Design Ground Motion Prediction Update for Islamabad, Pakistan

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SUMMARY:
Design ground motion (DGM) has been predicted at Islamabad, Federal Capital of Pakistan by determining the Design Response Spectrum (DRS) and generating compatible time histories. Design response spectra were determined with the help of codal approaches of Newmark and Hall, United States Nuclear Regulatory Commission (USNRC), Building Code of Pakistan – Seismic Provisions 2007 (BCP-SP 2007) and International Building Code (IBC). Time histories compatible with the DRS at Islamabad were generated utilizing Spectral Matching module of EZ-FRISK. For better comparative analysis, design values of PGA and seismic zones of BCP-SP 2007 were adopted. Results showed that IBC was found to be more conservative approach, while Newmark and Hall method gave least conservative results. This study provided DGM to the construction industry in order to have better designing and analytical capabilities. Generated Time Histories could be used in software such as SAP-2000 and Stad-Pro 2003 for the dynamic analysis of the structures.

Keywords: Design Ground Motion, Design Response Spectrum, Compatible Time Histories, Islamabad

1. INTRODUCTION

Earthquake Engineering is basically the study of effects of the earthquakes upon populace as well as their environment and methods to reduce these effects. The effort has been made in this study to contribute towards the better assessment of these effects. One aspect of the earthquake engineering is the structural engineering, which deals that how the existing and newly constructed building are made safe during an earthquake. Strong ground motion is motion having enough strength that affect populace as well as their surroundings. Evaluation of the effects of earthquakes at a particular site requires the objective, quantitative ways of describing these strong ground motions.

In natural disasters, Earthquakes are the major ones that are accountable for the loss of life as well as damage to the property. In this decade, the increased seismic activity and capital intensive nature of the structures has accomplished greater significance on the analysis of structure regarding seismic forces. Dynamic force depends a lot on Peak Ground Acceleration (PGA) as well as time period of the structure. During Muzaffarabad earthquake of 2005, structures experienced heavy damages resulting in great losses of life and property. Reconstruction in the area damaged by the earthquake should occur in conformance with the latest seismic building codes.

Assessment of the risk to a structure due to the future earthquakes requires evaluation of both the probability of occurrence of the future earthquakes (hazard) and resulting response of the structure (response). The study of strong earthquake ground motions, associated seismic hazard and seismic risk plays an imperative role for the sustainable development of the societies in earthquake prone areas. Design response spectra are useful to assess the response regarding linear systems having manifold modes of oscillation (MDOF systems). Design response spectra are quite helpful tools of earthquake engineering to analyze structural performance during the earthquakes by finding natural frequency concerning these structures; afterward peak response of structure can be checked with comparison to the Design Response Spectrum (DRS) for the same frequency (Kramer, 1996).

Many of the latest software and numerical techniques for the analysis and design of structures require the earthquake time histories. These expected ground motions are determined by finding time histories compatible to the design ground motion (DGM) just in the form of design response spectrum.

1.1. Design Ground Motion

Earthquake-resistant design of the new structures as well as evaluation of safety of existing structures requires analysis of their response to earthquake shaking. Evaluation of the geotechnical hazards, such as liquefaction and slope failure etc., also requires analysis in reference to some level of shaking. Level of shaking for which satisfactory performance of the structures and equipments is expected is often referred to as a design shaking level and is depicted as DGM. DGMs can, depending on how they are to be used later on, be specified in many different ways. Many analyses of soil and structural response require an entire time history of the ground motion while others require some or only one of the ground motion parameters. Peak horizontal acceleration, peak horizontal velocity, predominant period, response spectrum ordinates, and duration etc. are the most commonly used parameters for DGM specification (Kramer, 1996). These DGM parameters are determined mainly from the design earthquakes and the design response spectra. In this study, Design Response Spectra using different approaches have been determined and their compatible time histories have been generated.

