Comparative Study of Minor Box type Bridge by using Manual and Software Methods

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Abstract: This study demonstrates the structural analysis and design of RCC box type minor bridge using manual approach (i.e. MDM method) and by computational approach (Staad-pro) using IRS - CBC codes. The structural elements (top slab, bottom slab, side wall) were designed to withstand Ultimate Load criteria (maximum bending moment and shear force) due to various loads (Dead Load, Live Load, SIDL, LL surcharge, DL surcharge) and serviceability criteria (Crack width) and a comparative study of the results obtained from the above two approach has been carried out to validate the correctness of the results. Further, it was also observed that the analysis using manual calculation becomes very tedious and cumbersome and for a complex type of structure, thus it is quite a complex task to perform the analysis manually, so the use of computational method (Staad – pro and excel sheet) becomes the obvious choice for design. The results obtained using MDM method shows a good agreement with the results obtained from computational methods.

Keywords: *Box Bridge, Moment distribution Method, Railway Minor Bridge, STAAD.Pro.*

I. INTRODUCTION

Bridge construction nowadays has achieved a worldwide level of importance. With rapid technology growth the conventional bridge has been replaced by innovative cost effective structural system. The efficient dispersal of congested traffic, economic considerations, and aesthetic desirability has increased the popularity of box type bridges these days in modern highway systems, including urban interchanges. They are prominently used in freeway and bridge systems due to its structural efficiency, serviceability, better stability, pleasing aesthetics and economy of construction. They are efficient form of construction for bridges because it minimizes weight, while maximizing flexural stiffness and capacity. It has high torsional stiffness and strength, compared with an equivalent member of open cross section. Although significant research has been underway on advanced analysis for many years to better understand the behaviour of all types of box bridges, the results of these various research works are scattered and unevaluated. Hence, a transparent understanding of more recent work on straight and curved box bridges is highly desired which divulged the attention towards aiming a present study. The main objective is to provide a clear vision about the analysis and design of box type minor railway bridges. This study would enable bridge engineers to better understand the behaviour of Box Bridge outlining a different approach towards analysis and design. Some of the brief summary of the research are presented here:

A bridge is a structure providing passage over an obstacle without closing the way beneath. The required passage may be for a road, a railway, pedestrians, a canal or a pipeline. The obstacle to be crossed may be a river, a road, railway or a valley. In other words, bridge is a structure for carrying the road traffic or other moving loads over a depression or obstruction such as channel, road or railway. A bridge is an arrangement made to cross an obstacle in the form of a low ground or a stream or a river without closing the way beneath. Bridges constitute an essential link of a Railway system. There were 127154 bridges on Indian Railways system as on 31 March 2002. A large number of these bridges are between 80 to 100 years old, and were constructed to handle the lighter standard of loading then prevalent. Indian Railways has seen a tremendous growth in both freight and passenger traffic since the construction of these bridges. From an originating traffic of 93 million tonnes in the early 50s, it has reached 522 million tonnes in 2001-2002. Similarly, passenger traffic has increased from 67 billion passenger kilometres to over 493 billion passenger kilometres. With the introduction of heavier axle loads and higher speeds, clubbed with aging and fatigue, bridges need special attention and care, including rehabilitation where warranted, so as to ensure safety of rail traffic. Any damage to a bridge may take considerable time for repairs and the financial implications may also be quite severe on account of high cost of repairs and interruptions to traffic.

Greater emphasis on maintenance, proper and regular upkeep is, therefore, imperative for trouble-free existence of these bridges. A culvert is defined in the Standard Specifications as any structure, whether of single or multiple-span construction, with an interior width of 6.096 m (20 ft.) or less when the measurement is made horizontally along the centre line of the roa2.

Preliminary Information

This study was a part of contract package of Eastern Dedicated Freight Corridor – Design and Construction of Civil, Structures and Track works for double line Railway under which a box type minor bridge of 13.5 m span was supposed to be constructed along the route via Mughalsarai to New Karchana Station. Specific details for the design are discussed below:

• The box cross section for 1m strip is considered for analysis and the loads and load combinations are applied.

