Analysis of Concrete Load in Very Long Column Formwork by Using Finite Element

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Abstract: The purpose of this research is to analyze the pressure (P) or stress on concrete according to the AASHTO M85 railway platform construction standard. The railway platform formwork was made of SS400 steel. Four different thicknesses (t) of formwork were examined: 3 mm. 4 mm. 5 mm., and 6 mm, respectively. The vertical steel batten (pl) was kept at 20 cm, but there were four horizontal steel battens (ph), i.e., 10, 15, 20, and 30 cm. A finite element method (FEM) was used to solve the solution. The height of column formwork (h) was 900 cm. The initial pressure of liquid concrete (P) was done at the top of the long column (h = 900 cm). As the analysis, it was found that the maximum stress or P was increased as the thickness (t) reduced. Then, the maximum stress of t = 3 cm becomes 406, 440, 485, and 470 MPa for the horizontal steel battens (ph) of 10, 15, 20, and 30 cm, respectively. The formwork was not resistant to the deformation owing to the maximum strength of SS400 being 245 MPa leading to the analyzed result of the present study having higher than the strength of SS400.

Key words: Long column, railway platform formwork, finite element method

1. Introduction

Infrastructure development is an important part of laying the foundation for economic development. To increase competitiveness and attract investment according to the 20-year national strategy, 2018–2037 [1, 2] contains the topic of the plan for building competitiveness. Part of the content will focus on the infrastructure in the field of transportation to connect travel transportation with neighboring countries and to improve the linkage network to support the entry into the ASEAN Community through various channels in the strategy of developing Thailand's transportation infrastructure 2015–2022 [3, 4]. The 5 work plans are conducted. The plans include issues in the intercity railway network development plan. This is to improve the rail transport infrastructure system. A double-track railway system is ready to operate the first 6 lines, consisting of (1) Thanon Chira-Khon Kaen Junction Line (2) Bangkok Line-Thanon Chira Junction (3) Bangkok-Chumphon Line (4) Chumphon-Songkhla Line (5) Lop Buri-Chiang Mai Line and (6) Chachoengsao-Saraburi Line. This project expedites the push to be able to carry out the construction of a standard gauge double track linking with neighboring countries and the People's Republic. In South China constructing one more railway parallel to the original line from the existing track is also connected to the former railway network of the State Railway of Thailand (SRT).

In the route section Map Krabao-Khlong Khanan Chit, the CSP Technology Co., Ltd. was a subcontractor for the construction of a new Muak Lek Railway Station. It consisted of station buildings and platforms. Muak Lek station must be moved to a new place. The State Railway of Thailand (SRT) selected the most suitable area, but it was found that the construction area needed to be upgraded to the platform. To raise the original ground up to meet the design standard which is KKU S-T-003-256x [5–8] according to the rail construction standard, the slope (Gradients) normal limit was not more than 2% as shown in Fig. 1.

