التمنطق الزلزالي الدقيق وتأثير استجابة الموقع لمدينتي الدمام و الخبر شرق المملكة العربية السعودية

Seismic Microzonation and Site Effect Response of Dammam and Alkhobar Cities – Eastern Saudi Arabia

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SUMMARY

This proposal presents the methodology and the work plan to asses the seismic hazard in the eastern region of Saudi Arabia. Al-Dammam and Al-khobar are the most commercial and financial cities with high economic growth rate in the last 10 years. The ongoing construction projects are valued. They include the construction of several offshore islands. Although there is no known seismic source directly under this region, there are numerous sources nearby that can cause damaging seismic shaking in Al-Dammam and Al-Khobar cities.

The Arabian Gulf is underlain by deep sedimentary structure, nearly 10 km deep, and is adjacent to one of the most seismically active intra-continental fold-and-thrust belts on Earth, the Zagros Mountains. Broadband records in the western shore of the Gulf from earthquakes in the Zagros Mountains display long duration surface waves due to dispersion and possible conversions at basement-sediment interfaces. While shorter periods (< 1 s) are attenuated due to the large distance, long period energy persists. Consequently large earthquakes in the Zagros can result in felt and possibly damaging ground motions at long-periods (1-10 s). Such ground motions are of concern for large engineered structures, such as tall buildings and long bridges with resonant periods in the same band (1-10 s).

While the eastern part of Saudi Arabia is relatively quite seismically, it is adjacent to a zone of major earthquake activity. Dammam city is situated near the eastern margin of the Arabian plate about 300 kilometers from the collision zone between the Arabian and Eurasian plates. The Zagros fold belt (Iran) in the collision zone is a major source of large earthquakes: magnitude 5 earthquakes in the Zagros mountains are frequent, magnitude 6 earthquakes occur several times yearly, and magnitude 7 events occur every decade. It is an open question whether these large events can occur close enough to the eastern region to pose a hazard. These earthquakes may represent the classic low probability, high consequence risk for the population, buildings, and infrastructure of Dammam and Alkhobar cities. Moreover, the mechanism of these events is not understood: are they in some way related to the production of hydrocarbons or are they due to tectonic processes arising from the Arabian-Eurasian collision? If due to a tectonic process, are larger, potentially damaging earthquakes possible?

Due to the aforementioned status, we propose an integrated program to address these questions of seismic microzonation and site effect response for the eastern portion of Saudi Arabia. We will apply a probabilistic hazard assessment procedure, a modeling procedure producing maps that engineers and policy makers can use to design an appropriate response to seismic hazards. A

better understanding of the seismic hazards and risks is needed, particularly in the area of oil investment constructions over the eastern part of the Kingdom on the Arabian Gulf.

INTRODUCTION

Saudi Arabia is an area which is characterized very poorly seismically and for which little existing data is available. While for the most part aseismic, the area is ringed with regional seismic sources in the tectonically active areas of Iran and Turkey to the northeast, the Red Sea Rift bordering the Shield to the southwest, and the Dead Sea Transform fault zone to the north. Throughout recorded history many damaging earthquakes have occurred along the Arabian Plate boundaries. These events have damaged buildings, and resulted in injuries and fatalities. There is obviously potential for damaging earthquakes in the future. As the population increases and new areas are developed, the seismic risk to human life and infrastructure increases.

While the Zagros mountains are the primary source of earthquakes in the vicinity of the eastern region. On June 2, 1993, an earthquake of magnitude 4.7 occurred in Kuwait near the Minagish oil field. In spite of its modest magnitude, the earthquake was widely felt and caused panic in the city of Kuwait. More recent events in the Minagish area include a magnitude 3.9 earthquake on September 18, 1997 and a magnitude 4.2 event on December 30, 1997. On January 2002 a moderately large earthquake shook the Musadam Peninsula on the border region of Oman and the United Arab Emirates (Figure 1). Another major source is the Makran subduction zone, located at the southern end of the plate boundary, where the Arabian plate around the Gulf of Oman subducts underneath the Eurasian plate. Such subduction zones can create very large earthquakes. The great Makran earthquake of November 1945 had a magnitude of 8.1.

