Application of Nonlinear Static Pushover Procedure to the Displacement Based Approach of Seismic Analysis of G+10 Storey Building Structure for Indian Terrain

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Abstract: **The main objective of this study is to carry out seismic analysis for RCC G+10 storey building by application of nonlinear static pushover procedure as a tool to apply Performance Based Design Philosophy to the framed structure using displacement based approach of seismic analysis to determine the performance level of building in Surat city region by considering structural capacity obtained from pushover analysis and earthquake demand obtained from response spectra. Software used for analysis is finite element based software SAP2000. The determination of performance point is based on the Capacity Spectrum Method, which is a method prescribed by ATC Documents. Necessary changes have to be made in order to use this method as the parameters used differ from what are used in IS:1893. The applicability of the Capacity Spectrum Method has been justified for Indian context.**

Keywords: performance based structural engineering, capacity spectrum method, displacement based approach, static pushover, seismic analysis

I. INTRODUCTION

The purpose of this study is to give a realistic assessment of how a structure will perform when subjected to either particular or generalized earthquake ground motion. While the code design provides a pseudo-capacity to resist a prescribed lateral force, this force level is substantially less than that to which a building may be subjected during a postulated major earthquake. It is assumed that the structure will be able to withstand the major earthquake ground motion by components yielding into the inelastic range, absorbing energy, and acting in a ductile manner as well as by a multitude of other actions and effects not explicitly considered in code applications.[1] The present study develops a push over analysis procedure based on a continuous nonlinear post-elastic material model, which provides the capacity to monitor initial yielding and gradual progressive behaviour of both individual elements and overall structural systems.

Performance based structural engineering (PBSE) is not new. Automobiles, airplanes, and turbines have been designed and manufactured using this approach for many decades. But it is relatively a newer branch for civil engineering and especially structural engineering. In this method, one or more prototypes of the structure are built and subjected to extensive testing. The design and manufacturing process is then revised to incorporate the lessons learned from the experimental evaluations. PBSE is the design, evaluation and construction of engineered facilities that meet, as economically as possible, the uncertain future demands that both owner/users and nature will put upon them.[2]

A conceptual framework for implementing a PBSE can be summarised into three steps as below:

1. Identifying and formulating the relevant requirements of users.
2. Transforming the user requirements identified into performance requirements and quantitative performance criteria
3. Using reliable design and evaluation tools to assess whether proposed solutions meet the stated criteria at a satisfactory level

The CSM helps us execute the PBSE process, the above mentioned steps, with ease.

II. PROCEDURE

2.1. The Capacity Spectrum Method (CSM)

PBSE can be done using several methods. The CSM is one of those. The CSM is a nonlinear static analysis method, which compares the global force-displacement capacity curve of a structure with a demand (earthquake response) spectrum in a graphical shape. For this, both the capacity curve and the demand have to be converted into a spectral acceleration (S_a) spectral displacement (S_d) graph, called as acceleration deformation response spectrum (ADRS) curve. Due to this transformation, the global building will be reduced to an equivalent SDF-structure. So, after getting both the curves, on overlapping them, we get the performance point where the two curves intersect. At the performance point, we check the condition of building by assessing the hinges under consideration.[3]

2.2. Capacity Curve

Structure capacity is represented by a pushover curve. The most convenient way to plot the force-displacement curve is by tracking the base shear and the roof displacement. A pushover analysis is performed by subjecting a structure to a constantly increasing pattern of lateral forces, representing the inertial forces which would be experienced by the structure when subjected to ground shaking. Under incrementally increasing loads various structural elements yield sequentially. Consequently, at each event, the structure experiences a loss in stiffness. Using a pushover analysis, a characteristic nonlinear force-displacement relationship can be determined.[4] Figure 1 shows one such typical capacity curve.

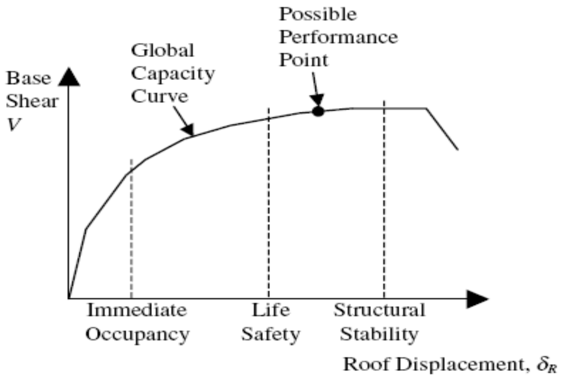

Figure 1. A typical capacity curve for a pushover

To convert this curve into ADRS curve, each point on the curve needs to be converted by using following formulae: [4]

$$S_{a_i} = \frac{V_i/W}{\alpha_1}$$

$$S_{d_i} = \frac{\delta_i}{PF_1 \ X \ \emptyset_{1,roof}}$$

Where,

S_{d_i} = spectral displacement

S_{a_i} = spectral acceleration

V_i = base shear

W = modal weight

δ = roof displacement (maximum)

$$\alpha_1 = \frac{[\sum_{i=1}^{n}(w_i\emptyset_{i1})/g]^2}{[\sum_{i=1}^{n} w_i/g][\sum_{i=1}^{n}(w_i\emptyset_{i1}^2)/g]}$$

$$PF_1 = \text{Performance factor} = \left[\frac{\sum_{i=1}^{n}(w_i\emptyset_{i1})/g}{\sum_{i=1}^{n}(w_i\emptyset_{i1}^2)/g}\right]$$

