A Study on Dynamic Amplification Factor for Highway Bridges

Mr. Prajwal Ulape[1], Dr. M.R. Shiyekar [2],

[1]PG Student, Structural Engineering Department, Government College of Engineering, Karad, Maharashtra, India.
[2]Professor, Structural Engineering Department, Government College of Engineering, Karad, Maharashtra, India.

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Abstract - *Moving vehicle mass induces significant vibratory effect on the bridge structure. Such dynamic effects on bridge can cause higher stresses and deflections in bridge than the static deflections and stresses of equal magnitude. Hence, dynamic effects of bridges are needed to be taken into considerations. The term Dynamic amplification factor (DAF) is used to evaluate the dynamic effect of the bridge. The total dynamic effect of live load is obtained by multiplying. DAF to static response of the structure Accurate investigation of dynamic response of the bridge is complicated and cumbersome procedure, which involves various parameters. Therefore, there is an urgent need to develop an accurate method to evaluate DAF. In actual practice, there exists no rational method to evaluate DAF caused due to moving load over structure. An analytical investigation is carried out to find the effect of vehicle velocity and span length on DAF for bridge structure using SAP2000. The main focus of this study is to analyze the static and dynamic behavior of RCC longitudinal girder and Concrete decks bridge caused by the vehicular loading IRC Class A and Class B loading with different vehicle velocity. Considering different span lengths subjected to IRC class A and class B loading with variable velocity, Dynamic amplification factor (DAF) is evaluated. It is observed that DAF varies with change in vehicle velocity. Also, DAF values for both class A and class B loading are different.*

Key Words: *DAF, impact factor, dynamic response, SAP2000, vehicle-bridge interaction, IRC loading, Finite element analysis.*

1. INTRODUCTION

The moving vehicle mass system causes vibration on the highway bridge, which has become a crucial problem that must be investigated. Moving vehicles on the bridge generate significantly more stresses and deformations than static deformations and stresses of equal magnitude at a single section [1]. The dynamic response of a bridge and its mechanism is complex problem involves vehicle bridge interaction and the influence of a large number of components such as bridge dynamic features, vehicle characteristics, road surface roughness, vehicle speed, traffic flow conditions, and so on [2]. Many bridge engineers tackle such induced vibration concerns by taking solely the impact factors stipulated in their national codes into account, even though vibration response may depend on factors mentioned above [3]. In past years, theories are proposed if the impact factors mentioned in various national specifications are adequate for present traffic flow and road conditions. According to reports, impact factors calculated using current codes may drastically underestimate bridge response in many circumstances.[4]. Dynamic effects caused due to live loads must be considered while bridge design. The dynamic amplification factor (DAF) can be defined as, a dimensionless number which describes how many times the deflections or stresses should be multiplied to the deflections or stresses due to static loads when structure is subjected to dynamic loading [5]. As referred in various national design specifications, the total dynamic effect of live load is calculated by multiplying DAF to static response of the structure [6]. In general, a dynamic amplification factor analysis of a highway bridge under moving loads is performed, which provides often accurate results depending on the parameters stated, and the value is compared to the standard values specified in national codes. In India IRC class A and class B loading are considered for designing bridges including impact factor as specified by Indian Road Congress in IRC-06. A specified in IRC-6[14]. impact factor for bridge structure subjected to moving vehicle of IRC class A and class B loading depends upon the bridge characteristics viz. if the bridge is Steel bridge or Reinforced Cement Concrete (RCC) bridge. Impact factor due to live loading is influenced by span length of the bridge. When bridge is subjected to moving vehicle loading dynamic response of the bridge changes with variation in vehicle velocity. At present vehicle velocity is completely ignored while designing bridge structure [7]. The research of all parameters is necessary to arrive at the correct quantitative value of DAF, and it is crucial to accurately analyse how a highway bridge behaves when heavily loaded both for the improvement of design methods and for the evaluation of existing bridges. This study mainly focuses dynamic response of five simply supported bridge structures subjected to moving vehicle load. IRC class A and class B loading are considered as design loads. Static and dynamic response of the bridge are computed for each span length and vehicle velocity. A simply supported 2-lane bridge structure is modelled [8] using bridge wizard provided in SAP2000 software. SAP2000 allows static and dynamic analysis of bridge structure subjected to vehicle-bridge interaction with ease and accuracy.

