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AGED TRANSPORT CONCRETE BRIDGES FATIGUE RELIABILITY IS EVALUATED USING PROBABILISTIC FRACTURE MECHANICS

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Abstract

India's transport system is the country's most important mode of transportation. Over a million important bridges, the majority of which are concrete bridges, focusing on concrete bridges, fatigue is frequently a significant issue and is one of the key variables influencing their lifespan. The goal of the current study is to use a linear elastic fracture mechanics approach to detect cracks in old simply supported slab bridge and T-beam bridges and assess their reliability index and likelihood of failure. The methodology is used to determine the reliability index and the appropriate number of cycles. The outcomes were utilised to construct an inspection plan after computing an acceptable risk level. This technique offers a rational basis for calculating the reliability index or chance of failure for any concrete bridges, and it may also be used to determine the ideal inspection interval.

Keywords: Concrete bridges, Fatigue - Reliability index, linear elastic fracture Mechanics

1. INTRODUCTION

In recent years, the Concrete old bridges are subjected to increased traffic intensity and higher traffic loads. As a consequence of this, the railway bridges become prone to fatigue failure. To track fatigue-related failures, the bridges must be inspected regularly. The proper identification and well-planned inspection intervals of fatigue-prone details in the concrete bridge is a vitally important task to give a guarantee of uninterrupted and acceptable performance during their service[. In the majority of fatigue situations, the crack will occur under elastic conditions. The concept of Linear Elastic Fracture Mechanics (LEFM) would be used since the plastic zone.is smaller**.** The parameters involved in fracture mechanics study such as fracture toughness, stress range, crack size cannot be quantified exactly. Hence, the principles of structural reliability can be made use of for determining the probability of failure. According to a survey by the ASCE Committee, 80–90% of steel structures fail by fatigue and fracture[. In the industry of transportation concrete bridges, the evaluation of fatigue and fracture reliability is a crucial task]. Numerous studies have been conducted worldwide in recent years to determine the fatigue strength of the entire bridge structure and its individual parts using the S-N curve and LEFM techniques, as well as reliability model development [Silva et al. 2021). There is still a dearth of fatigue data despite this new development about the fatigue performance of concrete bridges ((Bannantine et al. 1990). It is widely known that fracture mechanics can be used to predict the formation and propagation of fatigue cracks (Yazdani et al.1987; Timothy et al. 2004) The LEFM approach can be effectively employed in the instance of fatigue evaluation of concrete bridges (Tong et al. (2013). as an alternative to the AASHTO method

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Any concrete bridge detail can be applied with ease using the proposed generic probabilistic fracture mechanics methodology]. In the research by Tong et al., the examination of bridges tracked by the structural health monitoring system yielded results that were tolerable .The old, concrete bridges are put under stress by loads pressing on them as well as material deterioration

2. PROBLEM DESCRIPTION

This paper proposes a technique for calculating the fatigue life of service bridges that was developed using LEFM ideas. The probability of failure is determined at the end of certain desirable cycles using the Monte-Carlo simulation technique. Therefore, for a given detected crack size, the developed approach would provide the likelihood of failure of a structure or component for various values of intended life. In this analysis, only live loads resulting from defined truck loads are taken into account.

a) LEFM Model

The model used most frequently in the fatigue evaluation process is the Paris equation (Leander et al. 2016). The suggested approach used in the current work is outlined as follows.

