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A Comparison of Concrete Buildings for Hospital Use Designed Based on Standard 2800 3rd and 4th Editions in Iran

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Abstract: ***One of the main principles of any set of construction regulations is that configuration, structure, materials and details must be designed in a way that the building can show plasticity during earthquakes. A structure's plasticity is defined as the ability to withstand enormous pressure and transformation without suffering great damage or deterioration. Construction regulations consider a certain amount of plasticity for every structure and base their design hypotheses on that amount. In the present study, since performance-related design principles have changed in the 4th edition of construction regulations, structures that have been designed and implemented based on performance must react to their being fully operational. For this reason, performance of concrete essential buildings located in relatively high-risk sites and designed according to regulations provided by the standard 2800 3rd and 4th editions will be compared and analyzed. Also, eight concrete buildings with special bending frames with 4, 6, 8 and 10 floors for hospital use will be analyzed according to ACI regulations using the SAP application, and then using PUSHOVER analysis, the structures will be evaluated. The results indicate that the structures designed according to the 4th edition have more loading capacity compared to structures designed using the 3rd edition, and the structures have become out of performance before reaching their target replacement point.***

Keywords: Pushover, irregular structures, performance level, behavior coefficient, essential buildings with very high importance

1. Introduction

One of the most important topics in seismic design regulations is stating design purposes in which the structure's expected performance against various levels of risk is explained. It is in the purposes section that we determine for what level of security the structure is being designed. Purposes of designing and implementing buildings are discussed under clause 1.1 of standard 2800, and purposes of designing highly important buildings are mentioned under section C of clause 1.1 of standard 2800, stating that highly important buildings must maintain their ability to be operational without major damages to the structure when severe earthquakes occur [1] and [2].

In order to see if the purposes are realized, performance of concrete essential buildings located in relatively high-risk sites and designed according to regulations provided by the standard 2800 3rd and 4th editions will be compared and analyzed. Also, eight concrete buildings with special bending frames with 4, 6, 8 and 10 floors for hospital use will be analyzed according to ACI regulations using the SAP application, and then using PUSHOVER analysis, the structures will be evaluated.

2. Purposes of Standard 2800 for Essential Buildings

The purpose of standard 2800 is to determine the minimum regulations required to design and implement buildings against the effects of earthquakes and if followed precisely, essential buildings are expected to maintain their ability to be fully operational without major damages to the structure when severe earthquakes occur. A severe earthquake which is also called "design earthquake" is an earthquake whose probability of occurring, or with even greater magnitudes, is less than 10% in 50 years of a building's useful life [1] and [2].

3. The Philosophy Behind Using Behavior Coefficient in Structure Designs

Using non-linear analyses for structures that enter the realm of inflexibility is necessary. Since inflexible analyses are complicated and time-consuming, regulations take the structures' inflexible performance into consideration in designs by using a factor called the behavior coefficient (R) [3].

4. Performance of Structures against Seismic Hazard Levels

Normally, seismic structures are designed in a way that they are flexible against low-level earthquakes and return to their original condition after unloading and they can be used again. If the earthquake intensity goes beyond a certain magnitude, the structure passes the flexibility limit and enters the inflexibility phase. At this phase, after the earthquake (unloading), the structure cannot return to its original condition and may not be usable again. Therefore, the expected purpose in designing structures is to make them in a way that they can maintain their flexibility and can be used after an earthquake. However, if being usable after an earthquake is not a priority in the design, we can make use of a structure's inflexible performance up to the point of destruction in order to make the most of its strength (energy absorption in the inflexible phase) to make the design economic [4].

5. Stages of a Performance-Based Design

Generally, the process of a performance-based seismic design has the following steps:
1) Determining structural and non-structural performance levels for the building
2) Determining the seismic hazard level
3) Determining performance targets based on the intended performance levels and seismic hazard
4) Determining the structure's capacity and the earthquake's imposed requirement
5) Determining performance point and estimating forces and their corresponding displacements
6) Controlling the acceptable standards for the intended performance target

6. Choosing Buildings

To analyze the behavior of structures designed based on standard 2800 3rd and 4th editions, eight concrete structures which have special bending frame types with 4, 6, 8, and 10 floors have been analyzed and designed based on the 3rd edition of standard 2800 and then the 4th edition and principles of ACI. The building is for hospital use and its hypothetical location is Tabriz. Ceiling type is cement blocks, floor type is type 2, the dead load is 3500 kg/m, the live load is 2500 kg/m, the height of each story is 3 m, and the structure plan is irregular as follows (measurements are in meters):

Building analysis and design is done using SAP200, V14 application. The structure is designed based on gravitational and lateral loads.