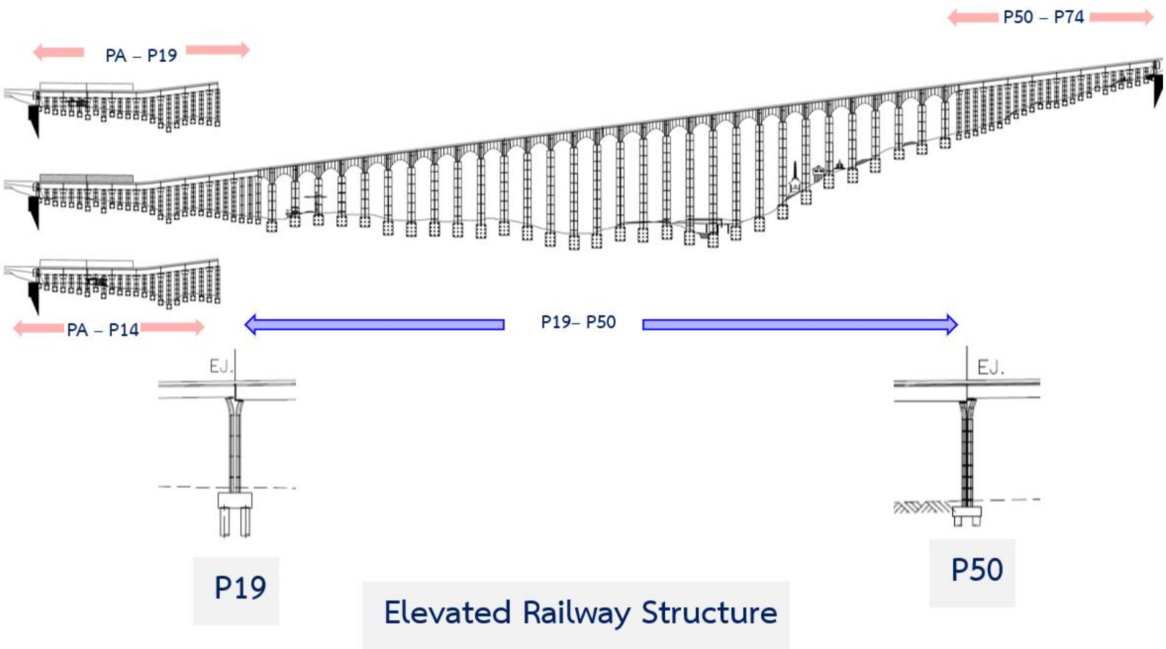


Fig. 1. The design of the double-track railway according to the KKU standard S-T-003-256x.

The design of the platform columns of Muak Lek Station (New) was a long column with a pair of platforms on a length of 400 m. The platform height was in the range of 4 m to 9 m which supports a total of 242 platforms. Conditions for casting columns with no joints will form if the liquid concrete [9] must be poured in time. A standard formwork was commonly used when the concrete was poured to a height of 5 m [10]. Standard column formwork cannot withstand the pressure of liquid concrete as shown in Fig. 2. This caused damage to the column formwork leading to the column formwork breaking. From the existing knowledge studies [11–17] no reference data to solve the problem in practice has yet been found.

From this problem, the researcher studied the literature on various research fields for comparative analysis. To solve problems in column casting, it has been found that there was research on the method of analyzing finite elements [18–25] which was the most widely used method for solving problems in continuum mechanics. Computers can be employed to make accurate and fast calculations. The general principle was to divide a continuous object into smaller parts called an element. It can be either a triangle or a square, or any other figure. Where these elements were separated by an imaginary line or another imaginary surface and connected by a node located on the boundary of the element as shown in Fig. 3. In calculating the unit of force and displacement in every element, a high-resolution value was obtained.

Fig. 2. Deformation at the edge of the column formwork.

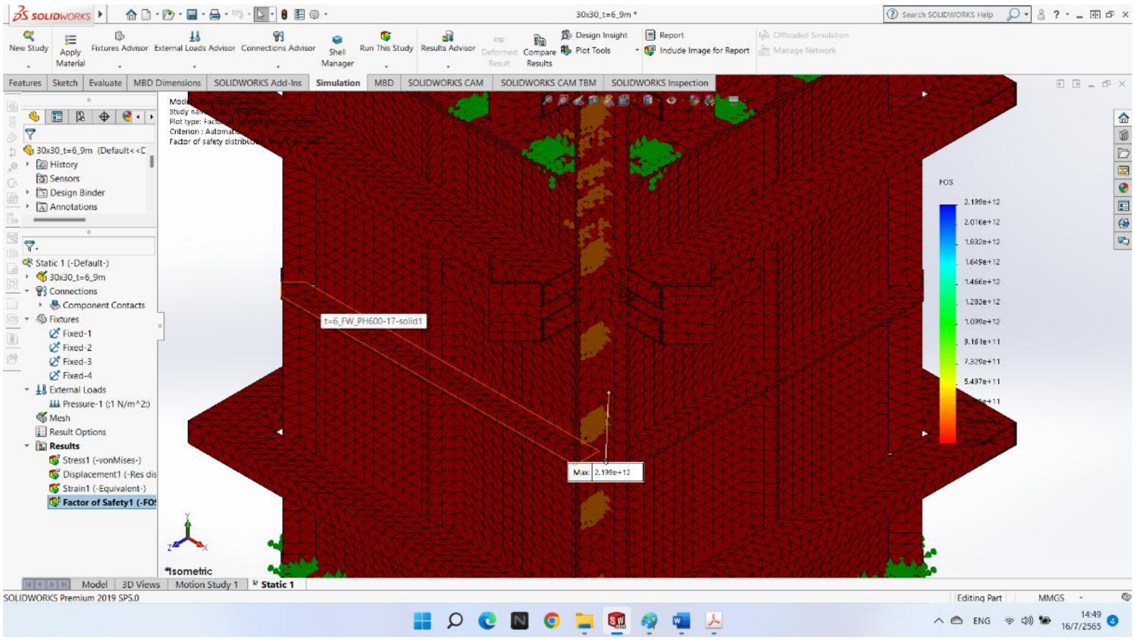


Fig. 3. Divide the work-piece into smaller elements to analyze the problem.