• Though the minimum ballast cushion is 400mm, for the dispersion width of live load, rail and sleeper load, cushion of 300 mm is considered as conservative approach and in accordance with the clause 2.2.2 of IRS Concrete bridge rule.

• Minimum Haunch size of 1 50 mm x 1 5 0 mm is considered for box vent size.

• 100 mm thick PCC shall be provided over 300 mm thick sand filling for Precast Box Segments.

• The minimum soil bearing capacity for RCC box Structures is assumed to be 100 kN/m2 (minimum), if the soil bearing capacity is less than 100 kN/m2 sand filling of appropriate thickness is to be done below founding level as per codal provision.

• The design life of a structure is that period for which it shall be designed to fulfil its intended function. The design life of all bridge structures is considered as 100 years .

A box structure with top slab, side wall and bottom slab is shown in Fig. 1 along with the loads and reactions. The top slab is subjected to uniformly distributed loads while the sidewalls are subjected to trapezoidal load varying along the height of the structure. The bottom slab is directly resting on soil and is taken as a spring supportedway from face-to-face of abutments or sidewalls.

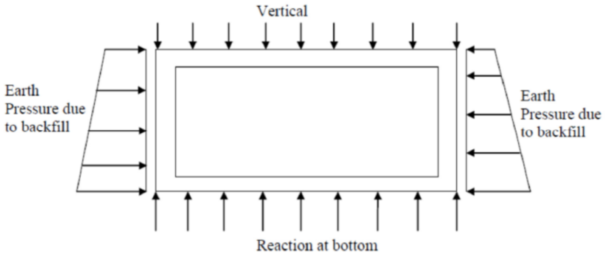

Figure 1.1: 2-D model showing with loads and reaction

Objectives of the Study

1) Manual analysis of RCC box has been done using Moment Distribution Method (MDM).
2) Manual design has been carried out using working stress method (WSM).
3) Computational analysis has been done using Staad-Pro.
4) Computational design for flexural behaviour has been done using Ultimate limit State (ULS) and crack check has been done using Serviceability limit State (SLS) [8].
5) Comparison of analysis from STAAD pro and MDM to observed that which method is more competent.
6) To check safety of bridge

II. METHODOLOGY

- Manual analysis of RCC box has been done using Moment Distribution Method (MDM).
- Manual design has been carried out using working stress method (WSM).
- Computational analysis has been done using Staad-Pro.
- Computational design for flexural behaviour has been done using Ultimate limit State (ULS) and crack check has been done using Serviceability limit State (SLS).

Design Consideration

Various cases generally adopted for design are:

Case 1: Dead load and live load acting from outside as well as earth pressure, while no water pressure from inside (i.e. Design of Box Bridge by considering the box as in empty conditions, no water will flow from it).

Case 2: Dead load and live load acting from outside as well as earth pressure, while water pressure acting from inside (i.e. designing the by considering that it is half full).

Case 3: Dead load and live load acting from outside as well as earth pressure, while water pressure acting from inside (i.e. designing the box by considering that it is full).

Note: General analysis for all the three cases were carried out. Based on the values of bending moment and shear force it was found that case 1 produces the critical values. Thus the design was carried out manually and computationally only for case 1 as it is the worst possible scenario.

