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A NEW METHOD FOR CALCULATION OF FUZZY RESPONSE SPECTRA OF EARTHQUAKE MOTION IN LOWLANDS

Ansari A.[1], Noorzad A.[2]

ABSTRACT: The characteristic parameters of a system which are involved in dynamic analysis of a structure i.e. mass, stiffness and damping in addition to the input excitation have got some kind of fuzziness and vagueness. This vagueness is due to imprecise determination of such parameters and the complexity of real dynamic systems which are common in lowlands. On the other hand, nonhomogenity in soil properties and complex topography of soil layers have a great influence on the response of the ground. As a result, the effect of uncertainty of these parameters on the ground response is very important. This kind of uncertainty is not like randomness and it is necessary to consider it with the help of Fuzzy mathematics. In this paper a new method for fuzzy dynamic analysis of systems is introduced. According to this model, by the means of a parallel system, the problem of combination explosion, which is due to fuzziness of system parameters, is solved. Moreover, the results of a study on the influence of different parameters' fuzziness on the response spectrum are presented and a comparison between results of fuzzy analysis and traditional sensitivity analysis is made. Meanwhile, the effects of such uncertainty on response spectra are described.

Key Words: Earthquake, Fuzzy logic, response spectrum, uncertainty

INTRODUCTION

The focus of this paper is on dynamic analysis of systems due to earthquake motions and considering the vagueness of system parameters such as mass, stiffness and damping, in addition to the fuzziness of ground motion as input of the system in such analysis. The fuzziness of ground motion is obvious due to erratic soil formation such as depth, geotechnical properties, unknown topography, etc in lowlands. It is obvious that precise values of different parameters that are involved in dynamic analysis of structures are not known and there are only some logical estimation from their real value. The aim of this paper is to quantify the amount of influence of such parameters' fuzziness and to compare the results of fuzzy analysis approach with other rival methods.

In dealing with engineering problems, there is a special kind of uncertainty. This kind of uncertainty is not resemble to the familiar randomness, for, the nature of these events is quite different from the nature of probabilistic events. The fuzziness and vagueness is due to lack of information, imprecise determination of characteristic parameters and the complexity of the real systems. This fact is clear in seismic geotechnical studies of lowlands. In other words, the topic of this kind of uncertainty is about the validity and credibility of what we know.

During previous years, few but fundamental studies were accomplished in the field of fuzzy dynamic analysis of structures. The pioneering studies of (Dong & Wong 1987) and (Dong & Shah 1987) became a benchmark and a starting point for many succeeding research programs. They introduced a new method, called Vertex Method, for evaluation of fuzzy operations; it means operations with fuzzy parameters. This method is an extension of simplex method in optimization. (Zang.Y, Wang.G & Su.F 1996) developed the general theory for response analysis of fuzzy stochastic dynamic systems. Although they didn't introduce a practical method for calculation fuzzy response of dynamic systems, their success in combining fuzzy analysis with traditional stochastic analysis and developing the formulation of dynamic analysis in a fuzzy stochastic space is very eye-catching. The effect of different parameters fuzziness is also studied by (G.Crstea 1997). In his paper, a practical method for calculating fuzzy

1 Ph.D student ,Civil Engineering Department , Faculty of Engineering ,Tehran University, Iran, E-mail : aansary@ut.ac.ir
2 Asst. Professor, Ditto, E-mail: noorzad@ut.ac.ir
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dynamic response of single degree of freedom systems was introduced and the influence of different parameters' degree of confidence was studied. However, there is a gap between his assumptions and the basic assumptions of fuzzy mathematics.

(Melall 2000) proposed a method for derivation of seismic response spectra via neuro fuzzy system identification. This method is based on doing many traditional crisp analysis and then training a neuro fuzzy system between inputs and outputs of such analysis. By this method, he proposed the site response spectra, including characteristics of soil, ground acceleration and other relevant parameters.

In this paper, we introduce a new method for calculating dynamic response of structures with fuzzy parameters. Our method is based on combining the results of two parallel systems and keeping the entropy of response in a reasonable limit. Using this method, the influence of different parameters' fuzziness on the response spectra of a single degree of freedom system is studied. We also present a comparison between the results of traditional sensitivity analysis and the new method of fuzzy analysis.

To this end, at the beginning, the basic and fundamental concepts and definitions of Fuzzy Logic theory is described in a nutshell. In the second section, the resources and reasons of vagueness of dynamic system parameters are illustrated. Afterwards, the computational method and the consequent results of such analysis are presented and the effects of such uncertainties on the response spectra are described.

