Design And Mechanical Analysis of Main Steel ISMB 600 Beam in Box Girder Formwork

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Abstract—**The intention of this report is to provide the Design and Mechanical analysis of the main steel I Beam of a formwork solution by Alsina Multiform decking + AR shoring + Vistaform slab system for concrete box girder to project six lane extra dosed cable stay bridge over river ganga, Patna by L&T infrastructure engineering limited. In this Project, Gantry solution has been used along with AR shoring, Multiform, Vistaform, Props Vertical Supports which are standard Alsina systems. Gantry Solution has been used worldwide where support for formwork cannot be taken from the ground. A definitive space needs to be kept for traffic. In this Report we focus on Mechanical analysis of main steel I Beam only. Various parameters will be verified, like Deflection, Shear Force, Bending Moment, Compressive Stress, Tensile Stress, Resistance Verification of steel components. It is verified that all structural elements of the molds support with assurance the considered loads in this study, based on India Standard, European and Spanish constructive regulations. This report only analysis the static states verification of ISMB 600, verification of other items, assembly method and procedure of the formwork system will not be included in this report.**

Index Terms—**Main steel I Beam, Gantry Solution, Formwork, L&T, Cable Stay Bridge, Mechanical Analysis.**

I. INTRODUCTION

For the six-lane extradosed cable-stayed bridge project over the River Ganga in Patna, Alsina's formwork solutions were utilized. These included the Multiform bridge decking, AR shoring, and Vistaform slab system to cast the concrete box girder for Span 2 (V1-P11R to V1-P12R). The span features a regular geometry with a cross-section measuring 20.65 meters in width, 3.20 meters in height, and a total length of 54.31 meters. Additionally, a gantry solution was required for a specific area involving section beams. Statistics located cation be considered that all created vertical and horizontal pouring pressures in the process of cast for the Box girder and the own weight of formworks are all supported by the Multiform decking system, also the Multiform system will be supported by AR shoring system which located and fixed on the ground. From this Designed Formwork we will Analys ISMB 600 Steel Beam for Various parameters.

II. LITERATURE REVIEW

[1] Donghua Zhou, Longqi Li, Jürgen Schnell, Wolfgang Kurz, Peng Wang - Elastic Deflections of Simply Supported Steel I-Beams with a Web Opening: In their paper they have done the Elastic Deflection of simply supported steel I beam with a web opening. Forming openings in the web of steel beam gives rise not only to strength problem but also stiffness problem, that is, the deflection of beam may be too large to meet the requirements. However, to calculate the deflection it is faced that the region of web opening is three times statically indeterminate, which makes the deflection calculation of perforated beams extremely complicated. To avoid solving the redundant forces and obtain applicable formulas for determining deflection of perforated beam the author of this paper have derived applicable formulas by direct solving differential equations and solving differential equations combined by using displacement method. Results from these formulas

are compared with those form finite element method and show a good agreement and high precision.

[2] Masoud Mohammadzadeh, Anjan Bhowmick - Behavior of steel I-beams reinforced while under load Steel I-beams often require reinforcing while they are under load. A common method for strengthening steel beams is by welding steel cover plates to the bottom flanges of the existing members. Very limited research has been conducted on the behavior of I-beams reinforced under load. This paper presents a finite element (FE) based study on steel I-beams welded with steel cover plates while under load. A series of simply supported steel I-beams reinforced with cover plates welded at the bottom flanges are analyzed. FE analysis shows that with increased preload, the capacity of the I-beam reinforced under load reduces when the failure mode of the beam is lateral-torsional buckling (LTB). On the other hand, the variation of the preload has an insignificant effect on the behavior and ultimate strength of the reinforced beam when the reinforced beam fails in flexural yielding. Also, effects of different parameters, such as residual stress patterns in the I-beam and cover plate, welding residual stress, type of welding patterns, the difference in steel grades between I-beam and reinforcing plate, on the behavior of the steel I-beams reinforced while under load are investigated numerically. Finally, the flexural capacities of reinforced I-beams with welded cover plates obtained from FE analyses are compared with the capacities predicted by the American (AISC 360-16) and Canadian (CAN/CSA-S16-19) steel design standards. FE analysis shows that AISC 360-16, when the effect of loading height is considered, can reasonably predict the capacity of I-beam reinforced with welded cover plate at the bottom flange.

