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Seismic Vulnerability & Retro Fit of RC Flat Plate Structure

Mohammad Jahangir Alam[1] and Ajoy Paul[2]

Abstract

Flat-plate system has become one of the most popular practices now-a-days, primarily for architectural flexibility, use of space, easier formwork and shorter construction time. However, the structural efficiency of the flat-plate is hindered by its poor performance under earthquake loading. Post-earthquake observations and experimental testing have shown that lateral movements induced by earthquake can make the connections between slabs and columns susceptible to punching shear failures. Though Reinforced Concrete Frame (RCF) is widely used in Bangladesh, flat-plate constructions are also becoming a common practice. BNBC and ACI have suggested that flat-plate frames can be designed either by Direct Design or Equivalent Frame Method. The present study deals with the seismic evaluation of existing flat plate structure using inelastic method (Pushover analysis). The load-deformation curve (i.e. capacity curve) is obtained using ETABS. The performance point has been determined by superimposing the capacity spectrum with the normalized response spectra for 5% damping ratio as mentioned in BNBC. The methods for evaluating the performance level have been determined using procedures presented in FEMA-356 & ATC-40. Many existing flat plate buildings in Bangladesh may not have been designed for seismic forces. Hence, it is important to study their response under seismic conditions and to evaluate seismic retrofit schemes. Based on the seismic evaluation results, two possible retrofit techniques were applied to improve the seismic performance of an existing Nine-storied flat plate building which was considered as a model representative of all flat plate buildings in Bangladesh.

Key Words & Phrases: *Punching shear, Pushover, Retrofit, unbalanced moment.*

1. Introduction

Earthquake phenomenon is not new in Bangladesh and often feels tremors that are caused by earthquake activities from countries nearby. The occurrence of earthquake does not only cause damage to properties but also threats to public safety.

Based on geometric location that quite near to an earthquake act zone, any structure has a chance to fail especially for flat Plate structures.

Many existing flat plate structures located in seismic regions are inadequate for lateral resistance based on current seismic design codes. In general, flat plate

1&2, Professor, Department of Civil Engineering & PhD Student respectively, Department of Civil Engineering, Chittagong University of Engineering & Technology, Bangladesh.

buildings that were constructed before the 1980s have significant deficiencies in their overall structural configuration, such as insufficient thickness of slab, discontinuity of positive reinforcement in edge beams and slabs, or wide spacing of transverse reinforcement.

A serious problem that can arise in flat plates is brittle punching failure due to the transfer of shearing forces and unbalanced moments between slabs and columns (Hueste and Wight, 1997; Megally and Ghali, 2000). Under earthquake actions, the unbalanced moments can produce high shear stresses in the slab-column connection. Because of the absence of deep beams and shear walls, are resulting in low transverse stiffness. This induces excessive deformations which in turn causes damage of structural & non-structural members even when subjected to earthquakes of moderate intensity.

This paper investigates the seismic performance of existing RC flat plate structure using both linear and non-linear analysis and evaluates of seismic performance of strengthened structure and compares it with the original structure.

2. Methodology

Seismic lateral forces on primary framing systems shall be determined by using either the Equivalent Static Force Method or the Dynamic Response Method as mentioned in Bangladesh National Building Code (BNBC). The Dynamic Response method, where used, shall be based on one of the dynamic analysis procedures like Response Spectrum Analysis. The normalized response spectra as given in Figure 1 shall be used in the dynamic analysis. The site soil characteristics as mentioned in BNBC are presented in Table 1.

The capacity curve is derived from an approximate nonlinear analysis (pushover) for the structure. In the process of performing this incremental nonlinear static analysis, a capacity curve is developed for the building. This capacity curve is simply the plot of the total lateral seismic demand "V", on the structure, at various increment of loading, against the lateral deflection of the building at the roof level, under that applied lateral force. The push-over analysis is performed using ETABS software. A Typical capacity curve has been shown in Figure 2.

