Structural performance of multi-storey building using flat slab and conventional slab to seismic loads (Case study: Faculty building of Sport Science in Universitas Negeri Malang, Indonesia)

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Abstract. Innovations to increase the effective height of storeys in buildings are using a flat slab system. Flat slab system is a slab that is only supported by columns without any supporting beam. By the abstain of beams, designers are able to reduce the storey height and to reduce the structural weight. Other than that, flat slabs offer a more flexible installation of building utilities, simpler reinforcement, and simpler installation of scaffolding and formwork. This study was conducted to analyse the performance of flat slabs when applied to buildings compared with the conventional slabs. The flat slab system is expected to be able to withstand gravity and earthquake loads. The Building of the Faculty of Sport Science, Universitas Negeri Malang, with a total of 7 floors and 1 semi-basement was used as research object. This research was conducted using programme simulation, ETABS and SAP2000. The research was intended to analyse the resulting seismic base shear, the fundamental period, the structural stiffness, the ultimate performance evaluation, and the storey drift if the building designed using flat slab system. Results showed that (1) Building with flat slab system has a lighter weight than the one with conventional slab system. Building weight affects the seismic base shear value of the building. The heavier a building is, the greater the seismic base shear value of a building; (2) The fundamental period analysis resulted the structural vibration time (Tc) in flat slab structure is greater than in the conventional slabs. The heavier the building weight, the structural vibration time (Tc) that occurs will be smaller; (3) The structural stiffness of building using flat slab system is less than in the conventional slabs system; (4) Both of building using flat slab system and conventional slabs meet the requirement of service performance and ultimate performance; and (5) The storey drift in building using flat slab system is larger than in the conventional slabs. This is due to the conventional slab structure has a greater stiffness than flat slab structure.

1. Introduction
The slab is a structural component in a building that functions to withstand the load transversely through bending action to each support. There are several types of slab construction systems, some of which are flat slabs and conventional slabs. The conventional slab is a slab supported with beams and columns and widely used in construction. Columns on conventional slabs function as elements that carry the load to the foundation, while the beam functions as a horizontal reinforcement framework of the loads.
However, the presence of beams in conventional slab systems will reduce the effective height of storeys in buildings [1-3].

Innovations to increase the effective height of storeys in buildings are using a flat slab system. Flat slab system is a slab that is only supported by columns without any supporting beam. The load from the slabs will be distributed directly to the supporting columns [4]. Flat slabs are often used in offices, residences, or other industrial facilities with medium height (medium-rise office) because of the efficiency of the span or thickness ratio; and economic aspects because it reduces floor height [5]. By the abstain of beams, designers are able to reduce the storey height and to reduce the structural weight. Other than that, flat slabs offer a more flexible installation of building utilities, simpler reinforcement, and simpler installation of scaffolding and formwork. However, due to the absence of beams, it reduces the ability of column-slab in holding the shear force that can cause a horizontal spread of damage and cause the slab to collapse (punching shear) [6-8]. It agrees with previous research findings stating that the behaviour of the flat slab structure is proven to be able to withstand the gravity load, but it is weak in accepting lateral loads [9-10].

Research shows that flat slab is still rarely used in buildings. This is because the plates in the flat slab system are thicker than the plates in conventional slab systems [2-3]. Therefore, this study was conducted to analyse the performance of flat slabs when applied to buildings. The flat slab system is expected to be able to withstand gravity and earthquake loads, like a diaphragm structure, thereby reducing structural failure.

Therefore, the Building of the Faculty of Sport Science, Universitas Negeri Malang is a tall building with a total of 7 floors and 1 semi-basement. In the current design, it uses conventional reinforced concrete slabs. With all these considerations, this building will be used as research object. The researchers intended to analyse the resulting seismic base shear, fundamental period, structural stiffness, ultimate performance threshold, storey drift if the building designed using flat slab system. The building is modelled using ETABS and SAP2000 with accommodating Indonesian code as provision (SNI 1727:2013; Peraturan Pembebanan Indonesia; SNI 1726:2012).

2. Research methodology

![Building structure using conventional slabs](image)

**Figure 1.** Building structure using conventional slabs

This research was conducted using programme simulation, ETABS. The research method was initiated with the literature review, defining design criteria, structural modelling, data analysis, and drawing
conclusion. The steps of building modelling in ETABS was begun with defining provision, material input, element properties, creating structures, defining working loads, and analysing the model.

