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Urban Geology, Earthquake and Subsurface Sediments, Planning by Means of GIS for Development Needs, a Case Study, Iran

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Abstract: *The role of geo-environmental information is becoming increasingly important as legislative changes have forced developers, planning authorities and regulators to consider more fully the implications and impact on the environment of large-scale development initiatives. The primary objective of the planning is to create healthy, reliable and durable living spaces. At this point, especially earthquakes and their effects in the countries that are located on the seismic belts of the world constitute the primary geologic threshold. Inadequate consideration of the geo-hazards and the constraining effects of the geological environment or lack of precaution due to improper projection of the analysis and synthesis results to the planning and the planning decisions give rise to the increase in earthquake damages. Geological studies aimed at reducing the effects of the ground movements due to earthquakes are of prime significance on the reduction of damage that constitutes the basis of earthquake sensitive planning studies.*

In Iran, studies commissioned by the Department of the Seismology of Building and housing research center (BHRC) in the last decade promoted the use of applied geological maps to identify the principal geological factors which should be taken into account in planning for development. Since this work was completed, advances in the use of Geographical Information Systems (GIS) and modeling packages have meant that there is now far greater opportunity to develop geo-environmental products that take greater account of the third dimension. This approach provides a more holistic view of the near-surface environment and provides a means of identifying potential problems and opportunities at an early stage in any proposed development. If implemented over a wider area, it could assist in designing site investigation strategies and reduce costs by ensuring a more focused approach to strategic planning. Because the information is captured and manipulated digitally, the outputs can be tailored to user needs, and more readily updated. The ultimate goal is to create a tool usable by the local authorities and the companies within the framework of regional planning.

Geologists, engineers, architects and planners, in creating the earthquake resistant cities, should determine the geologic hazard processes in advance and for the prevention of hazards turning into the risks and for the reduction of the damage, required precautions should take place in an interdisciplinary work. In this research, the main study is to conduct geological, geophysical and geotechnical analyses that will orient the suitability for settlement and land use decisions. Geological data that enable the earthquake damage reduction and are analyzed in every plan step separately should be evaluated in coordination with the criteria of planning and design. The risks resulting from urban texture, building quality, subsurface soil and sediment quality, settlement layout and macro form should also be integrated with the analyses and synthesis.

Keywords: *Urban geology, Earthquake, Geophysics, GIS, 2D and 3D models.*

1. Introduction

The rapid growth of the world's population over the past few decades has led to a concentration of people, buildings and infrastructure in urban areas. Urban planning is the organized planning of the physical environment that the mankind lives by providing the safety in line with the social, cultural and economical needs. The primary objective of the planning is to create healthy, reliable and durable living spaces. At this point, especially earthquakes and their effects in the countries that are located on the seismic belts of the world constitute the primary geologic threshold.

The tendency of urban areas to develop in sedimentary valleys has increased their vulnerability to earthquakes due to the presence of thick accumulations of soft sediment in these locations (Fig.1). Recent destructive earthquakes have shown evidences of the effects of surface and subsurface geology and topography on ground motion characteristics at a given site. Among these effects we have: amplification and attenuation patterns, strong spatial variability of amplification and polarization with in a small area [1,2,3]. Several earthquakes such as the 1985 Michoacan (Mexico), 1988 Spitak (Armenia), 1990, and 2003 Bam (Iran) earthquakes have clearly demonstrated that local soil and sediment conditions (site effect or site specific condition) can have a significant influence on the ground motion and damage pattern, respectively [1,2,4]. In the other word, Ground shaking and its associated damage to engineered structures can be strongly influenced, not only by source and path effects, but also by surface and sub-surface geological (depth and type of bedrock, underground sediments) and geomorphologic conditions in the vicinity, known as “local site effects”. To estimate correctly the site effects, accurate modelling of the subsurface geological structure is preferentially required [5,6,7]. Site effect interpretations provide a framework for establishing a first order classification of soil suitability for reconstruction and urban planning efforts and some locations with high hazard risk are selected for installation of pre-revealing systems around the cities. There are several ways of assessing site effects. The characterization of a given site can be achieved based on Instrumental or theoretical-analytical or numerical-approaches to the problem [8,9,10]. In order to classify the regions of the city in terms of site stability for building reconstructions for future urban planning, I performed several investigation case studies on soil and subsurface sediments in 5 cities of Iran and here I want to introduce some results of them in this paper. The projects focused on making detailed observations regarding the tectonic, seismology, soil, subsurface sediment, and geological properties of the each region. A primary goal of these projects is to establish the relationship between the buildings quality and the geotechnical properties of the materials beneath cities with the ultimate aim of generating an improved seismic hazard assessment [6,11].

