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Optimized Design and Analysis of a Minor Bridge Under Varying Parameters

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Abstract- Bridges are essential components of transportation infrastructure, providing safe and efficient passage over obstacles such as rivers, canals, and valleys. Among various types of bridges, minor box-type bridges are widely used in rural and semi-urban areas due to their structural efficiency, durability, and cost-effectiveness. The present study focuses on the optimized design and analysis of a minor box-type bridge under varying parameters using modern computational tools. In this study, the bridge structure is modeled and analyzed using STAAD Pro software, which allows accurate simulation of structural behavior under different loading conditions. The analysis is carried out by considering various loads as per Indian Roads Congress (IRC) guidelines, including dead load, superimposed dead load, live load (IRC Class A and 70R), earth pressure, temperature effects, and braking forces. Different load combinations are applied under both limit state of collapse and limit state of serviceability to ensure safety and performance of the structure. The results obtained from the analysis are evaluated in terms of bending moment (BM) and shear force (SF) at critical sections such as top slab, bottom slab, external walls, and internal walls. It is observed that maximum bending moment occurs at the corners and supports, while maximum shear force is observed at supports and wall bases. The bottom slab is found to be more critical compared to the top slab due to additional effects of soil pressure and load transfer. The design of structural components is carried out using Excel sheets based on the results obtained from STAAD Pro, ensuring compliance with IRC code provisions. The study also examines the effect of varying parameters such as loading conditions and geometric dimensions on the performance of the bridge. The results indicate that IRC 70R loading governs the design due to higher stress values.

Keywords: Bridge, STAAD Pro, Bending Moment, Shear Force, Box Bridge, Optimization, IRC Loads, Structural Analysis

I. INTRODUCTION

Bridges are among the most important and fundamental structures in civil engineering, playing a vital role in the development and functioning of modern transportation systems. They are constructed to provide safe, efficient, and uninterrupted passage over physical obstacles such as rivers, valleys, roads, railways, canals, and other natural or man-made barriers. By connecting separated regions, bridges not only facilitate the movement of people and goods but also contribute significantly to economic growth, social integration, and regional development. In a developing country like India, where infrastructure expansion is a key priority, bridges form an essential component of the transportation network and serve as lifelines for both urban and rural areas. The importance of bridges can be understood from their wide range of applications in highways, railways, irrigation systems, and urban infrastructure. They reduce travel time, improve accessibility, and enhance connectivity between remote and developed regions. In addition, bridges play a crucial role in emergency situations such as floods and natural disasters by providing reliable routes for rescue and relief operations. Therefore, the proper design, construction, and maintenance of bridges are essential to ensure safety, durability, and long-term performance. With the rapid growth in population, urbanization, and industrialization, the demand for transportation infrastructure has increased tremendously in recent years. The number of vehicles on roads has grown significantly, leading to increased traffic congestion and higher loading demands on bridge structures. This situation has created a strong need for efficient, safe, and economical bridge systems that can accommodate increasing traffic loads while maintaining structural integrity. Among various types of bridges, minor bridges are of particular importance as they are extensively used in rural and semi-urban areas for crossing small rivers, drainage channels, and canals.

Minor bridges are generally defined as bridges having a total span of up to 60 meters. These structures are widely used due to their simplicity, economy, and ease of construction. They are essential for providing connectivity in rural areas where major bridges may not be feasible due to economic or geographical constraints. Despite their relatively smaller size compared to major bridges, minor bridges play a critical role in ensuring smooth transportation and supporting local economies. However, in many cases, the design of minor bridges is carried out using conventional methods without considering optimization, which may result in inefficient use of materials and increased construction costs. Traditionally, bridge design was performed using manual calculations based on simplified assumptions and empirical formulas. While these methods were effective for basic design purposes, they had several limitations, especially when dealing with complex loading conditions and structural configurations. Manual methods are time-consuming, prone to human error, and often fail to accurately represent the actual behavior of structures under real-life conditions. With the increasing complexity of modern bridge designs and loading scenarios, there has been a shift towards the use of advanced computational tools for structural analysis and design. The development of computer-based analysis software has revolutionized the field of structural engineering. Among these tools, STAAD Pro has emerged as one of the most widely used and reliable software for structural analysis and design. It allows engineers to create detailed three-dimensional models of structures, apply various types of loads, and analyze the behavior of the structure under different conditions. The software provides accurate results in terms of bending moment, shear force, axial force, and deflection, which are essential for designing safe and efficient structures. The use of STAAD Pro in bridge design offers several advantages over traditional methods. It reduces the time required for analysis, minimizes calculation errors, and allows for the consideration of multiple load combinations and varying parameters. Engineers can easily modify the design parameters and study their effect on the structural behavior, which helps in achieving optimized designs. This is particularly important for minor bridges, where cost efficiency and material optimization are key considerations.

