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A New Viewpoint for Seismotectonic Zoning

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Abstract: Problem statement: Seismotectonic zoning has always been used to get access to intracontinental seismic deformation whereas zoning is not enough reliable in regard with small-scale studies. **Approach:** This research presents a theoretical model on the basis of plate tectonic theory to introduce a new approach to conduct zoning in terms of seismic deformation. **Results:** The result of this research not only has reliability but also is applicable to variety of research scales. **Conclusion:** The numerical techniques were used in the proposed model. Thus, this novelty model contains remarkable innovations: (1) Objectivity, accuracy and therefore reliability of zoning have been increased. (2) Numerical explanation of seismic deformation has been presented.

Key words: Tectonics, active faults, seismic deformation, earthquake, numerical techniques

INTRODUCTION

According to the classical plate tectonic theory, the present deformations of the earth's crust resulting from movement of tectonic plates are concentrated in plates boundaries and consequently the plates are stable internally. However, in fact the whole internal parts of the plates experience tectonic effects to some degree (Park and Jaroszewski, 1994). These deformations are exposed to be both seismic and aseismic in proportions (Davison, 1994; Masson *et al*., 2005). There is no doubt that the continental intraplate regions, unlike the oceanic ones (which are for the most part seismically quiescent), contains numerous weaknesses that are exploited due to stress impact arising from the movement of the plates (Park and Jaroszewski, 1994) and resulting in localized zones of movement. Consequently the seismic deformation zones are formed inside the continents where the most devastating earthquakes are expected. Therefore, specifying the pattern of intracontinental seismic deformation will be absolutely scientifically and also more significance.

In order to get access to distribution mode of seismic deformation various seismotectonic studies have been conducted (Unesco, 1985; Berberian, 1976; Nowroozi, 1976; 1979; Nowroozi and Ahmadi, 1986; Mirzaei *et al*., 1999; Tavakoli and Ghafory-Ashtiani, 1999; Ansari *et al*., 2009. However the seismic studies are important in various scales (Benmenni and Benrachedi, 2010; Amiri and Tabatabaei, 2008; Al-Zoubi, 2005; Chakraborty and Choudhury, 2009; Hazarika, 2009; Choopool and Boonyapinyo, 2011; Abu-Lebdeh *et al*., 2011; Teachavorasinskun *et al*., 2009; Escobar *et al*., 2008; Mayoral and Romo, 2008; Musmar, 2007; Singh and Roy, 2009), but the seismotectonic zoning are mainly conducted in large-scale without any effort on small-scale basis because of problems and disputes. It is possible to clarify the basis of ambiguities and disputes concerning on zonings through bringing up a basic problem and also considering subjectivity with regard to method and quality of zonings. This survey presents a scientific model for reliable seismotectonic zoning in order to remove the ambiguities.

MATERIALS AND METHODS

By reviewing performed seismotectonic zonings research, namely Nowroozi (1976), as an instance of small-scale zoning in which Iran that is subdivided into 23 seismotectonic provinces, we distinguished two main difficulties: to begin with, it is clear that the seismotectonic factors applied in the zoning are divided into two groups; the initial group are factors which make the boundaries of formed zones and the second one contains the factors characterizing the internal features of the zones. It should be pointed out that the important tectonic factors like seismically active faults play the role of boundaries for each new-formed zone in the mentioned zoning (Nowroozi, 1976). Significant

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features of seismicity are also mainly used to explain the difference of divided zones by active faults (Nowroozi, 1976) while faults and earthquakes are scientifically integrated, i.e., where there is a fault there had been earthquakes. Therefore, in accordance with given reason it would be sufficient to claim that this method of seismotectonic zoning is not suitable for explaining the mode of intracontinental seismic deformation. Figure 1-4 show details of the defects in the traditional zoning methods and how to resolve it in a modern zoning method through viewing of consequences resulting from those difficulties, so that fault and earthquake link in the modern zoning is evident.

