Title: **Overview of Seismic Loads and Application of Local Code Provisions for Tall Buildings in Baku, Azerbaijan**

Authors: Hi Sun Choi, Thornton Tomasetti
James Sze, Arup
Onur Ihtiyar, Thornton Tomasetti
Leonard Joseph, Thornton Tomasetti

Subject: Seismic

Keywords: Building Code
Seismic

Publication Date: 2014

Original Publication: International Journal of High-Rise Buildings Volume 3 Number 1

Paper Type:
1. Book chapter/Part chapter
2. **Journal paper**
3. Conference proceeding
4. Unpublished conference paper
5. Magazine article
6. Unpublished

International Journal of High-Rise Buildings
March 2014, Vol 3, No 1, 65-71

International Journal of
High-Rise Buildings
www.ctbuh-korea.org/ijhrb/index.php

Overview of Seismic Loads and Application of Local Code Provisions for Tall Buildings in Baku, Azerbaijan

Hi Sun Choi[1†], James Sze[2], Onur Ihtiyar[3], and Leonard Joseph[4]

[1]Thornton Tomasetti, Inc, 51 Madison Avenue, New York, NY, 10010, USA
[2]Arup, Level 5, Festival Walk, 80 Tat Chee Avenue, Hong Kong
[3]Thornton Tomasetti, Inc, 51 Madison Avenue, New York, NY10010, USA
[4]Thornton Tomasetti, Inc, 6080 Center Drive, Suite 260 Los Angeles, CA 90045

Abstract

Baku, the capital of Azerbaijan, has seen a boom in construction in recent years. The old Baku city has been rapidly transforming into a new hub of high-rise buildings and lively cultural centers hosting the Euro Vision Song Contest in 2012 and European Games in 2015. A major population shift to Baku from its suburbs and the countryside has resulted in the doubling of Baku's population in the 4 years between 2009 and 2013. As of January 2013, Baku's population reached four million people, 43% of the citizens in Azerbaijan according to The State Statistical Committee of Azerbaijan. With this trend, the city needs more high-rise buildings to accommodate rapidly increasing demands for more housing and business space. Until the Azerbaijan Seismic Building Code was published in 2010 and became effective, many different seismic criteria, in terms of building codes and seismic intensities, were used for all new high-rise projects in Baku. Some designers used the SNIP (Russian) code with seismic level 9 or level 8 with 1 point penalty. Others used the Turkish code with Seismic Zone 1, UBC 97 with Zone 2 through 4, or IBC with Sa = 0.75 g through 1.0 g. The seismic intensity is now clarified with the Azerbaijan Seismic Building Code. However, the Azerbaijan Seismic Building Code is appropriate for low-rise buildings applications but may be inappropriate for high-rise project applications. This is because the code-defined response spectrum yields unrealistically conservative seismic forces for high-rise buildings with long periods, as compared to those determined by other internationally accepted building codes. This paper provides observations and recommendations for code-based seismic load assessment of high-rise buildings in the Baku area.

Keywords: Baku, High-rise Buildings, Seismic building Code, Response Spectrum

1. Introduction

Baku, the capital of the Republic of Azerbaijan, has been rapidly growing in population and business activity. This has led to a dramatic increase in high-rise construction in the city. Although high-rise design is often controlled by wind-induced forces, this doesn't apply to Baku which is located in an area of high seismicity.

Before the Azerbaijan Seismic Building Code AZN10 became available, there was no seismic code reflecting local conditions. Designers of Baku high-rise projects applied seismic provisions from other codes including those from Russia (SNIP), Turkey and the United States (Uniform Building Code, International Building Code). To properly apply these codes, extensive efforts were put into researching area seismicity, performing seismic hazard assessments, establishing seismic characteristics, determining appropriate seismic ground accelerations and establishing suitable response spectrum curves for safe and economical high-rise building designs. Even so, seismic criteria varied over a wide range.