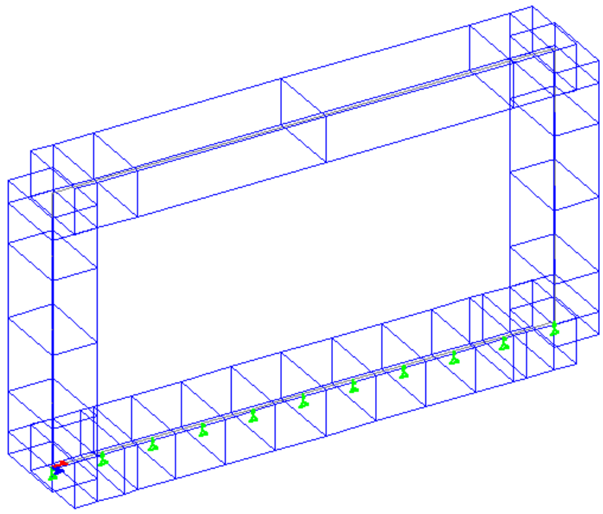

Figure 3.1 Sectional outline of Staad model

Geometry as Per General Arrangement Drawing (GAD)

Components and Section of Box Bridge is shown in Fig. 2 and Fig. 3. It depicts the position of rail level, sleepers, ballast, formation level and foundation level. A cushion of 100 mm is provided when the formation level doesn't coincide with the box top level. Side walls are subjected to earth filling and the bottom slab is provided with a 100 mm thick PPC concrete. It has a clear horizontal and vertical opening of 6 m and 3 m respectively in 0.2 m soil fill. The length of the span is 13.5 m. A uniform thickness of 600 mm is provided at top and bottom slab and at sidewalls. Haunches of 300 × 300 mm are provided with weep holes having perforated pipes 2 Nos. of 150 mm diameter to assist water pass easily. Concrete grade of M 35 and Steel grade of Fe 500 is adopted.

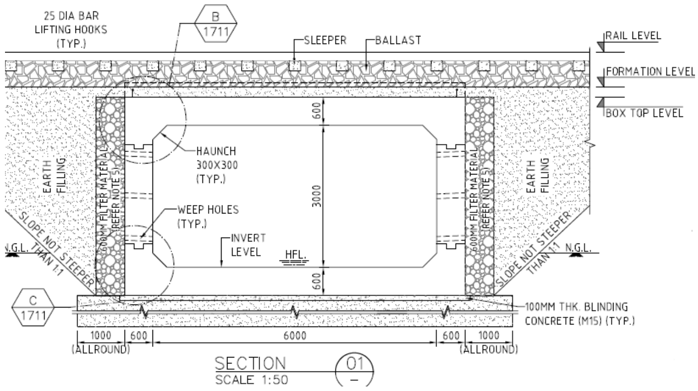

Figure 3.2 Components of box structure

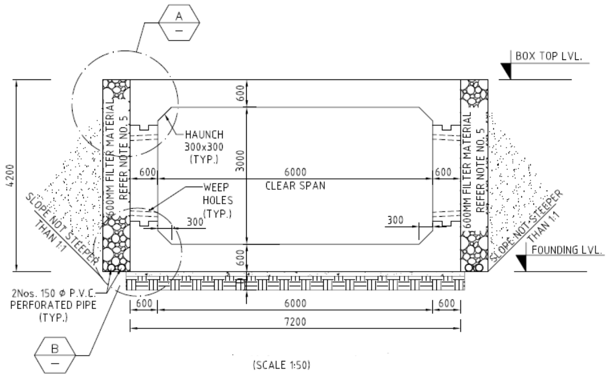

Figure 3.3 Cross section of cast in-situ box

Staad Sectional model of the box structure is shown in Fig. 3.1. The effective horizontal width and vertical height is 6.6 m and 3.6 m respectively. The bottom slab is assumed to the resting directing on soil and spring supports are applied to it.

Moment distribution Method (MDM) results

The analysis was done for all the three cases (as discussed in section 2.1). Table 1 shows bending moment and direct Shear values for Top Slab, Side Wall and Bottom Slab for all the three cases as shown above. However, the design has been done by Working Stress Method (WSM) for case 1 only as it gives the critical (maximum) values of the three cases.

Moreover, the reinforcement details for the critical condition (i.e. case 1) have been depicted in Table 2. The results obtained from manual calculations were comparable to the results obtained from computational calculations.