Faculty building of Sport Science Universitas Negeri Malang consists of 7 storeys with a typical height of 4 metres. The building is designed for teaching purpose. All of the building members is designed with 30 MPa concrete strength and 400 MPa of steel strength. The building structure designed with conventional slabs are shown in Figure 1; meanwhile the building structure designed with flat slabs are shown in Figure 2.

![Building structure using flat slabs](image)

The earthquake load on this building structure is designed based on SNI 1726: 2012. The building is located in Malang, Indonesia. The earthquake analysis is approached with response spectrum analysis. The soil mechanics data and earthquake acceleration data are approached using data in the Malang area. The slabs are considered as a rigid diaphragm.

### 3. Results and discussion

#### 3.1. Seismic base shear

The result of seismic base shear of building using conventional slab and flat slab system is shown in Table 1. Building with flat slab system has a lighter weight than the one with the conventional slab system. The conventional slab system is 12% heavier than the flat slab. This is because the flat slab system does not use beams. Building weight affects the seismic base shear value of the building. The heavier a building is the greater the seismic base shear value of a building.

| Slab system  | Building weight (kg) | \( 85%V_{\text{static}} \) (kg) | \( V_{\text{dynamic}} \) \( X \) (kg) | \( V_{\text{dynamic}} \) \( Y \) (kg) |
|--------------|----------------------|-------------------------------|---------------------------------|---------------------------------|
| Conventional slab | 10 084 090           | 903.219                       | 3 705.061                       | 2 111.518                       |
| Flat slab    | 8 914 885            | 795.654                       | 2 352.817                       | 1 375.845                       |
The dynamic response of the building structure must not be less than 85% of the static shear force of the structure. The x-direction of dynamic shear force on conventional slabs is 35% larger than the flat slab, while the y-direction dynamic shear force on conventional slabs is 33% greater than the flat slab. These findings agree with More's research stating the results of the dynamic base shear values in the x and y directions of conventional slab systems larger than flat slab structures. More [11] also stated that the increase in the basic shear force with changes in building weight is crucial.

3.2. Fundamental period
The fundamental period of the building using conventional slab and flat slab system is shown in Table 2. The maximum period of a structure is influenced by the height of the building, the type of structure, and the earthquake spectral acceleration, while the vibrational time of the structure is influenced by the elevation and weight of the building. Basically, the vibrational period of the structure is strongly influenced by mass and stiffness.

Table 2. The fundamental period of building using conventional slab and flat slab system

| Slab system     | Tmax (seconds) | Tc (seconds) |
|-----------------|----------------|--------------|
| Conventional slab | 13.511         | 1.669        |
| Flat slab       | 13.511         | 5.168        |

The fundamental period analysis resulted in the structural vibration time (Tc) on the conventional slabs equal to 1.669 seconds, 67% smaller than on the flat slab system that is equal to 5.168 seconds. This is caused by the weight of the building on the conventional slabs system is greater than the weight of the flat slab. The heavier the building weight, the structural vibration time (Tc) that occurs will be smaller. The structure vibration time (Tc) must not exceed the maximum structure vibration time (Tmax). If structural vibration time exceeds the maximum vibration time of the structure (Tmax), there will be a resonance in the building, and if there is a resonance the building will collapse. A building using a flat slab system has a greater vibration time than a building using a conventional plate structure.

3.3. Structural stiffness
The structural stiffness of building using conventional slab and flat slab system is shown in Table 3.

Table 3. The structural stiffness of building using conventional slab and flat slab system

| Storey level | X-direction | Y-direction |
|--------------|-------------|-------------|
|              | Conventional slab | Flat slab | Ratio | Conventional slab | Flat slab | Ratio |
|              | N/mm        | N/mm        |       | N/mm        | N/mm        |       |
| (1)          | (2)         | (3)         | (4)   | (5)         | (6)         | (7)   |
| 7            | 803.827     | 69.404      | 12x   | 755.933     | 74.019      | 10x   |
| 6            | 957.923     | 81.308      | 12x   | 923.550     | 105.150     | 9x    |
| 5            | 995.167     | 84.344      | 12x   | 958.469     | 109.300     | 9x    |
| 4            | 1.014.538   | 90.227      | 11x   | 980.176     | 113.393     | 9x    |
| 3            | 996.631     | 93.051      | 11x   | 984.357     | 136.915     | 7x    |
| 2            | 622.190     | 86.546      | 7x    | 677.081     | 140.400     | 5x    |
| 1            | 2.107.832   | 260.842     | 8x    | 2.255.716   | 426.199     | 5x    |

