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Comparison of Equivalent Static Analysis and Mode Combination Method for Concrete Buildings According to Turkish Standard

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Abstract: This study aims to define the impact of analysis methods that are used to design buildings and offers their analysis. As a matter of fact, there are several methods for fundamental analysis of buildings and other civil engineering structures under seismic situations. Both can be differentiated in the shape of the seismic involvement and in the structure idealization. There are two measures to identify seismic design forces: one is the equivalent static force, and the other is dynamic analysis which can be in many forms. One of these forms is the superposition mode. This research aims to study the impact of these methods in the analysis of a six story concrete building; both results, obtained from the static and dynamic, will be ultimately compared. The results show that in a MDOF system, such as with six floors or more, the dynamic analysis will lead to displacements and smaller forces compared with the static process.

Keywords: *Equivalent earthquake loads, mod combination method, Turkish standard, SAP2000.*

1. Introduction

Structural analysis is mostly related with identifying the reaction of a structure when exposed to certain action. This action could be structure of load due to heaviness of stuff such as folks, storm, and snow or it could be some different type of disaster, such as earthquake. All these masses together are dynamic with the self-weight of the structure. Both the dynamic and static analyses can be distinguished mainly based on whether the applied action has appropriate acceleration compared to the structure's natural frequency or not. If a load is applied slowly, the inertia forces can be disregarded, and the evaluation can be shortened as static analysis. Structural dynamics is a kind of structural analysis which presents the reaction of structures that are exposed to dynamic loading [3].

The essential principle after earthquake analysis of structures is to transform the earthquake dynamic forces acting on the structure to equivalent static forces which can be utilized later on as input data in a static structural analysis to acquire the forces, deformations in the structure, and interior stresses [1].

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The static methods indicated that the building codes depend on a single mode reaction with humble rectifications, containing high-mode effects. Even though it is suitable for simple regular structures, however, simplified procedures are not taking all seismic behavior of sophisticated structures into consideration. Consequently, the most appropriate method for building designing with rare or irregular geometry would be the dynamic analysis. In order to do dynamic analysis, there are two methods to be used: First method is elastic response spectrum analysis which is the ideal method due to the fact that it can be easily used. Second method is elastic or inelastic time history analysis; this method can be used only if it is critical to signify inelastic response features or to include time dependent effects when there is a calculation of the structure's dynamic response. Structures which are built on the ground, extent vertically at a distance above the ground in returning of simple or complex oscillators during seismic ground motions. The simple oscillators are characterized as single degree of freedom systems (SDOF), and complex oscillators are characterized as multi degree of freedom (MDOF) systems. A simple oscillator is characterized as a mass supported by two columns or as a single lump of mass on the upper end of a vertically cantilevered pole, Figure 1 shows the single degree for system of freedom [5].

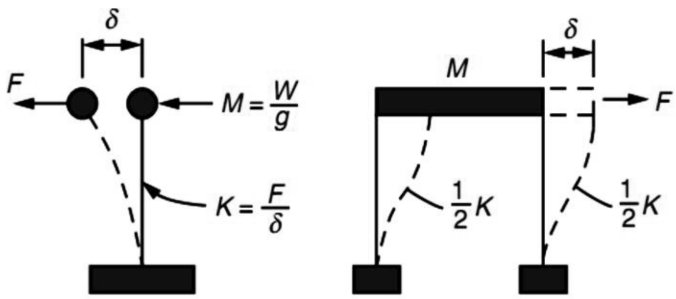

Figure 1: Single degree for system of freedom [5]

2. Implication Example

A 6-story moment resisting reinforced concrete framed building with 5m and 4 bays in both X and Y directions was selected. The plan and elevation of the model is shown in Figures 1 and 2; the building is assumed to have a fixed support at the base. ZB soil type, importance factor I= 1, R=4, D=2.5, the map of spectral accelerations of Turkey S_1 and S_S, found to be 0.243g and 0.87g, respectively (Figure 3), and a 5% damping ratio in accordance with Turkish provisions was selected. After calculating the base shear forces manually by using the equivalent static and mode superposition methods, the structure is modeled using SAP2000 software, then the internal forces such as normal forces, shear forces and bending moments for all members were found.