Historically, Iran is one of ten countries with most unexpected events and one of the most seismic countries in the world. Evidence of this can be found in three major seismic events in Iran in the past two decades -1990 Manjil–Rudbar, 2003 Bam and 2013 Varzaghan earthquakes-that resulted in a large number of casualties. Our past studies in Bam city have shown that there is a relationship between sediment properties and the distribution of structural damage [1]. According to seismological (instrumental) data, Iran have 4 regions of “very high to low seismicity and seismic hazard” (Fig.2)[12]. Although some of cities had comparatively low populations, the lack of suitable development and earth quake risk management led to high human and physical costs [1]. Approximately 60% of the buildings in cities have very weak and loose structure with old texture. Also, 96% of cities are located on alluvial sediments around Iran and such researches are necessary for them.

2. Methodology

In Iran, studies commissioned by the Department of the Seismology of Building and housing research center (BHRC) in the last decade promoted the use of applied urban geological maps to identify the principal geological factors which should be taken into account in planning for development. This approach provides a more holistic view of the near-surface environment and provides a means of identifying potential problems and opportunities at an early stage in any proposed development. Because the information is captured and manipulated digitally, the outputs can be tailored to user needs, and more readily updated.

The methodology of soil and sediment quality and site effect urban microzonation adopted in these studies falls into the category of Grade-3 zoning methods of the Japanese TC4 Zoning Manual,1999 [4,5,6] and previous experiences of Author. After dividing the cities into a grid of $500 \times 500 m^2$, the following steps were taken: 1- Preparation of a seismic hazard map of each study area for a return period of 475 years; 2- Gathering and investigation of the existent geological, geotechnical, sedimentological and geophysical data of area, including field observations and Sampling and aerial photo studies; 3-Conducting complementary geophysical investigation, as well as geoelectrical and seismology measurements and sedimentological studies, throughout each area; 4- Several experimental analyses on soil and sediment samples in KHU university laboratory. 5- Preparation of representative geotechnical profiles of the city based on the geological, sedimentological, geotechnical, geophysical and geoelectrical data; 6- Estimation of strong ground motion characteristics using one-dimensional site response analysis of the representative geotechnical profiles; 7- Preparation of the surface and sub-surface grain size maps of the study area in the Geography Information System (GIS) media and geological cross sections in various directions.8- Preparation of the final site periods and peak ground acceleration (PGA) maps of each area in GIS.