The Zagros Thrust Belt results from the collision of the Arabian Plate with the southern margin of Eurasia. This collision results in uplift of the Iranian Plateau and is evidenced by the high rate of seismicity along a broad northwest-southeast trending band (Figure 2). This zone marks one of the most intense regions of intra-continental seismicity on Earth. The nature of deformation across this zone is complex, involving both thrust and strike-slip as indicated by earthquake focal mechanisms (Telebian and Jackson, 2004). The Zagros experiences on average N earthquakes of magnitude 5.0 and greater each year.

The Arabian Gulf adjacent to the Zagros is composed of a deep sedimentary basin. Sediments of the Arabian Platform dip eastward, reaching a depth of over 10 km adjacent to the Zagros. The deep structure of the Gulf is composed of geologically old and consolidated sediments with moderately high shear velocities. However, the younger sediments near surface have much lower velocities. Basin structure of particular concern for earthquake hazard in the Gulf. Several large earthquakes in the Zagros have resulted in felt ground motions along the western coast of the Gulf. These events have been particularly strongly felt in high-rise buildings in the urban centers along the Gulf, such as Kuwait City (Kuwait), Doha (Qatar), Abu Dhabi, Dubai and Sharjah (United Arab Emirates, UAE).

Most seismicity occurs in the crustal part of the Arabian Plate beneath the Zagros folded belt (Jackson and Fitch, 1981). The Zagros is a prolific source of large magnitude earthquakes with numerous magnitude 7+ events occurring in the last few decades. The overall lack of seismicity in the interior of the Arabian Peninsula suggests that little internal deformation of the Arabian Plate is presently occurring.

It is well known that the lithosphere (crust and uppermost mantle) of Saudi Arabia is heterogeneous. Thick sediments cover the Arabian Gulf and Mesopotamian Foredeep. Basement rocks are exposed on the surface of the Arabian Shield. Models of the sediment and crustal thickness have been developed based on analysis of drill and gravity data as well as limited seismic refraction data (Seber et al., 1997).

Analysis of seismic data indicate that the Arabian shield (western Arabia) and platform (eastern Arabia) have different crustal thickness and velocities as well as different mantle velocities (e.g. Mokhtar and Al-Saeed, 1992; Al-Amri, 1998, 1999; Rodgers et al., 1999). Some of the difference in the seismically inferred crustal structure of eastern and western Arabia is due to the thick sediments of the Arabian Platform. However, recent waveform modeling results (Rodgers et al., 1999) suggest that there are also differences in the seismic velocities of the crystalline crust between the Arabian Shield and Platform.

Similarly, variations in the amplitudes of regional phases, such as those reported by Mellors et al. (1999). That study reported that Pn, Pg and Sn body-waves from the Gulf of Aqabah events to central Arabia are weak, while Lg along is strong. More normal continental energy partitioning of the regional phases is observed for earthquakes from the Zagros. These variations in regional phase propagation characteristics can make it difficult to develop detection algorithms for regional phases, most importantly the first arriving Pn phase.

Seismic hazard maps integrate the seismicity, attenuation rates of seismic wave propagation and the response to seismic waves of sites where structures and populations are located. In most modern approaches, seismic hazard is described in terms of probability that ground motion will exceed a specified acceleration (fraction of gravity) in a specified time interval. Probabilistic seismic hazard estimates of the Gulf of Aqabah have been reported by Al-Haddad et al. (1992). Peak ground acceleration (PGA) predicted for 10% probability of being exceeded in 50 and 100 years are about 0.20 g and 0.30 g, respectively.

