# Fatigue Life of Reinforced Concrete Integral Bridge

**M. Verma, S. S. Mishra**

***Abstract*****:** ***Integral bridges with long spans are becoming popular day by day, as they are easy to construct with long spans and require fewer maintenance efforts due to the absence of bearings. However, due to movement restraints, fatigue stresses build-up that leads to a reduction in a useful life. In this paper results of an analytical study are presented for the fatigue life of an integral bridge exposed to transient loads. Transient analysis of reinforced concrete integral bridge of total length 156 m having 5 continuous spans with the central maximum span of 40 m has been done using ANSYS. The roles of deformation and strain that occur in the bridge have been found to influence fatigue life. Further, midpoint deflection in the longest span, its variation with loading history and its influence on fatigue life has also been analyzed and found to match satisfactorily with standard results.***

***Keywords: Integral bridge, Fatigue life, Transient loading.***

## I. INTRODUCTION

Integral bridges in the simplest term can be classified as bridges with monolithic construction between the superstructure (deck, slab, and girders) and the substructure (piers and abutments). The deck-support joints become moment resistant rigid joints. In integral bridges, since bearings are absent, the problems associated with the installation, maintenance, and replacement of bearings are eliminated as they are very costlier and become very uneconomical for repair.

Transient loads are the loads that occur for a short time interval. For example, traffic over the bridge, wind gusts, humans walk over the floor, etc. These loads will not remain as it is for a long time. For the case of a bridge, these loads include traveling vehicular loads and sometimes including dynamic load allowance, braking force. These subsequent effects shall always be collectively considered with the gravity effects of live loads. For this study, only the vehicular load (70R) is considered according to Indian standard IRC-6:2014 and the permanent load that includes material load of bridge structural and nonstructural components. For simplicity down drag forces, horizontal earth pressure loads, vertical pressure due to a dead load of earth fill, earth surcharge load, force effects due to creep, shrinkage, secondary forces that are generated from post-tensioning of members, and other forces that are introduced due to construction process are not taken into consideration.

Due to the applied transient loading, the bridge deck deflects and expands. Other parts of the bridge also show such a tendency of deflection and expansion. This deflection and expansion from deck and girders are transferred to the piers because of the fixity of joints. The bridge girder in these types of loading shows a similar behavior as a fixed beam behaves [1]. As in the fixed beam, a large amount of deformation occurs in the integral bridge in the middle of the longest span and this deformation results in the plastic deformation at the same location [2]. Depending upon these variations in expansion and deflection, a bridge may show different types of mechanical responses [3].

There are three approaches to analyzing fatigue life and these are strain-based, stress-based, and fracture mechanics based. In ANSYS 17.1 Fatigue Module, only strain life and stress life methods are available.

At present, the approach based on strain is commonly used for fatigue life prediction. Strain life mainly deals with the occurrence of a smaller number of fatigue cycles so-termed as low-cycle fatigue. The strain life-based approach is based on crack initiation. By using this approach, the fatigue life can be predicted to the acceptable limit.

## II. METHODOLOGY

### A. Analysis Procedure

The following steps are performed for analysis-

- Generating a software-based model in ANSYS 17.1 for fatigue analysis.
- Applying the transient loads using (IRC:6-2014 70-R)
- Performing the analysis
- Validating the result obtained from the proposed model.
- Determining fatigue life of the integral bridge

### B. Mathematical formulation for fatigue life

The RC structural members fail due to the failure of steel rebars in tension. The fatigue life of steel rebars with and without plastic deformation is given as [4],

$$N_f = 2(13.35\varepsilon)^{-2.2173} \qquad (1)$$

where $\varepsilon$ is total strain amplitude, $N_f$ is the number of cycles to failure. The value of total strain can be obtained in terms of axial strain ( $\varepsilon_{xx}$ , $\varepsilon_{yy}$ , $\varepsilon_{zz}$ ) and