[3] Yufei Zhu a, Xiang Yun b, Leroy Gardner – Behavior and design of high strength steel homogeneous and hybrid welded I-section beams: The behavior and design of high strength steel (HSS) beams are addressed in the present study. Six in-plane three-point bending tests on three different welded I-sections − two homogeneous S690 steel welded I-sections, and one hybrid welded I-section with S690 steel flanges and an S355 steel web, were first conducted. The beam tests were carried out in major axis bending and a bespoke restraint system was designed and employed in the test programme to prevent lateral-torsional buckling. Following the experimental investigation, a thorough finite element (FE) modelling programme was performed, which included a validation study confirming the accuracy of the developed FE models in replicating the flexural behavior of HSS welded I-section beams, and a parametric study generating additional FE data on HSS welded I-section beams over a broader range of cross-sectional slenderness's, steel grades and loading configurations. The test results obtained in the present study and collected from the literature, together with the generated FE data from the parametric study, were used to evaluate the suitability of the current Eurocode 3 cross-section slenderness limits for HSS homogeneous and hybrid welded I-sections in bending. It is shown that the current Eurocode Class 2 and Class 3 slenderness limits are suitable for the classification of the outstand flange (in compression) and internal web (in bending) elements of both HSS homogeneous and hybrid welded I-sections subjected to major axis bending, while stricter Class 1 slenderness limits are considered necessary to achieve sufficient rotation capacity for plastic design. The findings from the present study indicate that plastic design can be used for HSS structures, provided the proposed stricter Class 1 slenderness limits are employed.

[4] Tarek A. Elbacklesh, Nader N. Khalil, Ibrahim M. El-Shenawy, A.M. Abou-Rayan - Flexural behavior of cold-formed steel I-beams strengthened in the web with different materials: This research presents an experimental and theoretical study investigating the flexural capacity of built-up steel cold-formed I-beams strengthened in the hollow web with different materials. Eight built-up cold-formed steel I-beams were prepared and experimentally tested. As a control specimen, one was not strengthened, steel shear connectors strengthened one without materials, and six specimens were strengthened by filling the hollow web with different materials. The strengthened materials used are wood wastes (Sawdust with epoxy- Sawdust with polyester), lightweight concrete, normal-weight concrete, High-Strength concrete, and polymer mortar. The specimens' method of failure, load at failure, and vertical displacements were recorded. The relationship between vertical load and deflection at the span's midpoint has been graphed to analyze the impact of strengthened materials. Using polymer

mortar resulted in the highest capacity, outperforming other materials. Finite element models of the tested beams were established. Good agreements between experimental and numerical models were observed. 84-FE numerical models were established to determine the effect of cover plate thickness on flange width ratios and the height-to-width of the strengthening material. Finally, new equations that calculate strengthened beam capacity were presented.

III. OBJECTIVES

1. Design Main steel I Beam for required superimpose loads with manual calculations.
2. Perform Analysis to evaluate various parameters like deflection, shear force, bending moment & stresses.
3. Compare Manual mathematical design calculation with software-based analysis results.

IV. APPLICABLE CODES

- "Guide to formwork for concrete" (Reported by ACI Committee 347R-14 USA).
- IS 808 - 2021 - Hot Rolled Steel Beam, Column, Channel & Angle Sections - Dimensions & Properties.
- IS 800-2007 - General Construction in Steel - Code of Practice (3rd Revision)
- "Basic Design Concepts" © 2006,2008 T. Section DC.
- "Steel Structures Project", UNE-EN 1993-1-1:2005 Eurocode 3.
- "Calculation criteria by Eurocode 1 and 3".
- "Estructuras de acero. Uniones y sistemas estructurales", 2 edición. (BELLISCO).
- "Structural steel instruction" (EAE).
- BS EN 10025-2-2019 Hot rolled products of structural steels Part-2 Technical delivery conditions for non-alloy structural steels.
- "Guidelines for formwork, falsework and temporary structures" (IRC:87-2011).
- ANSI/AF&PA NDS-2005 - National Design Specification for Wood Construction
- ACI 318S-14. "Requisitos de Reglamento para Concreto Estructural "
- ACI 147-14. "Diseño de encofrados "
- AISC LRFD. "Load and Resistance Factor Design Specification for Structural Steel "

"Viguetas prefabricadas de madera para encofrado", UNE-EN 13377.The SI unit for magnetic field strength H is A/m. However, if you wish to use units of T, either refer to magnetic flux density B or magnetic field strength symbolized as μ0H. Use the center dot to separate compound units, e.g., —A·m².‖

V. MATHEMATICAL CALCULATION

A. Mechanical Properties :
Steel beam ISMB 600:
Material of ISMB = S235JR

Figure 1: Mechanical Properties of ISMB 600

B. Calculation of Permissible Values :
B.1. Permissible Bending Moment of ISMB 600
Refer IS 800 : 2007, CL 8.2.2

λ_{LT} = 0.2
Φ_{LT} = 0.52
X_{LT} = 1.0
σ_{bd} = 213636.36 kN/m2
Z_p = 0.0030067 m3
β_b = 1.0
B.Mper = M_d = 642.3 kN-m
Permissible Bending Moment of ISMB 600 = 642 kN-m.
B.2. Permissible Shear Force of ISMB 600 :
Refer IS 800 : 2007, CL 8.4, TABLE 5
Permissible Shear Force of ISMB 600 = V_{per} = V_d

$V_d = V_n / \gamma_{m0}$, $V_n = V_p$,
$V_p = \frac{A_v \sigma_{yw}}{\sqrt{3}}$, $A_v = h*t_w$,

