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Static Analysis of Climbing Formwork System for High-Rise Building Construction

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Abstract: The prime objective of this research is to develop a comprehensive framework for the static analysis of crane-dependent climbing formwork system. In this research, one of the climbing formwork systems that are commonly used for the construction of high-rise buildings known as crane-dependent is contemplated. Initially, suitable design intends of the climbing formwork system are discerned from the literatures and formwork technical reports. Additionally, various other factors influencing the analysis of the climbing formwork system are taken from the real-time construction projects. Using these information a suitable 3D finite element model of the climbing formwork system is developed. The 3D model is then analysed using a superior finite element program. The result shows significant variations in terms of deflections and stress contours. Notwithstanding the application of the real-time parameters for the analysis of climbing formwork system, the results obtained are haphazard. To overcome these shortcomings and to apprehend the situation of lack of codal provisions for the analysis of climbing formwork, a sophisticated soft computing methodology, known as Genetic algorithm is trailblazed. The optimal parameters obtained from the Genetic algorithm is then used to formulate the modified 3D finite element model. The results of the modified 3D finite element model depicts the actual behaviour of the climbing formwork system in the real-time scenario. This research portraits the comprehensive procedure for the analysis of climbing formwork systems.

Keywords: Climbing formwork system, Finite element modeling, Genetic Algorithm, High-rise construction

I. INTRODUCTION

In recent times, global construction industry is witnessing a tremendous change, not only in adopting more modern and scientific construction methodologies but also various new techniques. With the economies of certain countries on a rapid rise, the challenge of mass housing can only be met by higher rise structures. It is in this scenario that self-climbing formwork systems gain importance. To provide a comprehensive solution to the construction of slender elements like shear walls, shaft members etc.., in high rise building the incorporation of sophisticated formwork systems known as 'climbing formwork systems' prove to be significant over conventional formwork systems on the basis of structural integrity.

Climbing formwork is a special type formwork used for

construction of vertical Reinforced Cement Concrete (RCC)
structures, which rises with the building process. This research seeks to develop a retrospective assessment procedure for analysis and design of climbing formwork structure to be used for real-time construction of high-rise buildings. In order to have a complete analogy of the assessment procedure, the computer simulation models are to be generated and validated .The main purpose of this research is to develop a 3D solid model for the formworks using Dassault Systèmes SolidWorks software and analyse the developed model using ANSYS software.

This research seeks to achieve the following three major objectives:

- To develop a comprehensive 3D solid model of climbing formwork used in the industry using SolidWorks software.
- To analyse the modelled formwork with loadings as per unified (BIS, DIN, Eurocode) standards in finite element analysis software, ANSYS.
- To determine the optimal climbing formwork systems, i.e., optimal components for adequate structural integrity using a soft computing methodology known as Genetic Algorithm.

Climbing formwork is the construction of tall structures such as high-rise buildings, sky scrapers and sky towers etc., rather than constructing laterally to accommodate large population in quiet a lesser area. The construction of high-rise buildings are highly complex and requires advanced construction techniques and equipment (Kannan and Santhi, 2013). One of the most important requirements is the advancement in forming technology (Kannan and Santhi, 2013, 2013a, 2018). The conventional or traditional method of forming high-rise building is economical, it suffers seriously on the time, quality, safety and sustainability factors. Therefore, the advanced systems known as climbing formwork was introduced later. The climbing formwork is relatively new technology developed from the slip form in the late 1960 (Kannan and Santhi, 2013).

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II. REVIEW OF LITERATURE

Kannan and Santhi (2013) provided a comprehensive comparison of different climbing formwork systems with the conventional formwork used for the construction of lift core-wall in a 20 storey high-rise building computerized model using Building Information Modelling (BIM). From the developed 3D BIM model, the cost, time, quality, safety and sustainability factors of both conventional and climbing formwork are explored in detail by quantitative and qualitative indices. An appreciable inference on the advantages of the Climbing formwork systems are portrayed in detailed.

Kannan and Santhi (2013a) provide a conceptual framework for developing 3D solid models for different concrete formwork systems using BIM. In addition to modelling, a simulation of different concrete formwork systems are effectuated to understand the goodness of layout and adaptability to enhance constructability (Kannan and Knight, 2012; Kannan and Santhi, 2018; Kannan, 2019).

Alamin (1999) presents analytical procedures for determining the loads on the shoring system and supporting slabs during the construction of multistory concrete buildings and for determining the lateral pressures imposed by fresh concrete against the wall forms. He considered two-dimensional frame models that requires both computer program (CPF) and the maturity-based model. The interaction of structure and compressible shoring, time-dependent concrete properties of strength, creep and shrinkage of concrete and the change in construction load during construction cycles are considered in the shoring system analysis. For wall formwork analysis, the time dependent concrete properties of strength and the properties of wall-element parts are highly essential. The analytical results obtained by both the shoring system and the wall formwork analyses are checked against the field measurements and several existing methods. Various parameters that affect the construction load distribution among shores and re-shores and interconnected slabs, and the fresh concrete pressure distribution on wall formwork are investigated The present method can be used to design and construct safe and economical concrete structures, especially during concrete placing and formwork removal operations.