To develop the most suitable Response Spectrum Curves to be applied for the design of high-rise structures, it is very important to start with a review of historical earthquake activity and study the seismic hazard assessment and seismic characteristic of Baku. The review of historic earthquakes in Baku and seismic hazard assessment research documentation published by the Global Seismic Hazards (GSHAP) and NATO Science for Peace and Security Programme determined that a seismic intensity of 8 with a Peak Ground Acceleration of 0.25 g is appropriate for building projects in Baku. This is comparable to criteria in the newly adapted Azerbaijan Seismic Building Code (AZN10). These criteria alone are not sufficient to establish appropriate response spectra for high rise design. This paper presents recommendations to that end.

2. Historical Earthquakes in Baku, Azerbaijan

The City of Baku is located in the Absheron Peninsula adjacent to the Caspian Sea which has witnessed many

†Corresponding author: Hi Sun Choi
Tel: +1-917-661-7800; Fax: +1-917-661-7801
E-mail: HChoi@ThorntonTomasetti.com

Table 1. Local Earthquake and Strong Events felt in Baku (Babayev 2010)

Data d/m/y	Magni-tude Ms	Depth km	Intensity MSK-64	Earthquake location/ Intensity in Baku
02/01/1842	5	3	VIII	Mashtaga, near Baku/V
11/06/1859	5.9±0.5	10	VIII-IX	Shamakha/V
28/01/1872	5.7±0.5	7	VIII-IX	Shamakha/IV
08/071895	8.2±0.3	60	X	Krasnovodsk/V-VI
13/02/1902	6.9±0.2	8	VIII–IX	Shamakha/V
06/07/1910	4.4±0.5	7	VI-VII	Surakhani, near Baku/V
07/06/1911	6.4±0.3	46	VI-VII	Caspian Sea/VI
22/11/1922	4.3±0.7	15	V-VI	Absheron Peninsula/VI
20/10/1931	6.2±0.5	70	VII-VIII	Caspian Sea
09/04/1935	6.3	100	VI	Caspian Sea
24/06/1935	3.5	5	V	Surakhani/Baku
06/09/1937	5	22	V-VI	Absheron Peninsula
23/02/1938	5.7	15	VI	Baku
06/09/1938	5.0±0.5	22	VI	Caspian Sea (northern part)
05/03/1946	4.8±0.3	11	VII	Absheron Peninsula
05/11/1958	4.0±0.5	12	V-VI	Caspain Sea
28/11/1958	2.2±0.7	3	V	Baku
27/01/1963	6.5	30	-	Caspian Sea
15/10/1971	4.0±0.5	13	VI	Caspian Sea
20/12/1971	5.5±0.1	5	VII	Absheron Peninsula
20/12/1971	5.3±0.2	12	VII	Absheron Peninsula
03/02/1972	4.9±0.2	5	VI	Absheron Peninsula
26/10/1973	5.1	80	-	Absheron Peninsula
14/12/1973	5.1±0.2	70	V	Caspian Sea (northern part)
02/08/1975	4.7	33	-	51 km eastward from Baku
16/01/1979	4.4	10	-	Baku
23/02/1983	5.0	10	V	Nardaran-Bilgah, near Baku
06/03/1986	6.3	33	VIII	Caspian/V-VI
11/05/1986	4.5	15	VI	Caspian/V
16/09/1989	6.5	55		Caspian/IV-V
06/01/1992	4.5	33		Baku
28/10/2000	4.6	33		Caspian Sea
25/11/2000	5.8	40	VII	Caspian Sea
25/11/2000	6.3	33	VIII	Caspian Sea
06/12/2000	7.3	33	IX	West Turk-menistan/IV
07/01/2001	5.5	48	IV-V	Caspian Sea/IV-V
11/02/2002	5.3	38	IV	Caspian Sea
04/10/2003	4.1	10		20 km southwest from Baku
24/10/2003	4.6	33		34 km northeast from Baku

seismic events in the past. A list of the most severe earthquakes and their intensities in Baku is provided by Babayev et al. (2010) in Table 1.

According to this table, the most severe earthquakes in the region occurred in Shamakha with intensities estimated as 9 to 10 in MSK-64 scale. These events generated moderate shaking with intensities around 5 in Baku City as the town of Shamakha is located approximately 110 km away.

