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# Performance Levels of Tall and Irregular RC Structures, before and After Reinforcing by Steel Bracing, under Nonlinear Static and Dynamic Analysis

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## 1. Introduction

A building may need retrofitting based on change of occupancy, change in design codes or deficiencies in design or performance. One method used in the early years for seismic retrofitting of reinforced concrete frames is using steel bracing. In this article, first the formation of plastic hinges and performance levels provided by RC structures are determined by nonlinear static and dynamic analysis. Then, these structures are reinforced by steel bracing and re-evaluated for performance levels and are compared with their initial conditions. Structures are selected of two different plans in 10- and 15-story buildings. Moreover, the structures of this studyare tall, and have been selected in an irregular fashion in plans to evaluate the effects of irregularity in the results.

## 2. Results of analysis of the primary model (non-reinforced)

In nonlinear static analysis, application of lateral load continues until roof displacement reaches the predetermined value or the structure collapses before this displacement. In the following, analysis of the results for S1-10 structure under lateral loading type 1 and in the x direction (with target displacement equals to 0.34968) are reported in Table 1.

According to the results shown in Table 1 it can be said that the studied structures do not fulfill the desirable target that is life safety. This is mainly due to the fact that plastic hinges have been created in life safety performance level before the structuresreach the target displacement and due to columns resistance preservation, plastic hinges creation in beams and in extensive parts of the structure and to some extent, permanent deformation in structures. Therefore, application of retrofitting program is investigated in order to achieve a higher performance.

Then the structures are evaluated dynamically. The results show that function range lower than that is suitable for the whole structure based on login of beams to the stage of collapse. Based on definition, the important organs of the system can provide necessary gravity resistance on the threshold of collapse. However, the structure is on the verge of overall collapse.

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In addition, major and permanent place shift in this range is predicted that is obvious in different models of this research. So, as the non-linear static method, the performance level of choice is to collapse the threshold. Deformation response of structure s1-10 is shown in Figure 1.

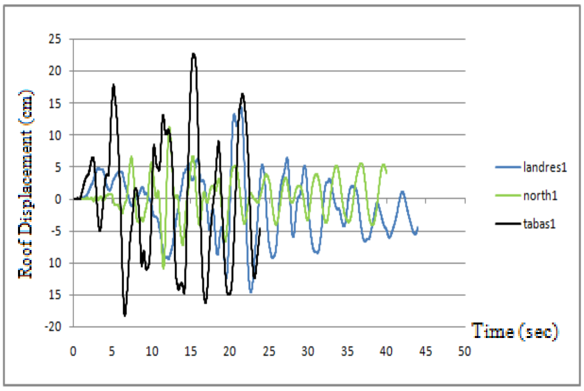


**Figure 1. Structure deformation reply in the direction of x under analysis state of type 1, under three acceleration -first mapping.**

## 3. Results of analysis of reinforced model

Primary steps for retrofitted structures are the same as primary structures. In the following the results of nonlinear static analysis for braced S1-10 structure, under type 1 lateral loading and x direction (with target displacement of 0.166) is mentioned in Table 2.

According to the investigations, all of the models upgrade performance and provide life safety performance after retrofitting with steel bracing. It is obvious in Table 2 that the plastic hinges are not created in the life safety range.

By usage of the mentioned earthquake mapping acceleration, resistant structures are under non-linear dynamic analysis. The maximum measures obtained from this stage, show significant decrease compared to primary manner responses (non-resistant). S1-10 structure deformation response is shown in Figure 2.
The results show that using steel bracing significantly promotes the level of performance and seismic capacity of structures.

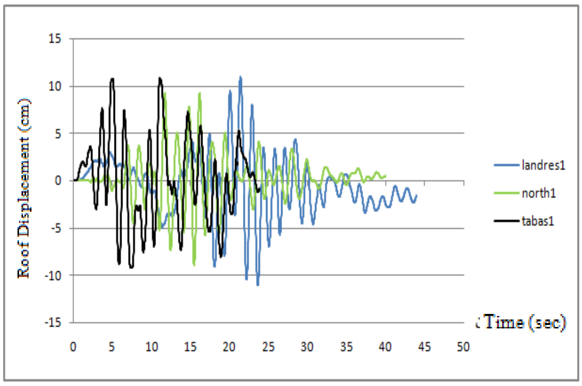


**Figure1. Reinforced structure deformation response in the direction of x under analysis state of type 1, under three acceleration - first mapping.**