2. DESIGN RESPONSE SPECTRUM DEVELOPMENT

The main purpose of the codes is to provide minimum standards to safeguard the life or limb, health, property, and public welfare by regulating and controlling the design, construction, quality of materials, use and occupancy, location and maintenance of the structures. Codes for highway, dams, bridges, nuclear power plants, and other types of structures have been produced by various regulatory agencies. The provisions of building codes are developed by the consent of a broad group of experienced practitioners and researchers.
Design of major structures is usually based on the Site-Specific Spectra because the structures are built at a specific location. Design Response Spectra described in the building codes are intended to specify the earthquake loading on a structure for life-safety performance. In such an event, the structure would be expected to yield but to maintain a substantial margin against the collapse (Kramer, 1996).
In the following sections, different methodologies to develop DRS have been employed on the case study of Islamabad.

2.1. Case Study

Usually the methodologies are well understood by their application or usage for different case studies. Federal capital of Pakistan, Islamabad was chosen for the case study. Islamabad has the administrative and operational setup of the government and other state organs and most of the critical infrastructure of national importance. This case study presented all important design response spectra for Islamabad. According to earlier seismic surveys, Islamabad was considered less prone to the earthquakes. Presently, however, due to the geotectonic activities and more detailed studies, it has been learned that it has been found to be more vulnerable to the earthquakes (PMD and NORSAR, 2007).

Hereby for the development of DRS, design g-value and seismic zoning parameters of Building Code of Pakistan – Seismic Provisions 2007 (BCP-SP 2007) have been utilized. These values are quite close to the findings of this study and have been preferred due to facilitate a meaningful comparative study of the design response spectra. Same input values for different methodologies will result in better comparison amongst the results. It is worth mentioning that according to International Building Codes (IBC) guidelines, ordinary structures should be designed for PGA values of 500 years return period, while all important structures should be designed for the PGA values of 2500 years return period (ERRA, 2009). BCP-SP of 2007 has put different cities of Pakistan in various Seismic Zones, which cover the areas with design values in certain acceleration ranges. If we follow basic figure of the PGA-values upon which this zoning depends, it yields to a certain design g-value for different cities. The PGA map of BCP-SP 2007 is a seismic hazard map having probability of exceedance level of 10% in 50 years.

2.1.1. Application of Newmark and Hall Method

Newmark and Hall in 1982 illustrated their approach to develop DRS by utilizing parameters of peak ground motion as well as proper spectral amplification factors. These parameters are peak ground acceleration (PGA), peak ground velocity (PGV) and peak ground displacement (PGD). In the Newmark and Hall approach, two options of 50 percentile and 84.1 percentile are available. 84.1 percentile was used because it gave more conservative approach and more smoothness in the DRS. Damping means the presence of frictional force in the structure that transforms mechanical energy of the system in to other forms of energy such as heat. Damping depends upon structural material, types of connections or joints in the structure etc. Values of damping ratio range from 2% to 10% depending upon the nature and orientation of the structures. Generally, 5% damping value is used for the reinforced concrete buildings having symmetrical sections (FEMA, 1997).

For determining DRS by Newmark and Hall Method, following steps were taken (Chopra, 1995):

i. Site at Islamabad had a design g-value of 0.22g as found from the concerned figure, in which PGA was given as having Probability of exceedance level of 10% in 50 years (NESPAK, 2007).
ii. Peak parameters for the ground motion PGA ($\ddot{u}_{go}$) = 0.22g, PGV ($\dot{u}_{go}$) = 10.56in/sec and PGD (u_{go}) =7.92in were selected. The line a=0.22g was plotted for natural time periods, T_n<1/33 sec.
iii. The amplification factors for median plus one standard deviation spectrum and 5% damping were obtained from table as $\alpha_A = 2.71$, $\alpha_V = 2.30$ and $\alpha_D = 2.01$.
iv. The ordinate for the constant-A branch was bc = 0.22g x 2.71 = 0.60g, for the constant–V branch was cd = 10.56 x 2.30 = 24.29in/sec and for the constant-D branch was de = 7.92 x 2.01 = 15.92in
v. The transition line b-a was drawn to connect Acc. = 0.60g at T_n = 1/8sec to $\ddot{u}_{go}$ = 0.20g at T_n= 1/33sec. Similarly the transition line e-f was drawn to connect the Disp. = 15.92in at T_n = 10sec to u_{go} = 7.92in at T_n = 33sec as shown in Fig. 2.1.
vi. For periods less than T_a (natural time period corresponding to point "a", i.e. T_n= 1/33sec), line A = PGA and for periods greater than T_f (natural time period corresponding to point "f", i.e. T_n= 33sec), line D = PGD was drawn, as presented in Fig. 2.1.

