International Journal of Structural Analysis & Design– IJSAD
Volume 2: Issue 1 [ISSN : 2372-4102]
Publication Date : 30 April, 2015

Confinement Effect of Transverse Reinforcement on Bilinear Capacity Curve of RC Structure

Tanvir Manzur, Asifur Rahman and Shohana Iffat

***Abstract*—Pushover analysis or nonlinear static analysis is a very important tool for vulnerability assessment of building during a seismic event since it is relatively simple and convenient as compared to inelastic dynamic analysis. Pushover curve or capacity curve derived from this analysis can be represented by a bilinear capacity curve which depends on various structural parameters. Confinement of reinforcement of column plays an important role in overall lateral capacity of a structure. This paper aims to study possible effect of column confinement on bilinear capacity curve of typical RC frame structures in Bangladesh. Reinforced concrete building are modeled and analyzed for different transverse reinforcement spacing. Some other parameters like column size, beam size are also kept as variable based on typical construction practice in Bangladesh. It has been found that transverse reinforcement can significantly improve the lateral resistance of a structure depending on its spacing and strength of concrete.**

Keywords-confinement, nonlinear static procedure, pushover analysis, transverse reinforcement.

I. Introduction

Bangladesh is a country that is vulnerable to earthquake. Although a good number of buildings of Bangladesh are engineered, the construction quality of them is not satisfactory. In recent years, relatively small earthquakes are becoming more frequent in Bangladesh. As a result, there is a possibility of extreme devastation of life and property in future. Therefore, estimation and improvement of lateral capacity for RCC structures is necessary in Bangladesh. Most structures behave nonlinearly during an earthquake. It is therefore necessary to adopt a nonlinear analysis tool to understand their behavior during a seismic event. Pushover analysis, a nonlinear, inelastic, and static analysis, is a popular and widely used method among engineers because it is relatively simpler [1], [2] and more convenient than nonlinear dynamic analysis and can provide information that cannot be provided by linear static or dynamic analysis alone. An attempt has been made in this study to investigate the lateral resistance capacity of commonly used RC frame structures of the country considering typical dimensions and material characteristics. Confinement effect of transverse reinforcement can play an important role on overall lateral behavior of structure. However, no study is available on effect of such confinement on capacity curve of RC structure in Bangladesh. The finding of this study will help in understanding the behavior of typical RC structure under lateral loading in post yield zone and in quantifying the contribution of confinement effect of transverse reinforcement on lateral capacity of structure.

Tanvir Manzur, Asifur Rahman & Shohana Iffat
Department of Civil Engineering
Bangladesh University of Engineering and Technology

II. Pushover analysis and performance level

Specialized computer program such as SAP2000, OpenSees or Drain2DX are often used to carry out pushover analysis [3]. The first step to perform pushover analysis is to design the structure and then it is modeled in a specialized computer program. After that, the structure is displaced laterally by applying incremental lateral deformation at the top story, which is increased monotonically with time [4]. This lateral displacement creates base shear, which also in turn increases as lateral displacement increases. At each increment of displacement, corresponding base shear is recorded by the analysis program. These recorded values are then used to plot a curve which is known as pushover curve. It consists of base shear in horizontal axis and lateral displacement in vertical axis. If done properly, this pushover curve can provide valuable information about overall lateral resistance capacity of structure. It can be converted to capacity curve, which is a plot of spectral acceleration versus spectral displacement. This capacity curve is used to find the amount by which a structure is likely to displace for a specific level of ground motion that is known as target displacement [5].

Using this target displacement, the performance level of the structure during quake can be determined. A typical base shear and deformation relationship with performance level is shown in Fig 1. These performance levels, which are defined in FEMA 356 [6], are of four types.

Operational Level (OL): Negligible structural and nonstructural damage or no damage at all, during an earthquake. The building is suitable for its normal function. Utilities are available after earthquake.