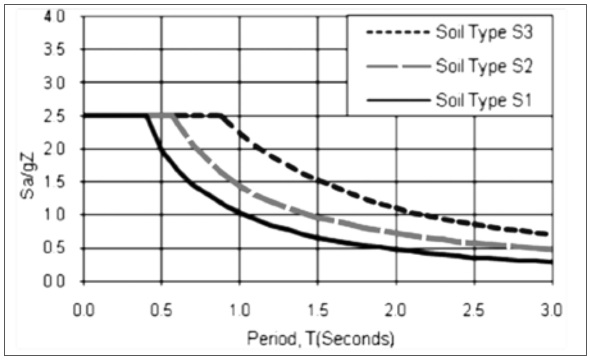

Figure 1: Normalized Response Spectra for 5% Damping Ratio as per BNBC

The existing flat plate structure is modeled using the concrete strength 3,000 psi and steel strength 60,000 psi and assigned all the columns, edge beams and slabs including with their reinforcement, all loads (dead load, live load and seismic load) and user defined hinges. P-M-M hinges are considered at the end of the column members.

Table 1 : The site soil characteristics for seismic lateral forces

Type	Description
S1	Rock and Stiff Soils
S2	Deep Cohesion less or Stiff Clay Soils
S3	Soft to Medium Clay and Sand

The frame is modeled considering the beam or girder as 'equivalent beam' having depth equal to thickness of the slab whereas the slab is considered as shell element.

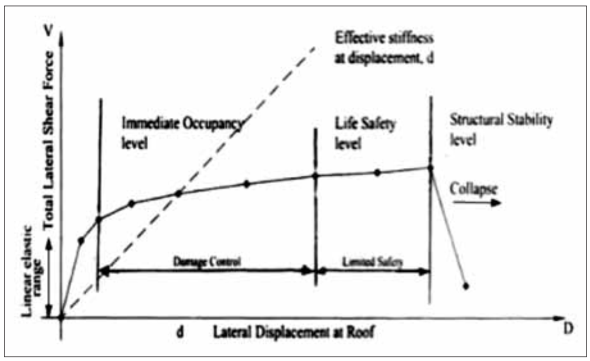

Figure 2: Typical Capacity Curve (ATC-40)

3. Push Over Analysis

Non-linear static pushover analysis is an attempt to evaluate the real strength of the structure and it promises to be a useful and effective tool for performance based design. The ATC-40 and FEMA-356 documents have developed modeling procedures, acceptance criteria and analysis procedures for pushover analysis. These documents define force-deformation criteria for hinges used in pushover analysis. As shown in Figure 3, five points labeled A, B, C, D, and E are used to define the force deflection behavior of the hinge and three points labeled IO, LS and CP are used to define the acceptance criteria for the hinge. (IO, LS and CP stand for Immediate Occupancy, Life Safety and Collapse Prevention respectively.)

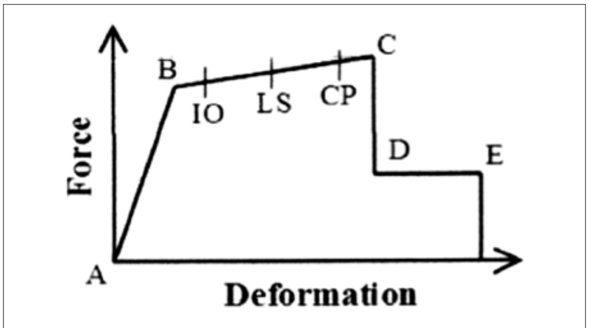

Figure 3: Force-Deformation for Pushover Hinge

A pushover analysis is performed by subjecting a structure to a monotonically increasing pattern of lateral loads, representing the inertial forces which would be experienced by the structure when subjected to ground shaking. Under incrementally increasing loads various structural elements may yield sequentially. Consequently, at each event, the structure experiences a loss in stiffness. Using a pushover analysis, a characteristic non linear force displacement relationship can be determined.

The ETABS having static pushover analysis capabilities, which are fully integrated into the program, allow quick and easy implementation of the pushover procedures prescribed in the ATC-40 and FEMA-356 documents for both two and three-dimensional analysis of structures.