III. MODELLING

The design and detailing were mostly done in accordance with values of Doka (2020). The sizing of the parts , loads to be applied were all determined. The loads were taken in accordance to DIN and Eurocodes. The concrete pressure on the formwork sheet were calculated using the formula accepted by CIRIA (Construction Industry Research Information Association) ,P= γh [h, vertical pour height: γ,kN/m^3]. The modelling of the climbing formwork systems are described as follow.

A. Model I

The modelling of the climbing formwork systems are carried out using SolidWorks as in Fig. 1. The design intends are taken from wide variety of sources such as research articles, handbooks and calculation guides (Doka, 2020; PERI, 2020). Various part of the model were designed separately and assembled. The total number of parts for one single model is more than 90 as shown in Figs. 2-5. The main parts of a climbing formwork are the plywood form-face, wooden H-beams, horizontal wailings (C sections back to back), vertical wailings(C sections back to back),vertical profile, horizontal profile, plumbing spindle, pressure struts (long and short), supporting platforms (top, middle, bottom) with protective railings, wind bracing.

Model I was designed first. First, the formwork sheet was designed in SolidWorks as in Fig. 3. The size of the sheet was 5500 X 3000 X 30 mm. Then the H-beams were designed with 20cm depth, 8 cm width and 4cm thickness. The length of the beams were same as the height of the sheet. The top bench was assembled as a separate assembly and mated to the H-beams. Then the horizontal and vertical wailings were attached to the sheet assembly with H-beams. Then the horizontal profile with travel gear is attached to the vertical wailing and the platform sheets are mated to it along with the horizontal H-beams for support. The middle platform along with the guard rails were mated after that to the horizontal profile. The plumbing spindle was attached to the end of the travel gear at the bottom and to the vertical wailing at the top.

Figure 1. Preliminary 3D solid model of climbing formwork system with associated components in Dassault Systèmes SolidWorks

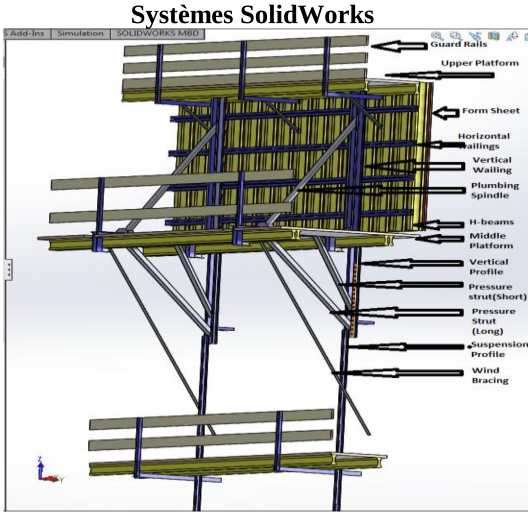

Figure 2. 3D solid (unified) model with all the parts mated/assembled.

Next, the vertical profile along with the suspension profile is mated to the horizontal profile. The pressure struts and the wind bracings are then mated to the vertical profile.

The bottom platform and supporting horizontal H-beams are then mated to this assembly to complete the model.