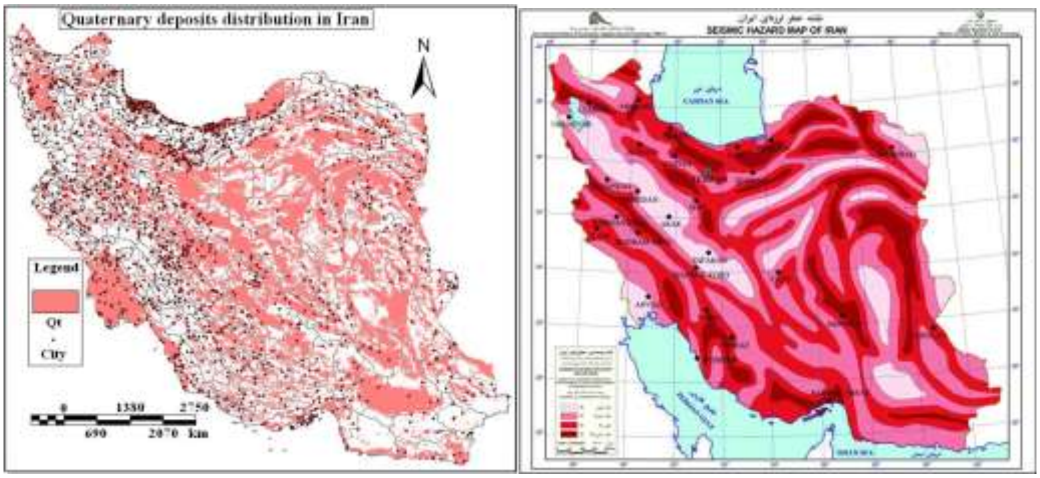

Fig. 1: a) Location map of cities on Quaternary loose soil and sediments in Iran. b) Seismic hazard zoning in Iran.

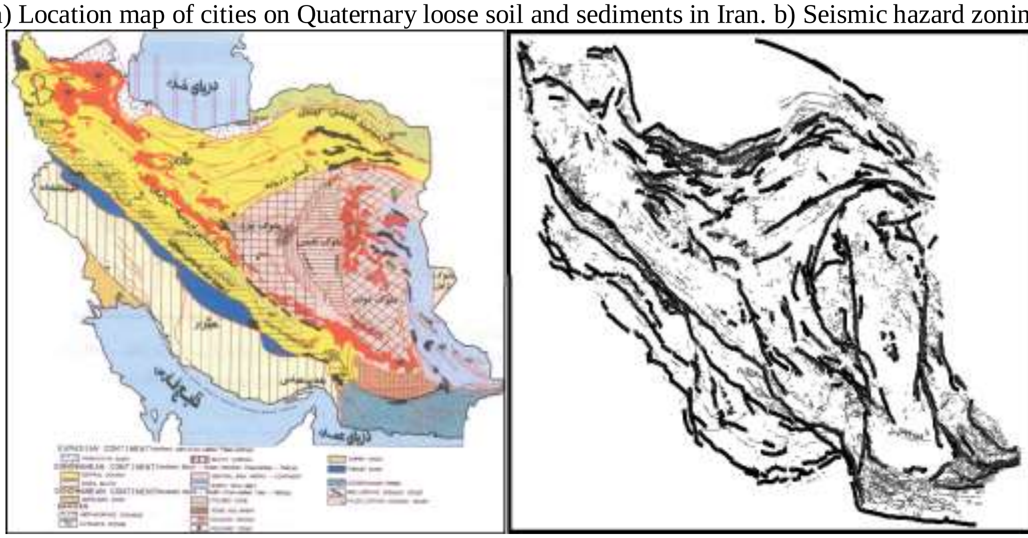
Fig. 2: a) Geologic map of Iran [10]. b) Major and minor active faults in Iran [7].

Geological, Geophysical and geotechnical investigations that include the details compatible to the planning scale before the planning and design of a city have an indispensible significance in the evaluation of suitability for settlement and land use decisions. The main stage of creating sustainable, durable and safe cities is to carry out natural structure analysis and synthesis by comprehensive investigations (geological, hydrological, engineering geology, geotechnical, seismicity, natural resource analysis etc.) and contemporary scientific methods (GIS, Multi Criteria Decision Analysis, Multi Criteria Decision Support Systems etc.).

The first step in our investigation was to collect all of the previously geotechnical and geophysical data. I reviewed the older data and determined that there were significant data gaps in the area. In particular, there were no enough subsurface geological data, patchy soil mechanics and seismology data. My measurements followed well known methods [15, 16, 17] and included representative geophysical and soil mechanical properties, such as grain size, sorting (an index for the compaction and porosity, permeability), Geoelectrical resistivity (Fig.2) and seismic wave velocity (Vs)(Fig.3). I calculated sediment thicknesses across each study area by making direct measurements in water wells and Qanats and by conducting geo-electrical soundings at using the Schlumberger method [18,19]. The GIS applications in geotechnical earthquake engineering are usually represented as seismic zonation and the seismic modeling [1,19]. The data base component here in contains information about the geotechnical and sedimentological sub-layers with their shear wave velocity (VS) and electric resistivity (ER) data and the spatial coverage data of buildings. Information in the database component is provided to the spatial analysis component, by the geostatistical kriging and radial basis function methods. The site visits for the extended areas were conducted to acquire data on geotechnical materials at the ground surface referenced by the spatial coordinates, using the global positioning system (GPS). Then, this information was available for 2D modeling to evaluate the site effects in each city. Finally, A Geotechnical information system was constructed for each city to predict more reliably the spatial geotechnical information such as the surface and subsurface geotechnical layers.

