Evaluation of slab and joist design on construction cost efficiency (case study: office building)

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Abstract. Design phase is an important step in order to plan a construction project. One of the determining factors is the building economical value. In the design phase, a method or a design alternative with the most efficient economical value is needed without compromising on the strength of the structure. In this research, the case study is based on an office building. It represents a low rise building with a typical upper structural component which are columns, beams, and slabs with concrete material. Several design alternatives related to the efficiency of structural components’ dimension will be analysed. This research is conducted through modelling the building structure by using the Finite Element Method. The calculation of the building structure construction cost will be evaluated for each design alternatives. The study shows that the most efficient design with joists reduction giving the cost reduction by 11.7%. On the other hand, thickening the slab and reducing the beam’s dimension increase the cost by 26.9%.

1. Introduction

The building process of a construction project has several stages in it, among them are the planning stage, the design state, the sourcing stage, the construction stage until the maintaining stage. Some of the stages can be done by using the latest technology which is inexpensive but with a good quality for construction method, or the easiest is by using dimension efficiency without changing many things in the project planning [1-4]. Dimension efficiency can be very influential on decreasing the construction total cost, since around 40-60% construction cost comes from the material volume [1]. By doing the structure dimension efficiency, a material volume efficiency can be achieved, in which, in the end will give impact on the construction cost [5-10].

According to the research done by Setiawan, Mungok and Budi [2], there is a correlation between the slab panel volume, as well as the joist usage towards the slab thickness. From many models which have been researched, it can be concluded that a slab with 5 m x 5 m volume, slab thickness of 125 mm is still able to fulfill without using joist. The elimination of joist will suppress the construction cost. Since by eliminating it, the concrete material frame and joist formwork will be not needed as well. In this research, the efficiency of the design phase will be realized by doing structure component dimension efficiency with few options, such as eliminating the joist and decreasing the beam dimension.
2. Research methodology

The research method is started by realizing the concrete structure modeling using the Finite Element Method (Figure 1) which later continued with the building construction cost study. The case study being learned is an office building which consists of 2 floors. The quality of the concrete used is 24 MPa. The height of the first and second floor are consecutively 4 m and 4.2 m with the total volume of the building is 1943 m$^2$.

![Figure 1](image1.png)

**Figure 1.** The building structure modeling with Finite Element Method.

Three models variations will be analyzed in this research. They are Model 1 (existing building model), Model 2 (existing building model efficiency by eliminating joists) and Model 3 (existing building model efficiency by decreasing the beam dimension and increasing the slab thickness). The cost analysis will be evaluated by comparing the cost of the existing structure model (Model 1), with few building options in which structure component efficiency had been conducted (Model 2 and Model 3) without decreasing the building structure strength. Second floor plan for Model 1 and Model 2 can be seen in Figure 2 and Figure 3.

Model 1 is an existing structure model with column dimension varies from 0.3 m, 0.35 m, and 0.4 m. On Model 1, there are four types of beams. They are B1, B2, B3, and B4, with the cross-section dimension are consecutively 0.3 m x 0.5 m, 0.2 m x 0.3 m, 0.4 m x 0.6 m and 0.3 m x 0.5 m. The concrete floor slab thickness is 0.12 m.

![Figure 2](image2.png)

**Figure 2.** Floor plan 2 for model 1.
3. Results and discussion

3.1. Concrete volume analysis
The volume of the concrete structure component covers slabs, columns, and beams for the three models can be seen in Table 1. Model 2 produced the least concrete work volume due to the modification of the building floor plan design, in which there is elimination of joists, also on columns and slab components there was no concrete work volume alteration. On the other side, Model 3 has the biggest slab component work due to the addition of the slab thickness, also the beam component volume of this model is the most efficient; whereas, the column component increase due to the safety structure adjustment from the modelling phase.

| Structure component | Concrete volume (m³) |
|---------------------|----------------------|
|                     | Model 1  | Model 2  | Model 3  |
| Columns             | 36.4     | 36.4     | 37.8     |
| Beams               | 55.5     | 48.8     | 39.2     |
| Slabs               | 151.1    | 151.1    | 201.5    |
| Total               | 243.0    | 236.3    | 278.5    |

3.2. Steel reinforcement volume analysis
The calculation of the steel reinforcement work volume on slabs, columns and beams structure component for the three models can be seen in Table 2. Model 2 produced the least iron volume due to the modification from the joists elimination, whereas the columns and slabs component need less iron reinforcing due to the decreasing load withheld by the structure component. Meanwhile, Model 3 produced a higher iron volume than the existing model (Model 1).
Table 2. The steel reinforcement work volume comparison for Model 1, Model 2 and Model 3.

| Structure component | Steel reinforcement volume (m³) |
|---------------------|-------------------------------|
|                     | Model 1 | Model 2 | Model 3 |
| Columns             | 15 680  | 14 094  | 20 002  |
| Beams               | 17 612  | 11 662  | 21 558  |
| Slabs               | 10 780  | 10 188  | 15 355  |
| Total               | 44 073  | 35 944  | 56 915  |

3.3. Formwork volume analysis

The calculation of formwork volume work resulted from three kinds of works. They are the formwork work cost, the formwork scaffolding work and the formwork unloading work [11]. The formwork work volume for Model 1, Model 2 and Model 3 can be seen in Table 3. Model 3 produced the least formwork work volume due to the result of beam component dimension efficiency with a little addition on slab for the exterior formwork as the slab thickness is added. On Model 2, the column formwork did not change since the modification is only on the elimination of the joist, in which the joist sticked on the beam and did not stick on the column. Meanwhile, for the beam component, there was a decrease on the joist formwork, along with a little addition due to the decrement of the margin of the overlapping area with the joist. Similar with the slab component there is an addition since the previous lower slab has joist, now the formwork also needs to be put on.