THE BASIC CONCEPTS OF FUZZY SETS

A Fuzzy Set A, defined in a universe of discourse X is expressed by its membership function (MF) $\mu_A(x)$.

$$\mu_A(x) : X \to [0,1] \tag{1}$$

Where the degree of membership $\mu_A(x)$ expresses the extent to which x fulfills the category described by A. We show fuzzy set A with a set of ordered pairs:

$$A = \{(x, \mu_A(x)) \mid x \in X\} \tag{2}$$

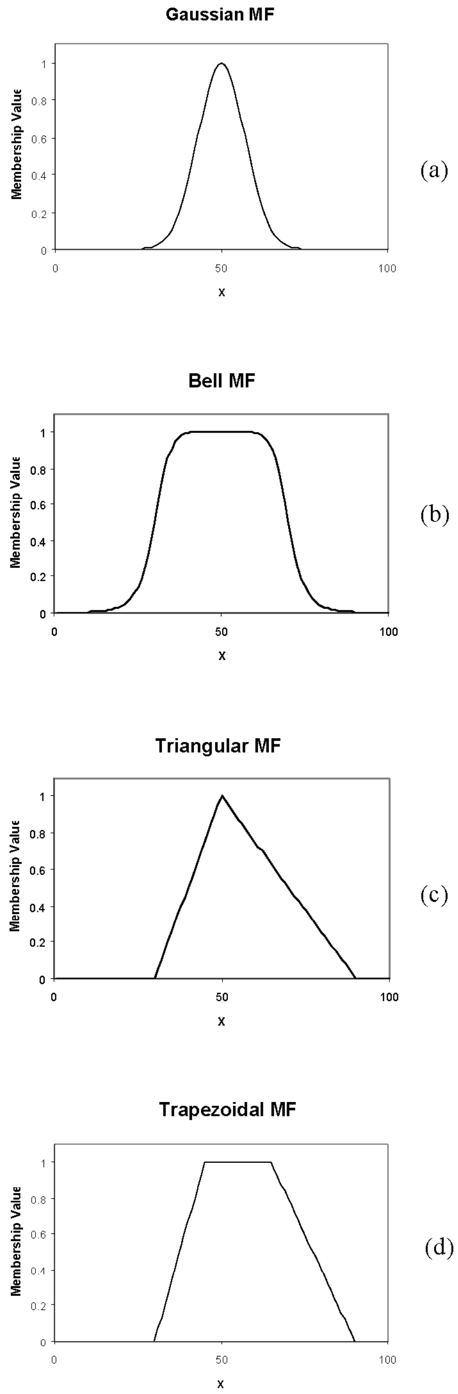


Figure 1: Some common membership functions. (a) Gaussian MF, (b) Bell MF, (c) Triangular MF, (d) Trapezoidal MF

The crisp set of elements that belong to fuzzy set A at least to the degree α is called α – level set or α - cut :

$$A_\alpha = \{x \in X \mid \mu_A(x) \geq \alpha\} \quad (3)$$

In practice, a fuzzy set is presented by a continues function. Some of these functions which are more popular are shown in Figure.1.

VERTEX METHOD

According to the extension principle (Zadeh, 1973), algebraic operations on real numbers can be extended to fuzzy numbers. However, the implementation of the computation is not trivial.

Vertex method (Dong, Shah. 1987) is a simple and efficient method for calculating algebraic functions which is extended to fuzzy numbers. This method is based on the concept of α-cut and the "Simplex Method" in optimization.

By implementation the definition of α-cut, a fuzzy number A is discretized into n interval number $A_\alpha = [A_\alpha^-, A_\alpha^+]$. All interval variables form an n-dimensional rectangular X1*X2 *…*Xn with 2^n vertices.

When y = f (x1,x2,…,xn) is continuous in the n-dimensional rectangular region, and also no extreme point exists in this region (including the boundaries), then the value of interval function can be obtained by

$$Y = f(X_1,...,X_n) = [\min(f(c_i)), \max(f(c_i))], \quad i = 1,...,n \quad (4)$$

Where ci is the ordinate of the i-th vertex.

THE ALGEBRA OF INTERVAL NUMBERS

The notion of vertex method which is based on constructing possible combinations with interval numbers boundaries at each α-level and deriving the boundaries of result is very innovative and applicable to every function. However, the amount of calculation increases as the number of parameters involved in the function increases.

On the other hand, if the function is a combination of basic algebraic operations, i.e., addition, subtraction, multiplication and division, it is possible to determine which vertex is the boundary of result. It can be achieved by the algebra of the interval numbers.

Let $A_\alpha = [a_\alpha^-, a_\alpha^+]$ and $B_\alpha = [b_\alpha^-, b_\alpha^+]$ be two interval numbers which are identical to α-cuts of two fuzzy numbers. Fuzzy basic algebraic operations can be expressed as follow:

1) Addition:

$$A_\alpha + B_\alpha = [a_\alpha^-, a_\alpha^+] + [b_\alpha^-, b_\alpha^+] = [a_\alpha^- + b_\alpha^-, a_\alpha^+ + b_\alpha^+] \quad (5)$$

1)Subtraction:

$$A_\alpha - B_\alpha = [a_\alpha^-, a_\alpha^+] - [b_\alpha^-, b_\alpha^+] = [a_\alpha^- - b_\alpha^+, a_\alpha^+ - b_\alpha^-]$$
…………………………………………………… (6)

3) Multiplication: There is not a general expression for multiplication. It is essential to distinguish between following cases:

$a/\quad a_\alpha^-, a_\alpha^+, b_\alpha^-, b_\alpha^+ \geq 0$

$$A_\alpha \times B_\alpha = [a_\alpha^-, a_\alpha^+] \times [b_\alpha^-, b_\alpha^+] = [a_\alpha^- \times b_\alpha^-, a_\alpha^+ \times b_\alpha^+] \quad (7)$$

$b/\quad a_\alpha^-, a_\alpha^+ \geq 0, b_\alpha^-, b_\alpha^+ \leq 0$

$$A_\alpha \times B_\alpha = [a_\alpha^-, a_\alpha^+] \times [b_\alpha^-, b_\alpha^+] = [a_\alpha^+ \times b_\alpha^-, a_\alpha^- \times b_\alpha^+] \quad (8)$$

$c/\quad a_\alpha^-, a_\alpha^+, b_\alpha^-, b_\alpha^+ \leq 0$

$$A_\alpha \times B_\alpha = [a_\alpha^-, a_\alpha^+] \times [b_\alpha^-, b_\alpha^+] = [a_\alpha^+ \times b_\alpha^+, a_\alpha^- \times b_\alpha^-] \quad (9)$$

$d/\quad a_\alpha^-, a_\alpha^+ \leq 0, b_\alpha^-, b_\alpha^+ \geq 0$

$$A_\alpha \times B_\alpha = [a_\alpha^-, a_\alpha^+] \times [b_\alpha^-, b_\alpha^+] = [a_\alpha^- \times b_\alpha^+, a_\alpha^+ \times b_\alpha^-] \quad (10)$$

e/ In other cases, it is necessary to use vertex method.

$$A_\alpha \times B_\alpha = [a_\alpha^-, a_\alpha^+] \times [b_\alpha^-, b_\alpha^+] = [\min(a_\alpha^- \times b_\alpha^-, a_\alpha^- \times b_\alpha^+, a_\alpha^+ \times b_\alpha^-, a_\alpha^+ \times b_\alpha^+), \max(a_\alpha^- \times b_\alpha^-, a_\alpha^- \times b_\alpha^+, a_\alpha^+ \times b_\alpha^-, a_\alpha^+ \times b_\alpha^+)] \quad (11)$$

It is worth mentioning that the amount of calculation with the help of these expressions is the minimum value which can be achieved.

SOURCES OF FUZZINESS OF STRUCTURAL PARAMETERS

As it is mentioned previously, all parameters of a dynamic system, including mass, stiffness and damping in addition to ground acceleration as the input of the system, are not crisp. In locations with high heterogeneousness of soil properties and complicated underground topography, the effect of these vagueness is very important. In this section, sources of fuzziness of these parameters are discussed in more detail.

FUZZINESS OF MASS

In comparison with other parameters of a dynamic system, mass has the least value of fuzziness and considering it as a crisp valve doesn't involve a great error in real modeling of the system. However, in any case, mass is also a vague parameter.

The differences between different codes in evaluating the dead loads and the live loads of a structure, is due to the vague nature of the mass. In addition, the accurate determination of the mass of a structure is not possible. However, the amount of this fuzziness is negligible in the analysis.

FUZZINESS OF STIFFNESS

Stiffness, is one of the major sources of vagueness in the structures. It is possible to classify the vagueness of the stiffness into two categories, the fuzziness due to specific models via vague parameters and the fuzziness according to vague behavior of the materials.

Due to definition of the characteristic strength of the concrete or the steel, it is the strength in which 90 percent of specimens have the strength more then it. The vagueness of material properties is now well understood from this definition. It means that none of the material properties such as yielding strength, ultimate strength, modulus of elasticity and Poisson ratio are crisp and accurate. This fact is more obvious about the characteristics of the soil, in which the vagueness of different parameters is much more, in comparison with steel or concrete.

On the other hand, the vagueness due to material and system behavior is more important. As it is well known the behavior of materials under cyclic loads and static loads is quite different, just like the behavior of the system. For instance, it is common to model the behavior of materials as elastoplastic. However, this assumption is quite subjective and the behavior of materials is different. In addition, for the sake of simplicity of model and less amount of calculation it is common to abnegate the effect of some relative phenomena. For example some nonstructural components like infill can have a great influence on the stiffness of the structure, and under cyclic loads, after a few cycles, because of cracking or collapse of such components, the stiffness of the structure changes suddenly. It is apparent that considering such effects precisely leads to a very complicated model.

One of the most important phenomenon which influences the response of the structure is the effect of "Soil Structure Interaction". The stiffness of the foundation is a function of Poisson ratio, variability of soil stiffness (isotropy and homogeneity of soil) and the foundation geometry. In common literature, it is rare to consider the effect of soil structure interaction, thus, the estimated stiffness and damping of the structure are not accurate and crisp.

FUZZINESS OF DAMPING:

Damping is another source of Fuzziness in the system. It represents the mechanism of energy dissipation in a system. This definition turns out the vague nature of damping since the mechanisms of energy dissipation in a system are very complicated. However, it is common to consider the damping to be viscous and represent it by "Damping Ratio", which is determined, more or less, by engineering judgment which is imprecise. Impreciseness of engineering judgment does not mean that it is wrong, but it means that if we say the damping ratio of a system is 5%, it can be 6% or 4% as well.

