International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-8 Issue-6, March 2020

Numerical Optimization of Half-Tunnel Concrete Formwork System using FEA

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Abstract**:** ***This research seeks to develop a comprehensive framework for the design of Half-Tunnel Concrete Formwork System (HTCFS). HTCFS are highly efficient systems that are used for the construction of modular RCC structural systems. Additionally, HTCFS are significant in terms of higher reuse in constructing modular units. Despite these advantages, the actual design procedure adapted for HTCFS was not well elucidated so far, many companies adapt their own design methodology and hence it is highly important to develop a simplified straight forward design methodology incorporating all comprehensive associated factors. Initially, the detail introspective assessment of various types of HTCFS are perceived. Then using this information, a 3D Solid model is developed, and eventually, the 3D model gets converted into 3D solid CAE model using sophisticated Finite Element package for the Finite Element Analysis (FEA). This procedure is repeated for different combinations of components that construed effective systematized HTCFS. From the FEA the optimal structural components required for the structural integrity of HTCFS are established.***

Keywords**:** ***Half-Tunnel Concrete Formwork System, Design intend, Finite Element Analysis, Numerical Optimization, Modular Construction.***

I. INTRODUCTION

Half-Tunnel Concrete Formwork Systems (HTCFS) are special types of concrete formwork systems that are used for the construction of repetitive modular RCC structural systems. Generally, HTCFS are used in the construction of modular RCC residential high-rise buildings that are symmetrical in terms of construction sequence, or in other words, repeatable construction patterns. There are many advantages of HTCFS, such as maximum formwork reuse, faster construction process, and lesser wastages of concrete and so on. The design of HTCFS is not well-established, as many construction companies that uses HTCFS develop their own design methodology based on their experience and knowledge derived from their respective codal provisions and standards, and from the knowledge obtained from the constructability review. Thus, a simplified and straight forward design methodology for the construction of HTCFS is necessitated.

Manuscript received on March 15, 2020.
Revised Manuscript received on March 24, 2020.
Manuscript published on March 30, 2020.

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II. REVIEW OF LITERATURE

HTCFS comprises of various parts such as corrugated metal sheeting, buildup section steel whaler beams, buildup steel section struts, and plumbing struts with rocker and so on. Moreover, the dimensions of these components may vary depending upon the dimension of the casting specimen, intensity of the pressure, environmental condition. The optimum dimensions of these components are arrived based on trial and error. Different companies have got different design intends. Neru Formwork Systems (2014) developed a railed tunnel formwork system to construct a modular RCC structural systems based on international standards with special structural components such as NPU120 steel profile, adjustable fixing props and so on. Outinord Formworks (2015) proposed a special type of mechanized Tunnel formwork system for the construction of multi-storey residential structure known as Modular Tunnel Formwork TMPH based on standard tunnel form. Dema Formwork Systems (2014) developed three intriguing types of tunnel formwork systems known as Dema Classic Tunnel Form Systems (DCTFS), Dema Classic Plus Tunnel Form Systems (DCTFS+), and Dema Advanced Tunnel Form Systems. These tunnel formwork systems are used for the construction of modular RCC residential construction projects as well as heavy infrastructure projects. Mesa formwork (2018) has introduced three types of advanced formwork systems such as Classic Tunnel Formwork (TRTF), Modified Tunnel Formwork (MKTF), and Modular Tunnel Formwork (ERTF). The remarkable features of ERTF is that it incorporates adjustable telescopic push-pull props, elevated bottom tie-rod level for higher kicker concrete, telescopic extension tunnel legs for non-typical floors, and stripping platform extension leg for non-typical floors.

The following are the some of the advantages of HTCFS:

- Maximum reuse or repetition
- Faster rate of construction
- Efficient cycle time
- Fair-faced concrete finishes
- Durable and sustainable concrete construction (Lean strategy in concrete construction)

- Quality of constructed facilities

Kanoglu (2020) has portrayed the advantages and disadvantages of tunnel formwork systems. Kanoglu also emphasized the limitation of the design and construction phases associated with the construction of the tunnel formwork systems.

