RESPONSE SPECTRA CONSIDERING RECORDED GROUND ACCELERATIONS IN PAKISTAN

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ABSTRACT: The large damage caused by October 08, 2005 Kashmir earthquake in Pakistan has raised several questions on the current design techniques and construction practices in the country. Realizing the enormity of the situation, the Government of Pakistan selected a committee of technical experts to provide guidance for the revision of the country's Building Code. Pakistan has now been classified into various seismic zones according to Building Code of Pakistan (BCP-07). BCP-07 now encompasses seismic provisions. Seismic Provisions used in BCP-07 are extracted from Uniform Building Code (UBC-97). Each building code has formulated design spectrum, like, Euro code (EC-08), International Building Code (IBC-03) and UBC-97. Since, BCP-07 follows UBC-97 design response spectrum (DRS), it is questionable that whether the UBC-97 DRS considers the zone characteristics of Pakistan. Response spectra are very useful tools and the DRS depends upon many factors including the magnitude of the earthquake, the fault mechanism and the distance of the site from the fault, the geology of the travel path of seismic waves and the local soil conditions at the site. Therefore, for the DRS seismicity of the area need to be considered. With the limited available data it is realized here that the design, based on UBC-97 DRS with site specific seismic coefficient, is safe. However, with the scaled up records according to the PGA maps of BCP-07, UBC-97 DRS is less conservative for rocky soil (high seismic risk zone 4). Considering stiff soil strata (Soil type D Zone 2A), peaks for UBC-97 and proposed spectra almost coincide with each other.

Key words: Building code of pakistan, Soil type, Seismic zones, Design response spectrum, UBC-97, EC-08.

INTRODUCTION

Earthquake, due to its unpredictable and random in nature attracted the modern researchers to create techniques for analyzing the structures to withstand these forces. The damage caused by October 08, 2005 Earthquake, in Kashmir, Pakistan, has raised several questions on the design and construction practices in the country. Realizing the enormity of the situation, the government of Pakistan has selected a committee of technical experts to provide guidance for revision of Building Code of Pakistan. Hence, Pakistan has been classified into various seismic zones. The trend to construct high rise buildings in Pakistan also demands that the local ground motion data and ground motion characteristics should be studeid and incorporated in the structure design. BCP-07 now encompasses seismic provisions. Seismic Provisions used in BCP-07 are extracted from UBC-97. Each building code has formulated design spectrum by using local seismic record, like, EC-08, IBC-03, National Building Code of Canada (NBCC-95) and UBC-97. Since, BCP-07 follows the formulation of UBC-97 DRS, it is realized that the ground motions recorded in Pakistan and their characteristics should be considered in the development of DRS.

Response spectra are very useful tools in earthquake engineering for analyzing the performance of structures in earthquakes. The DRS depends upon the magnitude of the earthquake, the distance of the site from the earthquake fault, the fault mechanism, the geology of the travel path of seismic waves from the source to the site and the local soil conditions at the site. Hence, DRS of Pakistan should be based on the ground motion records measured in Pakistan. In this study the main objective is to determine DRS for various regions of Pakistan considering the ground motions recorded here and their comparison with UBC-97 DRS. Furthermore, to compare the design response spectra of various codes like UBC-97, IBC-03 and EC-08.

Response Spectra: The concept of a response spectrum was familiarized in the mid 1930s for undamped systems. The considerable effort was dedicated in March 10, 1933 when actual accelerograms of Long Beach California Earthquake became available. Obtaining one point on the spectrum required determining the response of SDF system to a given ground acceleration. The SDF system response was determined in several ways:

i) Graphical integration using an instrument Integraph (Hudson 1956).
ii) Numerical evaluation of the Duhamel integral by White (1942).

iii) Using the torsion pendulum as a mechanical analog of the SDF system by Savage (1939) at the Bureau of Reclamation.

All of the above methods were time consuming and cumbersome. The peak response of the building can be estimated by reading the values from the response spectrum for a particular frequency if the natural frequency of the structure is known. To design the structure against the seismic forces, the codes suggest these values as a basis for calculating the forces on the structure.

Philosophy of design and response spectra: Earthquake loads are to be carefully modeled so as to assess the real behavior of structure. The main objective of the seismic design of buildings is to avoid total catastrophic damage so that structural damages caused, if any, could be repaired after the earthquake event. However, considering economic losses, the requirement for better performance has led to the development of the performance-based seismic design methodology (Chopra A. K. and R. K. Goel 2001 and 2002). Performance is generally of concern for lateral loads such as earthquake and wind. The main factor that affects performance is the ductility of the members on the critical load path. In frame structures, the design of the joints between columns and beams is critical. The graphical procedure by which the capacity of the structure is compared with the demand of the earthquake ground motion on the structure is known as Capacity Spectrum Method. A non-linear force displacement curve represents the capacity of the structure. The capacity of the structure is represented by a nonlinear force-displacement curve, sometimes known as a pushover curve. The roof displacements and base shear forces are converted to equivalent spectral displacements and spectral accelerations respectively, by means of coefficients that represent modal participation factors and effective modal masses. Capacity spectrum is represented by these spectral values. Spectra results in an intersection of the two curves that estimates the performance of the structure to the earthquake (Sigmund A. F. 2007).