In this research, we would like to present the development of (very) long column formwork using mathematical modeling. The formwork for the long column having a height of 900 cm. was made of SS400 steel. Four formwork thicknesses (t), consisting of 3 mm., 4 mm., 5 mm., and 6 mm., were examined. The horizontal steel battens (ph) were four different types (10, 15, 20, and 30. cm) but the vertical steel batten (pl) was kept at 20 cm. The initial pressure of liquid concrete (P) at a high level (h) of 900 cm was used. The finite element method (FEM) was applied to analyze the pressure or stress of concrete acting on the long column formwork. Therefore, the approach to the research process was to design the formwork structure with a Solid work program and to create a mathematical model to predict the physical formwork on withstanding the compressive stress of concrete. The Finite Element Method (FEM) was used for analysis. This research expected the results of the model and the experiments to guide the design of formwork for (very) long columns both in the construction of the platform of Muak Lek railway station (new) and the construction of other similar projects.

2. Theories Related to Research

2.1. Weight and pressure of concrete [26–34]

The pressure of concrete in the early stages was calculated with the same property as water. The pressure of concrete varied according to the depth and the density of the liquid were shown in Fig. 4.

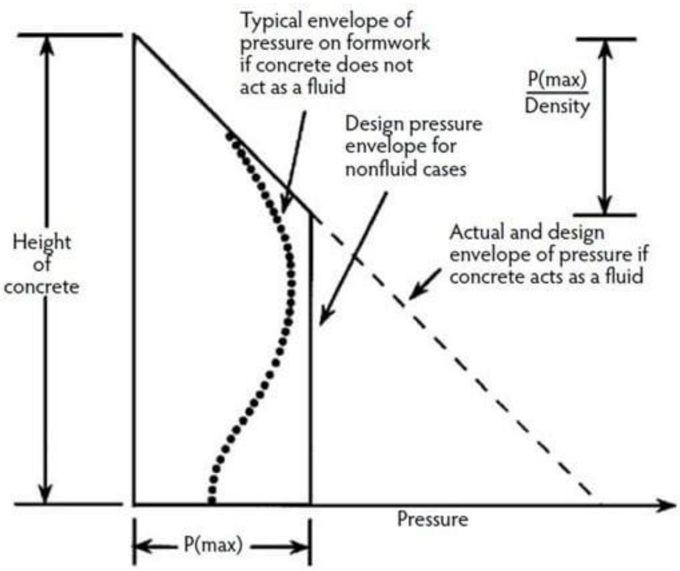


Fig. 4. The pressure of concrete comparison between liquid pressure and actual pressure.

Referring to Fig. 4, the pressure of the concrete acting as a fluid (liquid) and the concrete in the form of non-fluid were compared. The pressure of the concrete with a low height gave a value close to the pressure of the liquid calculated according to CEB (Comite Euro-International du Beton). So, we got Eq. (1).

$$Ph = \gamma H. \tag{1}$$

2.2. Principles and theories related to the problem of solid stress-strain and displacement

When an external force acts on an object, there will be internal forces against those external forces. The internal dissipation force that occurs in the material is called stress [35]. Stress can be divided into three categories: 1) Tensile stress occurs when the object is subjected to tensile stress, 2) Compression stress occurs when the object is under pressure, and 3) Shear stress is an external force that tries to cause an object to break along a plane parallel to the direction of the force, as shown in Fig. 5.

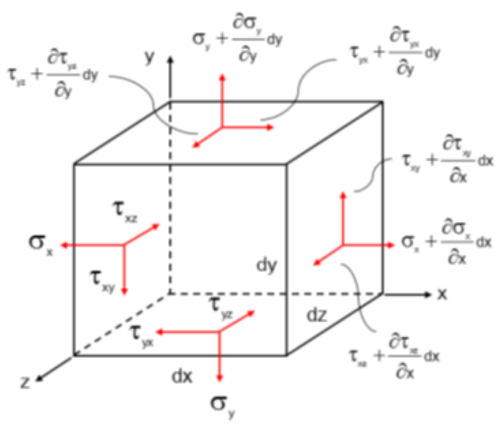


Fig. 5. A cubic shape with elements of perpendicular stress and shear stress acting.

