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Application of capacity spectrum method based on ATC 40 and BNBC 1993

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Abstract: In this paper seismic capacity of structure to resist earthquake force was estimated by the capacity spectrum method. To evaluate the performance of frame building under future expected earthquakes, non linear static pushover analysis was conducted following ATC 40 guidelines. A 2D Reinforced Concrete frame was modeled in SAP 2000 by incorporating plastic hinges at the end of the structural element. Capacity of the structure was obtained from pushover analysis. BNBC 1993 response spectrum was converted into ADRS format. Performance point of the structure was achieved from the intersection between capacity curve and ADRS spectrum.

Keywords: *Capacity, Demand, Performance, Pushover Analysis and Response Spectrum.*

Introduction:

In recent years the focus on Performance Based Design (PBD) concept get new dimension in the earthquake engineering. To evaluate the adequacy of existing building under earthquake load, simplified linear elastic method is not sufficient. Current interest in performance based seismic engineering showed that an inelastic procedure especially pushover analysis is an effective tool to assess the damage vulnerability of buildings. Even in few years earlier, the seismic design was carried out to provide sufficient lateral strength for the design earthquake. Actually the performance of a structure depends on satisfactory displacement capacity and ductility rather than high resistance (Kadid and Boumrkik, 2008). By introducing the ductility and displacement inside the structure it is possible to control damage and collapse mechanism. In the PBD procedure, risk level with specific allowable damage states are defined for the structure under a given seismic intensity level. The first classic document based on PBD is FEMA-356 (2000), which provided a significant improvement in both seismic analysis procedures and verification criteria accounted in two earlier reports, FEMA-273 and FEMA-274. A parallel effort that resulted in the publication of ATC-40 (1996) is limited to RC buildings but is more comprehensive in its treatment (Kunnath, 2006). Another guideline FEMA-350 was generated to apply for the new steel moment frames only. Significant research has been done to evaluate the existing buildings and PBD concepts have been included in the most advanced seismic codes, such as EC8 and IBC (Parisi, 2010).

The purpose of this study is to apply the ATC 40 capacity spectrum method for a simple Reinforced Concrete 2D frame building using design response spectra in Bangladesh National Building Code (BNBC). The method is a graphical procedure which compares the capacity of a structure with the demands of earthquake ground motion on the structure (See Figure 1). The graphical presentation makes possible a visual evaluation of how the structure will perform when subjected to earthquake ground motion (Freeman, 1998). The capacity of the structure represented by a force displacement curve is obtained by non-linear static pushover analysis. The base shear forces and roof displacements are converted to the spectral accelerations and spectral displacements of an equivalent Single-Degree-Of-Freedom (SDOF) system, respectively. These spectral values define the capacity spectrum. The demands of the earthquake ground motion are defined by highly damped elastic spectra. The Acceleration Displacement Response Spectrum (ADRS) format is used, in which spectral accelerations are plotted against spectral displacements, with the periods represented by radial lines (Fajfar, 1999). The intersection of the capacity spectrum and the demand curve provides an estimate of the inelastic acceleration and displacement demand. In this paper, the result of the pushover analysis was compared with the existing BNBC 1993 response spectrum.

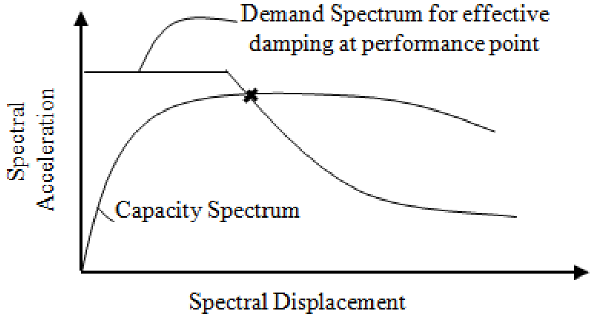


Figure 1: Capacity Spectrum Method

Response Spectra in BNBC:

BNBC was published in 1993. The seismic zoning map of BNBC was prepared based on peak ground accelerations estimated for a return period of 200 years. The existing BNBC 1993 response spectrum is developed for three soil types (see in Figure 2). These soil types are defined as soft to medium clay and sand (S3), deep cohesionless or stiff clay (S2) and Rock and Stiff (S1). However, another soil type, very soft clay (S4) was not defined in BNBC 1993 response spectra (BNBC, 1993). ADRS Demand spectrum was plotted according to ATC 40 guideline. The following equation was used to convert a standard time acceleration spectrum to ADRS format. Figure 3 represents the ADRS spectra for BNBC 1993.

$$S_d = \frac{T^2}{4\pi^2} S_a$$

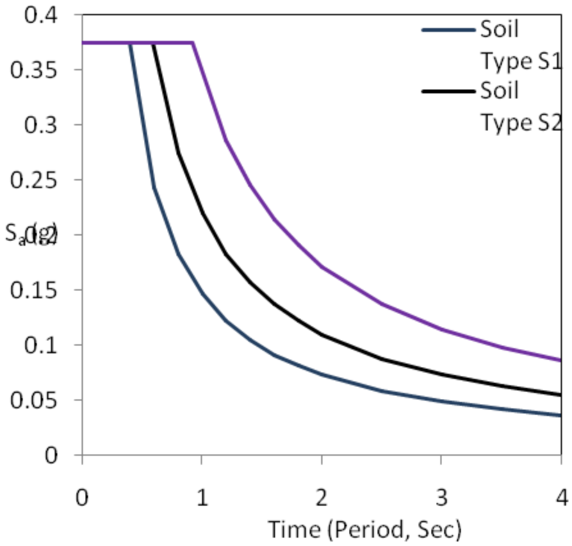


Figure 2: BNBC 1993 Response Spectra

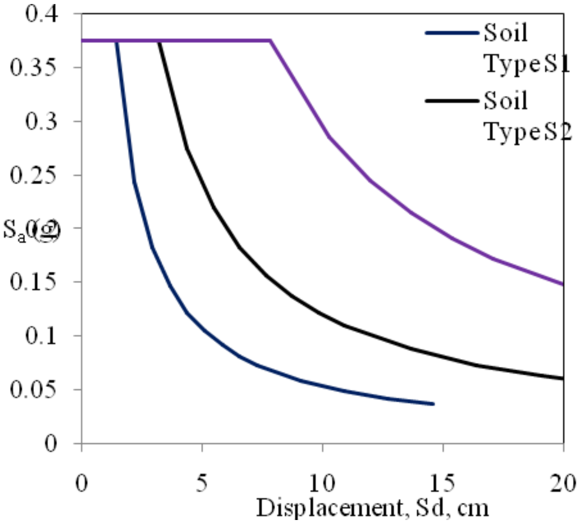


Figure 3: BNBC 1993 Spectra in ADRS format

ATC 40 Pushover Analysis:

Monotonically increased displacement based pushover analysis is performed under the application of gravity load. A six story 2D Reinforced Concrete (RC) frame structure modeled in SAP 2000 software to perform the pushover analysis. The nonlinear behavior is assumed to occur within frame elements with concentrated plastic hinges at the end. These plastic hinges are formulated as per ATC 40 guideline. To predict actual or close to the actual seismic behavior, different force distribution can be used to represent seismic load intensity. The magnitude of the lateral load is incrementally increased in accordance with predefined pattern as fundamental mode shape of the frame. The control node is used to monitor the displacement of the roof. Performance of the structure is evaluated if the structure meets a predescribed limit state.