The highest magnitude earthquake close to the center of Baku (35 km away from town center) was recorded in 2000 with a magnitude of 6.3 Ms. The intensity of this event was determined to be 8 (Babayev et al., 2010). Therefore, there were not any earthquakes reported with an intensity of 9 in Baku.

Panahi (2006) also clearly states, “Based on available sparse data, there is evidence that the level Caspian Sea seismicity is lower than adjacent areas” and concludes that “Character of seismicity of Azerbaijan and adjoining territory of the Caspian Sea is moderate”.

3. Seismic Hazard Assessment for Azerbaijan

A Seismic Hazard Assessment for Azerbaijan was performed in the framework of a NATO Science for Peace and Security Programme by Akhundov et al. (2011). A Seismic Risk Map for Baku City was provided by considering many factors, including seismic sustainability of physical objects, depth of underground waters, physical-mechanical and other features of the grounds. Figure 1 shows seismic zoning of areas in Baku City by the MSK-64 scale.

According to this map-schedule, the seismic zoning of the City of Baku is mainly 8 or below with some exception where the coastal territories with waters and loose soil conditions pose higher seismic hazard, potentially up to seismic Intensity 9 on the MSK-64 scale. However, if a high-rise building is expected to be constructed in this area, it would be reasonable to expect, or require, that the construction site will be carefully reclaimed and foundation soil improvement will be provided in the process of installing closely spaced piles. Therefore, watery and loose soil conditions which require the Seismic Intensity of 9 per ANZ 10 will not be found in the project site.

This document also reports the Maximum Peak Ground Acceleration (PGA) in the territory of Azerbaijan for a return period of 475 years as 0.22g (Figure 2) and PGA for Baku is around 0.13~0.16g[1]. Both values are less than

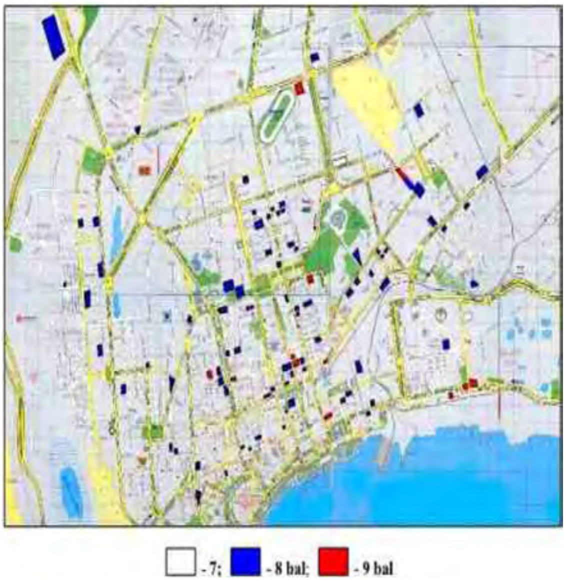

Figure 1. Seismic Zoning Areas in Baku City (NATO Science for Peace and Security Programme by Akhundov et al. (2011).

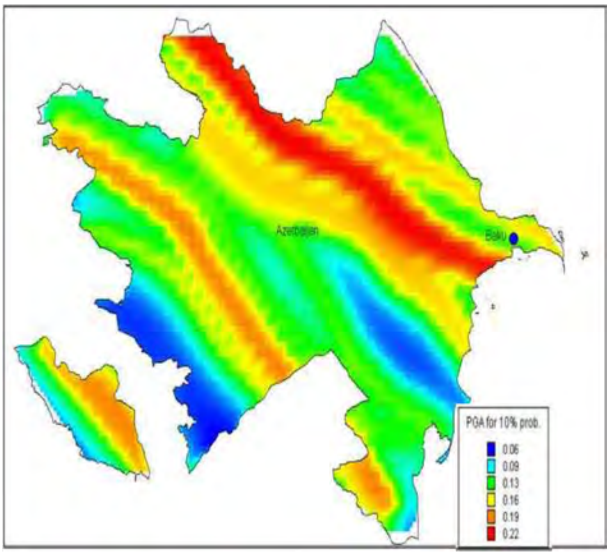

Figure 2. PGA for 475 Year Return Period by Akhundov et al. (2011).