Secondly, when the scale of zoning becomes small, the shortage or lack of boundary tectonic factors such as faults will be problematic and result in setting forth less reliable boundaries. Similarly, Berberian stated that many of divisions conducted by Nowroozi (1976) could be considered in a single unit; especially Nowroozi himself puts no considerable validation on his suggested boundaries (Berberian and Mohajer-Ashjaei, 1977; see also: Nowroozi, 1979). However, some attempts were done for tectonic zoning with the aim of removing ambiguities in the previous zoning while applying its relevant results could lead to some other problems. In such cases as locating the hypothetical quadrangular sites and their dimensions, type and number of variables, the distance formula and grouping method and finally locating the phonon-line, (all of them) could be considered controversial. The reason could be that this zoning attempted to use inductive reasoning to get the results, without any influence of an external model while it seems that an accepted and appropriate (external) model could help to resolve disputes in the cases mentioned above. So it would be worthier to find a way to increase the efficiency and influence of the external model instead of removal of that.

In this survey the researcher has tried to solve the first mentioned difficulty through a specific viewpoint to seismotectonic zoning and regarding that each zone has an equipotential seismicity (Nowroozi, 1976) likewise the author has tried to reintroduce the second mentioned problem in the mentioned research and with new-formed viewpoint has suggested a solution for that problem.

The distribution of earthquakes on the earth's surface follows a narrow and linear pattern which accords with plate boundaries based on plate tectonic theory. In other words the earth lithosphere is divided according to these active zones, into mosaic of plates moving towards each other (Kearey *et al*., 2009).

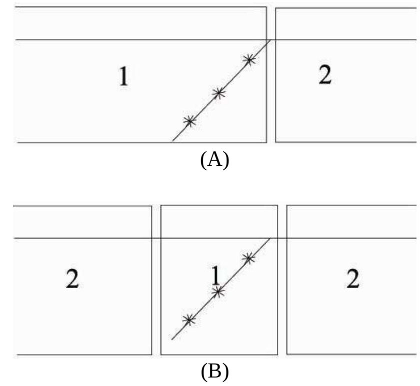

Fig. 1: Ideal mode of detection and separation of zones is that when there is a fault and recorded seismic data related to the fault. With cross-sectional drawing of this state (A) show that by traditional methods zoning, part of zone 2 (which is located below the fault surface) is considered for the zone 1. This is because of ignoring the adaptation of two phenomena: the fault and earthquakes, in the depth; by traditional seismotectonic zoning method. In the modern method that aim of the zoning has been changed, separation of zones is carried according to B in such a manner consistent with the logical and scientific principles and therefore the facing Problem is eliminated

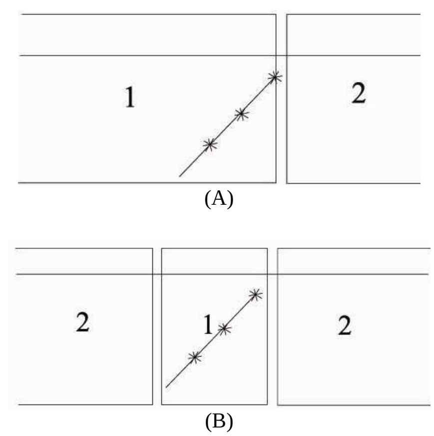

Fig. 2: Second mode is where a fault is not available, but seismic data indicates difference in the seismicity potential of the area: blind or hidden fault (Davison, 1994). In this case as shown in figure A, traditional methods have to use invalid boundaries where cause disagreements. According to figure B, use of modern method separation of zones will take in a form that resolved the considered ambiguity

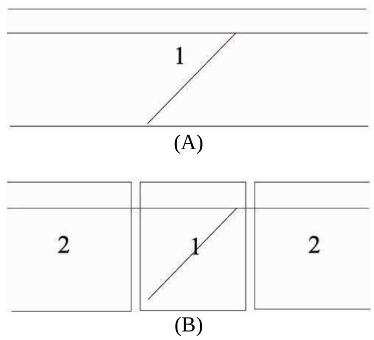

Fig. 3: Third mode is where a fault available but the seismicity potential of the zones on either side of the fault is not specified according to the weakness of data. In this case according to the figure A, traditional method could not be able to separate the mentioned zones based on seismic characteristics. Use of modern method, like the past two cases, zoning separation will be done in a way that is completely consistent with scientific principles