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shearing strain( $\gamma_{xy}, \gamma_{yz}, \gamma_{zx}$ ) as,

$$\varepsilon = \frac{\sqrt{(\varepsilon_{xx} - \varepsilon_{yy})^2 + (\varepsilon_{yy} - \varepsilon_{zz})^2 + (\varepsilon_{xx} - \varepsilon_{zz})^2 + \frac{3}{2}(\gamma_{xy}{}^2 + \gamma_{yz}{}^2 + \gamma_{xz}{}^2)}}{\sqrt{(2(1+\upsilon)}} \tag{2}$$

The values of axial strain and shearing strains are obtained from finite element analysis in ANSYS. The model correlates up to 98.5% with the experimental results [5]. In this model, the elements are sorted from the elements with the least number of cycles to failure to the highest number of cycles to failure. Elements with the least number of cycles to failure are killed which results in the decrease in the stiffness of that element to zero. The load-bearing capacity of that element becomes zero. The accumulated damage in the remaining elements is found by,

$$D_{accumulated} = N_{f1} \times D_{cycle1} \tag{3}$$

where $D_{cycle1}$ = damage after the first $N_{f1}$ cycles.
For each element, the value of damage after the first run is different as the stress and strain value is different for every other element. The value of damage after first FE analysis can be obtained as,

$$D_{cycle1} = 1/N_{f1} = 1/2(13.35\varepsilon)^{-2.2173} \tag{4}$$

where $\varepsilon$ = strain amplitude after $N_{f1}$ cycles.
The residual strength after the first FE run is equaled to the left out damaged after damage accumulation.
Mathematically,

$$D_{residual} = 1 - D_{accumulated} \tag{5}$$

And the remaining number of cycles to failure will be obtained as,

$$N_{f2} = D_{residual} \Bigg/ \left( \frac{1}{2(13.35\varepsilon)^{-2.2173}} \right) \tag{6}$$

The total number of cycles to failure $N$ is given as

$$N = N_{f1} + N_{f2} \tag{7}$$

Final number of cycles to damage can be calculated as,

$$N = 6.389 \times 10^{-3} \varepsilon^{-2.2173} + \frac{D_{residual}}{\left( \frac{1}{6.389 \times 10^{-3} \varepsilon^{-2.2173}} \right)} \tag{8}$$

Thus, this process propagates by killing the element until the structure fails to bear the applied stress.The presented model is validated by finding the fatigue life of target integral bridge using the model presented by Koh and Stephens [6],

$$\varepsilon = 0.0795\left(2N_f\right)^{0.448} \tag{9}$$

where $\varepsilon$ is strain amplitude in one cycle of loading and $N_f$ is number of cycles to failure.

## III. INTEGRAL BRIDGE UNDER STUDY

In this study, an integral bridge is considered which is similar to the existing Kalkaji Flyover at Okhla Industrial Area in New Delhi.