2. METHODOLOGY

In this study, RCC T-beam girder bridge is considered for investigating dynamic behavior of bridge structure subjected to moving load. The bridge is modelled as per IRC-06 and IRC-21 [13]. Five different span length of bridge subjected to moving vehicle is considered to study the dynamic response characteristics. Five typical R.C. girder bridges with span length ranging from 20, 25, 30, 35 and 40 meters are considered [15,16]. The bridge span is considered to be simply supported at both ends to investigate dynamic responses of vehicle-bridge interaction.

2.1 Design Considerations

- Span of Bridge: - 20mts – 40mts
- Width of Bridge: - 10mts
- Carriageway width: - 7.5mts
- Footpath length: - 1.25mts
- No. of longitudinal Girder: - 3 Nos
- Centre-to-center distance between longitudinal girders: 3.0mts
- Centre-to-center distance between cross girders: 5.0mts
- Material properties
- Grade of Concrete: - M30 grade
- Grade of steel: - Fe415

2.2 Design Vehicle Loads for IRC loading

- IRC-6 is used for designing bridges in India. Class A and class B loading is considered for this study.

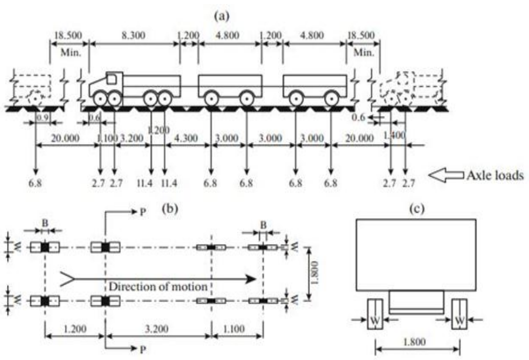

Fig -1: IRC class A vehicle loading

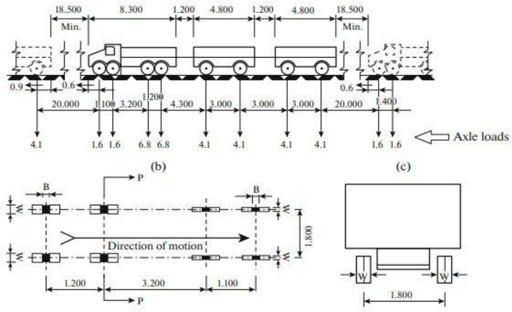

Fig -2: IRC class B vehicle loading

2.3 FEM modelling and Analysis

Finite element analysis software SAP2000 is used for modelling the RCC T-girder bridge.

Static Analysis

For obtaining static response of the bridge structure, we use Nonlinear Static Analysis. Using SAP2000 we obtain results in terms of bending moments, shear force and displacements for different vehicle velocity and span length of bridge under IRC class A and class B loading.

Dynamic Analysis by Time-History analysis

A random loading is applied to a time-history analysis to identify the dynamic response. When dynamic effects must be taken into account, such as when calculating the dynamic response to a time-varying load or when analyzing the propagation of waves in a structure, the dynamic equilibrium is applied. The dynamic equilibrium is given in form of

$Ku(t) + Cu'(t) + Mu''(t) = r(t)$ [9]

Where K is the stiffness matrix; C is the damping matrix; M is the diagonal mass matrix; u, u', and u'' are the displacements, velocities and accelerations of the structure; and r is the applied load. When the load includes ground acceleration, the displacements, velocities, and accelerations are measured in relation to this ground motion. The stiffness, damping, and load in a nonlinear analysis can all be influenced by displacements, velocities, and time. This requires and iterative solution to the equations of motion. Generally modal superposition is used in solving these equations of motion but the process becomes time consuming. SAP2000 version 14.A offers Direct integration of these equations without need of modal superposition [12]. For performing Direct integration Time-History analysis, the "Hilbert- Hughes-Taylor alpha" (HHT) method was used. In HHT a single parameter alpha is used. Values of 'α' ranges between 0 and -1/3. In HHT method $\alpha = 0$, the method can be same as the Newmark method [10], where $\gamma = 0.5$ and $\beta = 0.25$, which is equivalent to average acceleration method [12]. It is recommended that for higher accuracy results '$\alpha = 0$' should be used.

International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 10 Issue: 07 | July 2023 www.irjet.net p-ISSN: 2395-0072

3. RESULTS AND DISCUSSION

The dynamic response of the vehicle at lower speed such as 20kmph for each span of the bridge is evaluated. Vehicle velocity is then further increased gradually to 130 kmph and dynamic responses in terms of displacements, bending moment.

