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NUMERICAL ANALYSIS OF CONCRETE-FLY ASH AND CONCRETE-OPC IN MULTI-STOREY BUILDINGS DURING EARTHQUAKES

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ABSTRACT

OPC-concrete is the most commonly used type of concrete. The production of OPC produces CO2 emissions, which is one of the main causes of climate change and global warming. A recent innovation used as a high-strength concrete admixture is fly ash. Earthquakes pose a serious threat to the safety and stability of high-rise buildings. This study uses a finite difference method computational approach to analyze the seismic behavior of multi-storey buildings using fly ash concrete and opc concrete by utilizing data on stiffness, mass, damping, and earthquake acceleration. Based on the simulation results, the mode shape graphs of fly ash concrete and opc concrete are similar but the vibration frequencies of both are different, where the frequency of fly ash concrete is higher than the frequency of opc concrete. The displacements of the buildings with fly ash concrete and opc concrete still meet the applicable deviation allowance, where the maximum displacements of the buildings are 0.00308 m and 0.00342 m, respectively, while the maximum shear force of both buildings occurs on the first floor, which is 5967.59 N and 5104.78 N, respectively.

Kata Kunci: Earthquake, Ordinary Portland Cement, Fly Ash, Finite Difference Method, Sway Pattern, Displacement, Shear Force

INTRODUCTION

The construction of high-rise buildings is currently a priority for various parties, especially the government and the private sector, because the available land in big cities is very limited due to rapid population growth. Along with the increase in population density, various types of high-rise buildings are built, ranging from low height to skyscrapers. In designing high-rise buildings, one of the key factors that must be considered is earthquakes, as shocks caused by earthquakes can damage building structures. The taller the building, the higher the risk of earthquakes. Earthquakes are a natural phenomenon that often occurs in Indonesia and can cause damage to building structures, including a decrease in stiffness and strength (Wahyuningtyas et al., 2020)

The structural response of a building to an earthquake is strongly influenced by the concrete materials used in the construction of building. OPC (ordinary portland cement) concrete is the most common concrete used in construction in Indonesia, but the production of CO_2 produced by OPC concrete causes climate change and global warming. One of the latest innovations used as a high-strength concrete mix is fly . Fly ash is one of the by-products produced from the coal combustion process, which is flowed from the combustion chamber through the boiler as a smoke jet, and then used as a mixture in the manufacture of concrete (Sultan et al., 2019). So this research will compare fly ash concrete with opc concrete to see how the seismic behavior of multi-storey buildings using these materials.

This research uses a finite difference method numerical approach to connect the concept of earthquakes with vibrations. This numerical approach will display the seismic behavior of multi-storey buildings against earthquakes in the form of sway patterns, displacement and the amount of shear force experienced by multi-storey buildings.

Previous research from Nasution & Purqon (2016) entitled "Response Test of Multi-storey Building Structures to Earthquakes Using the Finite Element Method" states that the increasing value of the mass parameter (mass variation) at various levels has an impact on the behavior of multi-storey buildings during an earthquake, seen from the frequency of the building structure, the displacement of each level, and the amount of shear force at each level of the . Nasution (2021) conducted further research entitled "Analysis of the Effect of Mass on Multi-storey Building Structures During Earthquakes Using the Finite Element Method". The results of the study are that there is no extreme sway pattern at each level, then buildings that have similar masses at each level tend to experience more stable movements, and the largest shear force occurs at the first level.

Referring to this background, the researcher's interest was triggered to conduct a study on "Numerical Analysis of Concrete- Fly Ash and Concrete-Opc in Multi-Story Buildings During Earthquakes".

RESEARCH METHOD

Modeling Physis

The building structure model used in this study is a damped forced vibration model with n degrees of freedom and uses the concept of beam element and takes an 8- story building as the building structure that is the focus of the research, and uses data on stiffness (k_1 ,k_2 ,k_3 ,..., k_n), mass (m_1, m_2, m_3 ,...,m_n) and damping (c_1 ,c_2 ,c_3 ,...,c_n) at each level of the building. This condition is shown in Figure 1.