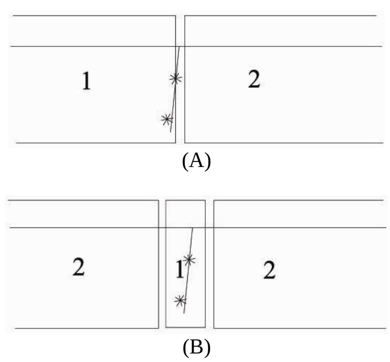

Fig. 4: Fourth mode is where a fault is vertical or semi-vertical. In this state, According to (A) applying traditional seismotectonic zoning, led to locate two heterogeneous zones with completely different potential seismicity in one zone. (B) Use of modern method, separation of zones will be done in accordance with the principles and logic of seismotectonic zoning

In fact the lithosphere is divided into two separate zones. The first one is the zone of relative high seismic potential (plates boundaries) and the second one is the zone of relative low seismic potential (intraplate zones). So, if we take this division a kind of zoning for seismic deformation in Global or Mega-scale, it is also claimed that inside of each tectonic plate one can perform Regional or Macro-zoning in terms of existing intraplate earthquakes which accord with active and linked fault systems (as new boundaries). In this manner each tectonic plate is divided also into two separate zones of relative high and low seismic potential. Of course the zone of relative high seismic potential has a role of boundary for new-formed zones as mentioned in mega-scale zoning. But the earthquakes show a diffuse pattern in smaller scale and the faults don’t form a linked system and gradually die out in lateral and vertical directions (Davison, 1994). Thus, due to shortage or lack of reliable margins inside any zone of regional zoning, it’s not possible to perform provincial or Meso-zoning under method of previous two scales because of personal taste influence on determining boundaries of smaller zones. This would result in further disputes and ambiguities. The above issue becomes more outstanding in later stage of zoning, i.e., local or Micro-zoning.

By taking advantage of the above points it is clear that if separating zones of relative high seismic deformation (seismic potential) from that of low ones be the purpose of zoning process in the primary step for all study-scales, the first mentioned difficulty will be solved. Now to overcome the second reintroduced difficulty and to get deep into distribution mode of intracontinental seismic deformation, a new idea is presented.

The seismicity of a site is assessed partly by its distance from any fault and partly from the frequency and size of earthquakes that have occurred in the past (Berberian and Mohajer-Ashjaei, 1979). Regarding both this point and the new mentioned purpose of zoning process, some zones inside the continent should be separated (for seismic deformation zoning) in terms of various concentrations of faults and earthquakes (in other words the various concentrations of seismic deformation). Obviously, if such separation is done mentally it shall not be sufficient accurate and Clair, specifically in the provincial and local scales (meso-zoning and micro-zoning). But in case of numerical presentation of seismic deformation in several different sites inside the continent, it’s possible to draw exactly the curves of equal seismic deformation. Thus, the pattern of above curves represents the amount and distribution mode of seismic deformation in different parts of the study area. In this manner a new unified method of reliable seismic deformation zoning shall be given for all various study-scales.

Moreover, the classification of study area in terms of seismic severity has been desirable in the continuation of seismotectonic studies. In this matter the proposed idea results in presenting various numeric value related to some zones of study area as the structure design have to be done in regard with the numeric values.

