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# DETERMINATION OF PERFORMANCE POINT IN CAPACITY SPECTRUM METHOD

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## ABSTRACT

Performance based seismic design (PBSD) method is getting wide recognition as the most suitable seismic design process. PBSD is essentially a displacement based seismic design process involving the determination of performance point. The capacity spectrum method is one of the most established and widely accepted displacement based seismic design method which is used for performance based seismic design. ATC 40 report published by Applied Technology Council identifies three capacity spectrum procedures A, B and C for determination of performance point. Procedure A is the most direct application of the theory while procedure B is based on the simplifying assumption of constant post yield slope. Procedure C is a purely graphical method that is not convenient for programming. The assumption may introduce some error into the procedure B. The conventional software packages like ETABS, SAP2000 are based on procedure B. The current study involves developing a program based on procedure A and comparing the outputs of the developed program and conventional software ETABS.

## NOMENCLATURE

$\beta_o$ Hysteretic damping represented as equivalent viscous damping

$\beta_{eq}$ The total damping is represented as equivalent viscous damping

$E_D$ The energy dissipated by the structure in a single cycle of motion

$E_{SO}$ The maximum strain energy associated with that cycle of motion

$SR_v$ Spectral reduction values in the constant velocity range

$SR_A$ Spectral reduction values in the constant acceleration range

$S_a$ Spectral acceleration value $S_d$ Spectral displacement value

$Q_i$ The maximum design lateral force at "i" th floor ($a_{pi}$, $d_{pi}$) Coordinates of trial performance point

($a_y$, $d_y$) Coordinates of equal area point

## 1. INTRODUCTION

Displacement based seismic design is broadly defined as any seismic design procedure in which displacement related quantities are used to judge performance of a structure. But in the traditional force based design procedures force related quantities are used to judge the performance of a structure. To prevent collapse in a major earthquake the ductility demand on the structural elements and the overall deformation of the structure should be controlled. This can be achieved rationally with a displacement based design method rather than force based method of seismic design.

A number of displacement based methods have been developed{1,2,3,4,6,7,8]. Out of the various methods capacity spectrum method is one of the most widely accepted and well established procedures. This method is based on the assumption, that the maximum lateral story drifts describe the seismic building response efficiently. The nonlinear response of the structure is described with the push over curve, which plots the base shear versus the roof displacement. This push over curve can be transformed into the "capacity spectrum" using the structure's originally elastic dynamic properties. The

Capacity Spectrum method requires that both the capacity curve and the demand curve be represented in response spectral ordinates. It characterises the seismic demand initially using a 5% damped linear-elastic response spectrum and reduces the spectrum to reflect the effects of energy dissipation to estimate the inelastic displacement demand. The point at which the capacity curve intersects the reduced response curve represents the performance point, at which capacity and demand are equal [2].

ATC 40 prescribes three procedures A, B, C for determining performance point. The procedure A has been identified as the direct application of capacity spectrum methodology. The objective of the current study is to create a program to determine performance point based on procedure A.

## 2. METHODOLOGY AND RESULTS

The methodology for the present study is classified into four phases. In the first phase, the structure is modelled using ETABS [5]. In the second phase pushover analysis of the structure is carried out using ETABS. The pushover loads is calculated using conventional pushover methodology based on IS 1893-2002. In the third phase the program for determining performance point of a structure using user defined response spectrum curves is written. The fourth phase involves validation of the program by comparing the output with that of the conventional non linear analysis packages for the same input response spectrum

### 2.1 Modelling Of Structure

In the present work, a four storied reinforced concrete frame building situated in Zone IV, is taken for the purpose of study. The plan area of building is 10 x 10 m with 3.75 m as height of each typical storey. It consists of 2 bays of 5 m each in X-direction and Y-direction. Hence, the building is symmetrical about both the axis. The total height of the building is 15 m. The building is considered as a Special Moment Resisting Frame.The building is considered to be an ordinary structure of Importance factor one. Medium soil conditions were assumed at the site of the structure. The columns have dimensions of 0.35x 0.35 m. The beams have dimensions of 0.4x0.5 m and the slab thickness was taken as 0.125 m.

The required structure has been modeled using ETABS (Fig.1).

