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Analytical Study of Load Rating on RCC Box Girder Superstructure Under the Effect of IRC Loadings

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Abstract
It is observed that over the course of time structural components weakens and their ability to carry the self weight along with the superimposed load decreases. Consequently, it becomes very much important and vital to periodically assess the strength, stability and the performance of the bridge and other structure in order to ascertain their remaining residual strength and to ensure safety. There are different experimental methods available which uses the concept of Non-Destructive testing in order to ascertain the performance and the condition of any structure at any point of time. There are numerous experimental method which are used to perform the Load Rating Analysis but there is no provision to perform the same rating analysis analytically as per the Indian code on bridge related software. This paper generally deals with providing an analytical solution which can be used in order to estimate the residual strength of the bridge structure and perform the Load Rating Analysis analytically on Midas Civil Software. The study basically involves the modelling and Analysis of 2 Reinforced Concrete Box Girder Superstructure, each of span length 40m situated in Lucknow analysed as per the Indian Standard Codes. Both of the bridge model represents the condition of the bridge structure at a specific time period. The time gap between the analysis of the two models is assumed to be 70 years. The bridge model is modelled and analysed with the help of Midas Civil Software and the Load carrying capacity of the structure is evaluated based on the different statistical parameters such as Vertical Displacement, Shear Force and Bending Moment. At last a comparative study is conducted between the two models. The analysis revealed that the Bridges Lose their load bearing capacity and strength after a time period of 70 years. A considerable increase in the value of vertical displacement and bending moment was observed beyond the safe and permissible limit of the structure. The analytical approach demonstrated in this study can be applied to various bridge structure such as RCC and PSC Tee Beam Bridge, I Girder bridge, cable stayed bridge etc.

Keywords: Bridge Load rating, PSC Box Girder Bridge, Creep, Shrinkage, Creep Coefficient, Rating factor, Non-Destructive testing.

1. Introduction

The method or the process which is used in order to evaluate the strength and the structural capacity of the structure is known as the Load Rating. Whereas the permissible load carrying capacity of the structure is known as the rating of the structure. When we talk about the process which is used to evaluate the residual or the remaining strength of the bridge structure then it is known as the Bridge Load Rating. With the passage of time and due to the wear and tear of the structure, the structure generally looses it's strength and capacity to bear the design load[1].

Bridge Load Rating helps us to evaluate the remaining strength left in the structure. Bridge Load Rating becomes essential in the following situations- a) When the design live load is not known, b) when the live load which is coming on the structure is greater than the design live load, c) when any initial information regarding the construction, material used is not known, d) it also becomes quite essential if during the inspection of the bridge there is doubt regarding structural serviceability.

The process of Load rating generally involves the information which is given in the plan, drawing and design calculation of the structure. It becomes a very hectic and quite difficult task for the engineers to evaluate the strength and capacity of any structure in the absence of these information. The main purpose of load rating is to get an idea about the residual strength of any structure so that proper retrofitting measures can be taken up during the time in order to maintain the structural stability and integrity.

According to the IRC-5-2011 guidelines, bridges are categorized according to various factors like length, superstructure type, construction material, technology, and significance. The specific bridge studied in this research is a Reinforced Concrete (RCC) Box Girder bridge with a span length of 40 meters.[2]

2. Literature Review-

Zhu Y et al. (2022),[3] conducted his research on the same identical bridge structure i.e. Box Girder Bridge Structure, it was discovered that utilizing ultra-high performance concrete joints significantly improves bridge performance. The utilization of these joints resulted in a decrease of approximately 20% in the ultimate deformation and rotation in Prestressed Concrete (PSC) bridges.

Naser AF et al. (2021),[4] The study involved analysing the ratings of a composite bridge under various international truck loads using CSI Bridge software in accordance with the AASHTO code. The findings indicated that structural members with higher load rating factors exhibited superior load-carrying capacity, strength, and stiffness when compared to other structural elements.

Sun Z et al. (2021) and Dong CZ et al. (2020),[5,6] The research focused on assessing the bridge's load carrying capacity by measuring displacement under moving vehicles, employing a camera and computer vision technique. The study found that the displacement technique allows for evaluating rating factors for various structural components in a cost-effective manner compared to traditional methods. Additionally, utilizing computer vision techniques enabled the evaluation of live load distribution and led to a 12% improvement in the rating factor.

Hemalatha K et al. (2020), Agarwal P et al. (2020) and Gupta T et al. (2018),[7,8,9] A study was carried out to assess how bridges perform under varied conditions. Through multiple investigations on bridge performance, it was determined that Pre-stressed Concrete Box Girder bridges are more cost-effective when compared to RCC T Beam Girder bridges. The ultimate shear strength values were found to be within permissible limits under the influence of Dead and IRC moving loads. Additionally, it was observed that highly skewed bridges are more economical than conventional ones due to the structure's low deflection.