V_d = Design Shear Strength
V_n = Nominal Shear Strength
V_p = Pure Shear Strength
For Hot-Rolled γ_{m0} = Partial Safety factor against shear failure
A_v = Shear Area under pure shear.
σ_{yw} = Yield strength of the web
h = Overall depth of the section
t_w = Thickness of the web
Av = 0.6 * 0.012   = 0.0072 m2

$\sigma yw = 235000 \ kN/m2$

$Vp = (0.0072*235000)/(\sqrt{3}) = 976.9 \ kN$

$Vn = 976.9 \ kN$

$Vd = (976.9/1.1)$

$Vd = 888 \ kN$

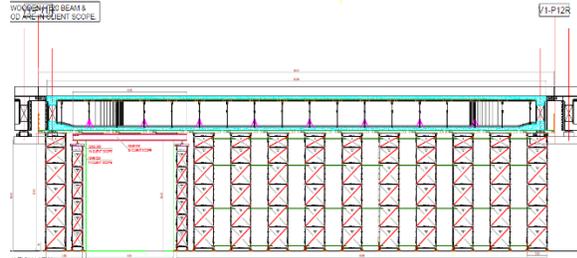C. Drawing and Calculation of Super Impose Loads :

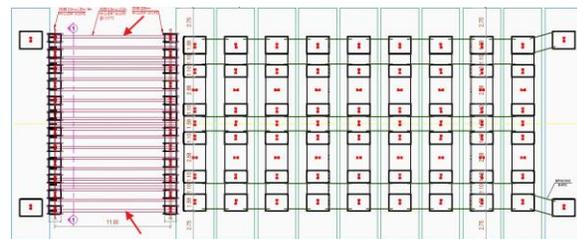Figure 2: Longitudinal Section View of Formwork

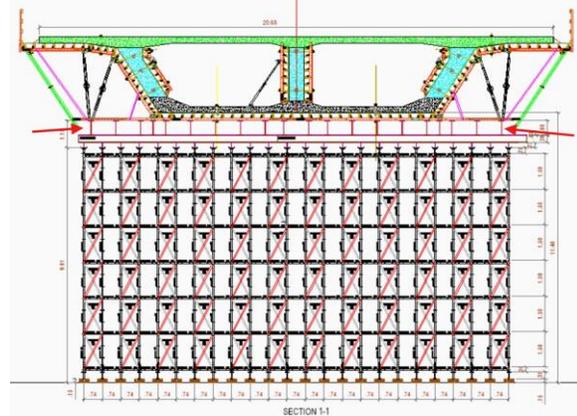

Figure 3: Plan View of Formwork
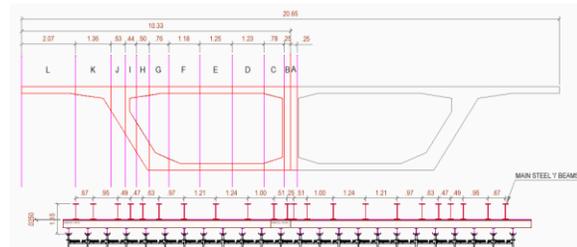

Figure 4: Transverse Section View of Formwork

Figure 5: Tributary Area Supported by Each ISMB 600

Table 1: Calculation of Linear Load on Each ISMB600

I Beam	Tributary Area (m²)	Tributary Span (m)	Concrete Density (kN/m³)	Live Load (kN/m²)	Formwork Load (kN/m²)	Level of Live Load to be consider	UDL on I Beam (kN/m)
A	0.8	0.25	26	1.5	0.5	1	21.3
B	0.8	0.25	26	1.5	0.5	1	21.3
C	0.7	0.78	26	1.5	0.5	2	21.32
D	0.64	1.23	26	1.5	0.5	2	21.56
E	0.65	1.25	26	1.5	0.5	2	21.9
F	0.65	1.18	26	1.5	0.5	2	21.62
G	0.79	0.76	26	1.5	0.5	2	21.24
H	0.74	0.5	26	1.5	0.5	2	21.24
I	0.75	0.44	26	1.5	0.5	2	21.26
J	0.73	0.53	26	1.5	0.5	2	21.1
K	0.6	1.36	26	1.5	0.5	2	21.04
L	0.54	2.07	26	1.5	0.5	2	22.32
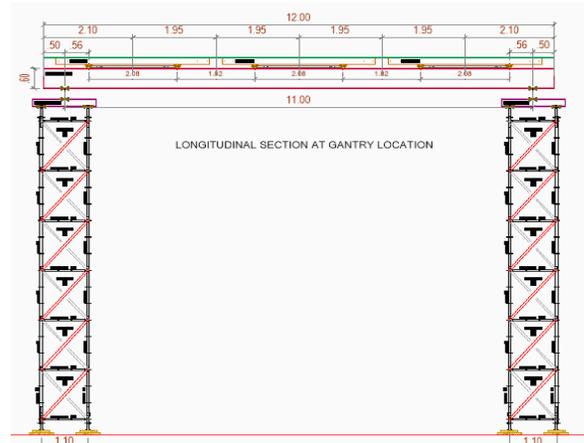
Figure 6: Formwork Arrangement Above ISMB 600
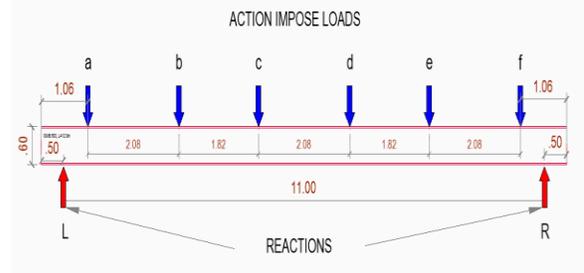
Figure 7: F.B.D of Super Impose Point Loads on ISMB 600

