Sensitivity analysis on deformation of woven polyethylene formwork

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Abstract. The use of different material quality and amount can affect formwork performance at the beginning of casting. Practical easy to install formwork such as woven polyethylene with wire mesh reinforcement makes field work easier. Sensitivity analysis on the elastic modulus and the thermal coefficient variables of woven polyethylene, fresh concrete temperature during casting and fresh concrete load model are the objectives of this research. The research is performed by comparing experimental data and the numerical modeling of woven polyethylene formwork using Finite Element Method. The formwork span and width dimension are 1 m x 0.3 m, with a variety of heights namely 0.6 m, 0.45 m, and 0.3 m. The sensitivity value for each variable will be evaluated based on Pearson coefficient or R. The sensitivity analysis of thermal coefficient showed no correlation to changes in formwork deformation. The sensitivity analysis of elastic modulus and fresh concrete temperature showed perfect correlation to changes in formwork deformation although the changes are small (around 0.0003 cm to 0.0006 cm). The fresh concrete load model showed perfect correlation to formwork deformation as well as becoming the determining variable of the changes in the formwork deformation values.

1. Introduction
Both in modeling and field construction, the ratio between material amount and quality of the formwork (in this case woven polyethylene formwork with wire mesh) influences the strength of the casting result. The use of tarp or fabric formwork according to Mark West[1-3] both for architectural and structural is easier and more efficient as well as more affordable compared to conventional formwork. The woven polyethylene formwork model is created using Finite Element Method to study variables such as the elastic modulus and thermal coefficient of woven polyethylene, fresh concrete temperature during casting, and concrete load model (based on ACI 347-04 [4] and DIN 18218:2008 [5]). The sensitivity level of each variable will be analyzed to see which variable is the most influential in woven polyethylene formwork deformation.

2. Research Methodology
This study is aimed at analyzing the sensitivity of the following variables: elastic modulus, thermal coefficient, fresh concrete temperature, and concrete load model based on ACI 347-04 and DIN 18218:2008. Therefore, several chapters will be dedicated to discuss how the research is conducted in detail, such as data collection method, types of data and research variables, and research instrument.
2.1. Data collection method
There are two data collection methods used by the author to obtain information namely literature study and analysis study. Literature study is required to analyze the sensitivity of each variable using the Pearson correlation coefficient. According to Sidebar [6], the Pearson coefficient can be used to identify the degree of correlation between two or more variables. The Pearson coefficient indicates such degree of correlation using the range of \(-1 < 0 < 1\). According to Sugiyono [7], \(0 – 0.19\) indicates no correlation, \(0.2 – 0.39\) indicates weak correlation, \(0.4 – 0.59\) indicates adequately strong correlation, \(0.6 – 0.79\) indicates strong correlation, and \(0.8 – 1\) indicates perfect correlation (the same also applies to value below 0 or minus). The analysis method used in this research is the formwork modeling using Finite Element Method. The resulting deformation for each variable is then processed using the Pearson coefficient formula or \(R\) according to Sudjana [8]. The value of \(R\) can be seen in equation 1:

\[
R = \left( \frac{\sum_{i=1}^{n} X_i Y_i - \left( \sum_{i=1}^{n} X_i \right) \left( \sum_{i=1}^{n} Y_i \right)}{\left( \sum_{i=1}^{n} X_i^2 - \left( \sum_{i=1}^{n} X_i \right)^2 \right) \left( \sum_{i=1}^{n} Y_i^2 - \left( \sum_{i=1}^{n} Y_i \right)^2 \right)^{1/2}} \right)^{1/2}
\]

(1)

2.2. Types of research data
There are two types of research data namely primary and secondary data. The primary data consists of the sensitivity analysis of formwork deformation caused by the research variables namely elastic modulus, thermal coefficient, fresh concrete temperature, and concrete load model (ACI 347-04 and DIN 18218:2008 standard) based on woven polyethylene formwork modeling with Finite Element Method. In the meantime, the secondary data refers to the comparison between the deformation values resulted from the performance of the modeling formwork and experimental data [9].

2.3. Research variable and instrument
There are two variables in this research: dependent and independent variables. Independent variable refers to variables to be researched (elastic modulus, thermal coefficient, fresh concrete temperature, and concrete load model). The dependent variable refers to the sensitivity analysis result of the deformation values from the four researched variables.

The research instrument used is the woven polyethylene formwork modeling with Finite Element Method to see the deformations of formwork, which will then be analyzed to check the sensitivity against the researched variables.

3. Research Results
This research compares the woven polyethylene formwork numeric modeling with similar experimental data: wire mesh diameter of 4 mm, space of 15 cm x 15 cm, a variety of formwork heights (\(H = 60\) cm, 45 cm, and 30 cm), span length (\(L\)) of 1 meter and a cross section of 0.3 meter.

Figure 1 shows woven polyethylene formwork modeling. After obtaining the deformation value, the sensitivity of the researched variables namely elastic modulus, thermal coefficient, fresh concrete temperature, and fresh concrete load model will be analyzed. The deformation value to be evaluated is located at the height of \(\frac{1}{2} H\) in the center of the formwork span for both sides (side A at coordinate \(Y= 0\) and side B at coordinate \(Y= 0.3\) m).
3.1. Sensitivity analysis of elastic modulus
The elastic modulus of woven polyethylene in this research has a range between 500 and 1200 N/mm². The standard deviation, slope, and error (e²) values are evaluated from the numerical modeling simulation using the Finite Element Method. The simulation showed a change of 0.0004 cm in deformation value when the magnitude of elastic modulus changed from 600 N/mm² to 700 N/mm² and from 900 N/mm² to 1000 N/mm² for every formwork height variation. The Pearson (R) value obtained was 0.9435, indicating a perfect correlation between the formwork deformation and the elastic modulus values (although the deformation value change was not significant).