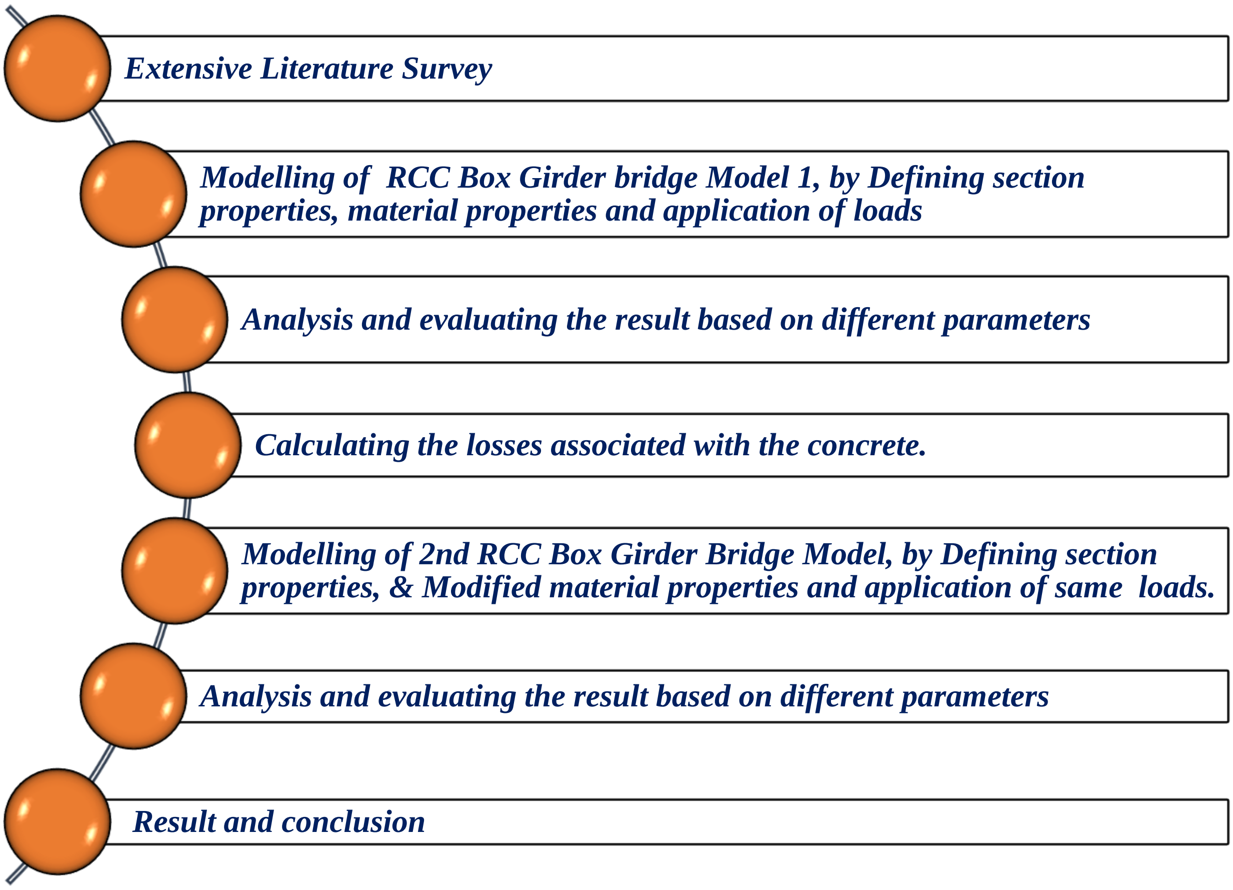
3. Objective-

The primary focus of this study is to perform a load rating analysis on an RCC Box Girder Superstructure spanning 40 meters, subjected to various IRC Loadings and to conduct a comparative study between the two RCC Models. The objective is to assess the load carrying capacity by considering different parameters, including:

1) Vertical Displacement
2) Factored S.F
3) Factored B.M

4. Research Methodology

In the present Study, analysis of two models of single span RCC Box Girder bridge of span length 40m is carried out using Midas Civil software. These models depicts the different stage of condition. The first model i.e. the Model 1 simulates the newly constructed bridge while the other model i.e. Model 2 simulates the condition of the same bridge after 70 years of time period. The following methodology was employed to accomplish the task:-



