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Evolving live load criteria in bridge design code guidelines – A case study of India based on IRC 6

P. Karthik*, Shashi Kant Sharma [a] and M. Abdul Akbar [b]

Department of Civil Engineering, Dr B R Ambedkar National Institute of Technology Jalandhar, GT. Road, Amritsar Bypass, Jalandhar- 144011, Punjab, India

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Abstract. One of the instances which demand structural engineer's greatest attention and upgradation is the changing live load requirement in bridge design code. The challenge increases in developing countries as the pace of infrastructural growth is being catered by the respective country codes with bigger and heavier vehicles to be considered in the design. This paper presents the case study of India where Indian Roads Congress (IRC) codes in its revised version from 2014 to 2017 introduced massive Special vehicle (SV) around 40 m long and weighing 3850 kN to be considered in the design of road bridges. The code does not specify the minimum distance between successive special vehicles unlike other loading classes and hence the consequences of it form the motivation for this study. The effect of SV in comparison with Class 70R, Class AA, Class A, and Class B loading is studied based on the maximum bending moment with moving load applied in Autodesk Robot Structural Analysis. The spans considered in the analysis varied from 10 m to 1991 m corresponding to the span of Akashi Kaikyo Bridge (longest bridge span in the world). A total of 182 analyses for 7 types of vehicles (class B, class A, class 70R tracked, class 70R wheeled, class AA tracked, AA wheeled, and Special vehicle) on 26 different span lengths is carried out. The span corresponding to other vehicles which would equal the bending moment of a single SV is presented along with a comparison relative to Standard Uniformly Distributed Load. Further, the results are presented by introducing a new parameter named Intensity Factor which is proven to relate the effect of axle spacing of vehicle on the normalized bending moment developed.

Keywords: absolute bending moment; finite element analysis; IRC 6; moving load analysis; special vehicle

1. Introduction

Bridges play a vital role in developing the region and connecting the people which is prudent in economic growth and increase in the standard of living. Though there is immense development in bridge infrastructure, the initial phase of it in developing countries is mostly restricted to the urban areas. Designers are vigorously working on refining the techniques to build durable and sustainable bridges to fit the local conditions. There are 152 developing nations in the world as per 2021 stats which are focused on the development of infrastructure and the upgradation of bridge

*Corresponding author, Post Graduate Student, E-mail: pathikonda61@gmail.com; pk.ce.20@nitj.ac.in
[a] Assistant Professor, E-mail: sharmask@nitj.ac.in
[b] Assistant Professor, E-mail: maakbar83@yahoo.co.in; akbarma@nitj.ac.in

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design codes of these countries presents an interesting yet challenging scenario for engineers.

India is one of the fastest developing countries in the world. It is focused on the enhancement of transportation infrastructure by allotting significant funds to it. In 1958, the Indian Road Congress (IRC) introduced code guidelines for live load combinations to be considered for bridge design in IRC 6 (IRC-SP004 (1966)). From then to its latest seventh revision in 2017, the code guidelines were updated from time to time by increasing the heaviest load to be considered in design from 700 kN to 3850 kN (IRC-6 (2019)). During this period, the length of the longest road bridge in India increased from 1936 m to 9150 m which indicates the pace of development. To put everything in context, a year-wise comparison of the code revision with a parallel comparison of the longest bridge at that time is presented in Fig. 1 (IRC-SP 004 (1966), IRC-6 (2000, 2010, 2014)). The year of commissioning along with the length is mentioned for each bridge in brackets.

Indian road congress has introduced a Special vehicle (Fig. 3(a)) in IRC 6-2017 edition as the longest and heaviest vehicle to be considered in the design. The Special vehicle is a humongous 20 axle trailer truck weighing 3850 kN which may be used to transport heavy machinery (IRC-6 (2019)). On a comparative note, the heaviest vehicle considered in developed nations like the United States of America according to AASHTO is 6667 kN in weight which is 1.7 times the Special vehicle (AASHTO and Officials (2010); AASHTO LRFD (2015); (IRC-6 (2019)). Special vehicle is not regular truck and the usage of such Special vehicle in India is still in its infancy when compared to the developed nations. Designers should keep an eye on changes introduced in code as the vehicle load should be analyzed as a moving load along with its inherent aspects such as wheel spacing, axle configuration, etc. (Wang *et al*. 2019). Analysis of large bridges invariably involves two steps. Firstly, a simplistic line model of the bridge is analyzed for moving loads to obtain the configuration of vehicles that would produce the maximum value of bending moment and stresses. Thereafter, a detailed finite element analysis is carried out for the configuration that will produce the maximum effect as obtained from the line model. This will avoid the need for moving load studies in the detailed finite element model which is already computationally intensive and what may have necessitated additional aspects like Python scripting to implement the programming. Fig. 2 shows the finite element model of a box girder bridge modeled and analyzed by the authors as part of ongoing research on fatigue. Monitoring the advancements in moving loads is very important for determining the fatigue deterioration (Gu *et al*. 2014, Mori

