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Analysis and Design of Formworks for Elevated Structure of High-rise Building

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ABSTRACT: The main objective of this study includes the design of formwork systems for elevation features in high-rise building in an isolated manner. In this context, the important aspects are considered in analysing and designing the formwork as per site condition, readily available choice of material, constraint with respect to height of building, mass concreting, safety measures, stability of formwork and corresponding organizational knowledge. The outcome of this study helps to establish the baseline to develop proper method of designing the formwork for elevational features for high-rise building with site conditions and available material.

KEYWORDS: Formwork, analysis and design, wind load, girder beam, staging, cuplock, bracing, couplers, struts, conventional, shoring.

I. INTRODUCTION

Formwork is a major component in any cast-in-situ construction. Thus, the choice of material, technical, functional, economical, and safety requirements are main aspects of formwork system. The main objective of this study includes the design of formwork systems for elevation features in high-rise building in an isolated manner. In this context, the important aspects are considered in analysing and designing the formwork to the experience as per site condition, readily available choice of material, constraint with respect to height of building, mass concreting, safety measures and stability of formwork. The outcome of this study helps to develop proper method of designing the formwork for elevational features for high-rise building with site conditions and available material.

II. RELATED WORK

Related study regarding the understanding of the design and formwork behaviour during the construction of concrete structures was initiated.

Summary -

- Improving the understanding of formwork behaviour during the construction of concrete structures and to determine the construction load distribution between shoring system, the lateral pressures exerted by fresh concrete on wall formwork.
- Analysis and design of falsework structure with allowable stress and properties of materials that are readily available in market.
- The importance of the sequences of placing concrete and other variables as a measurement to prevent elevated formwork failures in high-clearance reinforced-concrete buildings, it is important to consider the conditions based on the actual construction.

Gaps found in related work:

In all the above related reviews, design of formwork for elevations of high-rise building is not seen. As this portion is not the core part of the building and hence is much neglected when comes to formwork designing. However, this being crucial part considering the safety it is also required to design in the economical way and construct with available resources. Thus, can be jotted as:

- To design formworks for elevations over critical high-rise structures with considering high intensity wind loads.
- Identifying the different formworks that can be used for the construction of elevation on high-rise building.
- Site-specific problems and limitations and in usages of formwork in tall building.

Objectives

- Study and understand the formwork design parameters.
- To analyze and design formworks.

Scope

- To solve critical situations while considering high intensity wind loads on high rise elevational structures.
- To check the safety measures of formworks with IS codes.
- To generate multi-dimensional schematic diagrams of formworks to be provided on site.

Details of the Building

- Total number floors in the building are 36 floors with stilt plus 2 parking.
- Total length & width of building is 47.47 m & 34.11 m respectively.
- Height of building up to terrace is at 127.80 m & total height of building including elevational feature is 144.35 m thus, elevation height to be designed is 16.55 m.
- The elevational beam depth is 3.95 m with bottom projection of 2.5 m and top projection of 1.5m and column is 12 .6 m in height.

III. METHODOLOGY

An assessment of the loading conditions and combinations on the structure (dead, live, wind etc.), also the check of the capacities, stability and rigidity of the scaffold to sustain the loads and combinations of loads imposed upon them ensuring the factors of safety and to design.

Design Computation

- Wet Density of Concrete = 26 kN/m³ Max.
- Width & Depth of Beam = 0.4 m & 3.95 m resp.
- Live Load and Shuttering Load = 1.5 kN/m² & 0.5 kN/m² resp. Total Load = 69.69 kN/m
- Width of each bay (typ.) = 1.2 m. Hence, Load/Bay = 83.6 kN

Design Check for Primary member

Primary decking member above Cuplock staging (ISMC100) for 1.2m grid with 83.6 kN total load applied in the model on primary member. Analysis and Design check done using Staad pro.