On the other hand, the assumption of viscous damping is not true; it is obvious that the behavior of the dissipation mechanism in a system is hysteretic rather than viscous. It is common also- for the sake of simplicity- to ignore the effect of geometric damping which is due to radiation of elastic waves and should be considered through complex soil- structure analysis. The energy dissipation mechanism is strongly dependent on the behavior of the materials and the systems, and these are fuzzy, as it was illuminated in previous section.

FUZZINESS OF GROUND ACCELERATION:

In dynamic systems, not only the parameters of these systems are vague, but also ground acceleration as the input of the system is vague as well. There are at least three reasons for fuzziness of the ground acceleration.

First, the modifications of one particular record are different. It means that different individuals have different modifications on one specific record. Second, the accuracy of the different records is dependent on the time of earthquake occurrence, for example, the accuracy of the record in 70's is different from the accuracy of the records in 90's, and the accuracy of analog records is different from the accuracy of digital records. Third, the record of an earthquake is a function of the place of recording, in other words, for a specific motion, different stations record different motions, however, all of them are the records of one specific motion, so, it is meaningless to specify a crisp record to a motion especially in the regions with high heterogeneity.

According to the above discussion, it is obvious now that dynamic analysis is actually the fuzzy analysis, and it will be more appropriate to do a fuzzy analysis for such a nature.

DETERMINING MEMBERSHIP FUNCTION OF DIFFERENT PARAMETERS:

After investigating sources of different parameters' fuzziness, it is necessary to present such uncertainties through different membership functions.

It must be noticed that although fuzziness, by itself, is objective but presentation of this objectivity through membership function is subjective. It means that there is not a deterministic rule for determination of membership function. Fortunately, in fuzzy mathematics, the results are not sensitive to the details of different membership functions. This is because in fuzzy arithmetic, the α cut sets are of great importance and different membership functions that have identical α cut sets have identical influence on the final results.

On the other hand, determination the range of variation of different membership functions is very important. This determination is mainly done from our knowledge of different parameters' accuracy. For example, the range of variation of geotechnical parameters of soil is clear according to different experiments. There is a range of highest possibility and a range of least possibility. The most common and simplest shape for representing such variations is trapezoid. For this reason, in this paper, we use trapezoidal membership function for the calculations.

To make this issue more clear, we can consider the vibration of a shear beam. For many years, the shear beam model has been used to study the influence of local soil conditions on the characteristics of horizontal free-field surface ground motion. It assumes that strain energy is transmitted in the form of pure shear waves propagating in the vertical direction. The governing equation of shear beam vibration is as follow:

$$\frac{\partial^2 u}{\partial t^2} - \left(\frac{G}{\rho}\right)\frac{\partial^2 u}{\partial x^2} = -\frac{\partial^2 u_g}{\partial t^2} \tag{12}$$

In which G, ρ, v_g are shear modulus, density and ground displacement respectively. It is evident that the values of G and ρ are not crisp, especially for a deep layer of soil. For example, the values of G for a clay soil can be from 16 MPa to 22 MPa and the values of ρ can be from 17 kg/m^3 to 20 kg/m^3 according to experimental results (H.Y. Fang (1991)) . These values are due to the most possible cases so we can represent them as 1.0 in the membership level. Thus it is reasonable to represent these parameters with membership functions shown in Figure 2.

For concluding remark of this section, it must mention that there are different methods for constructing membership functions that are introduced in fuzzy literature and most of them are based on Fuzzy Statistics. Some of these methods are presented by (H.Li, C.L.Chen and H.P.Hung 2001).

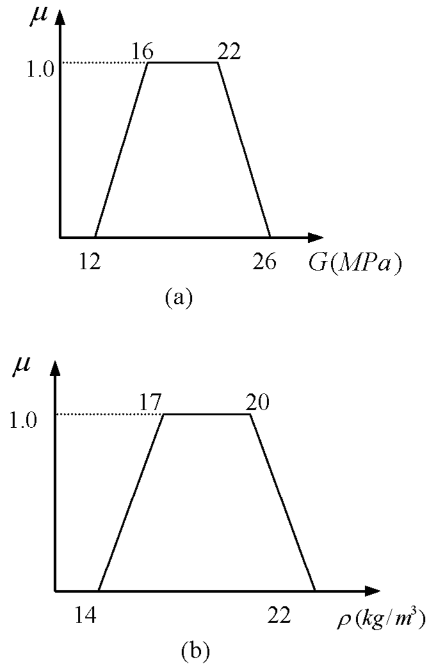


Figure. 2: Membership functions of (a) Shear Modulus and (b) mass per volume of an ordinary clay.