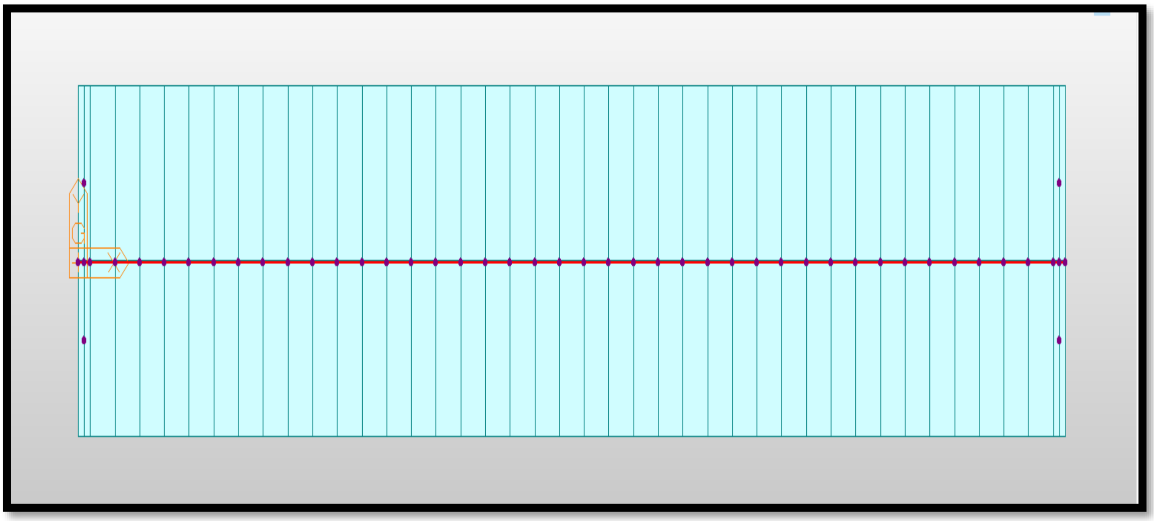
Flowchart -1- Research Methodology

5. Design Data & Specification

Table-1- Design Data

Bridge Type	RCC Box Girder Bridge
Span Length	40m
Width	8.5m (2 -lane) with 7.5m as clear carriageway width
Design Code	IRC :112-2011
Materials	M40 for Girders
Thickness of wearing course	100mm
Location	Lucknow (India)