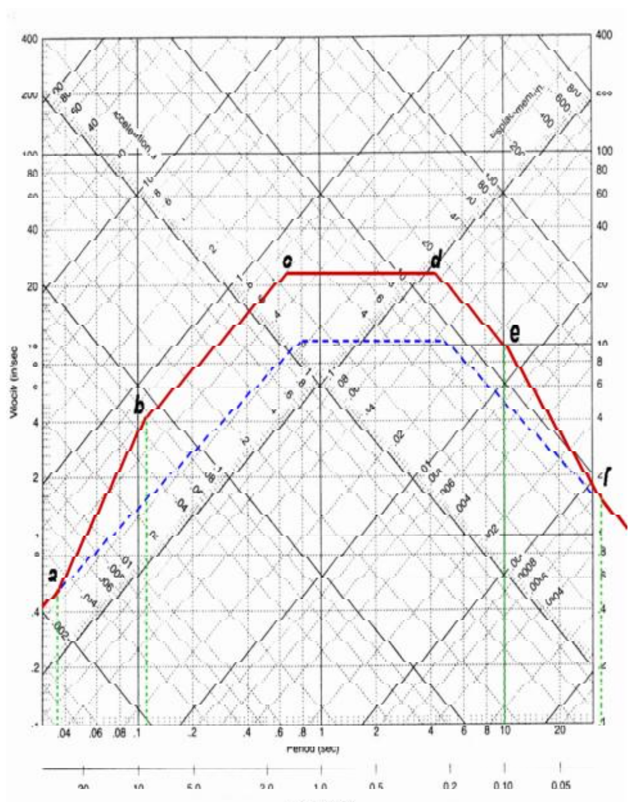

Figure 2.1. Final Shape of Newmark and Hall method for Islamabad

2.1.2. Application of U.S. Nuclear Regulatory Commission (USNRC)

Regulatory Guide 1.60 (RG-1.60) of the U.S. Atomic Energy Commission (USAEC) was published in 1973 (USAEC, 1973) and it established a DRS for seismic design of nuclear power plants. USNRC methodology was the newer one though it had adopted the results of many contemporary researchers (Takhirov et al., 2005). In USNRC methodology, four control points were used - three for the acceleration and one for the displacement. Peak Horizontal Acceleration (PHA) as well as Peak Vertical Acceleration (PVA) tables were available in the literature but in this study, PHA amplification table was used. PHA was commonly used to describe the ground motion potential to damage the structure by lateral inertial forces while PVA was less important because structures has sufficient margin of safety against the vertical loading. PGAs at three control points were 0.20g, 0.57g and 0.69g respectively while the displacement control point was 16.24in. Spectral velocity estimates were not obtained from amplification table but they could be found from the plot itself. The DRS used in the USNRC had two levels that represent Safe Shutdown Earthquake (SSE) and Operating Basis Earthquake (OBE). This method is used for all types of the soils or rocks except for very soft soil; in this case some modification is required. Design spectrum of the USNRC was very close to the Newmark and Hall method but it was more conservative design approach than the Newmark and Hall method. Following steps were involved (USAEC, 1973):

