COMPDYN 2013
4th ECCOMAS Thematic Conference on
Computational Methods in Structural Dynamics and Earthquake Engineering
M. Papadrakakis, V. Papadopoulos, V. Plevris (eds.)
Kos Island, Greece, 12–14 June 2013

A COMPARATIVE STUDY BETWEEN ACCELERATION AND ENERGY-BASED SEISMIC DEMAND SPECTRA COMPUTED BY AN EXTENSIVE COMPUTER ALGORITHM ON A GRID COMPUTER (COMPDYN 2013)

A.A. Dindar[1]*, C. Yalcin[2], E. Yuksel[3], H. Ozkaynak[4], O. Buyukozturk[5]

[1]Istanbul Kultur University, Department of Civil Engineering
Bakırkoy, İstanbul, Turkey
adindar@iku.edu.tr

[2]Bogazici University, Department of Civil Engineering
Bebek, İstanbul, Turkey
cem_yalcin@yahoo.com

[3]Istanbul Technical University, Department of Civil Engineering
Maslak, İstanbul, Turkey
yukselerc@itu.edu.tr

[4]Beykent University, Department of Civil Engineering
Ayazağa, İstanbul, Turkey
hasanozkaynak@beykent.edu.tr

[5]Massachussets Institute of Technology, Department of Civil and Environmental Engineering
Cambridge, MA, USA
obuyuk@mit.edu

Keywords: Energy Spectra, Response Spectra, Inelastic Response, Constant Ductility, Grid Computing.

Abstract. *This study aims to define the Seismic Energy that is imparted into the structure. When compared the energy-based spectra with the acceleration response spectra that are used in various codes, the latter do not take the duration and the frequency contents of the ground motion records, while the energy-based spectra takes these features into account and also combines the ground excitation and the structural response in its formulation. Therefore, enormous computations are required in the construction of the energy-based spectra while covering all the related parameters of ground motion and also the structural properties. This requirement is overcome by developing an extensive computer algorithm that ran in grid computer system in a computer laboratory of Istanbul Kultur University Civil Engineering Department.*

1 INTRODUCTION

The parameters used in the seismic analysis and the design of the structures range from the properties of the structures and the ground motion characteristics those are included in the computations. Most of the current building codes consider the dynamic response analysis (RHA) of linear-elastic structures in determination of the seismic demand values in terms of structural responses such as velocity and displacement as a part of force-based approach. According to the computed response values, the structural members are designed [1, 2]. For the last two decades, the performance-based design methodologies have been part of the earthquake resistant design philosophy where the deformation of the members, such as plastic strain and rotations, has been explicitly included in the computations [3].

Even though the researchers develop new ideas and propose innovative methodologies in seismic analysis and design, a key fact, energy, has been either disregarded or implicitly included in the computations. The energy, as a concept, has a great potential in the definition of the seismic demand and also design of the structural members since it couples the deformation of an element and acting force [4].

This proceeding describes the energy concept in seismic analysis, explains an energy-based seismic demand computation procedure and compares this procedure with the current demand methods.

2 ENERGY CONCEPT IN EARTHQUAKE ENGINEERING

The equation of the motion for a fixed based structure, represented by a Single Degree of Freedom System (SDOF), Fig. 1, contains the inertial, damping, kinetic and external forces acting on the system [5].

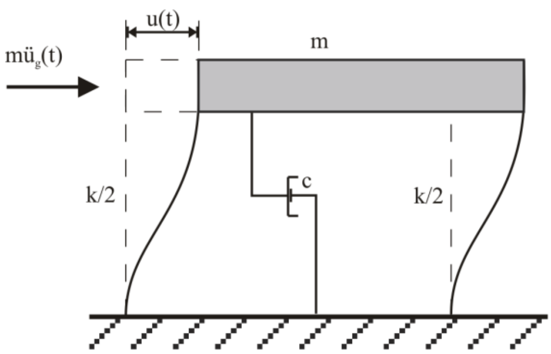


Figure 1: SDOF system.