II. METHODOLOGY

GEOMETRIC PARAMETERS:

The geometric parameters of the bridge are selected based on practical considerations, standard design guidelines, and project requirements. These parameters define the size, shape, and configuration of the bridge structure.

Table No. 3.1: Geometric Parameters of Box Bridge

S.No	Parameter	Value
1	Number of cells	8
2	Clear span of box bridge	4 m
3	Clear depth of box bridge	4 m
4	Overall width of bridge	12 m
5	Total length of bridge	35.6 m
6	C/C length of bridge	35.2 m
7	Thickness of top slab	0.4 m
8	Thickness of side wall	0.4 m
9	Thickness of bottom slab	0.45 m

LOADING DATA:

The bridge is subjected to various loads as per IRC:6 guidelines. These loads are considered under both Limit State of Collapse and Limit State of Serviceability.

Table No. 3.2: Load Cases and Load Factors

S.No	Load Case	Abbreviation	Collapse Factor	Serviceability Factor
1	Dead Load	DL	1.35	1
2	Superimposed Dead Load	SIDL	1.35	1
3	Wearing Coat	WC	1.75	1
4	Earth Pressure	EP	1.5	1
5	Live Load Surcharge (One Side)	LLS-One	1.2	1
6	Live Load Surcharge (Both Side)	LLS-Both	1.2	1
7	Temperature Rise	TR	1	1
8	Temperature Fall	TF	1	1
9	Breaking Force (Class A)	BF-Class A	1.5	1
10	Breaking Force (70R Tracked)	BF-70RT	1.5	1
11	Breaking Force (70R Wheeled)	BF-70RW	1.5	1
12	Breaking Force (70R Bogie)	BF-70RB	1.5	1
13	Temperature Gradient Rise	TG-Rise	1	1
14	Temperature Gradient Fall	TG-Fall	1	1

STAAD MODEL OF BOX BRIDGE:

The bridge structure is modeled in STAAD Pro software using the above geometric parameters. The model is created in a three-dimensional environment where nodes, members, plates, and supports are defined.

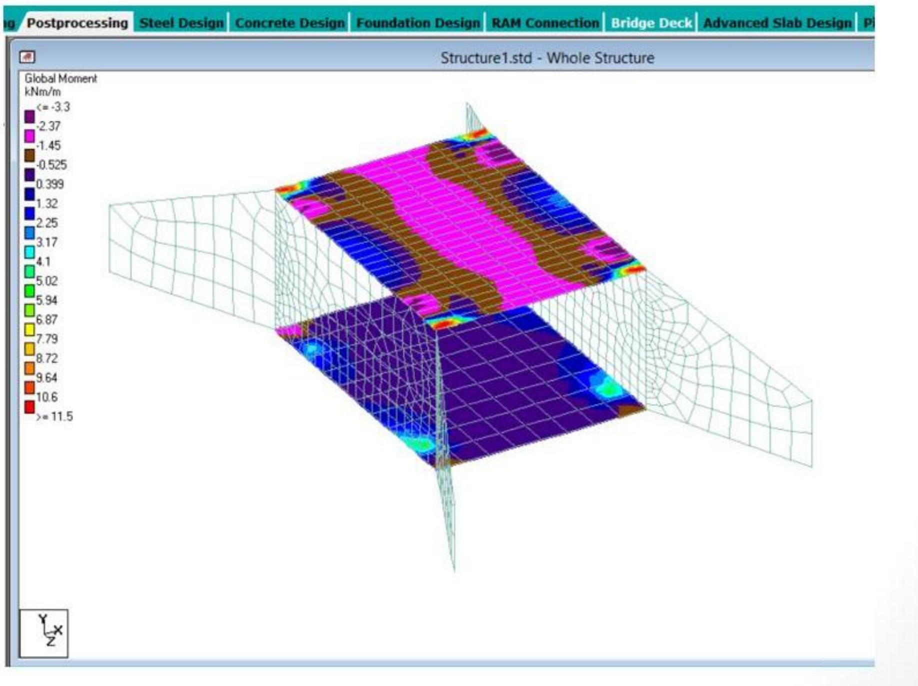


Figure No. 3.1: STAAD Pro Model of Box Bridge

III. RESULTS AND DISCUSSION

BENDING MOMENT RESULTS:

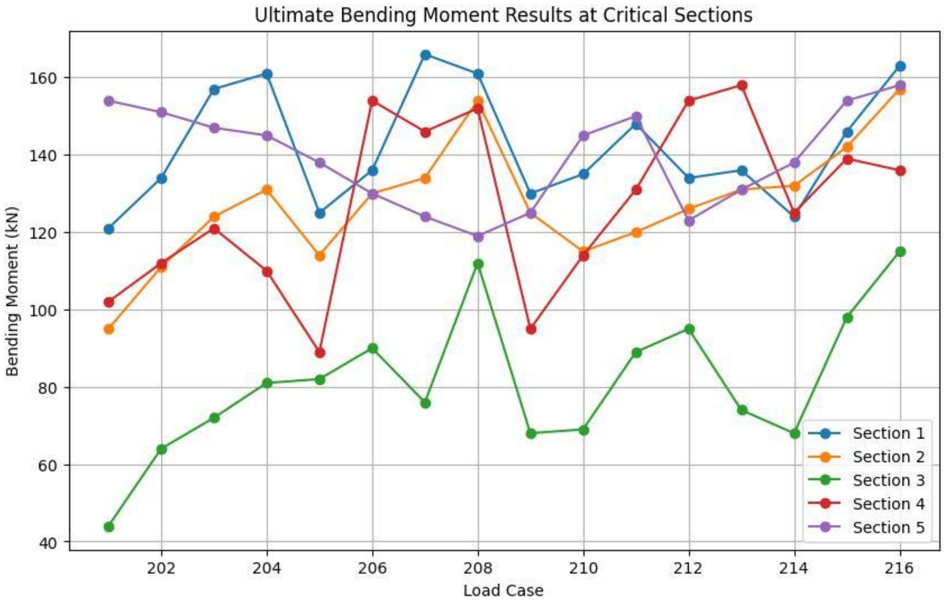
The bending moment values obtained from STAAD Pro analysis at critical sections for different load combinations are presented in Table No. 4.1.

Table No. 4.1: Ultimate Bending Moment Results at Critical Sections (kN)

L/C No.	Sec-1	Sec-2	Sec-3	Sec-4	Sec-5
201	121	95	44	102	154
202	134	111	64	112	151
203	157	124	72	121	147
204	161	131	81	110	145
205	125	114	82	89	138
206	136	130	90	154	130
207	166	134	76	146	124
208	161	154	112	152	119
209	130	125	68	95	125
210	135	115	69	114	145
211	148	120	89	131	150
212	134	126	95	154	123
213	136	131	74	158	131
214	124	132	68	125	138
215	146	142	98	139	154
216	163	157	115	136	158
MAX	166	157	115	158	158

Discussion of Table 4.1:

From the above table, it is observed that the bending moment varies significantly for different load cases and sections. The maximum bending moment value of 166 kN occurs at Section 1, indicating it as a critical region. Similarly, high values of 157 kN and 158 kN are observed at other sections, which confirms that the bridge is subjected to heavy stresses under certain loading conditions. The variation of bending moment clearly shows that the distribution of loads is not uniform and depends on the location and type of load applied. The higher values are mainly due to heavy vehicle loads such as IRC 70R loading.



Graph No. 4.1: Ultimate Bending Moment Results at Critical Sections (kN)

BENDING MOMENT IN TOP AND BOTTOM SLAB:

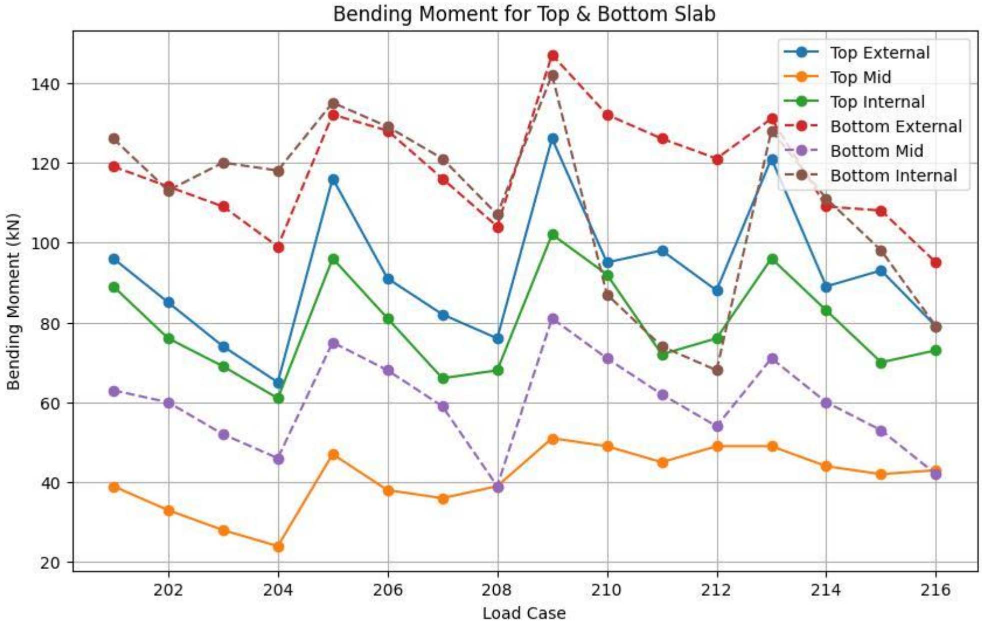
Table No. 4.2: Bending Moment for Top & Bottom Slab (kN)