III. PRELIMINARY ANALYSIS

The detailed analogy of various design intents are described in this section. Initially, a conceptual framework of HTCFS is considered for static analysis as shown in Fig. 1. The result obtained from the static analysis is tabulated in Table 1.

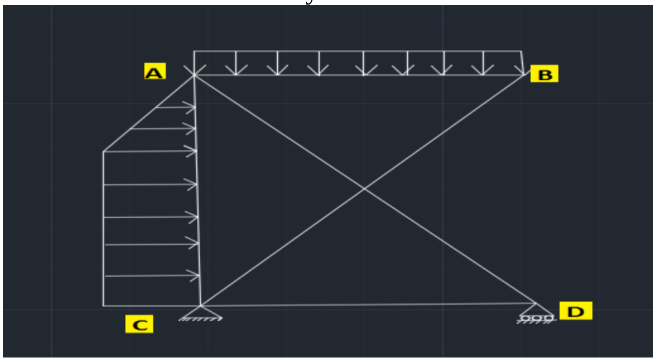

Fig 1. Conceptual skeletal framework for static analysis

Table 1. Result of the Static Analysis

S.No	Member /Support	Force	Description
1.	AB or BA	67.39 KN	Tension
2.	BC or CB	-110.69 KN	Compression
3.	CD or Dc	32.30 KN	Tension
4.	AD or DA	-53.82 KN	Compression
5.	AC or CA	184.58 KN	Tension
6.	Vertical reaction at support C	-96.81 KN	Downward
7.	Horizontal reaction at support C	35 KN	Rightward
8.	Vertical reaction at support D	30.07 KN	Upward

The results obtained from the skeletal framework are satisfactory and showing appreciable constructability charateristics to be incorporated for real-time construction process. The constructability consideration for formwork systems are paramound important (Kannan and Knight, 2012; Kannan and Santhi, 2013, 2013a, 2018, 2019).

IV. 3D SOLID MODELLING

From the preliminary design considerations, the 3D solid model of HTCFSs are developed using one of the industry standard solid modelling software known as Dassault Systemes Solidworks. The components of HTCFS and its design indents are tabulated in Tables 2 and 3.

Table 2. Dimension of the HTCFS main components

Component	Dimension
Wall Board	2150 X 2450 (L X H) T= 4, 8, 12 mm
Curtain Board	2450 X 2800 (L X H) T= 4, 8, 12 mm
Spindle	L= 3920 mm Diameter= 50 mm
Bolts	1. M 14 X 80 mm 2. M 14 X 30 mm

Table 3. Dimension of the HTCFS auxillary components

S.No	Components of Half-Tunnel Formwork	Dimension
1	Top plate or slab plate	1.5*2.5m
2	Wall plate or side plate	3*2.5m
3	Fasteners	50*50mm
4	Props	60 mm dia, 5mm thickness
5	Wheel post	20*20 cm
6	Bolts	Head diameter 30mm, pitch 2mm
7	Thickness of top and side slab	5mm

Using the design parameters and intends from Tables 2 and 3, the 3D solid HTCFS of variable thickness such as 4 mm, 8 mm and 12 mm are developed. The 3D solid HTCFS with 8 mm thickness is shown in Fig. 2.