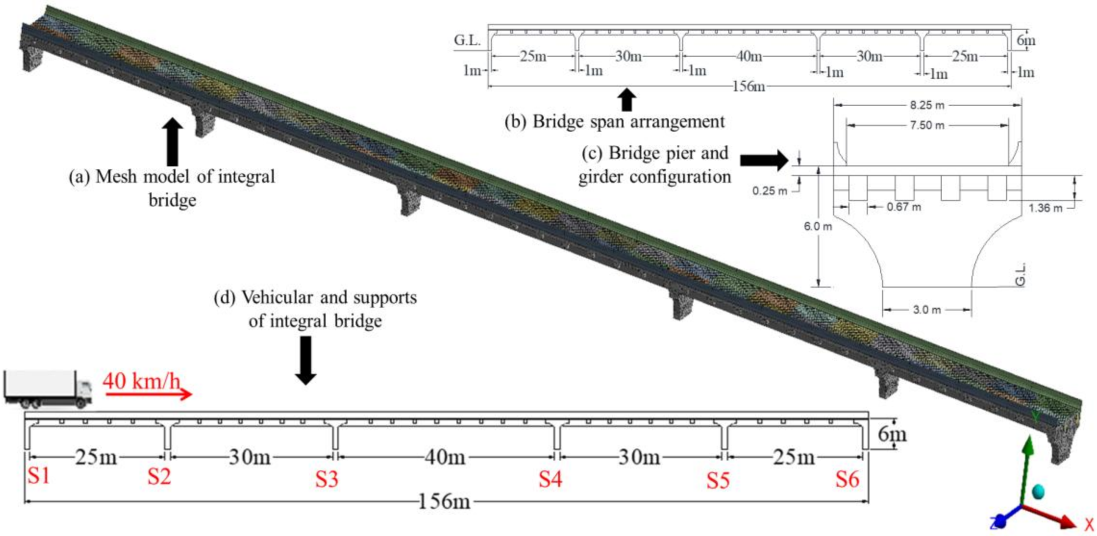

Fig. 1. Mesh Diagram of Integral Bridge with different grometical properties

This bridge is a 156m long flyover near Kalkaji Temple. The overall width of the deck is 8.25m having a carriageway width of 7.5m. It has five continuous spans of 25m + 30m + 40m + 30m + 25m. It has a total deck depth of 1.7m including the deck slab thickness of 0.24m and the main girder of size 0.67m x 1.36m. The transverse length of the pier is 3m which expands to the full width of the deck at the top.

The thickness of the pier is 1m uniform throughout its height. Hunches of size 0.5m x 0.5m have been provided at the junction of the deck girders and piers.

In this paper, soil properties are not considered and the foundation is assumed to be fixed. Fig. 1. shows the bridge model for analysis and the span arrangements of this integral bridge. The complete physical Finite element base mathematical model is prepared by ANSYS 17.1. The element used is SOLID185. IRC:6 [7] recommendations are considered for load analysis. The total bridge width was taken as 8.25 m having two lanes of 3.75 m each. A design load of a 70R wheeled vehicle is used in this analysis. A large number of field investigation has been done by taking such loads on Integral abutment bridge [8], [9].

## IV. ANALYSIS PROCEDURE

For analyzing the fatigue performance of an integral RC bridge, a vehicle of 100 tons is allowed to move from one end to another end. These loads are usually considered corresponding to a city vehicle speed of 40 km/h. Fig. 1 shows support S1, S2, S3, S4, S5, and S6, where maximum and minimum reaction force (Fig. 2) and moment reaction (Fig. 3) are extracted from ANSYS analysis results. Further, these results are used to find out the strain at a critical point to calculate the fatigue life of the bridge.