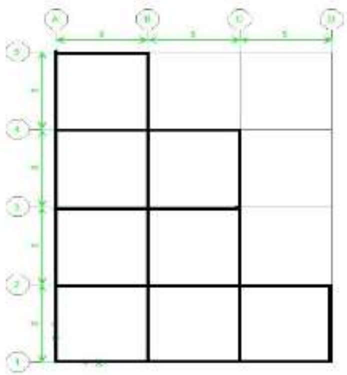

Figure 1: Plan of the intended structures

7. Evaluating the Performance of the 8 Fully Operational Buildings

After designing the structures, the amount of structure's displacement was controlled using standard 2800 and all the special design criteria such as strong pillars, weak shafts, connection cutting, and the structure's capacity against earthquake loads were controlled. After designing structures using the application, non-linear static analysis (PUSHOVER) was used to evaluate the fully operational structures.

In PUSHOVER, or gradual non-linear static analysis, the lateral load caused by an earthquake is applied statically and gradually to the structure until the control point is passed and the target displacement is reached or the structure approaches the point of demolition. Displacements and internal forces resulted from non-linear static analysis have to be checked and matched with the criteria mentioned under clause 2.4.3 of publication 360 [5].

According to FEMA-274&356 regulations, four structure performance levels are defined for structural components:

1) Being fully operational: at this level of performance, almost no damage is inflicted on structure parts and its functionality is completely maintained.
2) Immediate occupancy: at this level of performance, structure has little damages in the form of minor cracks or limited local openings and no major changes occur in the structure's resistance.
3) Life safety: at this level of performance, structure suffers from considerable damages and its resistance reduces significantly but it is a long way away from collapse.
4) Collapse prevention: at this level of performance, huge damage is inflicted upon the structure and it is very close to destabilizing and collapsing.

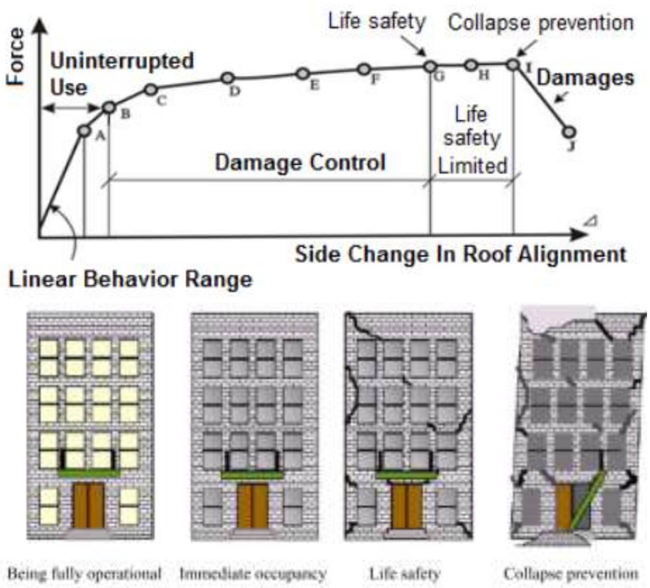

Figure 2: Schematic design of performance levels based on FEMA450

In figures 3, 4, 5 and 6, base reaction of structures with the same height are offered in order to simplify the job of analyzing structures using standard 2800 3rd and 4th editions.

