporate the design traffic in each lane in each direction. The year of the design was 2012/13, the handover of the project was done on 2018/19 (2019 January) and the design life of the road was 12 years.

4. Analysis and Results

4.1 Traffic Study

Traffic analysis was done to determine the total no. of axles repetitions over three years of time from the data obtained from Department of roads, Statistics of Strategic Road Network (SSRN). [10, 12]. From table 2 and section 3.2 we can conclude that the occurrence of cracks was not due to the completion of fatigue life or fulfillment of repitition of design traffic load which supports our literature with occurrence of premature cracks.

Table 2: Calculation of repitition of Standard axles on Study Section

Description	Year		
	2018/19	2019/20	2020/21
Daily Equivalent Axles as of AADT	2336.74	3974.36	5609.04
Yearly Passes of ESA (in millions)	0.852	1.45	2.048
Total ESAs (80 KN) (in millions)		4.35	

4.2 FWD Test and Back Calculation

4.2.1 Deflection Results

Deflection is the response of the pavement to the applied load. Deflection is an index that expresses the structural capacity of the pavement. The normalized central deflection was compared for all the pavement sections since the central deflection represents the overall reaction of the pavement. Figure 3 displays the variance in central deflection over the pavement sections by depicting the normalized central deflection.

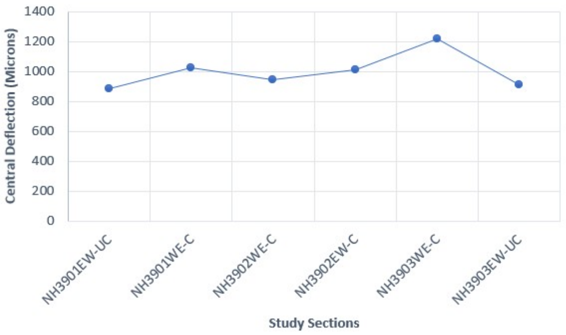

Figure 3: Normalized Center Deflection across the Pavement Sections

The normalized central deflection was somewhat affected by the presence of cracks. There was variation in deflection between the sections with cracks and those without cracks.

4.2.2 Back Calculation of Layer Moduli

Using the FWD deflection data and the back calculation program Elmod6.0 (Evaluation of Layer Moduli and Overlay Design), the stiffness moduli of the pavement layers were calculated. The surface moduli of pavement were determined from the software which uses the application of Boussinesq's equation. By computing the Surface Modulus, the non-linear behavior of the subgrade material was examined. According to the Surface Modulus plot results, the subgrade materials used in the pavement sections behave in a non-linear elastic manner as shown in figure 4.

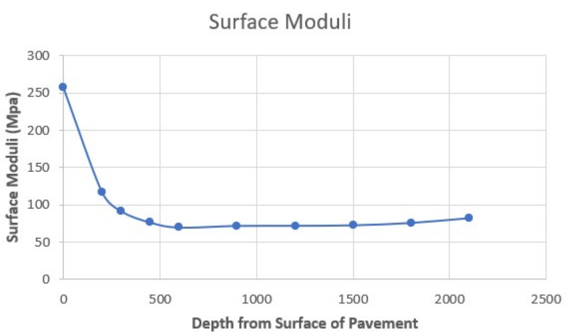

Figure 4: Variation of Surface Modulus along the depth

In this study back analysis was performed by the "Method of Equivalent Thickness" method as it gives adequately satisfactory results in comparison to other complicated methods like the Finite Element Method. Odemark's Method of Equivalent thickness was used in the calculation of layer moduli. [13]

Figure 5 illustrates comparisons of the average temperature corrected [14] back calculated layer moduli of the sections included in this study.