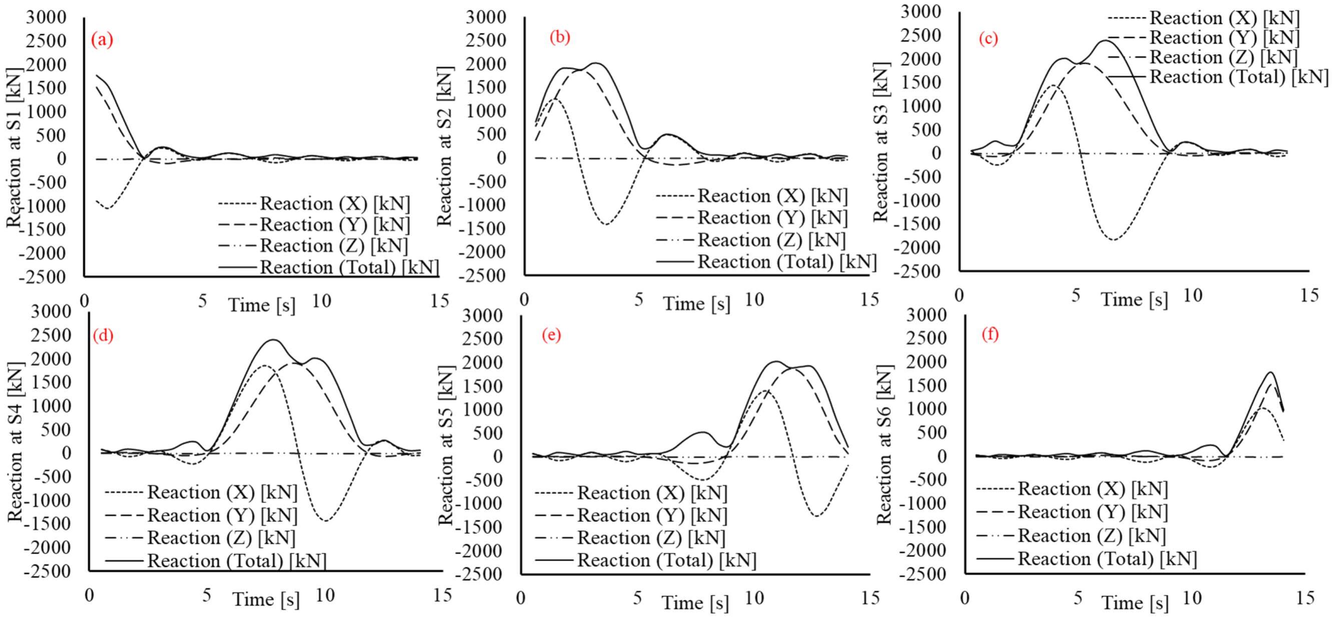

**Fig. 2. Reaction at Support (a) S1, (b) S2, (c) S3, (d) S4, (e) S5 and (f) S6**

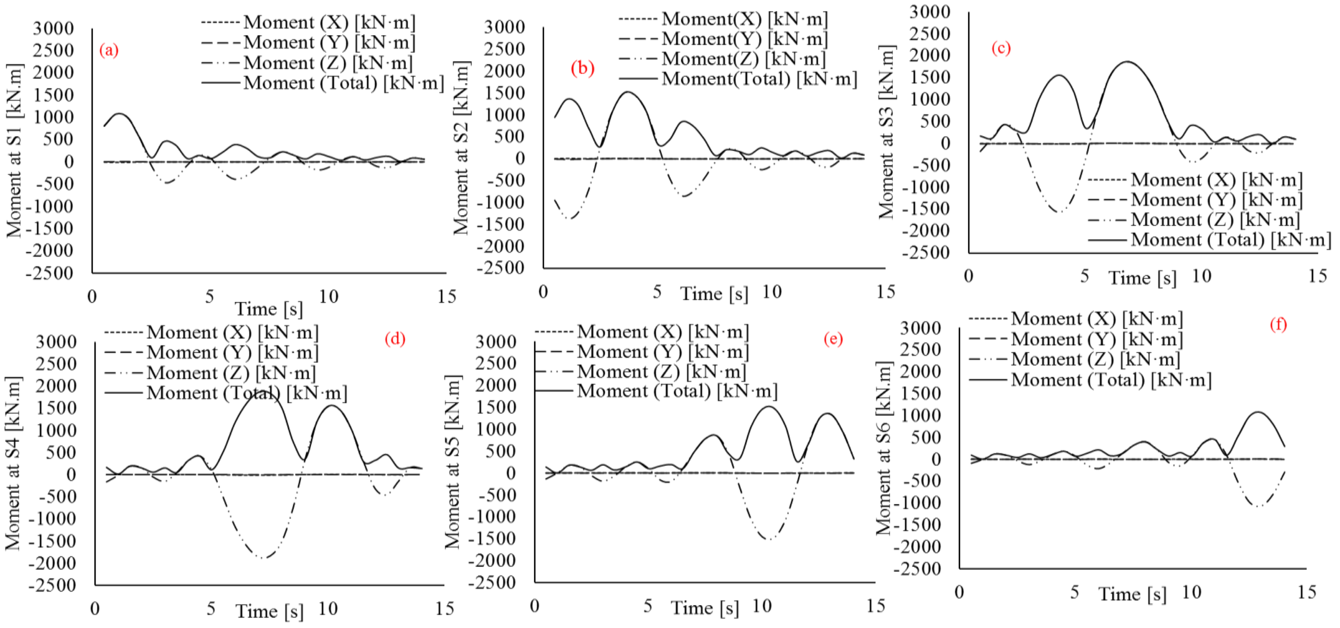

**Fig. 3. Moment at Support (a) S1, (b) S2, (c) S3, (d) S4, (e) S5 and (f) S6**

## V. RESULT AND DISCUSSION

The value of maximum and minimum resultant reaction forces and moments at each support are given in Table I & Table II respectively and Fig. 2 and Fig. 3 shows graphical variation. The strain amplitude obtained from the analysis is presented in Fig. 4.