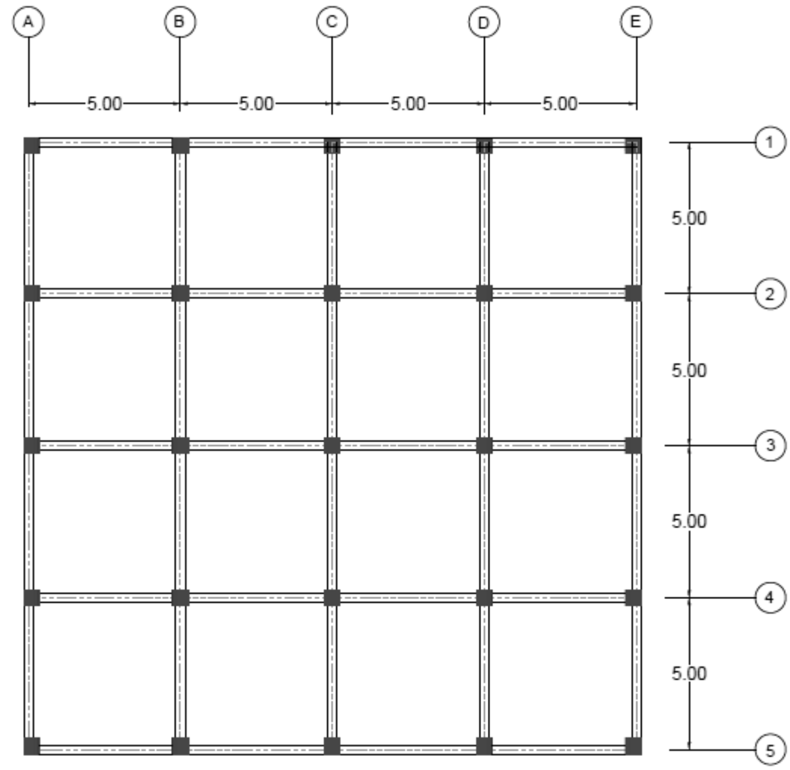

Figure 2: A Plan view of the building with its dimensions

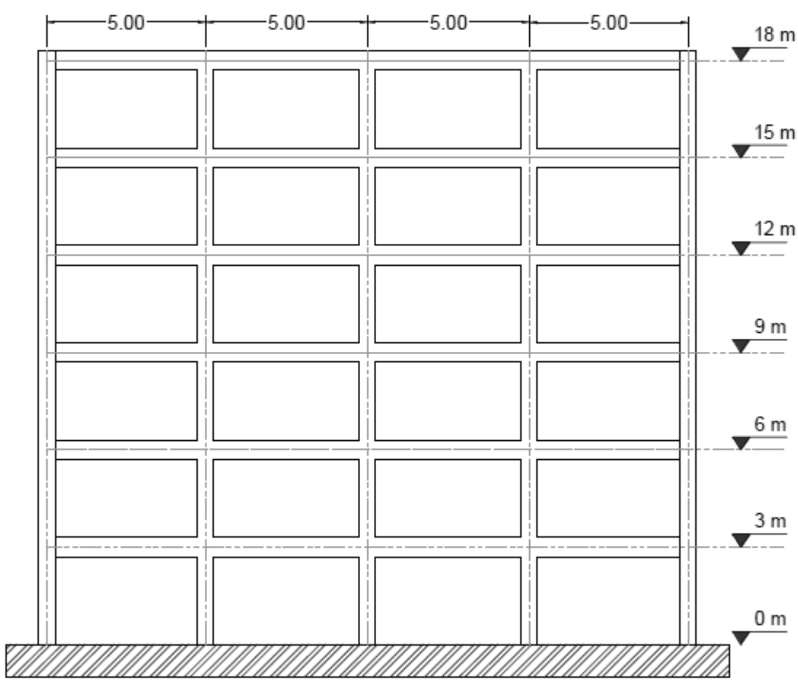

Figure 3: Section view of the building with its elevations

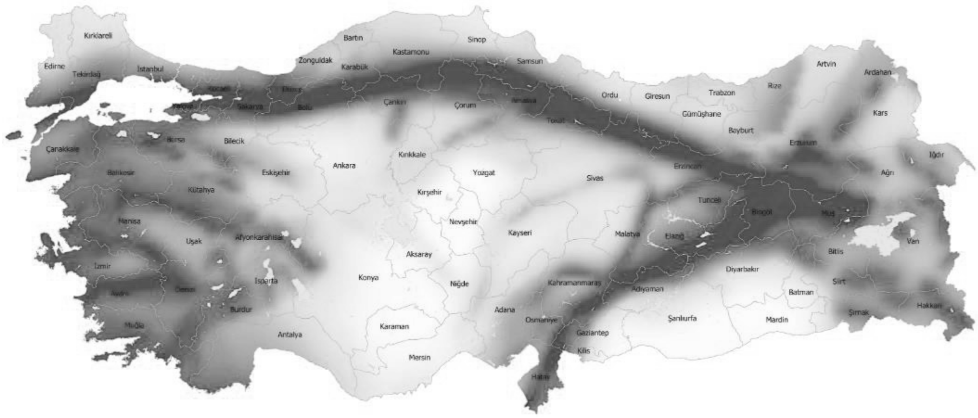

Figure 4: Earthquake map of Turkey [4]