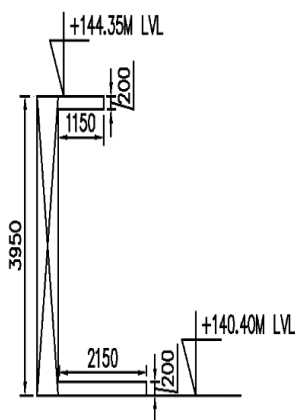


Figure 1. Elevation Beam

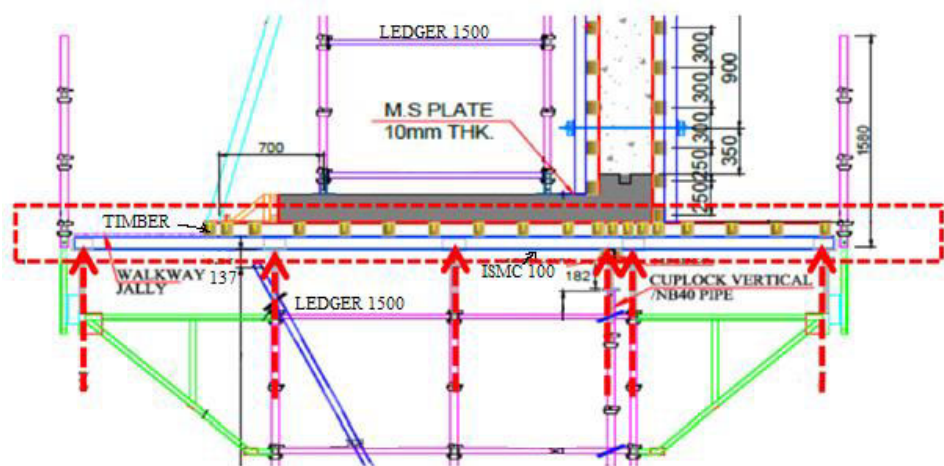


Figure 2. Section for formwork arrangement

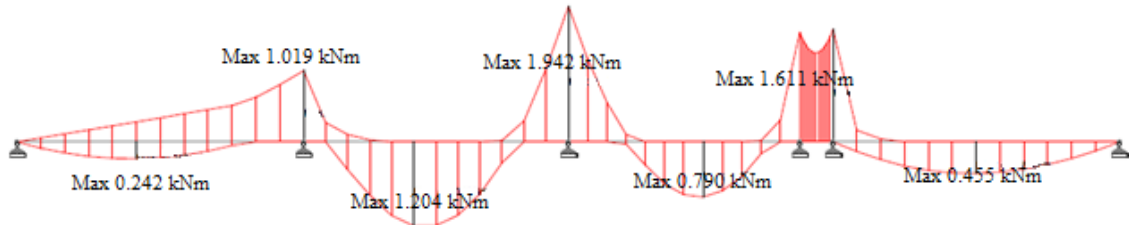
Primary decking member above Cuplock staging (ISMC100) for 1.2m grid with 83.6 kN total load applied on primary member. Analysis and Design check done using Staad pro.

Max. Moment = 1.942 kNm, Max. Shear = 20.40 kN, Max. Deflection = 0.175 mm

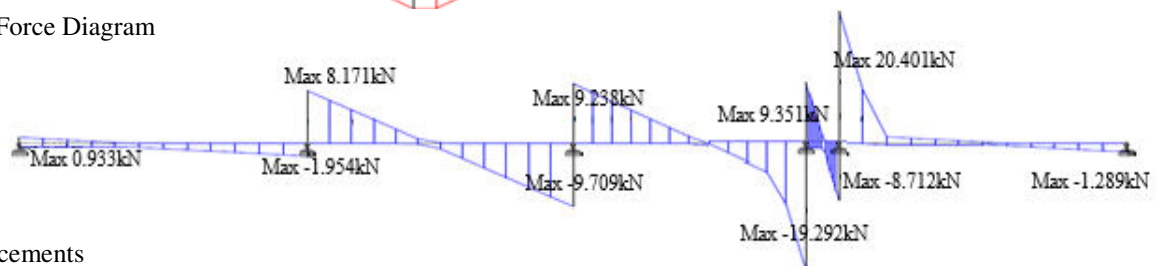
Reactions for the Load on supports from right to left.

