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# Fatigue analysis of Bridge -Case Study Mysore-Hunsur Concrete Bridge

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***Abstract*:** The work is concerned with the Concrete bridges, The study carried out involves a a RCC bridge on NH275, from Mysuru to Madkeri near Hunsur is chosen for further study. For this bridge, load data is collected so as to arrive at annualized traffic. Further cross sectional details are collected from records. Moving load analysis is carried out to determine the stress on the bridge. The parameters involved in LEFM are highly random and hence there is a significant uncertainty in quantifying the behavior under fatigue. To handle these uncertain random variables, the principles of structural reliability are put to use. The Reliability index (β) which is a measure of fatigue assessment is calculated using limit state formulation developed for Fatigue Reliability

Key Words: **Fatigue, Moving loads, Traffic Data, S N curve approach Latin Hyper cube sampling Technique.**

## 1.0 INTRODUCTION

Majority of bridges in India are more than 50 years old and are still in use. Furthermore, bridges are currently being subjected to more rigorous demands in terms of increased traffic intensity and higher traffic loads in order to meet the requirements for more efficient transportation systems under fatigue. Hence there is a need to understand concrete fatigue which refers to the phenomenon of rupture under repeated loadings. In Bridges, Dead Load is due to the self-weight of the structure which remains constant over entire service life of the structure. Live Load is mainly due to the vehicle weights which are repetitively applied. With the increase in axle loading and their frequency of occurrence, these bridges are subjected to relatively severe conditions and some of them may show signs of distress. Replacement of the old bridges with new ones is economically not viable. Hence development of a rational method of evaluation for these bridges will help in extending their service life at an acceptable risk level.

## 1.2 FATIGUE DAMAGE

The damage caused to the materials under cyclic loads is called fatigue damage. The failures due to fatigue generally take place at a stress much lower than the ultimate strength (yield stress) of the material, at a stress which is considered safe on the basis of static failure analysis. The progress of fatigue damage is quite complex involving different stages, despite these complexities fatigue damage assessment for design of components and structures must be made.

## 1.3 STAGES OF FATIGUE FAILURE IN CONCRETE

Following are the three important stages in the fatigue failure

(1) Crack initiation

(2) Micro-cracking

(3) Macro-cracking and rupture

## 1.4 FATIGUE CLASSIFICATION

Fatigues are classified into two types

High cycle fatigue: High cycle fatigue is one where the stress ranges (***fr)*** are low (within the elastic stress) with large number of load cycles. Here, elastic strain dominates and strength controls the performance.

Low cycle fatigue: Low cycle fatigue is one where stress ranges (***fr***) are high with less number of load cycles.In this case, plastic strain dominates and ductility controls the performance.

## 1.5 Fracture Mechanics Approach:

Fracture mechanics is the field of mechanics that deals with the study of propagation of cracks in materials. The scope of

Engineering Fracture Mechanics is concerned with macro- cracks which are either present in the components or develop during the service by various failure mechanisms such as fatigue or creep. Fracture mechanics is used to evaluate the strength of a structure or component in the presence of a crack or flaw.

There are three ways of applying a force to enable a crack to propagate;

**Mode I - *Opening mod*e: Mode II - *Sliding mod*e: Mode III - *Tearing mod*e:**

### 1.6 Linear Elastic Fracture Mechanics (LEFM)

LEFM is the basic theory of fracture, originally developed by Griffith and completed by Irwin and Rice. It is a highly simplified theory that deals with sharp cracks in elastic bodies In majority of fatigue situations the crack will occur under elastic conditions. Hence size of the plastic zone at the crack tip would be small compared to crack size. The complexity in concrete increases due to the presence of a large process zone ahead of the crack tip

**1.7 Structural Reliability**: As implied in the definition, structural failure and, hence, reliability, is influenced by many factors. In its simplest form, the measure of reliability is made by comparing a component's stress to its strength. Failure occurs when the stress exceeds the strength