3. Discussion

In accordance with the Turkish Standard (TBDY, 2018), the necessary data affecting the seismic action include the Mapped Spectral Response Accelerations S_1 and S_S, and Structural Occupancy, the Site Class, the Seismic Design Category, the Spectral Response Coefficients, SDs and SD1, Seismic Response Coefficient, and Seismic Importance Factor. The steps of calculation base shear by using Equivalent Static force are summarized below:

1. Based on Turkish Standard (TBDY, 2018), the base shear is found by the following equation

$$V_{tE} = m_t \cdot S_{aR}(T_P) \geq 0.04 \cdot m_t \cdot I \cdot S_{DS} \cdot g$$

2. The period is calculated

$$T_{pA} = C_t H_N^{3/4}$$

$C_t = 0.1$ is used for reinforced concrete frame system.

For horizontal-elastic-design spectral accelerations, $S_{ae}(T)$, which acts as the coordinates of the horizontal elastic design acceleration spectrum for any earthquake level considered, are described in the following Equation:

$$S_{ae}(T) = \left(0.4 \times 0.6\frac{T}{T_A}\right) S_{DS} \qquad (0 \leq T \leq T_A)$$

$$S_{ae}(T) = S_{DS} \qquad (T_A \leq T \leq T_B)$$

$$S_{ae}(T) = \frac{S_{D1}}{T} \qquad (T_B \leq T \leq T_L)$$

$$S_{ae}(T) = \frac{S_{D1}\, T_L}{T^2} \qquad (T_L \leq T)$$

Reduced design spectral acceleration $S_{aR}(T)$ is found from the following correlation

$$S_{aR}(T) = \frac{S_{ae}(T)}{R_a(T)}$$

3. After the base shear is determined, an additional force applied to the top of the building shall be determined from the equation:

$$\triangle F_{NE} = 0.0075 \cdot N \cdot V_{tE}$$

So, the summation of base shear in X-direction, $V^{(X)}$ is:

$$V^{(X)} = \Delta F^{(X)} + \sum_{i=1}^{N} F^{(X)}$$

4. The total equivalent base shear other than $\triangle F_{NE}$, shall be distributed to the building floors using the following equation:

$$F_{iE} = (V_{tE} - \triangle F_{NE}) \cdot \frac{m_i \cdot H_i}{\sum_{j=1}^{N} m_j \cdot H_j}$$

The forces at the top of each story is summarized in Table 1

Table 1: Distributed story forces calculated by Equivalent Static method

Story No.	F_{iE} (kN)
1st story	38.177
2nd story	76.354
3rd story	114.531
4th story	152.710
5th story	190.886
6th story	266.843
Total base Shear	839.5

The steps of calculation base shear by using mode superposition method are summarized below:

1. The mass matrix of the building was formed as:

$$[m] = \begin{bmatrix} 460 & 0 & 0 & 0 & 0 & 0 \\ 0 & 460 & 0 & 0 & 0 & 0 \\ 0 & 0 & 460 & 0 & 0 & 0 \\ 0 & 0 & 0 & 460 & 0 & 0 \\ 0 & 0 & 0 & 0 & 460 & 0 \\ 0 & 0 & 0 & 0 & 0 & 460 \end{bmatrix} kg$$

2. In this step the stiffness matrix of the building was formed as:

$$[K] = \begin{bmatrix} 138888 & -69444 & 0 & 0 & 0 & 0 \\ -69444 & 138888 & -69444 & 0 & 0 & 0 \\ 0 & -69444 & 138888 & -69444 & 0 & 0 \\ 0 & 0 & -69444 & 138888 & -69444 & 0 \\ 0 & 0 & 0 & -69444 & 138888 & -69444 \\ 0 & 0 & 0 & 0 & -69444 & 69444 \end{bmatrix}$$

3. The Eigen value problem solved as the following equation

$$([k] - \omega_0^2 [m]) = \{0\}$$

So, by assuming that $\omega_0^2 = \lambda$ the above equation was solved

$$[\lambda] = \begin{bmatrix} 1.7391 & 0 & 0 & 0 & 0 & 0 \\ 0 & 2.0911 & 0 & 0 & 0 & 0 \\ 0 & 0 & 2.9262 & 0 & 0 & 0 \\ 0 & 0 & 0 & 5.0805 & 0 & 0 \\ 0 & 0 & 0 & 0 & 13.0380 & 0 \\ 0 & 0 & 0 & 0 & 0 & 112.8398 \end{bmatrix}$$

Then

$$[\omega] = \begin{bmatrix} 1.7391 & 0 & 0 & 0 & 0 & 0 \\ 0 & 2.0911 & 0 & 0 & 0 & 0 \\ 0 & 0 & 2.9262 & 0 & 0 & 0 \\ 0 & 0 & 0 & 5.0805 & 0 & 0 \\ 0 & 0 & 0 & 0 & 13.0380 & 0 \\ 0 & 0 & 0 & 0 & 0 & 112.8398 \end{bmatrix}$$