Immediate Occupancy (IO): Negligible structural damage and nonstructural damage is minor. It is safe to reoccupy the building after the quake but utilities such as power or water are likely to be interrupted.

Life Safety (LS): Significant structural damage is expected while nonstructural damage is extensive. Repair may be required before reoccupy the building and it may not be economically practical to repair.

Collapse Prevention (CP): Structural and nonstructural damages are extreme. Substantial reduction of strength and stiffness of lateral force resisting system has occurred. Gravity load carrying capacity has reduced significantly. The structure is likely to be abandoned.

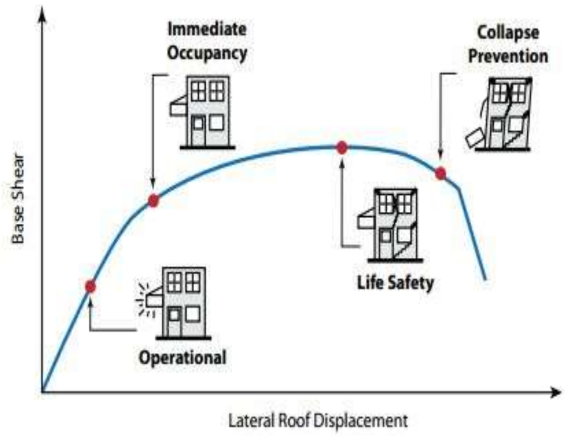

Figure 1. Performance level concept of FEMA 356

Modeling is an important step in pushover analysis. Nonlinear behavior of material, elements and structure must be considered. Modeling and analysis procedure for pushover analysis are documented in FEMA 356 [6] and ATC 40 [7]. These two documents are widely used due to convenience and simplicity. Programs like SAP2000, OpenSees or Drain2DX has already implemented these nonlinear modeling criteria. The OpenSees is used for pushover analysis in this study, which is a finite element program developed by Pacific Earthquake Engineering Research Center (PEER) and is being widely used for research purposes. Unlike other programs, OpenSees can create fiber based sections for concrete. Moreover user can place steel reinforcement at any location of that section according to their necessity. Open Sees also allows to model transverse reinforcement by providing a specific pattern and spacing of them Mazzoni et al. [8].

III. Bilinear representation of capacity curve

Capacity curve found from pushover analysis can be represented by a bilinear curve. A typical form of bilinear curve is shown in Fig 2. The base shear coefficient is the ratio of base shear to total building weight and drift ratio is the ratio of lateral displacement to total height of the building. The V_y and δ_y represent base shear and displacement when sufficient yielding of the system has taken place, V_u and δ_u corresponds to their values when the structure has reached to its deformation capacity.

IV. Description of structure

Most of the residential apartment buildings in Bangladesh are six stories in height, so the analysis was performed on a typical two dimensional reinforced concrete frame of six story. A survey was previously conducted by Manzur et al. [9] to obtain data on typical material properties and various members' dimensions of common residential buildings. It was found that most of the residential apartments are regular in shape and have typical dimensional ranges. Fig 3 shows the elevation of a two dimensional RCC frame structure used for pushover analysis in OpenSees environment. The frame structure is regular in shape with typical bay width and story height of 15ft and of 11ft, respectively.