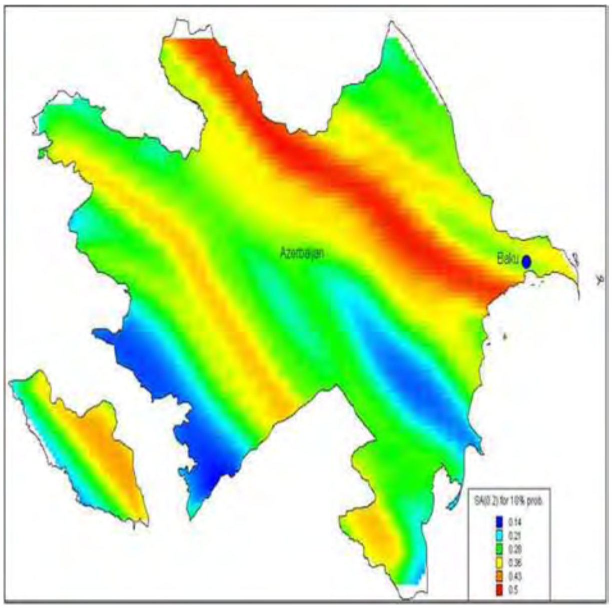

Figure 3. Spectral Acceleration for P = 0.2 sec with a Return period of 475 years by Akhundov et al. (2011).

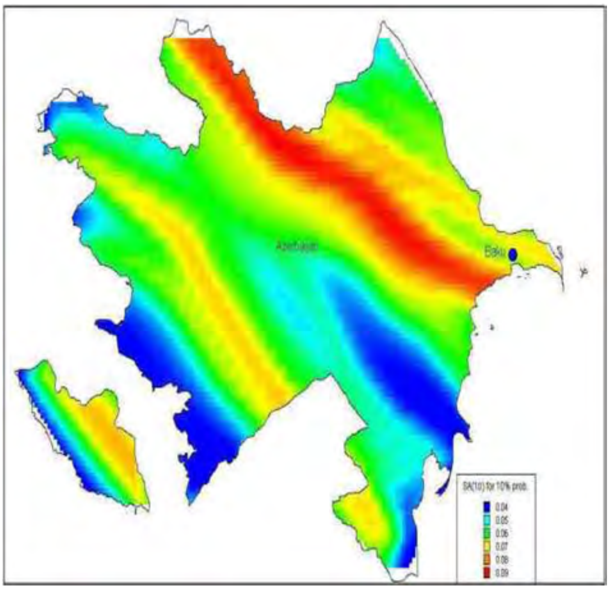

Figure 4. Spectral Acceleration for P = 1.0 sec with a Return period of 475 years by Akhundov et al. (2011).

the PGA value of 0.25 g reflected in AZN10 Pseudo-acceleration values for periods 0.2, 1.0, 2.0, 4.0 seconds are also available in this report. Spectral values for 0.2 sec, 1 sec and 2 sec are shown in Figure 3 to 5 respectively. These reported values are smaller than those values with the Intensity 8 reflected in AZN10.

4. Seismic Load Comparison

4.1. Azerbaijan code (AZN10)

AZN10 defines Baku Area as Seismic Intensity 8 with a return period of 1000 years, not 500 years as seen in Figure 6 which matches with the research documents presented in the previous pages. Peak Ground Acceleration (PGA), ao, for Intensity 8 is given as 0.25 g in the code. The code seismic parameters are calculated below:

- Intensity 8, ao = 0.25 g

[1]It should be noted that the authors of this documents are currently conduting further study to better estimate the ground accelerations for the Baku region and it is likely that the new values will more closely approach the PGA reflected in the code.