UBC-97 design response spectrum: The UBC-97 elastic DRS depends upon the site specific conditions and is constructed on the basis of Ca and Cv values. The spectral acceleration on the ordinate shall be multiplied by the acceleration due to gravity i.e., 9.81 m/sec^2 (UBC-1997). Elastic DRS for a specific site depends upon the tectonic, geologic, soil characteristics and seismology of the site. The specific damping ratio shall also be considered to develop it. Seismic Provisions of BCP-07 was one such effort towards the development of seismic zones. However, DRS based upon UBC-97 may not be a true representative of all zones/regions of Pakistan.

Data collection and compilation: The earthquake data were collected from various departments of Pakistan where the accelerometers are installed which includes Water and Power Development Authority (WAPDA) Pakistan, Meteorological Department (MET) Pakistan, Mangla Dam (MD) Pakistan and University of Engineering and Technology (UET) Lahore, Pakistan. Figure 1.0 represents the data collection chart and their file format.

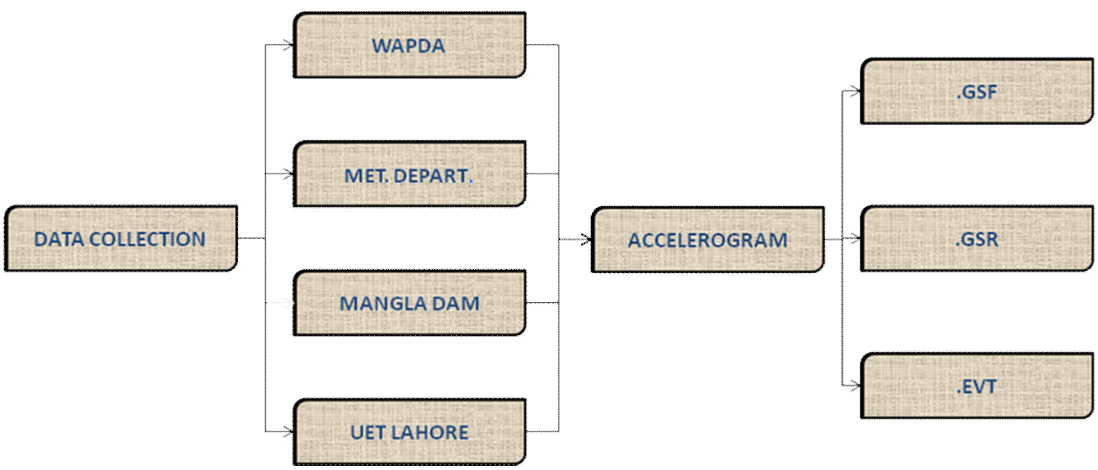

Figure 1.0 Sources of Data Collection.

There are some restrictions/limitations regarding the ground motion data collection and compilation presumably due to its classified nature. Moreover, the data record available for this study are very limited. Hence, only the recorded data of last two years (2009 & 2010) was accessible / available.

METHODOLOGY

Data from various cities of Pakistan were collected to develop site specific response spectra. Spectra developed are compared with the UBC-97 DRS. Also, the comparisons are made between UBC-97, IBC-

03 and EC-08 DRS. The cities that are considered for making DRS from the local recorded ground moton data are Chitral, Balakot, Quetta, Zhob and Lahore. DRS is based on some particular soil conditions.

i) Zone 4 = Rocky Soil, Chitral, Balakot and Quetta
ii) Zone 3 = Rocky Soil, Zhob
iii) Zone 2A = Stiff Soil, Lahore

Comparison between ubc-97, ibc-03 and ec-08 design response spectra: UBC-97 elastic DRS depends upon the site specific conditions and is constructed on the basis of C_a and C_v values. The spectral acceleration on the ordinate shall be multiplied by the acceleration due to gravity i.e., 9.81 m/sec^2. The design spectrum for zone 2A and for soil type S_D is calculated below.

i) On the basis of soil type and zone the values of C_a and C_v which are seismic coefficients are selected from UBC-97, Table 16-Q and 16-R respectively. So

$C_a = 0.22$
$C_v = 0.32$

ii) At T = 0, acceleration is equal to 0.22. and

iii) At T = T_o , $T_O = 0.2T_S$ (1)

Where, Ts is

$$T_S = \frac{C_V}{2.5C_a} \quad (2)$$

So,

$$T_S = \frac{0.32}{2.5x0.22} = 0.5818\sec$$

$$T_O = 0.2x0.5818$$

$$T_O = 0.116\sec$$

When T = T_o then the acceleration is

Acceleration = $2.5C_a$ (3)
= 2.5 x 0.22
= 0.55 m/sec^2

This acceleration will remain same up to T = T_s then the response spectrum curve changes and the acceleration is calculated as:

$$\text{Acceleration} = \frac{C_V}{T} \quad (4)$$

The DRS of IBC-03 is generated by the following procedure.

i) The parameters S_s and S_1 shall be determined from the 0.2 and 1-second spectral response accelerations from IBC-03.

Where,

a) S_1 is less than or equal to 0.04.
b) Ss is less than or equal to 0.15.

Here, in this study $S_s = 0.4$
$S_1 = 0.095$

Where,

S_S = Mapped spectral accelerations for short periods.

S_1 = Mapped spectral accelerations for a 1-second period.

ii) S_{MS} = Maximum considered earthquake spectral response accelerations for short period.

S_{M1} = Maximum considered earthquake spectral response accelerations for 1-second period.

$$S_{MS} = F_a x S_S \quad (5)$$

$$S_{M1} = F_v x S_1 \quad (6)$$

For soil type D and S_s = 0.4 the value of

$F_a = 1.42$ (From IBC-03)
$F_v = 2.4$ (From IBC-03)

F_a and F_v are the site coefficient

Here,

$$S_{MS} = 1.42x0.4$$
$$= 0.568$$
$$S_{M1} = 2.4x0.091$$
$$= 0.2184$$

iii) $$S_{DS} = \frac{2}{3} S_{MS} \quad (7)$$

iv) $$S_{D1} = \frac{2}{3} S_{M1} \quad (8)$$

Where,

S_{DS} = Spectral acceleration for short period.