i. Site had a design g-value of 0.22g as described earlier. The peak parameters for the ground motion $\acute{\ddot{u}}_{go}$ = 0.20g and corresponding u_{go} = 7.92in were used as presented in Fig. 2.2.
ii. The amplification factors for median plus one standard deviation spectrum and 5% damping were obtained as 1, 2.61, 3.13 and 2.05 from table.
iii. Values at various Control Points were found by multiplying peak parameters for the ground motion with the amplification factors and were plotted as shown in Fig. 2.2.
 At *A* (33cps=0.03sec): Acceleration = (1)(0.22) = 0.22g
 At *B* (9cps=0.11sec): Acceleration = (2.61)(0.22) = 0.57g
 At *C* (2.5cps=0.40sec): Acceleration = (3.13)(0.22) = 0.69g
 At *D* (0.25cps=4.00sec): Displacement = (2.05)(7.92) = 16.24in
iv. Lines *A-B*, *B-C* and *C-D* were joined.
v. For periods < *A*, Acceleration=PGA and for Periods > *D*, Displacement was parallel to PGD
vi. Final Shape of DRS by USNRC was presented as Fig. 2.2.

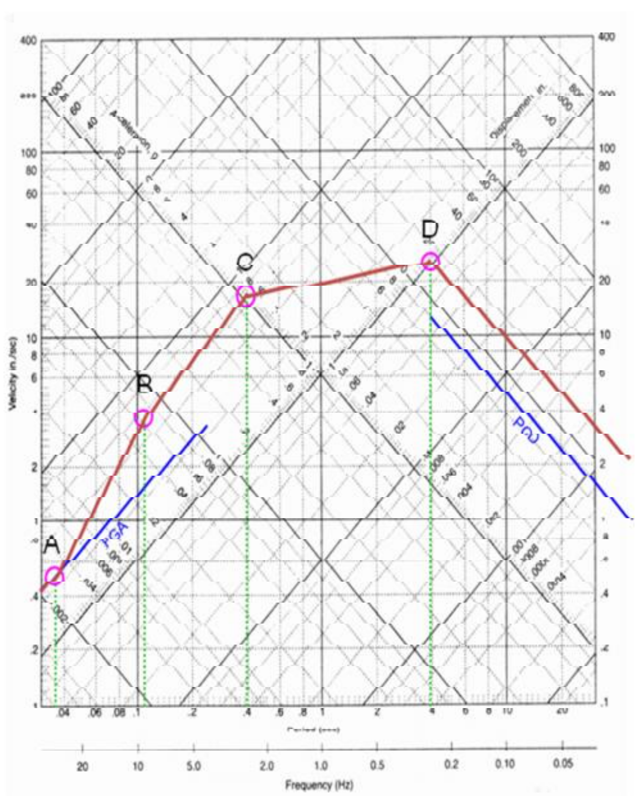

Figure 2.2. Final Shape of Design Response Spectrum in USNRC method for Islamabad

2.1.3. Application of Building Code of Pakistan – Seismic Provision 2007

In Pakistan, the design criteria for earthquake loading are based on the design procedures presented in Chapter 5, Division II of Building Code of Pakistan, Seismic Provision (BCP-SP) 2007, which have been adopted from Chapter 16, Division II of the Uniform Building Code (UBC) and is mandatory for the construction of new significant structures in Pakistan.

Following steps were taken to find the DRS by applying the methodology of BCP-SP 2007 for Islamabad (NESPAK, 2007):

- Study area Islamabad was in Zone 2B from the figure and table.
- Z value was 0.2 for Zone 2B from the table.
- Soil profile type D was determined by using the soil profile data.
- $C_a = 0.28$g and $C_v = 0.4$ from the tables.
- Value of 2.5 times C_a was determined as $2.5C_a = 0.7$g
- $T_s = 0.57$ sec and $T_o = 0.11$ sec from the equations
- For all values of $T > T_s$ (0.57 sec):

$$Acc. = \frac{C_v}{T} \tag{2.1}$$

So time period – acceleration pairs came out to be:
(T, Acc.) = (1,0.4), (2,0.2), (4,0.1), (8,0.05), (16,0.025), (32,0.0125)

DRS by BCP-SP 2007 was drawn by using the parameters of C_a, C_v, T_s, T_o and (T, Acc.) pairs, shown in Fig. 2.3.

