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Investigating the Structural Integrity and behavior of Bridge under Various Vehicle Loads

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Abstract—*Structural engineers face a significant challenge in keeping up with changing live load requirements in bridge design codes, especially in developing countries where infrastructural growth demands consideration of larger and heavier vehicles. The purpose of this study is to investigate the structural integrity and behavior of the bridge under these varying load conditions. This study investigates, massive special vehicle (SV) weighing 3850 kN and around 40 meters in length which has been amended in Indian Roads Congress (IRC) code 2017. For analysis, a span of bridge Han-Jiang at Shayang in Wuhan, China has been considered, and validated. The focus of the analysis is a specific span of the bridge, measuring 50 meters in length, which has been subjected to various vehicle loadings. To address these concerns, the effects of SV has been compared to other loading classes (Class 70R, Class AA, Class A, and Class B) by applying loads in ABAQUS and comparing maximum bending moment which is coming 9.47, 5.63, and 2.87 times greater than the maximum bending moment produced by class B, class A, and class 70R wheeled vehicles respectively.*

Keywords: *ABAQUS, Bending moment, FEM, IRC-6, Special Vehicle.*

INTRODUCTION

A bridge is a structure that is designed to provide a way to cross an obstacle, such as a river, a valley, by spanning it with a platform or roadway. They can also be classified based on their use, such as pedestrian bridges, road bridges, railway bridges, or aqueducts. Bridges can be made of various materials, such as steel, concrete, wood, or stone and can be designed in many different styles and configurations, depending on their purpose and the environment in which they are located.

Though bridge infrastructure is rapidly developing, the majority of it is concentrated in urban areas in developing nations. According to 2021 statistics, there are 152 developing nations in the globe that are concentrated on infrastructure development, and the upgrading of bridge design codes in these countries provides a fascinating yet challenging situation for engineers. Developing countries like India, focuses on improving transportation facilities by allocating substantial fund to it and revised specifications according to development of vehicles for perfecting methods for building long-lasting and sustainable bridges that are appropriate for the local circumstances. The main aim of the Standard Specifications and Code of Practice is to provide a uniform framework for the construction and design of road bridges in India. For instance, The Indian Road Congress (IRC) published code recommendations for live load combinations to be considered for bridge construction in IRC 6 in 1958 (IRC-SP004 (1966)). While this publication is intended to assist both the design and construction engineers, it should be noted that adhering to the guidelines outlined in the document does not absolve them of their responsibility for ensuring the structural integrity and stability of the bridge they construct and design. The code standards were revised from time to time between then and its most recent seventh revision in 2017. From then until its seventh revision in 2017, the code standards were updated on a regular basis, with the heaviest load to be considered in design rising from 700 kN to 3850 kN (IRC-6 (2019)). The length of India's longest road bridge grew from 1936 m to 9150 m during this time period, indicating the rate of growth. To place everything in context, Fig. 1 shows a year-by-year comparison of the code revision with a parallel comparison of the longest bridge at the time (IRC-SP 004 (1966), IRC-6 (2000, 2010, 2014).[1]

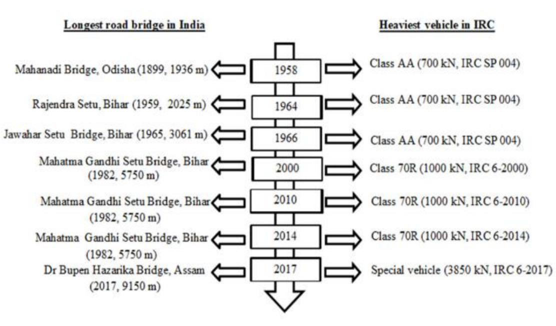


Figure 1: Longest bridge and heaviest IRC loadings in India[1]

Bridges typically consist of a sub-structure and a superstructure. When designing the bridge deck slab of the superstructure, traditional considerations include dead load, live load, and impact load. For highway bridges in India, the IRC code defines two types of live loads: Class-A and Class-70R/Class-AA. For two-lane Indian highway bridges, the IRC code requires that they be designed for Class-70R/Class-AA tracked and wheeled vehicles on one lane and evaluated for Class-A loading on both lanes. The moment generated on the deck slab is due to these loads. Therefore, bridge decks can be designed for the maximum moment caused by rupture.