CALCULATING FUZZY RESPONSE SPECTRA:

In obtaining response spectra of an earthquake, it is common in earthquake engineering to evaluate Duhamel's convolution integral or perform step by step methods. Although, there are some simple methods for this goal which require less computational effort, in this paper, we use traditional 'Constant Average Acceleration ' step by step method. The formulation of this method is as follow (R. W. Clough, J Penzien 1993)

$$K = \omega^2 + 4\omega\xi / h + 4 / h^2 \quad (13)$$

$$P_{i+1} = \ddot{u}_g + 2\xi\omega(2u_i / h + v_i) + (4u_i / h^2 + 4v_i / h + a_i) \quad (14)$$

$$u_{i+1} = P_{i+1} / K \quad (15)$$

$$v_{i+1} = (2 / h)(u_{i+1} - u_i) - v_i \quad (16)$$

$$a_{i+1} = -\ddot{u}_g - 2\xi\omega.v_{i+1} - \omega^2.u_i + 1 \quad (17)$$

Where $\omega, \xi, \ddot{u}_g$ are natural frequency, damping ratio and ground acceleration, $u_i, v_i, a_i, u_{i+1}, v_{i+1}, a_{i+1}$ are displacement, velocity and acceleration of the system in step $i, i+1$ respectively, h is time interval.

It is obvious that all the above expressions are combinations of basic algebraic operations, so it is rational to use algebra of interval numbers and obtain fuzzy response spectra. However this in not the case. The operation sequence leads, theorically, to a combination explosion. In other words, the dispersion of fuzzy numbers after each step increases rapidly. Therefore, after a few steps, the fuzzy numbers of response become so wide and meaningless that the computational procedure can not be continued.

Cristea (1997) avoided practically this problem by keeping after each operation, only a small number from the result based on a selection criterion (e.g. the highest values of membership function). Although this solution could avoid the problem, but some portion of information would be abolished, for, keeping a small number from the result means a partial defuzzification of the results after each operation. (Zhang, Wang & Su 1996) have another solution for this problem . They define

$$\tilde{X} = \bigcup_{\alpha\in[0,1]} \alpha X_\alpha = \bigcup_{\alpha\in[0,1]} \alpha\left[X_\alpha^-, X_\alpha^+\right] \quad (18)$$

This solution results in a unusual shape of membership function, and in some cases the convexity property of membership function will be vanished.

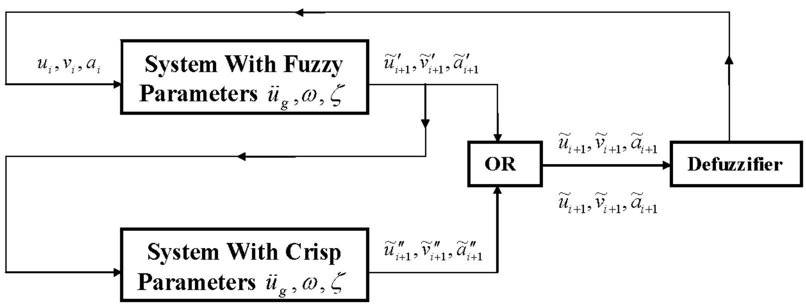
Here, we will suggest a new method to avoid that problem. This new method overcomes the problems of other mentioned methods too.

THE NEW METHOD OF COMBINATION FUZZY OPERATIONS:

This method is based on using a fuzzy system in addition with a crisp system as two parallel systems and then combining the results of these two systems. The algorithm of this method is shown in figure 3.

This system is resemble to multi rule fuzzy systems, in which the results of different rules are combined according to "OR" operator. Such systems are used widely in control engineering applications and known as the Mamdani inference systems.

Details of this method are presented in (Ansari 2000). Here, in brief, we describe the characteristics of this method.



Parameters with ~ are fuzzy.

Figure 3: Algorithm of new method of algebraic fuzzy operations.

Each fuzzy number has an entropy which reflects the degree of uncertainty related to that fuzzy number. After each fuzzy operation, the entropy of result is greater than the entropy of primitive fuzzy numbers. In our method, the entropy of ui , vi and ai as relating parameters between two separate steps, is a function of entropy of ω, ξ and $\ddot{u}_g$ of the same step, not the other steps. As a result, the entropy of ui , vi and ai remains at the entropy level of ω, ξ and $\ddot{u}_g$ of the step.

THE EFFECTS OF FUZZINESS OF SYSTEM PARAMETERS ON RESPONSE SPECTRA

As it was illuminated in third section, the vagueness and fuzziness is spreading every corner of dynamic analysis. In this section, the effect of fuzziness of different system parameters is considered. To study the effect of different parameters' fuzziness on response spectra, 10 records from Iranian strong motions are selected. These records have got different frequency content, duration and site condition. The characteristics of these records are presented in Table 1.

THE EFFECT OF NATURAL FREQUENCY VAGUENESS:

The influence of stiffness and mass fuzziness are considered in the fuzziness of natural frequency of the system according to eq. 19:

$$\omega = \sqrt{\frac{k}{m}} \qquad (19)$$

Used the method illustrated above, the fuzzy response spectrums of different famous earthquakes are prepared. In Figure 4 through Figure 7, the response spectrums of Tabas earthquake are presented. In these figures, the crisp spectrum in addition with two fuzzy spectrums which are due to α -cut 1.0 are presented (U denotes upper limit and D denotes lower limit of α -cut 1.0 of spectrum. In other words, the curve denoted by U is the supremum of the set representing α -cut 1.0 and the curve denoted by D is the infimum of this set). The crisp spectrum is obtained with crisp values of different parameters. These crisp values are the average of the set associated with α -cut 1.0.