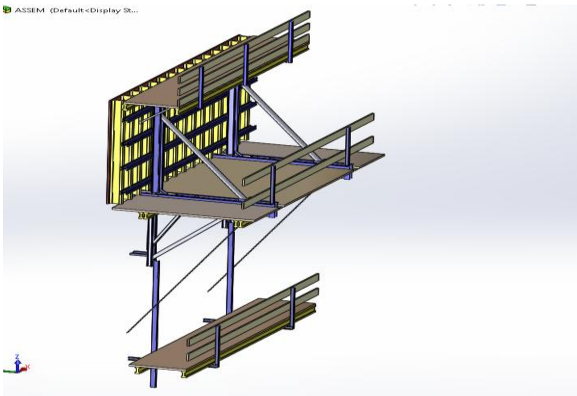

Figure 3. Perspective view of the Model I

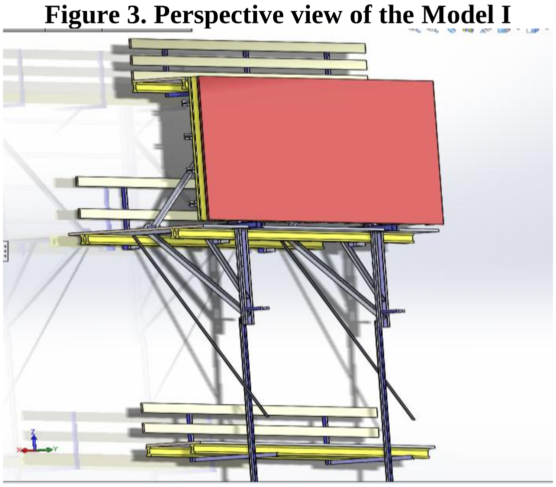

Figure 4. Rear view of the Model I

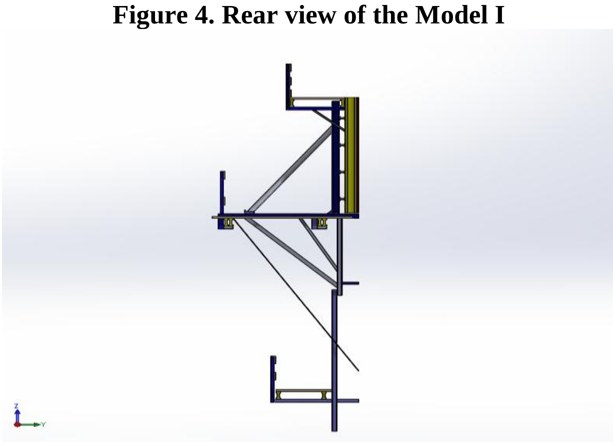

Figure 5. Cross-sectional view of the Model I

The design intends of Model I Climbing Formwork Systems are enlisted in the Table I.

Table I. Dimensions of the components for Model I

S.no	components	Length (mm)	Width (mm)	Thickness (mm)	Height (mm)	Depth (mm)	Ø (mm)
1	Upper platform	5000	880				
2	C-section		50	8		70	
3	H- beam		80	8		200	
4	Formwork sheet	5000		30	3000		
5	bolt						14
6	nut						16
7	Middle platform	5000	2400				
8	Bottom platform	5000	1120				
9	Long pressure strut	3000		8			50
10	Small pressure strut	2000		8			40
11	Wind bracing	6000		5			20

B. Model II

The second model is a larger formwork area with a form sheet size of 5500X4500 mm. The thickness of the sheet is same as that of model I (30mm). The height of the H-beams also vary according to the height of the sheet. All the other parts and their assembly are similar. The number of horizontal wailings of model II were increased later so as to achieve lesser deflection.

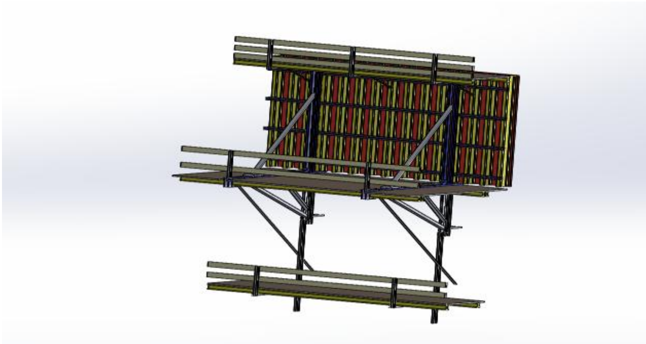

Fig 6: Perspective view of the Model II

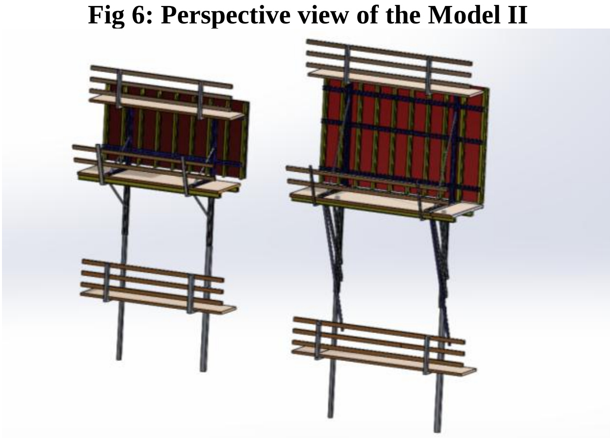

Figure 7. Comparison of Model I & II

Model I has a form face of dimension 5.5 m x 3 m whereas the bigger model 2 is having a form face of dimension 5.5Mx4.5m .The plumbing spindle of second model is having an outer diameter of 10cm and thickness of 3mm. It has 4nos of horizontal wailing made up of U-sections placed back to back whereas the smaller model has only 2 horizontal wailings. The upper platform is of 95cm width, middle platform is of 2.4m width and the lower platform is of 1m width. The platform width and size of other supporting structures are given same for both the models.