S_{D1} = Spectral acceleration for 1sec period.

Here, in this study

$$S_{DS} = \frac{2}{3} x0.568$$
$$S_{DS} = 0.378$$
$$S_{D1} = \frac{2}{3} x0.2184$$
$$S_{D1} = 0.1456$$

v) This acceleration will remain same up to T = T_s then the response spectrum curve changes and the acceleration is calculated as:

$$S_a = \frac{S_{D1}}{T} \quad (9)$$

$$S_a = \frac{0.14156}{T}$$

Following procedure is adopted for making EC-08, DRS.

$$0 \le T \le T_B \qquad S_e(T) = a_g.S.(1 + \frac{T}{T_B}.(\eta.2{,}5 - 1)) \quad (10)$$

$$T_B \le T \le T_C \qquad S_e(T) = a_g.S.\eta.2{,}5 \quad (11)$$

$$T_C \le T \le T_D \qquad S_e(T) = a_g.S.\eta.2{,}5(\frac{T_C}{T}) \quad (12)$$

$$T_D \leq T \leq 4s \qquad S_e(T) = a_g.S.\eta.2{,}5(T_C.\frac{T_D}{T^2}) \qquad (13)$$

Where,
S_e (T) = Elastic Response Spectrum
a_g = Design ground acceleration on type A ground
T_B, T_C, T_D = corner periods in the spectrum
S = Soil Factor
η = Damping correction factor (η = 1 for 5% damping)

On the basis of the above parameters the response spectra are generated for the same soil type and zone for UBC-97, IBC-03 and EC-08. Figure 2 represents the plotting of design response spectra based on UBC-97, IBC-03 and EC-08 in one single graph for the same soil type and zone.

The comparison between these code spectrums results in the following conclusions:

i) UBC-97, DRS is found to be more conservative in short period.
ii) The UBC-97 shows higher spectral acceleration.
iii) IBC-03 design spectrum is least conservative as compared to UBC-97 and EC-08.

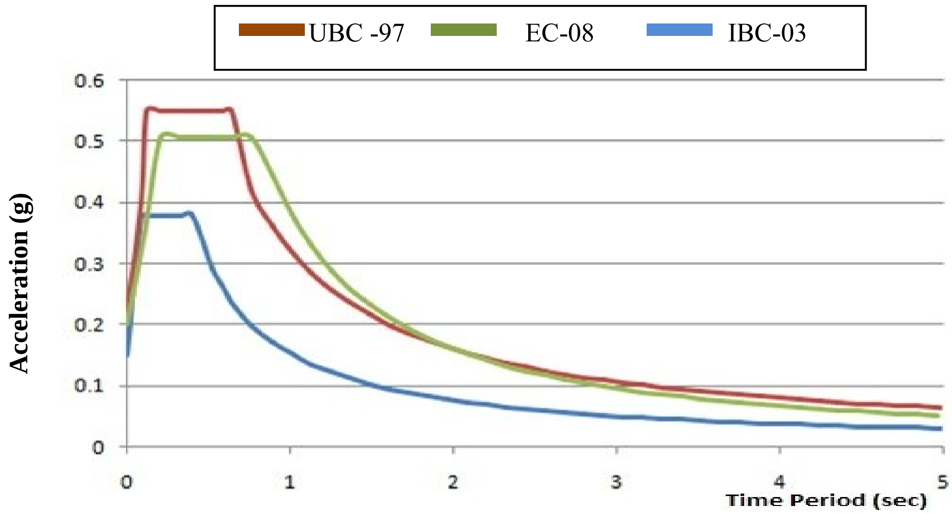

Figure 2 UBC-97, IBC-03 and EC-08 Design Response Spectra

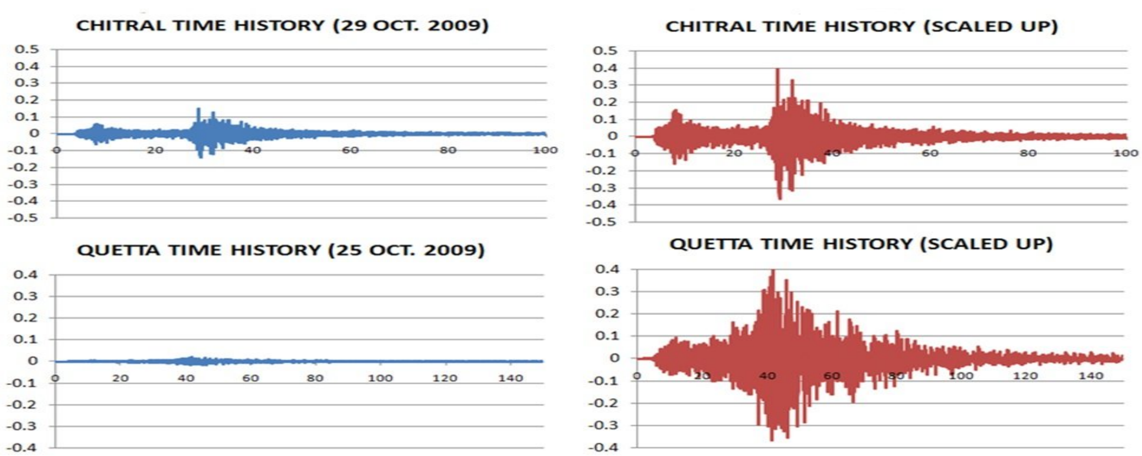

Figure 3 Scaled up time history records.