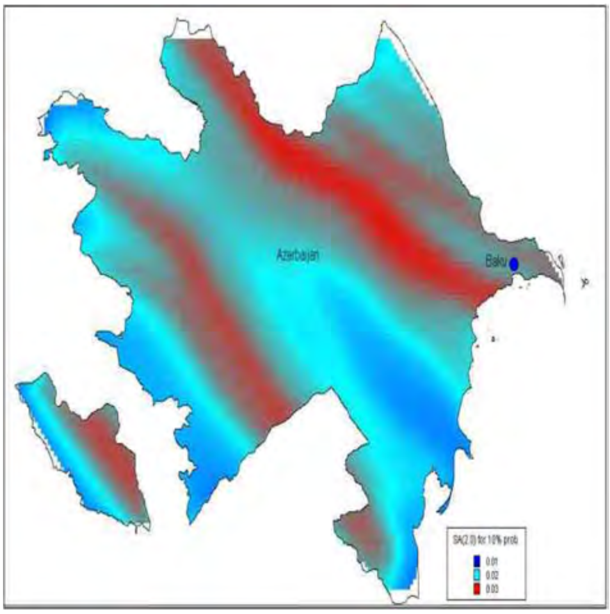

Figure 5. Spectral Acceleration for P = 2.0 sec with a Return period of 475 years by Akhundov et al. (2011).

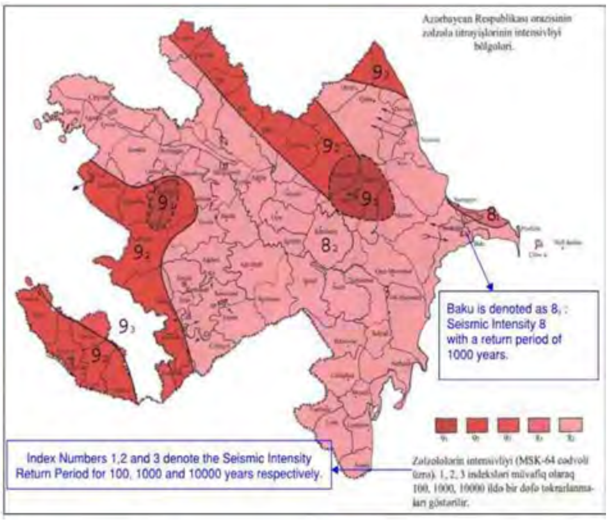

Figure 6. Seismic Intensity Zones of Azerbaijan (AZN10).

- Soil Parameter Kq is defined as 1.2 for Soil Type 3
- Acceleration for Short period, Sds is defined as:

$$Sds = 2.5 \times kq \times ao = 0.75\ g \quad (1)$$

- Accelerations for periods higher than Tb = 0.6 seconds is defined as:

$$S(T) = 2.5 \times kq \times ao \times (Tb / Ti)^{0.5} \quad (2)$$

4.2. Uniform Building Code (UBC-97) / International Building code (IBC-06)

It is instructive to compare IBC-06 and AZN10. However, IBC-06 is based on the Maximum Considered Earthqake (MCE) with a much longer return period than used in AZN10. Therefore, UBC-97 is used for comparisons because its approach is more consistent with AZN10. Parameters for UBC-97 are defined as follows:

- PGA is defined in parallel with AZN10 as 0.25 g for comparison purposes.
- For Soil Class D (Equiv. of Soil Type 3 in AZN10), Ca = 0.3 g, Cv = 0.475 g
- Accelerations for periods higher than Ts = 0.63 seconds are defined as:

$$S(T) = Cv / T \quad (3)$$

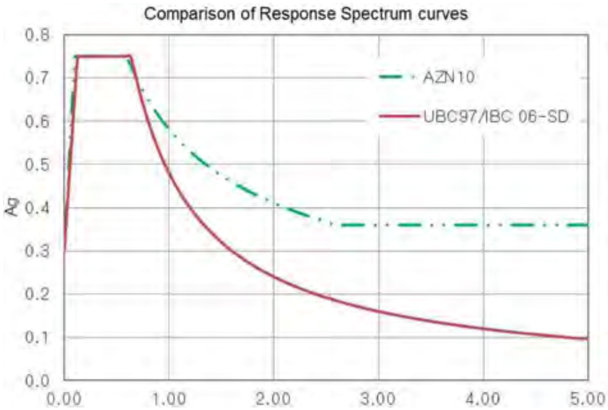

Figure 7. Comparison of Response Spectrum Curves, (AZN vs UBC/IBC).