3. Discussion

Urban settlements have the tendency to develop with a varying pace depending on the policy of the urban development, economy, geographical features and geologic hazards. Geological data with suitability to settlement analysis determine the development potential of the city by revealing the geologic threshold and restrictions such as geo-hazards, geological, geotechnical and geophysical information. The selection of the methods of threshold analysis or habitability analysis is based on the number of criteria in the analysis, their quality, self values of the city and made by planners and project group (geological engineer, civil engineer, architect etc). In literature [22; 23] there developed several mathematical and statistical methods analyzing based on the space to be used in settlement analysis and land use decisions. These geo-environmental thresholds affect the development and the settlement of the city in different ways.

In urban settlements and development areas, the distance to the fault, the features of the ground, topographic factors, liquefaction requirements, landslides and floods should be analyzed. In the settlements with earthquake risk, hazard mitigation studies before an earthquake is the most significant stage of disaster preparation process. The first step of the determination of the risks at urban areas is to understand the soil behavior that the city rests on by investigations. Besides, the identification of the building quality of the building stock and the revealing of the soil-structure interaction define the type and the approach of the precautions. The resistance of the settlements that have high quality and earthquake resistant buildings resting on hard soil to the same magnitude earthquake, certainly, will be higher than that of ordinarily constructed areas on problematic and loose soil conditions due to their geotechnical properties. The closeness to the fault in settlements is not a sole requirement, although it is very important, in the development of urban risks. Certainly, the constructions on the active fault line will feel the quaking more than others. The most important risks due to soil-structure interaction are that resonance causing the collapse (prevailing natural period of the building being equal to that of the soil) and soil amplification. The velocity of the earthquakes waves in the soil changes with the hardness and the properties of the soil. For instance, the waves passing through a hard rock mass pass very quickly and the quake is less felt due to the firmness and the void less nature of the rock while those passing through loose and weak ground pass very slowly filling the voids in the ground and result in the severe feeling of the quake. This behavior of the soil is defined as soil amplification. Microzoning maps depend upon the local geological, seismological and geotechnical conditions (Fig.3). Geological studies and the synthesis of the data used in the planning exhibit a rapid development in terms of directing the planning.

TABLE I: Ground type classification from soil and rock types point of view(2800 standard).

Ground type	**Vs(m/s)**	**Soil, sediment and rock description**
1	More than 750	Intrusive and extrusive igneous rock, hard sedimentary rocks, massive metamorphic rocks, hard soil with less than 30m thickness, compacted conglomerates, sand and gravel with less than 60m thickness
2	375-750	Loose and weathered igneous, sedimentary and metamorphic rocks, tuff, hard soil with more than 30m thickness, compacted conglomerates, sand and gravel with more than 60m thickness
3	175-375	Very weathered rocks, medium compacted soil, medium cemented sand and gravel layers, uncompacted clay layers with less than 10m thickness
4	Less than 175	Loose, wet and fine soil with shallow water table, every type of soil with at least 6m clay, humidity more than 40%, loose gravel and sand, uncompacted clay layers with more than 10m thickness