Figure-1 – Top View of PSC Box Girder Bridge Model



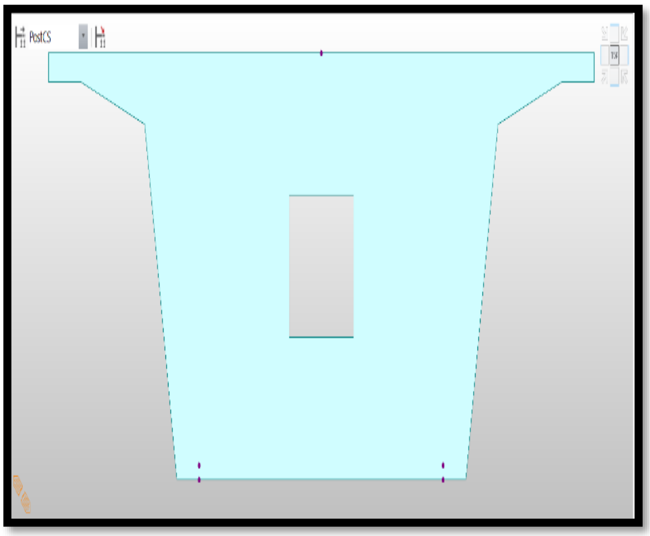


Figure-2- Isometric View

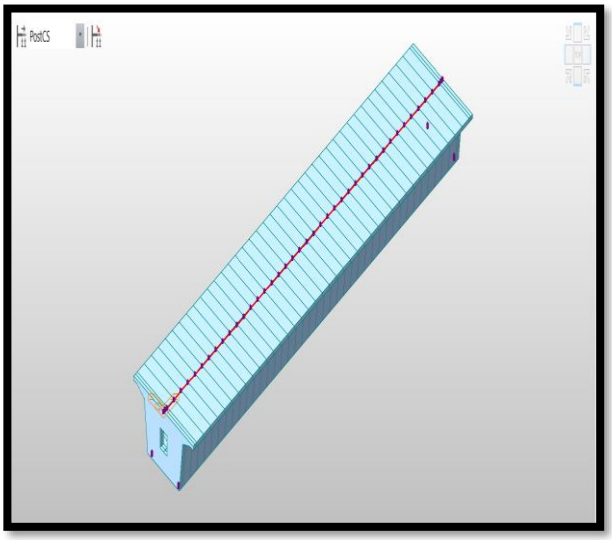


Figure-3- Front View

6. Loads Considered During the Analysis

Table-2- Loads Considered

Loads considered during Analysis	
Self Weight Of the Structure	
Dead Load Of the wearing course (100mm)=	22*7.5*0.1= 16.5 kN/m
Superimposed load of the crash barrier=	25*1*0.3=7.5kN/m
IRC Moving Loads	a) One Lane of Class 70R loading b) Two Lane of Class A Loading
Temperature Rise	
Temperature Fall	
Positive Temperature Gradient	
Negative Temperature Gradient	
Wind Force	a) Transverse Force On SS (FT)= 4.93kN/m b) Longitudinal Force On SS (FL)= 1.2325kN/m c) Uplift Force per Girder (Fu)=5.38kN/m d) Transverse Force on LL (Ftl)=2.03kN/m e) Longitudinal force on LL (Fll)=0.5075kN/m