L/C No.	Top Ext.	Top Mid	Top Int.	Bottom Ext.	Bottom Mid	Bottom Int.
201	96	39	89	119	63	126
202	85	33	76	114	60	113
203	74	28	69	109	52	120
204	65	24	61	99	46	118
205	116	47	96	132	75	135
206	91	38	81	128	68	129
207	82	36	66	116	59	121
208	76	39	68	104	39	107
209	126	51	102	147	81	142
210	95	49	92	132	71	87
211	98	45	72	126	62	74
212	88	49	76	121	54	68
213	121	49	96	131	71	128
214	89	44	83	109	60	111
215	93	42	70	108	53	98
216	79	43	73	95	42	79
MAX	126	51	102	147	81	142

Discussion of Table 4.2:
From the above table, it is observed that:

- The bottom slab experiences higher bending moment compared to the top slab.
- Maximum BM in top slab = 126 kN
- Maximum BM in bottom slab = 147 kN

This is mainly due to the additional effect of soil pressure and load transfer from the superstructure. The mid-span values are comparatively lower, indicating that supports and edges are more critical regions.



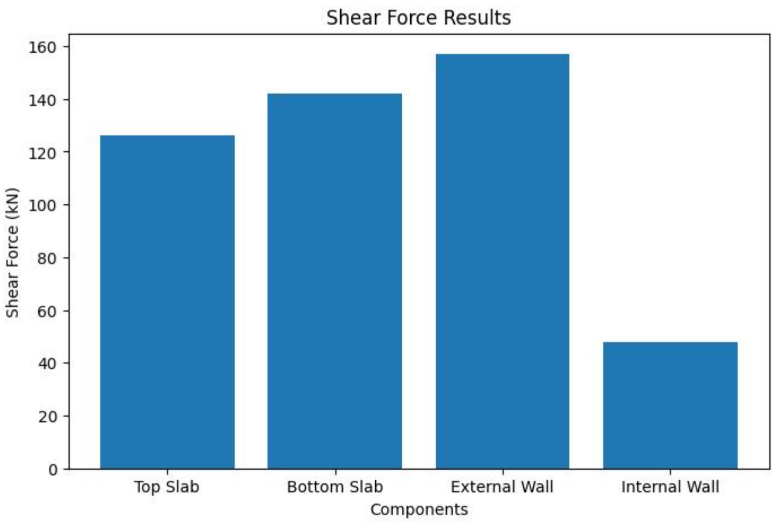
Graph No. 4.2: Bending Moment for Top & Bottom Slab (kN)

SHEAR FORCE RESULTS:

Table No. 4.3: Shear Force Results (kN)

Component	Shear Force (kN)
Top Slab	126
Bottom Slab	142
External Wall	157
Internal Wall	48

Discussion of Table 4.3:
The shear force results indicate that:
- Maximum shear force occurs in external wall (157 kN)
- Bottom slab also experiences high shear (142 kN)
- Internal wall has minimum shear force (48 kN)



Graph No. 4.3: Shear Force Results (kN)

CONCLUSION

The important conclusions drawn from the present study are as follows:

1. The structural analysis of the minor box-type bridge using STAAD Pro provides accurate and reliable results for design.
2. The critical sections of the bridge are identified at:
   - Mid-span of slabs
   - Supports
   - Junctions (haunch regions)
3. The maximum bending moment occurs at:
   - Corners of slabs
   - External and internal supports
4. The bottom slab is more critical than the top slab due to:
   - Soil pressure
   - Load transfer from superstructure
5. In walls:
   - Maximum bending moment occurs at bottom of walls
   - Minimum bending moment occurs at top of walls
6. The external walls carry more load than internal walls due to earth pressure and environmental effects.
7. The maximum shear force occurs at supports and wall bases, making these regions critical for design.
8. Among all loading conditions, IRC 70R loading produces maximum BM and SF, hence it governs the design.
9. Temperature effects (rise, fall, gradient) produce additional stresses and must be considered in design.
10. Load combinations (DL + LL + EP + Temperature) produce critical conditions and must be used for safe design.
11. The use of STAAD Pro reduces manual errors and improves efficiency in analysis.
12. The design verified using Excel sheets ensures compliance with IRC codes.
13. The study confirms that optimization of design is possible by varying parameters such as thickness and span.
14. Optimized design helps in:
    - Reducing material cost
    - Improving structural efficiency
    - Ensuring safety and durability
15. Overall, the study proves that minor box bridges can be designed safely and economically using modern analysis tools.

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