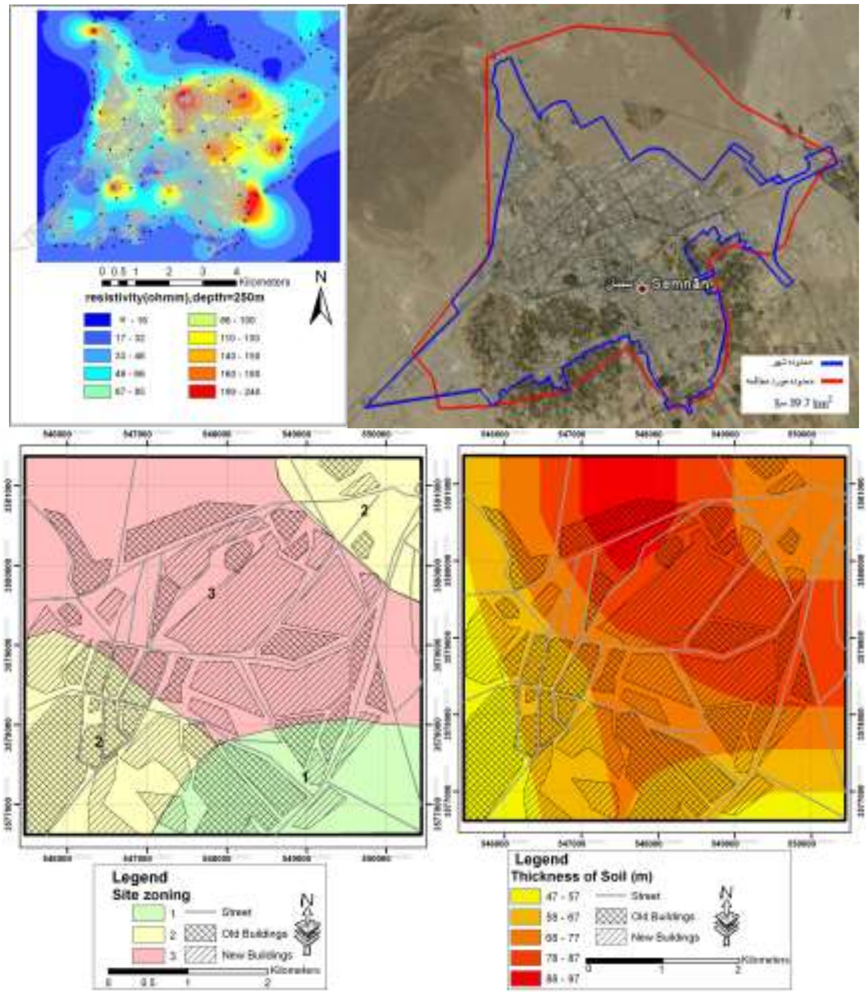

Fig. 3: Two examples from previous studies in Semnan and Mobarakeh cities.

Based on site observations, the distribution of the damage across most of cities in Iran will not uniform. The average level of destruction for these cities will ~45% but locally will reach 100% destruction level. An important control on the distribution of damages during earthquakes is the distance of a given site from the seismic source. Fig.1and 2 shows distribution map of cities and major and minor faults in Iran. It shows more than 90% of cities have no long distance to faults. This illustrates the importance of other factors, like building type and site effects, on controlling the extent of the future damage in Iran. The building style (traditional mud brick construction) will more or less uniform damaged throughout the cities. The sediments and soils in some area belong to fluvial and alluvial sedimentary facies (Fig.4). On the other hand, the solidity of sediment affects shear wave attenuation (increasing solidity results in greater attenuation) and that the solidity is dependent on sorting and compaction. High sorting values are correlated with low permeability and high compaction [18, 1, 20, 21]. The loose sand has very low shear strength and clayey soils have very low permeability, low seismic wave velocity, and high plasticity and compression index characterizes the sediment types which are associated with the greatest probability of damage new buildings. In contrast, the areas underlain by bedrock or coarse-grained sediments with high permeability, low (or zero) compressibility and high seismic velocity (with type I-resistant and rigid- soils being rare, ISIRI standard -2800, table.1), will associate with less structural damage. According to soil classification from the Iranian National Seismic Code for Buildings [standard 2800, http://isiri.org/std/2800.htm], soil and sediment classified to 4 types. The areas underlain by bedrock or near-surface coarse-grained soil and sediments, exhibiting high permeability, low (or zero) compressibility and high seismic velocity are associated with lower structural damage. There was a direct relationship between the depth to bedrock and the probable degree of damage [1,2].