**Table 1. Plastic hinges and performance level formation.**

| Step | Displacement | Base Force | A-B | B-IO | IO-LS | LS-CP | CP-C | C-D | D-E | >E | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | -7.893E-04 | 0.0000 | 1516 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1516 |
| 1 | 0.0517 | 78815.9297 | 1516 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1516 |
| 2 | 0.1042 | 157631.9219 | 1516 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1516 |
| 3 | 0.1567 | 236447.9688 | 1516 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1516 |
| 4 | 0.2092 | 315264.0938 | 1516 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1516 |
| 5 | 0.2617 | 394080.2500 | 1502 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 1516 |
| 6 | 0.3128 | 470718.2188 | 1387 | 129 | 0 | 0 | 0 | 0 | 0 | 0 | 1516 |
| 7 | 0.3415 | 499900.7813 | 1353 | 46 | 117 | 8 | 0 | 0 | 0 | 0 | 1516 |
| 8 | 0.4055 | 530860.5625 | 1320 | 42 | 6 | 148 | 0 | 0 | 0 | 0 | 1516 |
| 9 | 0.4967 | 558129.8750 | 1320 | 28 | 20 | 146 | 0 | 2 | 0 | 0 | 1516 |
| 10 | 0.5054 | 560535.8125 | 1320 | 28 | 20 | 135 | 0 | 0 | 10 | 3 | 1516 |
| 11 | 0.3520 | 324990.3125 | 1516 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1516 |

**Table 2. Plastic Hinges formation and retrofitted structure performance.**

| Step | Displacement | Base Force | A-B | B-IO | IO-LS | LS-CP | CP-C | C-D | D-E | >E | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | -1.124E-04 | 0.0000 | 1876 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1876 |
| 1 | 0.0248 | 169605.4063 | 1876 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1876 |
| 2 | 0.0497 | 339211.3438 | 1873 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1876 |
| 3 | 0.0691 | 471716.4063 | 1819 | 57 | 0 | 0 | 0 | 0 | 0 | 0 | 1876 |
| 4 | 0.0946 | 641244.3750 | 1789 | 83 | 2 | 0 | 0 | 2 | 0 | 0 | 1876 |
| 5 | 0.1001 | 675291.7500 | 1787 | 83 | 3 | 0 | 0 | 0 | 3 | 0 | 1876 |
| 6 | 0.1001 | 666171.1875 | 1782 | 86 | 4 | 0 | 0 | 1 | 3 | 0 | 1876 |
| 7 | 0.1023 | 680433.3125 | 1780 | 86 | 5 | 0 | 0 | 0 | 5 | 0 | 1876 |
| 8 | 0.1023 | 673366.9375 | 1726 | 135 | 8 | 0 | 0 | 2 | 5 | 0 | 1876 |
| 9 | 0.1120 | 730070.7500 | 1710 | 146 | 10 | 0 | 0 | 0 | 10 | 0 | 1876 |
| 10 | 0.1120 | 712565.0625 | 1662 | 191 | 12 | 0 | 0 | 1 | 10 | 0 | 1876 |
| 11 | 0.1193 | 754438.7500 | 1646 | 203 | 14 | 0 | 0 | 0 | 13 | 0 | 1876 |
| 12 | 0.1193 | 743630.0000 | 1645 | 204 | 13 | 0 | 0 | 1 | 13 | 0 | 1876 |
| 13 | 0.1198 | 746609.0000 | 1643 | 204 | 14 | 0 | 0 | 1 | 14 | 0 | 1876 |

## 4. Conclusion

1. Brace installation on structure increases structure's stiffness and decreases structure's period which leads to increase of base bear in the structure. However, the performance level of all the models is upgraded due to proper structural behavior by using dual system.
2. Appending steel bracing to concrete frames makes moment loads on the columns axialsuch that the stress ratio decreases to less than one. Axial seismic load, decreases the stress ratio proportion to admissible stress levels in columns and also transfers plastic hinges from columns to beams. This is while more than 80% of columns in this retrofitting method are secured from damage.
3. By comparison of performance of structures' beams and columns, it is found that in structures retrofitted by steel bracing, less plastic hinges are created in beams and columns and the structure would be in a better condition.
4. By comparison of force-displacement curves, it can be noted that braced concrete structures present more shear capacity than primary concrete structures. Thus, they increase the capacity of structures.
5. In reinforced structures, target displacement of the structure in comparison to primary concrete structures is decreased and the benefit of using dual system and interaction of moment frame and bracing is highly obvious.
6. By comparison of force-displacement curves for different models, it is s found that in all of them, the second type of lateral load distribution (proportional to each story weight) compared to the first type of lateral load (proportional to lateral force created from spectral dynamic analysis) would create higher base shear.
7. Hinge formation process in braced structures shows that using steel bracing leads to more force appliance to the frame in upper stories and creation of plastic hinges in beams. Although this factor does not lead to significant decrease of performance of structures finding a way to remove that, leads to improving the results.