COMPARISON OF RESULTS

Two Earthquakes (22nd and 29th October 2009) resulted in a peak ground acceleration of 0.265g in Zone 4 (Chitral City) and remaining showed PGA less than 0.03g. Since, for DRS generation, two or three years ground motion records are insufficient. In this study one limitation is that the data about ground motions is limited. Therefore, recorded ground motions in Pakistan are scaled up according to the PGA maps in BCP-07. The Chitral and Quetta ground motion time histories and their scaled up records are shown in fig. 3. On the basis of scaling up of the ground motion records, the response spectra are plotted for Balakot, Chitral, Quetta, Lahore and Zhob cities in figs. 4, 5, 6, 7 and 8.

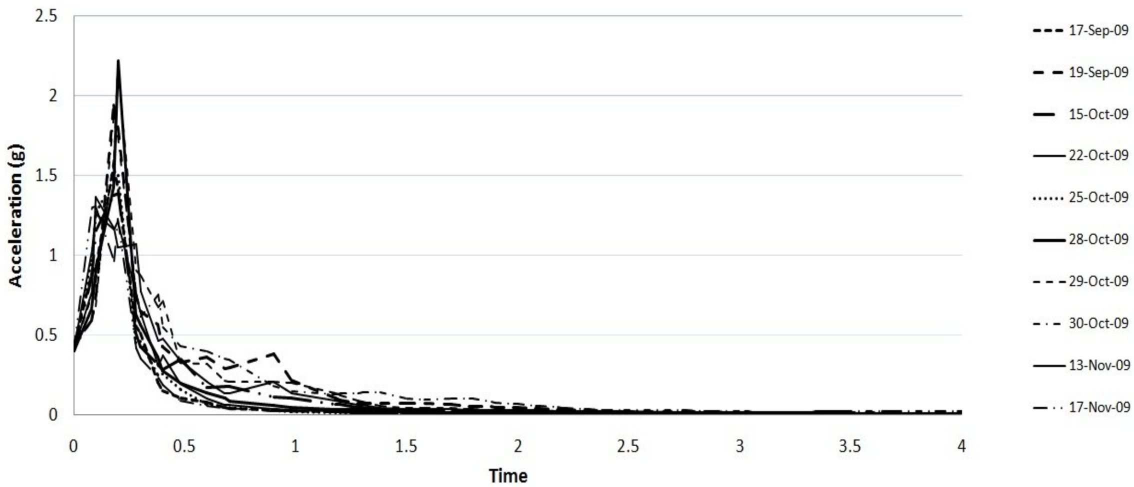

Figure 4 Response spectra of Balakot city with scaled up ground motion records

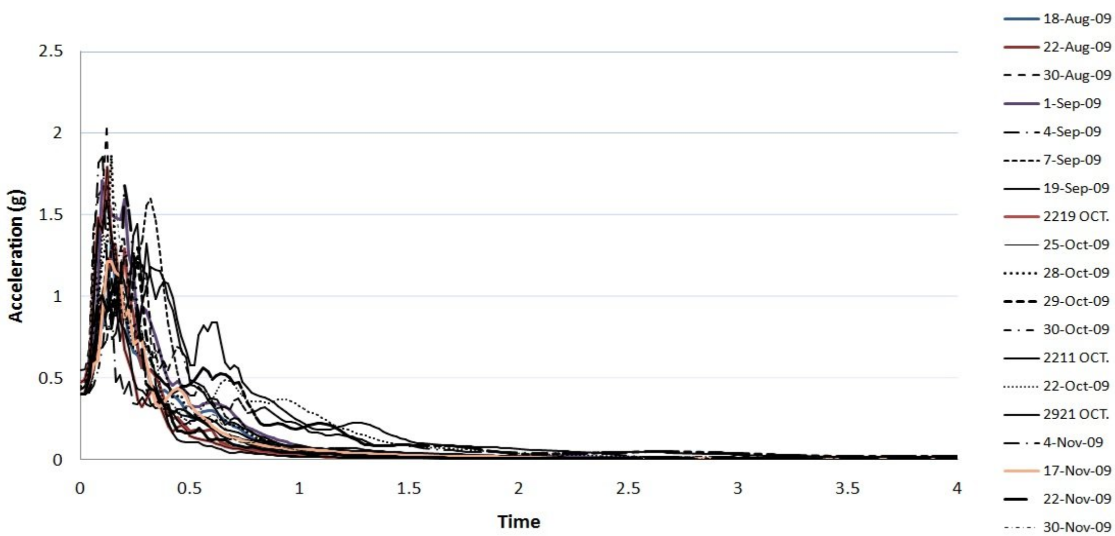

Figure 5 Response spectra of Chitral city with scaled up ground motion records.