### 2 Description of the bridge considered for the Study:

Data Collection: A bridge built in 2007 is located in hunsur, Mysore –Hunsur highway considered for the case study. It is a composite concrete bridge of with three different spans of total length 21 m.

| | |
|---|---|
| **1. Bridge Location** | **Hunsur, Mysuru- Madkeri Highway, (NH275)** |
| **2. Type of Bridge** | **Slab Culvert** |
| **3. Total Span** | **21m** |
| **4. Distance Between Piers** | **7m** |
| **5. Year of Construction** | **2007** |

**2.2 Traffic data collected:** A definite knowledge of the volume and composition of traffic is essential for fatigue analysis. The information can be obtained by periodic traffic census and sample surveys, which are required to be judiciously conducted at periodic trends on many roads.

2. 3 **Features of the Traffic Census**: The traffic data for the road NH275 from Mysuru to Madkeri is obtained. The traffic survey was conducted for seven days at hunsur Mysore. Following is the list of vehicles that had been observed during the traffic counting

| Sl no. | VEHICLE TYPE | Year-2018 |
|---|---|---|
| 1 | BUS | 1391 |
| 2 | TWO AXLED TRUCK | 1822 |
| 3 | MULTIAXLED TRUCK | 289 |

As per IRC: SP: 72 – 2007 [10], The large number of cars, two wheelers and light commercial vehicles are of little consequence and only the motorized commercial vehicles of gross laden weight of 3 tones and above (i.e. BS, 2AT and MAT) are to be considered for computation of design traffic.

2**.4 Identification of Vehicles**: The details of the vehicles considered along with its specification are tabulated as shown below

| Vehicle type | BUS (BS) Tata LP 1512 TC | 2AT LPT 1613 | MAT LPT 2521 |
|---|---|---|---|
| Wheel base | 5.895 m | 4.225 m | 4.165 m & 1.43 m |
| length of vehicle | 10.025 m | 7.38 m | 9.26 m |
| Width of vehicle | 2.434 m | 2.115 m | 2.44 m |
| Kerb Weight | 40.13kN | 44 kN | 60.36kN |
| GVW | 145.63kN | 158.76kN | 245kN |
| FAW(unloaded) | 14.85 kN | 16.3 kN | 14.5 kN |
| RAW(unloaded) | 25.28 kN | 27.7 kN | 46.2 kN |
| Maximum FAW | 46 kN | 58.8 kN | 58.8 kN |
| Maximum RAW | 99.63 kN | 99.96 kN | 186.2 kN |

## 3 Moving Load Analysis for the Collected Data:

In practical situations, live loads such as vehicular loads act on bridges. "The loads whose position changes with respect to time are called moving loads". By virtue of its motion, such loads generally induce a dynamic response in the structure

### 3.1 Influence Lines

Shear force and bending moment at different sections will vary with the movement of the load train. The maximum shear force and bending moment at any section can easily be determined with the help of the influence line diagrams

### 3. 2 Algorthim: The Developed algorithm is efficient for the identification of composition of traffic.

A train of loads is run on a bridge.

- ☐ The spacing between the loads, the magnitude of each and every load is defined by the user.
- ☐ Span of the bridge and geometry (section modulus) is user defined.
- ☐ The concept of ILD is adopted in computation of Design BM and bending moments at any section on the bridge for each and every increment of load head is tabulated.
- ☐ The stress variation due to train of loads is thus obtained by the equation M/I = f/y
- ☐ Impact effect is also considered in the computation of stresses.

A graph indicating the variation of the bending stress with movement of load train plotted is used as the data for Fatigue analysis

**3.3 Identification of Vehicle:** The vehicular combination is identified for live load positions in order to determine the maximum bending moments.