As it is shown throughout these figures, the fuzziness of the natural frequency mainly affects the high frequency portion of the response spectra. In other words, the fuzziness of the stiffness and the mass are more important for the structures of short period. This fact is very important in the case of establishing seismic codes, for in these codes, determination of natural frequency of the structures is

No	Code (BHRC)	Station	Site	Peak Ground Acceleration (cm/s²)			Date	Ms	mb	Mw	Focal Depth (km)	Epicentral Distance (km)	Hypocentral distance	Intensity (MSK)	Focal Mechanism
				H1	V	H2									
1	1084-1	Tabas	1	1103	848	841	16/09/1978	7.3	6.7	7.4	10	27	28	X	Rv
2	1052	Gheshm	1	29	15	21	21/03/1977	7.0	6.2		29	71			Rv
3	1082-1	Deyhuk	1	309	176	377	16/09/1978	7.3	6.7	7.4	10	36	28	VII+	Rv
4	1107	Khezri	1	16	12.5	26	16/01/1979	6.8	6.0		33s	61			Rv
5	1139	Ghaen	1	228	136	132	27/11/1979	7.1	6.1		10	55	44	V+	SS
6	1362-1	Abbar	1	526	548	503	20/06/1990	7.7	6.8	7.3	19	43	40	VIII+	Rv/SS
7	1109	Gonabad	4	18	19.5	32.5	16/01/1979	6.8	6.0		33s	86	64		Rv
8	1142-1	Gonabad	4	81	61	86	27/11/1979	7.1	6.1		10	103	92	V	SS
9	1174	Kerman	4	91	69	108	28/07/1981	7.1	5.7		11	55	48	VII	Rv/SS
10	1355	Rudsar	4	102	69	83	20/06/1990	7.7	6.8	7.3	19	89	68	VI+	Rv/SS

Table 1: 10 Iranian Strong Motions. Site 1 is hard rock and site 4 is soft soil, H1 and H2 are two horizontal components and V is vertical component. (Zare. 1998)

performed roughly and this vagueness of natural frequency has a great influence on the response of the structure.

Other fact that is dedicated from these spectrums is that the region of natural frequency influence is a function of the characteristic of record. In other words, if the motion is narrow banded, the region of natural frequency influence is wider. In the contrary, if the motion is limited broad band, the region of natural frequency influence is small. However, in all cases, it is possible to obtain the frequency in which the influence of natural frequency vagueness becomes constant or negligible.

THE EFFECT OF DAMPING RATIO VAGUENESS:

In comparison with the effect of natural frequency vagueness, the response spectrum has less sensitivity due to damping fuzziness. This means that approximate estimation of damping ratio does not affect the response of the structures a lot.

THE EFFECT OF GROUND ACCELERATION VAGUENESS:

In contrary to natural frequency influence, the ground acceleration vagueness affect the high period portion of response spectrum. This result is obtain by considering fuzzy spectrums of 10 different records. However, this is not a strict rule. There are some records in which the effect of ground acceleration fuzziness is quite similar to what was mentioned about the influence of natural frequency vagueness. However, the effect of ground acceleration on the high period portion of the spectra is noticeable.

The effect of ground acceleration fuzziness in high period portion of spectra is very important in regions with relatively soft soil. Conventionally, the effect of soft soil is considered in the design spectrums by shifting the peak of acceleration spectra towards the period of 1 seconds. Fuzzy analysis that is performed in this paper shows that the effect of ground acceleration fuzziness is very important for systems with high period, as in the case of lowlands with soft soils. As a result, an especial attention must be given to the uncertainty of ground acceleration in the sites with soft soils.

It must be mentioned that fuzzy analysis is a kind of nonlinear analysis and its mathematical framework is rather sophisticated, as a result, determining the influence of different parameters' vagueness on response spectrum requires more mathematical studies.

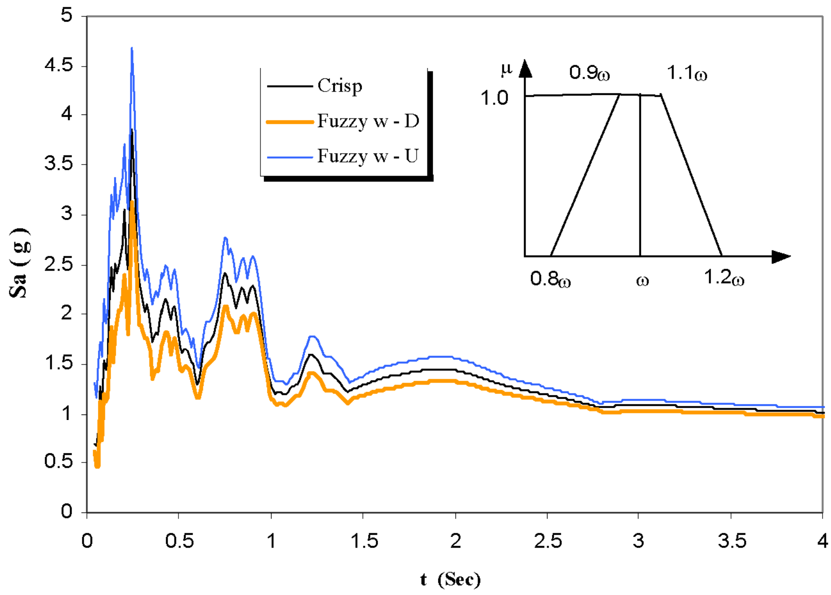


Figure 4: Fuzzy acceleration spectrum of Tabas earthquake with" ω "as fuzzy parameter (the MF used for " ω " is also shown).