P1 = 1.289 kN, P2=29.112 kN, P3=27.441 kN, P4=18.947 kN, P5 = 10.125 kN, P6 = 0.386 kN

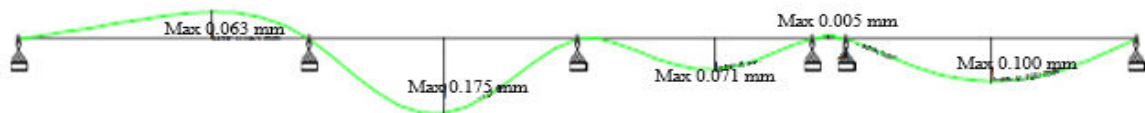
Bending Moment Diagram



Shear Force Diagram



Displacements



Design for Beam Bottom

Wet density of Concrete = 26 kN/m ³	Live Load = 1.5 kN/m ²	Shuttering Load = 0.5 kN/m ²
For Depth = 0.35 m (1 st Pour) the Load per sqm is 11.10 kN/m ²		
For Ply 12 mm		
Max. Moment = 0.100 kNm	Max. Shear = 1.99 kN	Max. Deflection = 1.077 mm
For primer runner (Timber Patti) use 3'' x 4'' @ 300 mm c/c		
Max. Moment = 0.48 kNm	Max. Shear = 2.39 kN	Max. Deflection = 2.32 mm

Design for Staging (Cuplock)

40NB pipe for safe working load of 44.4 kN.

Design for Bracings & Couplers

Horizontal Load = 2.09 kN. (No. of Bays = 5)

Bracings & Couplers 40NB pipe for load of 24.3 kN & 6.25kN respectively.

Design for Girder Beam Sides

Wet density of Concrete = 26 kN/m ³		
For Depth of Beam = 3.95 m (2 nd Pour) the Load per sqm is 102.70 kN/m ²		
For Ply 12 mm		
Max. Moment = 0.103 kNm	Max. Shear = 6.162 kN	Max. Deflection = 0.123 mm
For primer runner (Timber Patti) use 3'' x 4'' @ 100 mm c/c		
Max. Moment = 0.370 kNm	Max. Shear = 3.697 kN	Max. Deflection = 0.44 mm
For Secondary runner (Waller Back to Back) ISMC100 @ 600mm c/c vertical		
Max. Moment = 4.991 kNm	Max. Shear = 33.274 kN	Max. Deflection = 0.37 mm
Load on Tie Rod = 28.08 kN, Thus, Tie Rod @ 16 mm dia		

Design for Spanning Girders

Description	Max Reaction	Max bending moment	Max shear force	Max Deflection
SPG-01 ISMC100	29.112 kN	3.540 kNm	25.991 kN	1.036 mm
SPG-02 ISMB450 + 200 x10 Plates	29.200 kN	147.46 kNm	73.00 kN	0.935 mm
SPG-03 ISMC 150 B/B with 20mmgap	29.112 kN	15.510 kNm	37.569 kN	3.372 mm
SPG-04 ISMC 200 F/F with 20mmgap	18.947 kN	34.105 kNm	28.421 kN	7.206 mm
SPG-05 ISMB250+ 200 x 6mm Plates	29.200 kN	70.080 kNm	43.800 kN	2.271mm
SPG-06 ISMB250	29.200 kN	50.005 kNm	47.632 kN	7.785 mm

Calculation for Wind Load for beam sides

Basic Wind Speed considered for Mumbai Terrain is 44 m/s
 Design Wind speed,
 $V_z = 41.595 \text{ m/s}$
 Design Wind Pressure,
 $P_z = 1.038 \text{ kN/m}^2$
 Load carried by Strut = 8.59 kN
 The load carrying capacity of 40 NB (light) pipe used as struts.
 Load Carrying capacity of Vertical = 8.79 kN hence safe
 Thus, use 40NB pipe as strut at 1.2m

Calculation for Design Wind Load

Wind load per tower i.e Wind Force (P1) = 4.92 kN

For Conventional Formwork,
 Overturning Moment (OTM1) = 36.90 kN
 Wind Force (P2) = 15.69 kN