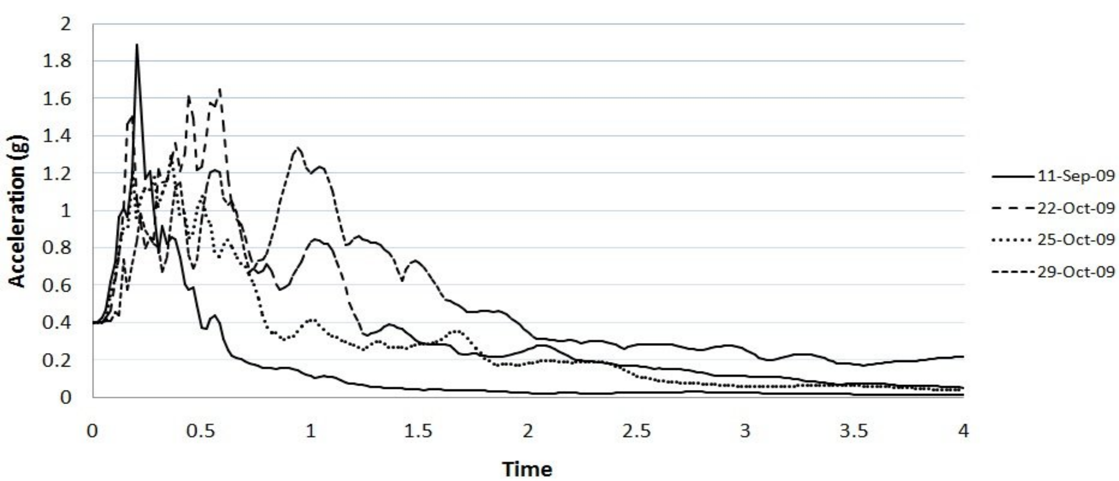

Figure 6 Response spectra of Quetta city with scaled up ground motion records

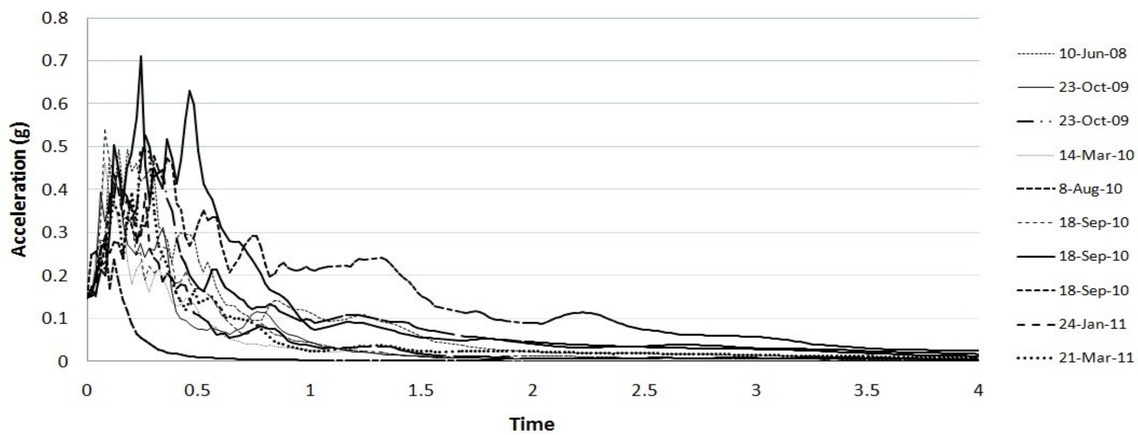

Figure 7 Response spectra of Lahore city with scaled up records

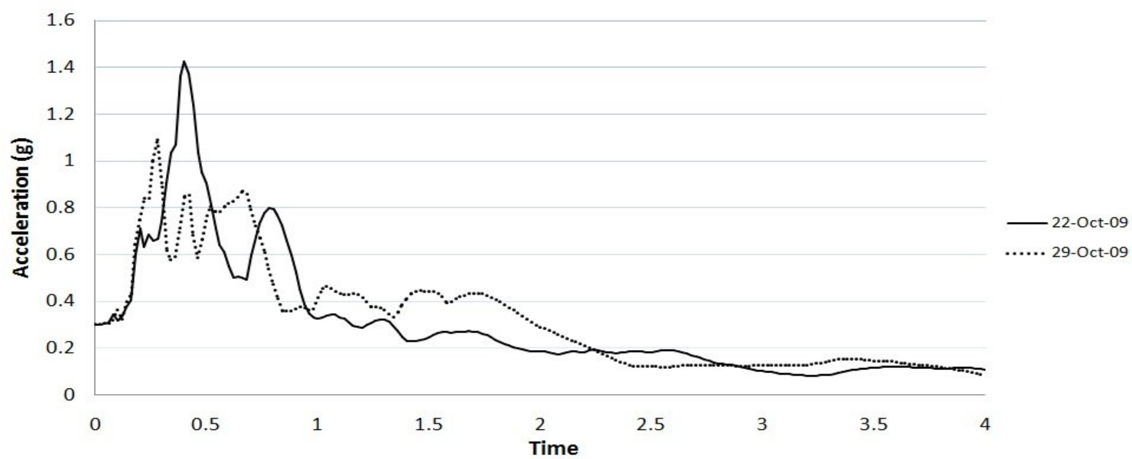

Figure 8 Response spectra of Zhob City with scaled up records

Comparison of UBC-97 and proposed design response spectra: On the basis of available recent data recorded in Pakistan proposed DRS are developed and then are compared with the DRS of UBC-97. The design response spectra are generated on the basis of available scaled up data and are compared with UBC-97 DRS for Balakot, Chitral, Quetta, Lahore and Zhob cities as are shown in figs. 9, 10, 11, 12 and 13.