1. Consideration is given to a concrete T-bridge that is 50 years old and situated on the Bannur -Mysore Kankapura Road. The Cross-section details are obtained from the public works department Karnataka.
2. The impact factor (IF), stress modelling parameter (B_m), initial crack size (a_i), crack growth parameters (C & n), and mean (m) and COV (δ) of variables are taken from well-known works of literature.
3. The reliability index is calculated using the limit state equation for fatigue reliability. Developed by (Monte-Carlo simulation technique used (Ranganathan 1999).
4. The following fracture mechanics idea is used to calculate the bridge's stability measure, failure probability, and number of cycles before failure. The number of simulations is fixed based on Shooman'scriteria (Ranganathan 1999)

β - Reliability Index

ai - Initial crack size

af - The final or critical crack size

Δk - Stress intensity factor range

F (Θ) and Y (a) - A factor depend upon the dimension of the component

SIF - Stress Intensity Factor

ad - Detected crack size

C and m - Crack growth parameters

KIC - A plane strain Fracture toughness for mode 1 type of loading

Bm - Stress Modelling parameter

Nf - Number of cycle to failure

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Z - Limit state function
Pf - Probability of failure
Ns - The desired life in terms cycles
nf -The number of times Z<0 during simulation
Ses - Equivalent stress range
Φ - Cumulative distribution function of standard normal variate
μ - Mean
σ – Standard deviation
ẑ - Mean of Ln Z.
σlnz - standard deviation of Ln Z
COV – Coefficient of Variation
Fx (X) – Cumulative distribution function
Sf – Fatigue Limit
I – Moment of Inertia
Pi - frequency of occurrence of the ith stress range
fi - ith stress range in load spectrum

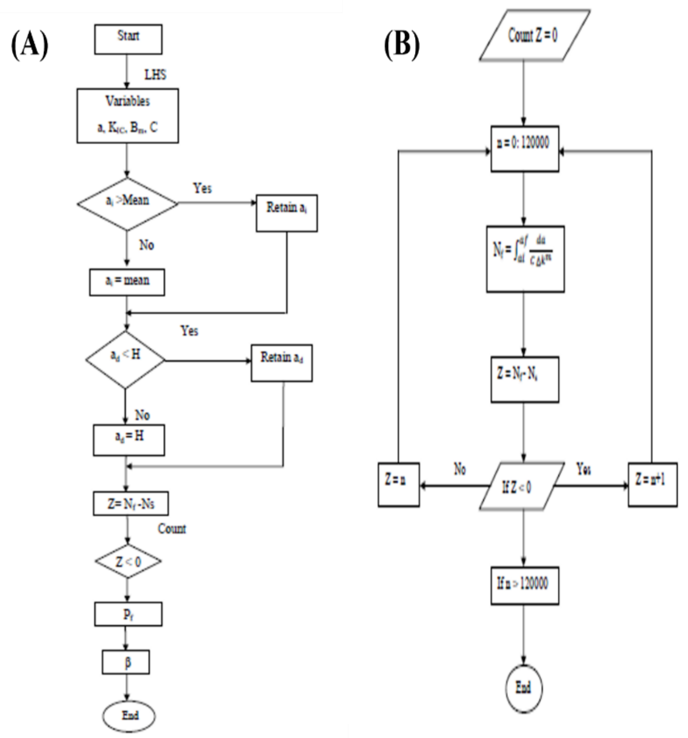

Fig 1: (A) Flow chart for Evaluation of bridge (B) Flow Chart for Evaluation of Nf

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b) Input Variables

It is anticipated that the crack will only begin at the intersection of the angle and web. This fracture will eventually develop an edge crack and fail because of its eccentric nature. The crack is only expected to start at the edge junction, it should be emphasised. The size of a visible crack has been assumed because exact information on the frequency of cracks and their values cannot be discovered in the public domain. When the first fractures started to show, values discovered during a routine check by the highway department. The mean, coefficient of variation (COV), and distribution used for various variables are shown in the following table. These standards were derived from well-known literary works.

Table 1: Showing Statistical parameters

Variable	Distribution	Mean	COV
ai (26)	Log-normal	0.00041	0.15
C(22)	Log-normal	$2x10^{-10}$	0.3
$B_{m(12)}$	Log-normal	1.0198	0.2
$K_{Ic(16)}$	Extremal	0.803	0.083

c) Data for Bridge and Loading

A concrete T-beam girder bridge is shown in Figures 1and is situated between the Bannur and Kankapura Mysore highways. For the two years 2019 and 2020, various vehicle combinations and traffic information were recorded while moving from to and fro motions. Only vehicles that can have an impact on bridges are taken into consideration for the study, such as buses, loaded trucks, and unloaded trucks, as well as various combinations.