Figure-4- Isometric View Of Crash Barrier Load on the Bridge

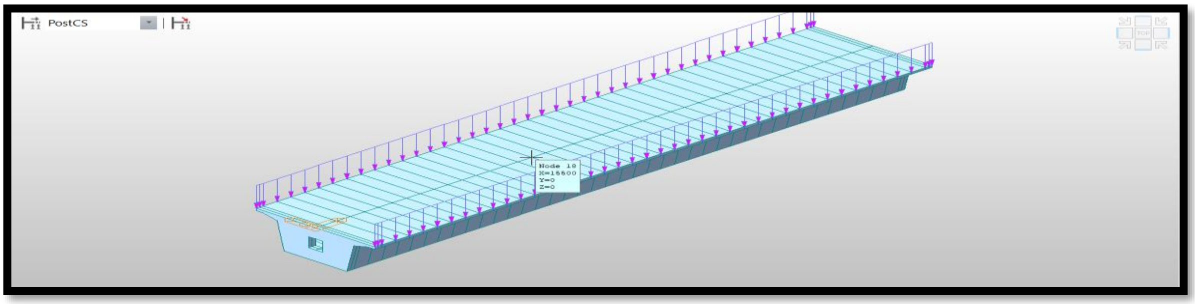


Figure-5-Isometric View Of One Lane Of 70R Loading on the Bridge

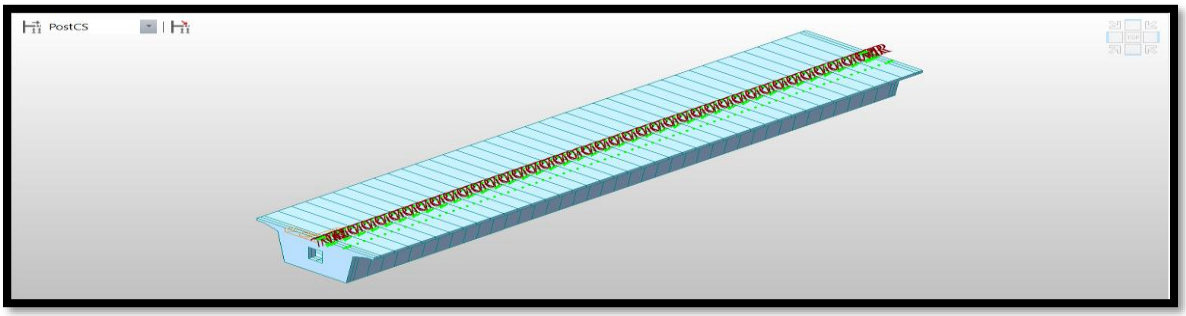


Figure-6-Isometric View Of Two Lane Of Class A Loading on the Bridge

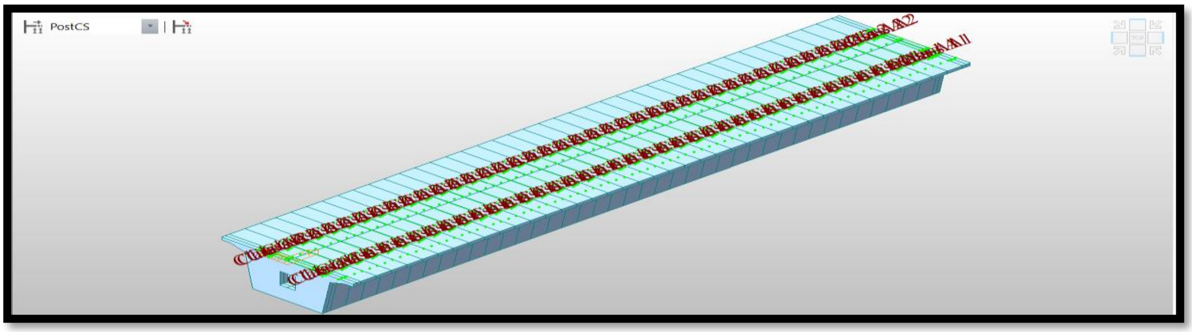
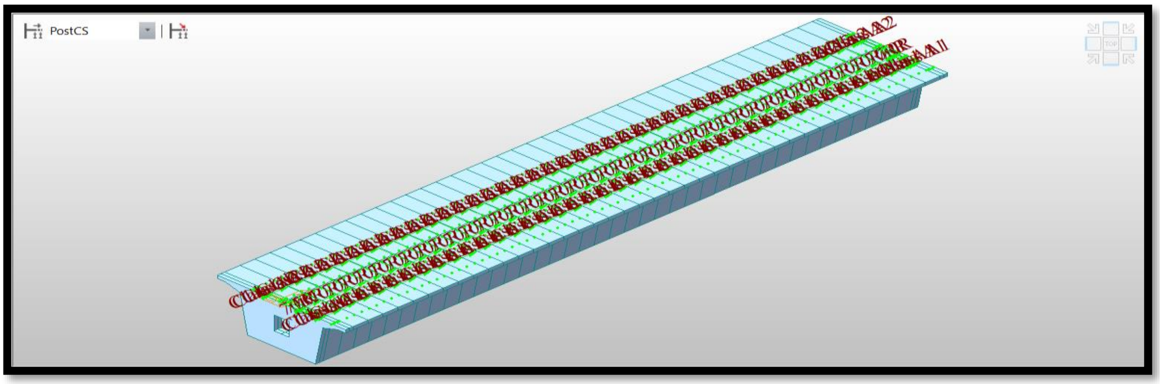


Figure-7- Combine Effect Of Two Lane Of Class A Loading and One Lane of 70R Loading on the Bridge



7. Result and Output

7.1 Displacement (Dz)- The following results were obtained:-

Node	Load	Dz (mm) Model 1	Dz (mm) Model 2
1	cLCB5(max)	0.45582	2.6219
2	cLCB5(max)	-0.28263	-0.45334
3	cLCB5(max)	-14.0585	-34.878
4	cLCB5(max)	-18.1115	-45.1285
5	cLCB5(max)	-25.8988	-64.8256

6	cLCB5(max)	-36.2565	-91.0201
7	cLCB5(max)	-39.253	-98.6007
8	cLCB5(max)	-46.6579	-117.334
9	cLCB5(max)	-48.5563	-122.137
10	cLCB5(max)	-50.1526	-126.176
11	cLCB5(max)	-51.4391	-129.43
12	cLCB5(max)	***-53.3847***	***-134.353***
13	cLCB5(max)	-52.4079	-131.882
14	cLCB5(max)	-50.1499	-126.169
15	cLCB5(max)	-44.463	-111.782
16	cLCB5(max)	-41.9902	-105.526
17	cLCB5(max)	-36.2517	-91.0084
18	cLCB5(max)	-25.8944	-64.8145
19	cLCB5(max)	-22.0635	-55.1243
20	cLCB5(max)	-18.108	-45.1197
21	cLCB5(max)	-14.0556	-34.8708
22	cLCB5(max)	-9.92221	-24.4192
23	cLCB5(max)	-5.72129	-13.7918
24	cLCB5(max)	-0.44273	0
25	cLCB5(max)	0	-0.4594