2.3. Demand Curve

Ground motions during an earthquake produce complex horizontal displacement patterns in structures that may vary with time. Tracking this motion at every time step to determine structural design requirements is judged impractical. Traditional linear analysis use lateral forces to represent a design condition. For a given structure and ground motion, the displacement demand is an estimate of the maximum expected response of the building during the ground motion. It is given by spectral acceleration (S_a) vs. Time period (T) as shown in figure 2 below.[4]

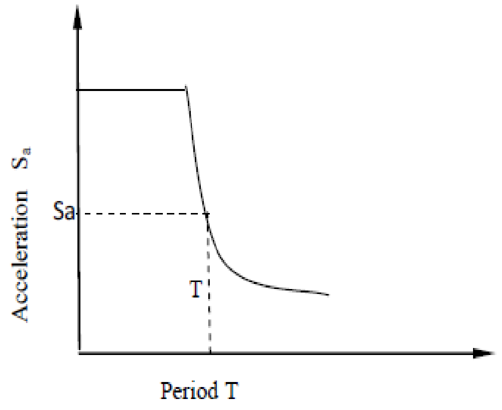

Figure 2. A typical demand curve

To convert this curve into ADRS curve, each point on the curve needs to be converted by using following formula:

$$S_{d_i} = \frac{T_i^2}{4\pi^2} S_{a_i} g$$

Where,

T_i = time period

g = gravitational constant

Figure 3 shows the demand curve obtained from Is Code.

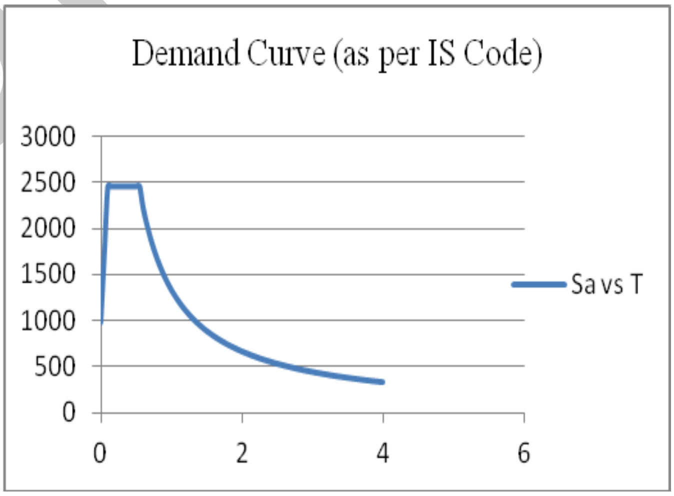

Figure 3. Demand curve obtained from IS Code

III. MODELLING

The model used in research is a g+10 storey symmetric (on floor plan) RCC frame. The plan dimensions are 7.5mX7.5m. The location of building has been selected as Surat, Gujarat, India and so various parameters of soil, earthquake and wind have been selected accordingly. The modelling is done in SAP2000. The figure shows the wire frame structure of building in 3-d and its elevation. Various loads as per IS Code have been applied. Non-linear static push loads have also been applied in x and y direction modal and uniform.

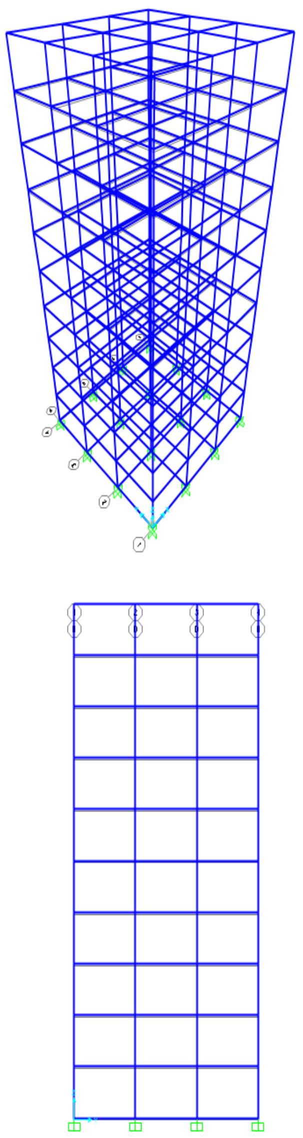

Figure 4. 3D wire frame structure of model and its elevation (right)

IV. ANALYSIS AND RESULTS

The model prepared as mentioned above was analysed in SAP2000.

The capacity curve of the model, for various load cases, was exported to excel and was converted into ADRS format. The demand curve was made from specifications given in IS Code as given above. It was converted into ADRS format. Both the converted curves were superimposed and performance point was obtained. The plastic hinges formed at the performance point were obtained and the building was found to be safe.

