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JOURNAL OF CIVIL ENGINEERING RESEARCHERS

Determination of the capacity curve of a concrete building with a nonlinear static analysis method (Pushover)

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Abstract

The 2800 standard is used as the main reference for the seismic design of structures in Iran. Structural analysis methods consist of two groups of linear and nonlinear analyzes that each has different parts. In this regard, the nonlinear static analysis method (Pushover) is applicable in accordance with the existing code. In this method, the capacity curve, which indicates the changes of the basic shear relative to the structure of the roof's displacement. In this paper, we have investigated how to determine the capacity curve of a three-storey residential building with a bending frame system in two main directions, based on the fourth edition of the 2800 standard.

Keywords: Capacity curve, static nonlinear analysis, Pushover, seismic design, 2800 standard

1. Introduction

Nonlinear static analysis is a suitable tool for determining the seismic performance level of existing and new structures and it provides appropriate information about Seismic Damand applied to structures and its members under earthquake movements. Nonlinear static analysis is presented as a series of step by step linear analysis. In every step of this analysis, the reduction of the stiffness of members is considered due to the creation of plastic joints for loading and analyzing the next step. In this method, the lateral load caused by the earthquake is applied statically and then it will be applied dramatically to the structure in a smooth rate, as long as the displacement of the control point (the center of mass of the roof floor) under the lateral load reaches a certain value that is called the target shift, or then the structure collapses. The deformations and forces created in the members are compared with their acceptance criteria at different levels of performance and the level of performance of structures and structural components is determined. In the case of a

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displacement of location, the target indicates the demand of earthquake displacement [1].

2. The Types of Structural Analysis Techniques

The analytical method are composed of two groups of linear and nonlinear analysis, each containing the parts as shown below

- **linear analysis**
  - Static
  - Dynamic
    - Spectral (pseudo-dynamic)
    - Timeline
- **Nonlinear analysis**
  - Static
  - Dynamic
    - Spectral (pseudo-dynamic)
    - Timeline

Among the above methods, the nonlinear static analytical method (overflow or Pushover or thrust is the subject of this research.

It can be noticed that a nonlinear static analytical method only can be used if the criteria in clause 2-3 apply from the second appendix of code 2800. In other words, only when the static method is used, the structure response is due to its first mode, and this will be happened when the structure is short and regular [2].

In the beginning, the design of the structure and the software used for the analysis have been discussed. In the following, a summary of the step-by-step stages of the Pushover analysis in this study and finally the capacity curve obtained from the analysis and conclusion are presented.

3. The Studied Concrete structures:

The considered structure has three-story of 3.1 meters height and it is of concrete type. The use of all storyes of residential buildings is considered (I = 1). The location of the building is Rudsar (A = 0.3). Also, according to Figure1, plan is regular. The lateral load-bearing system of the building is in two directions of moderate bending frame (R = 5).

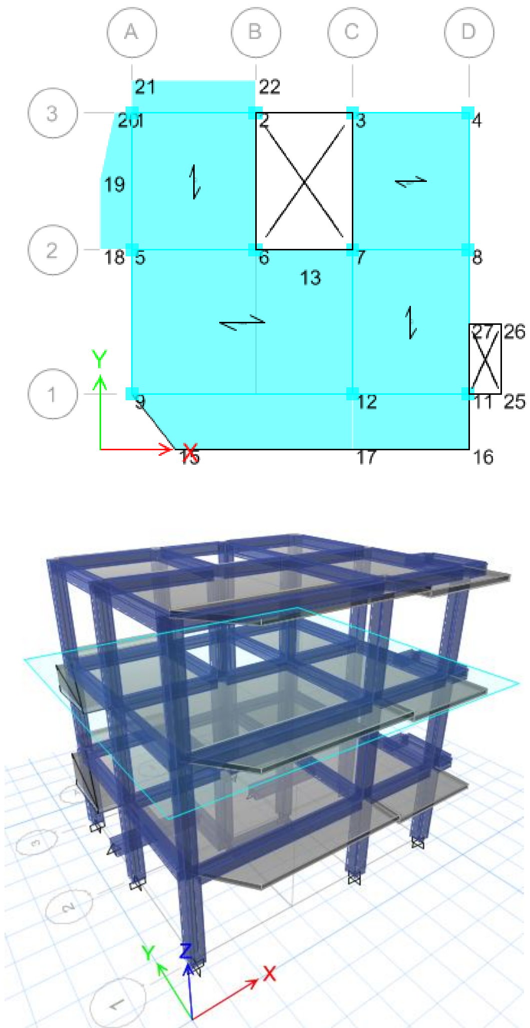

FIG.1: The considerated plan

4. Structural analysis and design:

Structural design is done by ETABS V9.7.4[3] software and the rest of the steps are related to the Pushover analysis using ETABS 2015[4] software.