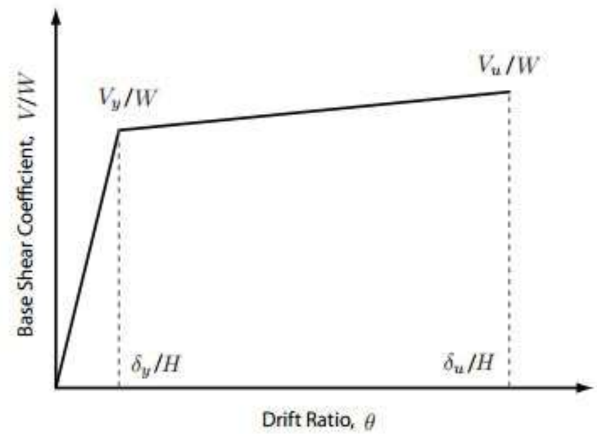

Figure 2. A typical bilinear capacity curve

Concrete compressive strengths were varied to reflect the common design practice and field condition of mixing in the country. For Case A, mean compressive strength of 2000 psi and standard deviation of 400 psi was considered. For Cases 2 and 3, these values were 3000 psi, 300 psi and 4000 psi, 200 psi, respectively. These data were collected from Public Works Department of Bangladesh [9]. Since steel is manufactured in mill, its quality is not ensured by field workers. That is why yield strength of it was considered fixed, equal to 60000 psi.

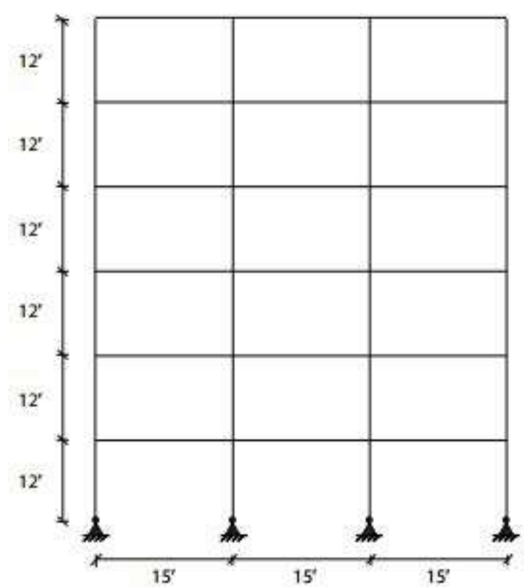

Figure 3. Six story 2D RCC frame developed in OpenSees

The beams were designed according to gravity load of the structure. For a single case, beams were considered equal in size but are deviated by ±0.5 inch, which are typical construction error in Bangladesh [9], [10]. Concrete cover from center of the outermost reinforcement to the edge of concrete was taken as 2.5 inch. Reinforcement and concrete cover are kept constant.

Mean column sizes were taken equal to 10 by 10 inch, 12 by 12 inch and 15 by 15 inch to incorporate variability in column sizes. However, columns were also deviated by ±0.5 inch to accommodate typical construction error. The amount of reinforcement was kept around 2~3 percent and #10 transverse reinforcement was used (see, Fig 4) for their arrangement.

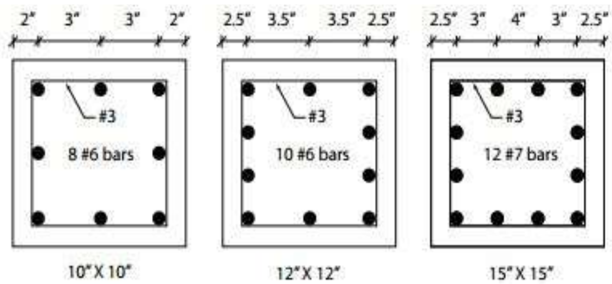

Figure 4. Reinforcement detail of column

V. Analysis procedure

Since probabilistic analysis requires a set of data, a program needs to generate this data set. MATLAB function random is useful for this purpose. It can create specific amount of sample, say 20 or 50, if mean and standard deviation is provided. For each test case, 50 random samples of concrete compressive strength were generated among which 10 were randomly chosen for pushover analysis. Same procedures were adopted for dimensional parameters of beam, column and slab, i.e. 10 samples were chosen among 50 random samples of each criteria.

The analyses were carried for column with transverse reinforcement spacings of 4, 6, 8, 10 and 12 inch. For each selected case, all of the spacings were analyzed. For example, for Case A, those chosen ten random samples of concrete compressive strengths and dimensional parameters were used to analyze the structure ten times only for 4 inch spacing, resulting ten pushover curves. After that analysis was carried for 6 inch spacing and so on. Similar procedure was adopted for other test cases.