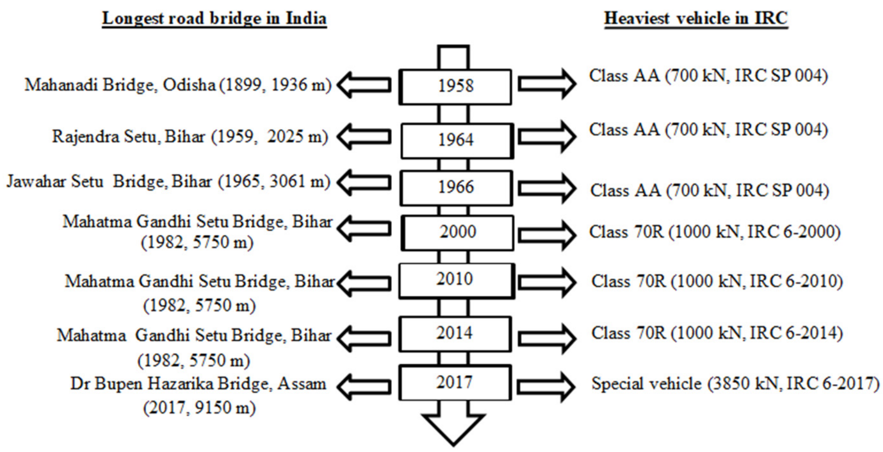

Fig. 1 Longest bridge and heaviest IRC loadings in India

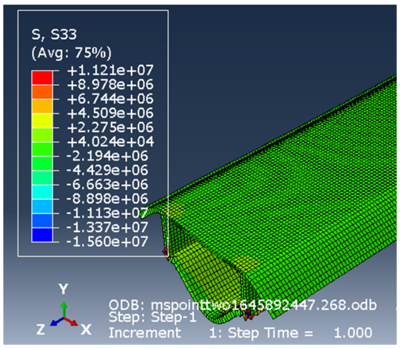

Fig. 2 Finite element model of box girder bridger

et al. 2007) and remaining service life of the bridge (Kim 2012, Yang *et al*. 2004). To help the designers, this paper presents a quantitative and qualitative comparison of the Special vehicle to other four classes of vehicles: class B, class A, class 70R (wheeled & tracked), class AA (wheeled & tracked) already mentioned in the earlier code (Fig. 3). Moving load studies were carried out using Autodesk Robot Structural Analysis Professional 2020 (Autosesk RSA manual 2013). Comparison of live loads in IRC 6-2014 and IRC 6-2017 based on the inclusion of the Special vehicle and additional insights are presented relating to other classes of vehicles.

Bridge engineers are always on the vigil as the updated vehicular load needs to be considered in the bridge design. The response of bridge structures is to be understood as it is essential for design considerations (Erdogan and Catbas 2020). There is a need for design aids that will eliminate the need for detailed moving load studies for every scenario that is present. Although newer bridges can be designed for the vehicular live loads specified in the latest codes available, there is a need to quantify the effect of heaviest vehicles from a research point of view. In this context, Shipman has calculated the maximum bending moment produced by the HL-93 truck for spans greater than 12 m and developed an expression for it by considering lane load (Shipman 2014).

Further, Gupta and Kumar (2017) have calculated the critical load and position of class 70R, class A vehicles that produce maximum bending moment for spans up to 50 m by using rolling load concepts as design aids for the design of bridges. The study has shown that as the critical load approaches the mid-span, the length of the span increases (Gupta and Kumar 2017). Though the occurrence of maximum bending moment is under the critical load (Karnovsky and Lebed 2010), its position may not be strictly at the center of the span because the centroid of loading changes with an increasing number of vehicles and length of the span. Hence, the absolute bending moment has to be calculated by moving the vehicle completely over the span. The moving load study should include the complete range of motion with the front wheel entering the bridge through one end and the rear wheel exiting through the other end with additional vehicles following the first vehicle in accordance with the minimum spacing specified in the code. The authors are yet to see such studies which deal with the complete sequence and hence have been taken up in this work. The concept is illustrated in Fig. 4. Till now, much research on the Special vehicle has not been carried out as IRC 6 included it in the code from the 2017 edition only. IRC did not mention the minimum distance between successive Special vehicles in the longitudinal direction which was mentioned for other classes of vehicles.

This is understood to mean that as the Special vehicle is very large and heavy, only one of them is likely to cross the bridge at an instance. However, interestingly, the code has also mentioned that