**Single vehicle Combinations**

| | | |
|---|---|---|
| 1.ULBS | 2.UL2AT | 3.ULMAT |
| 4.LBS | 5. L2AT | 6.LMAT |

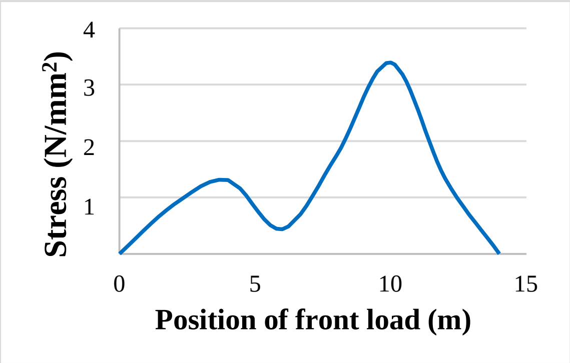
1. Unloaded Bus 2 .Unloaded 2 axle truck 3. Unloaded Multi axle truck

4. Loaded Bus 5. Loaded 2 axle truck 6 .Loaded multi axle truck

**4 Results of Moving Load Analysis: Moving load analysis is thus done for three types of vehicle movements**

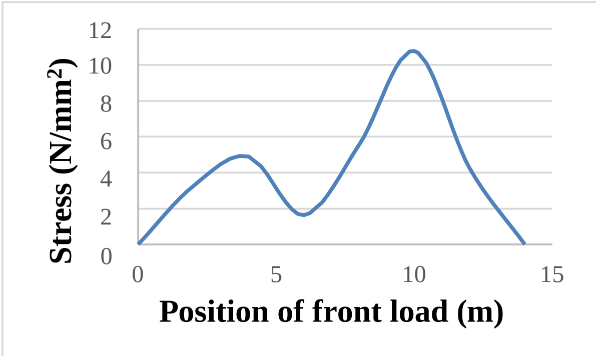
**Single Vehicles**

**Case 1:- ULBS**



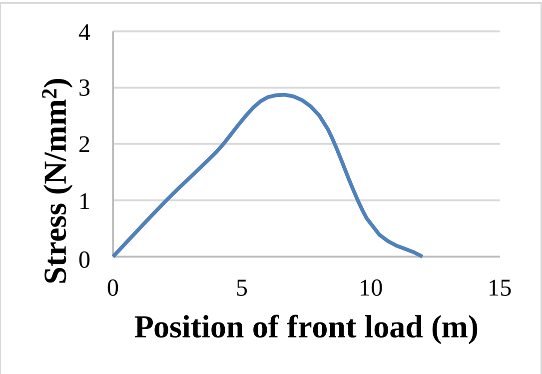

**Graph 4.0: Stress variation for ULBS**

**Case 2 :- LBS**



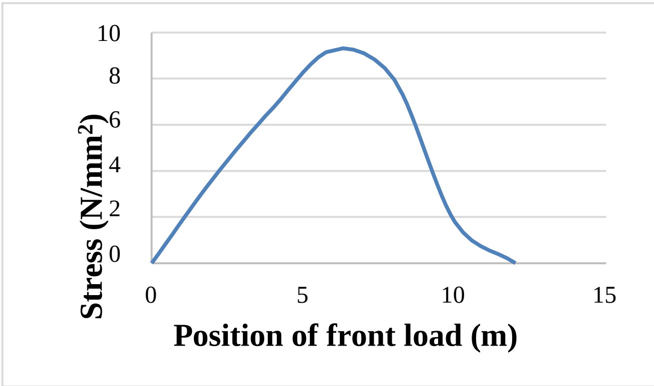

**Graph 4.1: Stress variation for LBS**

**Case 3 :- UL2AT**



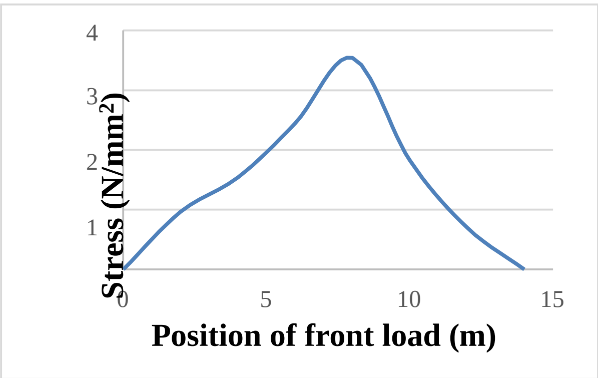

**Graph 4.2: Stress variation for UL2AT**

**Case 4 :- L2AT**



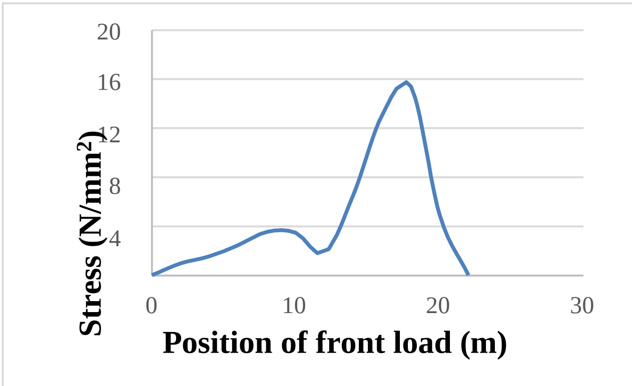

**Graph 4.3: Stress variation for L2AT**

**Case 5 :- ULMAT**




**Graph 4.5: Stress variation for ULMAT**

**Case 6 :- LMAT**




**Graph 4.6: Stress variation for LMA**

**5 FATIGUE ANALYSIS**: The fatigue life of actual structural components subjected to variable-amplitude loading (such as random traffic loads) can differ greatly from components subjected to constant amplitude stress cycles. For classical fatigue analysis, the Palmgren-Miner rule (or simply Miner's rule) of linear damage accumulation is frequently used to account for variable-amplitude stresses. Thus the stress variations obtained from moving load analysis for different vehicle combinations are variable amplitude stress ranges. Hence Miner's rule and rainflow counting is used to determine the equivalent effect of moving loads. i.e. equivalent number of cycles and the corresponding stress range.

**5.1 EQUIVALENT EFFECT OF MOVING LOADS**: The results of moving load analysis shown in graphs 4.0 to 4.6 along with the concepts of Miner's cumulative damage model and rain flow counting is considered for further analysis

The equivalent stress range is expressed in the following form:

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

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

| **Single moving Vehicles** | | | **Srmax (Mpa)** | **n (Cycles)** |
|---|---|---|---|---|
| **Case 1** | LBS | 2.515 | 1.018 | |
| **Case 2** | ULBS | 1.111 | 1.041 | |
| **Case 3** | L2AT | 2.594 | 1 | |
| **Case 4** | ULAT | 1.177 | 1 | |
| **Case 5** | LMAT | 3.787 | 1.001 | |
| **Case 6** | ULMAT | 1.413 | 1 | |

## 6 Fatigue Evaluation procedures:

Random variables used in fatigue reliability analysis are Initial crack size (ai), Detected crack size ($a_d$), C and m are Fatigue crack growth parameters, Equivalent stress range (Se), Stress modelling parameter ($B_m$). All the parameters involved in for determining the fatigue life N, are random in nature. Thus fatigue life also would be random which brings the concept of probability of failure into computation. In this study, ***Latin hypercube sampling*** technique for computing probability of failure is used.