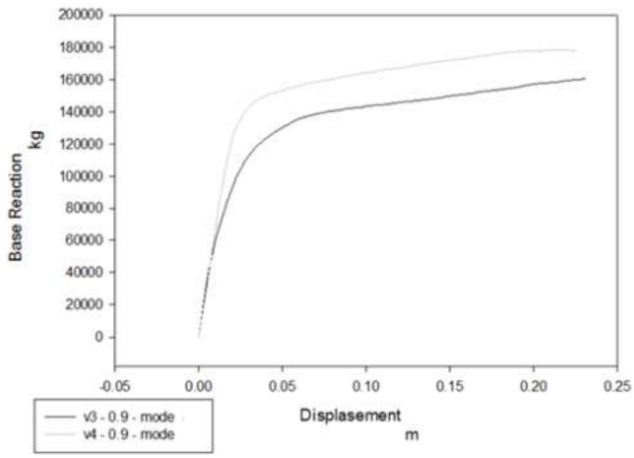

Figure 3: Base reaction of 4-floor structures

In this chart, distribution of lateral load is Mode with a coefficient of 0.9 in Y axis, and with a target displacement of 4.9 cm and base cutting of 128.1 tons for the 3rd edition and a target displacement of 5.2 cm and base cutting of 153.8 tons for the 4th edition respectively.

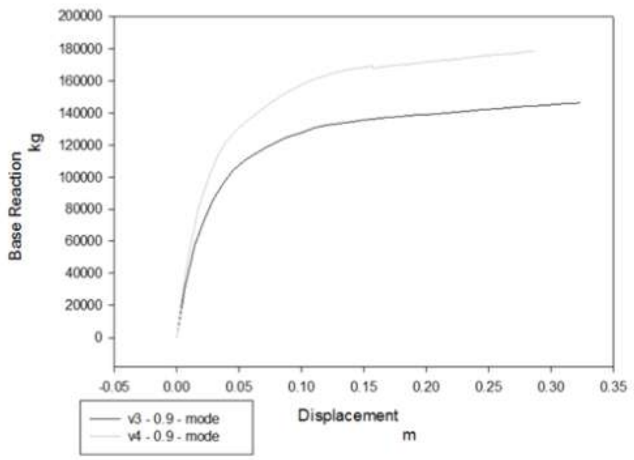

Figure 4: Base reaction of 6-floor structures

In this chart, distribution of lateral load is Mode with a coefficient of 0.9 in Y axis, and with a target displacement of 14 cm and base cutting of 134.5 tons for the 3rd edition and a target displacement of 11.6 cm and base cutting of 162.4 tons for the 4th edition respectively.

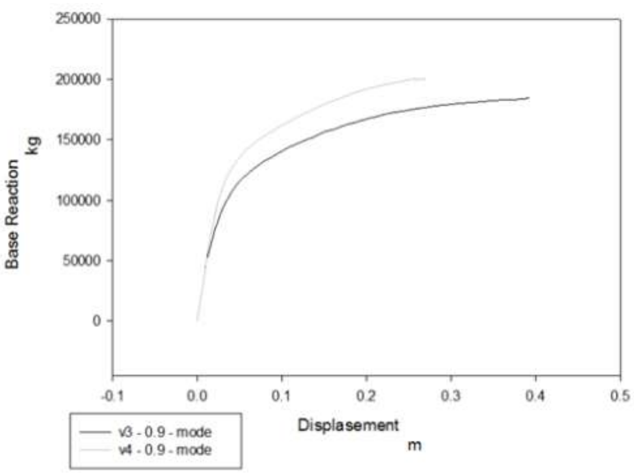

Figure 5: Base reaction of 8-floor structures

In this chart, distribution of lateral load is Mode with a coefficient of 0.9 in Y axis, and with a target displacement of 16.3 cm and base cutting of 159.5 tons for the 3rd edition and a target displacement of 15 cm and base cutting of 179.3 tons for the 4th edition respectively.