Plastic Hinge:

Plastic hinges are defined at the end of the Beam and Column element as per FEMA 356 standard. The nonlinear load deformation relationship is shown in the Figure 4 where generalized force versus deformation curves used to specify component modeling and acceptance criteria for deformation-controlled actions (FEMA 356, 2000). The unloaded condition is expressed as point A whereas B corresponds to effective yield point. The slope of BC is generally taken from 0 to 10 percentage of the initial slope. This line BC represents strain hardening phenomena of the material. Point C represents the nominal strength and an abscissa value at which significant strength degradation begins (line CD). Beyond point D, the component responds with substantially reduced strength to point E. At deformations greater than point E, the component strength is effectively zero. These five points are used to define the hinge rotation behavior of RC members according to FEMA. Three more points corresponding to the target Building Performance Levels such as Collapse Prevention (CP), Life Safety (LS), and Immediate Occupancy (IO) are used to define the acceptance criteria for the hinge of primary members (P) and secondary members (S) as shown in Figure 4 ((FEMA 356, 2000).

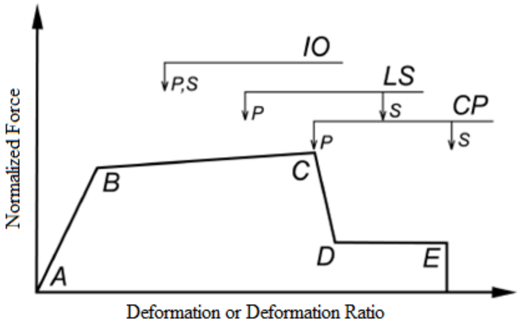


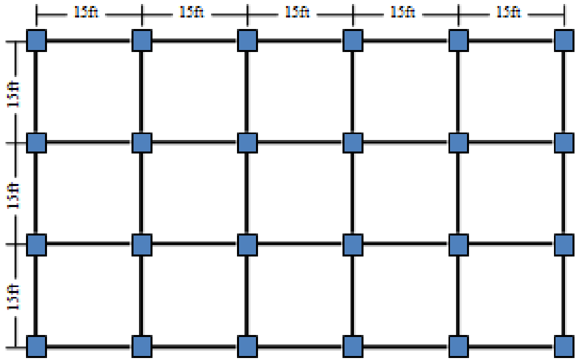
Figure 4: Force – Deformation Relation

Description of the Structure and Model:

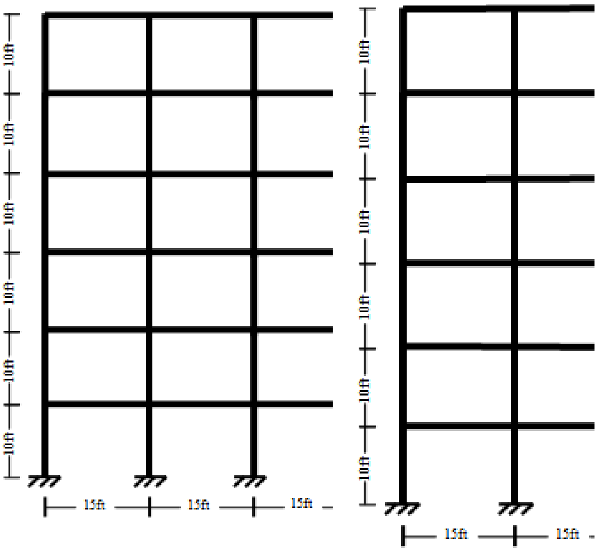
Two frames were chosen in this study for pushover analysis. One frame was considered from long direction and another was taken from short direction of the building. The frames are designed according to current BNBC 1993 codal provision with a moderate seismicity region with peak ground acceleration 0.15g. Material properties are assumed to be 3 Ksi for the concrete compressive strength and 60 Ksi for the yield strength of the longitudinal and transverse reinforcement. The building was 75 ft by 45 ft in plan dimension and the typical floor height is 10 ft. The building is symmetrical in the x and y directions, layout of the building and elevations are shown in the Figure 5. From the modal analysis it has been obtained that response of the structure is dominated by the first mode with a 79 percent participation factor, it is expected that the pushover analysis will yield realistic results. Parameters of the building are shown in table 1.