**Table- I: Reaction at Supports**

| Reaction Force [kN] | | | | | | |
|---|---|---|---|---|---|---|
| | S1 | S2 | S3 | S4 | S5 | S6 |
| Maximum Value Over Time | | | | | | |
| X Axis | 208.35 | 1215.5 | 1440.7 | 1845.7 | 1396.5 | 1022 |
| Y Axis | 1524.6 | 1857.6 | 1898.7 | 1901.5 | 1863 | 1522.5 |
| Z Axis | 0.22 | 0.45 | 0.36 | 0.54 | 0.65 | 0.28 |
| Total | 1765.7 | 2018.2 | 2356.6 | 2374.6 | 2016.1 | 1759 |
| Minimum Value Over Time | | | | | | |
| X Axis | -1045 | -1409 | -1829 | -1443 | -1234 | -207.2 |
| Y Axis | -101.4 | -146.2 | -73.42 | -74.32 | -145.7 | -94.73 |
| Z Axis | -0.31 | -0.35 | -0.44 | -0.47 | -0.57 | -0.36 |
| Total | 3.47 | 7.26 | 5.13 | 11.49 | 0.59 | 0.54 |

**Table- II: Moment at Supports**

| The moment at Support [kN.m] | | | | | | |
|---|---|---|---|---|---|---|
| | S1 | S2 | S3 | S4 | S5 | S6 |
| Maximum Value Over Time | | | | | | |
| X Axis | 1.02 | 7.22 | 10.65 | 4.95 | 4.65 | 7.2 |
| Y Axis | 5.82 | 3.16 | 8.95 | 1.75 | 0.73 | 0.6 |
| Z Axis | 1076 | 1493.4 | 1850.9 | 1548 | 1337.3 | 1634.3 |
| Total | 1076.1 | 1493.4 | 1851 | 1861 | 1477.7 | 1903.1 |
| Minimum Value Over Time | | | | | | |
| X Axis | -9.62 | -3.68 | -7.26 | -10.58 | -7.56 | -8.58 |
| Y Axis | -2.33 | -12.06 | -1.35 | -5.77 | -6.64 | -6.33 |
| Z Axis | -451.1 | -1351 | -1551 | -1861 | -1478 | -2107 |
| Total | 9.78 | 15 | 5.29 | 13.76 | 1.73 | 3.91 |

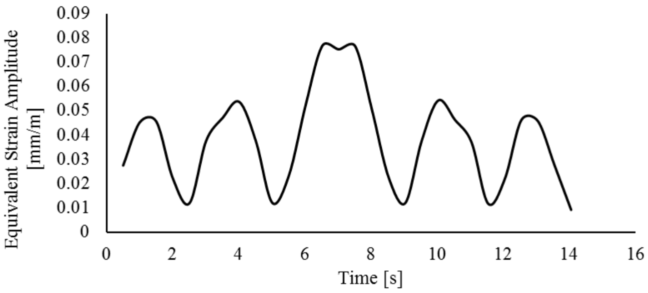

**Fig. 4. Equivalent strain variation w.r.t time.**

From the ANSYS the equivalent strain amplitude is found as 0.08mm/m at the middle of central span. This strain is used to calculate the fatigue life using equation (8) and same strain value is used in equation (9) for validation of result from proposed model. There are 1584700 fatigue cycle obtained from presented model and 1521000 cycles obtained from validation model. The result approximately corelated well with the proposed model. Converting the values of obtained fatigue cycle in terms of years by using the number of truck load passing through bridge per year. The fatigue life is obtained as 76 years.

## VI. CONCLUSION

In this paper, a finite element modeling and analysis has been conducted for estimating the fatigue-life for integral bridges of 156m length. Fatigue life is evaluated from a strain-based approach. The finite element modeling confirms that the fatigue life of an integral bridge will reduce when the total strain amplitude increases due to an increase in the length of the bridge. Fatigue behavior of integral bridge of 156m that was subjected to transient loading of 70-R as per as IRC:6-2014 is studied. The Fatigue life of integral bridge was found to be approximately 76 years for an integral bridge of total 156 m long with a maximum span of 40 m.

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