For Shoring,
 Overturning Moment (OTM2) = 98.85 kN
 Resultant Wind load (DWL) = 10.77 kN & Load for vertical (P2) = 29.112 kN
 Therefore, total load carried by vertical = P2 + DWL = 39.88 kN
 Hence safe as it is < 44.4 kN i.e. Load carrying capacity

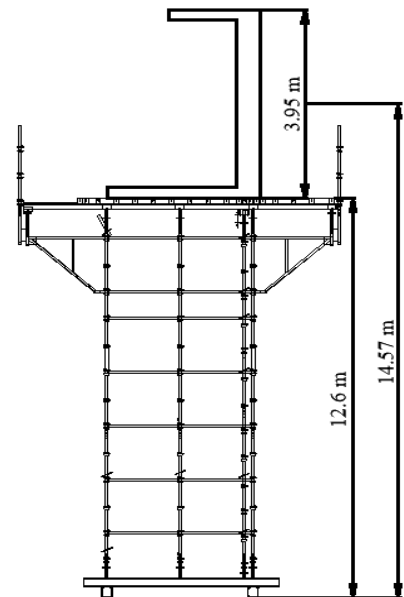


Figure 2. Section for wind load calculation

IV. RESULTS

Design Check for Primary decking (ISMC100)								
Bending Stress	Permissible Bending stress	Remark	Max Shear Stress	Permissible Shear Stress	Remark	Deflection	Permissible Deflection	Remark
26.03 N/mm ²	165 N/mm ² As per IS 800	Hence safe	0.0087 N/mm ²	100 N/mm ² As per IS 800	Hence safe	0.175 mm	13.88 mm As per IS800	Hence safe

Design Check for Beam Bottom								
Bending Stress	Permissible Bending Stress	Remark	Max Shear Stress	Permissible Shear Stress	Remark	Deflection	Permissible Deflection	Remark
12mm thick ply								
4.16 N/mm ²	13 N/mm ² As per IS4990	Hence safe	0.25 N/mm ²	1.05 N/mm ² As per IS883	Hence safe	1.077 mm	1.11 mm As per IS4990	Hence safe
Primer runner (Timber Patti) use 3'' x 4'' @ 100 mm c/c								
4.98 N/mm ²	18 N/mm ² As per IS883	Hence safe	0.32 N/mm ²	1.05 N/mm ² As per IS883	Hence safe	2.32 mm	5.00 mm As per IS883	Hence safe



Description	Safe Working Load	Maximum load	Remark
Design Check for Staging Cuplock (40NB Pipes)	44.4 kN	29.112 kN	Hence safe
Design Check for Bracings (40NB Pipes)	24.3 kN	10.45 kN	Hence safe
Design Check for Couplers (40NB Pipes)	6.25 kN	2.61 kN	Hence safe

Design Check for Girder Beam Sides								
12mm thick ply								
Bending Stress	Permissible Bending Stress	Remark	Max Shear Stress	Permissible Shear Stress	Remark	Deflection	Permissible Deflection	Remark
4.28 N/mm ²	13 N/mm ² As per IS4990	Hence safe	0.77 N/mm ²	1.05 N/mm ² As per IS 883	Hence safe	0.123 mm	0.37 mm As per IS4990	Hence safe
Primer runner (Timber Patti) use 3'' x 4'' @ 100 mm c/c								
3.82 N/mm ²	18 N/mm ² As per IS 883	Hence safe	0.49 N/mm ²	1.05 N/mm ² As per IS 883	Hence safe	0.44 mm	2.50 mm As per IS 883	Hence safe
Secondary runner (Waller Back to Back) ISMC100 @ 600mm c/c vertical								
66.91 N/mm ²	165 N/mm ² As per IS 800	Hence safe	14.22 N/mm ²	100 N/mm ² As per IS 800	Hence safe	0.37 mm	2.50 mm As per IS 800	Hence safe
Tie Rod Capacity @ 16 mm dia for Permissible axial tensile stress = 1500 kg/cm ²								
Load on Tie Rod = 28.08 kN < Capacity of tie Rod in axial tension = 30.14 kN, hence safe								