The following is the screenshot of the capacity spectrum method that can be applied directly in SAP2000 for ATC-40 standards. So we can similarly apply it for Indian standards and codes.

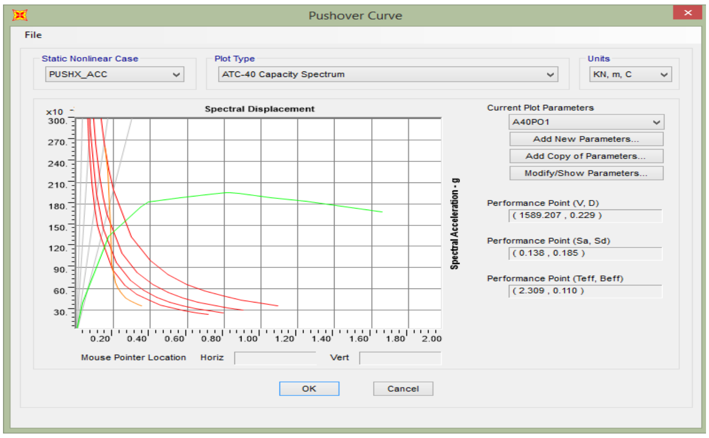

Figure 5. A screenshot of CSM obtained for ATC+40 documents through SAP2000

The curves obtained for uniform push in X direction are as in the graph below and they been superimposed to get the performance point. (The blue colored line indicates demand curve and red colored line indicates capacity curve.)

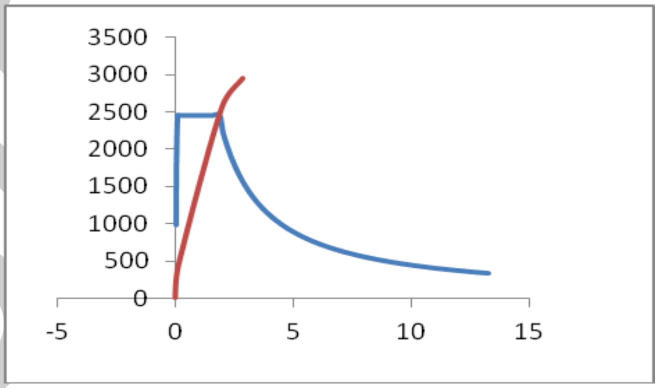

Figure 6. CSM obtained manually for pushover in X direction as per IS standards

Similarly, the curves obtained for uniform push in Y direction are as in the graph below and they been superimposed to get the performance point. (The blue colored line indicates demand curve and red colored line indicates capacity curve.)

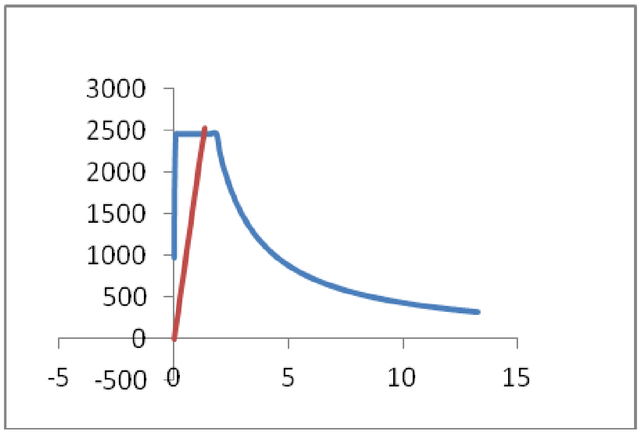

Figure 7. CSM obtained manually for pushover in Y direction as per IS standards

V. CONCLUSIONS

The following points have been concluded at the end of this project:

Non-linear pushover analysis serves the basis for determining the capacity of the structure in terms of base shear and roof displacement when displacement based approach is adopted.

Displacement based approach tends to give realistic idea of demand over the structure as it uses roof displacement as preliminary input parameter.

The non-linear failure of structural components (beams and columns) can be easily simulated using non-linear hinge models prescribed by FEMA 356, FEMA 273. This can be modelled and M-ϕ relationships of structural components can be visualised which predicts the degree of capacity deterioration of structural elements.

The demand over the structure is estimated by the hazard analysis in terms of maximum displacement or maximum base shear using any of the static or dynamic analyses methods like response spectrum method, static coefficient method or time history analysis etc.

The capacity curve of both structural elements and of a structure as a whole predicts the overall capacity estimation and structural performance for given demand.

The novel method of capacity spectrum method prescribed by ATC (Applied technology council) documents gives more rational approach towards earthquake–resistant economical design as the acceptance criteria are governed by the client specification.

The acceptance criteria prescribed in FEMA documents predict the performance and damage levels of the structure for minor, moderate and severe earthquake event. These levels typically range from immediate occupancy (IO) to collapse prevention.

SAP2000 is a powerful tool to implement performance based design approach using various methods like FEMA Coefficient method and ATC Capacity Spectrum Method.

Application of capacity spectrum method to structures in Indian terrain still requires due modifications and adaptions in the analysis and design process.

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