Typically, the design moment for an elastic bridge is determined by superimposing the maximum moments caused by dead load and live load effects. The highest bending moment is caused by evenly distributed loads at mid-span, where the IRC Class-70R tracked vehicle is placed symmetrically to create maximum moment. However, for wheeled vehicular loads with multiple axles, the absolute maximum bending force in a simply supported bridge occurs beneath one of the wheels, which is not necessarily at mid-span. Figure 2 illustrates the load arrangements based on vehicle movement in a particular direction.

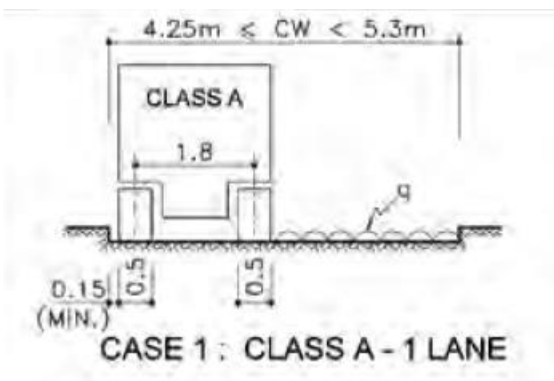
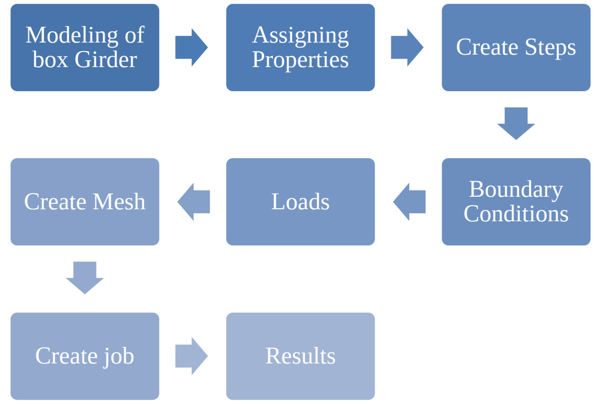


Figure 2: Load arrangements[3]

METHODOLOGY

To investigate the influence on bending and flexural properties due to the vehicle loads according to IRC-6 by using the real dimensions of a bridge named Han-Jiang bridge at Shayang in Wuhan, China and validate the bridge using Finite element (FE) analysis in ABAQUS software. After validating the model in ABAQUS various bridge component design will be developed and various loads (according to IRC-6) is applied to test the bending moment of the bridge for various vehicle loading.



MODELING OF DECK SLAB (BOX GIRDER)

The Han-Jiang bridge is a straight and non-skew structure that spans a 50m distance while being supported at both ends. It measures 10.8 meters and is constructed as a single cell box section with an overall depth of 2.96 meters. The bridge consists of a top slab that is 250mm thick, a bottom slab that is 280mm thick, and a web that is 360mm thick. Additionally, the structure features a 200mm wide curb on both sides, which results in a clear highway width of 10.4 meters, as depicted in Figure 3.[4] The span of bridge is taken 50m. Partitions are also created for applying load based on stopping sight distance.

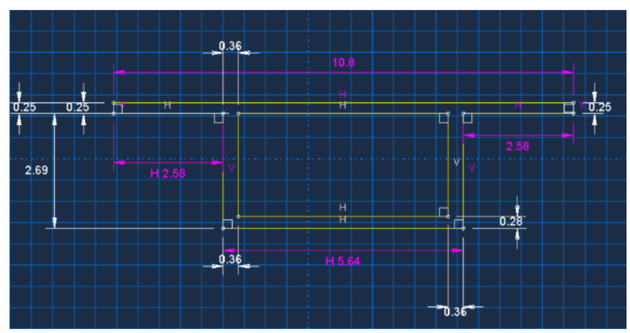


Figure 3: Cross-section of Han-Jiang Bridge (dimension in m).

