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Effect of Minor Variations in Characteristics of Beam on the Safety of 2D Steel Moment Frame under Dynamic Loads

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ABSTRACT: Increasing the strength of members or enhancing the redundancy does not jeopardize the overall safety of the structure. This can be proved under static loads by the safe theorem, which is one of the fundamental theories of plastic analysis. Although this theorem has not been proved in the case of dynamic loads, it has been widely applied to the design of systems under dynamic loads. Therefore, this paper aims to make use of the results of this theorem in the numerical analysis of structures subjected to dynamic loads. Since the structural instability mechanism and collapse do not occur under transient loads, an adequate level of ductility demand has been assigned to the structural components to ensure the safety of the structure. For this purpose, the plastic rotation of the members is determined after a minor variation in strength and stiffness of the beams in a 2D five-story steel moment-frame structure by performing dynamic analysis. To compare the ductility demand obtained by the dynamic analysis with the criteria values, the performance of the structure is also evaluated by conducting nonlinear static analysis. The analysis results showed that the increase in the strength of the beam members generally leads to a lower ductility demand; however, in some cases, the maximum ductility demand increased by about 7.3%. With the increase in the stiffness of the beams, the ductility demand increased by up to 16%. It can be concluded that with the increase in the stiffness and strength of the beams, a lower ductility demand is obtained by the dynamic analysis compared to the static analysis, and thus the structural collapse has not occurred under dynamic loads.

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1. INTRODUCTION

One of the most important issues in the field of seismic evaluation of structures is the difference in strength and stiffness of a part of the designed structure with those of the existing one. This difference is due to construction problems such as construction error, inaccuracy of the dimensions of the sections, lack of fixed or pinned supports, differences in material specifications, etc., which will cause changes in the expected responses and analysis results. However, this becomes important when these changes cause instability, changes in the mechanism of the structure, or an increase in the responses, including displacement and drift, beyond the allowable limit. This issue has been discussed for constant and specific static loads under the heading of plastic analysis fundamental theorems called safe and unsafe theorems. According to the safe theorem, if in a structure a set of bending moments can be found that satisfy both the equilibrium condition and the yield condition under the load coefficient λ, then λ is always less than or equal to the true collapse load coefficient [3]. From this theorem is concluded that if the considered sections have more strength or stiffness than the original design, the design will be safe. To prove these theorems, hypotheses have been considered that have limited their widespread application. These assumptions include static loading of the structure, a specific amount of loading, and sufficient ductility in the members. Therefore, under dynamic loading, as is the case with earthquake excitation, due to the variable nature of the load and its dynamic effects on the structure, the use of theorems may lead to unreliable results. However, in the common design of structures, the results of these theorems are used. To evaluate the reliability of the theorems, in this study, the application of these theorems in structures under the influence of earthquake excitation is investigated.

Various studies have been performed to investigate the seismic behavior of structures with different properties. Most of these studies have examined changes in the number of floors, the number of bays, or the type of lateral load resisting system. Another group of studies has examined the effect of structural changes in detail. Previous studies have not been conducted to apply plastic theorems in evaluating the dynamic responses. For this purpose, changes in strength and stiffness of beam connections in a two-dimensional five-story steel moment-frame case study structure have been investigated. To perform nonlinear dynamic analysis in this research, 29 earthquake ground motion records have been used.

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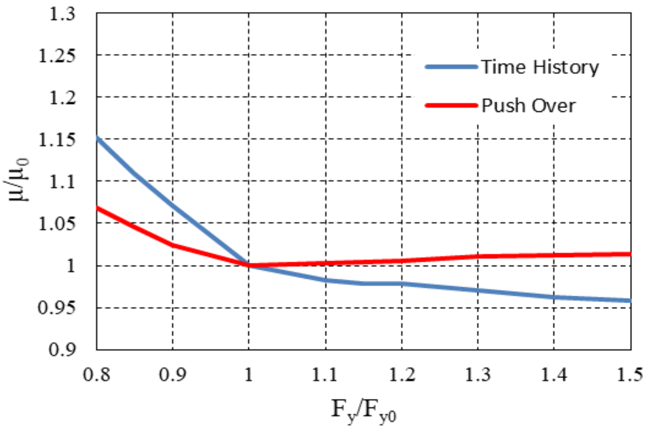