**Crack Growth Law**

The rate of fatigue crack propagation following Paris law (1945) is given by,

$$da/dN = C(\Delta k)^{M}$$

Where, a = crack size,

N = Number of cycles

C & m = crack growth parameters The fatigue life Nf, is given by

Nf=

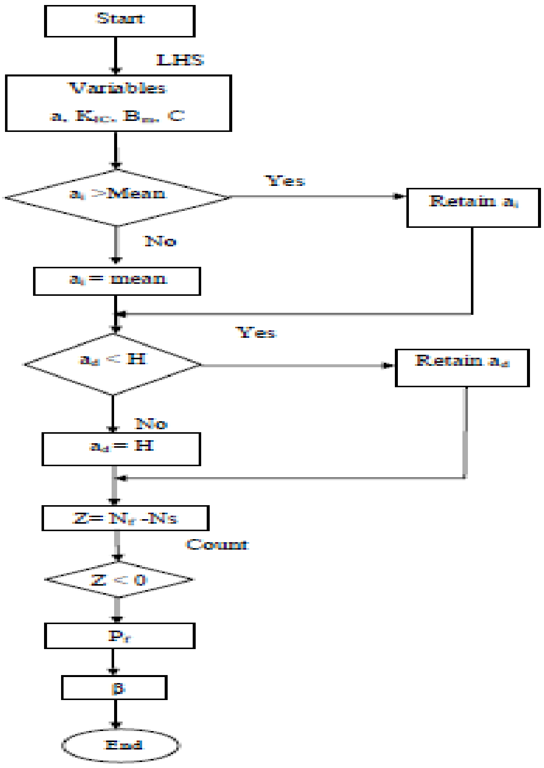
$$\int_{ai}^{af} \frac{da}{C \, \Delta k^{m}}$$

Where, ai = Initial crack size

af = Final crack size

Statistical Parameters: The mean, Coefficient of variation (COV) and distribution used for various variables are taken from literature and it is shown below.

| **Variable** | **Distribution** | **Mean** | **COV** |
|---|---|---|---|
| $a_i$ **(Initial crack size)** | Log-normal | 0.00041 | 0.15 |
| C**(Crack growth parameter)** | Log-normal | $2x10^{-10}$ | 0.3 |
| $B_m$**(Stress modelling parameter)** | Log-normal | 1.0198 | 0.2 |
| **KIc(Fracture toughness)** | **Extremal** | **0.803** | **0.083** |




Flow chart for Evaluation of bridge

**7 : Results and Discussions:**

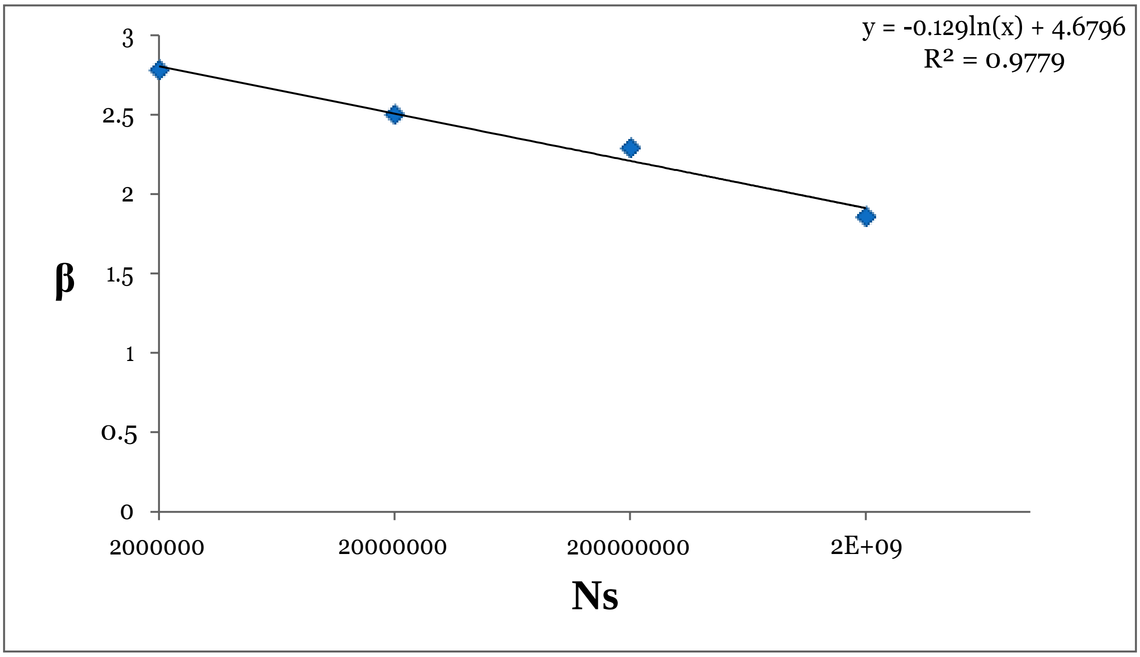
The number of cycles to failure (Nf), final crack size (af), probability of failure (Pf) and reliability index ($\beta$) of the bridge is computed using the flow chart equations

**CASE STUDY 1 :** Case study 1 pertains to a bridge which is newly built havingan initial crack of size 0.00041m according to ACI 224R-01, ACI committee.