4. Performance Point & Levels

Performance point can be obtained by superimposing capacity spectrum and demand spectrum and the intersection point of these two curves is called performance point. The main output of a pushover analysis is in terms of response demand versus capacity. If the demand curve intersects the capacity envelope near the elastic range, then the structure has a good resistance. If the demand curve intersects the capacity curve with little reserve of strength and deformation capacity, then it can be concluded that the structure will behave poorly during the imposed seismic excitation and need to be retrofitted to avoid future major damage or collapse.

The structural performance level shall be selected from three discrete performance levels as mentioned in section 3. For evaluating the structure based on the FEMA 356 global-level criteria, the maximum inter story drift values (Table 2) are taken from the inter story drift limits for three structural performance levels for concrete frame structure.

Table 2 : Global-level drift limits in FEMA 356

Structural performance level	Drift (%)
Immediate Occupancy (IO)	1
Life Safety (LS)	2
Collapse Prevention (CP)	4

5. Case Study

To evaluate the seismic performance of a flat plate RC frame structure, analyses of a typical prototype of a nine storied residential building in Chittagong, port city of Bangladesh has been selected as shown in Figure 4. The soil profile has been characterized and selected as S3. Beams are found at the periphery of the structure. Ground floor is used for parking space (soft story). The structure is found irregular in plan and elevation. A three-dimensional model for this structure has been established using ETABS as shown in Figure 5. The structure has been considered as Ordinary Moment Resisting Frame (OMRF).

Linear static & dynamic analysis has been performed and the seismic lateral force and shear force at each floor have been presented in Table 3. The dynamic properties e.g. natural periods and mode shapes have been carried out by free vibration analysis. The three mode shapes with different time periods T1=0.841 sec for mode 1, T2=0.382 sec for mode 2 and T3=0.254 sec for mode 3 have been calculated and represented in Figure 6.

It has been seen that the first mode excites 82% of the total mass. Hence, in this case, total requirements on number of modes to be considered tends to or more than 90% of the total mass is excited will be satisfied by considering the first mode of vibration only. However, for illustration, solution to this example considers the first three modes of vibration.