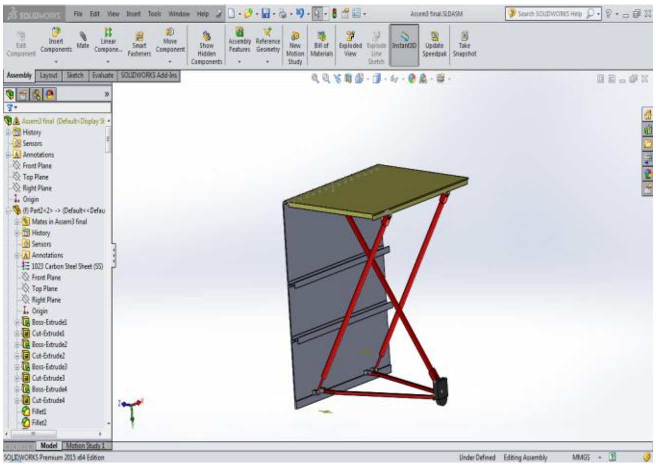

Fig 2. 3D solid HTCFS model with 8 mm thickness plates

A preliminary static analysis is performed in Dassault Systemes Solidworks for the three models, i.e., 3D solid HTCFS model with thicknesses 4 mm, 8 mm, and 12 mm. The 4 mm model and 12 mm model does not show appreciable result in terms of deformation, i.e., the 4 mm shows huge deformations (low-strength design) and on the otherside, 12 mm model shows no deformation (very conservative design) and hence a linear programming problem is carried out to determine the optimal thickness (Naidu and Kannan, 2015). From the LPP, the optimal thickness achived is 7.82 mm, and hence 8 mm thickness is considered for practical consideration.

Retrieval Number: F9225038620/2020©BEIESP
DOI: 10.35940/ijrte.F9225.038620
Journal Website: www.ijrte.org

Published By:
Blue Eyes Intelligence Engineering
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V. FEA OF HALF TUNNEL FORMWORK SYSTEM

From the optimization, the 3D solid HTCFS model with optimal thickness (i.e., 8 mm) is considered for Finite Element Analysis. Initially, a detailed meshed model from the optimal 3D solid HTCFS model is created in ANSYS as shown in Fig. 3. The design parameters are tabulated in Table 4.

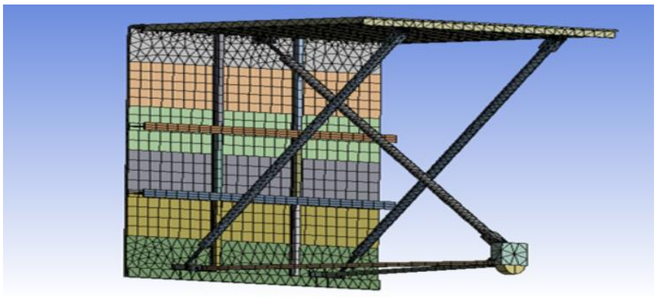

Fig 3. 3D solid meshed HTCFS model (Preliminary mesh showing different mesh pattern for illustration only)

Table 4. Design parameters for the HTCFS

Parameters	Numbers
Bodies	38
Active bodies	38
Nodes	433274
Elements	222967

The types of mesh considered is triangular very fine or very condensed mesh pattern. Finer the mesh, the more accurate the result or consensus but the computation time will be higher. Using the selected meshed type, the FEA is performed in ANSYS. The results obtained from the FEA are illustrated in the Figs. 4-7.