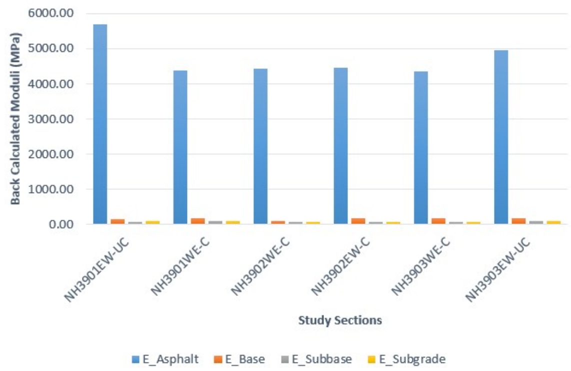

Figure 5: Average Back Calculated Modulii

From above results we can conclude that the Modulus of asphalt in uncracked section was greater than those of cracked section. The Modulus of Cement Stabilized gravel base was much lower than the design value and the value was less in cracked section than in uncracked section. The Modulus of Cement Stabilized gravel base was found much lower than the required design value and the value was less in the cracked section than in the uncracked section. There is the possibility of cracks in the Cement Stabilized Gravel base which might be reflected in the surface layer.

4.3 Finite Element Analysis

A set of field data obtained from FWD at cracked and uncracked sections of the same pavement structure were used and analyzed for stress variation using a simple 2D Finite Element Model in ELMOD6.0 software. [15] The sections used for analysis are given in Table 3. For the two different types of models with symmetrical load, the distribution of stresses in the bituminous layer was examined. The distribution of horizontal and shear stresses is shown in Figures 6 through 10.

An analysis of the findings from the two models reveals that the size of the stresses is impacted by the existence of cracking in the stress distribution. The vertical stress distribution for both models did not significantly change. Tensile stresses were further studied since they are linked to fatigue. As can be observed from the preceding, the presence of cracks may slightly impact the tensile stresses in bituminous surfacing. Shear stresses were higher in the center and top of the surfacing when a crack was present, while they were higher at the bottom of the asphalt pavement when the surfacing was uncracked.

Table 3: Pavement structural data used for FEA

Surface Condition	Thickness of Layer(mm) AC	CSB	GSB
Cracked	100	320	180
Uncracked	100	320	180

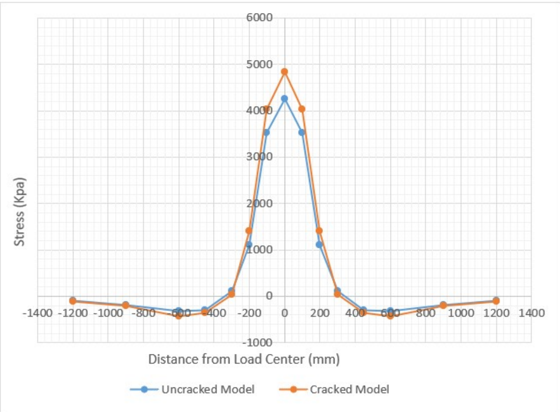

Figure 6: Horizontal stresses at the surface of the bituminous surface layer

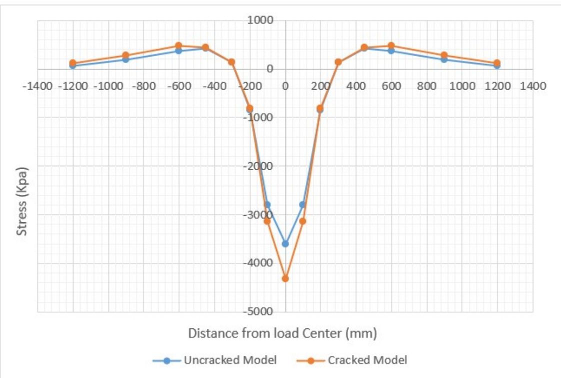

Figure 7: Horizontal stresses at the bottom of the bituminous surface layer

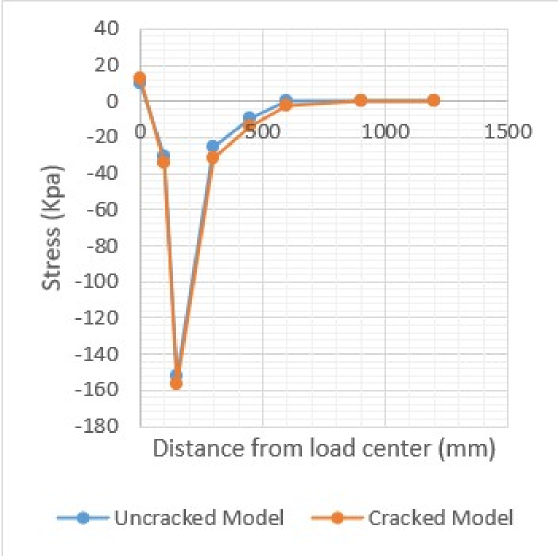

Figure 8: Shear stresses at the surface of bituminous surface layer

5. Conclusion

The findings of this report are concluded as follows:

- Visual distress analysis revealed that all of the portions exhibiting longitudinal wheel path cracking and transverse cracking tended to originate from the longitudinal cracks, which formed alligator-like cracks (i.e., fatigue crack)
- FWD tests were conducted to evaluate the structural capacity of cracked and uncracked pavement. Based on the deflection result, FWD tests indicated that the surface deflection on the cracked section was slightly greater than on the Uncracked Section.
- The Modulus of Cement Stabilized gravel base was found much lower than the required design value and the value was less in the cracked section than in the uncracked section. There is the possibility of cracks in the Cement Stabilized Gravel base which might be reflected in the surface layer.
- Presence of Cracks in the Surface layer does not affect the vertical stress regime on the pavement whereas the horizontal and shear stress regime are somewhat affected.

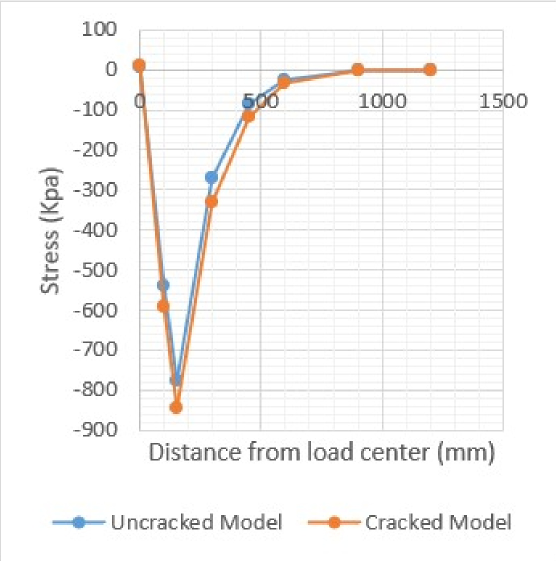

Figure 9: Shear stresses at the middle of bituminous surface layer

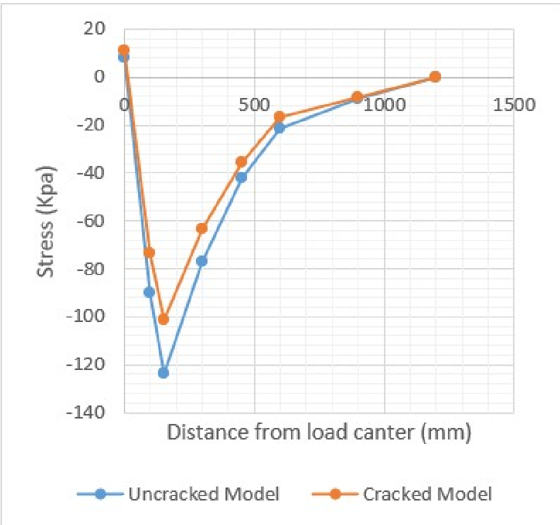

Figure 10: Shear stresses at the bottom of bituminous surface layer

6. Recommendations for Future Study

The following can be looked into while doing further study on asphalt concrete cracks:

- Non-Destructive testing was performed to determine the pavement performance and evaluation. Destructive tests like coring and trenching can be performed to visualize and analyze the cracks beyond the Surface layer.
- 3D Finite Element Analysis can be done using this research data to study about the crack initiation and propagation.

Acknowledgments

The authors are grateful to Department of Roads (DoR) for providing the opportunity to take part in the training program of Falling Weight Deflectometer and to use the equipment for study. Thanks are due to the personnel of Department of Roads, and friends for the assistance they have provided during this study.

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