For these parameters, the AZN10 Response Spectrum Curve does not attenuate as rapidly with increasing modal period as UBC or IBC curves would, as shown in Figure 7. Instead, a minimum acceleration 'floor' occurs for periods longer than about 2.5 seconds, yielding unrealistically high seismic forces for a long period high-rise building. This is probably due to the fact that the AZN10 mainly focuses on low-rise structures with very short periods. Both UBC and IBC have their own minimum base shear 'floors' to cover both higher mode shaking (drives shear but not overturning) and sufficient story strength to avoid a 'ratcheting' failure of progressive post-yield deformations all in one direction. However, AZN10 has a relatively very high base shear 'floor', therefore, it might not be appropriate for high-rise building application.

According to Panahi (2006), the seismic character of the Baku area is more intra-plate (near-source). As shown in Figure 8 for typical characteristics comparison of intra-plate and inter-plate earthquakes, the intra-plate curve pattern matches well with that of UBC or IBC but not with AZN10. Therefore, there is no evidence that Baku should have relatively high acceleration values for long period ranges.

For all these reasons, we recommend that a response spectrum approach consistent with IBC2006 is more appropriate than AZN10 for high-rise design.

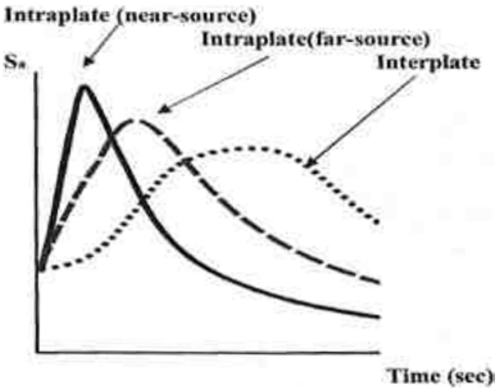

Figure 8. Comparison of Inter and Intra-Plate Earthquakes by Gioncu, Mazzolani (2011).

4.3. Case study: Site specific seismic assessment of an on-shore towers in Baku

For site specific seismic assessment, a probabilistic seismic hazard analysis (PSHA) gives more accurate information since the analysis considers a variety of sources that contribute to the seismic hazard at the site of interest. The typical steps in a PSHA are to:

i. Derive a source model containing the tectonic environment where active faults and fault zones contributing to seismic hazard at the site.

ii. Derive the source characteristics for each fault or fault zone on the basis of earthquake catalogues from various agencies including the United States Geological Survey (USGS) and the International Seismological Center (ISC) etc.

iii. Specify the major crustal features, generally subduction zones and assign earthquakes to them.

iv. Treat other sources as a collection of area sources and again assign observed seismicity to them.

By inputting all the sources within a study area of sufficiently large footprint into a computational shaking model, the ground shaking intensity at the site of interest can be obtained. Ground shaking intensity means the ground acceleration characteristic at the bedrock (or very stiff soil). Considering ground shaking intensity and the site-specific soil profile and parameters, the design response spectrum at ground surface can be derived.

To illustrate the adequacy of adopting IBC (2006) design spectrum, two PHSA study samples were done for two different sites, one near the Port Baku area and the other located in the Caspian Sea, which is about 140 km east of the Port Baku at the boundary of intensity 8 and 9 . This is a short distance in terms of tectonic movement. The study covers source data enclosed by an area of 1,100 km × 1,100 km and the earthquake data reflected in the shaking model comprises the records back to the 15th Century.