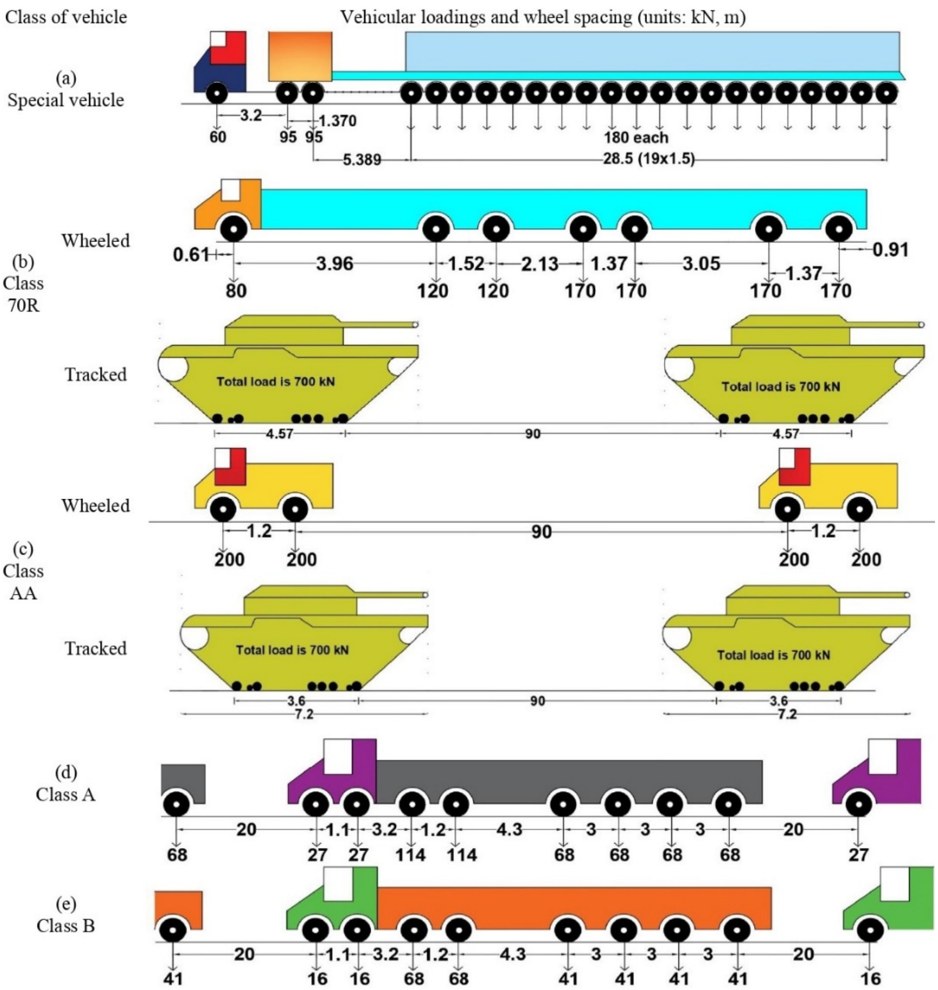

Fig. 3 Vehicles drawn according to IRC 6-2017

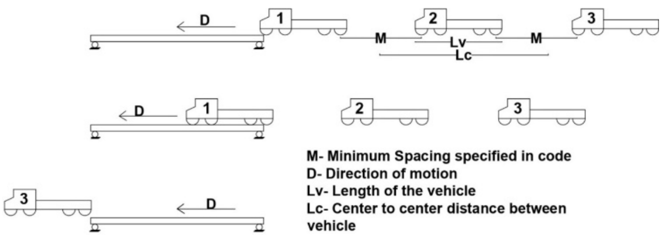

Fig. 4 Range of movement of the vehicle to be considered

no other live load needs to be considered on the bridge when the Special vehicle is present (IRC-6 (2019)). These two guidelines have altogether restricted the number of Special vehicles on single span bridges to one irrespective of the span length which is an erroneous scenario as will be proven in this study. Thus, there is a need to study and quantify the absolute bending moment produced when only one Special vehicle is run over different span lengths when compared to other classes of vehicles loaded over the entire span with minimum spacing as recommended by the code. In this study, the impact of Special vehicle compared to other classes of vehicles studied for spans ranging from 10 m to 1991 m and the results are also presented in terms of Standard Uniformly Distributed Load (SUDL) and Intensity factor (γ).

2. Moving load studies

Moving loads were considered according to IRC 6-2017 and the bridge considered is simply supported single span bridge. Wheeled vehicles were modeled as concentrated loads which were applied along the center to center distance from the front axle to the rear axle whereas tracked vehicles were modeled as linear loads by considering it as uniformly distributed load in Autodesk Robot Structural Analysis. As the purpose of the study was only to compare absolute bending moment as the vehicle moves from one end to the other, the bridge was modeled as an equivalent simply supported beam. The maximum bending moment was calculated by moving the complete vehicle from one end support to the other end support. The movement of SV, class 70R wheeled, class AA tracked, class A and class B vehicles on 50 m span bridge are shown in Figs. 5-9 respectively. The number of vehicles that can be accommodated on each span depends upon the