Fig 2: showing the diagram, the bridge diagram which is considered for the study

Table 2: shows the traffic data

Sl no	Vehicle Type	Traffic Census for the year -2019	Traffic Census for the year -2020
1	BUS	642	589
2	TWO AXLED TRUCK (2AT	869	728
3	MULTIAXLED TRUCK (MAT)	513	456

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Table 3: shows the different vehicle combination for the study

1.LMAT+ULMAT	6. L2AT + ULBS	11. LMAT + LBS
2. LMAT + UL2AT	7. LBS + ULMAT	12. L2AT + LBS
3. LMAT + ULBS	8. LBS + UL2AT	13. ULMAT + UL2AT
4. L2AT + ULMAT	9. LBS +ULBS	14. ULMAT + ULBS
5. L2AT + UL2AT	10. LMAT + L2AT	15. UL2AT + ULBS

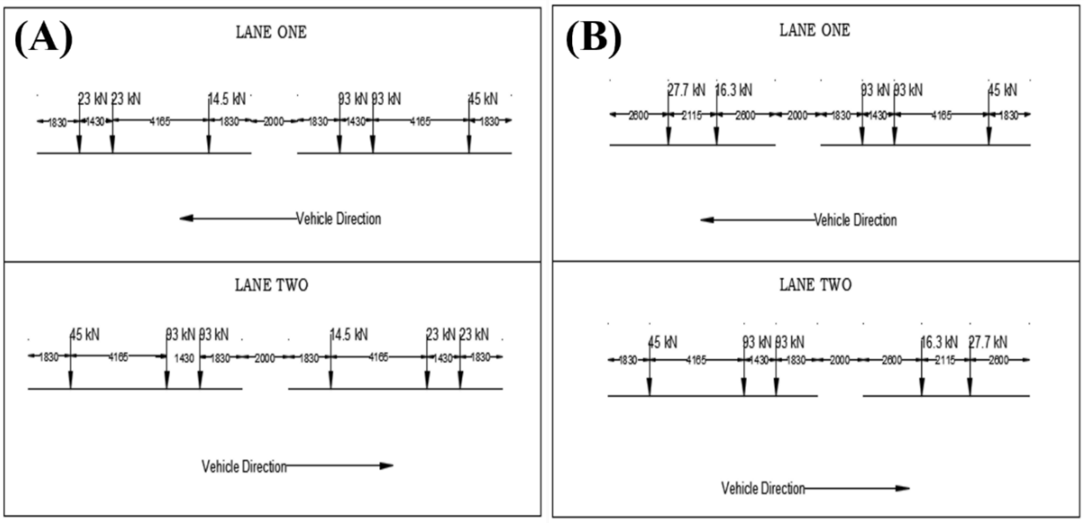

Fig 3: (A) Example of Vehicle Moving case-1 (B) Example of Vehicle Moving case-2

Plotting the stress spectrum is necessary to calculate the fatigue damage to Concrete bridges under moving Vehicle axle loads. The stress spectrum is nothing more than a collection of stress levels brought on by different positions of the axles of a moving vehicle on the bridge. It is well known that the mid-span of a simply supported member is where Bending Moment (BM) has its greatest impact. This serves as the foundation for a Moving Load Analysis (MLA), which is used to determine the stress spectrum. The stress spectrum is shown for 15 various truck combinations and 6 individual truck examples passing across predetermined bridges. A sample stress spectrum for a realistic moving vehicle load of goods is shown in Fig. 4. It is not possible to calculate fatigue damage directly using the stress spectrums, which are variable amplitude spectrums that are converted to constant amplitude stress ranges by the Rain flow cycle counting technique [17]. In the current experiment, the stress range is determined using this method for all loading scenarios and stress spectra.