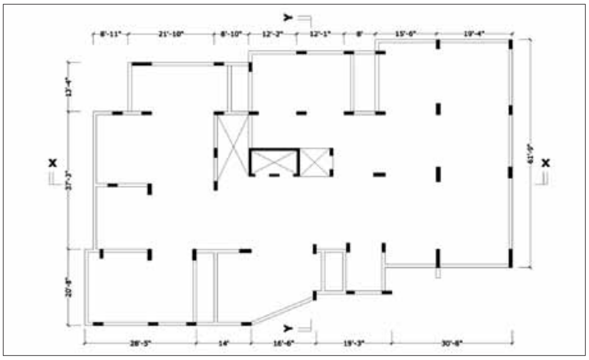

Figure 4: Characteristic plan of the structure

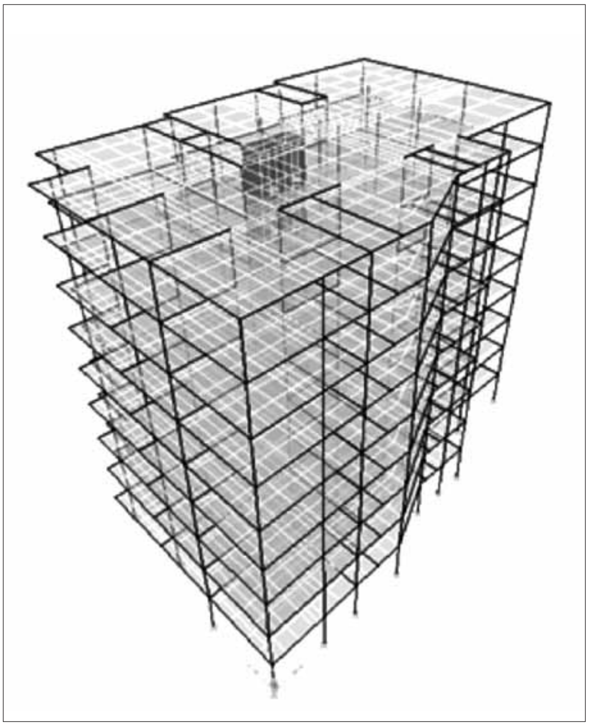

Figure 5: Characteristic 3D model of the structure

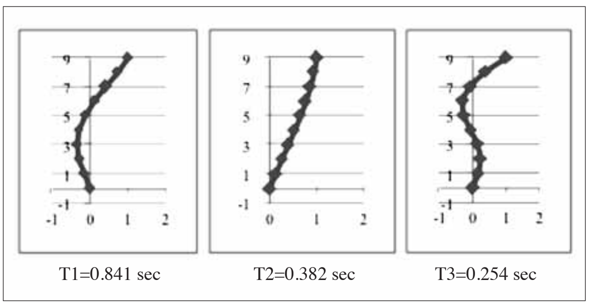

Figure 6: The Mode shapes of first three modes

Table 3 : Comparison of seismic lateral force (Q) and shear force (V) at each floor by linear analysis

Mass No.	Q		V	
	Static	Dynamic	Static	Dynamic
i	kN	kN	kN	kN
9	606.65	163.31	606.65	163.31
8	582.74	254.46	1189.39	417.77
7	509.90	239.61	1699.29	657.38
6	437.05	216.24	2136.34	873.61
5	364.21	185.18	2500.55	1058.79
4	291.37	147.53	2791.92	1206.32
3	218.53	104.65	3010.45	1310.97
2	145.68	58.04	3156.13	1369.01
1	72.84	9.37	3228.97	1378.37

6. Result And Discussions

The building performance level has been evaluated by FEMA 356 acceptance criteria as shown Table 2 and obtained close to as Immediate Occupancy (IO) level for both X & Y direction as shown in Figure 7 and Figure 8. In Push over analysis hinges started forming in A-B stage and subsequently proceeding to B-IO and IO-LS stage.

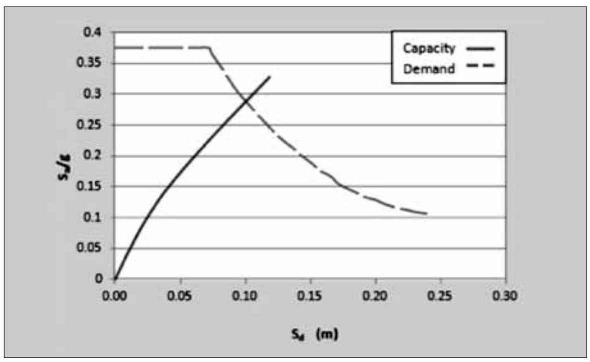

Figure 7: Seismic Demand vs Capacity in X direction

At performance point, where the capacity meets demand, in X direction out of 2124 assigned hinges 1653 were in A-B stage, 460, 11 and 0 hinges are in B-IO, IO-LS and LS-CP stages respectively. Similarly, in Y direction out of 2124 assigned hinges 1685 were in A-B stage, 391, 48 and 0 hinges are in B-IO, IO-LS and LS-CP stages respectively.

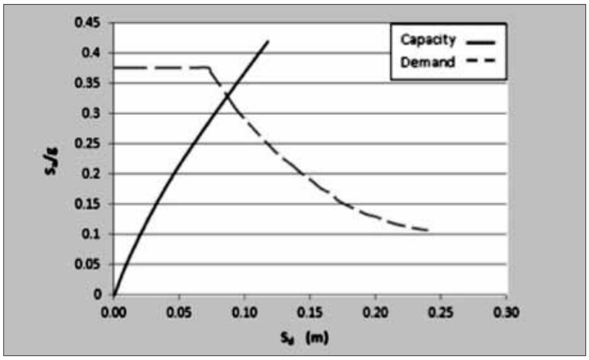

Figure 8: Seismic Demand vs Capacity in Y direction

7. Retrofitting Techniques

The retrofitting of the reinforced concrete structures usually has the objective of increasing the strength, the stiffness and/or the capacity of post-elastic deformation of the existing structural elements (e.g. beam, column, slab) or the transformation of the entire structural system. In present case study the following two cases have been modeled and analyzed in order to increase the structural performance by strengthening of the existing structure.