The stress analysis [36] arising within the material is performed by considering the cross-section of a cubic material with a cubic volume, as presented in Eq. (2)

$$[\sigma]T= [\sigma x\ \sigma y\ \sigma z\ \tau\ xy\ \tau yz\ \ \tau xz\ ] \tag{2}$$

where σx, σy, and σz represent the perpendicular stress. The τxy, τyz, and τxz are the shear stress. γx, γy, and γz represent the specific weight of this cube using Newton's first law. In addition, the displacement of the material is deformed (Deformation) due to an external force being higher than the adhesion force within the material. The vector of the displacement can be written as Eq. (3).

$$\vec{\delta}\ = u(x\ ,y\ ,z)\vec{\imath} + \ +\mathrm{v}(\mathrm{x}\ ,\mathrm{y}\ ,\mathrm{z})\vec{\jmath} + \mathrm{k}(\mathrm{x}\ ,\mathrm{y}\ ,\mathrm{z})\ \vec{k} \tag{3}$$

where $\vec{\delta}$ is the displacement vector. Stress part is the term for the change in the shrinkage distance between the points within the material to the original length. There are six independent variables of stress components as shown in Eq. (4).

$$[\varepsilon]T= [\varepsilon x\ \ \varepsilon y\ \ \varepsilon z\ \ \tau xy\ \gamma yz\ \ \gamma xz\ \ ], \tag{4}$$

where εx ,εy, and εz represent the normal stress and γxy, γxz, γyz are shear stress.

2.3. Theories used in stress analysis

In this research, maximum distortion energy theory [36] or von Mises theory and a theory of failure derived from the Strain energy principle are used to calculate the maximum value that the formwork can accept before failure. For the result in the case of 3D stress, von Mises can be obtained as shown in Eq. (5).

$$\sigma_v = \sqrt{\frac{1}{2}(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2} \tag{5}$$

where σ_v represent the von Mises stress and σ_1 , σ_2 , and σ_3 represent the primary stress.

2.4. Finite Element Method (FEM) [37, 38]

Finite elements now play an important role in the design and have been continuously improved to provide very sophisticated analysis having higher accuracy. This has resulted in improvements and changes to both the design process and the design results. The development of this finite element caused the development of computational tools that can calculate and store more data as well. The finite element method (FEM) is a numerical process to obtain an approximate solution by dividing the domain into smaller, aligned elements. The entire domain without overlapping is called "Mesh" and then constructs each element of the equation. On the principle that the equations created must be consistent with the control equations of the problem being considered. Problems in engineering, science, and others are covered by these three elements. The finite element method of analysis is therefore applied to solve a wide variety of problems.

2.5. Solid works [39]

Solid works [39] fabricated at the Massachusetts Institute of Technology by Jon Hirsch tick and continue to evolve. It is software to use as an engineering design tool and to create a mock product example before creating a real prototype product. The software is in the Computer-Aided Design (CAD) family, which creates 3D model parts. Solid work is a program that is very flexible in work and able to work in many forms. Whether it is a workpiece that needs to be solid or surface, there is a machine that supports it very well. When the workpiece is finished, it can be assembled in the mode of the assembly instruction set, including those who want the drawing of the workpiece, just drag the workpiece and place it in the worksheet.

3. Operation Steps

3.1. Formwork structure design

Solid Works was used to design column formwork. The actual size was width x length equal to 60 cm × 60 cm. The material used for building concrete formwork was Carbon steel type SS400. The properties of steels were based on the Thailand Industrial Standard reference, TIS. 1227–2538 [40] as shown in Table 1. Four formwork thicknesses (t), consisting of 3 mm., 4 mm., 5 mm., and 6 mm., were examined. The horizontal steel battens (ph) were four different types (10, 15, 20, and 30. cm) but the vertical steel batten (pl) was kept at 20 cm. The model of this work is presented in Fig. 6.