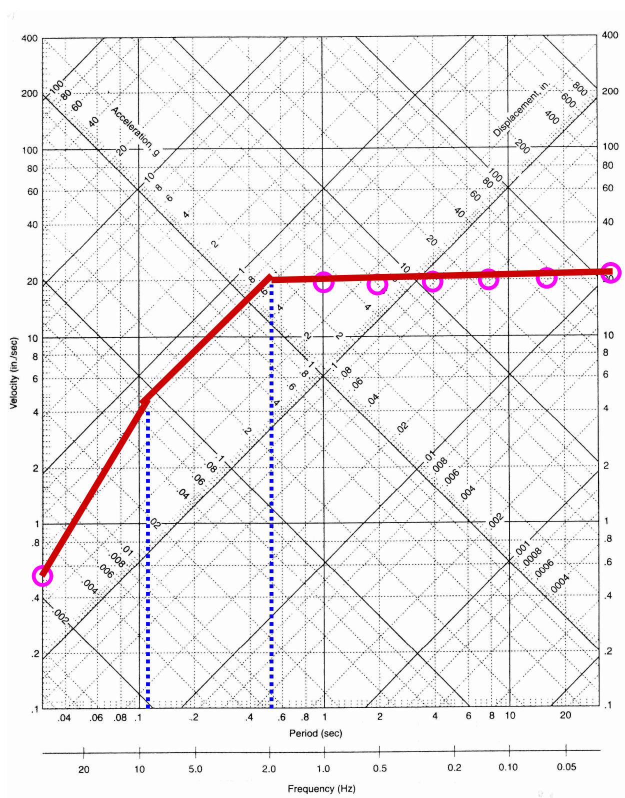

Figure 2.3. Plot of Design Response Spectrum by BCP-SP 2007 Method for Islamabad

2.1.4. Application of International Building Code (IBC)

The International Building Code was originally presented by the International Code Council in 2000. This code combines the three model building codes published by the Building Officials Code Administrators, International Conference of Building Officials and Southern Building Code Congress International (Wikipedia, 2009).

Methodology for determining the Earthquake Ground Motion to draw the DRS was: First selected the mapped short period spectral response acceleration period at short period and the mapped spectral response acceleration period at one second from the table, which mentioned values for different cities of Pakistan (UFC, 2002). Then the soil profile as discussed in the BCP-SP 2007 method was selected. Values of the response coefficient F_a and F_v were determined from the Tables (FEMA, 1997).

Following steps were carried out to determine the DRS from IBC methodology for Islamabad:

- Soil Class *D* was selected by using SPT data and concerned equation.
- From different tables, it was found that
  S_S = 1.68 and S_1 = 0.75 while
  F_a = 1.00 and F_v = 1.50.
- From different equations, it was found that
  S_{MS}= 1.68 g and S_{M1}= 1.125 g while
  S_{DS}= 1.12 g and S_{D1}= 0.75 g while
  T_S = 0.669 sec and T_o = 0.134 sec.
- At T = 0 sec, $0.4S_{DS}$ = 0.672 g
- For $T > T_s$, time period – acceleration pairs came out to be:
  (T, Acc.) = (1,0.75), (2,0.375), (3,0.25), (5,0.15), (10,0.075), (25,0.03)

DRS by IBC was drawn by using the parameters of S_1, S_S, F_a, F_v, S_{MS}, S_{M1}, S_{DS}, S_{D1}, T_s, T_o and (T, Acc.) pairs, shown in Fig. 2.4.