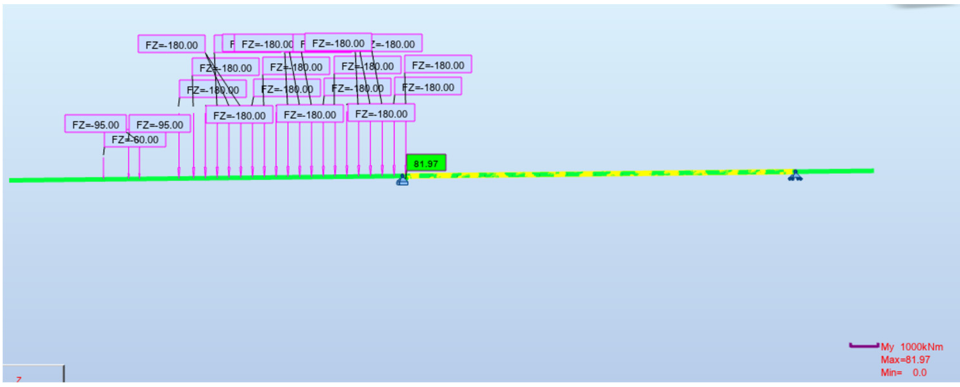

Fig. 5 Special vehicle entering 50 m bridge

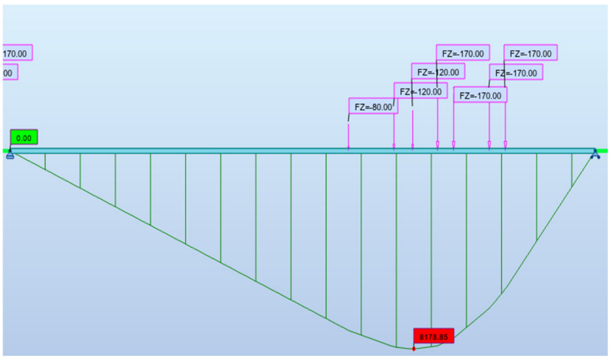

Fig. 6 Class 70R vehicle on 50 m bridge

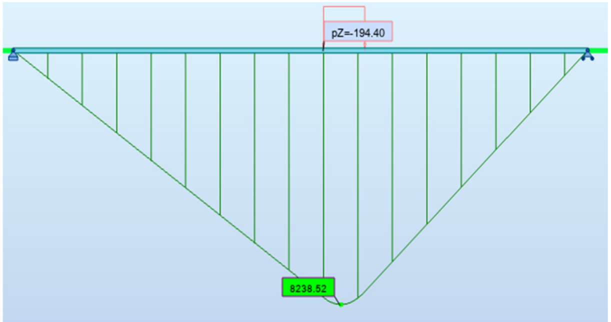

Fig. 7 Class AA wheeled vehicle on 50 m bridge

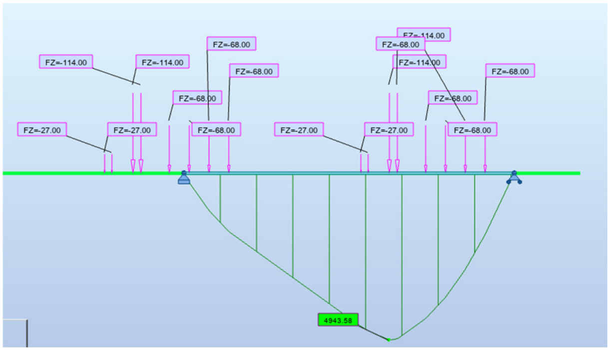

Fig. 8 Class A vehicle on 50 m bridge

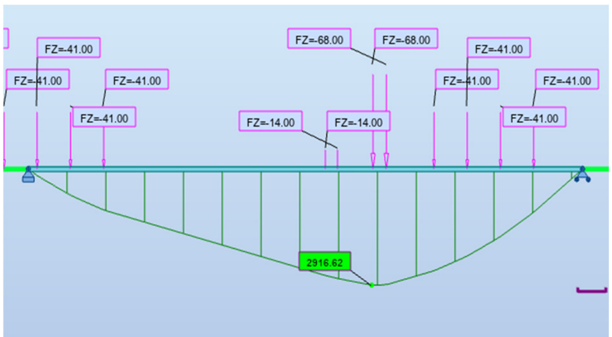

Fig. 9 Class B vehicle on 50 m bridge

class of vehicle, span length, spacing between vehicles, and center to center distance between wheels. The length of the span from 10 m to 50 m was chosen as per earlier studies. Further, the span length was increased in intervals of 10 m up to 100 m, intervals of 20 m up to 200 m, and 25 m up to 250 m. The span length of 500 m, 1000 m and 1500 m were chosen as an academic exercise to study whether the absolute bending moment of other classes of vehicles exceeds the absolute bending moment produced by the Special vehicle. The longest bridge span in the world is 1991 m (Akashi Kaikyo Bridge, Japan) and it was also considered in this study. A new parameter μ

was defined to calculate the number of vehicles as mentioned in Eq. (1) using the philosophy illustrated in Fig. 4. For example, μ of class 70R wheeled vehicle on 30 m bridge is calculated as 30/((31.52/2+13.4+31.52/2)). The center to center distance between vehicles is the sum of the spacing between vehicles (31.52 m) and center to center distance between the front and rear wheel of 70R wheeled vehicle i.e., 13.4 m. Except for class A and class B, for all other classes, the minimum distance between vehicles was specified in terms of distance between the body of the vehicle. This distance was used to obtain the center to center distance between the last wheel of a vehicle and the first wheel of the following vehicle.

$$\mu = \frac{\text{Span length } (L)}{\text{Center to center distance between vehicles (Lc)}} \tag{1}$$

Table 1 Number of vehicles on different spans

Span (m)	μ						
	Class B	Class A	Class 70R Tracked	Class 70R Wheeled	Class AA Wheeled	Class AA Tracked	Special vehicle
10	0.26	0.26	0.11	0.22	0.11	0.10	0.26
15	0.39	0.39	0.16	0.33	0.16	0.15	0.39
20	0.52	0.52	0.21	0.45	0.22	0.20	0.52
25	0.64	0.64	0.26	0.56	0.27	0.26	0.65
30	0.77	0.77	0.32	0.67	0.33	0.31	0.78
35	0.90	0.90	0.37	0.78	0.38	0.36	0.91
40	1.03	1.03	0.42	0.89	0.44	0.41	1 (Due to restriction from code)
45	1.16	1.16	0.48	1.00	0.49	0.46	
50	1.29	1.29	0.53	1.11	0.55	0.51	
60	1.55	1.55	0.63	1.34	0.66	0.61	
70	1.80	1.80	0.74	1.56	0.77	0.72	
80	2.06	2.06	0.85	1.78	0.88	0.82	
90	2.32	2.32	0.95	2.00	0.99	0.92	
100	2.58	2.58	1.06	2.23	1.10	1.02	
120	3.09	3.09	1.27	2.67	1.32	1.23	
140	3.61	3.61	1.48	3.12	1.54	1.43	
160	4.12	4.12	1.69	3.56	1.75	1.64	
180	4.64	4.64	1.90	4.01	1.97	1.84	
200	5.15	5.15	2.11	4.45	2.19	2.05	
225	5.80	5.80	2.38	5.01	2.47	2.31	
250	6.44	6.44	2.64	5.57	2.74	2.56	
500	12.89	12.89	5.29	11.13	5.48	5.12	
1000	25.77	25.77	10.57	22.26	10.96	10.25	
1500	38.66	38.66	15.86	33.39	16.45	15.37	
1991	51.31	51.31	21.05	44.32	21.83	20.40	

Though the spacing between the vehicles can be increased as the codal guidelines are only relating to the minimum distance, the values were restricted to the minimum itself in this study. As the spacing of the Special vehicle was not mentioned in the code, only one Special vehicle was moved over all spans. Hence, the μ of the Special vehicle cannot be greater than 1 ($\mu \leq 1$). The values of μ are presented in Table 1.

A Total of 182 analyses were carried out for 7 types of vehicles (class B, class A, class 70R tracked, class 70R wheeled, class AA tracked, AA wheeled, and Special vehicle) on 26 different span lengths (Table 1). Moving loads changes its time and space simultaneously (Pan *et al*. 2018). The challenge was to model wheel loads with spacing as the number of loads to be placed increases with the increase in length of the span. An extensive study was carried out in determining the position of wheel loads by creating a spreadsheet. The wheel loads were placed at minimum spacing on each span corresponding to the number of vehicles that can be accommodated by modeling it as a single-vehicle.