Table-3- Displacement (Dz) Values for RCC Model 1 & 2

Figure-8- Model 1 RCC Displacement Graph

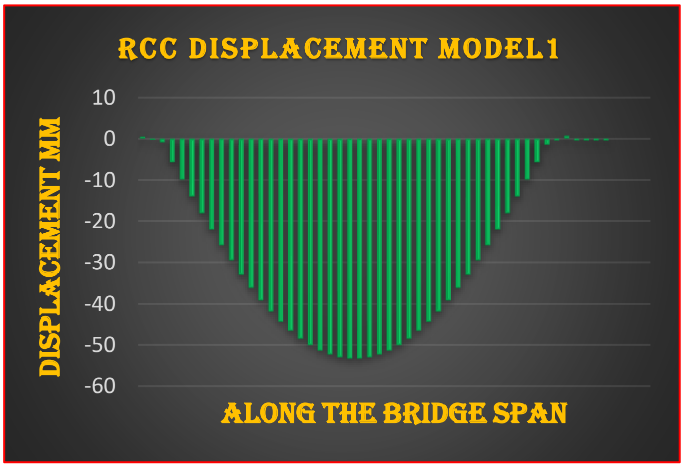


Figure-9- Model 2 RCC Displacement Graph

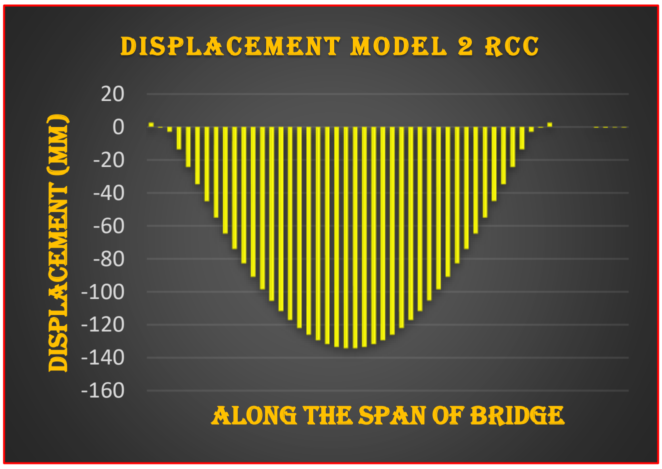


Table-4- Maximum Displacement (Dz) Value

Maximum Vertical Deflection (mm)	
Model 1	53.38mm
Model 2	134.35mm

7.2 Shear Force (Fz)- The following results were obtained:-

Table-5- Shear Force (Fz) Values for RCC Model 1 & 2

Element	***Load***	***Part***	***Shear-z (kN) Model 1***	***Shear-z (kN) Model 2***
1	cLCB5(max)	I[1]	0	0
2	***cLCB5(max)***	***I[2]***	***-5513***	***-5513***
3	cLCB5(max)	I[4]	-5027.46	-5027.51
4	cLCB5(max)	I[6]	-4319.42	-4319.46
5	cLCB5(max)	J[10]	-3070.24	-3070.29
6	cLCB5(max)	J[12]	-2499.03	-2499.08
7	cLCB5(max)	J[16]	-1339.7	-1339.75
8	cLCB5(max)	J[18]	-740.81	-740.85
9	cLCB5(max)	J[22]	431.92	431.87
10	cLCB5(max)	J[24]	1030.81	1030.77
11	cLCB5(max)	J[26]	1638.25	1638.2
12	cLCB5(max)	J[32]	3403.79	3403.74
13	cLCB5(max)	J[34]	4002.69	4002.64
14	cLCB5(max)	J[38]	5258.85	5258.81
15	***cLCB5(max)***	***J[43]***	***6910.5***	***6910.46***
16	cLCB5(max)	I[43]	-139.67	-139.67
17	cLCB5(max)	J[44]	0	0

Figure-10 Model 1 RCC Shear Force Graph

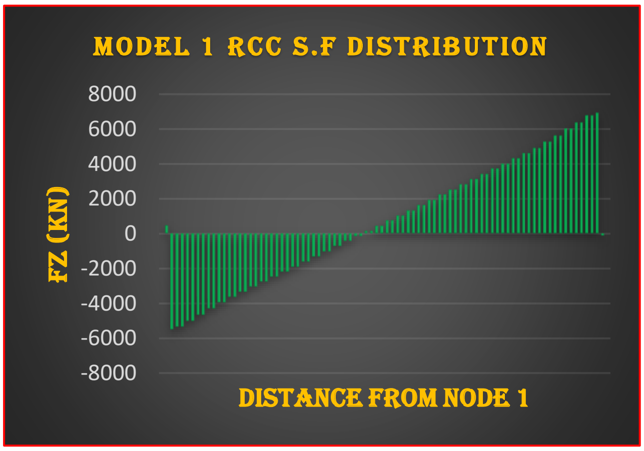


Figure-11 Model 2 RCC Shear Force Graph

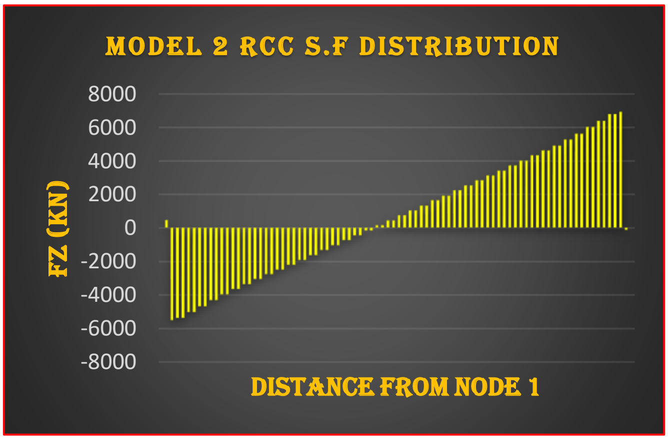


Table-6- Max & Min Shear Force Value

Shear Force Value (kN)		
RCC Model	***Max***	***Min***
Model 1	6911	-5513
Model 2	6911	-5513