5. Nonlinear analytical process:

After constructing the structure using linear static analysis and obtaining sections, the following nonlinear static analysis is performed.

According to Appendix 2, Clause 2-1 of Standard 2800, before carrying out nonlinear analysis, the gravity load shall be applied in accordance with the load combination factors associated with the structural model [2].

It can be mentioned that the combination of gravity loads is 0.9 D, 1/2 D + L which D is Dead load and L is Live load. The Live load is calculated according to the criteria of the sixth chapter of the National Building Code. Also, in cases where the mat live load is less than 400 kg per square meter, reducing this load to 50% is allowed [2].

5.1. The Definition of gravity loading combination:

First, in the Define menu and in the Load case field, we combine the loads below with the above note.

There is something to be noted that Given structure is involved with gravity loads in the first stage and, even after continuous operation, it tolerates its skeleton weight. Hence, first, gravity loads are applied to the structure and then the structure is subjected to an earthquake drift. In what follows we just introduce two different kinds of combinates [2].

1. First gravity loading combination:
   Gravity 1: 1.2 Dead + Live
2. Second gravity loading combination:
   Gravity 2: 0.9 Dead

5.2. The Definition of lateral loading patterns:

- Push1-Ex

This lateral load pattern is applied to the structure after the combination of Gravity 1 gravity load.

From the Define menu and in the Load Pattern field, we define the EQX load as in the Figure 2 (It should be noted that the value of K should be zero).

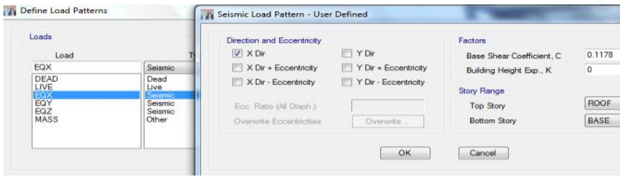

FIG.2:Seismic Load Pattern-User Defined

In the next step of the Define menu, in the Load case field (load case Push 1-Ex), add the EQX lateral load with coefficient 1 we enter.

In the opened window to calculate the load combination above the Load Application menu and in the Control Displcement section, we compute and enter the value of the target area displacement according to the low relationship (provided in Appendix 2 of the 2800 standard) [2].

$$\delta_{t=} C_0 C_1 S_a \frac{{T_e}^2}{4\pi^2} g$$

δ_t denotes the target displacement and C_0 is correction coefficient for the relation of the spatial displacement of the system with a degree of freedom to target displacement of the system with several degrees of freedom, and in the first stage is considered to be 1.3 and after the analysis according to the results obtained is corrected.

C_1 is the correction coefficient for applying inelastic system displacements, and in the first step, it is equal to 1, and after the analysis, it is corrected according to the results obtained.

S_a is equal to the spatial acceleration at the time of the Effective main period, and in the first step, it is equal to A * B (the acceleration of the design basis * reflection coefficient) of the clauses 2-2 and 3-2 of the standard 2800 (It should be mentioned that in the first stage, the empirical period of the structure should be used), but after a structural analysis, the resulting period is used and the results are corrected.

There is something to be noted that in accordance with clause 1-3-7 of Appendix 2, Standard 2800, the displacement obtained from the above equation must be multiplied by a factor of 1.5, and the structure should be analyzed to achieve this displacement based on the load patterns indicated above [2].

In the monitored displacement field, the control point is determined, where the target displacement is controlled. This point is selected on the roof level and close to the center of mass.

- Push2-Ex

This lateral load pattern applies after the Gravity 2 is combined with the structure.

This mode is similar to the previous one, but with the difference that the Nonlinear Case menu combines Gravity 2 gravity load.

5.3. Assign joints to beams and columns:

In this step, we select all the beams and then use the Assign-Frame-Hinges menu to auto-M3 in the ratio of intervals 0.05 and 0.95, and assign the defined relationship to the beginning and end of the beams.

Then we select all the columns and enter the intervals 0 and 1 in the Auto P-M2-M3 mode as in the Assign-Frame-Hinges menu, and assign the defined joints to the beginning and end of the columns.