Fig. 1. Average ductility demand values for different strength values under the nonlinear dynamic and static analysis

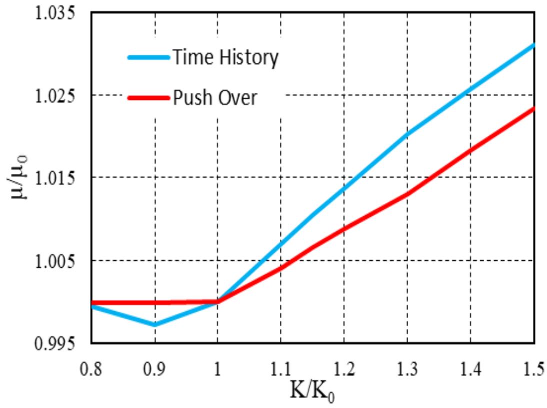

Fig. 2. Average ductility demand values for different stiffness values under the nonlinear dynamic and static analysis

2. METHODOLOGY

As mentioned earlier, there are assumptions in the theorem adopted in this paper, such as the existence of sufficient ductility, which in reality it is not possible to make; As a result, local damage due to insufficient ductility in members is likely to occur. For this reason, to investigate the behavior of the modified structure, the ratio of the maximum ductility demand of the members in the modified structure is compared with that of the original structure.

3. Results and Discussion

In the following, to perform a numerical evaluation of the plastic theorem, the maximum rotation of members has been presented in two sections including change in strength and stiffness.

3.1. Graphs for change in the strength of members

Fig. 1 shows the average values of ductility demand concerning the change in strength obtained by both the dynamic and the static analysis.

As can be seen, with increasing strength, the ductility demand obtained by the static analysis is more than the corresponding value obtained by the nonlinear dynamic analysis. However, with decreasing strength, the opposite is true. Therefore, as mentioned earlier, it can be said that in general, in the existing models, with increasing ductility demand in the case of increased strength, the ductility of the proposed design will not exceed the allowable limit specified by the codes.

3.2. Graphs for change in stiffness of members

Fig. 2 compares the average ductility demand concerning the change in stiffness of members under both the static and dynamic analysis.

With increasing stiffness, the average values of ductility demand obtained by static analysis are approximately equal to the corresponding value obtained by dynamic analysis. With decreasing stiffness, on the other hand, the ductility demand due to dynamic analysis has become more than nonlinear static analysis.

4. CONCLUSION

In this research, a total number of 1160 analyzes were performed on the two-dimensional moment-frame case study structure to investigate minor modifications in the strength and stiffness of the beam connections. Due to the nonlinearity of the analyzes and the absence of failure in the members, as well as the lack of significant change in the displacement of the roof of the structure, to evaluate the safety of the structure against collapse, the results of plastic rotation of hinges were used. According to the analysis results, with a slight increase in the strength of the most critical joint in the beams, the ductility demand decreased. In some cases, with a 50% increase in strength, the ductility demand increased by a maximum of 7.3%. The rate of these changes is very low compared to the increase in strength.

The reason for the increasing ductility demand in a few special cases can be a change in the displacement pattern of the structure. Based on the results of nonlinear static analysis, the maximum increase in the ductility demand as a result of the increase in strength was about 17%. Comparing the results of dynamic analysis with nonlinear statics and considering the limits recommended by the codes, it can be said that with a slight increase in strength of the beams, the structure with a certain ductility capacity, can remain safe under the applied earthquake records. With the increase in the stiffness of the beams, the ductility demand increased. The amount of increase in the case of dynamic loads was up to 16% and in the case of static loads was up to 22%. With increasing stiffness, the average ductility demand in the dynamic analysis was less than one percent higher than that obtained in the static analysis, and the amount of increase was generally small (about 3% with a 50% increase in stiffness). As a result, it can be concluded that with increasing stiffness of the structure, the ductility demand did not change greatly and it was below the ductility capacity of the structure, which is designed according to the provisions of the codes.

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