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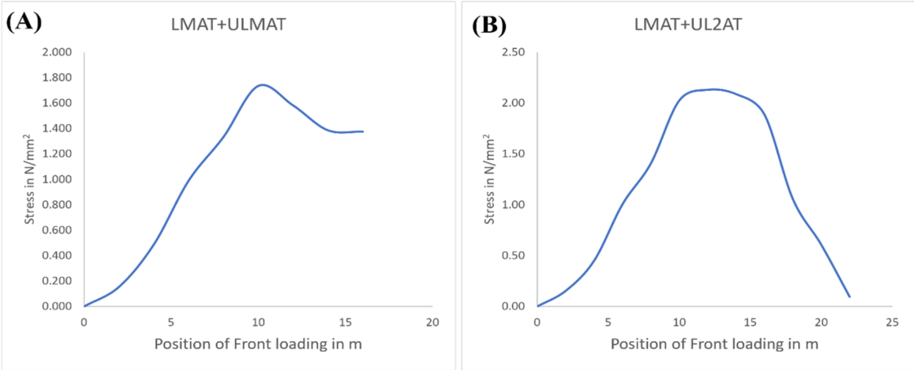

Fig 4: (A) sample showing Stress Spectrum, (B) sample showing Stress Spectrum

d) Equivalent Stress Range

The loading pattern on the T-bema concrete girder bridge is actually a series of varying amplitude and frequency loading, as opposed to cyclic amplitude loading. The Miners' Cumulative Damage Hypothesis converts these varying amplitude loads into constant amplitude loads.[18] The equivalent stress range is the name given to this transformed constant amplitude stress range.

$$E = \left(\sum_{i=1}^{B} P_i f_i \right)^{1/m}$$

Where, Pi = frequency of occurrence of the ith stress range

fi = ith stress range in load spectrum

B = Numbers of stress range blocks in a histogram

m = slope of the S-N curve

Table 4: showing an Equivalent stress for Different Vehicle combinations

	Vehicle Combinations	Srmax (Mpa)	n (Cycles)
Case-1	LBS+ULBS	1.05	1.01
Case-2	LBS+L2AT	1.719	1.06
Case-3	LBS+UL2AT	1.021	1.041
Case-4	LBS+LMAT	1.89	1.199
Case-5	LBS+ULMAT	0.61	1.023
Case-6	ULBS+L2AT	1.22	1.01
Case-7	ULBS+UL2AT	0.475	1.12
Case-8	ULBS+LMAT	1.476	1.028
Case-9	ULBS+ULMAT	0.47	1.013
Case-10	L2AT+LMAT	3.153	1.02
Case-11	L2AT+ULMAT	1.106	1.03
Case-12	UL2AT+LMAT	2.13	1.09
Case-13	UL2AT+ULMAT	0.561	1.01
Case-14	L2AT+UL2AT	1.121	1.088
Case-15	LMAT+ULMAT	1.923	1.022