Table 2: Calculation of Point Loads on ISMB600 Receiving Maximum Linear Load

LOAD CONVERSION FROM UDL TO POINT LOAD			
Point of contact on I beam	Support Span (m)	Max. UDL (kN/m²)	Point Load (kN)
a	2.1	22.32	46.87
b	1.95	22.32	43.52
c	1.95	22.32	43.52
d	1.95	22.32	43.52
e	1.95	22.32	43.52
f	2.1	22.32	46.87

Figure 8: Converting 6 Point Loads to 2 Point Loads

Reactions : Taking Moment @ L

RR x 11 = (133.92 x 2.64) + (133.92 x 8.36) + (1.21 x 11 x 5.5)

RR = RL = 140.57 kN

Deflection Check : As per Code : ANSI/AF&PA NDS-2005 NATIONAL DESIGN SPECIFICATION FOR WOOD CONSTRUCTION
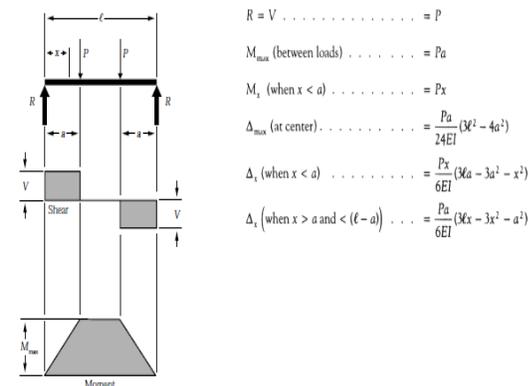
Figure 9: Formula for Deflection, Shear Force & Bending Moment

δ_{maxact} = (133.92/(24*189420)*(3(112)-4(2.642))

δ_{maxact} = 26.06 mm

δ_{maxper} = 11000/300 = 36.67 mm

Shear Force Check :

V_{maxact} = 133.92 kN

Permissible Shear Force of ISMB 600 V_{per} = 888 kN

Bending Moment Check :

$B.M_{maxact}$ = 353.5 kN-m

Permissible Bending Moment of ISMB 600

$B.M_{per}$ = 642 kN-m

Compressive Stress Check :

$\sigma_{cmaxact}$ = (353.5)/(1.0*0.0030067)

$\sigma_{cmaxact}$ = 117572 kN/m2

Permissible Compressive Stress = 213636 kN/m2

Tensile Stress Check :

$\sigma_{tmaxact}$ = $\sigma_{cmaxact}$

$\sigma_{tmaxact}$ = 117572 kN/m2

Permissible Tensile Stress = 213636 kN/m2

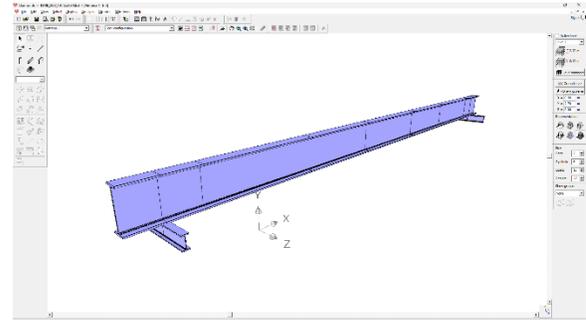## VI. ANALYSIS IN DIAMOND SOFTWARE

Model :
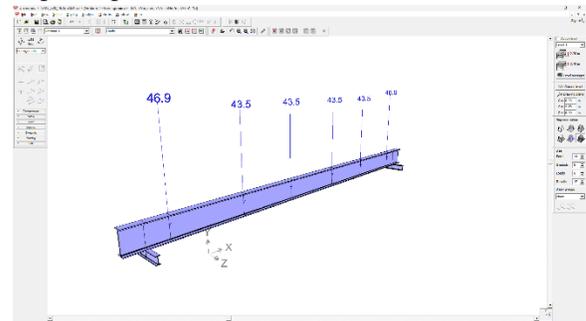

Figure 10: ISMB 600 Model

Super Impose Point Loads :