3. Results and discussions

Similar to design aids, SP 16 (SP16, 1980) available for IS: 456 (IS 456, 2007), which is meant to aid calculation for design of structures, there is a need to have similar code for IRC 6-2017. The results of this study, in addition to the insights that it provides, is also expected to be a starting point for development of design aids for bridge designs.

3.1 Validation of model

For validation, the maximum bending moment obtained in the case of Special vehicle, class 70 R wheeled, and class A on 50 m span was calculated manually using rolling load concept and was compared with the values obtained from Autodesk Robot Structural analysis as shown in Table 2. The resultant of loads acts at the centroid of loading. The absolute bending moment acts under critical load which lies at either immediate left or immediate right to the resultant. The sum of loads on the left side and right side of the resultant, respectively are compared with each other and the critical load is determined on the side which has greater value. The midpoint of the critical load

Table 2 Validation of model

Vehicle	Span (m)	Manual calculations (kN-m)	Robot structural analysis (kN-m)	Percentage difference
Special vehicle	50	32070	32030	0.1
Class 70R Wheeled	50	10889	10867	0.2
Class A	50	5561	5556	0.08

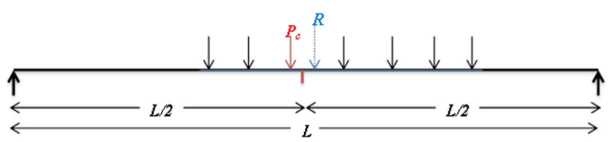

Fig. 10 Illustration of rolling load concept

and resultant should coincide with the center of the bridge to get the maximum bending moment. Fig. 10 illustrates the rolling load concept by assuming the span length of the bridge as L, and the loads on the left side of the resultant R to be greater than the loads on the right side. Hence, critical load P_c is on the left side of the resultant.

3.2 Absolute bending moment

The variation of absolute bending moment produced by the Special vehicle with other classes of the vehicle is shown in Figs. 11 and 12. From Fig. 11, it can be understood that there is a significant increment in absolute bending moment produced by Special vehicle when compared with other classes of vehicles up to 250 m. At 70 m span, the absolute bending moment produced by the Special vehicle is 10.29, 6.16, and 3.23 times the absolute bending moment produced by class B, class A, and class 70R wheeled vehicles respectively. The values of bending moment obtained for spans up to 50 m for all class of loadings is shown in Appendix. The absolute bending moment produced by the Special vehicle on 140 m span is 8.55 times the absolute bending moment produced by class AA wheeled vehicle for the same span. At 160 m span, the absolute bending moment produced by Special vehicle is 4.94 and 4.98 times the absolute bending moment produced by class 70R tracked and class AA tracked vehicles respectively. As the span length increases, the number of vehicles that can be accommodated on the span increases, and at a certain

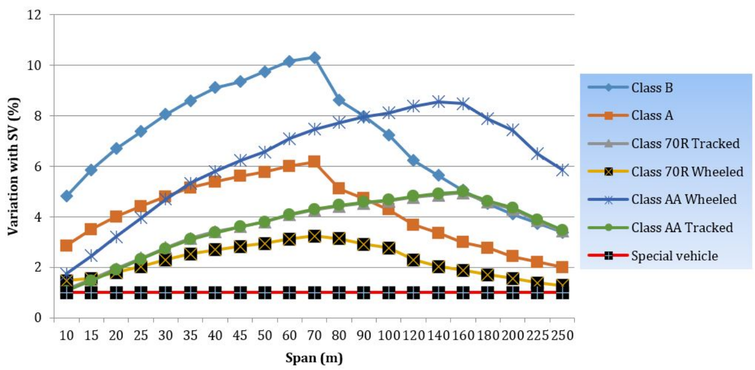

Fig. 11 Comparison of absolute bending moment for spans up to 250 m according to IRC 6

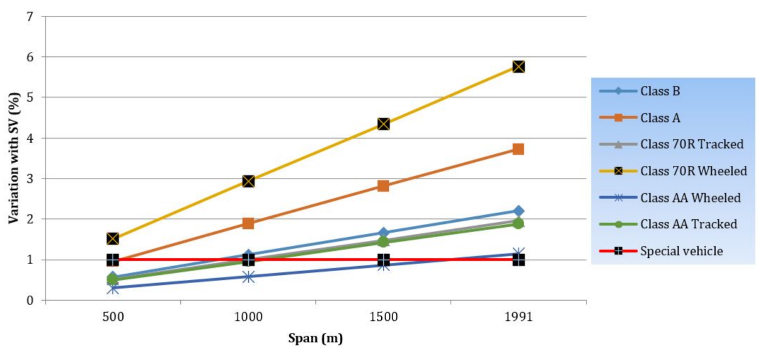

Fig. 12 Comparison of absolute bending moment for spans greater than 250 m according to IRC 6

point, the absolute bending moment produced by multiple vehicles of other classes will exceed the absolute bending moment produced by the single Special vehicle on the same span. Hence, the study was continued for longer spans to obtain the difference in absolute bending moment produced by the Special vehicle and other classes of vehicles. For this purpose, span length was further increased from 250 m to 500 m, 1000 m, 1500 m, and 1991 m till all the classes of vehicles exceed the absolute bending moment produced by the Special vehicle. At 500 m span, only 70R wheeled vehicle exceeds the absolute bending moment produced by Special vehicle by 1.57 times as shown in Fig. 12. Then at 1000 m span, the absolute bending moment produced by class B, class A, and class 70R wheeled vehicles exceeds the bending moment produced by the Special vehicle by 1.12, 1.89, and 2.93 times, respectively. An interesting observation is that the absolute bending moment of class 70R tracked vehicle and Special vehicle is almost equal at 1000 m span. Except for class AA wheeled vehicle, all other classes of vehicles exceed the absolute bending moment by the Special vehicle at 1500 m span.