The integration of this equation according to the relative displacement of the system, *u(t)*, under the ground motion results a new equation those are in energy units (1). The new equation governs the balance of the energy components found in the given SDOF system [5] and hence it is named as Energy Balance Equation (EBE).

$$\int m\ddot{u}(t)du + \int c\dot{u}(t)du + \int f_s du = -\int m\ddot{u}_g(t)du \tag{1}$$

The terms on the left hand side of EBE represent the energy components of the structure, namely, kinetic (E_K), damping (E_D) and absorbed (E_A) energies. The right-hand side of the equation represents the total input energy (E_I) that is imposed to the structure (2).

$$E_K + E_D + E_A = E_I \tag{2}$$

The input energy (E_I) in EBB represents the demand of the ground motion on the structure, Eq. 3.

$$E_I = -\int m\ddot{u}_g(t)du \tag{3}$$

The absorbed energy (E_A) in Eq. 2 is indeed contains the energy conserved by the elastic and inelastic deformations on the system. The inelastic deformations are actually the main parameter used in the performance-based seismic design in the next generation building codes. In this study the E_I will be taken into account and the comparison of the conventional demand values.

3 ALGORITHM AND COMPUTER ENVIRONMENT

3.1 Algorithm

The formulation given in Eq. 3 is computed after a dynamic time-history analysis is conducted on a linear SDOF system, Fig. 2. Therefore, the algorithm used in this study is developed in MATLAB® program [6]. The algorithm estimates the effective duration portion of the given earthquake record according to [7] and arrange the natural period of the system by changing the mass of the system so that the natural period is in the range of 0s and 3.0s. After the preparation phase in MATLAB®, the input parameters are sent to the time-history analysis program IDARC2D [8] that is ran within MATLAB command window. When IDARC2D completes the analysis, the MATLAB® scripts read the results of the response time-histories are then incorporates in the Eq. 3 to calculate the Input Energy (E_I) time-history values for the spectral analysis.

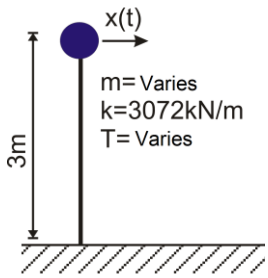


Figure 2: SDOF system.

The entire algorithm is developed in a way that it runs automatically, without any human intervention, for the given input variables such as ground motion, seismic intensity, a set of system mass, damping ratio and even different constitutive models. The further information is found in [9].

3.2 Computer Environment

The developed computer as a part of an extensive PhD thesis [4] has been conducted in a special grid computing system in Istanbul Kultur University (IKU) Department of Civil Engineering, Istanbul. The amount of the input variables considered in [4] requires enormous computer resource that is pretty challenging if a single personal computer is used. Therefore, 25 computers in the department's computer laboratory were integrated in a grid computing work frame which was again developed in MATLAB® program. The configuration of the each computer in the lab was Dell Precision T3500 Tower Computer Workstation with Windows XP operation system with Intel® Xeon® Processor X5570 2.93GHz and 4GB DDR3 RAM.

The computers were run during the no class periods, nights and weekends. The computers were programmed in a special grid system that divides the number of the large set of the ground motions into the small groups so that approximately 9 hours of spectral analysis computation between 7pm and 7am. In case the spectral computation is interrupted due to exceeding run time, the latest analysis level is kept in the memory to be continued in the following process time. The number of the time-history analysis conducted in the grid computer system was about 250,000 and it took in total 16 calendar days. At the end of every input parameter range completed, the algorithm compressed the results in zipped files and pushed to the data packages to a FTP server where the results were examined. Meanwhile, the algorithm sent the briefing emails to the researchers at the given process steps in order to keep them informed.