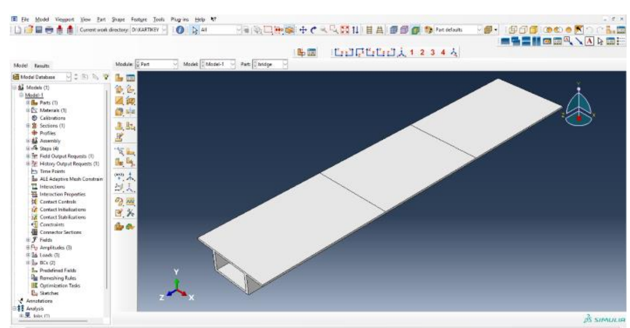


Figure 4: 3D FEM model of Han-Jiang Bridge (span 50m)

ASSIGNING PROPERTIES

We assign properties to define the characteristics of the parts and elements in the model. Assigning properties is essential because it allows us to specify the material properties and section properties of the model's parts and elements.[5] Material properties include the material's density, elastic modulus, Poisson's ratio. Assigning properties in ABAQUS is done through defining sections and elements. When you assign a section to a part, ABAQUS/CAE automatically assigns that section to each instance of the part, and the elements that are created when you mesh those part instances will have the properties specified in that section. We assigned concrete's material qualities are as follows: Poisson's ratio 0.2, density 25 kN/m3, typical strength 25 MPa, and modulus of elasticity 2.5107 kN/m2.[4] Material properties are assigned for doing elastic analysis of the FEM modelled bridge. After the properties is assigned, it should be homogenously applied to whole modelled bridge as shown in Fig. 5 below

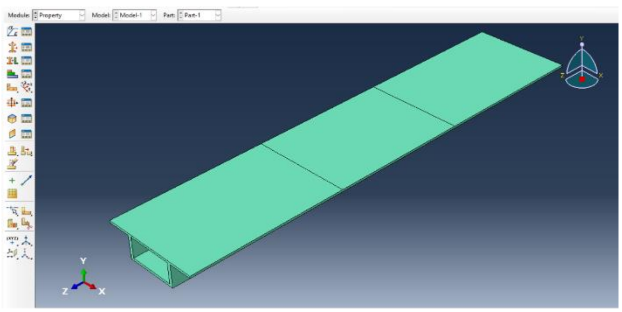


Figure 5 3D Modelled bridge with homogenous property

CREATING STEPS

In ABAQUS, steps are established to divide the problem history into manageable phases. There are various reasons for using multiple phases in an analysis, such as changing the type of analysis technique or changing output requests, contact pairings, boundary conditions, or loading. Furthermore, in ABAQUS/Standard, such steps are considered as a linear perturbation about the preloaded, prepared state generated by any preceding general steps. This enables more general linear simulations than a strictly linear analysis programme. As a result, creating steps in ABAQUS bridge modelling helps to break down the problem into manageable phases and allows for greater flexibility in the study.[5]

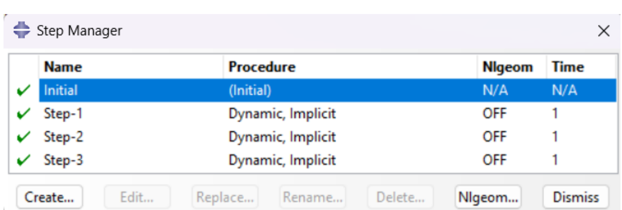


Figure 6: Created steps as per partition of deck slab

BOUNDARY CONDITIONS

Simply-supported bridges (hinges at one end and rollers at the other) were explored in this study because they are the least redundant and so represent the most essential scenarios. Simple support conditions were modelled as follows: no z(depth) displacement at supports. At the supports, rotations about the three axes (X, Y, and Z) are permitted.

LOADS

The loads applied according to IRC-6 in the design of bridges in India are based on the weight of the bridge components and the standard vehicle loads specified by the guidelines. These loads can be applied to the bridge in a variety of ways, depending on the design of the bridge and the type of analysis being performed.[2] For example, in a finite element analysis, the loads can be applied to the bridge deck or the roadway surface, and the load distribution can be adjusted according to the specific requirements of the analysis. In accordance with IRC 6-2017, the study examined moving loads on a single span bridge that was simply supported. Wheeled vehicles were simulated as uniform loads applied between the front and rear axles, while tracked vehicles were simulated as linear loads distributed uniformly in ABAQUS. The maximum bending moment was determined by moving the entire vehicle from one end support to the other.[2] The study analyses the movement of different classes of vehicles on 50m span length, considering factors such as vehicle class, spacing between vehicles, center to center distance between wheels, and stopping sight distance to determine the number of vehicles that can be accommodated on each span.