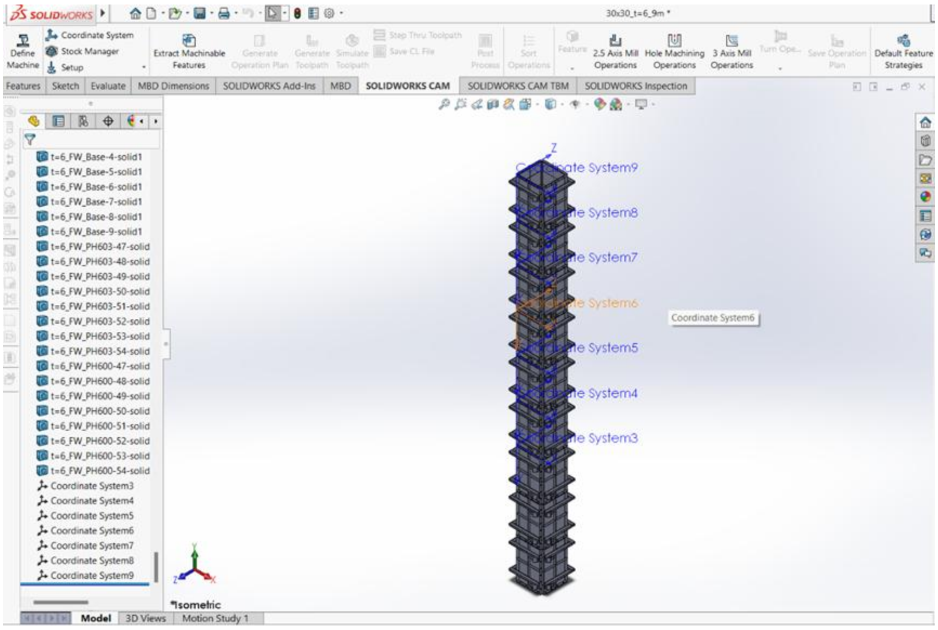


Fig. 6. Model.

Table 1. SS400 carbon steel properties.

Property details	Volume	Unit
Tensile strength at the lowest yield point	245	MPa
Tensile strength	400-510	MPa
Shear modulus	800	MPa
Density	7860	kg/m3

3.2. Assumptions and analysis condition

The assumptions and the analysis conditions used in analyzing the force (pressure) acting on the concrete formwork were presented in Tables 2 and 3. The cross-section of the column formwork was square and had the following dimensions: 60 cm x 60 cm. The properties of concrete were based on the standards of the State Railway of Thailand (SRT). The finite element method (FEM) was used to solve the pressure or solution. The initial pressure was analyzed at the top level (h) of 900 cm.

Table 2. The assumptions used in the equation.

NO.	Assumptions
1	The pressure of the concrete acts is directed from the top
2	The pressure acting on the concrete formwork is constant.
3	There is no lateral force on the outer formwork
4	The physical properties of steel are constant.

Table 3. Analysis conditions.

Parameters	Factor	Unit
Concrete density	2320	kg/m^3
Height levels (h) of initial pressure	900	cm
The thickness of steel (t)	3, 4, 5 and 6	mm.
Vertical steel battens (pl)	20	cm.
Horizontal steel battens (ph)	10, 15, 20 and 30	cm.

4. Analyzed Results and Discussion

4.1. Mesh independence analysis

To make the reliable results obtained from the model with the finite element method (FEM), first, the mesh independence was investigated. The mesh of a long column formwork was studied with twelve different elements in the range of 246511 to 6247369 elements. The maximum stress was proposed to calibrate the mesh independence depicted in Fig. 7. As the investigation, the maximum stress was saturated if the mesh element became in the range of 4350153 to 6247369. Therefore, in the simulation, the mesh of 4597358 elements was chosen for calculating the long-column formwork because this element was enough accuracy.

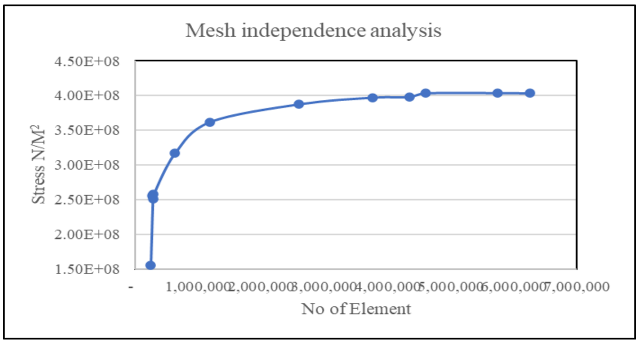
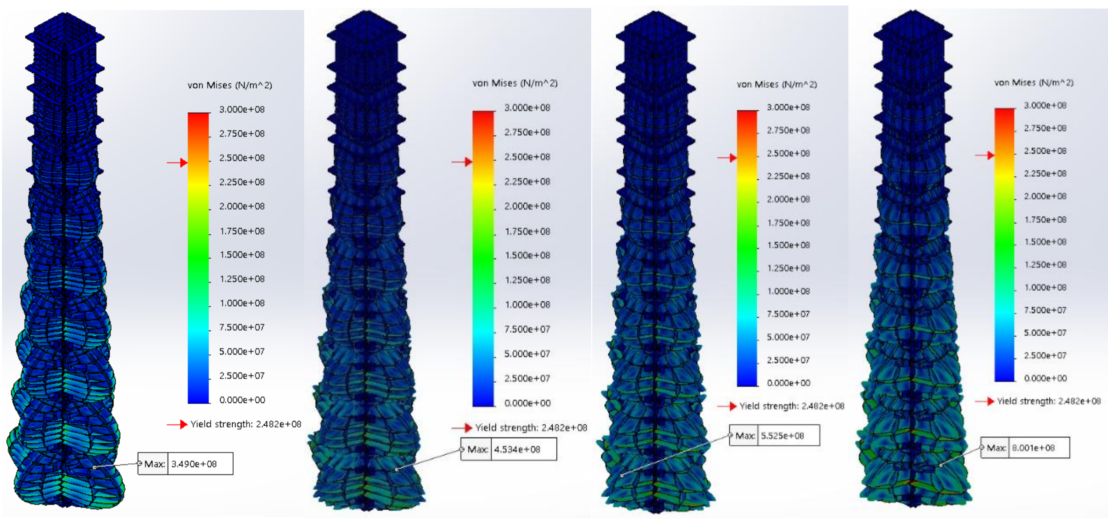