6. Analysis of output:

In this step, we analyze the structure. After performing the analysis steps, in the first step of the Display-Deformed shape, we execute the program by selecting the Load case type including Push1-EX or Push2-EX, and then in the software home screen, we check the different steps of the nonlinear analysis in order to see which of the joints has passed through the level of performance known as Life-Safety. In the following figure, a sample of the frame is shown in one of the steps of the Push2-EX load state case. Figure 3 shows an example of Hinges formed in a frame in one of the nonlinear analysis steps.

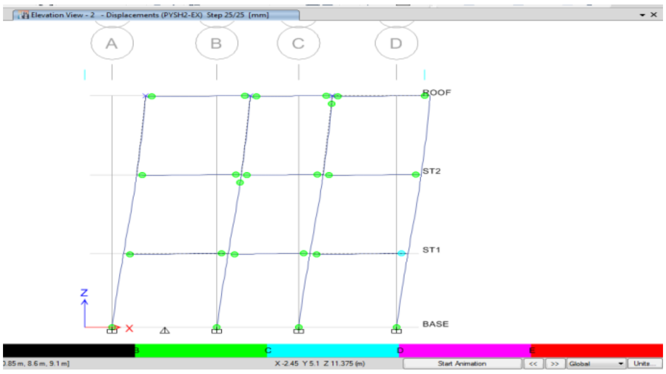

FIG.3: The process of the formation of Hinges in one of the frame of the structure

Next, in order to evaluate the position of the joints, we just select one of the beams, and in the Display-Hinge-Results section, we enter the relevant bead number and examine the joint. In the Figure 4, it is shown a sample of one of the selected beams.

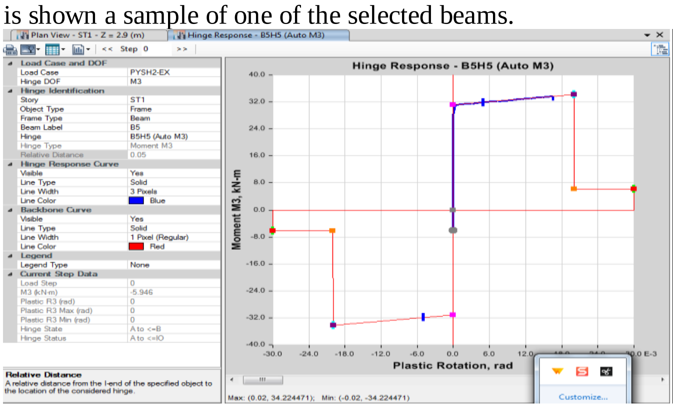

FIG.4: B5H5 Beam Hinges Plastic

The next step goes into Display-Static Pushover Curve, based on the results of the analysis, we modify the target's displacement.

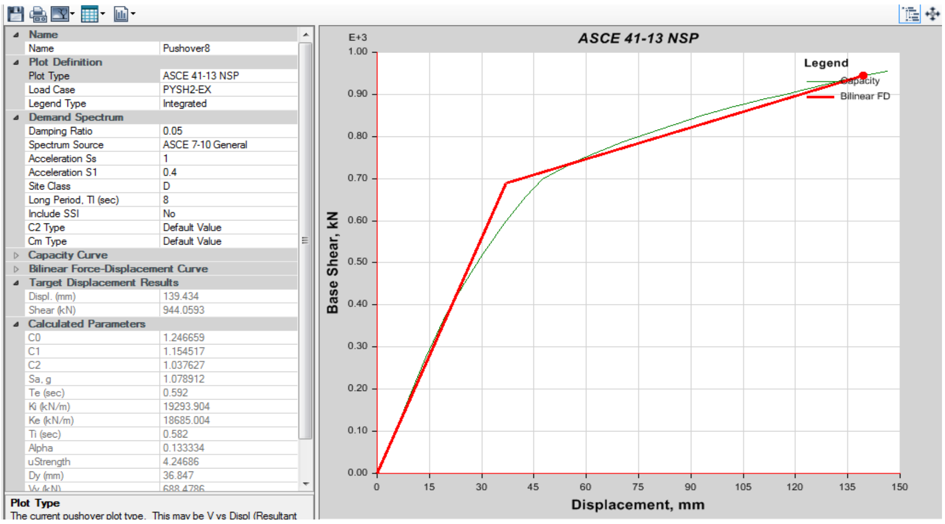

FIG.5: Target displacement Curve-based on nonlinear analysis (Pushover)

As seen in the Figure 5, the displacement of the target calculated by the software is 139.43 mm, which is very close to the initial calculated value by the 2800 code.