Retrofit level	Retrofit Technique	Rehabilitation objective
Global	Addition of shear wall at Parking floor.	To reduce the lateral deflection.
Member	Addition of column drop panel.	To resist the punching shear failure.

For Global level retrofitting, the shear walls are selected to add in Ground floor in both x and y directions at suitable locations without making any obstacles for the drive ways. Both exterior and interior shear walls have been selected for this purpose. The connection between the existing column and the new shear wall has been considered as pinned joint. The thickness of new shear wall has been considered as 0.30 m which is as equal as column width. All geometry, load, material, support data are same as previous analysis. Non-linear Pushover analysis has been performed and the performance of the structure has been found improved as compared to original structure in both x and y direction as shown in Figure 9 and Figure 10.

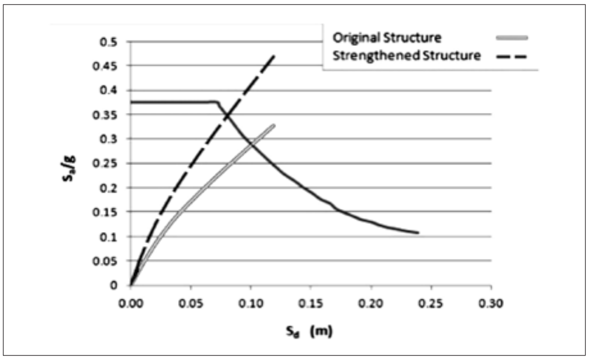

Figure 9: Effect of structural strengthening (X direction)

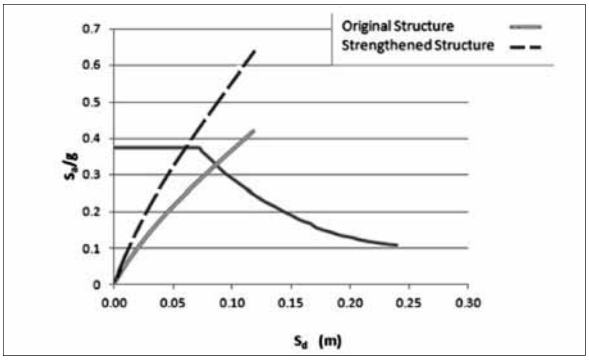

Figure 10: Effect of structural strengthening (Y direction)

For Member level retrofitting, addition of column drop panel may be the suitable solution to resist the punching shear failure. The punching phenomenon is preceded by the opening of circular cracks around the top part of the column due to radial negative bending moments, then radial cracks start to open from the column due to tangential bending moments.

8. Conclusion & Recommendation

Based on the present study, the following conclusions can be drawn:

a) From the study, it can be concluded that the purely flat-slab RC structural system is considerably more flexible for horizontal loads than the traditional RC frame structures which contributes to the increase of its vulnerability to seismic effects.

b) The shear force distribution given by the linear static method on the higher side as compared to the linear dynamic method. The linear static method may be deemed to be a sort of upper bound.

c) The capacity curves developed for flat plate slab system gets steeper even in the inelastic range. This is due to the high structural stiffness especially for the columns. The variability of the inter-story drift at high seismic intensity levels is much more pronounced relative to the variability at low intensity levels.

d) In case of strengthening the structure using shear walls at parking floor, the lateral deflection has been reduced by 25.81% in X direction and 29.63% in Y direction. Because the stiffness of the shear wall in Y direction is more than in X direction.

e) In this study when shear wall is provided in the X direction of the building, an increase of 15.28% of base shear results a decrease of 23.53% of lateral drift and whereas in the Y direction an increase of 15.32% of base shear results a decrease of 30.0% of lateral drift.

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