Seismic Vulnerability Assessment and Evaluation of High Rise Buildings in Islamabad

A.Q. Bhatti
National University of Sciences and Technology (NUST), Islamabad, Pakistan

H.Varum
University of Aveiro, Portugal

Zeeshan Alam
National University of Sciences and Technology (NUST), Islamabad, Pakistan

SUMMARY

Primarily the aim of this research is to carry out seismic evaluation study of buildings structures in Islamabad in order to propose basic guidelines and suggestions for Pakistan Code. Knowing the important nature of the subject, the earthquake based organizations are serious to compile a document for seismic threatened countries and areas. It is aimed that the document will work as a guideline source for the seismic evaluation, calculation and assessment of strength, behavior and expected performance and also the safety of already existing buildings. This study is based on review of already available documents on seismic vulnerability and evaluation of present buildings at different sites is carried out in order to know the key components of this very procedure so that it can be used in Pakistan and also in other developing countries as well. This would not only be robust, safe and reliable, but also can be convenient to use within the domain of available resources. ASCE 31-03 guidelines among the available documents are considered to be a suitable and the most reliable for to be in Pakistan.

Keywords: ASCE 31-03, Evaluation Procedures of Existing Building, Nonlinear Dynamic Analysis

1. INTRODUCTION

Oct. 8, 2005 Earthquake is a parameter for seismic vulnerability and seismic risks of buildings that are present in Pakistan. Soon after the devastating earthquake the code writers made a revision for the design provision of newly constructed buildings to make an adequate ductility in order to resist high magnitude earthquakes, but the issue remains still aggravated as there is magnitude of thousands of square feet in concrete buildings which are non-ductile. This general risk is inevitable as it could lead to a huge catastrophe as a consequence. Seismic retrofitting for the existing structures can be one of the significant and most effective ways to reduce the indicated risk. The possible deficiencies in these buildings structures are usually not clearly apparent. Unluckily guidelines to identify and then to retrofit effectively those which are vulnerable to damage or collapse have not yet included in Building Code of Pakistan. (BCP, 2007). It is therefore important to include guidelines for seismic vulnerability and evaluation of buildings in building code of Pakistan. Islamabad is a city of numerous moderate to high rise buildings many of which were constructed before the gigantic earthquakes on October 8. Therefore it is the hardest requirement to carry out the seismic evaluation of these buildings for the sake of safer human lives.

2. DESCRIPTION OF BUILDING & BUILDING SITE

The building under study has ten storey's including basement. RC Frame structure where a shear wall was constructed at one end i.e. Lift Well. The wall was constructed in 1991 as per Building Code of Pakistan 1985. The building under consideration has a raft foundation with bearing capacity of 1 tsf and site class D (ASCE, 2005). The Building lies in Seismic Zone 2B as per BPC 2007. The seismic hazard indicated by Bhatti et al, 2011a and 2011b, Spectral acceleration at 1 second, S_1 = 0.15g and Shorter period spectral acceleration, S_S = 0.82g. The considered tower has another tower of same story heights in the surroundings. The nature of partition walls is Brick masonry and Block masonry. Building also contains some minor level cracks. Presently the building is kept vacant because of seismic risk. The analysis regarding material strength are, *f'c = 3 ksi*, & *fy = 60 ksi* (Clough and R.W., 1960). Since the structural drawings of the said building were available so it is therefore believed that building construction is as per drawing, also since the adjacent building has the same story heights with same number of stories (D'Ayla et al, 2002).

Photo 1. Collapse of Margalla Tower during Oct 8, 2005 Earthquake

2.1 BASIC STRUCTURAL GERNAL CHECKLIST

The non Structural checklists should be considered in Tier 1. The evaluation procedure carried out for the existing high rise building is described as follow (ASCE 31-03, 2003).

General

C NC N/A LOAD PATH: For Life Safety and Immediate Occupancy the structure must contain a complete load path for the effects of seismic force from any horizontal direction which serves as to translate the inertial forces to foundation from bulk.