The supporting H-beams are of wood with a depth of 20cm, width of 8cm and thickness of 4cm. The wood selected was of density 700kg/m^3 and modulus of elasticity 1.25 kN/m^2. The Poisson ratio for various similar type woods are in the ratio 0.036 to 0.61. A mean Poisson ratio of 0.45 was selected. All the material properties of wood varies with moisture content and the wood selected was considered to have a moisture content of 12%. The form face used was of plywood with higher modulus of elasticity than normal wood.

IV. STATIC FINITE ELEMENT ANALYSIS

Both the SolidWorks models were saved as IGES (.igs) files and imported to ANSYS for static analysis.

A. Boundary Conditions

The following are the boundary conditions considered for the analysis of 3D solid models.

- The 3 platform loading mentioned in 4.2 were applied to both the models.
- The bottom end of the models including the suspension profile and the end face of the horizontal profile were held in position using fixed supports.

B. Meshing

The meshing of Model I is done with default meshing size of the software except for two parts of the model which were having only one element throughout their thickness as shown in Fig. 8. Those elements were meshed separately with an element size of 30 mm. The total number of finite elements of model I was 27029 elements.

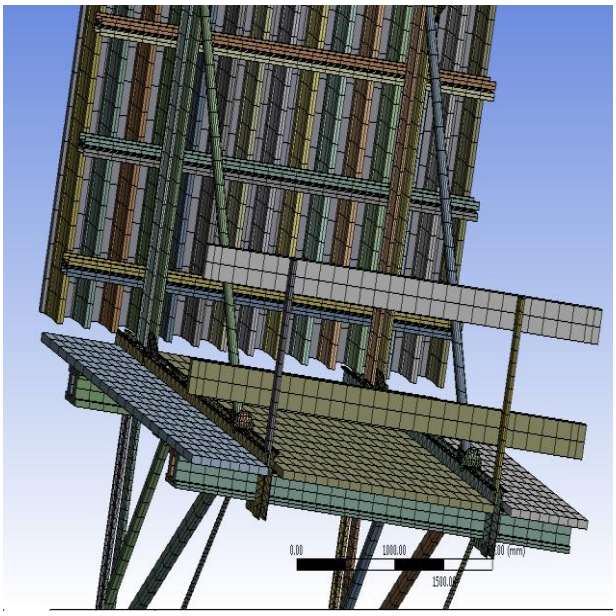

Figure 8. Meshing for 3D FEA of Model I

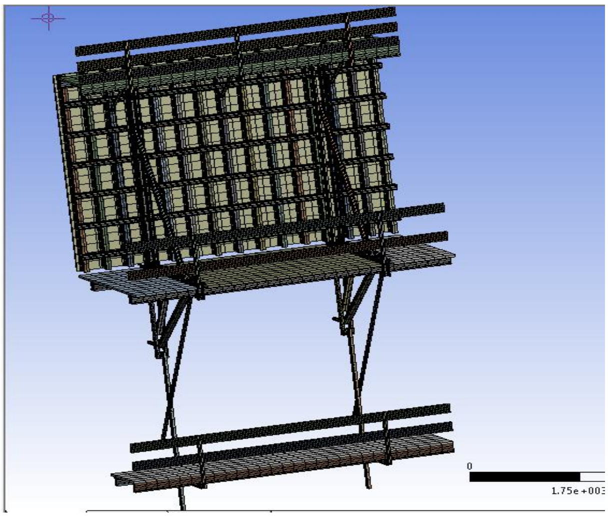

Figure 9. Meshing for 3D FEA of Model I

The total number of meshes for Model II are 32124 as shown in Fig. 9. The basic meshing size of model II was 200 mm. there were 21 total parts which had only one element through their thickness which were meshed fine seperately with 30mm and 15 mm sizing. The load cases for the analysis are derived from a mixture of BIS, DIN, Eurocode standards and incorporated for the models as in Fig. 10.