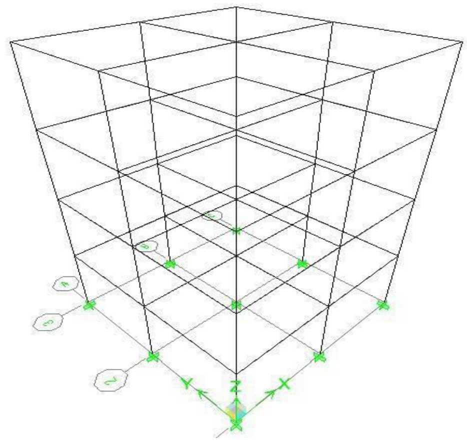

FIGURE 1. THREE DIMENSIONAL VIEW OF THE BUILDING

**2.2 Pushover Analysis of the Structure**

The pushover analysis of the structure is done to obtain the pushover curve of the structure. The lateral loads for pushover analysis were determined based on IS 1893 (2002).

The maximum design lateral force, $Q_i$, was computed for each storey level and was distributed at each node as follows.

$Q_4$ = 86.82 kN
$Q_3$ = 52.638 kN
$Q_2$ = 23.394 kN
$Q_1$ = 5.848 kN

This load was applied to the structure for pushover analysis. The modeling and pushover analysis was done using ETABS.Two pushover load cases were defined for the analysis. The first pushover load case called PUSH 1 was used to apply the static loads, (dead load and live load). PUSH 1 was a combination of 1 dead load + 0.25 live load. The second pushover load case called PUSH 2 was used to apply the lateral loads. PUSH 1 was force controlled while PUSH 2 was displacement controlled. PUSH 2 was made to start from the final conditions of PUSH 1. In this analysis, PMM hinges have been defined at both the column ends and M3 hinges have been defined at both the ends of all the beams. The basic static analysis was run first followed by the non linear pushover analysis. Both the pushover curve and capacity spectrum were generated from the analysis (Fig.2).

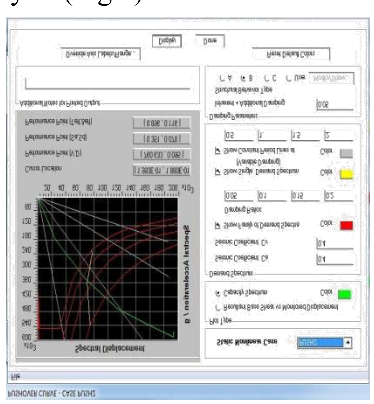

FIGURE 2. CAPACITY SPECTRUM

### 2.3 Creating a Program for Determining Performance Point

The program for determination of performance point is based on the procedure A given in ATC 40. Procedure A is one of the three procedures A, B, C given in ATC 40. Procedure A is the most direct application of the theory. But in procedure B a simplifying assumption that post yield slope remains constant is made. The procedure B is inherited with some error due to this assumption. But this assumption makes procedure B much simpler than procedure A. Procedure C is a purely graphical method that cannot be used for programming. Conventional softwares like ETABS and SAP 2000 are based on the procedure B [5,10]. This might introduce some error in the performance point calculation in these software packages. In this study a program is developed in C++ for determination of performance point using capacity spectrum procedure A.

The point of intersection of capacity spectrum and reduced response spectrum is taken as the performance point. The capacity spectrum is generated with the help of suitable non linear analysis software's like SAP2000 and ETABS. The response spectrum needs to be input by the user based on the seismogram of an event. This response spectrum is reduced to take into account of the damping. But the damping in the system when it is driven into an elastic range is a sum of viscous damping and hysteresis damping. Effective damping needs to be considered for the reduction of response spectrum.

A bilinear representation of capacity spectrum is needed to estimate the effective damping and appropriate reduction of spectral demand. Construction of bilinear representation require the definition of performance point $a_{pi}$, $d_{pi}$. This is the trial performance point which is estimated by the engineer to develop reduced response spectrum. If the reduced response spectrum is found to intersect the capacity spectrum at the estimated point $a_{pi}$, $d_{pi}$, then that point is the performance point.

To construct the bilinear representation draw one line up from the origin at the initial stiffness of the building. Draw a second line back from the trial performance point, $a_{pi}$, $d_{pi}$. Slope the second line such that when it intersects the first line, at point $a_y$, $d_y$, the area designated $A_1$in the figure 3 is approximately equal to the area designated $A_2$ .i.e. area under capacity spectrum will be equal to area under its bilinear representation.