C NC N/A ADJACENT BUILDINGS: For Life Safety and Immediate Occupancy the adjacent building should not be located in the premises of building being evaluated at about 4%. Moreover the adjacent buildings are of same number of stories and height.

C NC N/A MEZZANINES: Interior mezzanine levels should be anchored to the lateral-force-resisting elements of the main structure or braced independently from the main structure.

Configuration

C NC N/A WEAK STORY: For Life-Safety and Immediate Occupancy lateral force re-sisting system should be of strength not less than 80% in stories adjacent "Lateral force resisting system reduces to half from story 7 to 8"
\

C NC N/A SOFT STORY: In any story the lateral-force-resisting system should be stiff enough that it for any story its stiffness shout not be less than 70% of the stiffness of adjacent story above or below it and should not be less than 80% of the average stiffness of the three stories above or below for Life-Safety and Immediate Occupancy.

C NC N/A

GEOMETRY: The lateral-force-resisting system should be saved from more than 30% changes in horizontal dimension for a story adjacent to relative stories for Life Safety and Immediate Occupancy, excluding one-story penthouses.

C NC N/A

VERTICAL DISCONTINUITIES: lateral-force-resisting system should contain all the vertical elements in continuous way in to the foundation.
"All columns and shear walls are continuous to the foundation"

C NC N/A

MASS: For Life Safety and Immediate Occupancy the effective mass should not be changed more than 50% from one story to the next story.
"There is about 50% difference of mass b /w story 7 &8"

C NC N/A

TORSION: For Life Safety and Immediate Occupancy the distance b/w center of mass of one story and the center of rigidity should be less than 20% of the building width in either plan dimension. (Tier 2: Sec. 4.3.2.6)
"Center of mass & centre of rigidity differ by more than 20%. The difference is shown in the table given in the appendix c"

Condition of Material

C NC N/A

DETERIORATION OF CONCRETE: In any vertical- or lateral-force-resisting elements there should be no visible denaturing and deterioration of steel or concrete.
"On the site visit, visible cracks were observed in the building"

C NC N/A

POST-TENSIONING ANCHORS: In the region of end fittings or post-tensioning there should be no corrosion or spelling. The use of Coil anchors should be avoided.

2.2 LATERAL FORCE RESISTING SYSTEM

General

C NC N/A

REDUNDANCY: The total number of lines of moment frames in all principal direction should be greater than or equal to two for Life Safety and Immediate Occupancy. The total number of bays of moment frames in each line should be greater than or equal to two for Life Safety and three for Immediate Occupancy.

Moment Frames With Infill walls

C NC N/A

INTERFERING WALLS: All the infill walls which are placed in moment frames should be isolated and separated from structural elements.

Concrete Moment Frames

C NC N/A

SHEAR STRESS CHECK: The magnitude of shear stress in concrete columns which are calculated by the Quick Check procedure at Section 3.5.3.2, should be less than 100 psi or two for Life Safety and Immediate Occupancy.
"Calculation of Average stress is shown in appendix B; the average shear stress is exceeding the limit in all the stories"

C NC N/A

AXIAL STRESS CHECK: The magnitude of axial stress which is due to the gravity loads in the columns shall be less than 0.10f'c for Life Safety and Immediate Occupancy, or Alternatively, the axial stresses due to overturning forces alone, calculated using the Quick Check Procedure of Section 3.5.3.6, shall be less than 0.30f'c for Life Safety and Immediate Occupancy.

Concrete Shear Walls

C NC N/A SHEAR STRESS CHECK: In the concrete walls, the shear stress calculated by using the Quick Check procedure of Section 3.5.3.3, should be less than 100 psi for Life Safety and Immediate Occupancy.
"Shear stress is greater than 100 psi"

C NC N/A REINFORCING STEEL: The net ratio of area of reinforcing steel to the net area of concrete should be larger than 0.0015 in vertical direction while in the horizontal direction it should be greater than 0.0025 for Life Safety and Immediate Occupancy. The gaps between reinforcing steel should be equal to or less than 18" for Life Safety and Immediate Occupancy.
"Structure drawing shows that these limits are fulfilled"

2.3 CONNECTIONS

C NC N/A CONCRETE COLUMNS: All the concrete columns should be doweled into foundation for Life Safety and also the dowels should be able to create tensile capacity of the column for quick and immediate Occupancy.