Figure 11: Super Impose Point Loads
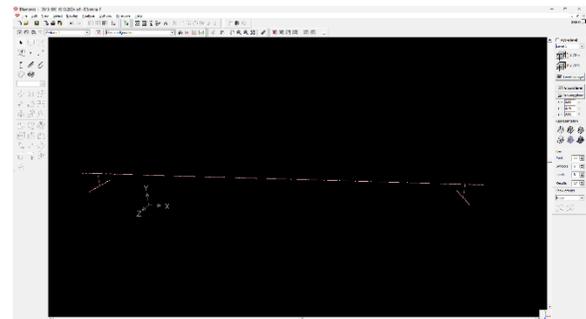
Mesh Model of ISMB 600 :

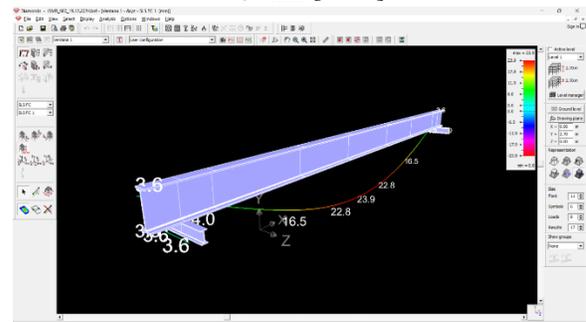Figure 12: Mesh Model

Maximum Deflection, δ_{1max} [mm] :

Figure 13: Maximum Deflection

Maximum Deflection δ_{1max} = 23.9 mm

Permissible Deflection δ_{maxper} = L/300

As per IS 800 : 2007, Table 6

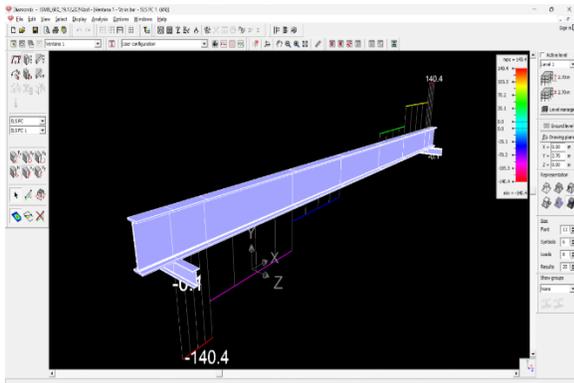δ_{per} = 11000/300 = 36.67 mm

Shear Force, V_{1max} [kN] :

Figure 14: Maximum Shear Force

Maximum Shear Force, V_{1max} = 140.4 kN

Permissible Shear Force, V_{per} = 888 kN
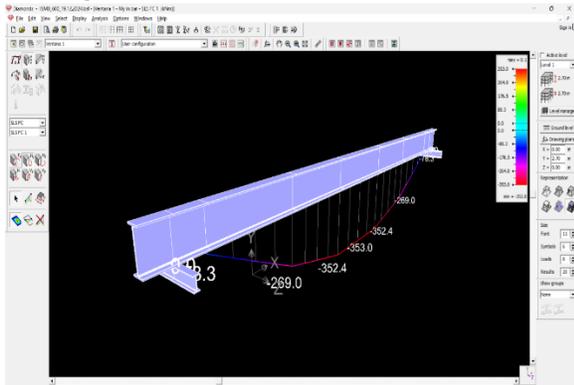
Bending Moment, $B.M_{1max}$ [kN-m] :

Figure 15: Maximum Bending Moment

Maximum Bending Moment = 353 kN-m

Permissible Bending Moment = 642 kN-m

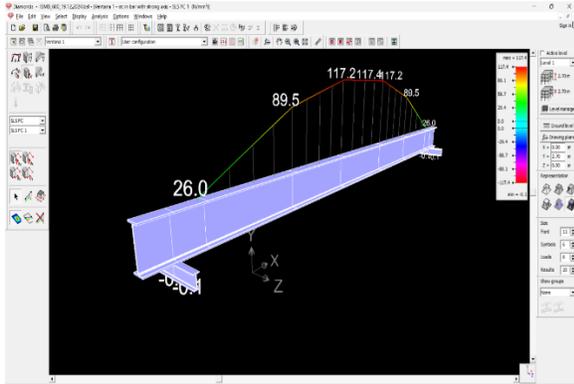Compressive Stress, σ_{1cmax} [N/mm2] :

Figure 16: Maximum Compressive Stress

Maximum Compressive Stress = 117.4 N/mm2

Maximum Compressive Stress = 117400 kN/m2

Permissible Compressive Stress = 213636 kN/m2
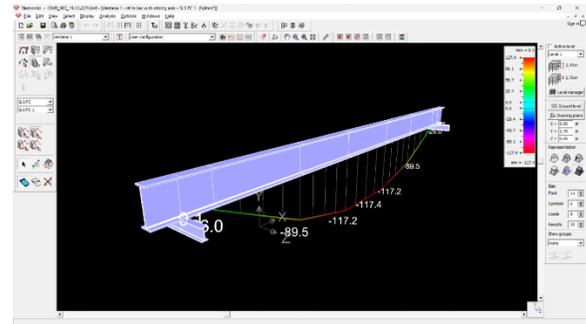
Tensile Stress, σ_{1tmax} [N/mm2] :