Fig. 7. Grid independence test results.

4.2. The stress of formwork thickness (t) of 3 mm

Fig. 8 presents the stress acting on the very long column formwork of the simulation analyzed at a thickness (t) of 3 mm. The initial pressure of concrete was operated at high levels (h) of 900 cm. The simulation was investigated at vertical steel battens (pl) of 20 cm. The horizontal steel battens (ph) with four difference values (10, 15, 20, and 30 cm.) were analyzed. Thus, the results of ph = 10, 15, 20, and 30 cm. were depicted in Fig. 8(a), Fig. 8(b), Fig. 8(c), and Fig. 8(d), respectively.

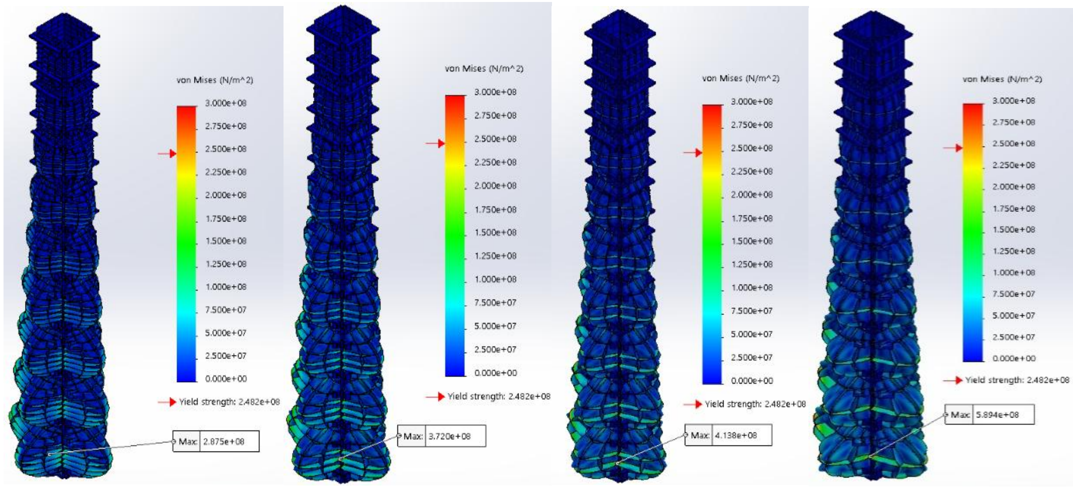


(a) ph = 10 cm. (b) ph) = 15 cm. (c) ph = 20 cm. (d) ph = 30cm.

Fig. 8. The stress of t = 0.3 cm.

4.3. The stress of formwork thickness (t) of 4 mm

Fig. 9 presents the stress acting on the very long column formwork of the simulation analyzed at a thickness (t) of 4 mm. The initial pressure of concrete was operated at high levels (h) of 900 cm. The simulation was investigated at vertical steel battens (pl) of 20 cm. The horizontal steel battens (ph) with four difference values (10, 15, 20, and 30 cm.) were estimated. Thus, the results of ph = 10, 15, 20, and 30 cm. were depicted in Fig. 9(a), Fig. 9(b), Fig. 9(c), and Fig. 9(d), respectively.