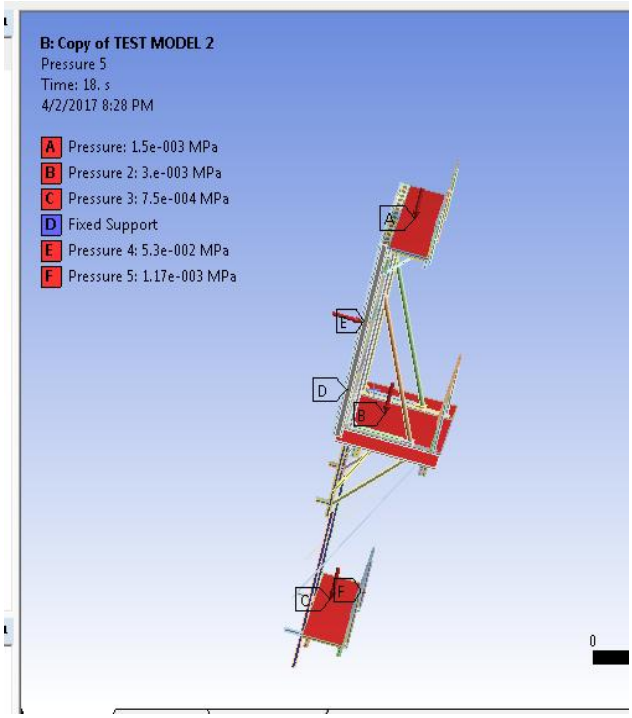

Figure 10. Loading cases details for the Model I & II

Using the designated design intends and parameters, and loading cases, the 3D solid models are analyzed by Finite Element Method using an industry standard cutting edge software known as ANSYS.

V. RESULTS AND DISCUSSIONS

The models are then analyzed for maximum deflection, stress and strain. Model I was analyzed first and the max. Deflection, stress and strain were found out. The detailed parameters set for the analysis are enumerated in Table II & III.

Table II. Specifications for Model I

	length	width	thickness	height	depth	in	⌀out	angle
form sheet		5500mm		3000mm				
vertical H beam		80mm	40mm	3000mm	200mm			
horizontal wailing		100mm	9mm		45mm			
c-section back to back	19.5mm							
spacing from bottom of sheet	300mm							
spacing c/c of 2 wailing	700mm							
vertical profile		120mm	9mm		45mm			
c-section back to back	100mm							
c/c spacing b/w 2 profile	3181mm							
plumbing spindle	2810mm					60mm	100mm	
distance of plumbing spindel bottom from vertical profile	1488.38mm							
angle b/w spindle and platform bench								57.02°
horizontal profile	120mm	55mm	9mm					
distance b/w c section	100mm							
c/c b/w 2 horizontal profile	3181mm							

Table III. Specifications for Model II

	length	width	thickness	height	depth	in	⌀out	angle
form sheet		5500mm		4500mm				
vertical H beam		80mm	40mm	4500mm	200mm			
horizontal wailing	5500	80mm	9mm		55mm			
c-section back to back	12.5mm							
spacing from bottom of sheet	300mm							
spacing c/c of 2 wailing	700mm							
vertical profile		120mm	9mm	4300	55mm			
c-section back to back	100mm							
c/c spacing b/w 2 profile	3200mm							
plumbing spindle	3800mm					80mm	100mm	
distance of plumbing spindel bottom from vertical profile	1488.38mm							
angle b/w spindle and platform bench								68.12°
horizontal profile	100mm	45mm	9mm					
distance b/w c section	100mm							
c/c b/w 2 horizontal profile	3200mm							

The material properties of the components are given in the Table IV & V.

Table IV. Properties of materials (wood)

Properties of Outline Row 3: oak wood

	A	B	C
1	Property	Value	Unit
2	Density	700	kg m^-3
3	Isotropic Elasticity		
4	Derive from	Young's Modulus a...	
5	Young's Modulus	1.25E+10	Pa
6	Poisson's Ratio	0.036	
7	Bulk Modulus	4.4899E+09	Pa
8	Shear Modulus	6.0328E+09	Pa
9	Field Variables		
13	Tensile Yield Strength	4.5E+07	Pa
14	Compressive Yield Strength	4.024E+07	Pa
15	Tensile Ultimate Strength	6E+07	Pa
16	Compressive Ultimate Strength	5.03E+07	Pa

Table V. Properties of materials (structural steel)

Structural Steel > Tensile Ultimate Strength

Tensile Ultimate Strength MPa
460

TABLE 74
Structural Steel > Isotropic Secant Coefficient of Thermal Expansion

Reference Temperature C
22

TABLE 75
Structural Steel > Alternating Stress Mean Stress

Alternating Stress MPa	Cycles	Mean Stress MPa
3999	10	0
2827	20	0
1896	50	0
1413	100	0
1069	200	0
441	2000	0
262	10000	0
214	20000	0
138	1.e+005	0
114	2.e+005	0
86.2	1.e+006	0

TABLE 76
Structural Steel > Strain-Life Parameters

Strength Coefficient MPa	Strength Exponent	Ductility Coefficient	Ductility Exponent	Cyclic Strength Coefficient MPa	Cyclic Strain Hardening Exponent
920	-0.106	0.213	-0.47	1000	0.2

TABLE 77
Structural Steel > Isotropic Elasticity

Temperature C	Young's Modulus MPa	Poisson's Ratio	Bulk Modulus MPa	Shear Modulus MPa
	2.e+005	0.3	1.6667e+005	76923

TABLE 78
Structural Steel > Isotropic Relative Permeability

Relative Permeability
10000

The deformations, equivalent elastic strain, and equivalent stress of the Model I are visualized in Figs. 11-13.