VI. Discussion of results

For all the cases, i.e. Case A to Case C, it was observed that increase in column size and column reinforcement resulted in increase in base shear capacity. Mean base shear coefficient for Case A was around 0.030, for Case B was 0.065 and for Case C was around the value of 0.150 according to Fig 5, 6 and 7.

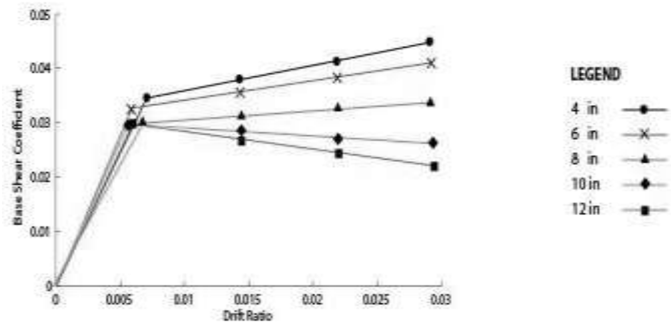

Figure 5. Bilinear capacity curves for Case A

At a particular case, for any value of transverse reinforcement spacing, the first segment of bilinear curve remains very close to each other up to any hinge formation. After that, nonlinear behavior of structure starts and the bilinear curves are found to be governed by their respective transverse reinforcement spacing. It is also observed that, before yielding, transverse reinforcement spacing does not play any noticeable behavior in bilinear capacity curve of the structure. But as soon as the structure experiences nonlinearity, transverse reinforcement spacing plays a significant role in post yielding behavior.

MATLAB function “trapz” can calculate the area covered by any arbitrary curve by dividing it into small trapezoidal segments, which is illustrated in Fig 8. Using this function, it is found that, changing transverse reinforcement spacing form 8 inch to 4 inch, increases the total energy absorption capacity of the frame structure by about 12 percent for Case A, 8 percent for Case B and 6 percent for Case C.