Finally, the absolute bending moment produced by class B, class A, class 70R tracked, class 70R wheeled, class AA wheeled and class AA tracked vehicles exceeds the absolute bending moment produced by Special vehicle for the longest span in the world (1991 m) by 2.2, 3.73, 1.96, 5.76, 1.14 and 1.88 times respectively.

4. Standard Uniformly Distributed Load (SUDL) and intensity factor

Road and railway bridge live loads are very different from loads experienced by typical civil engineering structures. Loads depend upon weight, size, and spacing of wheels and for the heaviest vehicle that is commercially produced. To provide additional insights on vehicle live loads, two factors namely, Standard Uniformly Distributed Load (SUDL) and an Intensity Factor (γ) (a dimensionless quantity) is introduced in this study.

4.1 Standard Uniformly Distributed Load (*SUDL*)

SUDL is introduced to make the wheel loads more relatable to the uniformly distributed loads often used for the design of buildings. In concept, this is similar to the Equivalent Uniformly Distributed Load (EUDL) that is described in the railway bridge code (Railway bridge rule 2014) as a measure for simplification of the analysis.

SUDL was calculated for a simply supported beam supporting a slab of 4.5 m × 4.5 m with a masonry wall of 3 m height placed over it as shown in Fig. 13. The thickness of the masonry wall and slab is assumed to be 0.2 m and 0.15 m respectively.

The live load and superimposed dead load acting on the slab is assumed to be 4 kN/m^2 and 1 kN/m^2 respectively. The density of masonry wall and concrete is assumed to be 18 kN/m^3 and 25 kN/m^3 respectively. The size of the beam is 0.2 m × 0.4 m. SUDL calculations are as follows assuming the beam receives a quarter of the load from the slab due to two-way action (Eq. (2)). The maximum bending moment obtained for all classes for vehicles are expressed in terms of EUDL (Eq. (3)) and the values are presented in Table 3. SUDL is compared with the EUDL of all classes of vehicles (Table 3) when they are moved over the 26 spans as mentioned in Table 1. The values of EUDL which exceed the SUDL are shown with a highlight for clarity of interpretation.

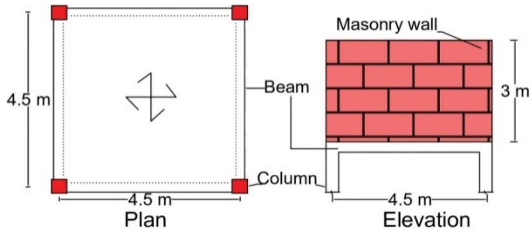

Fig. 13 Slab and Masonry Wall considered for SUDL

Table 3 EUDL for all classes of vehicles mentioned in IRC 6-2017

Span (m)	EUDL for all classes of vehicles (kN)						
	Class A	Class A	Class 70R Tracked	Class 70R Wheeled	Class AA Wheeled	Class AA Tracked	Special vehicle
10	25.36	42.72	108.24	82.96	70.40	114.64	122.08
15	20.59	34.52	79.22	77.23	49.10	82.03	120.53
20	18.02	30.08	62.06	67.50	37.62	63.66	120.52
25	16.32	27.32	50.92	59.25	30.46	51.93	120.33
30	14.92	25.01	43.14	52.22	25.60	43.85	119.96
35	13.67	22.80	37.41	46.56	22.07	37.92	117.40
40	12.36	20.91	33.02	41.88	19.40	33.41	112.51
45	11.52	19.23	29.92	38.04	17.30	29.86	107.62
50	10.52	17.78	27.07	34.77	15.62	26.98	102.50
60	9.12	15.41	22.73	29.71	13.07	22.62	92.54
70	8.13	13.58	19.60	25.92	11.23	19.48	83.68
80	8.85	14.93	17.22	24.35	9.85	17.10	76.10
90	8.74	14.76	15.36	23.95	8.77	15.24	69.63
100	8.86	14.97	13.86	23.16	7.90	13.74	64.10
120	8.88	15.00	11.59	24.12	6.60	11.49	55.21
140	8.60	14.42	9.97	23.86	5.67	9.87	48.42
160	8.54	14.42	8.72	22.95	5.09	8.65	43.09
180	8.60	14.08	8.49	22.68	4.94	8.39	38.81
200	8.60	14.53	8.21	22.72	4.75	8.11	35.28
225	8.50	14.35	8.25	22.89	4.88	8.15	31.68
250	8.50	14.36	8.39	22.54	4.92	8.28	28.74
500	8.48	14.22	7.73	22.51	4.49	7.46	14.88
1000	8.46	14.28	7.55	22.18	4.42	7.23	7.57
1500	8.46	14.28	7.51	22.03	4.39	7.22	5.08
1991	8.45	14.28	7.52	22.09	4.39	7.20	3.83

$$\frac{1}{2} \times \left\{\frac{4.5}{2} \times (4 + 1 + 25 \times 0.15)\right\} + 3 \times 18 \times 0.2 + 25 \times 0.2 \times 0.4 = 22.64 \text{ kN/m} \quad (2)$$

$$\text{EUDL} = \frac{8 \times \text{Maximum bending moment}}{(\text{Span Length})^2} \quad (3)$$

The EUDL of class B exceeds the SUDL only once on the 10 m span. The EUDL of class AA wheeled, class A, class AA tracked, class 70R tracked, class 70R wheeled, SV vehicles exceed the SUDL till 30 m, 35 m, 50 m, 60 m, 225 m, and 250 m span lengths respectively. The EUDL of SV was least among all the vehicles on the 1991 m. The comparison of EUDL with standard value gives clarity to the designers about the variation in the intensity of loading. It must be kept in mind that the definition of SUDL includes dead and live loads whereas the definition of EUDL includes only the live load due to the vehicle. The comparison may be different if the dead load of the bridge is also considered.