Figure 17: Maximum Tensile Stress

Maximum Tensile Stress = 117.4 N/mm2

Maximum Tensile Stress = 117400 kN/m2

Permissible Tensile Stress = 213636 kN/m2
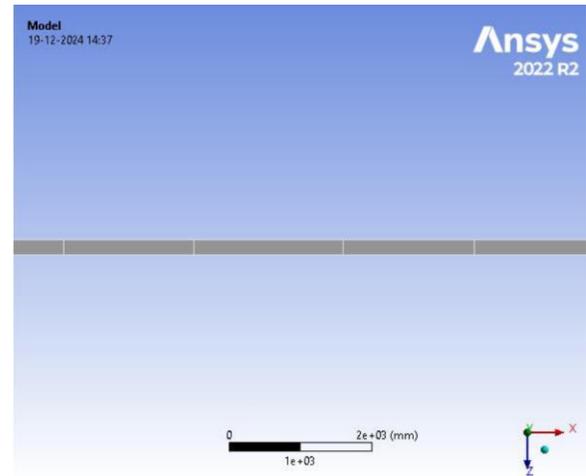
VII. ANALYSIS IN ANSYS SOFTWARE

Model :

Figure 18: ISMB 600 Model in Ansys
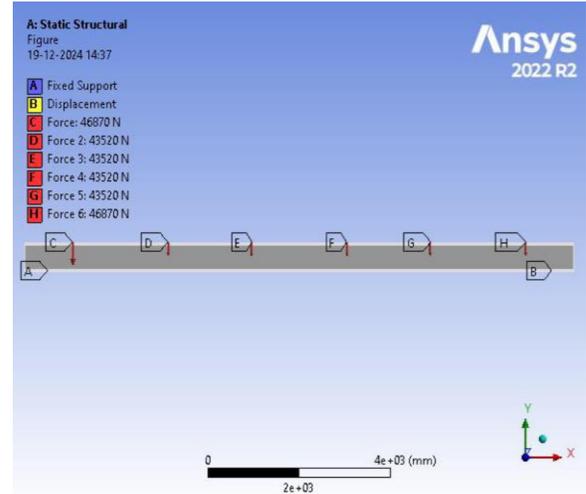
Super Impose Point Loads :

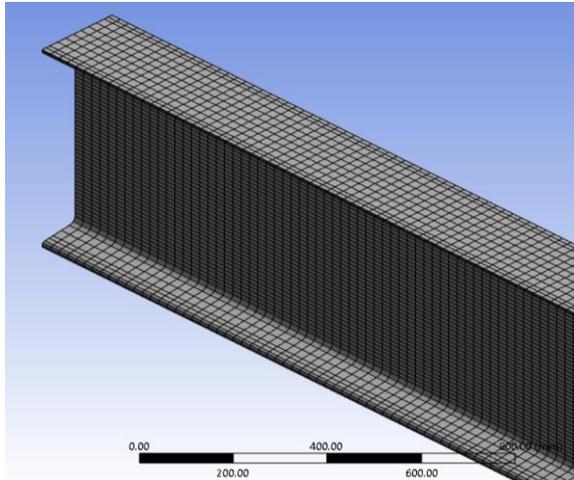Figure 19: Super Impose Point Loads

Mesh Model :

Figure 20: Mesh Model
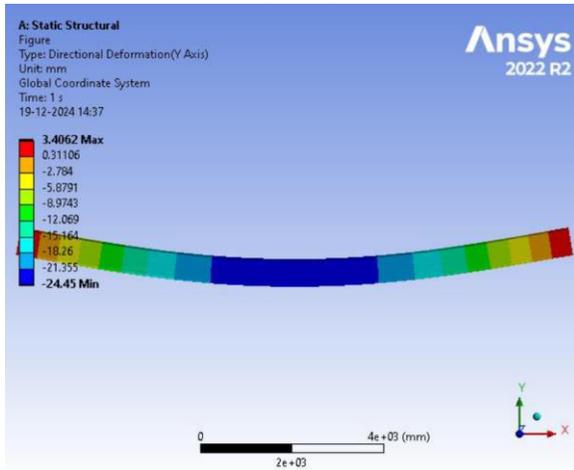
Deflection Check, δ_{2max} [mm] :