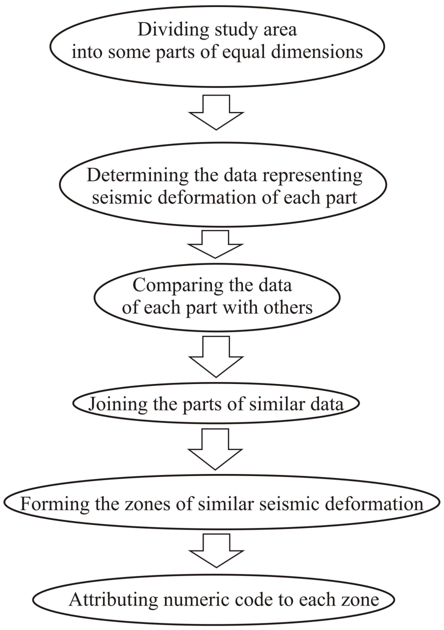

Fig. 5: Flow chart of various steps in the research idea

To realize aforementioned idea, primarily the study area should be divided into some assumed parts with equal area and then the data representing the seismic deformation concentration of each part would be determined. Secondly, the data set relating to each part will be compared with other parts and the similar parts are categorized in one zone. It is expected that a numeric value can be applied through continuation of above steps in numerical approach, in order to present the seismic deformation of each individual zone (Fig. 5). Moreover the application of numerical techniques makes the similarity measuring between group members more accurate and also the zoning objective, so that the origin of discrepancies is eliminated.

Clustering method is one of the most effective numerical techniques to perform zoning. It is normally applied for classification in the cases that both the number of classes and their properties are to be determined (Everit, 1993). Clustering or Grouping is a more primitive technique than classification, in that no assumptions are made concerning the number of groups or the group structure (Johnson and Wichern, 2007).

Clustering is done on the basis of similarities or distances (dissimilarities) of each assumed part with the others. The required inputs are data, which distances can be computed (data representing the seismic deformation of each part). Several formulas may be applied to get the distance parameter (Johnson and Wichern, 2007; Everit, 1993).

RESAULTS AND DISCUSSION

In order to achieve seismic deformation zoning, at first the study area should be divided into some quadrangular or circular sites (Fig. 6). The dimensions of these sites, to some extent, the accuracy of grouping, should be selected in proportion to completeness and accuracy of accessible data.

Afterwards, "p" selected variables defining the seismic deformation of an area (variables representing seismicity and fault propagation) are collected numerically for each of "n" assumed quadrangle. Upon completing the values of each variable, "n×p" matrix is achieved. This matrix is called "raw data matrix" (Fig. 6).

In the later stage, the data should be carefully studied to prepare, if necessary, for main stage of grouping. It can be presented two processes for preparation operation in this theoretical model:

At first, "Standardization" that is the most frequent stage of preparation is done in order to give equal weight to each of the variables, which may be measured in various units (Everit, 1993).

Secondly, as mentioned earlier the variables representing seismic deformation are selected in two groups of seismicity and fault propagation. Thus, there is an interrelationship between raw data due to relation of these two groups of variables. To explain more, based on a simple assumption each quadrangle may be placed in following groups in terms of available data:

Group 1: Containing specified fault and seismic data
Group 2: Containing no specified fault and no seismic data

Thus, a high correlation will be present between seismicity variables and variables representing fault propagation. In this matter some quadrangles may be exceptionally placed in one of following groups:

Group 3: Containing specified fault but no seismic data (due to data shortage)
Group 4: Containing seismic data but no specified fault (due to blind fault)

Now, in order to disregard the difference among groups 1, 3 and 1, 4 in double or multiple forms-through all defined variables- the correlation of variables should be deleted. Consequently the individual variables may influence on grouping according to degree of defined sole variance by their values.

The data correlation would also be present when some variables are used to calculate some other ones. This unwanted correlation has also to be eliminated.