Design Check for Spanning Girders								
Bending Stress	Permissible Bending Stress	Remark	Max Shear Stress	Permissible Shear Stress	Remark	Deflection	Permissible Deflection	Remark
SPG-01 ISMC100								
50.174 N/mm ²	165 N/mm ² As per IS 800	Hence safe	0.011 N/mm ²	100 N/mm ² As per IS 800	Hence safe	1.036 mm	8.33 mm As per IS 800	Hence safe
SPG-02 ISMB450 + 200x10 Top & Bottom plates								
67.27 N/mm ²	165 N/mm ² As per IS 800	Hence safe	0.006 N/mm ²	100 N/mm ² As per IS 800	Hence safe	6.927 mm	21.11 mm As per IS 800	Hence safe
SPG-03 ISMC 150 B/B with 20mm gap								
74.639 N/mm ²	165 N/mm ² As per IS 800	Hence safe	0.009 N/mm ²	100 N/mm ² As per IS 800	Hence safe	3.372 mm	10.00 mm As per IS 800	Hence safe
SPG-04 ISMC 200 F/F with 20mm gap								
93.747 N/mm ²	165 N/mm ² As per IS 800	Hence safe	0.005 N/mm ²	100 N/mm ² As per IS 800	Hence safe	7.206 mm	12.50 mm As per IS 800	Hence safe
SPG-05 ISMB250 + 200x6mm Top & Bottom Plates								
119.442 N/mm ²	165 N/mm ² As per IS 800	Hence safe	0.007 N/mm ²	100 N/mm ² As per IS 800	Hence safe	2.271 mm	15.56 mm As per IS 800	Hence safe
SPG-06 ISMB250								
121.815 N/mm ²	165 N/mm ² As per IS 800	Hence safe	0.010 N/mm ²	100 N/mm ² As per IS 800	Hence safe	7.785 mm	12.50 mm As per IS 800	Hence safe

- The casting is to be done in two stages i.e. pour 1 and pour 2 for elevational beam. The schematic diagram shown gives the idea of placement of formwork on site.
- The shear wall height is 12.6 m, thus this was casted in stages of 2.4 m.