Computational results (STAAD Pro Analysis)

Analysis of the box type minor bridge for empty box condition with dead loads and live loads on top and earth pressure and surcharges at the side wall has been done using excel sheet and Staad-pro . Load cases were formed based on IRS-CBC codal provisions (clause no 11.2)followed by several load combinations for SLS and ULS moment and shear. Fig. 5 to Fig. 7 shows accordingly the variations of B.M and S.F at top slab, side wall and bottom slab for the worst possible load combination obtained using Staad Pro. These B.M and S.F values were used to design the minor bridge based on ULS and SLS criteria.

Table 5.1 B.M and Direct Force Result for Top Slab, Side Wall and Bottom Slab

Elements	Case	B.M at Centre (F) (N-m)	B.M at end (D) (N-m)	Direct Force (for depth hd) (N)
Top slab	i	642641	100057	154721
	ii	86711	307679	53908
	iii	510471	272521	17048
Side Wall	i	-177465	114624	504121
	ii	273024	350687	274975
	iii	343126	272521	274975
Bottom Slab	i	717176	114624	190498
	ii	103209	350687	70890
	iii	559278	272521	34552

Table 5.2 Reinforcement Details for Top Slab, Side Wall and Bottom Slab

Elements	Ast (mm2)	Bar ϕ (mm)	Spacing (mm)	Distribution steel (mm2)	Stirrup bar ϕ (mm)	Spacing (mm)
Top slab	4718	20	110	1410	8	100
Side Wall	3066	20	100	1200	8	100
Bottom Slab	5000	20	100	1480	8	100

Serviceability Limit State [SLS] condition

In this the structural members are to be checked for stresses in materials i.e., concrete and steel. Parameters like crack width, deflection, shrinkage and creep are required to be checked under SLS condition. In the present study, crack width is the defining parameter and the limiting value of crack was found to be 0.2 mm.

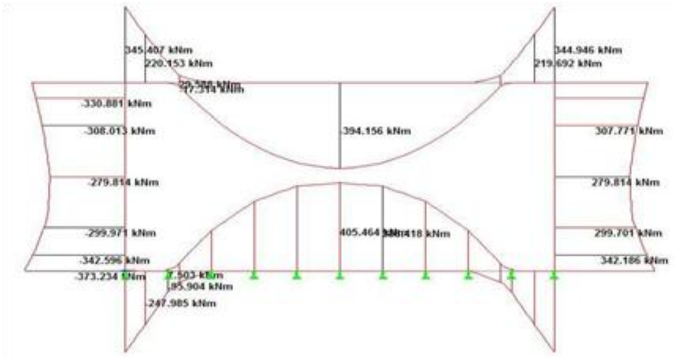

Figure 5.1 Maximum B.M diagram (SLS)

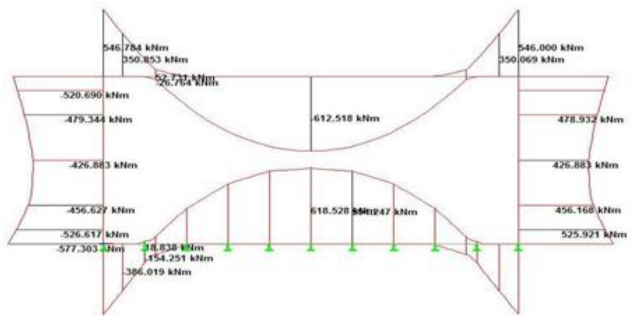

Figure 5.2 Maximum B.M diagram (ULS)