4.2 Intensity factor

It is known that a heavier load will produce a higher bending moment. However, there is a need to quantify the effect of each vehicle by a non-dimensional number normalizing the total load acting through the vehicle. In this regard, a parameter named "Intensity Factor (γ)" has been defined in Eq. (4). As will be shown in the paper, this factor is beneficial to estimate the impact of the loading, especially on smaller spans. The Intensity Factor was calculated for all classes of vehicles for all spans and is plotted in Fig. 13. From Fig. 14, it can be inferred that the values of all the vehicles except the Special vehicle converge to 0.125 for larger spans.

$$\text{Intensity Factor} = \frac{\text{Maximum bending moment produced}}{\mu \text{ x span length x loads of the vehicle}} \quad (4)$$

For shorter spans, the intensity of tracked vehicles and class AA wheeled vehicles is much higher compared to others. This means that the overall impact of the vehicle (except the Special vehicle) is equivalent for large spans but differs greatly for smaller spans. As the definition of Intensity Factor is independent of the magnitude of load, a possible explanation for this trend was examined. For the same, the centroid of the wheel loads and the center to center distance between extreme wheels for all classes of vehicles was tabulated and shown in Table 4.

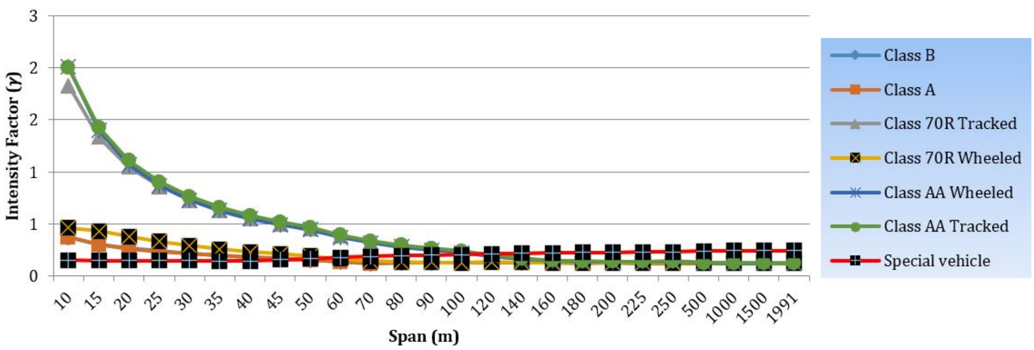

Fig. 14 Intensity Factor for all vehicles mentioned in IRC 6-2017

Table 4 Intensity factor

Class of vehicle	Load (kN)	Centroid of loads (m)	C/C distance between extreme wheels (m)	Percentage of centroid in terms of C/C distance between extreme wheels
Class B	328	9.22	18.80	49.0
Class A	554	9.09	18.80	48.3
Class 70R Wheeled	1000	8.27	13.40	61.7
Class AA Wheeled	400	0.60	1.20	50
Special vehicle	3850	22.82	38.45	59.3
Class 70R Tracked	700	2.28	4.57	50
Class AA Tracked	700	1.80	3.60	50

It was seen that the vehicles which gave a high-Intensity Factor for small span were having a lesser center to center distance between extreme wheels. This means that the total load is concentrated within a smaller distance and hence loading to higher bending moments. This effect reduces as the span length increases. The only exception to this rule is the tracked vehicle as the load is distributed over a length. In UK codal guidelines (Masrom and Goh 2018), the spacing between the axles and the number of units (each unit = 10 kN) for HB Vehicles is flexible which is recommended to be implemented in IRC 6 as the Intensity Factor-based study has shown that the distance between axles has an impact on bending moment for small spans.

5. Conclusions

A case study on changes in IRC 6 codal guidelines was carried out to study the impact of live loads on the design of bridges. Absolute bending moments produced by the Special vehicle introduced in IRC 6-2017 edition were compared with absolute bending moments produced by the already existing class of vehicles by performing 182 analyses for 7 types of vehicles on 26 different span lengths. The conclusions are as follows:

- Till 250 m span, the absolute bending moment produced by Special vehicle was 10.29, 6.16, 3.23, 4.94, 8.55, and 4.98 times the class B, class A, class 70R wheeled, class 70R tracked, class AA wheeled and class AA tracked vehicles at 70 m, 70 m, 70 m, 160 m, 140 m, 140 m respectively.
- The absolute bending moment produced by other classes of vehicles exceeds the values produced by the Special vehicle at longer spans. This is because, as the span length increases, the number of vehicles that can be accommodated on the span increases whereas only one special vehicle will be present on the span at an instant due to codal guidelines.
- On the longest span bridge in the world i.e., 1991 m (Akashi Kaikyo Bridge, Japan), the absolute bending moment produced by Special vehicle is 2.2, 3.73, 1.96, 5.76, 1.14, 1.88 times the absolute bending moment produced by class B, class A, class 70R wheeled, class 70R tracked, class AA wheeled and class AA tracked vehicles.
- The EUDL values produced by all classes of vehicles are less than SUDL values for spans greater than 250 m.
- The intensity factor of all vehicles except the Special vehicle converges to 0.125 for larger

spans. Tracked vehicles and Class AA wheeled vehicle shows higher intensity in shorter spans as the spacing between wheels is lesser.

The codal guidelines of IRC 6 for the Special vehicle should be revised allowing multiple vehicles in a single lane bridge for large spans. SUDL and Intensity Factor should be used for a better interpretation of the impact of vehicle loads on bridge design.

References

AASHTO (2010), American Association of State Highway and Transportation Officials, and Transportation Officials, “Physical and Performance Characteristics of Heavy Vehicles”, 3–30.

AASHTO (2015), Load and Resistance Factor Design (LRFD) for Highway Bridge Superstructures.