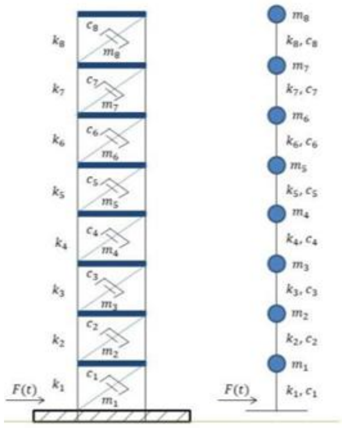

Figure 1. 8-story building structure model

Mathematical Model

One method used to describe the equation of motion of a mass is to use the d'Alembert principle approach, which is based on Newton's Law II (Respati, 2001). By using the d'Alembert principle, the equation of motion of the system can be expressed as follows (Indarto, 2005):

$$F_1+F_D+F_S=F_{(t)} \quad (1)$$

Where the inertial force (F1) is the product of mass (m) and acceleration ($\ddot{x}$), the damping force (F_D) which affects the damping ratio (c) and velocity (x), and the spring force (F_S) which affects the stiffness (k) and displacement (x). So from the above statement, equation (1) can be written as:

$$m\ddot{x} + c\dot{x} + kx = F(t) \quad (2)$$

In a building structure subjected to seismic shaking with an acceleration time history x g̈ basically, the applied external load is proportional to the mass and can be calculated as follows (B. Nasution, et al., 2023):

$$F(t) = -m\ddot{x}_g(t) \quad (3)$$

So the equation of motion due to an earthquake is written as follows:

$$m\ddot{x} + c\dot{x} + kx = -m\ddot{x}_g(t) \quad (4)$$

According to Panagiotis (2021), in the difference method, the first and second derivatives in the equations of motion are approximated as:

$$\{\dot{x}\}_t = \frac{1}{2\Delta t}(\{x\}_{i+1} - \{x\}_{i-1}) \quad (5)$$

$$\{\ddot{x}\}_t = \frac{1}{\Delta t^2}(\{x\}_{i+1} - 2\{x\}_i + \{x\}_{i-1}) \quad (6)$$

which is the approximate derivative of the vector xiby the center difference method, then substitute equations (5) and (6) into equation (4):

$$\left(\frac{1}{\Delta t^2}[m] + \frac{1}{2\Delta t}[c]\right)\{x\}_{i+1} = (-m\ddot{x}_g) - \left([k] - \frac{2}{\Delta t^2}[m]\right)x_i - \left(\frac{1}{\Delta t^2}[m] + \frac{1}{2\Delta t}[c]\right)\{x\}_{i-1} \quad (7)$$

Furthermore, using the finite difference method algorithm and the help of Matlab software, we can obtain the value of $x_{(i)}$ (D. A. Nasution, 2022).

Numerical Calculation

Numerical calculations are performed according to the flowchart below.

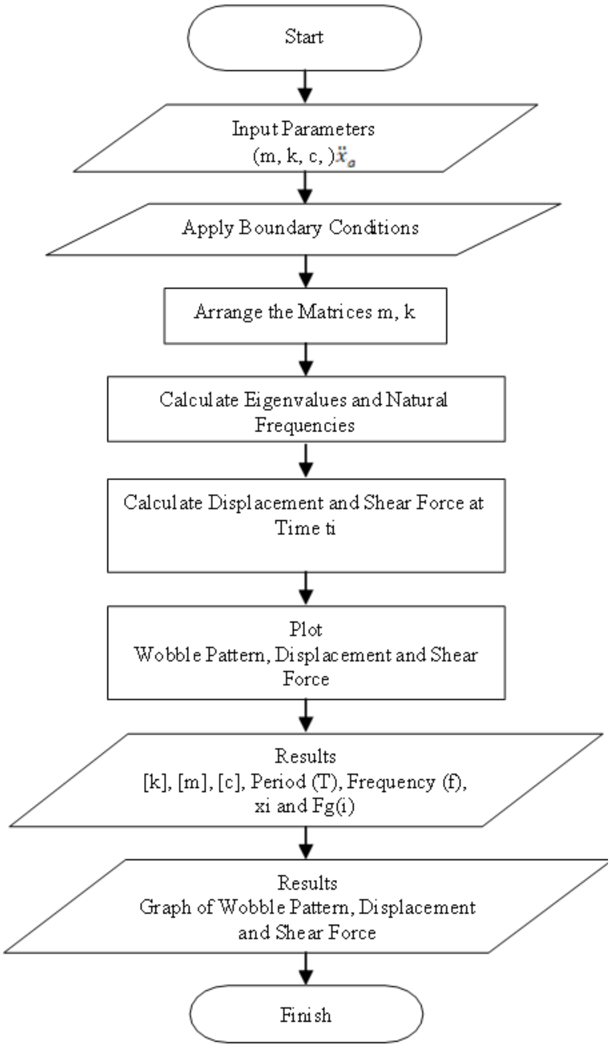

Figure 2. Flowchart of numerical calculation

Data

The building load data used refers to previous research conducted by Wibawa, (2018). The dead load data in the study amounted to 7,417 kg and live load of 1,198 kg. Then the total dead load and live load is 8,615 kg.