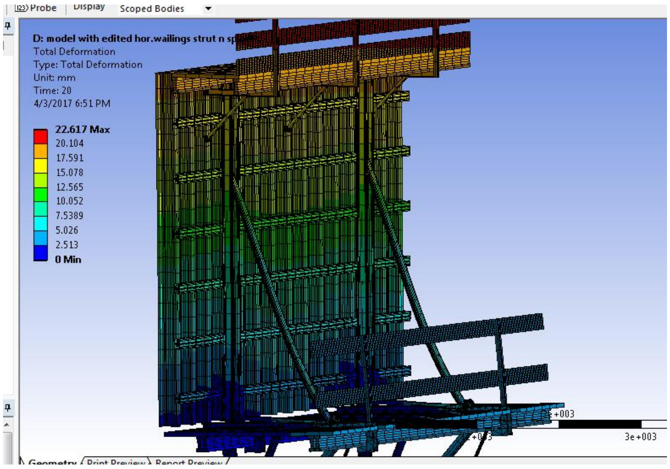

Figure 11. Total deflection of Model I

The maximum deflection at the top of the form sheet was found to be 22.61 mm.

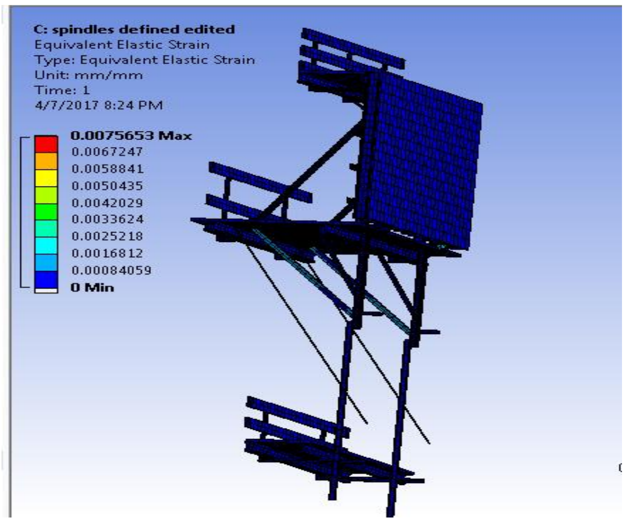

Figure 12. Equivalent elastic strain of Model I

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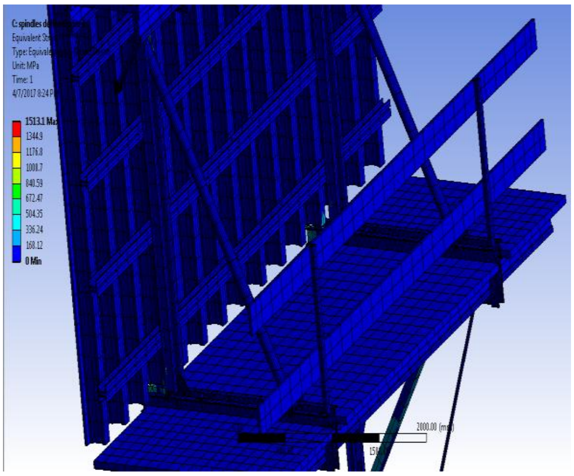

Figure 13. Equivalent elastic stress of Model I

The deformations, equivalent elastic strain, and equivalent stress of the Model II are visualized in Figs. 14-13.

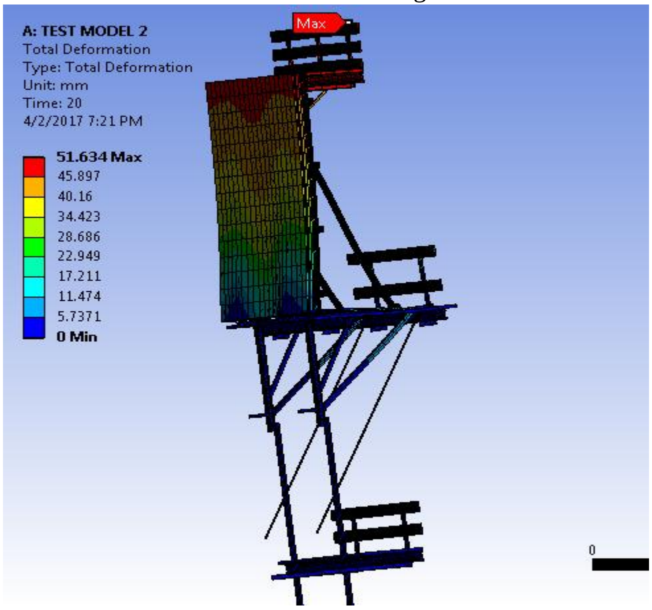

Figure 14. Total deflection of Model II

The stress and strain values were also off the limits and hence an editing of the model was deemed necessary. The size of the wailings were increased and the spacing between the horizontal wailings were decreased.