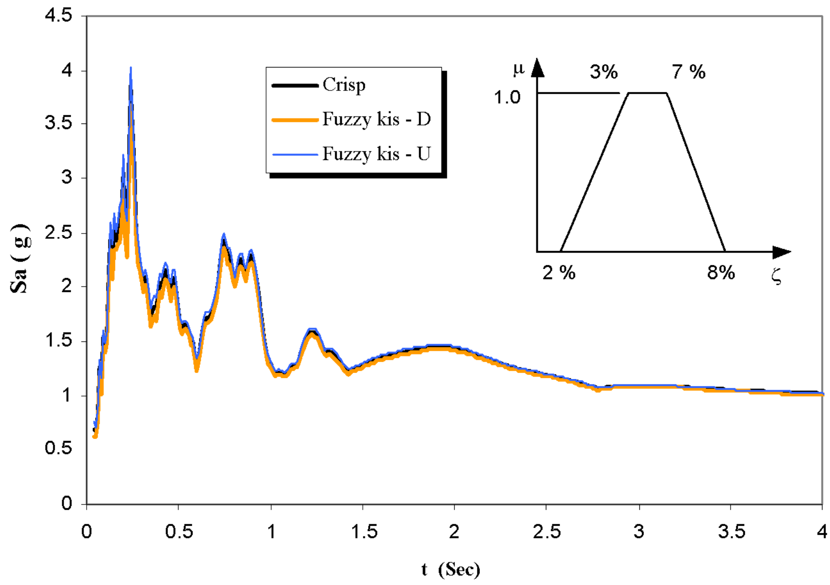


Figure 5: Fuzzy acceleration spectrum of Tabas earthquake with ξ as fuzzy parameter (the MF used for ξ is also shown).

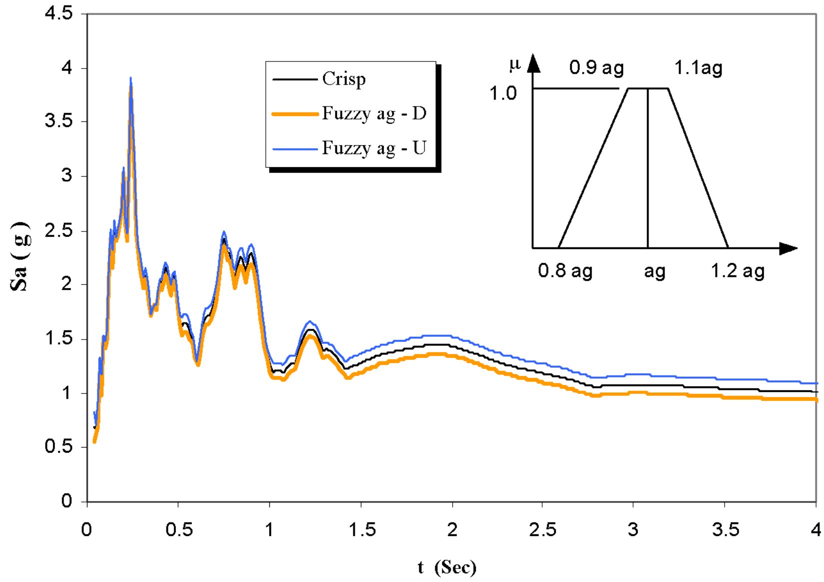


Figure 6: Fuzzy acceleration spectrum of Tabas earthquake with a_g as fuzzy parameter (the MF of a_g is also shown).

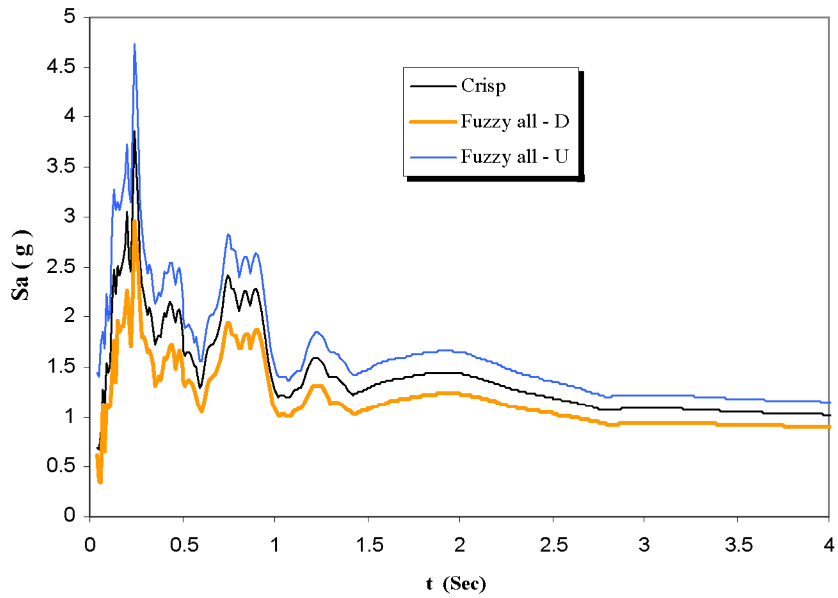


Figure 7: Fuzzy acceleration spectrum of Tabas earthquake with all parameters to be fuzzy.