Autodesk - Modeling of the Foundation in the Foundation - Structure - System under Static Loads in the Calculation Complex Robot Structural Analysis Professional.

Erdogan, Y.S. and Catbas, N.F. (2020), “Seismic response of a highway bridge in case of vehicle-bridge dynamic interaction”, *Earthq. Struct., Int. J.*, **18**(1), 1-14. https://doi.org/10.12989/eas.2020.18.1.001

Gu, Y.M., Li, S.L., Li, H. and Guo, Z.M. (2014), “A novel Bayesian extreme value distribution model of vehicle loads incorporating de-correlated tail fitting: theory and application to the Nanjing 3rd Yangtze River Bridge”, *Eng. Struct.*, **59**, 386-392. https://doi.org/10.1016/j.engstruct.2013.10.029

Gupta, T. and Kumar, M. (2017), “Influence of distributed dead loads on vehicle position for maximum moment in simply supported bridges”, *J. Inst. Engr.* (*India*): *Series A*, **98**(1-2), 201-210. https://doi.org/10.1007/s40030-017-0188-0

Indian Road Congress Round the World (SP 004 1964), India.

Indian Roads Congress (2000), Standard Specifications and Code of Practice for Road Bridges Section : II Loads and Load Combinations, Irc 6-2000. 1–107, India.

Indian Roads Congress (2010), Standard Specifications and Code of Practice for Road Bridges Section : II Loads and Load Combinations, Irc 6-2010. 1–107”, India.

Indian Roads Congress (2014), Standard Specifications and Code of Practice for Road Bridges Section : II Loads and Load Combinations, Irc 6-2014. 1–107”, India.

Indian Roads Congress (2017), Standard Specifications and Code of Practice for Road Bridges Section : II Loads and Load Combinations, Irc 6-2019. 1–107”, India.

IS 456 (2007), Indian Standard Plain and Reinforced Concrete Code of Practice (Fourth Revision), Bur. Indian Standards, Dehli, India, 1–114.

Karnovsky, I.A. and Lebed, O. (2010), *Advanced Methods of Structural Analysis*, Springer, New York Dordrecht Heidelberg, London.

Kim, Y.J. (2012), “Safety assessment of steel-plate girder bridges subjected to military load classification”, *Eng. Struct.*, **38**(4), 21-31. https://doi.org/10.1016/j.engstruct.2012.01.002

Masrom, M.A. and Goh, L.D. (2018), “Comparative study of bridge traffic loadings between British standards and Eurocodes”, In: *AIP Conference Proceedings*, October. https://doi.org/10.1063/1.50626

Mori, T., Lee, H.H. and Kyung, K.S. (2007), “Fatigue life estimation parameter for short and medium span steel highway girder bridges”, *Eng. Struct.*, **29**(10), 2762-2774. https://doi.org/10.1016/j.engstruct.2007.01.019

Pan, C.D., Yu, L., Liu, H.L., Chen, Z.P. and Luo, W.F. (2018), “Moving force identification based on redundant concatenated dictionary and weighted l1-norm regularization”, *Mech. Syst. Signal Pr.*, **98**, 32-49. https://doi.org/10.1016/j.ymssp.2017.04.032

Railway bridge rule (2014), Government of India (in Si Units), Rules Specifying the Loads for Design of Super Structure and Sub Structure of Bridges and for Assessment of the Strength of Research Designs and Standards Organisation, India.

Shipman, C.L. (2014), “Finding maximum moment: Determining HL-93 truck position on simple spans”, *J. Bridge Eng.*, **19**(3), 1-3. https://doi.org/10.1061/(ASCE)BE.1943-5592.0000591

SP16 (1980), Design Aids for Reinforced Concrete to IS: 456.
Wang, H., Zhu, Q., Li, J., Mao, J., Hu, S. and Zhao, X. (2019), "Identification of moving train loads on railway bridge based on strain monitoring", *Smart Struct. Syst., Int. J.*, **23**(3), 263-278. https://doi.org/10.12989/sss.2019.23.3.263
Yang, S.I., Frangopol, D.M. and Neves, L.C. (2004), "Service life prediction of structural systems using lifetime functions with emphasis on bridges", *Reliab. Eng. Syst. Saf.*, **86**(1), 39-51. https://doi.org/10.1016/j.ress.2003.12.009

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Appendix

Maximum bending moment of all vehicles for all spans up to 250 m (kN-m)

Span (m)	Maximum bending moment of all vehicles (kN-m)						
	Class B	Class A	Class 70R Tracked	Class 70R Wheeled	Class AA Wheeled	Class AA Tracked	Special vehicle
10	317	534	1353	1037	880	1433	1526
15	579	971	2228	2172	1381	2307	3390
20	901	1504	3103	3375	1881	3183	6026
25	1275	2134	3978	4629	2380	4057	9401
30	1679	2814	4853	5875	2880	4933	13496
35	2093	3491	5728	7129	3380	5807	17977
40	2472	4182	6603	8375	3880	6682	22501
45	2917	4867	7574	9630	4380	7557	27240
50	3288	5556	8458	10867	4880	8431	32030
60	4104	6934	10230	13368	5880	10181	41643
70	4981	8318	12002	15875	6880	11933	51255
80	7077	11941	13776	19480	7880	13683	60877
90	8848	14942	15549	24247	8880	15433	70502
100	11079	18717	17326	28947	9880	17179	80127
120	15982	26994	20860	43410	11880	20678	99377
140	21069	35340	24419	58444	13880	24169	118627
160	27337	46157	27908	73445	16276	27688	137877
180	34819	57014	34385	91859	19987	33997	157187
200	43012	72651	41042	113605	23761	40567	176377
225	53782	90832	52199	144861	30900	51599	200460
250	66437	112215	65507	176106	38400	64707	224502