C NC N/A TRANSFER TO SHEAR WALLS: Diaphragms should be connected and reinforced so that, they can transfer the loads to the shear walls for Life Safety while the connections between them should be able to create the shear strength of the walls for Immediate Occupancy.

C NC N/A WALL REINFORCING: Walls should be doweled into the foundation for Life Safety and also the dowels should be able to create the strength of the walls for Immediate Occupancy.

C NC N/A SHEAR-WALL-BOUNDARY COLUMNS: The shear wall boundary columns should be connected and anchored to the foundation of the building for Life Safety and the anchorage should be able to create the tensile ability or capacity of the column for Immediate Occupancy.

Geologic Site Hazards

C NC N/A LIQUEFACTION: Within the foundation soil at about 50 feet deep the presence of loose granular soils, Liquefaction susceptible, saturated should not be present because they could jeopardize the building's seismic efficiency or performance. So this could be done for Life Safety and Immediate Occupancy. (Tier 2: Sec. 4.7.1.1)

C NC N/A SLOPE FAILURE: The building site must preferably be significantly remote from the possible earthquake-induced slope failures or due to the rock falls to be unaffected by such failures or should be able for accommodating and supporting any predicted movements without any failure. (Tier 2: Sec. 4.7.1.2)

C NC N/A SURFACE FAULT RUPTURE: The surface fault rupture or surface displacement at the building site not to be anticipated. (Tier 2: Sec. 4.7.1.3)

Condition of Foundations

C NC N/A FOUNDATION PERFORMANCE: There should be no question of excessive or increased foundation motion such as settlement or heave which would ultimately affect the unity or strength of the structure. (Tier 2: Sec. 4.7.2.1)

Capacity of Foundations

C NC N/A

POLE FOUNDATIONS: The Pole foundations should have the minimum embedment depth of 4 feet for Life Safety and Immediate Occupancy. (Tier 2: Sec. 4.7.3.1)

3. CONCLUSION OF TIER 1 ANALYSIS

Since the configuration of the building is usually irregular therefore the detailed analysis of the building must be made by considering three dimensional model of the building as per Tier 2 provisions. Also the shear stress in columns and shear wall exceeds the limits which are highlighted in Table 1 & Table 2.

Table 1. Comparison of Moment Demand with Capacity of Basement Columns

ID	X-SEC	Moments (K-ft)			Q_{UD}/m (k-ft)	Q_{CE} (k-ft)	DCR
		Grav.	EQ_X	EQ_Y			
2B	C1	186	1050	2939	2084	6468	0.32
2G	C4	59	168	1	151	1306	0.11
3B	C5	27	15	65	62	616	0.1
4D	C2	111	284	210	263	1713	0.16
4G	C2	96	231	162	217	1713	0.12
5B	C5	1.75	110	22	68.5	616	0.112
$5B^+$	C5	3.5	134	20	92	616	0.15
5D	C1	134	3804	682	2625	6468	0.4
5G	C2	75	604	114	453	1713	0.26
6B	C4	11	108	425	292	1306	0.224
6D	C4	95	687	197	522	1306	0.4
7B	C5	5.5	144	43	100	616	0.16
7C	C1	79	5061	1620	3427	6468	0.55
7E	C2	169	831	264	666.66	1713	0.4
8F	C1	56	5548	1974	3736	6468	0.58
8H	C4	10	931	332	628	1306	0.48
9B	C5	4	21	94	66	616	0.106
9C	C2	82	1247	576	886	1713	0.52
9E	C2	92	1291	597	922	1713	0.54
9F	C4	14.5	1316	609	887	1306	0.68
9H	C4	20.5	1230	571	834	1306	0.64
10E	C4	28	1705	905	1156	1306	0.88
10H	C6	2.25	304	161	205	350	0.732
11C	C1	132	9752	5204	6596	6468	1.02
11H	C4	72	1655	1151	1152	1306	0.88