To calculate the total damping of the system, we need to represent the hysteresis damping of the system as equivalent viscous damping. The total damping is represented as equivalent viscous damping represented by $\beta_{eq}$ .

$$\beta_{eq} = \beta_o + .05 \qquad (1)$$

where, $\beta_o$ = hysteretic damping represented as equivalent viscous damping and 0.05 is the assumed 5 percent viscous damping of the system.
The term

$$\beta_o = (1/4\pi)(E_D/E_{SO}) \qquad (2)$$

where, $E_D$ is the energy dissipated by the structure in a single cycle of motion, that is, the area enclosed by a single hysteresis loop. $E_{SO}$ is the maximum strain energy associated with that cycle of motion, that is, the area of the hatched triangle.

$$E_D = 4(a_y d_{pi} - d_y a_{pi}) \qquad (3)$$

$$E_{SO} \quad \underline{a_{pi}\, d_{pi}} \qquad (4)$$

2

Once the equivalent viscous damping of the system is calculated, the response spectrum input by the user is reduced to obtain the reduced response spectrum. For this spectral reduction values in the constant velocity range, $SR_v$ and constant acceleration range $SR_A$ are determined [1].

$$SR_A = [3.21-(0.681 x \ln \beta_{eq})] /2.12 \quad (5)$$

$$SR_V = [2.31- (0.41 x \ln \beta_{eq})] \quad (6)$$

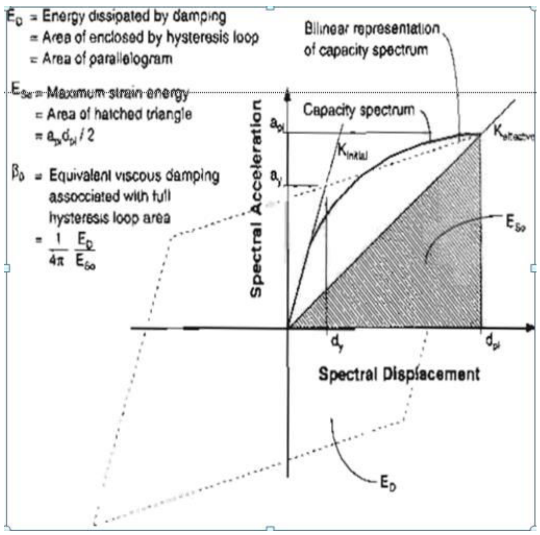


FIGURE 3. BILINEARISATION OF CAPACITY SPECTRUM

These values of the response spectrum in the constant velocity range and constant acceleration range is multiplied by the spectral reduction values $SR_V$ and $SR_A$ respectively to get the reduced response spectrum (Fig.4). Then the reduced response spectrum and capacity spectrum was plotted to obtain the point of intersection of the two curves. If the reduced response spectrum is found to intersect the capacity spectrum at the estimated point $a_{pi}$, $d_{pi}$, then that point is the performance point. If not, the procedure will be repeated by taking a different trial performance point.

### 2.4 Comparison of the program with conventional softwares

The comparison was done by comparing the output of the program with conventional software ETABS for the same input values of capacity spectrum and response spectrum.

The data for input response spectrum used by ETABS was obtained in the form of coordinate values of different points in response spectrum. This response spectrum was the standard response spectrum provide in IS 1893-2002 The capacity spectrum used for validation is the output capacity spectrum curve was obtained after analysing the model developed in ETABS. The data for the capacity spectrum was also collected in form of coordinate values. The values of points in response spectrum and capacity spectrum used for validation are tabulated in Table 1.