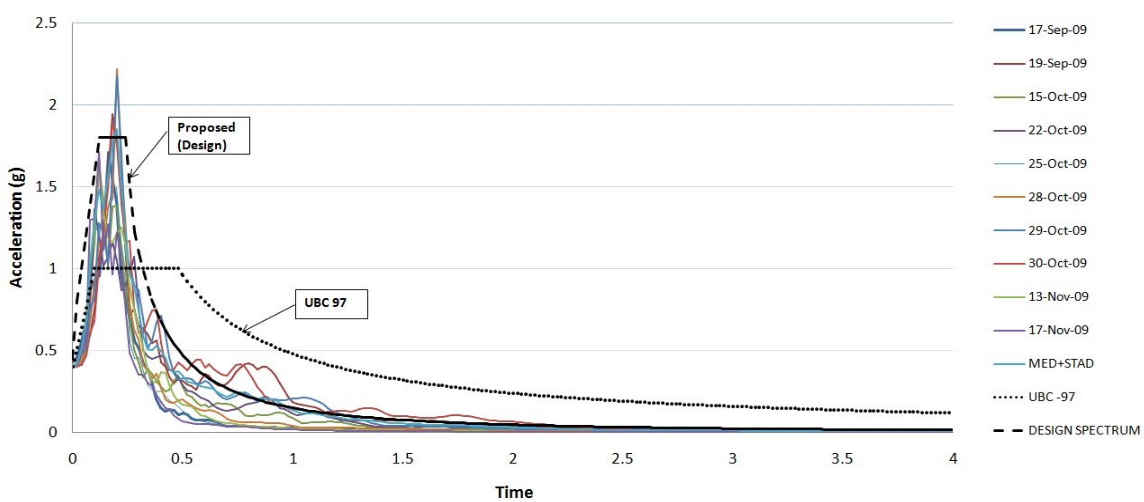

Figure 9 Comparison between proposed and UBC-97 DRS for Balakot city

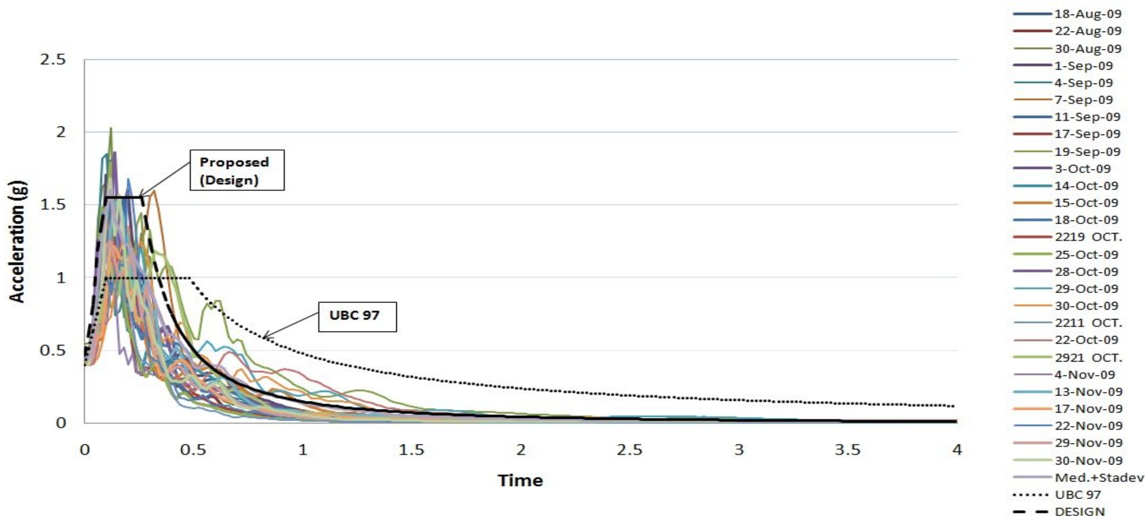

Figure 10 Comparison between proposed and UBC- 97 DRS of Chitral city

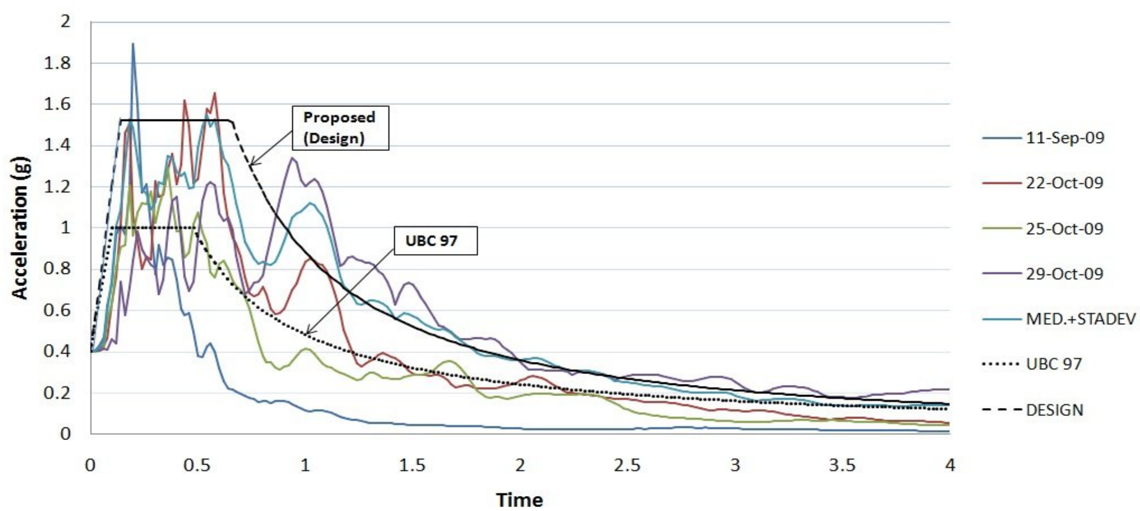

Figure 11 Comparison between proposed and UBC-97 DRS for Quetta city

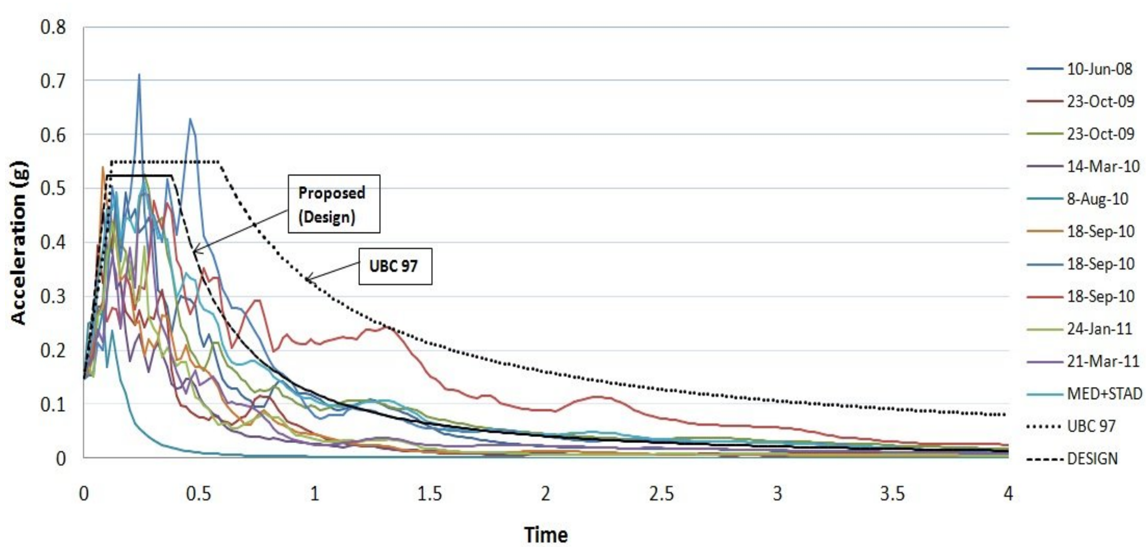

Figure 12 Comparison between proposed and UBC-97 DRS for Lahore city

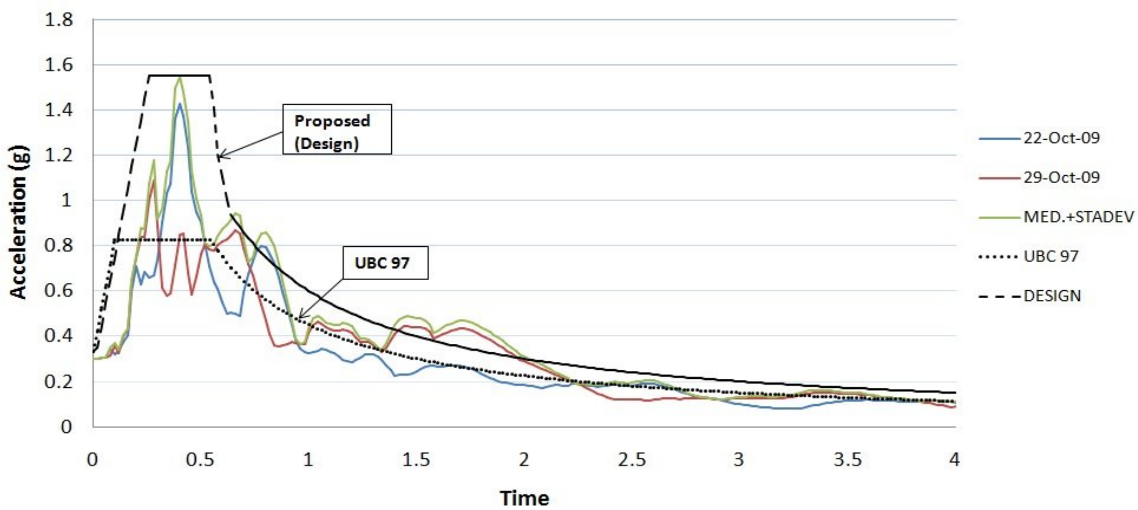

Figure 13 Comparison between proposed and UBC-97 DRS for Zhob city

Design spectrum for rocky soil: The soil of Balakot, Chitral and Quetta is rocky known as soil type 'B' according to UBC-97/BCP-07. These cities are located in zone 4 according to seismic zoning map of Pakistan. Response spectra generated from local ground motions recorded in these cities can be compared with UBC-97 DRS. The comparison between these spectra is presented in fig. 14.