4 DEMAND SPECTRA FOR RESPONSE AND ENERGY VALUES

4.1 Response Spectra

For the linear elastic SDOF models with the changing natural period in a selected range, the dynamic time-history analyses result in the different responses (displacement, velocity and acceleration). The relation between the changing natural period and the response values are the basis of the spectral approach in the seismic design [10] and this is used in the force-displacement and performance-based design methodologies. Contrary to its wide use, the way of determination of the response spectrum inherently carries some major drawbacks. Since the absolute extreme response values are taken out from the dynamic time-history analyses, neither the entire ground motion duration nor the frequency content is taken into the extreme value computations which is extremely important from the view of accumulated damage propagation [11]. By this way, very important information on the destructiveness of the earthquake ground motion record is involuntarily lost in the estimation of the seismic demand values.

4.2 Energy Spectra

The input energy (E_I) in EBB, Eq. 3, and is influenced by the ground motion and structural characteristics concurrently. This fact increases the potential of the energy concept because the E_I term estimated in the integral is accumulated throughout the ground motion. By this way, the E_I covers the entire ground motion duration and its frequency content, Fig 3.

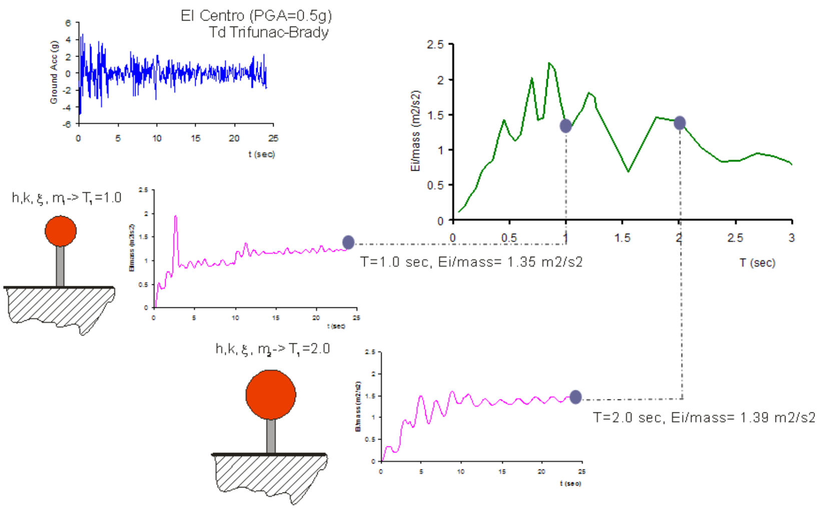


Figure 3: Energy Spectra.

Even if the interim values in the energy time history graph seem higher than the accumulated final value, Fig. 2, these interim values do also include the kinetic and elastic strain energies those diminish at the end of the motion record [12].

4.3 Comparison

The distinction between the conventional response and proposed energy demand spectra is apparent when two different earthquake records, given in Table 1, are examined [13].

Ground Motion Record	PGA (g)	Soil Condition (USGS)	T (sec)	T_d (sec)	Magnitude (Mw)	Focal Distance (km)
Chile Llolleo (3.Mar.1985) 10 component	0.71	A- Sandstone and volcanic soil	116	35.85	7.8	4.5
San Salvador (10.Sept.1986) 90 component	0.87	B- Shallow (stiff) soil	10	4.49	5.4	9.0

Table 1: Properties of the ground motions examined.

The duration, PGA values, Fig 4, and the frequency content, Fig. 5, of the both ground motions show that these records should have different effects on a structure. The darker portion of the ground motion record represent the effective duration according to [7].