Table 2. Shear Demand & Capacity of Basement Columns

Grid Reference	Col. Sec	Shear (Kips)			V (kips)	V_c (kips)
		Grav.	EQ_X	EQ_Y		
2B	C1	7	94	142	151	282
2G	C4	8	18	32	40	66
3B	C5	4	2	6	6	30.56
4D	C2	12	26	20	38	66
4G	C2	13.5	14	10	27.5	66
5B	C5	0.2	12	2.5	12.2	30.56
5B+	C5	0.2	17	2.5	17.2	30.56
5D	C1	9	1.23	20	29	143
5G	C2	10	44	11	54	66
6B	C4	1.1	45	40	46.1	66

6D	C4	12.1	13	16	28.1	66
7B	C5	0.8	16	4.5	17	30.56
7C	C1	7.5	286.5	103	294	133
7E	C2	9	64	21	73	66
8F	C1	6	324	125	330	133
8H	C4	1.1	76	28	77	66
9B	C5	0.6	21.5	10	22	30.56
9C	C2	11	100	47	111	66
9E	C2	11	110	52	121	66
9F	C4	0.2	116	55	116.2	66
9H	C4	1.6	96.5	46	98	66
10E	C4	1.9	153.3	82.5	155.2	66
10H	C6	0.6	36.5	20	37.1	30.56
11C	C1	10.5	542	287	552.5	131
11H	C4	6.4	135	72.5	1141.4	66

4. MODEL ANALYSIS

4.1 Frequency Calculation

Ground motion causes a building to oscillate in a manner that depends both on the characteristics of the incoming seismic waves (such as amplitude, frequency, and time of arrival) and on the configuration and natural period of the building (ASCE/SEI 31-3, 2003). Modal analysis was carried out using ETABS, frequencies and time periods computed are tabulated in Table 3. (Computer and Structures Inc. CSI, 1998).

Table 3. Natural Frequencies and Mode Shapes

Mode number	Period sec	Frequency	Modal mass participation in %				
			X	**Y**	**RX**	**RY**	**RZ**
1	1.59	0.63	0.3	38.38	52.73	0	30.47
2	1.39	0.72	69.61	0.08	0.08	98.86	1.19
3	1.13	0.88	0.93	30.19	45.91	0.13	39.23
4	0.56	1.78	2.8	7.3	0.41	0.02	7.70
5	0.41	2.42	0.01	0.06	0	0	0.11
6	0.39	2.58	14.49	3.29	0.11	0.62	0.05
7	0.30	3.32	0.6	4.15	0.2	0.03	10.40
8	0.28	3.58	0.31	7.71	0.37	0.02	0.03
9	0.21	4.72	1.64	0.27	0	0.03	2.55
10	0.17	5.78	3.94	1.94	0.06	0.19	0.37
11	0.12	8.33	1.14	4.98	0.12	0.04	1.99
12	0.09	10.97	3.48	0.78	0.01	0.04	0.06

4.2 STRUCTURAL RESPONSE

In structural response study is restricted to displacement, storey drift and base shear only. (Bracci J. M et al, 1997). Certain dynamic equations can be solved using different approaches to get the displacement vector {Y}. The most classic method is ‘direct integration method’, in which the equation of motion is solved for, $t = \Delta t, 2\Delta t, 3\Delta t \ldots N\Delta t$. N is large enough to cover the entire duration of excitation, such that $N.\Delta t$ is $\geq$ than duration. The solution of such differential equations N times will give complete time history response of the structure at an interval of Δt.

Table 4. Centre of Mass and Centre of Rigidity

Story	Mass	Cumulative mass	Coordinates for Centre of cumulative mass		Coordinate for Centre of rigidity		Remarks
	Kip-sec^2 per inch		X	Y	X	Y	
Roof	0.697	0.697	188.718	521.30	143.513	607.62	**Coordinates are measured in inches from origin.**
9th	2.63	3.33	309.196	474.348	152.410	641.115	
8th	2.77	6.1	326.307	469.048	152.126	670.056	
7th	4.78	10.88	318.838	608.212	146.504	686.525	
6th	5.03	15.9	315.372	672.445	142.701	689.551	
5th	5.03	20.94	313.570	705.824	138.561	689.181	
4th	5.03	25.96	312.467	726.276	134.330	686.535	
3rd	5.70	31.66	317.446	751.393	129.920	678.415	
2nd	5.78	37.44	321.552	769.881	127.384	664.342	
1st	6.25	43.69	330.071	789.559	127.265	642.587	
Ground Floor	6.3	49.99	337.045	804.897	132.627	615.458	
Basement	6.95	56.94	341.500	816.223	146.480	595.785	