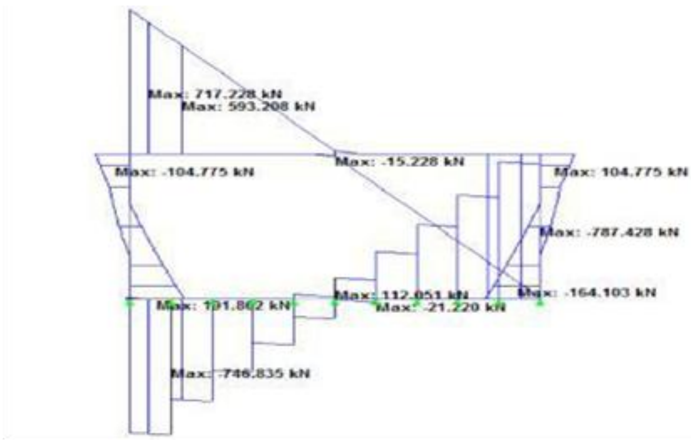

Figure 5.3 Maximum SF diagram (ULS)

Ultimate Limit State [ULS] condition

In this the structural members are to be checked for flexure, shear and torsion. In the present study torsion was not applicable, thus critical bending moment and shear values were calculated and design has been done accordingly based on ULS criteria.

Note: The ultimate limit and service limit state load factors are directly applied in model in terms of load combinations to get worst stresses. The combinations considered are shown in Tables 4-6 for both SLS and ULS conditions.

Table 5.3 Load Factor for SLS Moment for Load Combinations from 50-56

Load Comb.	**Load Factors (SLS MOMENT)**							
	DL	**EP**	**SIDL**	**DLS**	**LL**	**LLS1**	**LLS2**	**REMARKS**
50	1	1	1.2	1	1.1	1	1	MAXV+MAXH
51	1	1	1.2	1	1.1	-	-	MAXV+MINH
52	1	1	1.2	1	-	1	1	MINV+MAXH
53	1	1	1.2	1	-	1	-	MIN V + PARTIAL H
54	1	1	1.2	1	1.1	1	-	MAX V + PARTIAL H
55	1	1	1.2	1	-	-	1	MIN V + PARTIAL H
56	1	1	1.2	1	1.1	-	1	MIN V + PARTIAL H

Table 5.4 Load Factor for ULS Moment for Load Combinations from 100-106

Load Comb.	**Load Factors (ULS MOMENT)**							
	DL	**EP**	**SIDL**	**DLS**	**LL**	**LLS 1**	**LLS 2**	**REMARKS**
100	1.25	2	2	1.7	1.75	1.7	1.7	MAXV+MAXH
101	1.25	2	2	1.7	1.75	-	-	MAXV+MINH
102	1.25	2	2	1.7	-	1.7	1.7	MINV+MAXH
103	1.25	2	2	1.7	-	1.7	-	MIN V + PARTIAL H
104	1.25	2	2	1.7	1.75	1.7	-	MAX V + PARTIAL H
105	1.25	2	2	1.7	-	-	1.7	MIN V + PARTIAL H
106	1.25	2	2	1.7	1.75	-	1.7	MIN V + PARTIAL H

Table 5.5 Load Factor for ULS Shear for Load Combinations from 200-205

Load Comb.	**Load Factors (ULS SHEAR)**							
	DL	**EP**	**SIDL**	**DLS**	**LL**	**LLS 1**	**LLS 2**	**REMARKS**
200	1.25	2	2	1.7	1.75	1.7	1.7	MAXV+MAXH
201	1.25	2	2	1.7	1.75	-	-	MAXV+MINH
202	1.25	2	2	1.7	-	1.7	1.7	MINV+MAXH
202	1.25	2	2	1.7	-	1.7	-	MIN V + PARTIAL H
203	1.25	2	2	1.7	1.75	1.7	-	MAX V + PARTIAL H
204	1.25	2	2	1.7	-	-	1.7	MIN V + PARTIAL H
205	1.25	2	2	1.7	1.75	-	1.7	MIN V + PARTIAL H

Design Summary

Summary of Design Bending Moment and Shear Force is shown in Table 5.6. Load combination from 50-56 is for Maximum B.M (SLS condition), load combination from 100-106 is for maximum B.M (ULS condition) and load combination from 200-206 is for maximum S.F (ULS condition). To calculate permanent SLS B.M (Mg), all live loads were turned off in staad editor and then critical B.M value was extracted from case 50-56. Live load SLS B.M (Mq) is calculated by subtracting permanent SLS B.M (Mg) from Total SLS B.M (M). After critical values for each section has been obtained design is carried out based on ULS and SLS criteria.