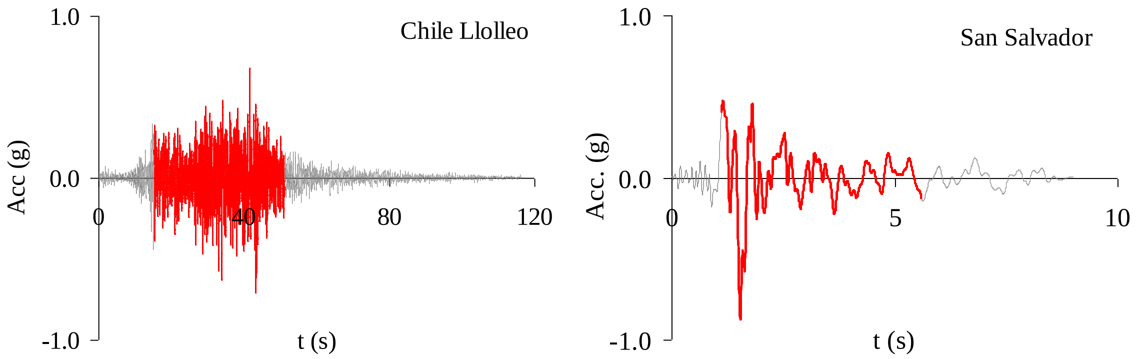
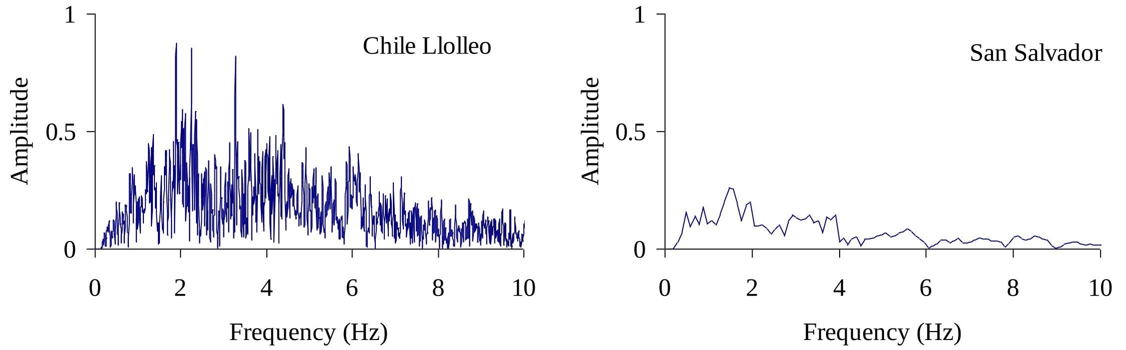


Figure 4: Duration of the two different earthquake motion records.



.

Figure 5: Frequency content of the two different earthquake motion records.

The drawback of the construction of the response spectra to the energy spectra is apparent when the both spectral values of the both earthquake motions are compared. Contrary to the distinction of the both earth records, the acceleration response values are almost identical throughout the entire natural period range, Fig 5a. However, the mass normalized Input Energy (E_I) spectrum significantly displays the gap between the energy spectra values that reflects the destructiveness of the earthquake records, Fig. 6b.

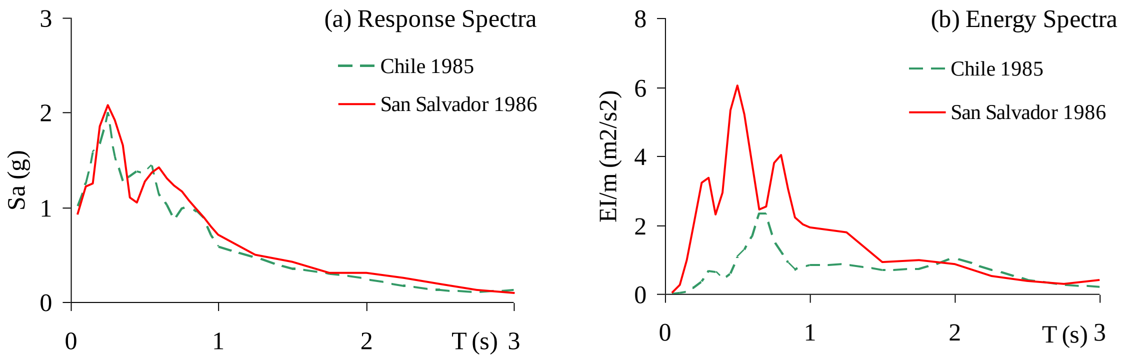


Figure 6: Response and Energy Spectra of the two different earthquake motion records.