Before re-analysis of the structure, the characteristics of the joints of the beams and columns are derived based on the results obtained and the quantities presented in the 360 publication [5].

7. The re-analysis of the structure and Output Control:

In this step, again, we analyze the structure and control the outputs in accordance with clause 1-12-3 and clause 2-12-3 of appendix 2 of standard 2800.

Finally, after the structural analysis and necessary controls, the structural capacity curve (Figure 6 and Figure 7) for the two combinations of the Push1-EX side-by-side and Push2-EX combinations is obtained as follows.

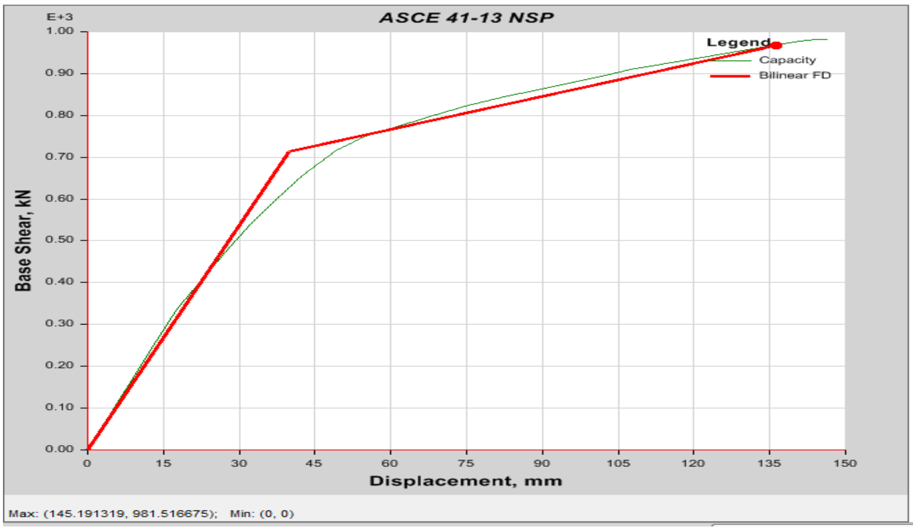

FIG. 6: (Push 1-EX) Static Pushover Curve

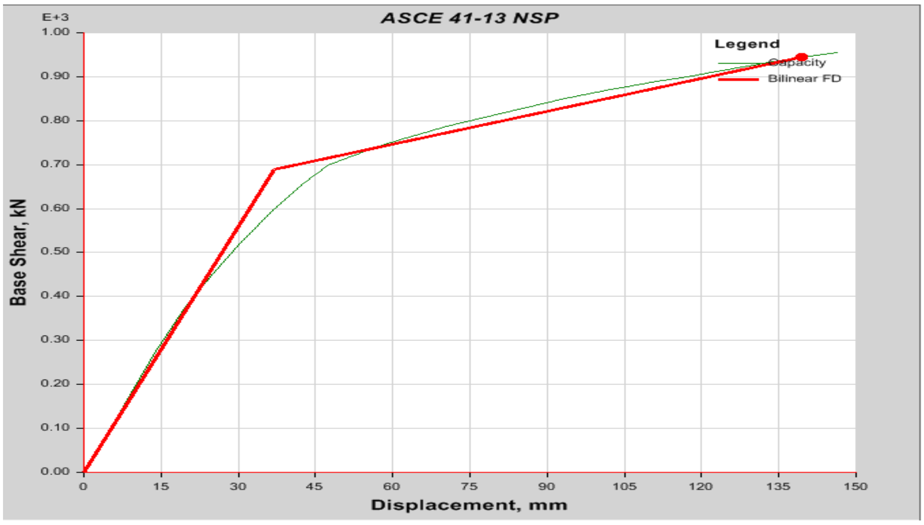

FIG. 7: (Push 2-EX) Static Pushover Curve

8. Conclusion

In this research, the performance of a three-storey concrete structure has been investigated. All design standards of the fourth edition of the 2800 standard have been considered in the design of the structure. After designing the building, along with the step-by-step steps of performance review, Pushover analyses with two patterns of lateral load were done. Due to the regularity, Pushover analyses were considered in one direction and were generalized for the other direction. Given the formation of the plastic joints in different components of the structure, the level of performance of the life safety was evaluated which corresponded to the standard 2800 goals.

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