Reinforcement detailing like bar diameter, bar spacing, Reinforcement provided and minimum reinforcement required (based on IRS CBC) is shown in Table 7. The minimum reinforcement was 0.2 % of the area of concrete (Ac) . The reinforcement provided was more than the minimum reinforcement requirement. Hence the reinforcement detailing was acceptable and safe according to the Ultimate Limit State criteria.

Note: The bar number provided in Table 5.7 helps in scheduling of reinforcement as shown in Fig. 8, thus by only showing bar number in the reinforcement diagram, details like diameter provided and bar spacing can be understood thereby reducing the complexity of the reinforcement diagram.

Serviceability criteria were based on crack width calculations. The calculated crack width was found to be within the permissible crack width limit of 0.2 mm. Hence the design was acceptable and safe according to serviceability Limit State criteria.

The detailed reinforcement drawing of the box structure is shown in Fig. 5.8. Reinforcement Scheduling has been done using bar number notation like 01, 01a, 02 etc to reduce the complexity of the drawing. Bar diameter, spacing and link (tie) (if any) can be easily understood from the bar number.

Table 5.6 Summary of Design Bending Moment and Shear Force

BM position			**Beam no. (BM/ shear**	**Load comb. SLS/ULS**	**Max SLS BM (kNm)**	**SLS BM permanent (kNm)**	**Max ULS BM (kNm)**	**ULS SF (kN)**	**Live load BM SLS (kNm)**
	Location	Face							
1	Top Slab - Mid part	Top	32-30	51/101	1	1	1	718	1
		Bottom	32-30	51/101	395	92	613		303
3	Top Slab - Haunch Zone	Top	28-4	56/106	221	49	351		172
		Bottom	28-4	56/106	1	1	1		1
4	Side Wall - Haunch Zone	Outside	26-2	56/106	331	71	521	105	260
		Inside	26-2	56/106	1	1	1		1
6	Side Wall - Mid part	Outside	24-22	56/106	280	55	427		225
		Inside	24-22	52/102	1	1	1		1
7	Bottom Slab - Haunch Zone	Top	14-1	54/106	1	1	1	747	1
		Bottom	14-1	56/106	248	76	387		172
9	Bottom Slab - Mid part	Top	8/9	51/101	406	124	619		282
		Bottom	8/9	51/106	1	1	1		1

Table 5.7 Main Reinforcement Detail

BM POSITION		Bar No.	Bar dia Provided (mm)	Bar spacing c/c (mm)	Reinforcement provided (mm^2)	Min Reinf (0.2% of effective A_c) rqd as per IRS – CBC(mm^2)	Check
Top Slab	Mid span	6	25	220	4460	3122	OK
		6a	25	220			
	Support	7	20	220	5085	1393	OK
		4a	25	220			
		4	20	220			
Bottom Slab	Mid span	1	25	220	4460	3153	OK
		1a	25	220			
	Support	2	20	220	5085	1536	OK
		4a	25	220			
		4	20	220			
Side Wall	Outer Face	4	20	220	5085	2124	OK
		4a	25	220			
		2	20	220			
	Inner Face	5	16	220	1427	1052	OK
		5a	12	220			

Discussion

Calculations were done using manual approach and computational approach and Results were compared in the table below (Table 5.8). Comparison of manual and staad results is shown in Table 5.8. It is seen that results obtain from Staad pro is much higher than that of manual approach. This is due to the fact that Staad keeps much higher factor of safety than prescribed by the code in order to ensure that the structure is safe. Disparity in Bending Moment for Top slab may be because of different method (WSM and LSM) adopted for design.