Table 1. Physical parameter data of fly ash-concrete

Floor	m (kg)	k (N/m)	c
1	8615	10,2 x 10^6	0,45
2	8615	10,2 x 10^6	0,45
3	8615	10,2 x 10^6	0,45
4	8615	10,2 x 10^6	0,45
5	8615	10,2 x 10^6	0,45
6	8615	10,2 x 10^6	0,45
7	8615	10,2 x 10^6	0,45
8	8615	10,2 x 10^6	0,45

Table 2: Physical parameter data of 100% opc concrete

Floor	m (kg)	k (N/m)	c
1	8615	7,8 x 10^6	0,45
2	8615	7,8 x 10^6	0,45
3	8615	7,8 x 10^6	0,45
4	8615	7,8 x 10^6	0,45
5	8615	7,8 x 10^6	0,45
6	8615	7,8 x 10^6	0,45
7	8615	7,8 x 10^6	0,45
8	8615	7,8 x 10^6	0,45

The earthquake data used in this study is the Denali, Alaska earthquake (March 11, 2002) with a magnitude of 7.9.

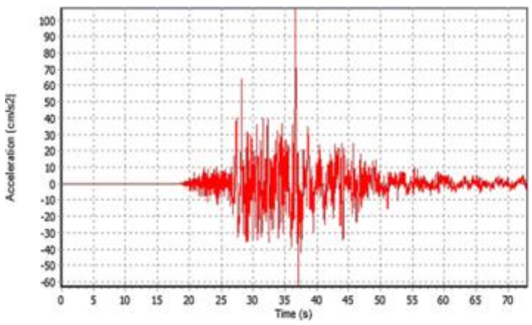

Figure 3. Accelerogram of the Denali, Alaska earthquake (2002)

RESULT AND DISCUSSION

Results

Wobble Pattern (Mode Shape)

The mode shape graph provides an overview of the swaying pattern of the 8-storey building structure using concrete-fly ash and concrete-opc during an earthquake. The following are the results of the mode *shape* graph of the 8-storey building with the use of *concrete-fly ash* and concrete-opc:

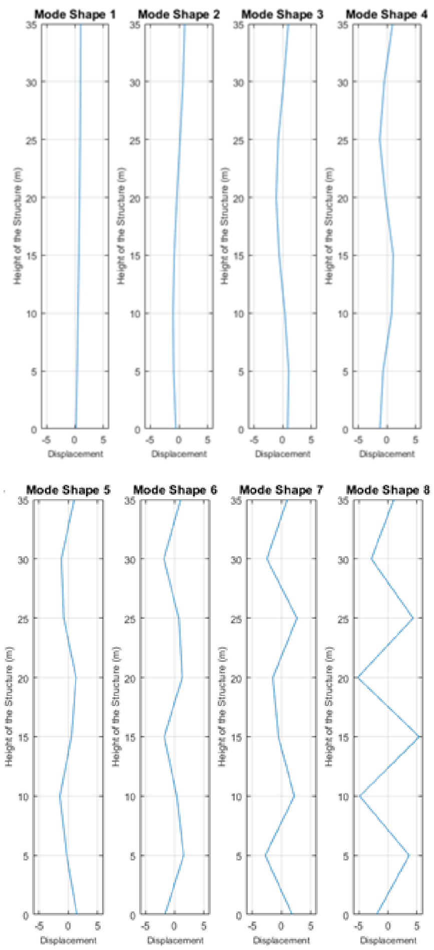

Figure 4. Sway pattern of 8-storey building using fly ash concrete

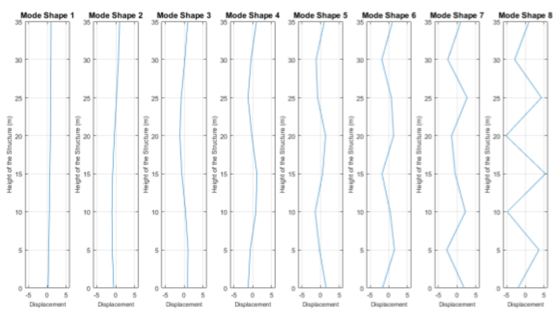

Figure 5. Sway pattern of 8-storey building using concrete-OPC

Based on the simulation results in Figure 4 and Figure 5, it can be seen that the 8-storey building structure with concrete-fly ash and concrete-opc has similar mode shapes and it can be seen that the most likely building structure to be destroyed occurs in the 8th mode shape, which is in accordance with the frequency generated from the simulation. In the 8-storey building, there are differences in each mode shape. Each mode shape has a different frequency and period and causes the building to vibrate with a distinctive pattern. The first mode shape is generally the main vibration mode or dominant vibration mode which has the lowest natural frequency. Subsequent mode shapes have higher natural frequencies.

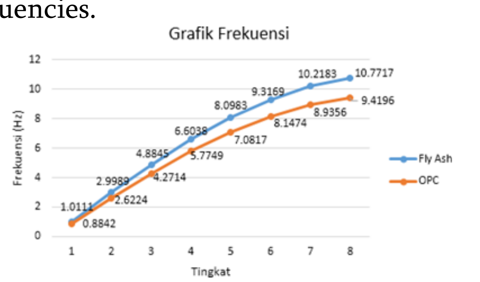

Figure 6. Vibration frequency graph of multi-storey building with fly ash concrete and opc concrete

The simulation results in Figure 6 show that the highest frequency occurs at mode shape 8 and the lowest frequency occurs at mode shape 1 for both materials used, namely *concrete-fly ash* and concrete-opc. The higher the building, the higher the frequency of the building. This is consistent with the results of research conducted by Nasution (2021) which shows that the highest building vibration frequency occurs at mode shape 8 and the lowest frequency occurs at mode shape 1. The maximum frequency of fly ash- concrete greater than that of opc-concrete.

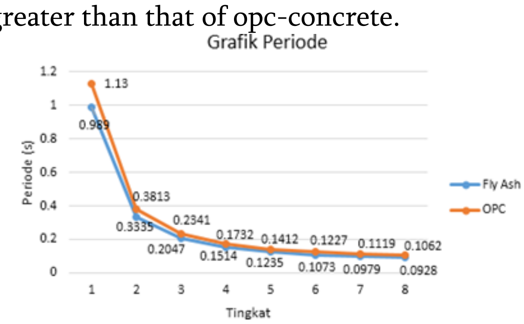

Figure 7: Vibration period graph of multi-storey building with fly ash concrete and concrete-opc

Figure 7 shows that the highest vibration period of the multi-storey building structure occurs in mode shape 1 and the lowest period occurs in mode shape 8. Based on SNI-1726:2019 the building structure is said to be non-rigid or flexible if the period of each floor is greater than 0.06 seconds. From the research results, it can be seen that all eight levels tested with fly ash concrete and opc concrete show periods greater than the existing SNI. Buildings that have a higher degree of flexibility or are less rigid tend to be more resistant to earthquakes than buildings that are too rigid. This is because buildings that are very rigid have limitations in resisting changes in shape (Riyanto & Andriany, 2001).

Displacement

When an earthquake occurs, an 8-story building structure will experience displacement. This is caused by seismic forces generated by earthquake vibrations and interacting with the building structure.

This study used the acceleration of the Denali, Alaska earthquake that lasted for 72 seconds. The following graph presents the maximum displacement of the 8-story building due to the Denali, Alaska earthquake with fly ash concrete:

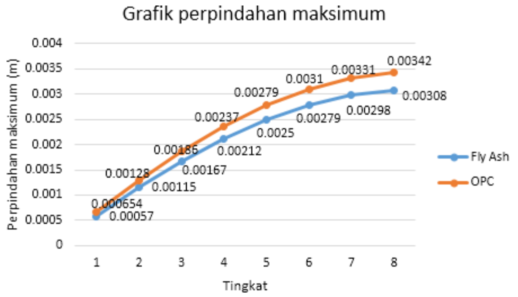

Figure 8. Maximum displacement of each building level with concrete-fly ash and concrete-opc