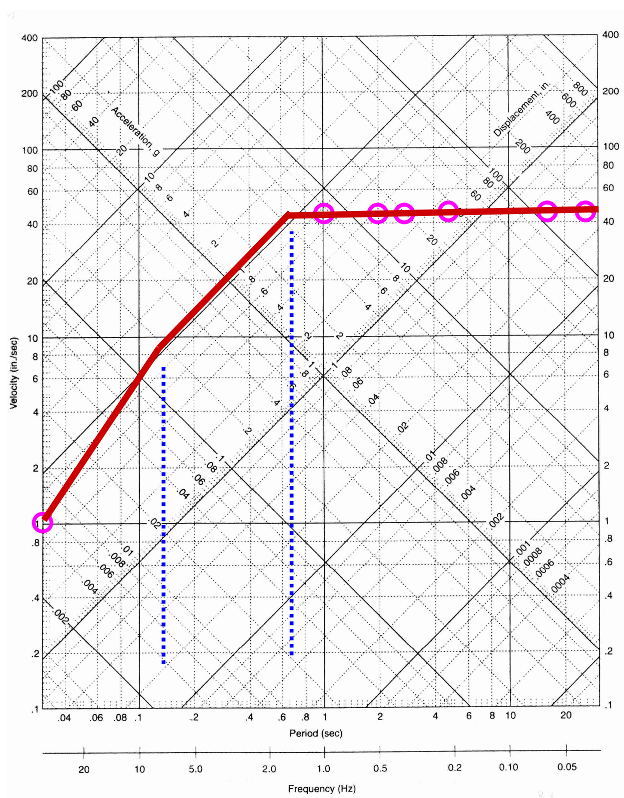

Figure 2.4. Plot of DRS by IBC methodology for Islamabad

2.1.5. Comparative Analysis

Fig. 2.5 was drawn for the comparison of DRS by different methodologies. When the DRS determined by all the methods were analyze, it was discerned that they were a bit in conformity to each other in some of the ranges while ideally speaking Newmark and Hall method was the least conservative and IBC method gave highest conservative approach. Newmark & Hall and USNRC method were easy to construct as they depended on damping values and PGA while BCP-SP 2007 and IBC methods needed soil profile studies. BCP-SP 2007 had intermediate values and this approach was seen to be good for generating the DRS and compatible time histories as this approach was particularly developed for Pakistan as compared to IBC. IBC gave higher values of acceleration due to the higher values of S_1, S_s, F_a and F_v while this approach could be used only for four cities of Pakistan namely Islamabad, Karachi, Lahore and Peshawar. Therefore, its usage was restricted to these cities only.

Summary for various approaches of DRS determination at Islamabad was given by Table 2.1.

Table 2.1. Summary of Design Response Spectrum at Islamabad with Different Approaches

Parameter\Approach	Newmark & Hall	USNRC	IBC	BCP-SP
Damping	5%	5%	5%	5%
Site dependency	N.A.	N.A.	Yes	Yes
Amplification factors	For PGA, PGV and PGD used	For PGA and PGD used	N.A.	N.A.
Frequency Range	0.0303-33 Hz	0.25-33 Hz		
Max Spectral Acc.	0.60g	0.63 g	1.12 g	0.7 g
To (sec)	0.11	0.11	0.134	0.11
Ts (sec)	0.7	0.4	0.69	0.57