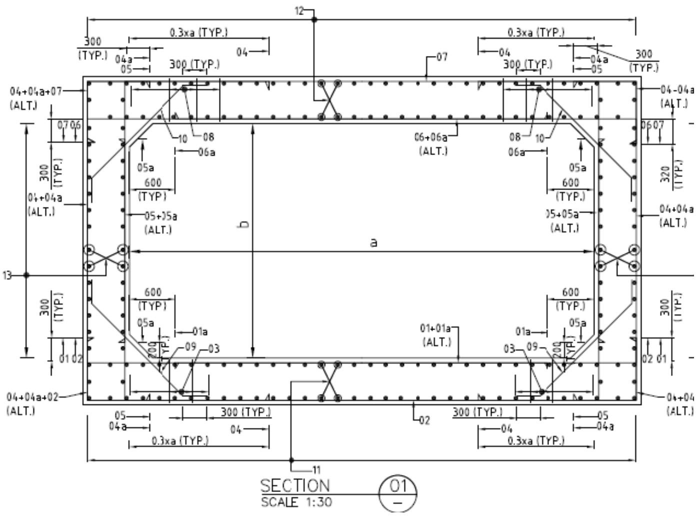

Figure5.4 Detailed reinforcement drawing for box structure

Table 5.8 Comparison of B.M between Manual and Staad- Pro Calculations

Position	MDM B.M (kN-m)	Staad – Pro B.M (kN-m)
Top slab (mid)	642	613
Bottom slab (mid)	717	917
Side wall (mid)	350	427

Table 5.9 shows the comparison of reinforcement obtained from manual and computational approach. The detailing was found to be similar for both cases and hence validate the results.

Table 5.9 Comparison of Reinforcement between manual and Staad-pro calculations

Position		Reinforcement (Manual)	Reinforcement (Staad pro)
Top slab (mid)	A_{st} (mm^2)	4718	4462
	Diameter (mm)	20	25
	Spacing (mm c/c)	100	220
Bottom slab (mid)	A_{st} (mm^2)	5000	4462
	Diameter (mm)	20	25
	Spacing (mm c/c)	100	220
Side wall (mid)	A_{st} (mm^2)	3066	3659
	Diameter (mm)	20	25
	Spacing (mm c/c)	100	220

CONCLUSION

The main objective of this project was to study the behaviour of box type minor railway bridge when subjected to different combination of loads in terms of bending moment and Shear force variations. The design was completed by using Working Stress Method in case of Manual Approach and using Ultimate Limit State method and Serviceability Limit State method in case of Computational Approach (Staad Pro).So from analysis and design we concluded:

1) The critical sections considered are the centre of span of top and bottom slabs and the haunch and at the centre and haunch of the vertical walls since the maximum design forces develop at these sections due to various combinations of loading patterns.
2) The study shows that the maximum design forces developed for the loading condition when the top slab is subjected to the dead load and live load and sidewall is subjected to earth pressure and surcharges, and when the culvert is empty.
3) The maximum negative moment develop at the mid section of the top slab for the condition that the box is empty and the top slab carries the dead load and live load.
4) The maximum positive moment develop at the haunch section of the top slab for the condition that the box is empty and the top slab carries the dead load and live load.
5) The maximum positive moment develop at the mid section of the bottom slab for the condition that the box is empty and the top slab carries the dead load and live load.
6) The maximum negative moment develop at the haunch section of the bottom slab for the condition that the box is empty and the top slab carries the dead load and live load.
7) The maximum positive moment develop at the haunch of vertical wall when the box is empty and when lateral pressure (Earth pressure, Live Load Surcharge and Dead Load Surcharge) acts.
8) It was observed that Computational method (Staad Pro) was much more competent than Moment Distribution Method (MDM) in term of efficiency of result and time consumption.
9) The dimension of a bridge plays a governing role for the involvement of various loads and there cases for the designing purpose.

10) It is found that for designing any railway bridge relevant IRS codes were to be very meticulously followed.

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