Bending moment

- It can be observed that maximum value of bending moment for span length 20-30mts is observed for vehicle velocity of 90 kmph. Positive correlation between vehicle velocity and bending moment can be observed.

- For span lengths35mts and 40mts maximum value of bending moment is observed at vehicle velocity of 110 kmph and 130 kmph respectively.

- For all span lengths considered in study about 5-11% increase in bending moment is observed when vehicle velocity is increased from 20 kmph to 90 kmph for IRC class A loading

- For IRC class B loading, for all span lengths considered in study about 8-22% increase in bending moment is observed when vehicle velocity is increased from 20 kmph to 130 kmph.

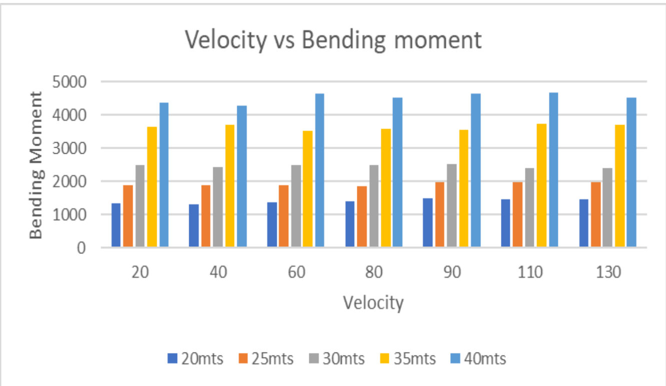

Chart -1: Bending moment for Class A loading

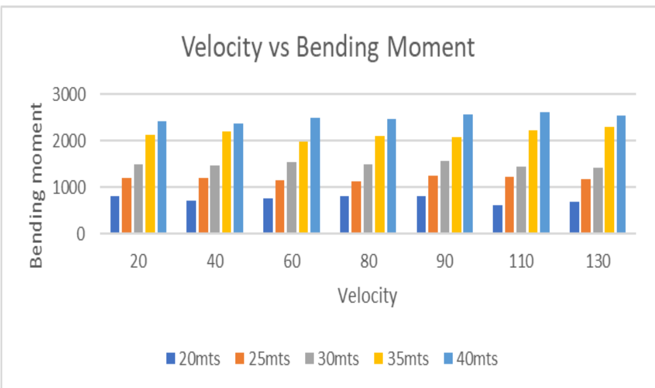

Chart -2: Bending moment for Class B loading

Displacements

- Maximum dynamic displacement is observed near mid-span of the section. Displacement values were increasing with increase in velocity of loading.

- For class A loading- For all span lengths dynamic displacement increases 20-39% as vehicle velocity increases from 20kmph to 130 kmph.

- For class B loading- It is observed that dynamic displacement for all span lengths increases 18-36% as vehicle velocity is increased from 20kmph to 130 kmph.

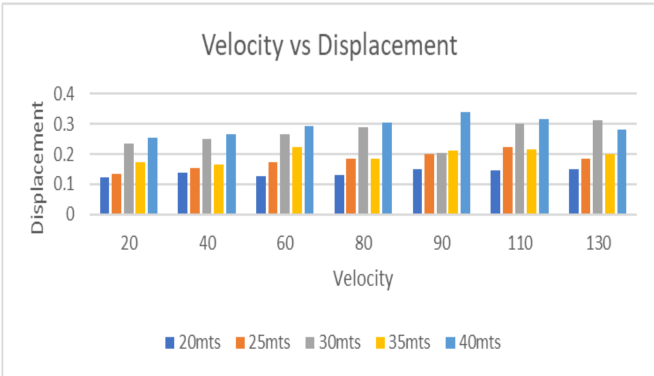

Chart -3: Displacements for Class A loading

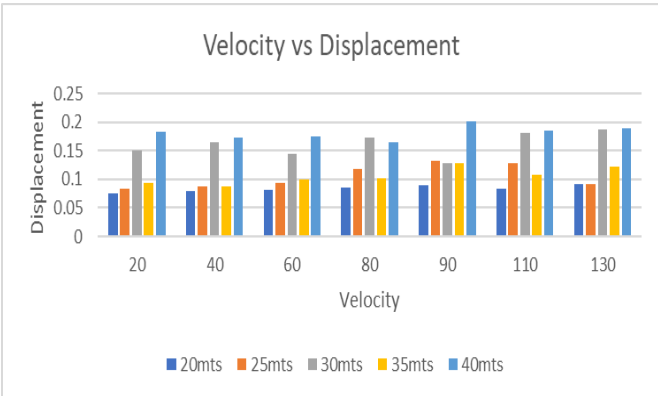

Chart -4: Displacements for Class B loading

3.1 Dynamic Amplification Factor (DAF) calculations Sub

Dynamic Amplification factor DAF can be evaluated as ratio of maximum dynamic effects to the maximum static effects on the bridge structure caused by the vehicle loading.