COMPARISON BETWEEN FUZZY ANALYSIS AND SENSITIVITY ANALYSIS:

A common and traditional way of considering uncertainties of different parameters is sensitivity analysis. In fig 8, a comparison between the results of fuzzy analysis and sensitivity analysis is presented. In this figure, only the vagueness of damping is taken into account. In both cases, it is assumed that and the length of the cracks are variable and this variability affect the response of the next step. In fuzzy analysis, this fact is considered through the basic definition of extension principle. In the contrary, crisp analysis is only an abstractive analysis.

There is another point in commentary of the result of sensitivity analysis and the fuzzy spectrum. Two curves in sensitivity analysis represent the response spectrums corresponding to 1 and 9 percent damping

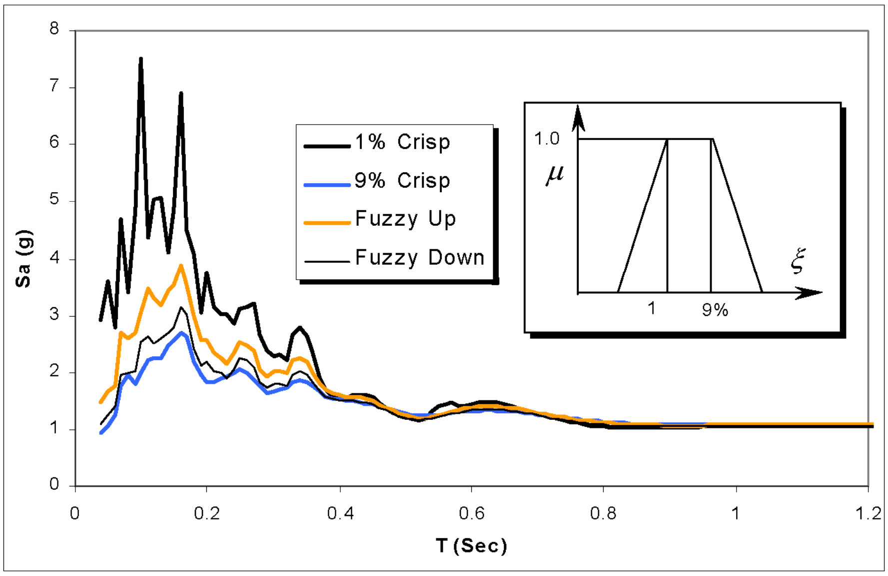


Figure 8: Comparison between Sensitivity and Fuzzy analysis (Tabas strong motion) and membership function of damping ratio used in fuzzy analysis.

damping ratio has a vague amount between 4 and 9 percent. As it can be observed, the results of these two kinds of analysis are not coincident at all. There is a logical reason for this difference. The sensitivity analysis is nothing but doing traditional dynamic analysis with different values of damping ratio. Thus, the results of such analysis are absolutely independent. It means that there is no interaction between the spectrum with 1% damping ratio and the spectrum whose damping ratio is 9%. On the other hand, the fuzzy analysis is an integrated analysis in which the response in each step is directly affected by the vagueness of the damping ratio. For example, if it was assumed that the only mechanism of energy dissipation be cracking, the value of damping ratio would be different in each time step, for, the width separately. However, two curves of fuzzy analysis are two bounds of the response of fuzzy model. They do not represent response due to 1 or 9 percent damping, they represent fuzzy spectrum due to vague value of damping ratio that is between 1 and 9 percent. In conclusion, the fuzzy analysis is the way in which the reality of the model is more satisfied.

CONCLUSION:

In this paper, the resources of vagueness of different parameters that are involved in dynamic analysis of systems were described. In addition, a new method for calculating fuzzy dynamic response of structures was introduced. It is based on using two parallel crisp and fuzzy systems and combining the results of these two separate systems. Moreover, the fuzzy response spectrums for different earthquakes were calculated and the effects of different parameters' fuzziness were studied. From this analysis, it was obtained that the natural frequency fuzziness, which is due to mass and stiffness fuzziness, affects the high frequency portion of the spectrum. In contrary, the fuzziness of ground acceleration affects the high period portion of the spectrum which is very important in the case of soft soil sites that commonly have high natural period. In comparison with the effects of natural frequency and ground acceleration fuzziness, the effect of damping fuzziness on response spectrum is not noticeable. In the end, it must mention that the results of fuzzy analysis are quite different from the results of sensitivity analysis.

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