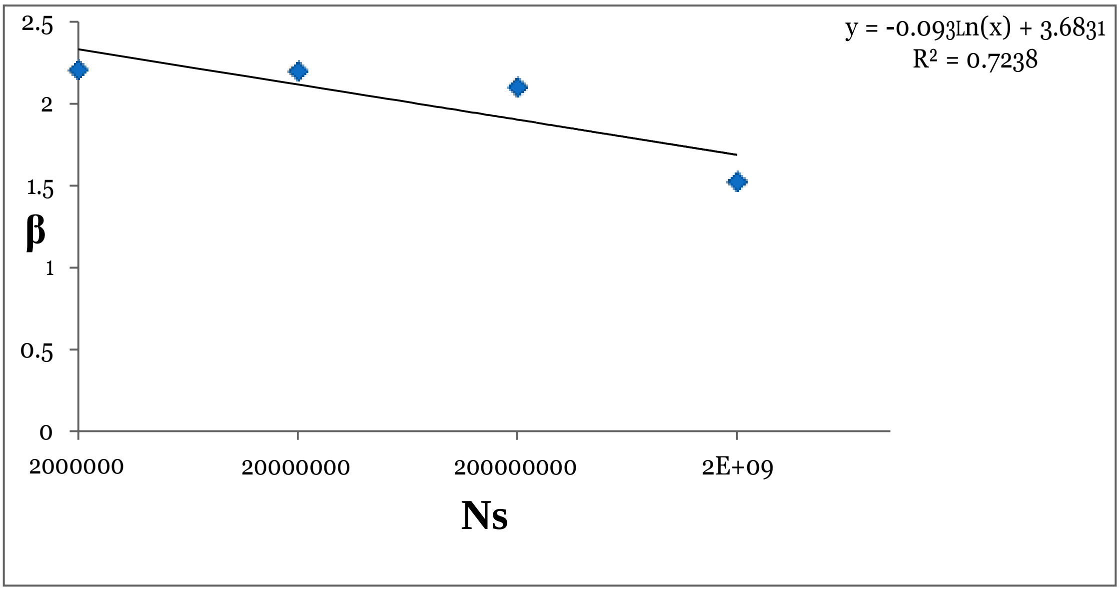
**CASE STUDY 2 :** Case study pertains to a bridge which has been considered for study. The bridge is 13 years old and the traffic data collected is given in table. Bridge with current crack size 0.00073m is detected due to single moving vehicles

Values of β for higher stress levels

| $N_s$ | Case study 1 | Case study-2 |
|---|---|---|
| 2x10^6 | 3.306 | 2.209 |
| 2x10^7 | 2.412 | 2.201 |
| 2x10^8 | 1.89 | 2.102 |
| 2x10^9 | 1.78 | 1.827 |




**Graph 7.1: β versus log Ns for case study 1**




**Graph 7.2: β versus log Ns for case study 2**

**SUMMARY AND CONCLUSIONS**

While designing fatigue sensitive structures like bridges, the designer must ensure that the structure is adequate against fatigue failure also. Fatigue being a complex phenomenon requires to be addressed in a rational way. Typically, fatigue is affected by every repetitive load which acts on the structure.

1. The developed stress spectrums are useful for evaluating/analyzing the reliability of the existing bridges for actual load effects with regard to fatigue.
2. The value of Reliability index (β) decreases with increase in number of cycles for all the case studies
3. Further the graphs can be used to arrive at an optimal inspection interval

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