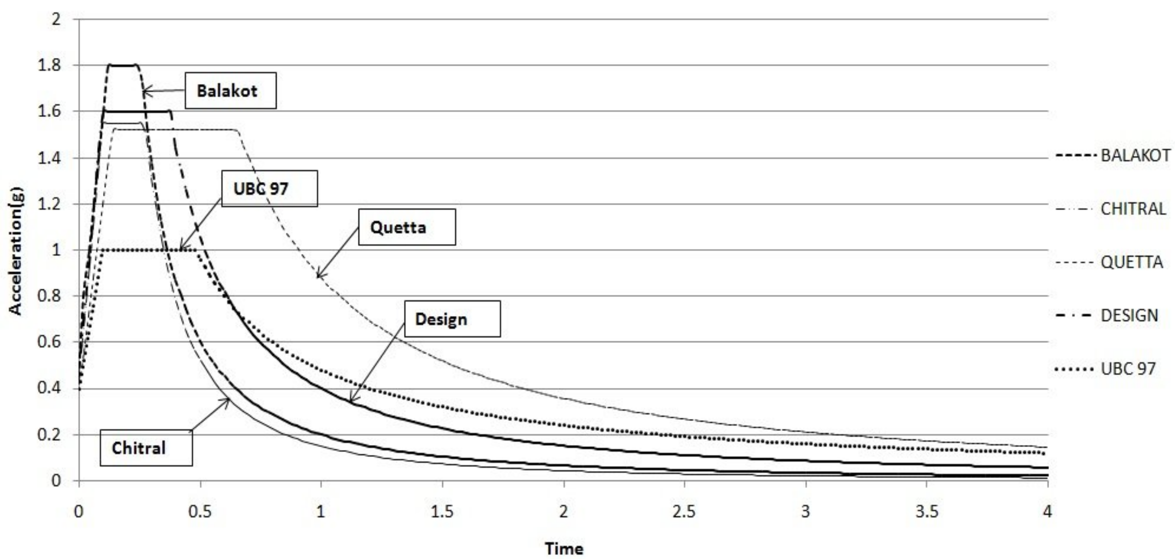

Figure 14 Comparison between UBC 97 and Proposed DRS for rocky soil.

These are scaled up ground motions and is evident that the time period to attain peak spectral acceleration is less in case of proposed DRS as compared to UBC-97. Moreover, the peak spectral acceleration is higher as proposed here for the same soil type. So, UBC-97 design spectrum is less conservative for rocky soil in zone 4.

Design spectrum for stiff soil: The soil of Lahore is stiff soil known as soil type 'D' according to UBC-97 soil characterization. The Lahore city is located in zone 2A according to seismic zoning of BCP-07. Fig. 15 represents the comparison of UBC-97 with the proposed DRS for the Lahore city. It is evident that the time period to attain peak spectral acceleration is less in case of proposed DRS as compared to UBC-97. Similarly, the peak spectral acceleration is also less in the proposed design spectrum as compared with UBC-97 for the same soil type. So, UBC-97 design spectrum is conservative for stiff soil in zone 2A.

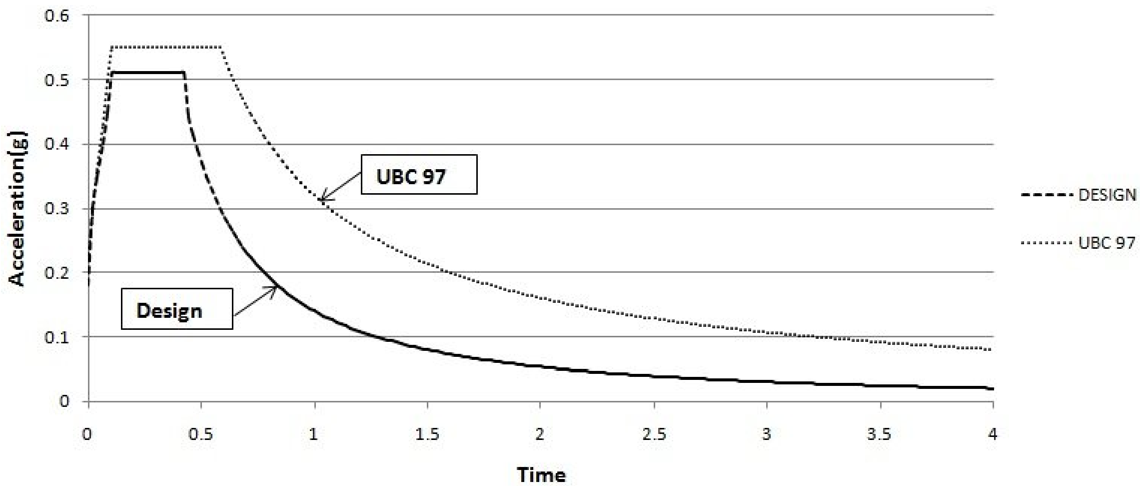

Figure 15 Comparison of UBC-97 and Proposed DRS for Zone 2A Stiff Soil Condition

Conclusions: Proposed spectrum is based on very limited scaled up records and should be regularly improved by incorporating original recorded ground motions over the coming years. This study is very preliminary and probablistic seismic hazard assessment should also be considered in future. Based on the original and scaled up ground motions response spectra following conclusions can be drawn.

1. The design is safe by using UBC-97 DRS, considering two years recorded ground motions in Pakistan (2009 and 2010). Two earthquakes (22nd and 29th October 2009) give a peak ground acceleration of 0.265g (Chitral city Zone 4) and remaining earthquakes show PGA less than 0.03g. So, on the basis of available current data UBC-97 DRS, gives conservative results.
2. For rocky soil (zone 4), the time period to attain peak acceleration is less in case of proposed DRS based on scaled up records as compared to UBC-97. But the peak acceleration is higher in the proposed spectrum for the same soil type. So, UBC-97 design spectrum is less conservative here.
3. For stiff soil (zone 2A), the time period against peak acceleration is less in proposed DRS as compared to UBC-97. Moreover, the peak acceleration is also lower in proposed spectrum for the same soil type. So, UBC-97 design spectrum is conservative for stiff soil in zone 2A.

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