Table 1: Building Parameters

Floor Level	Beams (in x in)	Columns (in x in)		Modal Information		
		Interior	Exterior	Mode Number	Period	Participation Ratio
1-3	10 X 18	16 X 16	14 X 14	1 mode	0.93	0.796
4-6	10 X 18	14 X 14	12 X 12	2 mode	0.30	0.107



a) *Layout of the frame*



b) *Frame in the short direction*

c) *Frame in the long direction*

Figure 5: Plan and elevation of the structures

Results and Discussion:

2D model was created for two frames to perform the non linear static pushover analysis as per ATC 40. Beams and columns are modeled as nonlinear frame elements with lumped plasticity at the start and the end of each element. M3 hinges for beam and PMM hinges for column are applied as per FEMA-356. Two resulting capacity curves generated for the short and long direction are shown in Figure 6. These two curves reveal relatively similar behavior. The curves undergo inelastic formation after certain deformation obtained in the structure. For the short direction frame base shear obtained was 1335 KN, base shear for the long direction frame was 2118 KN. The target displacement obtained for the frame was 18 cm. The performance of the frames can be obtained from the intersection of the demand curve and capacity curve as shown in Figure 7. The short direction frame has relatively higher reserve strength than longer direction during lateral loading. The plastic hinges obtained at different performance levels are shown in figure 8. For both frames, plastic hinges formation started with beams and columns of lower stories, then propagated to upper stories and continue with yielding of interior columns in the upper stories. Damage will be limited in this building as the yielding is occurred up to LS limit.

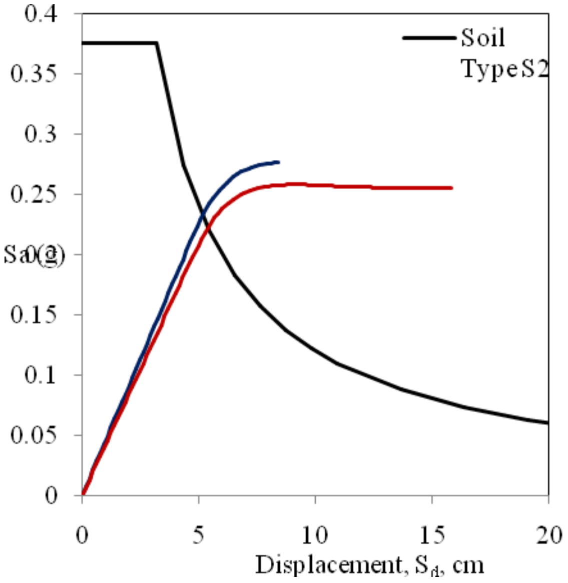


Figure 6: Elastic demand spectra versus capacity diagram

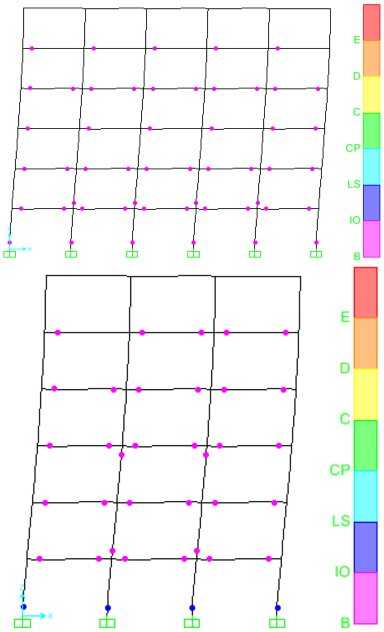


Figure 8: Formation of Plastic hinges.

Conclusions:

Pushover analysis for the reinforced concrete frame was evaluated following ATC 40 guideline. Then performance point was obtained from the capacity spectrum method. Response spectrum in BNBC 1993 was converted to acceleration demand spectra to evaluate the performance of the RC frames. The pushover analysis was relatively simple to identify the non linear behavior of the building. These reinforced concrete frames are adequate as indicated by the intersection of the demand and capacity curves and the distribution of hinges in the beams and the columns. Most of the hinges developed in the beams and few in the columns within the LS limit state. Performance of the structure can be termed as good as the building has a reasonable reserved strength under the design earthquake ground motion. A very few members of the frames are expected to experience limited damage under the design earthquake ground motion.

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