The average floor stiffness from 1st to 7th level in the x-direction of conventional slab system is 10 times greater compared to the flat slab system, whereas in the y-direction the conventional slab system
is 8 times larger compared to the flat slab. This is because the conventional slab has a greater weight than the flat slab. Beams in conventional slabs have a big influence on structural stiffness. In the calculation of structural stiffness, it requires data of column stiffness and beam stiffness. In a flat slab system, the plate replaces the role of the beam. The stiffness of the x-direction and y-direction in both conventional and flat slab has significant differences. This is because the configuration of different dimensions between columns. The buildings using conventional slab system have a greater stiffness than buildings using flat slab. He also stated that the stiffness is influenced by the weight of the building and the configuration of the structure.

3.4. Ultimate performance limit
The performance evaluation to service performance limit and ultimate performance limit of building using conventional slab and flat slab system is shown in Table 4 and Table 5.

**Table 4. Performance evaluation to service performance limit**

| Slab system    | Top displacement (mm) | Service performance limit (mm) |
|----------------|-----------------------|--------------------------------|
| Conventional slab | 3.138                 | 15                             |
| Flat slab       | 4.263                 | 15                             |

The top displacement of the conventional slab is 28% smaller than the flat slab. This is because the conventional slab has a greater weight than the flat slab. The great building weight causes large structural stiffness and small structural vibrational time (Tc). If the structural vibration time (Tc) is small, the displacement that occurs is small. Based on the results of the analysis, the performance in service stage is still safe both in conventional slabs and in the flat slabs.

**Table 5. Performance evaluation to the ultimate performance limit**

| Slab system  | 0,02h (mm) | Ultimate performance limit (mm) |
|--------------|------------|--------------------------------|
| Conventional slab | 80.00      | 16.453                          |
| Flat slab     | 80.00      | 25.553                          |

Based on Table 5, the performance of building in the ultimate limit on the conventional slabs is 36% smaller than in the flat slab. This is because the top displacement on conventional building is smaller than the displacement value of the flat slab structure. The function of the ultimate limit performance is to find out the maximum drift of structures.

3.5. Storey drift
The storey drift of building using conventional slab and flat slab system is shown in Table 6. The storey drift in the conventional building is 56% smaller than in the building using flat slab. This is due to the conventional slab structure has a greater stiffness than flat slab structure. The stiffness is inversely proportional to the value of the storey drift. The occurring storey drift does not exceed the limit, indicating that the structural performance per storey is still safe.

The graph representing the relationship of drift on each storey level is shown in Figure 3. Figure 3 shows that building with the conventional slab and the flat slab exhibits a significant increase in the 4th to 7th storey. It is due to the structural stiffness of the upper floor decreased significantly. This finding agreed with Mohana [12] which stated that buildings using conventional slab structures have smaller floor deviations than buildings using flat slab.
Table 6. Storey drift of building using conventional slab and flat slab system

| Storey level | h (mm) | Δ flat slab (mm) | Δ conventional slab (mm) | (0.03/R)*h (mm) |
|--------------|--------|-----------------|--------------------------|-----------------|
| 7            | 4000   | 14.631          | 11.506                   | 15              |
| 6            | 4000   | 12.511          | 9.658                    | 15              |
| 5            | 4000   | 10.010          | 7.025                    | 15              |
| 4            | 4000   | 6.879           | 4.961                    | 15              |
| 3            | 4000   | 5.269           | 2.658                    | 15              |
| 2            | 5500   | 3.197           | 1.599                    | 15              |
| 1            | 3500   | 1.478           | 0.961                    | 15              |

Figure 3. Storey drift of building using conventional slab and flat slab system

4. Conclusion

- Building with flat slab system has a lighter weight than the one with the conventional slab system. Building weight affects the seismic base shear value of the building. The heavier a building is the greater the seismic base shear value of a building.
- The fundamental period analysis resulted in the structural vibration time \((T_c)\) in flat slab structure is greater than in the conventional slabs. The heavier the building weight, the structural vibration time \((T_c)\) that occurs will be smaller.
- The structural stiffness of building using flat slab system is less than in the conventional slabs system.
- Both of building using flat slab system and conventional slabs meet the requirement of service performance and ultimate performance.
- The storey drifts in the building using a flat slab system are larger than in the conventional slabs. This is due to the conventional slab structure has a greater stiffness than flat slab structure.

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