Based on the simulation results in Figure 8, the building with fly ash concrete shows that the largest maximum displacement is at level 8, which is 0.00308 m and the smallest maximum displacement occurs at level 1, which is 0.00057 m. While the maximum displacement in the building with concrete-opc shows that the largest maximum displacement also occurs on the 8th floor which is 0.00342 m and the smallest maximum displacement occurs at level 1 which is 0.000654 m. The results show that in both concrete-fly ash and concrete-opc buildings, the displacement increases with the height of the building. This is in accordance with research conducted by B. Nasution, et al. (2023) that the higher the building, the greater the displacement due to the earthquake, this occurs because the lower floors of the building are more solid due to the foundation so that the displacement is smaller than the upper floors which are more free so that they are easy to shift or move. Calculation of the deviation clearance limit shows that the concrete-fly ash and concrete- opc structures studied still meet the applicable deviation clearance in each category, where the maximum displacement limit of the concrete-fly ash is 0.00308 m and the maximum displacement limit of the concrete- opc is 0.00342 m.

Shear Force

During an earthquake, a building structure is subjected to seismic forces that cause displacement and deformation of building. Shear force is one of the forces generated by earthquakes and plays an important role in responding to the ground motion that occurs.

The following is a graph of the building-level shear force with fly ash concrete due to the Denali, Alaska earthquake versus time:

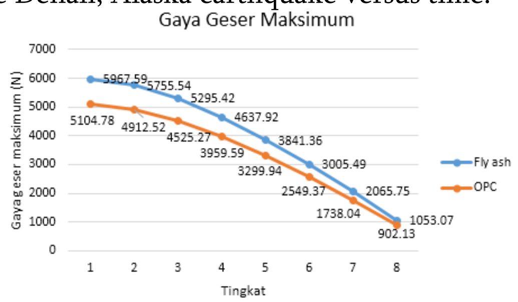

Figure 9. Maximum shear force of each building level with concrete-fly ash and concrete-opc

Based on Figure 9, it is obtained that the maximum shear force of the building with fly ash concrete is the largest on the 1st floor at 5967.59 N and the smallest shear force occurs at level 8 at 1053.07 N. While the maximum shear force of the building with opc concrete is the largest on the 1st floor at 5104.78 N and the smallest shear force occurs at level 8 at 902.13 N. The data obtained shows that the higher the level of the building, the lower the shear force will be during an earthquake, both buildings with fly ash concrete and buildings with opc concrete. This is because when an earthquake occurs, the shear force acting on the building is proportional to the acceleration of ground vibrations. However, the higher the building level, the smaller the ground vibration acceleration felt at that level so that the shear force will be lower. Research conducted by B. Nasution, et al. (2023) revealed that the largest shear force occurs at the first level, this is due to the ground floor being the most affected by the earthquake acceleration, as the ground floor of the building is directly connected to the ground. addition, the maximum level shear force occurs at lower floors because the shear force from the floor above will be resisted by the floor below. The largest level shear force occurs at the lower floors because the increase in displacement or displacement at the lower floors is smaller, while the increase in displacement or displacement at the upper floors is smaller, which causes the shear force at the upper floors to be small.

CONCLUSION AND SUGGESTION

The highest frequency occurs at mode shape 8 and the lowest frequency occurs at mode shape 1 for both structures used, namely concrete-fly ash and concrete-opc. The maximum frequency of the buildings with concrete-fly ash and concrete-opc occurred at mode shape 8, which was 10.7717 Hz and 9.4146 Hz, respectively. Buildings with concrete-fly ash and concrete-opc are buildings that are not too rigid (flexible) because the vibration period that occurs meets SNI, which is greater than 0.06 seconds. Buildings with fly ash concrete experience smaller displacements than buildings with opc-concrete. The maximum displacement of the building with fly ash concrete is 0.00308 m, while that of opc concrete is 0.00342. The maximum shear force of the building with fly ash concrete occurred at the 1st floor of 5967.59 N and the smallest shear force occurred at the 8th level of 1053.07 N, while the maximum shear force of the building with opc concrete occurred at the 1st floor of 5104.78 N and the smallest shear force occurred at the 8th level of 902.13 N. This condition shows that the higher the level of the building, the lower the shear force during an earthquake.