This substantially reduced the deflection values and brought the results within general acceptable limits. The maximum deflection is 51.634 mm at the sheet top. The exaggerated scale of the same are shown in Fig. 15. The defection obtained is very high for the given set of load cases (Naidu and Kannan, 2015). However an optimal model is to be generated based on these two models, Model I and Model II. To achieve an optimal dimensions for the components, an intriguing soft computing technique known as Genetic Algorithm (GA).

A. Genetic Algorithm

Genetic Algorithms (GAs) are non-traditional meta-heuristic search strategies based on the evolutionary principles of natural selection and genetic recombination, a class of Evolutionary Algorithms (EAs). The term 'Genetic Algorithm' was first coined by Holland (1992) at University of Michigan while working on his student's dissertation. The application of genetic algorithms for adaptive systems is later popularized by Goldberg (1989). GAs are generally stochastic that mimics the biological evolution to solve problems that does not even requires the user-specific and priori knowledge in solving that problem, thus, GAs are also considered as 'meta-learning' strategies (Kannan and Santhi, 2019).

The detailed description of the steps involved in incorporating GA for parametric characterization are as follows. The process of incorporating GA for problem-solving is mainly categorized into two phases. The first phase is called 'preparation stage' that includes parameters setting and initiation, and the other phase is 'search phase' which involves experience generation and genetic operations such as selection, crossover and mutation and so on (Kannan and Santhi, 2019).

The population size is 1000, the generation size is 3000, linear rank-based section function, two-point crossover function, uniform mutation function, 0.9 cross-over rate, 0.1 mutation rate, 0.6 improvement rate is derived based on trial and error and applied for the assessment. In addition to the numerical optimization of the parameters using Genetic Algorithm, topological optimization is carried out to determine the optimal geometry for the optimized model. The consensus arrived from the topological optimization are as follows:

- The deflection tends to be decreasing as the spacing between the horizontal wailings are reduced.
- The use of 'tie rods' between two sheets of the same formwork will reduce the deflection further. .
- If only one plumbing spindle is being used, it is advisable to use the smaller model, otherwise two plumbing spindles should be provided.
- For concreting larger areas ,exceeding heights of 3m it is advisable to have one more plumbing spindle fitted to the formwork

The deformations, equivalent elastic strain, and equivalent stress of the optimal model are visualized in Figs. 15-17.

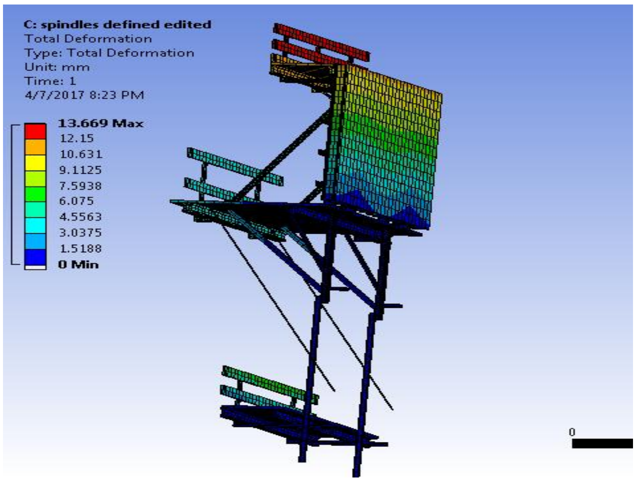

Figure 15. Total deflection of optimized model

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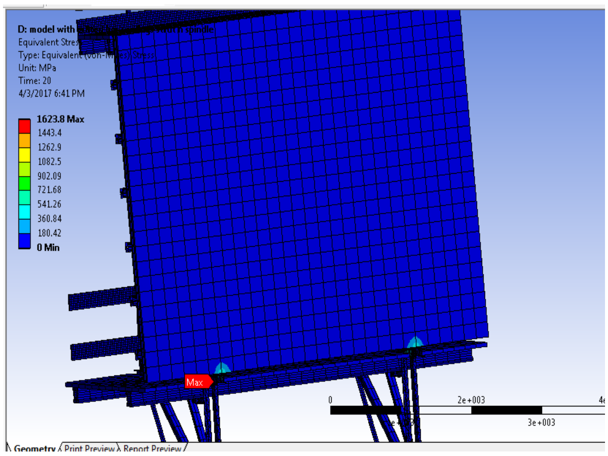