Table 3. Comparison of formwork volume for model 1, model 2 and model 3.

| Structure component | Formwork volume (m²) |
|---------------------|----------------------|
|                     | Model 1 | Model 2 | Model 3 |
| Columns             | 374.9   | 374.9   | 386.7   |
| Beams               | 608.5   | 509.2   | 478.9   |
| Slabs               | 1095.6  | 1132.9  | 1105.8  |
| Total               | 2079.0  | 2017.0  | 1971.4  |

3.4. Structure construction cost analysis

According to Government Regulation PU No.11 year 2013 article 1 [12], it is explained that the unit work price analysis is the calculation of the work force cost need, material and equipment to earn per unit price for one type of work. Each item of the construction work has Work Unit Price (WUP); each one is in accordance with the work force need, material, and also the equipment and its coefficient. The Number of Work Unit Price of all of the work related to this research is obtained from the Government Regulation PUPR number 28 year 2016 [13], while the material price and the work force wage are obtained from the Construction Price Journal 38th Edition year 2019 [14].

It is concluded that the most economical building from the building structure construction cost is Model 2. Model 2 turned out to be the cheapest among other models. This is because Model 2 got modification such as elimination on all the joists. Therefore, when it is compared to Model 1, there will be a margin of 11.7% cheaper than Model 1. Whereas Model 3 generate more expensive structure construction cost from Model 1, about 26.9% more expensive than Model 1.

In conclusion, Model 2 is the most efficient design alternative overall in dimension and structure design. Thus, generating the most economical structure construction cost.
4. Conclusion
From the research study above, it can be concluded that:

- Model 1 is the existing model or control model as the comparison base.
- Model 2 had modification on the building structure design such as the elimination of all joists without the alteration of the building dimension. The design efficiency influencing the efficiency of the building structure cost. Thus, it becomes the most economical model.
- Model 3 had modification of the building structure component dimension without alteration on the building design. The main modification is on the addition of slab thickness by reducing the dimension of some beams. However, there are few adjustments on Model 3 in order to produce a safe building, such as few columns dimension addition. In other words, there are dimension alteration on the column, beam or slab component. However, on this model, there is no dimension efficiency resulted which generate a cheaper structure construction cost compared to Model 1.

From all of the models, Model 2 is the most economical modification model and resulting a building structure construction cost which is cheaper 11.7% from the existing model (Model 1) by eliminating the use of joists.

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References
[1] Ritz G J 1994 Total Construction Project Management
[2] Setiawan E, Mungok C D and Budi G S 2015 Studi Penggunaan Balok Anak pada Struktur Pelat Beton Bertulang Jurnal Teknik Sipil Universitas Tanjungpura
[3] Frederika A, Wiranata A A and Larasati K R 2014 Perbandingan Biaya dan Waktu Pelaksanaan Pekerjaan Balok Struktur Beton antara Metode Konvensional dengan Precast Jurnal Ilmiah Teknik Sipil 18(2) pp 122 – 129
[4] Ervianto D, Indryani R and Wahyuni E 2012 Studi Perbandingan Pelat Konvensional, Ribslab dan Flatslab berdasarkan Biaya Konstruksi Jurnal Teknik Pomits 1(1) pp 1- 5
[5] Mubarak M, Abdullah A, Azmeri A and Hayati Y 2019 Cost Estimation of Structural Components of a Building by Considering the Seismic Load on Different Regions Advances in Civil Engineering 2019(1a) pp 1-8
[6] Belnia S, Lesniak A, Plebankiewicz E and Zima K 2013 The Influence of the Building Shape on the Costs of its Construction Journal of Financial Management of Property and Construction 18(1) pp 90 – 102
[7] Ruuska A and Hakkinen T 2014 Material Efficiency of Building Construction Buildings 4(3) pp 266 – 294
[8] Pflug J, Vangrimde B and Verpoest I 2003 Material Efficiency and Cost Effectiveness of Sandwich Materials 48 pp 1925-1937.
[9] Wille K and Boisvert-Cotulio C 2015 Material Efficiency in the Design of Ultra-High Performance Concrete Construction and Building Materials 86 pp 33 - 43
[10] Jarkas A M 2010 Analysis and Measurement of Buildability Factors Affecting Edge Formwork Journal of Engineering Science and Technology Review 3(1) pp 142 – 150
[11] Pawar S P and Atterde P 2014 Comparative Analysis of Formwork in Multistory Building International Journal of Research in Engineering and Technology 03 special issue 09 pp 22 – 24.
[12] N. 1. Permen PU PR 2013 Permen PUPR No 11/PRT/M/2013
[13] Permen PU PR No. 28/PRT/M/2016 (Indonesia).
[14] Basari R 2019 Jurnal Harga Satuan Bangunan ed. 38/Konstruksi dan Interios (Indonesia: Pandubangun Persada)