Following Figs. 1-6 show different mode shapes (Edward L. Wilson, 2000), for different time periods, T, for the existing buildings.

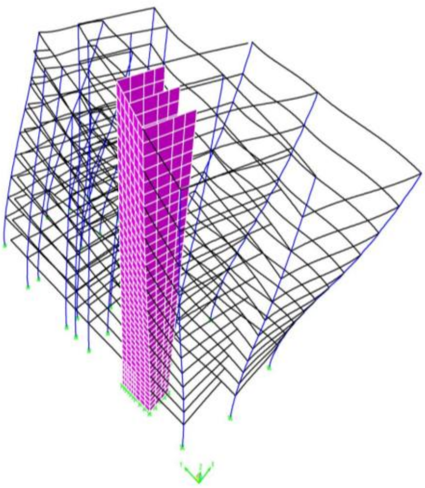


Figure 1. Mode shape 1 Period 1.59 seconds

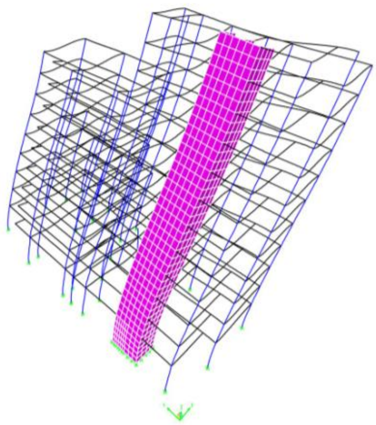


Figure 2. Mode shape 2 Period 1.39 seconds

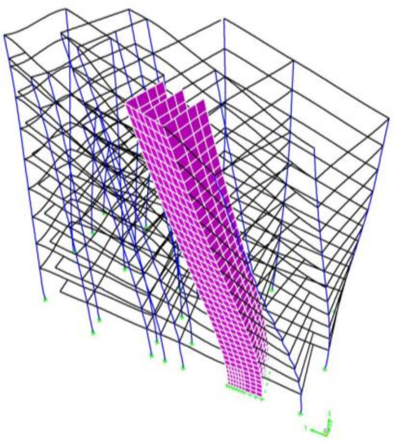


Figure 3. Mode shape 3 Period 1.13 seconds

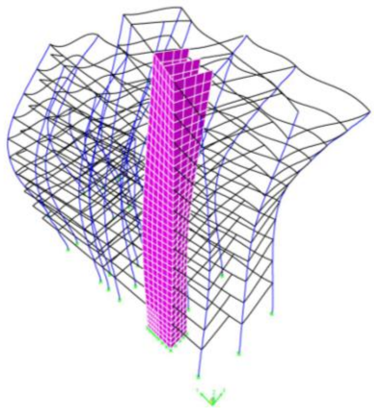
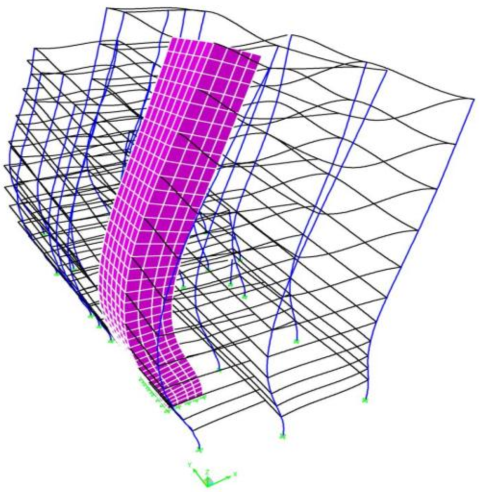