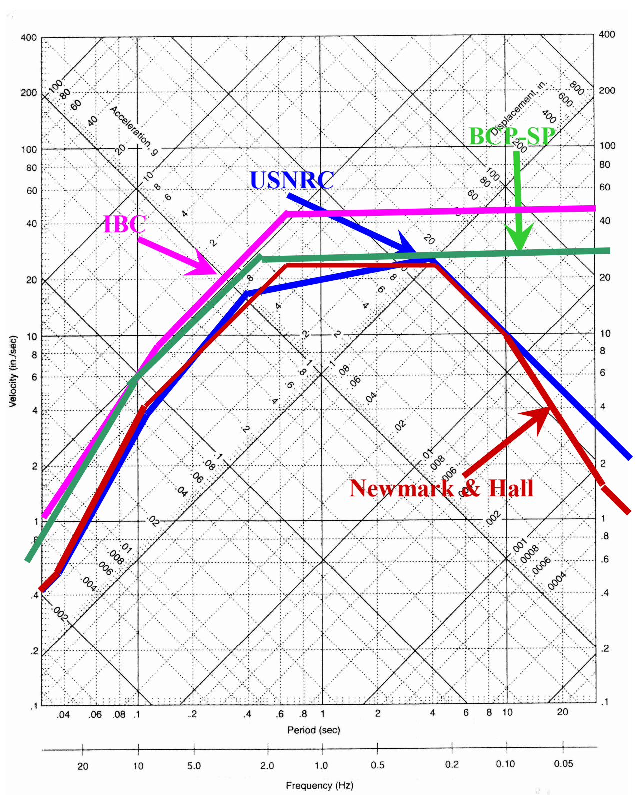

Figure 2.5. Comparison among different methods of DRS for Islamabad

3. GENERATION OF COMPATIBLE TIME HISTORIES

Structural and earthquake engineers have their basic ambition and objective on making the new and existing structures safe during any seismic event. This goal is mainly achieved by the analysis of the existing structures and the earthquake-resistant design regarding new structures. Many of modern software and numerical techniques for analysis and design of structure necessitate the earthquake time histories to be applied at the structure during a seismic event.

Time histories of ground motion, in fact, numerically describe the variation of a ground motion parameter with reference to time and they fully describe the earthquake motion, as having amplitude as well as frequency content. These earthquake time histories are obtained from a number of sources. In our case, time histories compatible with the DRS determined by methodology of BCP-SP 2007 has been utilized. These time histories are utilized for dynamically analyzing the structures and are becoming very common due to advancement in analytical capabilities as well as computer modeling techniques (Mahin, 2003).

In this study, there was neither a very thick strong motion network nor have a long strong motion observational history. Therefore, the approach of Spectral Matching in the time domain was employed. This approach is meant for the generation of an artificial time history within time domain which typically involves multiplying a stationary, filtered white noise signal by an envelope function that describes the buildup and subsequent decay (Chopra, 1995). RSPMATCH is an example of the software that is based on a time domain approach. Again, several iterations are generally required for achieving a match with target spectrum. Currently, time domain scaling is the usually preferred frequency modification approach for matching to target criteria for evaluation of matched accelerogram (Little and Eng, 2007). So, in this study, technique for using strong motion records of regions of the same seismo-tectonic environment was adopted and used them to produce time histories compatible with design response spectra. Expected ground motions were determined by finding time histories compatible to the DGM in the form of DRS. Compatible Time Histories are obtained through stochastic process in these cases.

3.1. Application of Software

There were a number of software and techniques available for the Generation of Time Histories compatible with certain benchmarks such as DRS. In this study, spectral matching module of software EZ-FRISK was utilized to achieve the goal.

The Spectral Matching module of EZ-FRISK created required earthquake time histories. Firstly, a target DRS was provided; then actual seismogram was selected; lastly spectral matching algorithm of software resulted seismogram adjustment to match the DRS. Time histories are afterwards utilized by the structural engineers for conducting non-linear analyses etc. (EZ-FRISK, 2010).

The spectral match module of EZ-FRISK was run for 475 years return period i.e. probability of exceedance level of 10% in 50 years, as is needed by the BCP-SP 2007. Fig. 3.1 represented the acceleration, velocity and displacement time histories having compatibility with the DRS by BCP-SP 2007 at Islamabad. Fig. 3.2 was the plot regarding Spectrum Match of Target DRS with Response Spectrum of the matched compatible time histories.