4. In order to find the patriation factors and calculate the acceleration for each mode shapes, the following equation was solved and the results are summarized in Table 2

$$([k] - \omega_0^2[m])\{\Phi\} = \{0\}$$

Table 2. Acceleration for all mode shapes for the building

Mode Number (n)	λ_n	ω_n	t_n	S_{rn}	S_{t1}
1	0.0018	23.8595	0.2633	0.1846	0.7382
2	0.0021	21.7588	0.2888	0.1683	0.6732
3	0.0030	18.3936	0.3416	0.1423	0.5691
4	0.0051	13.9594	0.4501	0.1080	0.4319
5	0.0132	8.7139	0.7211	0.0674	0.2696
6	0.1140	2.9620	2.1213	0.0225	0.0916

After calculating the acceleration of each mode, the above data was inserted to SAP2000 and the analysis was run to find the internal forces for each member. Figure 3 and 4 show the building modeled in SAP2000.

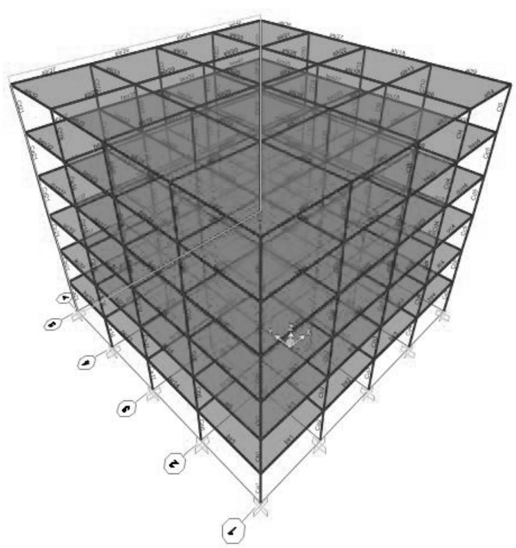

Figure 5: 3-D Model of the building in SAP2000

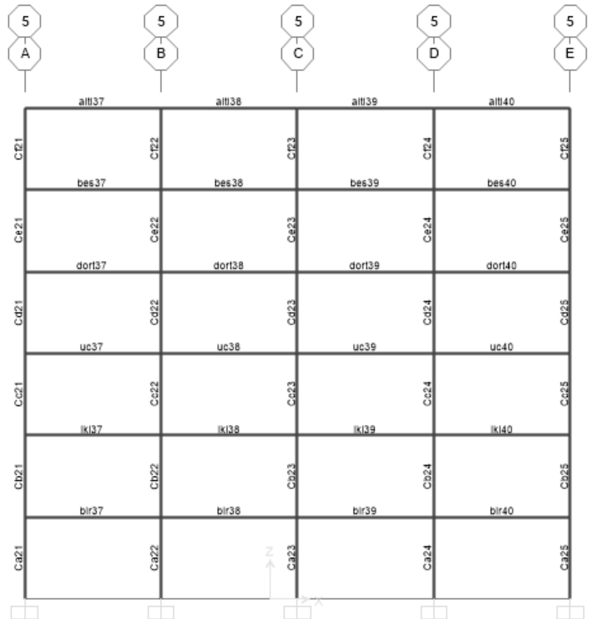

Figure 6: Elevation view of the building in SAP2000

4. Results and Conclusion

The main challenge for structural engineers is how to determine a realistic seismic response for MDOF systems. Two methods were utilized: the identical static analysis strategy that a set of static horizontal forces have applied to the structure. These forces are planned to coordinate the greatest impact in a structure that a dynamic analysis would forecast. This method works fine because our structure is modest and slight.

However, a dynamic analysis is the default method as identified by several building codes. We have used the modal analysis method as this method is the simplest type of dynamic analysis. This method entails of a dynamic analysis to define the mode shapes and age of the structure. In order to define the response of each mode, the method continues using response spectrum. It has been approved that the response of each mode is independent of the other modes, and then the modal responses were joint to define the total structural response.

For MDOF systems, such as six floors or more, dynamic analysis will lead to displacements and smaller forces compared with static process.

As a conclusion, there are two different analyses for floor forces. For the floor forces at the upper floors acquired by modal analysis are less than the static forces, however, this result does not continue with the lower floors; the opposite can be observed. This difference between the higher floors and the lower floors is due to the influence of the higher modes on the floor forces. In order to maintain the required safety level, as seismic design is achieved by using equivalent static analysis procedure, the forces on the level of the floor must be used in linking the floors to the lateral load resisting elements.

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