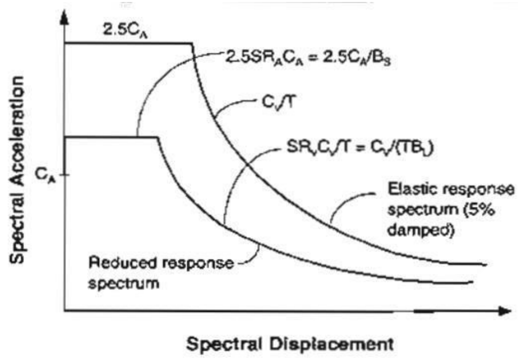


FIGURE4. REDUCED RESPONSE SPECTRUM

The data for input response spectrum used by ETABS was obtained in the form of coordinate values of different points in response spectrum. This response spectrum was the standard response spectrum provide in IS 1893-2002 The capacity spectrum used for validation is the output capacity spectrum curve was obtained after analysing the model developed in ETABS. The data for the capacity spectrum was also collected in form of coordinate values. The values of points in response spectrum and capacity spectrum used for validation are tabulated in Table 1.

The value of performance point from ETABS are spectral acceleration, $S_a$ = 0.07 g and spectral displacement, $S_d$= 0.351m

The output value of the created program for the same input are spectral acceleration, $S_a$ = 0.0649 g and spectral displacement, $S_d$= 0.32923m respectively.

The screen shot of the result from output of the program is shown in Fig. 5.

The variation in spectral acceleration value obtained through the created program from the output obtained from ETABS is 7.28% and the corresponding variation in spectral displacement value is found to be 6.25%. The error can be attributed to the fact that ETABS and other conventional softwares like SAP follow a modified procedure which involves development of single variable demand spectrum. In this procedure, it is assumed that yield point and post yield point of the bilinear representation remains constant. These assumptions though adequate for most cases, may induce some error in the results of ETABS.

TABLE 1.INPUT VALUES OF CAPACITY AND RESPONSE SPECTRUM

| capacity spectrum | | response spectrum | |
|---|---|---|---|
| Sd | Sa (g) | Sd | Sa (g) |
| 0 | 0 | 0 | 0.36 |
| 0.02 | 0.1493 | 0.002236 | 0.9 |
| 0.024 | 0.173 | 0.067632 | 0.9 |
| 0.04 | 0.232 | 0.097301 | 0.612 |
| 0.06 | 0.3041 | 0.121626 | 0.4896 |
| 0.067 | 0.34 | 0.145951 | 0.408 |
| 0.08 | 0.376 | 0.17027 | 0.3497 |
| 0.1 | 0.4313 | 0.194602 | 0.306 |
| 0.114 | 0.469 | 0.218927 | 0.272 |
| 0.12 | 0.4783 | 0.243252 | 0.2448 |
| 0.14 | 0.5088 | 0.304003 | 0.1958 |
| 0.155 | 0.535 | 0.364879 | 0.1632 |
| 0.16 | 0.5419 | 0.425735 | 0.1399 |
| 0.18 | 0.5696 | 0.486505 | 0.1224 |
| 0.193 | 0.588 | 0.615733 | 0.1224 |

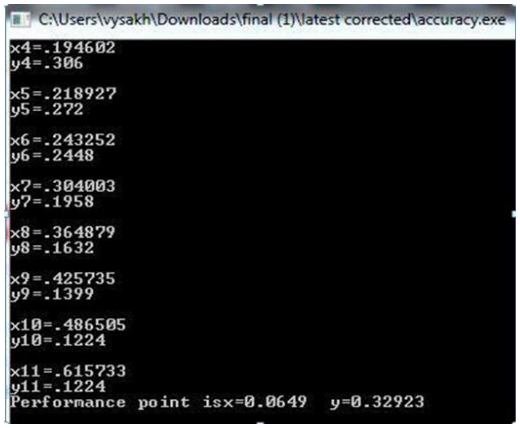


FIGURE 5.SCREEN SHOT THE RESULT FROM PROGRAMME

## 3. CONCLUSIONS

Following conclusions are drawn from this study.

1. A difference is found in the results obtained from ETABS and the program based on procedure A. ETABS is based on procedure B in which a simplifying assumption that post yield stress remains constant is made. This assumption is concluded to be the source of this difference.

2. For the case study conducted in this work considering a four storied structure having regular configuration, the variation in spectral acceleration value with respect to ETABS is 7.28% and the corresponding variation in spectral displacement value is 6.25%. A difference of 22 mm is found between the design displacement values between the two procedures in the four storied structure.

3. The results from procedure A and procedure B shows minor difference in their values. This variation is negligible for actual design purpose. Hence the conventional software packages based on procedure B is found to be performing satisfactorily.

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