3.2. Sensitivity analysis of thermal coefficient
The thermal coefficient (A) of polyethylene has a range between $1 \times 10^{-6}$ /°C and $2 \times 10^{-6}$ /°C. The standard deviation, slope, and error (e²) values are evaluated from the numerical modeling simulation using the Finite Element Method. The simulation showed that the deformation of the formwork did not change for every formwork height variation, indicating that the Pearson (R) value is equal to 0, meaning that there is no correlation between the deformation value and the thermal coefficient.

3.3. Sensitivity analysis of fresh concrete temperature
The researchers simulated different fresh concrete temperatures in a numerical modelling to observe their sensitivity towards formwork deformation. The variations for different fresh concrete temperatures are as follows: 60°C, 70°C, and 80°C for 60 cm height; 45°C, 50°C, and 55°C for 45 cm height; and 20°C, 30°C, and 40°C for 30 cm height. The simulation results showed that for every 10°C increase in temperature (at 60 cm and 30 cm formwork height), there was a 0.0006 cm change in the formwork deformation value whereas for every 5°C increase in temperature (at 45 cm formwork height), there was only 0.0003 cm change. The Pearson (R) value was obtained within the range of 0.8 – 0.93, indicating a perfect correlation between the magnitude of formwork deformation and the fresh concrete temperature.

3.4. Sensitivity analysis of fresh concrete load model
The standards used in fresh concrete load model variable are ACI 347-04 and DIN 18218:2008 (trapezoid geometry concept) to fulfil the need for assumption from prior experiment data; this research uses the ACI 347-04 standard. In general, the difference between the two standards lies on the concrete load geometry assumption in the formwork. The DIN 18218:2008 standard focuses on the fresh concrete and hardened concrete phases. The comparison between the formwork deformation values in the numerical modeling and the experimental data from every formwork height variation can be seen in Table 1, Table 2 and Table 3. The deformation value difference in the fresh concrete load model of this DIN 18218:2008 with hardened concrete assumption still contributes to the wire mesh deformation in woven polyethylene formwork.

Figure 1. Illustration of woven polyethylene formwork modeling using the Finite Element Method in a 1-meter span with the following formwork heights (H): (a) 60 cm, (b) 45 cm, and (c) 30 cm.
Table 1. Sensitivity analysis on the deformation values of woven polyethylene formwork (H= 30cm) due to fresh concrete load model.

| Type of fresh concrete load | ACI 347-04 (Geometry) | Experimental Data | ACI 347-04 (Geometry) | Experimental Data |
|-----------------------------|------------------------|-------------------|------------------------|-------------------|
| Load per Millimeter (x) (N/mm) | 2.115 | 3.4122 | 2.115 | 3.4122 | 2.115 |
| Deformation (y) (cm) | 2.165 | 3.5423 | 1.833 | 2.165 | 3.1627 | 1.6667 |
| Deviation Standard | 0.6115 | 0.6115 | 0.6115 | 0.6115 |
| $e^2$ | 0.9665 | 0.893 |
| Pearson (R) | 0.9831 | 0.9450 |

Table 2. Sensitivity analysis on the deformation values of woven polyethylene formwork (H= 45 cm) due to fresh concrete load model.

| Type of fresh concrete load | ACI 347-04 (Geometry) | Experimental Data | ACI 347-04 (Geometry) | Experimental Data |
|-----------------------------|------------------------|-------------------|------------------------|-------------------|
| Load per Millimeter (x) (N/mm) | 3.1725 | 5.5272 | 3.1725 | 5.5272 | 3.1725 |
| Deformation (y) (cm) | 9.2225 | 12.0347 | 7.33 | 9.222 | 12.03 | 7.6667 |
| Deviation Standard | 1.11002 | 1.11002 |
| $e^2$ | 0.8402 | 0.8763 |
| Pearson (R) | 0.9166 | 0.9361 |

Table 3. Sensitivity analysis on the deformation values of woven polyethylene formwork (H= 60cm) due to fresh concrete load model.

| Type of fresh concrete load | ACI 347-04 (Geometry) | Experimental Data | ACI 347-04 (Geometry) | Experimental Data |
|-----------------------------|------------------------|-------------------|------------------------|-------------------|
| Load per Millimeter (x) (N/mm) | 4.23 | 7.6422 | 4.23 | 7.6422 | 4.23 |
| Deformation (y) (cm) | 21.9778 | 44.08985 | 9.3333 | 21.9778 | 44.08985 | 6.3333 |
| Deviation Standard | 1.6085 | 1.6085 |
| $e^2$ | 0.8708 | 0.82998 |
| Pearson (R) | 0.9332 | 0.9110 |

The Pearson value (R) obtained from the three tables above is within the range of 0.9110 – 0.9831, which signifies a perfect correlation between the fresh concrete load model and the deformations value of the woven polyethylene formwork. It also indicates that the fresh concrete load model determines the deformations occurring on the formwork.

4. Conclusion

The sensitivity analysis on the researched variables (namely modulus of elasticity, thermal coefficient, fresh concrete temperature, and load model) resulted in a Pearson (R) value within a range of 0.8 – 0.9831, indicating a perfect correlation with the woven polyethylene formwork deformation values (except thermal coefficient with a Pearson value of 0, meaning there is no correlation).
However, our research analysis showed that the fresh concrete load model was the most influential variable in determining the deformation values as proven by the highest Pearson value obtained at 0.9831. This is because the phases of concrete (fresh and hardened) are the most influential on the final woven polyethylene formwork. Assumptions such as wire mesh diameter, distance between wire mesh, and formwork height also determine its strength in bearing the applied load.

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