7.3 Bending Moment (Mz)- The following results were obtained:-

Table-7-B.M Value for Model 1 & 2 Of RCC

Element	***Load***	***Part***	***Mz (kN*m) Model 1***	***Mz (kN*m) Model 2***
1	cLCB5(max)	I[1]	0	0
1	cLCB5(max)	J[2]	0.071077	0.073418
2	cLCB5(max)	I[2]	246.4578	343.2766
2	cLCB5(max)	J[3]	233.7385	329.577
6	cLCB5(max)	I[6]	92.19549	176.6359
6	cLCB5(max)	J[7]	49.67912	130.4738
7	cLCB5(max)	J[8]	9.469495	86.69435
8	cLCB5(max)	J[9]	-28.4184	45.3131
10	cLCB5(max)	J[11]	-97.7597	-30.8029
11	cLCB5(max)	J[12]	-129.018	-65.3366
14	cLCB5(max)	I[14]	-184.712	-127.356
14	cLCB5(max)	J[15]	-209.147	-154.841
15	cLCB5(max)	I[15]	-209.147	-154.841
15	cLCB5(max)	J[16]	-231.307	-179.976
21	cLCB5(max)	J[22]	-316.502	-281.45
24	cLCB5(max)	J[25]	-328.391	-300.469
25	cLCB5(max)	I[25]	-328.391	-300.469
25	cLCB5(max)	J[26]	-327.806	-302.109
26	cLCB5(max)	I[26]	-327.806	-302.109
30	cLCB5(max)	J[31]	-290.757	-275.068
31	cLCB5(max)	I[31]	-290.757	-275.068
42	cLCB5(max)	I[42]	-9.52901	-9.28101
42	cLCB5(max)	J[43]	0.071488	0.074254
43	cLCB5(max)	I[43]	0.071077	0.073418
43	cLCB5(max)	J[44]	0	0

Figure-12- Model 1 RCC B.M Graph

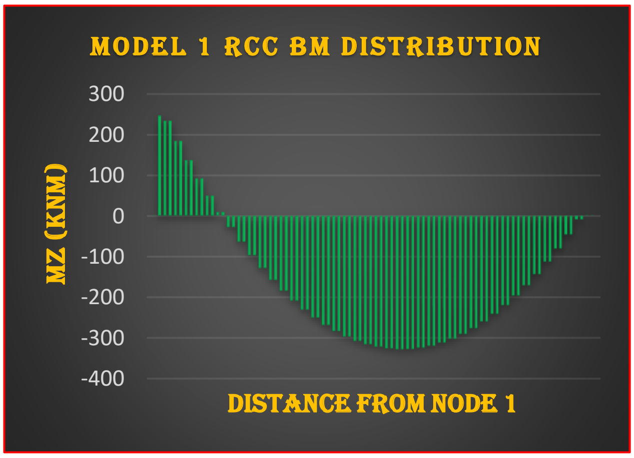


Figure-13- Model 2 RCC B.M Graph

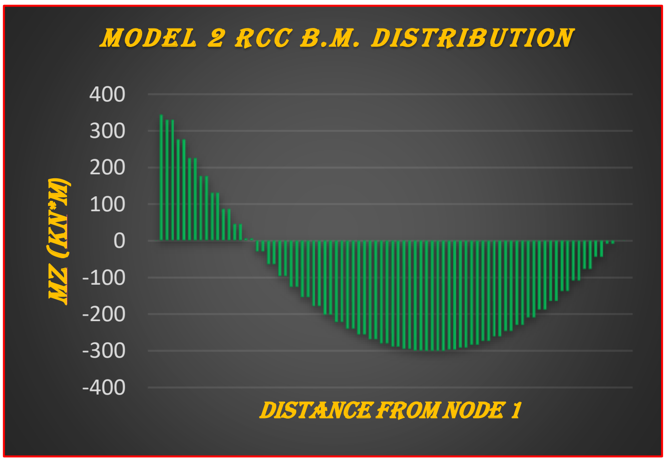


Table-8- Max & Min B.M. Value

Bending Moment (KN*m)	
Model 1	***Model 2***
Max= 246.45	Max= 343.27
Min= -328.4	Min= -302.109