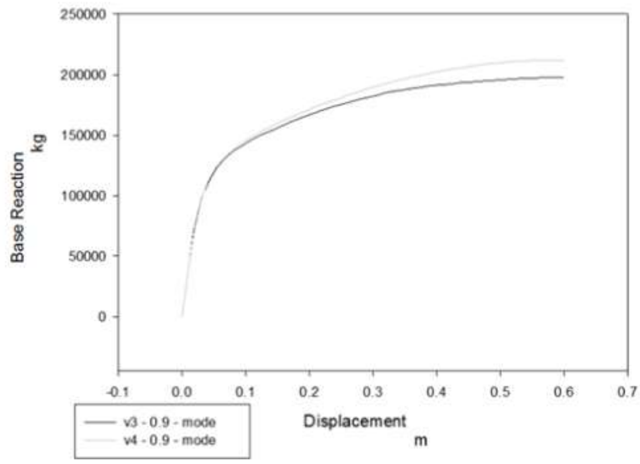

Figure 6: Base reaction of 10-floor structures

In this chart, distribution of lateral load is Mode with a coefficient of 0.9 in Y axis, and with a target displacement of 17 cm and base cutting of 194.2 tons for the 3rd edition and a target displacement of 16.8 cm and base cutting of 205 tons for the 4th edition respectively.

8. Results of Comparing Buildings' Resistance

In the following tables, maximum results of comparing the buildings' non-linear analysis are provided. In this chart, each building's resistance is given in both 3rd and 4th editions of standard 2800 and both fully operational (SA) and immediate occupancy (IO) modes.

Table 1: Comparison of 4-floor Buildings

Performance mode	Resistance based on 3rd edition of standard 2800 (tons)	Resistance based on 4th edition of standard 2800 (tons)
SA	135.4	175.5
IO	162.3	195.1

Table 2: Comparison of 6-floor Buildings

Performance mode	Resistance based on 3rd edition of standard 2800 (tons)	Resistance based on 4th edition of standard 2800 (tons)
SA	160.9	204.8
IO	180.3	231.5

Table 3: Comparison of 8-floor Buildings

Performance mode	Resistance based on 3rd edition of standard 2800 (tons)	Resistance based on 4th edition of standard 2800 (tons)
SA	186.4	221.8
IO	232.9	273

Table 4: Comparison of 10-floor Buildings

Performance mode	Resistance based on 3rd edition of standard 2800 (tons)	Resistance based on 4th edition of standard 2800 (tons)
SA	160	253.5
IO	183.2	299.2

9. Results of Comparing Roof Displacement and Target Displacement

In these structures, not knots (plastic joints) must pass the immediate occupancy stage. However, considering the maximum results, some structure components pass this stage before reaching this point and do not realize the goal of immediate occupancy for 457-year earthquakes.

Table 5: Roof Displacement and Target Displacement for 4-floor Buildings

	Resistance based on 3rd edition of standard 2800 (cm)	Resistance based on 4th edition of standard 2800 (cm)
Target displacement	6.7	9.7
Roof displacement	7.3	7.6

Table 6: Roof Displacement and Target Displacement for 4-floor Buildings

	Resistance based on 3rd edition of standard 2800 (cm)	Resistance based on 4th edition of standard 2800 (cm)
Target displacement	14	17
Roof displacement	11.2	10.1

Table 7: Roof Displacement and Target Displacement for 4-floor Buildings

	Resistance based on 3rd edition of standard 2800 (cm)	Resistance based on 4th edition of standard 2800 (cm)
Target displacement	19.6	19.9
Roof displacement	14.6	14.3

Table 8: Roof Displacement and Target Displacement for 4-floor Buildings

	Resistance based on 3rd edition of standard 2800 (cm)	Resistance based on 4th edition of standard 2800 (cm)
Target displacement	20.6	20.7
Roof displacement	17.8	17.3

10. Conclusion

With the help of building resistance tables provided here, we can see that in structures designed using 4th edition of standard 2800, base cutting is more compared to the 3rd edition, and target displacement and roof displacement in structures designed using both editions have failed to be fully operational before reaching the target displacement, and only 4-floor buildings have reached their target displacement. Generally, compared to structures designed using the 3rd edition, the capacity of structures designed using standard 2800 4th edition against applied loads has been increased.

Considering the results, we can make use of standard 2800 criteria and section 9 of National Construction Regulations in designing concrete essential buildings if slight changes are made in behavior and importance coefficients. Thus, behavior coefficient must be reduced in order to reach the standard 2800 target of being fully operational for highly important buildings because these structures waste a big part of earthquake energy, in severe earthquakes, in the non-linear area and it is not clear if they can return to their initial state after wasting the energy and realize the targets of standard 2800.

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