Although Port Baku is not located at the center of the above study area, the response spectrum can still be approximately obtained from the computational model. The

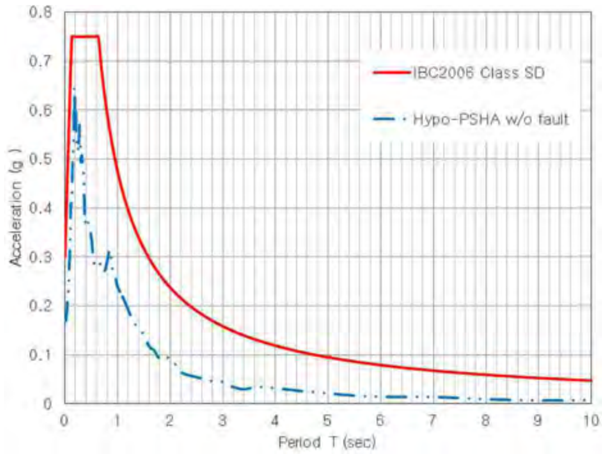

Figure 9. Comparison of design horizontal response spectra.

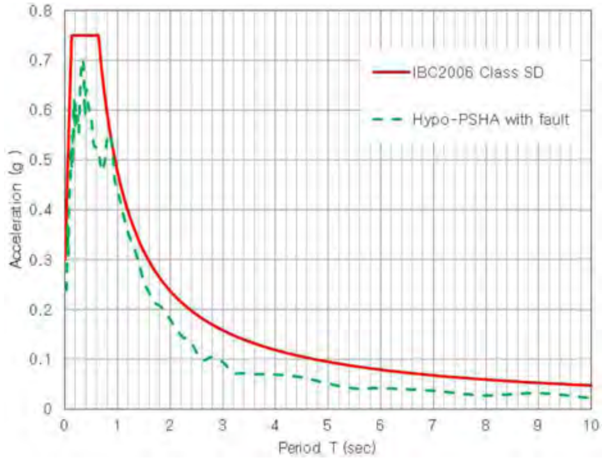

Figure 10. Comparison of design horizontal response spectra with fault underneath the Site.

corresponding horizontal peak acceleration at bedrock is about 0.5 g. For building design the horizontal response spectrum at ground surface is more relevant since the foundation level is about 100~120 m above the bedrock (stiff soil). Soils have an amplification effect and the weaker the soils, the greater the effect. Shear wave velocities obtained from three boreholes near Port Baku in 2010 ranged from 300 m/s to 400 m/s which matched well with Class “SD” in IBC(2006) and Class “III” in the Azerbaijan Code. The resulting response spectrum, as shown using a dashed line in Figure 9 is shown for comparison with the IBC(2006) design spectrum used for high-rise projects in Baku.

The site specific peak acceleration is around 0.65 g which is 13% smaller than the current design peak acceleration. While this seems a small difference, for the design of the high-rise towers the difference is greater. For tall building overturning moments, the more important range of values is at the longer period, say 4 s or longer, which is the natural frequency of the towers. From the figure it can be seen that the acceleration of site specific curve 4 s is significantly lower than the proposed spectrum. From the figure, it can also be seen that the site specific spectrum is not as smooth as the theoretical code spectrum. The site-specific spectrum reflects soil characteristics at the site which causes a "spike" at a period close to 0.9 s.

Baku city is close to the boundaries of tectonic plates and the seismic report produced by SRIFSE also indicated "tectonic cracks" underneath the Port Baku area. In view of this, another preliminary model simulates a major fault located directly underneath the site which could trigger an earthquake of magnitude 7 (based on historical record, Baku has recorded majority up to magnitude 6 earthquakes except one with magnitude 7 in year 2000). The resulted response spectrum at ground surface compared to IBC (2006) design spectrum is shown in Figure 10.

Under this scenario, the peak horizontal ground acceleration increased from 0.65 g to 0.70 g, which is still below 0.75 g. The "spike" near 0.9 s has been further amplified and locally reaches the IBC (2006) design spectrum. In the important range of interest for high-rise building design, periods 4 s or longer, the corresponding site-specific values are still well below the recommended design spectrum.

5. Conclusion

Based on the paper review of the history of earthquake activities, the seismic hazard assessment by a NATO Science for Peace and Security Programme by Akhundov et al. (2011), and seismic characteristics of Baku as well as a site specific seismic assessment by Arup and a seismic code comparison study performed by Thornton Tomasetti, seismic parameters required to determine adequate seismic response spectrum curves are confirmed to be appropriately addressed by a response spectrum proposed to follow the IBC2006 approach.