Figure 21: Maximum Deflection

Maximum Deflection δ_{2max} = 24.45 mm
Permissible Deflection δ_{maxper} = L/300
As per IS 800 : 2007, Table 6
δ_{per} = 11000/300 = 36.67 mm
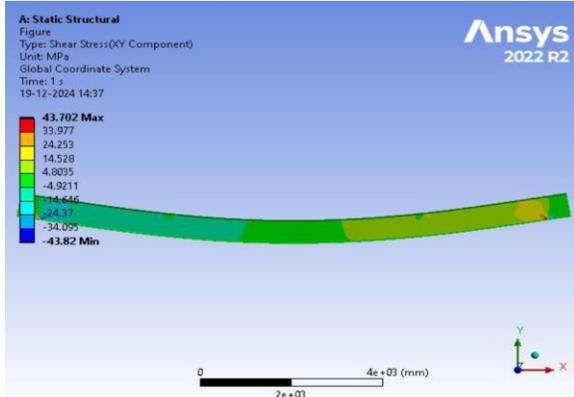Shear Force, V_{2max} [kN] :

Figure 22: Maximum Shear Force

Maximum Shear Force, V_{2max} = (9090) x (0.0154)

Maximum Shear Force, V_{2max} = 140 kN
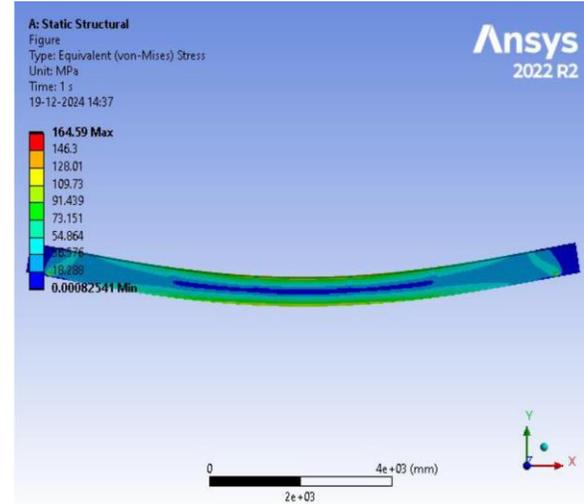Permissible Shear Force, V_{per} = 888 kN
Bending Moment, $B.M_{2max}$ [kN-m] :

Figure 23: Maximum Bending Moment

Max. Bending Moment, = (117405*0.000902)/(0.3)
Max. Bending Moment, $B.M_{2max}$ = 353 kN-m
Permissible Bending Moment, $B.M_{per}$ = 642 kN-m

VII. COMPARISON OF RESULTS

Table 3: Result Comparison

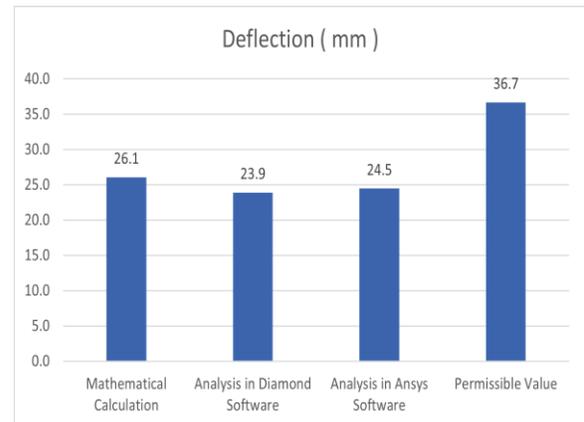| Parameter	Unit	Mathematical Calculation	Analysis in Diamond Software	Analysis in Ansys Software	Permissible Value
Reactions	kN	140.6	141.3	144.5	320.0
Deflection	mm	26.1	23.9	24.5	36.7
Shear Force	kN	133.9	140.4	140	888
Bending Moment	kN-m	353.5	353	353	642
Compressive Stress	kN/m^2	117572	117400	117405	213636
Tensile Stress	kN/m^2	117572	117400	117405	213636

Figure 24: Deflection Comparison
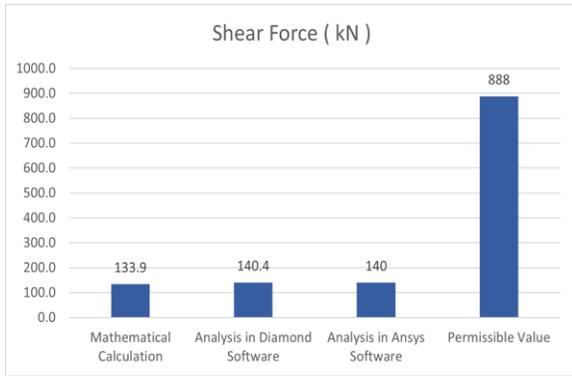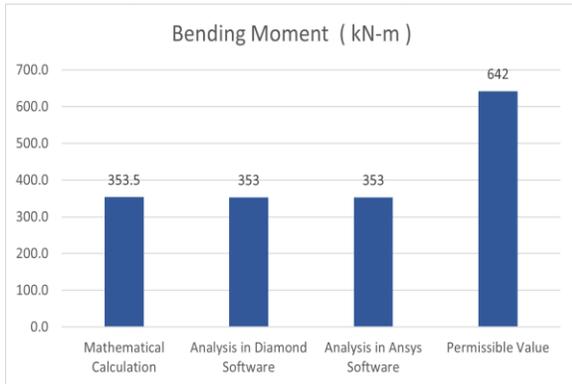
Figure 25: Shear Force Comparison