Figure 4. Mode shape 4 Period 0.56 seconds



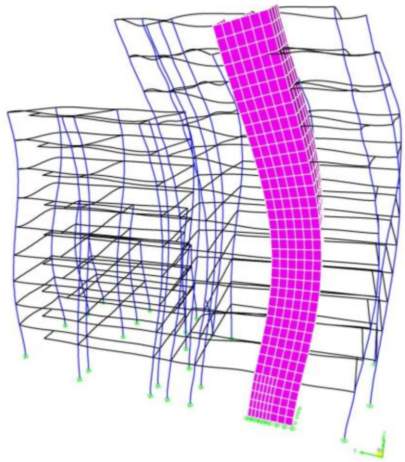


Figure 5. Mode shape 5 Period 0.41 seconds

Figure 6. Mode shape 6 Period 0.39 seconds

5. CONCLUSIONS

Linear dynamic analysis was carried out using scaled strong motion records and design spectra. Results are comparable with static analysis. Dynamic analysis generally gives lower forces hence the computation is rewarded by accurate result. The response is more sensitive to individual characteristics of strong motion record hence as more as possible number of records shall be used for time history analysis.

This study reveals that seismic vulnerability and evaluation of building structures is done on the basis of ASCE 31-03 provisions so as to know the main procedure in detail. ASCE 31-03 is oriented in three main tiers, which are of ascending analytical detail, descending limitlessness towards safety measures. Before conducting Tier 1 Evaluation, degree of desired performance like “Life Safety or Immediate Occupancy” seismic region like “low, moderate, or high” and kind of building has to be defined. The Screening Phase of Tier 1 is aimed to be the quick seismic investigation for structural elements within the building with a purpose to screen out buildings which satisfy the provisions of this nature or to rapidly signify the potential loopholes. Tier 2 Evaluation Phase aims to find and investigate further potential loopholes which were already highlighted in Tier 1 Screening Phase using “Linear Static Analysis or Linear Dynamic analysis”. For sites of Islamabad a Response Spectra has been developed by “Mapped Spectral Acceleration approach” using “spectral response acceleration and short period response acceleration” at one-second. Those buildings which require further investigation and evaluation, Tier 3 Evaluation should be made. The detailed nonlinear static analysis i.e. pushover or nonlinear dynamic analysis should be carried out.

REFERENCES

ASCE/SEI 31-0.3 (2003). Seismic Evaluation of Existing Buildings, *American Society of Civil Engineers*, Reston, VA.

ASCE SEI/ASCE 7-05. (2005). Minimum Design Loads for Building and Other Structures, *American Society of Civil Engineers*, Reston, VA.

BCP. (2007). Seismic Provision for Building Code of Pakistan. *Ministry of Housing and Works Government of Pakistan Islamabad*.

Bhatti A.Q, Hassan SZ, Rafi Z, Khatoon Z, Ali Q. (2011a). Seismic Hazard Analysis of Islamabad Pakistan. *Journal of Asian Earth Sciences.* **42:3**,468-478

Bhatti A.Q, Kishi N. and Tan KH. (2011b). Impact resistant behaviour of an RC slab strengthened with FRP sheet. *Material and Structures.* **44:10**:1855-1864

Bracci J.M., Kunnath S.K. and Reinhorn A.M., 1997. Seismic Performance and Retrofit Evaluation of Reinforced Concrete Structures. *Journal of Structural Engineering*, ASCE. **123**: 3-10.

Computers and Structures Inc CSI. (1995). ETABS Extended Three Dimensional Analysis of Building Systems Non linear Version 9.5. *Berkeley, California USA*

Clough, R.W. (1960). The Finite Element Method in Plane Stress Analysis.

D'Ayla,D. and Charleson,A.W. (2002). Review of seismic strengthening guidelines for R.C. buildings in developing countries. *12th European Conference on Earthquake Engineering*, London, UKs

Edward L Wilson. (2000). Three Dimensional Static and Dynamic analysis of Structures" 3rd Edition. *Computers and Structures,* Inc. Berkeley, California, USA