$$DAF = \frac{R_{dynamic}}{R_{static}} \quad [11]$$

$R_{dynamic}$ – Total dynamic load effects

R_{static} – Total static load effects

• For IRC class A loading – DAF value increases 3-6% when vehicle velocity is increased from 20 kmph to 130 kmph.

• For IRC class B loading – DAF value increases 5-13% when vehicle velocity is increased from 20kmph to 90 kmph.

• It can be observed that DAF values are different for IRC class A and class B loading which is contradictory to the as mentioned in IRC-06.

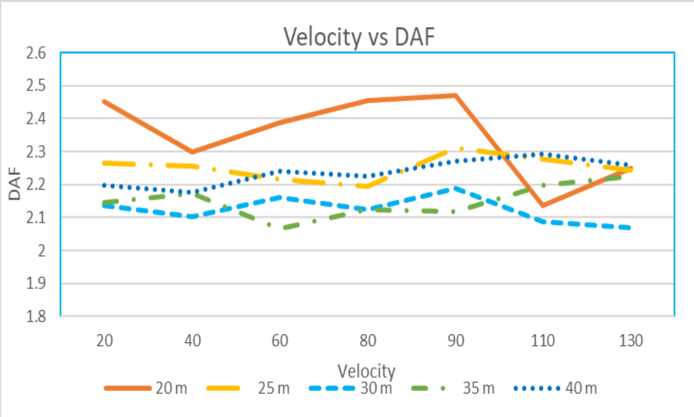

Chart -5: Velocity vs DAF for each span length and IRC class A loading

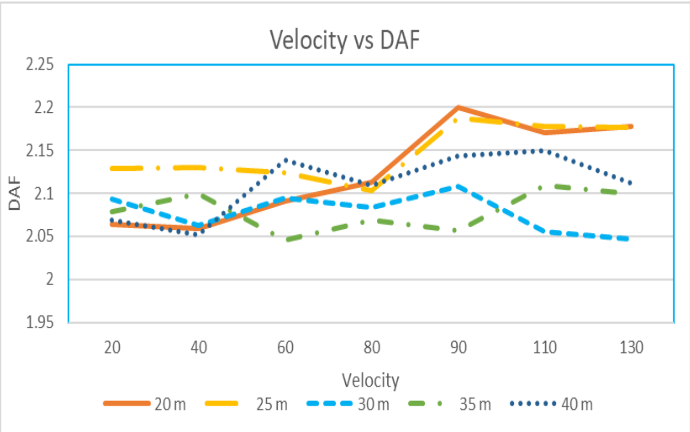

Chart -6: Velocity vs DAF for each span length and IRC class B loading

4. CONCLUSIONS

The main aim of this study was to investigate effect of vehicle velocity on dynamic response of the bridge. From the results obtained, it can be observed that, vehicle velocity plays an important role in influencing dynamic response of bridge structure. The DAF is evaluated for IRC class A and class B loading accordingly. From the results obtained it can be observed that DAF varies significantly with increase in vehicle velocity and hence vehicle velocity must be included as an important parameter to investigate DAF along with other parameters.

Following conclusions can be drawn,

• Bending moment and displacement increases with increase in vehicle velocity and span length of the bridge.

• Vehicle velocity plays an important role in influencing Dynamic amplification factor, it can be observed that DAF increases as vehicle velocity increases maximum value of DAF is calculated at vehicle velocity 90 kmph – 130 kmph.

• It is clearly observed that DAF values for IRC class A and class B loading are different.

• Maximum calculated value of DAF obtained was 2.47, which was achieved on a 20mts span length bridge by IRC class B loading moving at 90 kmph. Lowest calculated value was for Span length 30mts subjected to IRC class A loading with 130kmph vehicle velocity 2.046.

• Hence, it can be observed that the DAF value for lighter vehicle is 16.68% more than that for heavier vehicles even though considered same in IRC-06.

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