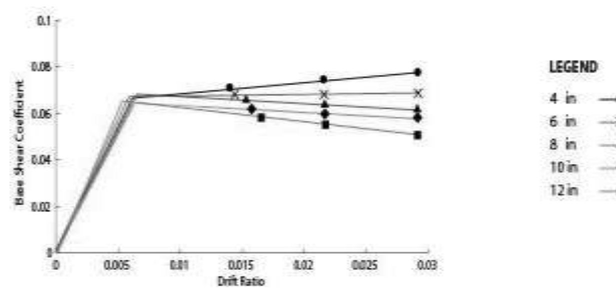

Figure 6. Bilinear capacity curve for Case B

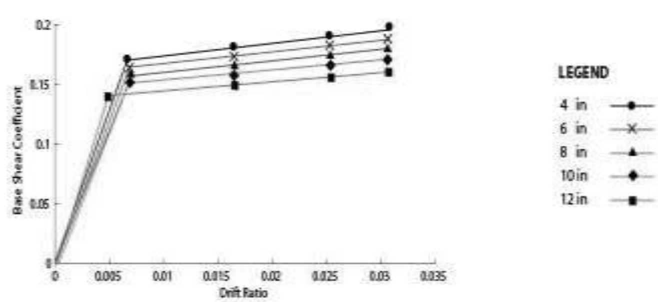

Figure 7. Bilinear capacity curve for Case C

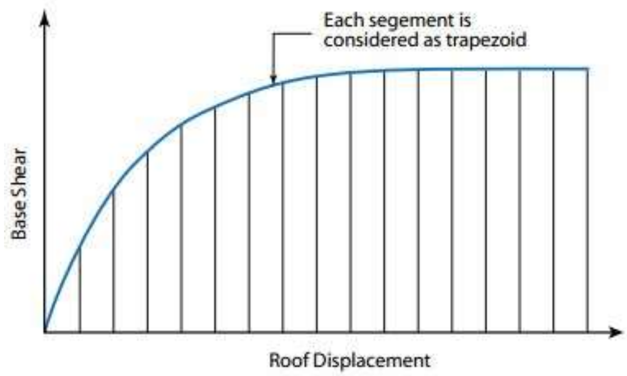

Figure 8. Area calculation by trapezoidal rule

Another noticeable characteristic of bilinear curves is that, increasing transverse reinforcement spacing in Case A and B, causes the bilinear curve to slope from upward to downward in post yield segment. But for Case C, post yield slope is almost same and always slopes upward, but with decreasing base shear coefficient. It indicates that, with higher concrete strength and steel percentage, capacity curves have higher slopes during post yield segment in all cases.

VII. Conclusion

For seismic vulnerability assessment of building, pushover analysis is a widely used analysis tool. It is obvious that confinement mechanism of transverse reinforcement has effect on pushover curve and thus on bilinear capacity curve of any RCC structure. An attempt has been made in this study to quantify the effect of transverse reinforcement on lateral capacity of RCC frame structure. From the analyses, it is observed that, changing transverse reinforcement spacing of column has significant effect on base shear capacity and energy absorption of a reinforced concrete structure. The controlling factors are spacing of transverse reinforcement and strength of concrete. High strength concrete is less affected by spacing of transverse reinforcement of column rather than that of relatively lesser strength of concrete. Findings of the study show the potential to carry out further research to obtain an optimum transverse reinforcement spacing and corresponding strength of concrete for RCC structures of Bangladesh to optimize lateral resistance.

References

[1] G. Panagopoulos, C. Panagiotopoulos and A. Kappos, Derivation of capacity curves for reinforced concrete frame and dual structures, European Conference on Earthquake Engineering, Ohrid, Macedonia, 2010.

[2] P. Fajfar, A nonlinear analysis method for performance based seismic design, Earthquake Spectra, 16(3), 573-592, 2000.

[3] M. Inel and H. B. Ozmen, Effects of plastic hinge properties in nonlinear analysis of reinforced concrete buildings, Engineering Structures, 28, 1494-1502, 2006.

[4] P. Poluraju and P. V. S. N Rao, Pushover analysis of reinforced concrete frame structure using SAP2000, International Journal of Earth Sciences and Engineering, 4(6),684-690, 2011.

[5] A. Kadid and A. Boumrkik, Pushover analysis of reinforced concrete frame structures, Asian Journal of Civil Engineering (Building and Housing), 9(1), 75-83, 2008.

[6] FEMA-356, Prestandard and Commentary for the Seismic Rehabilitation of Buildings, 2000.

[7] ATC-40, Seismic Evaluation and Retrot of Concrete Buildings. USA, 2006.

[8] S. Mazzoni, F. McKenna, M. H. Scott and G. L. Fenves, OpenSees Command Language Manual, 2007.

[9] T. Manzur and M. A. Noor, Displacement Based Fragility Curves for R.C.C. Frame Structures in Context of Dhaka, Bangladesh, Proceedings of the 6th APSEC Conference, Kuala Lumpur, Malaysia, 2006.

[10] M. A. Noor and T. Manzur, Development of fragility curves for RCC frame structures : Bangladesh context, First Bangladesh Earthquake Symposium, Dhaka, Bangladesh, 2005.

About Author (s):

Tanvir Manzur, Ph.D., Assistant Professor, Bangladesh University of Engineering and Technology
Changing transverse reinforcement spacing of column has significant effect on base shear capacity and energy absorption of a RCC structure.

Asifur Rahman, Undergraduate Research Student, Bangladesh University of Engineering and Technology
It is obvious that confinement mechanism of transverse reinforcement has effect on pushover curve and thus on bilinear capacity curve of any RCC structure.

Shohana Iffat, Lecturer, Bangladesh University of Engineering and Technology
High strength concrete is less affected by spacing of transverse reinforcement of column rather than that of relatively lesser strength of concrete.