It is necessary to conduct further research on the seismic behavior of multi-storey buildings by comparing two materials that have large differences in stiffness and using two different earthquake data to see more clearly the response of building structures and investigate more deeply about which materials are good to use as concrete mixtures during earthquakes.

REFERENCES

Aji, G. D., Budi, A. S., & Saifullah, H. A. (2019). Kapasitas Geser Balok Beton Bertulang Hvfa Memadat Sendiri Dengan Kadar Fly Ash 50% Terhadap Beton Normal. Matriks Teknik Sipil, 7(4), 387–394.

BSN. (2019). SNI 1726:2019, Tata cara perencanaan ketahanan gempa untuk struktur bangunan gedung dan nongedung. Jakarta: Badan Standarisasi Nasional.

Indarto, H. (2005). Buku Ajar Mekanika Getaran dan Rekayasa Gempa. Semarang: Jurusan Teknik Sipil, Universitas Diponegoro.

Ivan, L., & Leo, D. E. (2019). Analisis Dinamik Perilaku Gedung Dengan Ketidak-beraturan Massa Pada Masing-Masing Tingkat Terhadap Beban Gempa. Jurnal Mitra Teknik Sipil, 2(3), 245–254.

Nasution, B. (2021). Analisis Pengaruh Massa Pada Struktur Bangunan Bertingkat Pada Saat Gempa Bumi Menggunakan Metode Elemen Hingga. Jurnal Hasil Penelitian Bidang Fisika, 9(1), 53–58.

Nasution, B., & Purqon, A. (2016). Uji Respon Struktur Bangunan Bertingkat Terhadap Gempa Bumi Menggunakan Metode Elemen Hingga. Prosiding SNIPS, 150–158.

Nasution, B., Amdani, K., Kadri, M., Nasution, H. A., Sari, S. D., Barus, E. L. B., Nst, D. A., Suryani, L., & Afala, I. (2023). Numerical Test of the Use of CO2 in Multy Storey Building Structures During an Earthquake. Advances in Science and Technology, 126, 18–26.

Nasution, B., Nasution, H. A., Amdani, K., Kadri, M., Sari, S. D., Barus, E. L. B., Nst, D. A., Suryani, L., & Afala, I. (2023). Simulation of the Response of Multi-Story Buildings with Concrete-Silica Fume and Concrete-Liquid Carbon Dioxide. Science and Technology Applications, 126, 3–17.

Nasution, D. A. (2022). Simulasi Respon Struktur Bangunan Bertingkat Dengan Beton Campuran Nanosilika Terhadap Gempa Bumi Menggunakan Metode Beda Hingga. Skripsi. Medan: Universitas Negeri Medan.

Panagiotis, G. (2021). A machine learning approach to earthquake response analysis of structural systems. Athens: National Technical University of Athens.

Respati, K. D. (2001). Pengaruh Variasi Massa Tingkat Terhadap Simpangan, Gaya Geser Dasar, Dan Momen Guling Pada Bangunan Bertingkat 5 Akibat Riwayat Waktu Goyangan Gempa El Centro. Skripsi. Yogyakarta: Universitas Islam Indonesia.

Riyanto, S., & Andriany, H. (2001). Analisis Pemahaman Tukang Bangunan Terhadap Bangunan Sederhana Tahan Gempa Dan Pelaksanaan Bangunan Sederhana (Studi Kasus Di Empat Kabupaten Di Propinsi Daerah Istimewa Yogyakarta). Thesis. Yogyakarta: Universitas Islam Indonesia.

Sultan, M. A., Imran, I., & Faujan, M. (2019). Pengaruh Penambahan Limbah Pembakaran Batubara (Fly Ash) Ex PLTU Rum Pada Campuran Beton. Teras Jurnal, 9(2), 83.

Wahyuningtyas, W. T., Krisnamurti, K., & Afrida, I. (2020). Analisis Ketahanan Gedung Apartemen Surabaya dengan Menggunakan Metode Respon Spektrum (Performance Analysis of Surabaya Apartment Using Response Spectrum Method). Berkala Sainstek, 8(4), 132–139.

Wibawa, I. A. (2018). Modifikasi Struktur Gedung Perkuliahan 8 Lantai Di Surabaya Menggunakan Dual System. Skripsi. Surabaya: Institut Teknologi Sepuluh November.