(a) ph = 10 cm. (b) ph) = 15 cm. (c) ph = 20 cm. (d) ph = 30cm.

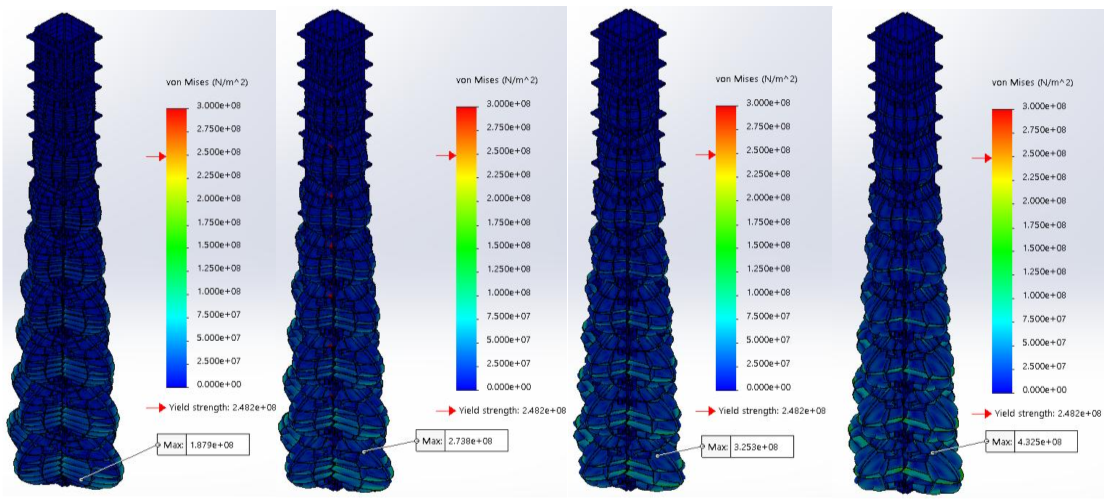
Fig. 9. The stress of t = 0.4 cm.

4.4. The stress of formwork thickness (t) of 5 mm

Fig. 10(a), Fig. 10(b), Fig. 10(c), and Fig. 10(d) illustrate the stress acting on the very long column formwork for the horizontal steel battens (ph) of 10, 15, 20, and 30 cm., respectively. The simulation analysis was conducted at a thickness (t) of 5 mm. The initial pressure of concrete was operated at high levels (h) of 900 cm. The vertical steel batten (pl) of 20 cm was used.

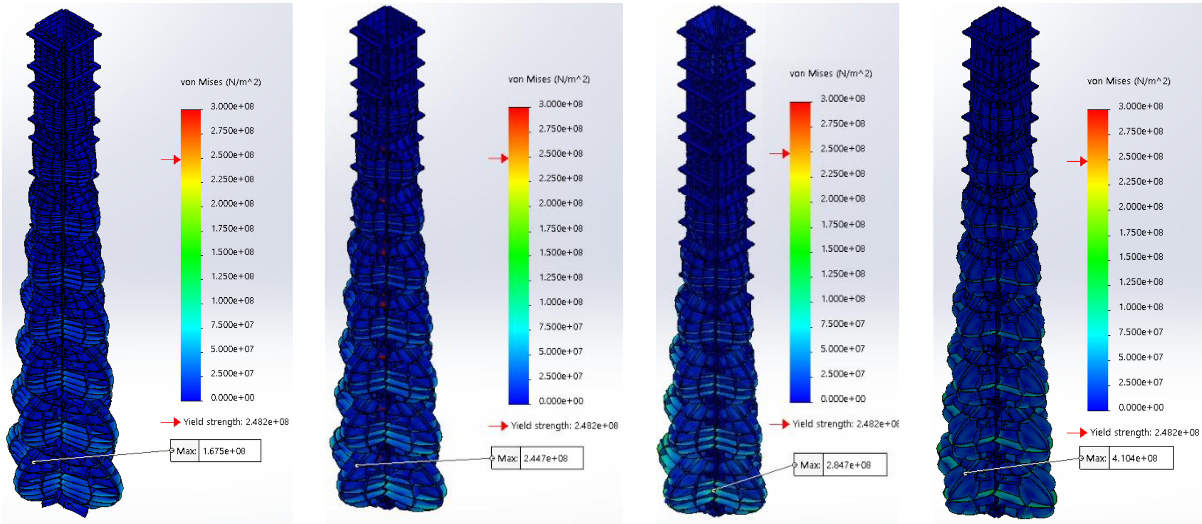
4.5. The stress of formwork thickness (t) of 6 mm

Fig. 11(a), Fig. 11(b), Fig. 11(c), and Fig. 11(d) illustrate the stress acting on the very long column formwork for the horizontal steel battens (ph) of 10, 15, 20, and 30 cm., respectively. The simulation analysis was conducted at a thickness (t) of 6 mm. The initial pressure of concrete was operated at high levels (h) of 900 cm. The vertical steel batten (pl) of 20 cm was used.