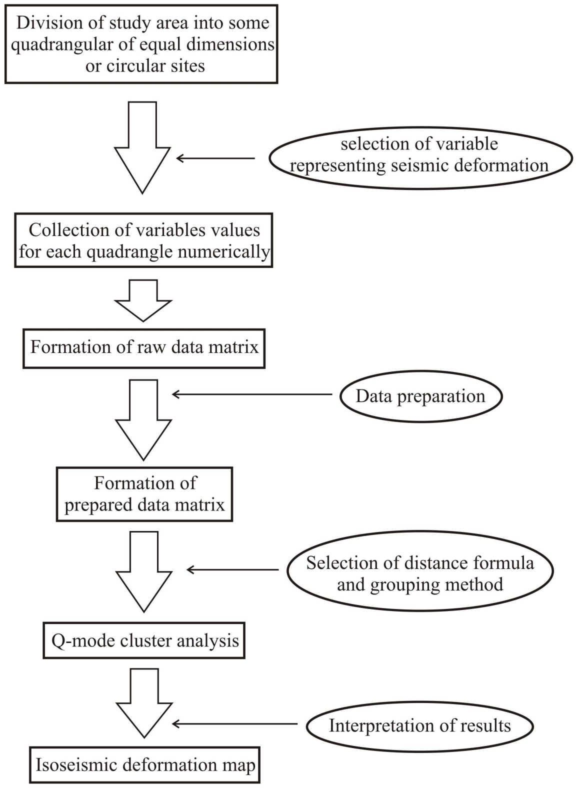

Fig. 6: Flow chart indicating consequent steps of the model

One of the effective numerical techniques to delete correlation of variables is Principal Component Analysis (PCA) which results in substitution of correlated variables by non-correlated components of PCA (Everit, 1993).

However, as a result of preparation operation, prepared data matrix instead of raw data matrix will be the basis for cluster analysis (Fig. 6).

Upon making of prepared data matrix, the Q-mode cluster analysis has to be performed based on selection of appropriate formula to calculate the distance of each quadrangle with that of others. Therefore, the prepared data matrix is converted to distance matrix. Afterwards, the grouping method is chosen and the similar quadrangles are classified in different groups based on their similarities (Fig. 6).

It should be kept in mind that to choose the distance formula and grouping method, the practical objective of cluster analysis would not be achievement of the best grouping but achievement of a good grouping (Johnson and Wichern, 2007). In this research (regarding the purpose of seismic deformation zoning) a good grouping is accomplished under a method by which the separation of quadrangles is achieved in following conditions:

- The values of variables in one quadrangle are different from those in other one
- The ratio of one variable value to another one in one quadrangle is different from the ratio of the same variables in the other one

According to above conditions and through application of various approaches (distance formula and the grouping method) on tentative data, e.g. different geometrical forms in various dimensions, the best alternative for distance formula and appropriate method of grouping becomes clear in this research. Application of geometrical forms on tentative data is proposed due to the fact that definition of quadrangles through the values of selected variables implies imagination of their special geometrical forms (Everit, 1993). The later steps (applying distance formula and grouping methods) have also the function of declaring and determining the result on similarity or dissimilarity of imagined geometrical forms with each other. It is obvious that the above position 1 and 2 represent respectively the “size” and “shape” of the geometrical forms.

Taking the above-mentioned points into account, Euclidean Distance to come to Distance Matrix has been chosen as well as Average Linkage method for grouping (Johnson and Wichern, 2007; Everit, 1993).

However, the above operations result in setting the quadrangles into separate groups, which can be shown in different forms. Through interpretation of these results not only the zones are formed but also a numeric value of seismic deformation is attributed to each zone or quadrangle (considering distance matrix). Therefore, the “Isoseismic Deformation Map” together with relevant contours becomes available (Fig. 6).

CONCLUSION

Considering the achievement quality of seismotectonic zoning, so far applied, they have not been an appropriate or reliable means of presenting intracontinental seismic deformation.

If the separation of zones having different amount of seismic deformation is considered as the first objective of seismic deformation zoning in all study-scales, it will be possible to define a new theoretical model in this matter. Based on this model, the seismic deformation in several sites inside a continent may be stated numerically. According to these numeric values, isoseismic deformation contours are drawn in order to achieve the relevant map.

As per above attitude, the seismic deformation zoning are categorized in to four scales of global, regional, provincial and local. Obviously, as the delicate and precise observations are requisite of any detailed study, the proposed model will be of higher precision and more accurate in the case of smaller scale studies. This model is more delicate due to smaller dividing of the area and more precise due to replacement of variables with more number of variables indicating the same concept in small-scale zoning.