Figure 11 shows the comparison of all Response Spectrum curves from the proposed curve with reference to UBC/IBC, PSHA study with fault and without fault consideration and NATO research by Akhundov et al. (2010). As shown, both Site Specific Response Spectrum curves reasonably match the form of, but at values below, the Proposed Response Spectrum curve. The authors of the NATO paper (Akhundov et al., 2010) are currently working on revising their values and it is likely that the new results might get closer to the proposed spectrum values.

Therefore, it can be concluded that provisions in the current local code are not appropriate to reflect seismic effects on high rise structures. Instead it is recommended that the proposed Response Spectrum Curve shown with a solid line below based on IBC2006 methods can be applied to determine seismic demands for high-rise projects in the Baku area.

Note that Performance Based Design, including Nonlinear Response History Analysis is sometimes being applied to high rise buildings in high-seismic regions. This

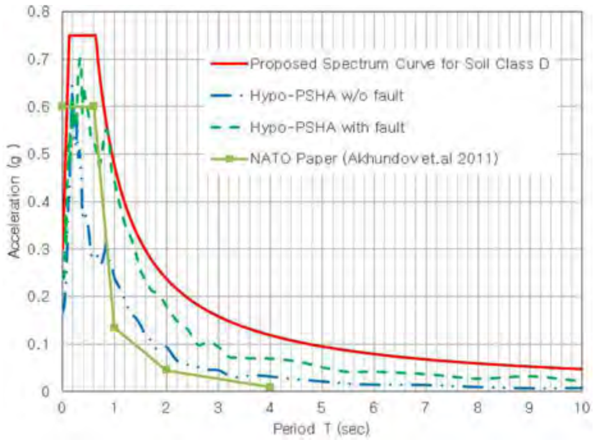

Figure 11. Comparison of Response Spectra.

most often occurs for buildings intended to exhibit improved seismic performance to reduce post-quake repair costs and downtime, and for buildings with structural systems that are not listed within the prescriptive code provisions, such as core-and-outrigger systems. However, any high rise building design can benefit from PBD since it considers actual non-linear behaviors to reveal actual building responses rather than relying on the assumed behaviors and responses reflected in prescriptive code methods.

In this way the design can be optimized to put material where it is useful, and trim material where it is not useful. Typically nonlinear performance is checked for shaking with a 2% probability of exceedance in 50 years per Recommendation for the Seismic Design of High-rise Buildings published by CTBUH Seismic Working Group. Linear performance may be checked for short-return-period service level shaking as well.

This study was a result of collaboration between Thornton Tomasetti, Inc. and Arup Geotechnical engineers through numerous projects conducted in Baku area.

References

Akhundov, A., Mammadli, T., Garaveliyev, E., Yethirmishli, Q., and Tanircan G. (2010). "Seismic Hazard Assessment for Azerbaijan," The NATO Science for Peace and Security Programme.

Babayev, G., Ismail-Zadeh, A., and Le Mouel, J. (2010). "Scenario-Based Earthquake Hazard and Risk Assessment for Baku (Azerbaijan)," Natural Hazards and Earth System Sciences, Published 22 December 2010.

Gioncu, V. and Mazzolani, F. (2011). "Earthquake Engineering for Structural Design", Spon Press.

International Code Council (ICC). (2006). "International Building Code", IBC-2006.

International Conference of Building Officials. (1997). "Uniform Building Code", UBC-97.

Panahi, B. (2006). "Seismicity of Azerbaijan and Adjacent Caspian Sea", Proceedings of the International Workshop: CP825 Recent Geodynamics, Georisk and Sustainable

Development in the Black Sea to Caspian Sea Regions.

The State Statistical Committee of the Republic of Azerbaijan, Retrieved on January 13 2014 from http://www.stat.gov.az/indexen.php

The State Structures and Architecture Committee of the Republic of Azerbaijan. (2010), “Construction in Seismic Regions”, AZN-10.