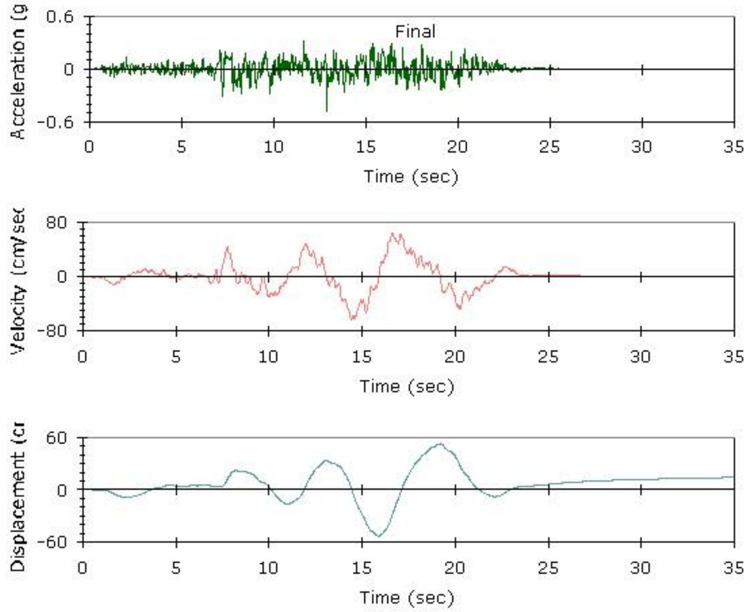

Figure 3.1. BCP-SP 2007 Design Response Spectrum compatible Time Histories at Islamabad

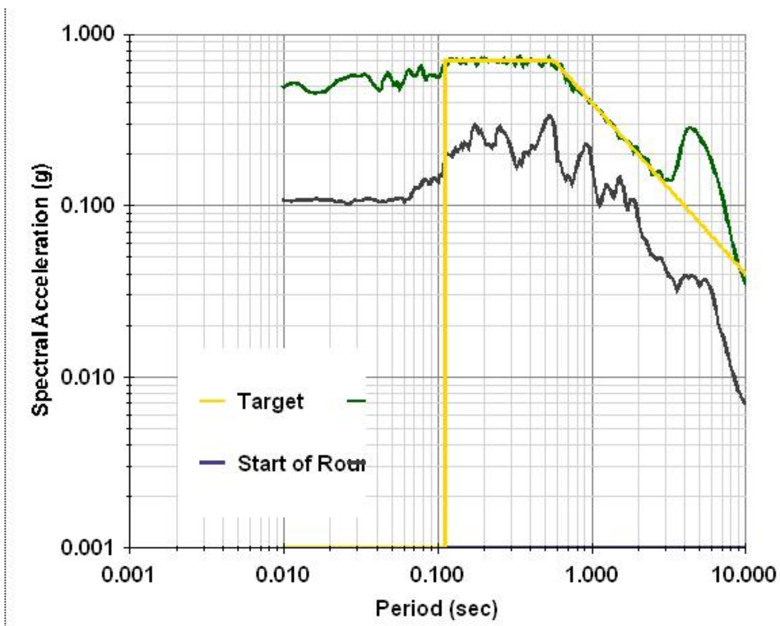

Figure 3.2. Spectrum match graph between BCP-SP 2007 DRS and Response Spectrum of compatible Time Histories at Islamabad

4. CONCLUSIONS

Following points are concluded from the results:

- This study enabled us to present DGM in the form of DRS and their compatible time histories to the construction industry or other relative populace so as to have better designing and analytical capabilities.
- Newmark & Hall and USNRC method were easy to construct as they depend on damping values and PGA while BCP-SP 2007 and IBC method needed soil profile.

- BCP-SP 2007 had intermediate values and this approach was seen to be good for generating the DRS and compatible time histories as this approach was particularly developed for Pakistan as compared to IBC.
- IBC gave higher values of acceleration. This approach could be used only for four cities of Pakistan due to the quoted higher values of S_1, S_s, F_a and F_v. So, overall, its use was limited.
- Newmark & Hall method was least conservative in all approaches while IBC method gave highest conservative approach.
- Generated Time Histories could be used in software such as SAP-2000 and Stad-Pro 2003 for the dynamic analysis of the structures.

AKCNOWLEDGEMENT

We would like to sincerely thank Tariq Mahmood for his help in manuscript revision and other issues. We also wish to pay our gratitude to Suhail Ahmed for his helpful comments and suggestions that also significantly improved the quality of this article.

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