(a) ph = 10 cm. (b) ph) = 15 cm. (c) ph = 20 cm. (d) ph = 30cm.

Fig. 10. The stress of t = 0.5 cm.



(a) ph = 10 cm. (b) ph) = 15 cm. (c) ph = 20 cm. (d) ph = 30cm.

Fig. 11. The stress of t = 0.6 cm.

4.6. The discussion on the effect of analyzed parameters

From the analysis, it was found that the stress on the formwork can be summarized in Table 4. The calculated stress yielded in the range of 238 MPa to 470 MPa. The formwork did not resist deformation due to the maximum stress of SS400 being 245 MPa. There was only one case where ph = 10 cm. and t = 6 mm, the calculated stress gave lower than the strength of SS400. In addition, to make it easier for understanding the effect of thicknesses (t) and horizontal steel battens (ph) on the stress of the formwork caused by the pressure of concrete, Fig. 12 is reported. It can be observed that the stress acting on the formwork increased as the horizontal steel battens (ph) increased. With the increase of the formwork thickness (t), the stress decreased.

Table 4. Stress at Horizontal steel battens difference level

Thickness, t (mm.)	Stress at horizontal steel battens, ph (N/m.^{2})			
	ph = 10 cm	ph = 15 cm	ph = 20 cm	ph = 30 cm
3	406,568,384	440,652,960	458,758,752	470,569,056
4	345,758,656	367,052,640	379,497,184	402,135,520
5	254,173,184	264,620,864	279,450,208	289,975,232
6	238,166,896	257,689,952	268,486,272	277,161,600

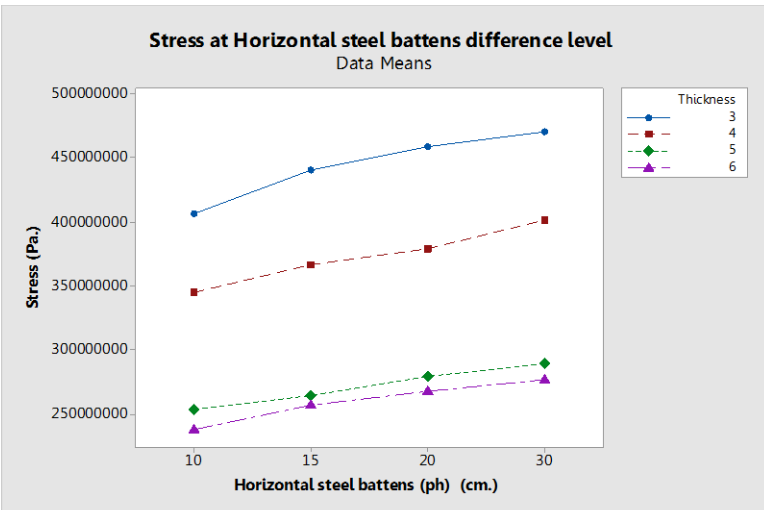


Fig. 12. Stress acting on the formwork.

5. Summary of the Analysis

The pressure analysis using the Finite Element Method (FEM) of liquid concrete or Pressure (P) applied to the railway platform column formwork was constructed from SS400 steel based on AASHTO M85 Railway Station Construction Standards. In the present study, it was found that the stress tended to increase with the decrease in thickness of the formwork (t) and the increase of the horizontal steel battens (ph). The maximum stress obtained from the calculation was higher than the strength of SS-400 steel (245 MPa) except in the case of t = 3 mm and ph = 10 cm (238 MPa). Therefore, this preliminary information can lead to improving the formwork structure. For example, the design of casting formwork for very long columns of this work can be used in the construction of the platform of Muak Lek Railway Station (new), Muak Lek District, Saraburi including in the construction of other projects that have a similar nature.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Tawatchai Kraisee, Pilin Hankhuntod, and Niwat Ketchat analyzed the model with the finite element method (FEM). Tawatchai Kraisee and Bundit Krittacom wrote the paper. The results were discussed and gave the reasons or the related theories in the paper by all authors. Also, the final version had proven by all authors.

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