8. Conclusion

Figure-14- Displacement for Model 1 & 2

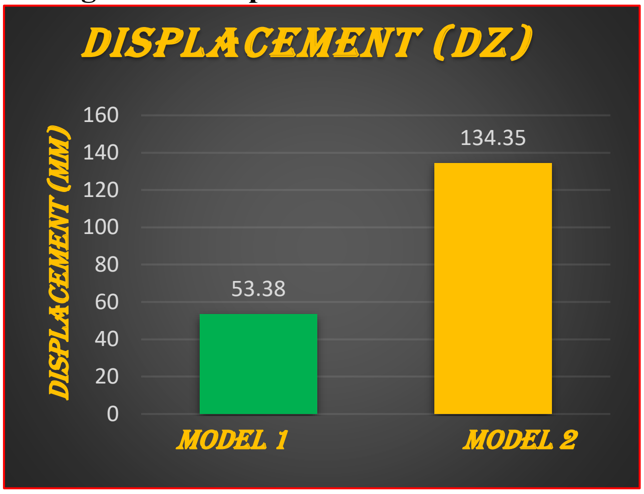


Figure-15- Shear Force for model 1 & 2

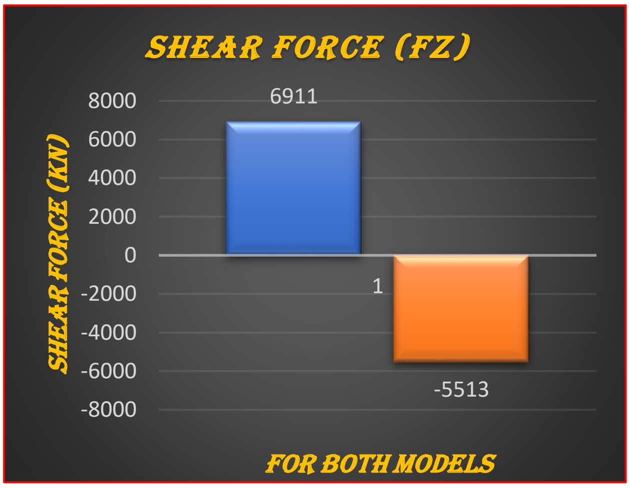
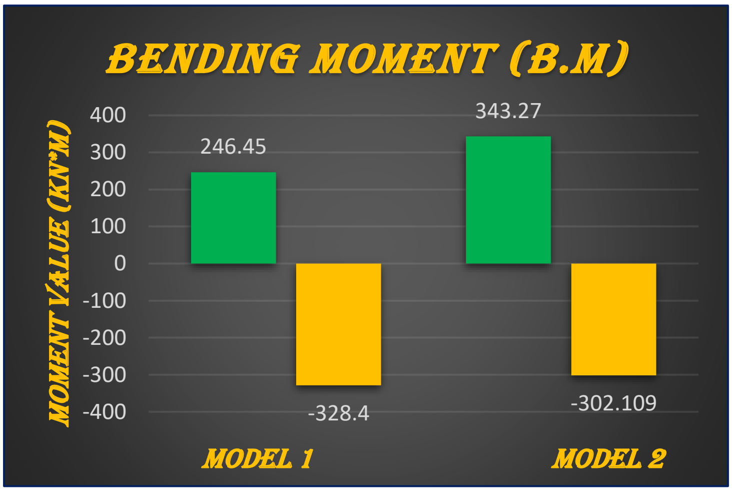


Fig-16- B.M for Model 1 & 2



- Based on the research conducted on the two model of Reinforced Concrete Box Girder Superstructure subjected to IRC Loadings, it can be concluded that :-

1. Bridge load rating can be conducted analytically according to the Indian Code. Utilizing this method provides insights into the bridge's reserve strength. This information is crucial for implementing timely measures to prevent structural damage or minimize its extent.
2. After 70 years, it can be concluded that bridge structural capacity, strength and durability have considerably diminished.
3. A considerable increase in the value of Displacement and Bending moment is observed beyond the safe permissible limit, hence appropriate retrofitting measures should be adopted in order to limit the damage and to ensure the serviceability of the structure.

4. Vertical displacement in model 2 was found to be greater than in model 1. Displacement under the effect of different loads in model 2 was found to be 151.68% greater than that in model 1.
5. There was no effect on the value of applied shear force.
6. A considerable increased in the value of B.M was observed. B.M in model 2 was found to be 39.28% greater than in model 1.

9. Future Scope-

The methodology employed in this research work to conduct the load rating analysis can be applied to various types of bridge structures such as- RCC and PSC Tee-girder Bridge, I-Girder Bridge, Cable stayed Bridge, Box Girder Bridge etc.

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