The Indian Road Congress (IRC) has established various loadings for the design of bridges and culverts. For highways intended for Class 70R traffic, Class 70R loading should be used and verified for Class A loading as well, as greater strains may occur under Class A loading in certain conditions. Class AA loading is required for bridges inside certain municipal boundaries, in designated industrial districts, and along certain routes. Bridges designed for Class AA loading should also be examined for Class A loading, as it may result in greater pressures in some cases. Class A loading is typically used for permanent bridges and culverts on all roads, while Class B loading is for timber bridges. Special Vehicle (SV) loading should be used for the design of new bridges in specific corridors where trailer vehicles carrying heavy equipment and machinery may occasionally pass, as determined by the relevant authorities. Incorporating this loading, which represents a range of special vehicles in the nation, is encouraged whenever possible.[3]

Table 1: Different type of loading according to IRC-6[3]

CLASS OF VECHILE	LOAD (KN)
Class B	**328**
Class A	**554**
Class 70R Wheeled	**1000**
Class AA Wheeled	**400**
Special vehicle	**3850**
Class 70R Tracked	**700**
Class AA Tracked	**700**

CREATE MESH

Meshing is done in ABAQUS for a number of purposes, including to split the domain into parts, each of which represents an element, and to make the issue solvable using the Finite Element Method. Additionally, meshing enables the choice of several meshing methods that offer various degrees of human control and automation. The number of elements involved in discretizing the bridge deck slab has been varied from 1800 to 2000 elements.

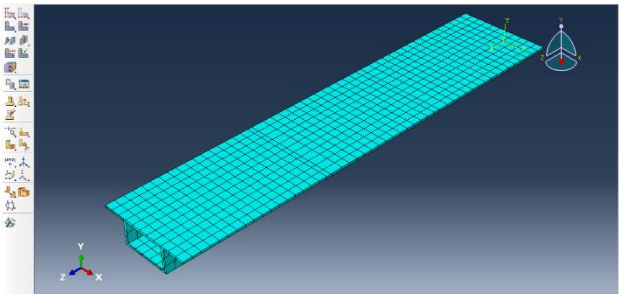


Figure10 1800 to 2000 elements mesh

RESULTS AND DISCUSSION

Validation of Model

The maximum bending moment for Special vehicle, class 70R wheeled, and class A on a 50 m span was determined manually through the rolling load concept. This value was then compared with those obtained from Autodesk Robot Structural analysis as shown in Table 2.

Table 2 Validation of model [1]

VECHILE	SPAN (M)	MANUAL CALCULATIONS (KN-M)	ABAQUS ANALYSIS	PERCENTAGE DIFFERENCE
SPECIAL VEHICLE	50	32070	32030	0.1
CLASS 70R WHEELED	50	10889	10867	0.2
CLASS A	50	5561	5556	0.08

The loading centroid was used to calculate the resultant of loads, with the absolute bending moment acting under critical load on either the immediate left or right of the resultant. The critical load was determined by comparing the sum of loads on the left and right sides of the resultant. To obtain the maximum bending moment, the midpoint of the critical load and resultant should coincide with the centre of the bridge. Assuming that the loads on the left side of the resultant R are greater than the loads on the right side, for a bridge with a span length of L.[1]

RESULTS

An exhaustive 3D finite element analysis has been undertaken to examine the effect of different vehicle loading (acc. To IRC-6) on simply supported single cell concrete box-girder bridges. Results from the above study can be summarized as follows:

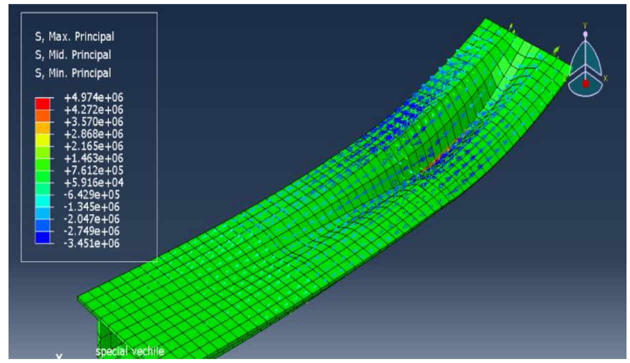
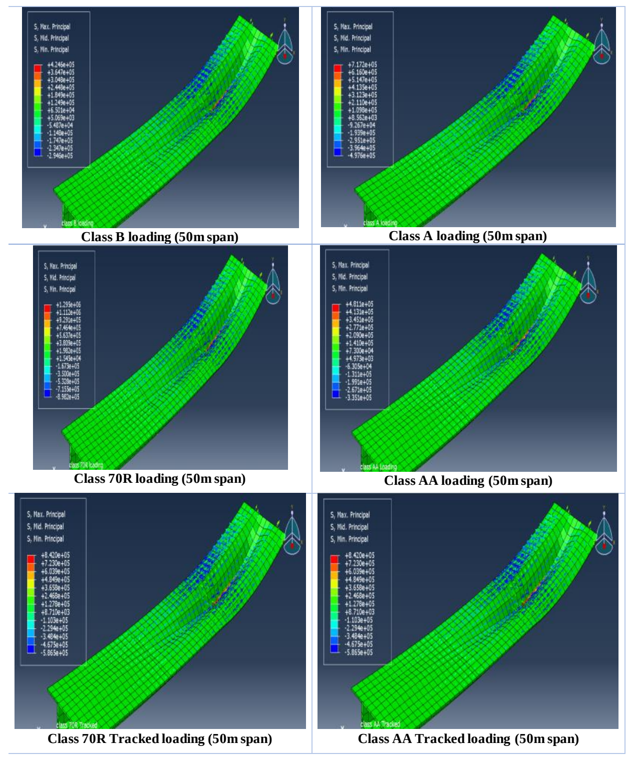


Figure 11: Special Vehicle Loading

Table 3 Different stresses after loading



Class B loading (50m span) | Class A loading (50m span)

Class 70R loading (50m span) | Class AA loading (50m span)

Class 70R Tracked loading (50m span) | Class AA Tracked loading (50m span)

DISCUSSION

The figures in Fig.11 demonstrate the difference in absolute bending moment generated by different vehicle. Based on Fig.11, it is evident that the Special vehicle produces a significantly higher absolute bending moment than other vehicle classes for 50m. At a 50 m span, the absolute bending moment produced by the Special vehicle is 9.47, 5.63, and 2.87 times greater than the maximum bending moment produced by class B, class A, and class 70R wheeled vehicles respectively.

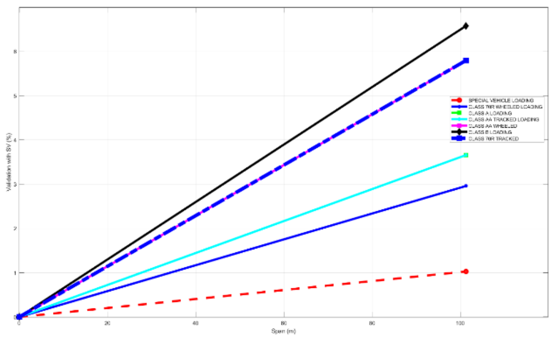


Figure 12: Comparison of absolute bending moment for spans 50 m according to IRC 6

CONCLUSION

The study highlights the challenges faced by structural engineers in designing bridges to withstand changing live load requirements, especially in developing countries with increasing demands for infrastructural growth. The investigation focused on the structural integrity and behavior of a bridge span under the impact of a massive special vehicle (SV) with a weight of 3850 kN and length of around 40 meters. The analysis was carried out on a specific span of the Han-Jiang bridge at Shayang in Wuhan, China, measuring 50 meters in length, and subjected to various vehicle loadings. The results showed that the maximum bending moment produced by the SV was significantly higher than those produced by other loading classes, indicating the need for careful consideration in the design of bridges to withstand such loads. The findings of this study can help inform the development of improved bridge design codes that can accommodate the increasing demands for larger and heavier vehicles in developing countries.

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