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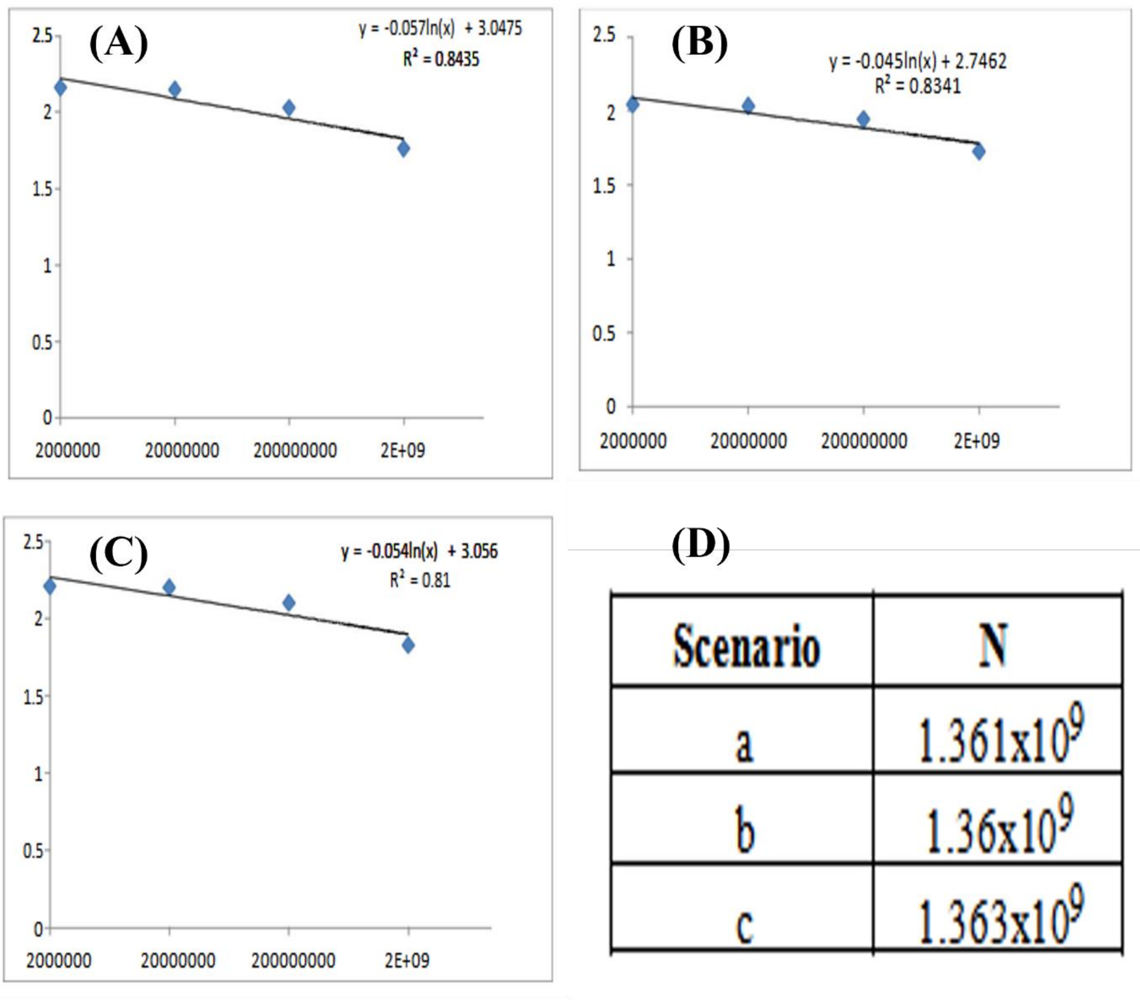
Table 5: Reliability Index for various desired number of cycles

Ns	2a	2b	2c
2x10^6	2.16	2.043	2.209
2x10^7	2.146	2.033	2.201
2x10^8	2.028	1.943	2.102
2x10^9	1.762	1.727	1.827
2x10^10	-	-	



Scenario	N
a	$1.361x10^9$
b	$1.36x10^9$
c	$1.363x10^9$

Fig 5: (A) β versus log Ns for case study 2a (B)β versus log Ns for case study 2b (C) β versus log Ns for case study 2c (D) Computation of remaining life

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3. RESULTS AND DISCUSSIONS

The tables and graphs given above demonstrate how important the crack discovery is to the developed approach. The assumed value of a detected crack is built up in example studies so that it can be easily found during a normal examination of the bridge. In addition, the break is eccentric, and its position has a big impact on the results.

Relates to a bridge that has been given research consideration.

The bridge is 48 years of age old, and a table with the traffic statistics is provided. It is estimated that throughout the past 48 years, the bridge was subjected to the current traffic level. In addition to that Bridge's present crack size is calculated using Equation 1 for the number of cycles it has experienced over the course of 48 years for the various scenarios.

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