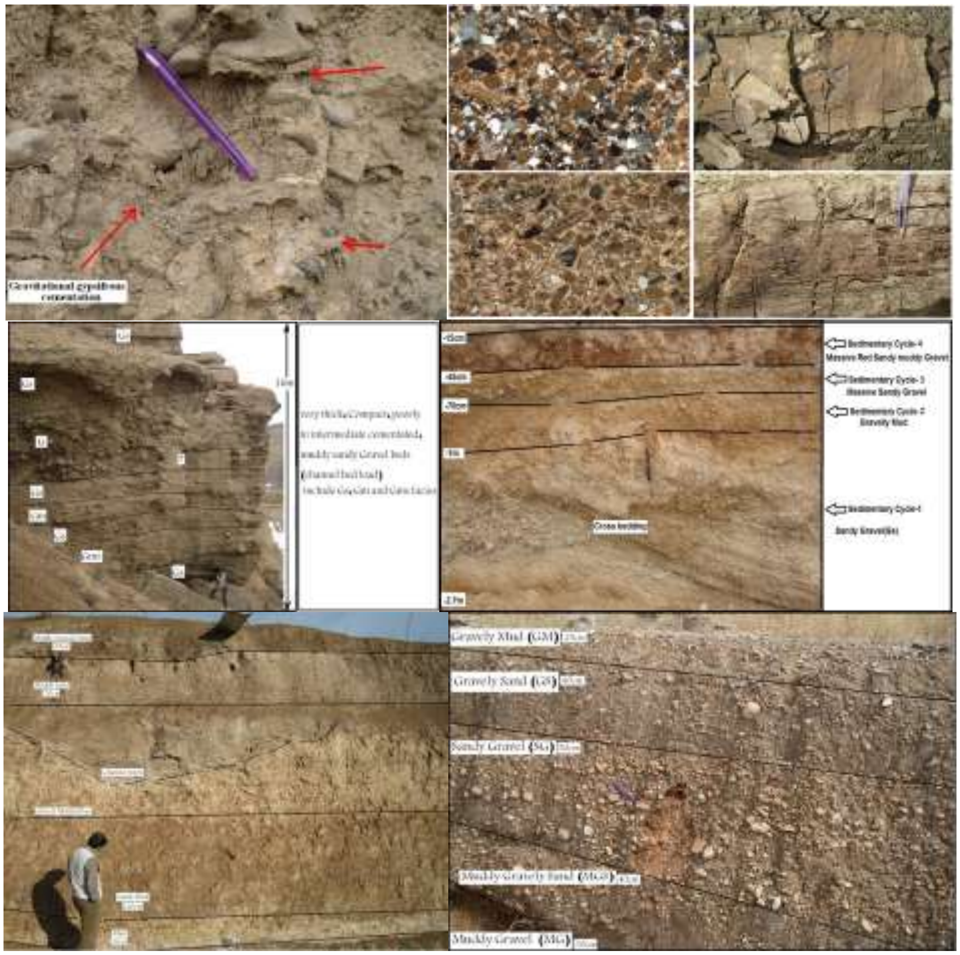

Fig. 4: Samples of representative geological outcrops and cross sections.

4. Conclusion

In the planning and the design of new settlement areas and the environment with current settlement, in every stage of the plan geological data for the reduction of urban earthquake risks should be functionalized in compliance with the objectives. In the process of creating earthquake resistant safe cities, geological, geophysical and geotechnical investigations and micro zoning maps play a key role in the integration of hazard mitigation precautions to the planning. In the urban areas with high earthquake risk, the improvement of the current plans, the reconfiguration in the required locations and the planning of development areas based on the micro zoning maps and probable earthquake scenarios would decrease the probable earthquake damages.

The main factors effective in the distribution of earthquake damage can be summarized as the distance of the settlement to the active fault line, geological structure, local soil and subsurface sediments conditions, the state of ground water, site selection and land use, population density and distribution, building density, quality, order and design. These studies confirm the importance of site specific conditions and local geology in the amplification or attenuation of ground motions and related damage patterns during future earthquakes. During the new construction of the cities, particular attention has to be paid to the characteristics and distribution of surface and subsurface sediment and soil. Finally, based on all information and their spatial coordinate, these results can propose several locations for installation pre-revealing systems in urban planning for future earthquake events in cities.

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