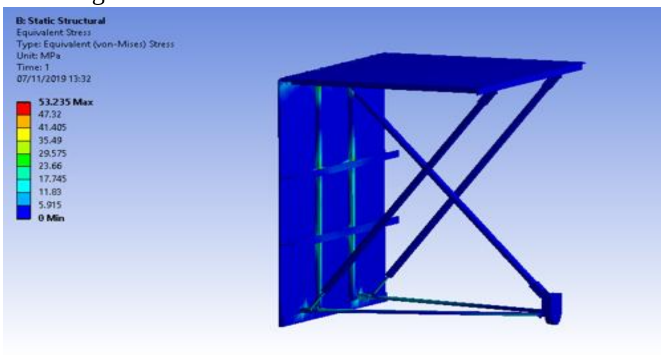

Fig 4. Equivalent stress in the HTCFS model

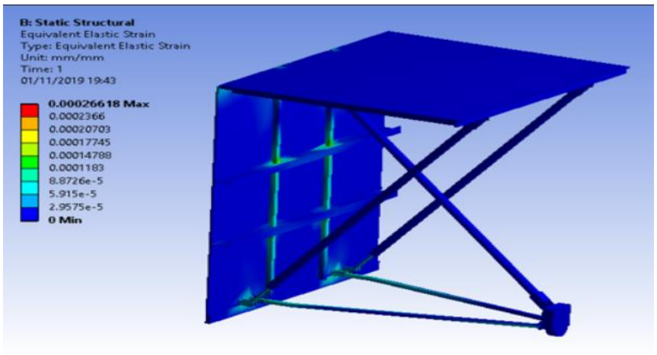

Fig 5. Equivalent elastic strain in the HTCFS model

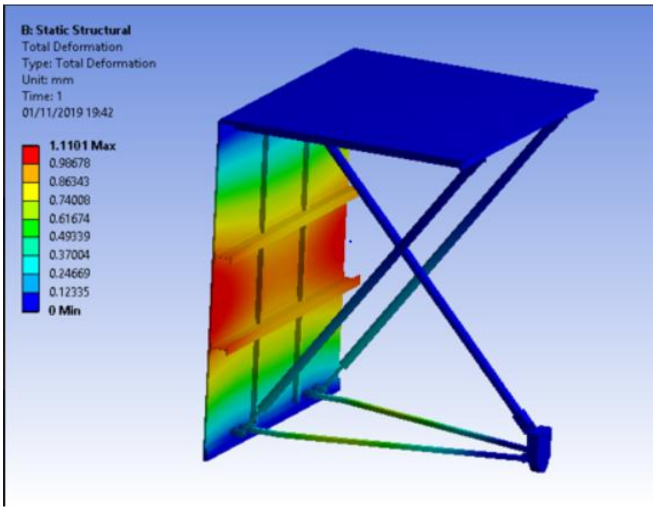

Fig 6. Total deformation in the HTCFS model

From Fig. 6, the total deformation is within the allowable limit and hence this model sustanciate the constructability conditions.

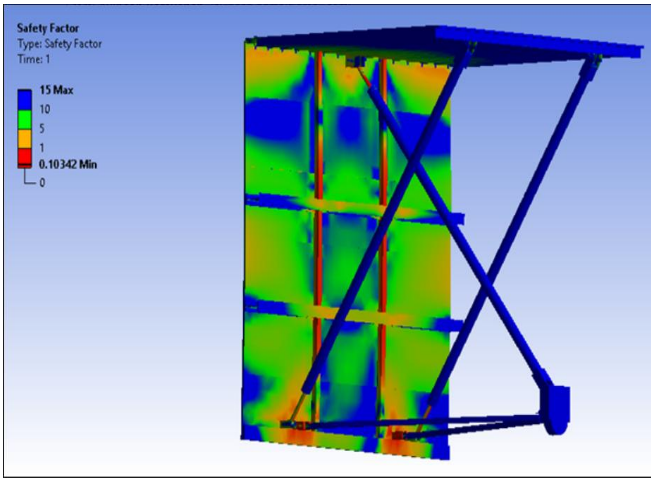

Fig 7. Safety factor for the HTCFS model.

VI. RESULTS AND DISCUSSIONS

Since the resulting 3D FEA models (Figs. 4-7) gives comprehensive and promising results in the statics analysis, it is thus expanded to dynamic analysis in ANSYS. The outcomes of the dynamic analysis are reported in Table 5.

Table 5. Result of dynamic analysis (frequency, time period, total deformation of modal analysis) for HTCFS

Mode	Frequency (Hz)	Time period (sec)	Total deformation (mm)
1	1.6626	0.6024	1.7114
2	3.8217	0.2617	2.8874
3	11.428	0.0874	4.7633
4	11.844	0.0844	3.6382
5	17.414	0.0574	2.959
6	21.264	0.0470	6.1804

VII. CONCLUSION

The FEA methodology adopted for the HTCFS in this research, provides a comprehensive analysis design strategy to the HTCFS, which would certainly enhance the designing of this special type of formwork system and also enrich the constructability consideration in the real-time construction site. Albeit the static analysis shows promising results, the dynamic analysis could not portray much on the significance of the structural behavior or structural integrity of the HTCFS, however a detailed study including the time effects of concrete, rheological or thixotropic behavior of concrete (Kumar and Kannan, 2015; Tamrakar and Kannan, 2015; Shanmughan and Kannan, 2016) in the 3D FEA can be carried to infer the dynamic response of the HTCFSs.

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