Therefore the numerical characteristics of the proposed model makes it possible to study those differences in various aspects of seismic deformation (and apply to zoning process) which are not considered in ordinary methods of seismotectonic zoning or considered with low accuracy. In other words, the quantity relevant to each variable becomes the substitution of quality of the same variable as the effective factor in zoning procedure. Due to this substitution the collecting of quantities related to variables results in large and complicated dataset which cannot be interpreted mentally. Application of a variety of statistical processes on dataset is aimed to convert data to simply structured data so that to be fully expressive and ordinary. Seismic deformation zoning as an expressive and ordinary form of data resulted from the statistical processes which presents precise and desirable outcome for earthquake researchers.

Moreover, the numerical characteristic of the proposed model brings about elimination of subjectivity in zoning, as the origin of ambiguity and disputes in usual seismotectonic zoning.

Having emphasis on this point that precision and validity of the model is due to precision and validity of data collection, it is claimed that this theoretical model deserves to undergo practical test in a variety of areas and types. It means that different researchers may have different practical models due to theoretical and empirical reasons. Therefore, a comprehensive and unified approach is made for presenting the pattern of intracontinental seismic deformation that is highly significant both scientifically and socially.

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REFERENCES

Abu-Lebdeh, T., S. Hamoush, W. Choi and M. Al Nasra, 2011. High rate-dependent interaction diagrams for reinforced concrete columns. Am. J. Eng. Applied Sci., 4: 1-9. DOI: 10.3844/ajeassp.2011.1.9

Al-Zoubi, A.S., 2005. The 11th February, 2004 earthquake of the dead sea, Jordan. Am. J. Environ. Sci., 1: 142-148. DOI: 10.3844/ajessp.2005.142.148

Amiri, A. and R. Tabatabaei, 2008. Earthquake Risk management strategy plan using nonparametric estimation of hazard rate. Am. J. Applied Sci., 5: 581-585. DOI: 10.3844/ajassp.2008.581.585

Ansari, A., A. Noorzad and H. Zafarani, 2009. Clustering analysis of the seismic catalog of Iran. Comput. Geosci., 35: 475-486. DOI: 10.1016/j.cageo.2008.01.010

Benmenni, M.S. and K. Benrachedi, 2010. Impact of earthquake demolition debris on the quality of groundwater. Am. J. Applied Sci., 7: 545-550. DOI: 10.3844/ajassp.2010.545.550, URL: http://www.thescipub.com/abstract/10.3844/ajassp.2010.545.550

Berberian, M. and A. Mohajer-Ashjaei, 1979. Seismic risk map of Iran, A Proposal. Geol. Surv. Iran, 40: 121-148. http://manuelberberian.com/Berberian%20and%20%20Mohajer%201977%20-%20Seismic%20Risk.pdf

Berberian, M., 1976. Seismotectonic map of Iran. the Regents of the University of California. http://nisee.berkeley.edu/elibrary/Text/S32110

Chakraborty, D. and D. Choudhury, 2009. Investigation of the behavior of tailings earthen dam under seismic conditions. Am. J. Eng. Applied Sci., 2: 559-564. DOI: 10.3844/ajeassp.2009.559.564, URL: http://www.thescipub.com/abstract/10.3844/ajeassp.2009.559.564

Choopool, N. and V. Boonyapinyo, 2011. Seismic performance evaluation of reinforced concrete moment resisting frames with various ductility in low seismic zone. Am. J. Eng. Applied Sci., 4: 17-36. DOI: 10.3844/ajeassp.2011.17.36

Davison, I., 1994. Linked Fault Systems; Extensional, Strike-Slip and Contractional. In: Continental deformation, Hancock, P.L. (Ed.). Pergamon Press, Oxford New York, ISBN: 0080379311, pp: 121-142.

Escobar, J.A.S., J.A. Mendoza and M.R. Gḿez, 2008. Effect of earthquakes on some kind of buildings. Am. J. Environ. Sci., 4: 189-197. DOI: 10.3844/ajessp.2008.189.197, URL: http://www.thescipub.com/abstract/10.3844/ajessp.2008.189.197

Everit, B.S., 1993. Cluster Analysis. 3rd Edn., E. Arnold, London, ISBN: 0340584793 pp: 170.