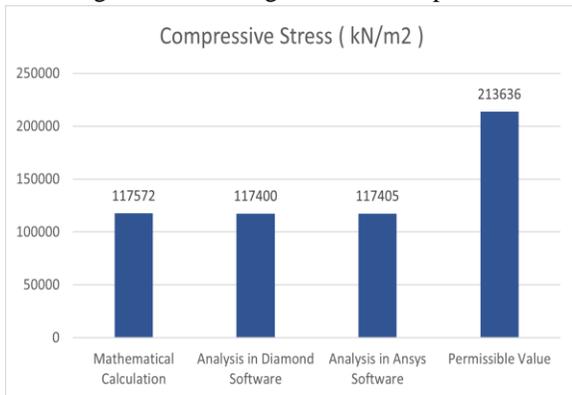Figure 26: Bending Moment Comparison

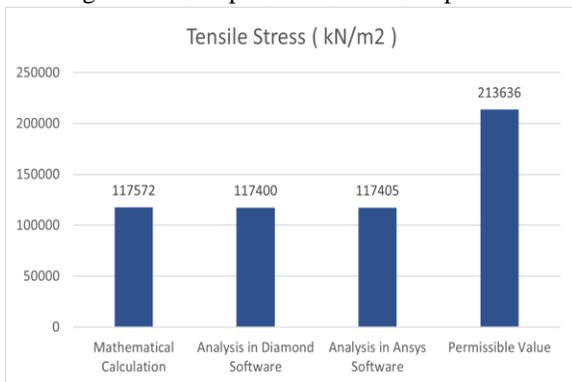Figure 27: Compressive Stress Comparison

Figure 28: Tensile Stress Comparison

VIII. CONCLUSION

Based on the Design input, we did the Manual Mathematical calculations, analysis in Diamond 2021 and Ansys 2022 R2 Software for ISMB 600 steel beam. After comparing various parameters values with their respective permissible values, ISMB 600 of material S235JR is safe to use for given different loads, conditions and simply supported span in this project. While using ISMB 600, Wooden pre camber should be used if end client wants flat bottom surface of box girder. The Bridge Gantry Formwork solution has been Designed as per end client requirements. Based on Design we calculated Superimpose loads coming on each I beam then we selected the I beam which receives maximum loads for calculation and analysis. We used various IS codes, European codes, American Standards and Spanish Construction regulations for calculations. Based on the results we calculated through different methods, it is found that values of various parameters like Maximum Deflection, Max Shear force, Maximum Bending Moment, Maximum Compressive stress & Maximum Tensile stress are the more or less the same. Also based on the results, this design is safe to carry give loads with specified simply support span while in fully operating conditions.

IX. FUTURE SCOPE

This project presents an exciting opportunity for extensive research and development to optimize gantry formwork solutions. Based on respective goals and requirements, here's a structured approach for future studies and experiments:

1. Structural Studies:

Explore Alternate Sections: Investigate the performance of other steel sections (e.g., HSS, tubular sections, or custom profiles) under similar conditions. Material Alternatives: Study the use of advanced materials like high-strength steel, composites, or hybrid materials for enhanced properties. Special Engineering Beams: Experiment with non-standard designs like castellated beams or honeycomb beams to improve strength-to-weight ratios. Welded Stiffeners: Analyze the effects of adding stiffeners on strength, deflection, and load distribution. Ensure welding methods and patterns maintain structural integrity.

2. Design Optimization:

Safety and Stability: Focus on failure modes (buckling, fatigue, etc.) and ensure the design complies with relevant codes. Ease of Execution: Study modular designs for simplified assembly and disassembly. Economic Analysis: Optimize materials and construction methods to reduce costs without compromising safety.

3. Advanced Analyses:

Lateral Loading Conditions: Simulate wind loads, live loads, and unexpected lateral forces to assess behavior under real-world scenarios. Thermal Analysis: Evaluate thermal expansion, contraction, and stress in regions with high temperature fluctuations. Vibration Analysis: Identify natural frequencies, mode shapes, and damping characteristics to avoid resonance under operational conditions. Wind and Seismic Analysis: Model extreme wind conditions and seismic forces to ensure stability under worst-case scenarios.

4. Software & Tools Integration:

Continue leveraging Diamond and ANSYS for numerical and FEA simulations. Incorporate parametric studies and optimization tools like MATLAB or Python for sensitivity analyses. Use Building Information Modeling (BIM) software for integrated design and documentation.

5. Validation and Prototyping:

Build scale models or prototypes for experimental testing under various load and environmental conditions. Compare experimental data with simulation results to refine models and improve prediction accuracy.

6. Documentation and Guidelines:

Compile findings into design guidelines for future gantry formwork projects. Include safety factors, best practices, and recommendations for customization.

REFERENCES

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