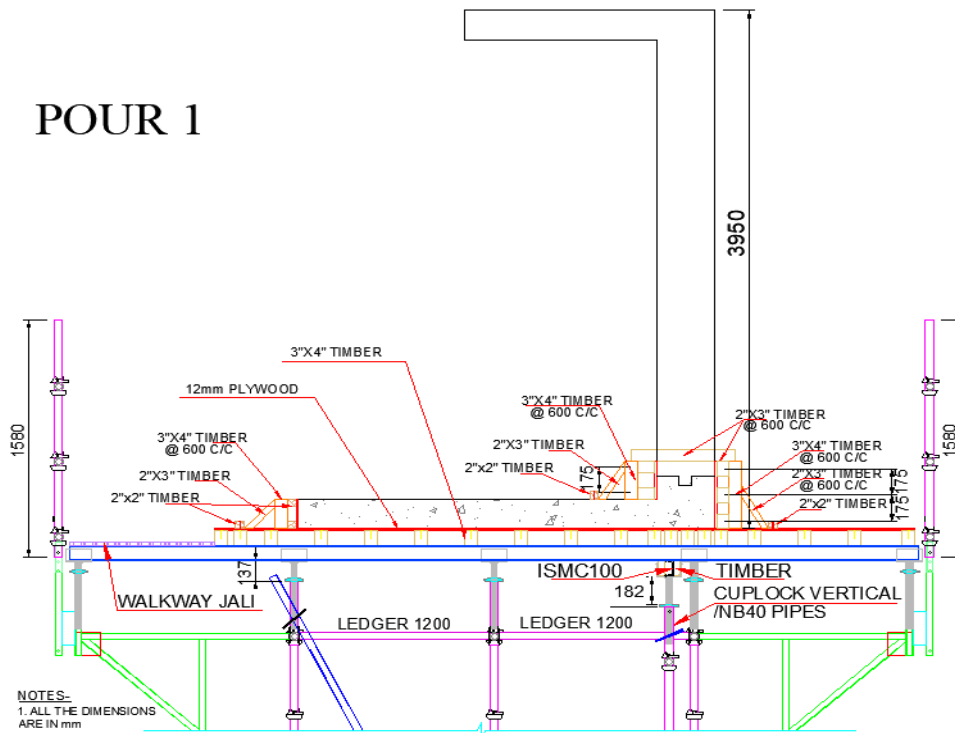


Figure 3. Section of Bottom Crown Formwork

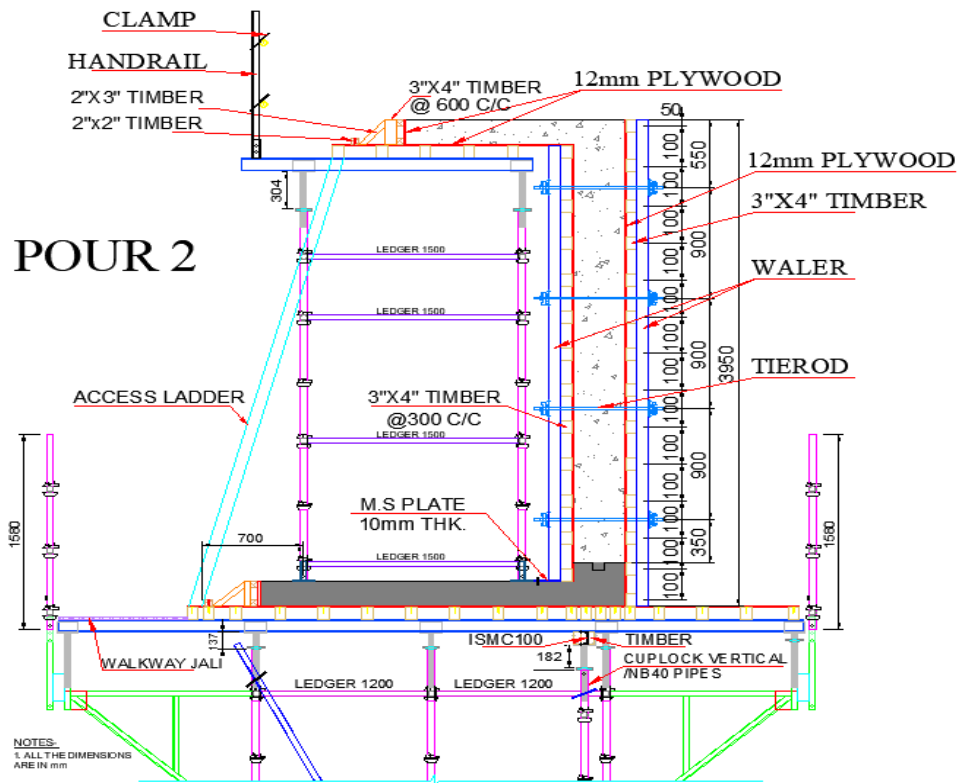


Figure 4. Section of Top Crown Formwork

V. CONCLUSIONS

- In this project the formwork design for the elevation feature is carried out considering the wind load at the height of building including elevational feature of 144.35 m.
- The elevation beam depth of 3.95 m is casted in two pour level keeping in mind the stability.
- The design is done as per the Indian standard with the readily available material on site considering cost effectiveness.
- Site specific problems are addressed by laying horizontal supports on the verticals while designing formwork with respect to load transfer of the form on already casted slab.
- This project can be used as future reference for formwork design for elevation at high level considering wind load.
- Slowly and steadily formwork designing is becoming a proper business module and there is a future for full-time formwork designers. More and more companies are making it compulsory to submit their formwork designs before execution.

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Design Codes

- Indian Steel Table
- IS 4990: 2011
- IS 883:1994
- IS 800: 2007
- IS 1161: 1998
- IS 806: 1968
- IS-14687: 1999



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