Figure 16. Equivalent elastic stress of optimized model

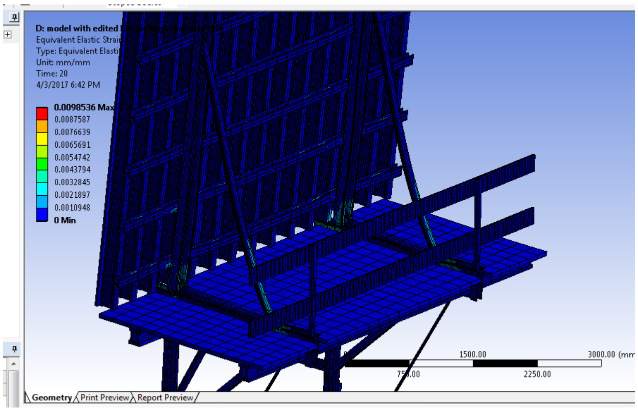

Figure 17. Equivalent elastic stress of optimized model

The results obtained clearly shows that the resultant deflection of the formwork sheet is decreased in the optimal design. The optimal model has the least deflection owing to despite the lesser amount of hydrostatic load acting on the sheet face. The analysis shows that the maximum stress concentration is occuring towards the joining point of the horizontal profile and the vertical wailing. The deflection of the guard rails (13 mm) can be neglected since it is never a structural part and only act as a guide/safe parapet for the construction workers.

VI. CONCLUSIONS

This research provides a holistic static analysis framework for climbing formwork system, which is one of the most complex formwork system that consists of components of varied geometry and materials. However, a detailed introspective assessment of climbing formwork system is carried in this research. This static analysis procedure can be extended to dynamic analysis of the climbing formwork system incorporating the wind effects on structures, fluid dynamics, temperature effects and rheological characteristics (Kumar and Kannan, 2015; Tamrakar and Kannan, 2015; Shanmughan and Kannan, 2016) of concrete and so on. The effect of hydraulic jack has to be included in the analysis of self-climbing formwork systems, these formwork systems are not part of this research. The result obtained from this research is to be correlated with the behavior of actual climbing formwork systems as a verification in future.

REFERENCES

1. B. Alamin, Analysis of Construction Loads on Concrete Formwork, Master Thesis, Building, Civil & Environmental Engineering, Concordia University, Canada, 1999.
2. D. Goldberg (1989), Genetic Algorithms in Search, Optimization and Machine Learning, Addison Wesley.
3. J. H. Holland (1992), Adaptation in Natural and Artificial Systems, Second ed., The MIT Press.
4. Kannan, M.R., Santhi, M.H. Automated constructability rating framework for concrete formwork systems using building information modeling. Asian J Civ Eng, 2018, vol. 19, pp. 387–413.
5. M. R. Kannan and S. Knight. "Constructability – the paradigm shift in the construction engineering and management." In Proceedings of the International conference on emerging technological trends in advanced engineering research, Baselios Mathews II College of Engineering, Kollam, Kerala, India. 2012.
6. M. R. Kannan, Constructability Analysis of Concrete Formwork Systems, PhD Thesis, Vellore Institute of Technology, 2019.
7. M. R. Kannan, M. H. Santhi, Automated construction layout and simulation of concrete formwork systems using building information modeling. In Proceedings of the 4th International Conference of Euro Asia Civil Engineering Forum, National University of Singapore, Singapore, 2013a, vol. 64, pp. C7-C12.
8. M. R. Kannan, M. H. Santhi, Constructability Assessment of Climbing Formwork Systems Using Building Information Modeling, Procedia Engineering, vol. 64, 2013, pp. 1129-1138.
9. N. Kumar and R. Kannan, Experimental Investigation of Lateral Pressure on Vertical Formwork Systems using Self Compacting Concrete, International Journal for Trends in Engineering & Technology, 2015, vol. 5, issue 2, pp. 54-58.
10. R. Tamrakar, R. Kannan, Response of Slab Form for Different Concrete Pressure, International Journal for Trends in Engineering & Technology, 2015, vol. 7, issue 1, pp. 54-58.
11. S. Naidu, R. Kannan, Numerical Optimization of Shoring Towers for Slab Formwork Systems, International Journal For Trends In Engineering & Technology, vol. 5(1), pp. 114-120.
12. S. Shanmughan, and R. Kannan, Modelling of Formwork Pressure Using Self-Compacting Concrete by Numerical Methods for Attaining Environmental Sustainability. Key Engineering Materials 2016, vol. 692, pp. 119–28.
13. Technical Committee, Climbing Formwork System, Technical/Product Manual, Doka GmbH, Austria, 2020 (Accessed on March 2020).
14. Technical Committee, Climbing Formwork System, Technical/Product Manual, PERI GmbH, Austria, 2020 (Accessed on March 2020).

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