Hazarika, H., 2009. Prediction of seismic active earth pressure using curved failure surface with localized strain. Am. J. Eng. Applied Sci., 2: 544-558. DOI: 10.3844/ajeassp.2009.544.558, URL: http://www.thescipub.com/abstract/10.3844/ajeassp.2009.544.558

Johnson, R.A. and D.W. Wichern, 2007. Applied Multivariate Statistical Analysis. 6th Edn., Pearson Prentice Hall, Upper Saddle River, NJ., ISBN: 0135143500 pp: 773.

Kearey, P. K.A. Klepeis and F.J. Vine, 2009. Global Tectonics. 3rd Edn., Wiley-Blackwell, Oxford, ISBN: 1405107774, pp: 482.

Masson, F., J. Chery, D. Hatzfeld, J. Martinod and P. Vernant *et al*., 2005. Seismic versus aseismic deformation in Iran inferred from earthquakes and geodetic data. Geophys. J. Int. 160: 217-226. DOI: 10.1111/j.1365-246X.2004.02465.x

Mayoral, J.M. and M.P. Romo, 2008. Geo-seismic environmental aspects affecting tailings dams failures. Am. J. Environ. Sci., 4: 212-222. DOI: 10.3844/ajessp.2008.212.222, URL: http://www.thescipub.com/abstract/10.3844/ajessp.2008.212.222

Mirzaei, N., M. Gao and Y. Chen, 1999. Delineation of potential seismic sources for seismic zoning of Iran. J. Seismol., 3: 17-30. DOI: 10.1023/A:1009737719013

Musmar, M.A., 2007. A comparison between the new and the old versions of Jordan seismic code. Am. J. Applied Sci., 4: 229-232. DOI: 10.3844/ajassp.2007.229.232, URL: http://www.thescipub.com/abstract/10.3844/ajassp.2007.229.232

Nowroozi, A.A. and G. Ahmadi, 1986. Analysis of Earthquake risk in Iran based on seismotectonic provinces. Tectonophysics, 122: 89-114. DOI: 10.1016/0040-1951(86)90160-5

Nowroozi, A.A., 1976. Seismotectonic provinces of Iran. Bull. Seism. Soc. Am. 66: 1249-1276. http://bssa.geoscienceworld.org/cgi/content/abstract/66/4/1249.

Nowroozi, A.A., 1979. Reply to Berberian comparison between instrumental and macroseismic epicenter. Bull. Seism. Soc. Am., 69: 641-649. http://bssaonline.org/cgi/content/citation/69/2/641.

Park, R.G. and W. Jaroszewski, 1994. Craton Tectonics, Stress and Seismicity. In: Continental Deformation, Hancock P.L. (Ed.). Pergamon Press, Oxford New York, ISBN: 0080379311, pp: 200-222.

Singh, R. and D. Roy, 2009. Estimation of earthquake-induced crest settlements of embankments. Am. J. Eng. Applied Sci., 2: 515-525. DOI: 10.3844/ajeassp.2009.515.525, http://www.thescipub.com/abstract/10.3844/ajeassp.2009.515.525

Tavakoli, V. and M. Ghafory-Ashtiani, 1999. Seismic hazard assessment of Iran. Annal. Geofis., 42: 1013-1021. http://www.annalsofgeophysics.eu/index.php/annals/article/view/3781/3845

Teachavorasinskun, S., P. Pattararattanakul and P. Pongvithayapranu, 2009. Liquefaction susceptibility in the northern provinces of Thailand. Am. J. Eng. Applied Sci., 2: 194-201. DOI: 10.3844/ajeassp.2009.194.201

Unesco, 1985. Seismotectonic map of Iran Afghanistan and Pakistan. 1st Edn., Renouf Pub Co Ltd., Tehran, Iran. ISBN: 9231998129.