5 CONCLUSIONS

The conventional response spectrum is widely used in the current building codes in order to determine the seismic demand on the structure. However, the construction of the response spectra inherently loses the valuable information in the ground motion records such as duration and the frequency content. The recently developed performance-based and also limit-state design approaches those are the preliminary examples of the next-generation seismic codes require the use of the ground motion data and also the structural properties comprehensively in the computations. Energy-based seismic demand analysis, explained in this study, and the design methodologies overcome the major drawback of the use conventional response spectrum by coupling the ground motion and structural properties. Hence, the energy-balance equation has the potential in giving a better-understanding in the destructiveness of the ground motion on the structures that is the key parameter in seismic design.

The computation resource in the construction of the dynamic time-history analysis and also determination of the energy demand spectral values were enormous in terms of the input parameters in the study. About 250,000 time-history analysis were conducted in an extensive PhD study. A well-developed computer algorithm with the use of grid computing system in the computer laboratory of an engineering department enabled the completion of the analyses in a very short time period. The success of the algorithm and the grid computing system proves that even if the next-generation design codes require extensive computations, the conditionally available computers in the engineering departments can be invaluable resources for the researches in the universities without going for investment of High Performance Computing (HPC) systems.

ACKNOWLEDGEMENT

The support of the Istanbul Kultur University Department of Civil Engineering in providing the computer laboratory to this study is gratefully acknowledged.

REFERENCES

[1] ACI 318, Building Code Requirements for Structural Concrete and Commentary, *American Concrete Institute*, 2005.

[2] Turkish Earthquake Code (TEC). Specification for Structures to be Built in Disaster Areas, *Ministry of Public Works and Settlement, Government of the Republic of Turkey*, Ankara, 2007.

[3] FEMA 273, Performance Based Seismic Engineering of Buildings, *Structural Engineers Assn. of California (SEAOC)*, 1997.

[4] A.A. Dindar, Energy-Based Earthquake Response Analysis and Design of Reinforced Concrete SDOF Columns, *Ph.D. Thesis*, Bogazici University, Istanbul, 2009.

[5] V.V., Bertero and C.M. Uang, Evaluation of seismic energy in structures, *Earthquake Engineering and Structural Dynamics*, **19**, **77-90**, 1990.

[6] MathWorks Inc., MATLAB R2010a. Natick, Massachusetts-USA, 2010.

[7] M.D. Trifunac, and A.G. Brady, A study of the duration of Strong Earthquake Ground Motion, *Bulletin of The seismic Society of America*, **65**, **581-626**, 1975.

[8] A. M Reinhorn, H. Roh, M. Sivaselvan, S. K. Kunnath, R. E. Valles, A. Madan, , C. Li, R. Lobo, and Y. J. Park, IDARC2D version 7.0: A Program for the Inelastic Damage Analysis of Buildings, Tech. Rep. MCEER-09-0006, *Multidisciplinary Center for Earthquake Engineering Research*, Buffalo, N.Y, 2009.

[9] A.A., Dindar, C. Yalçın, H. Özkaynak, E. Yüksel, and O. Büyüköztürk, The Use of Earthquake Energy Demand in Seismic Design of Structures, *submitted to Earthquake Spectra and under review*, 2012.

[10] A.K. Chopra, *Dynamics of Structures: Theory and Applications to Earthquake Engineering*, 3rd edition, Prentice Hall, Englewood Cliffs, NJ, 2006.

[11] A.K Gupta, Response Spectrum Method, *CRC Press Inc*, 1990.

[12] A.A. Dindar, C. Yalçın, H. Özkaynak, E. Yüksel and O. Büyüköztürk , Energy-Based Analysis and Design of RC members. *Advances in Civil Engineering (ACE2008)* Proceedings, **4**, **51-59**, Magosa, Turkish Republish of North Cyprus, 2008.

[13] V.V. Bertero and C.M. Uang, Implications of recorded earthquake ground motions on seismic design of building structures, *Research Report (UCB/EERC-88/13)*, University of California at Berkeley, USA, 1988.