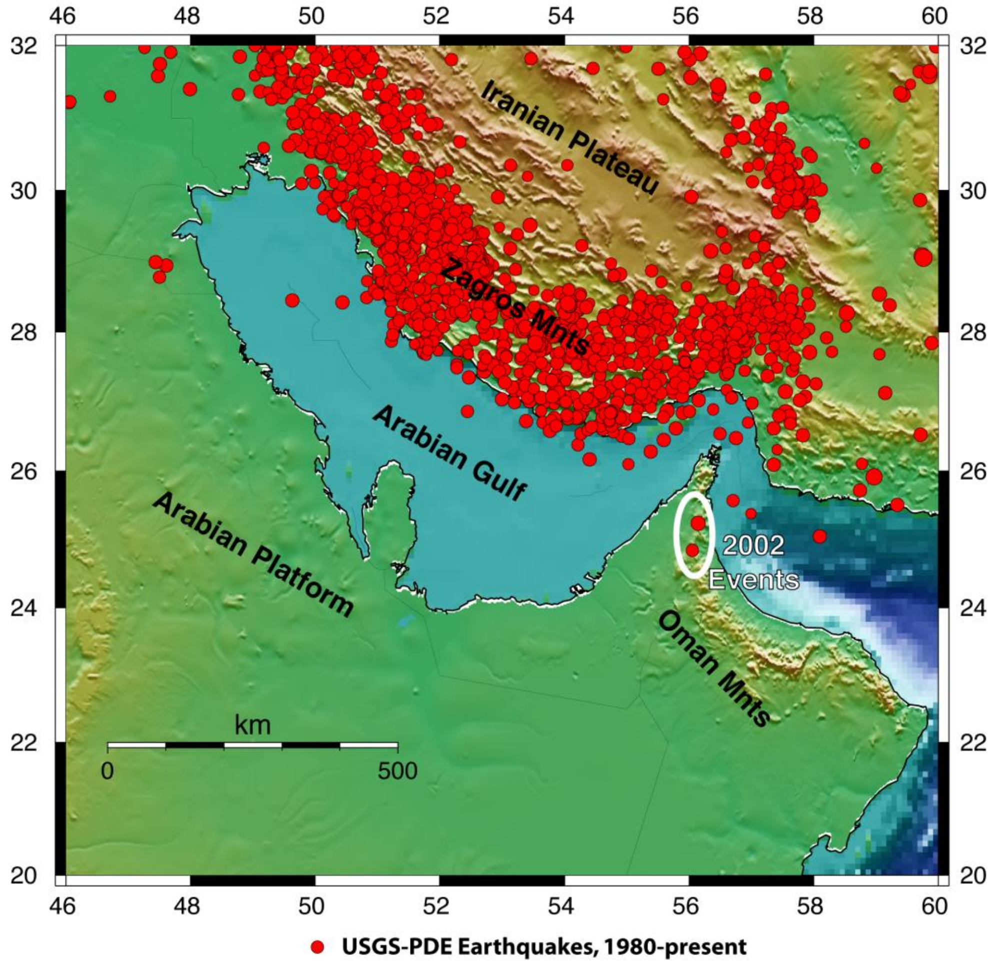

Fig. 1 Recent Seismicity of the Arabian Gulf Region (1980-2007).

GEOTECTONIC SETTING

The Arabian platform consists of the Paleozoic and Mesozoic sedimentary rocks that unconformably overlays the shield and dip very gently and uniformly to the E-NE towards the Arabian Gulf (Powers et al., 1966). The accumulated sediments in the Arabian platform represent the southeastern part of the vast Middle east basin that extend eastward into Iran, westward into the eastern Mediterranean and northward into Jordan, Iraq and Syria.

The Arabian shield isolated the Arabian platform from the north African Tethys and played an active paleogeographic role through gentle subsidence of its northern and eastern sectors during the Phanerozoic, allowing almost 5000 m of continental and marine sediments deposited over the platform. This accumulation of sediments represents several cycles from the Cambrian onward, now forms a homocline dipping very gently away from the Arabian shield.

Several structural provinces can be identified within the Arabian platform : 1) An interior homocline in the form of a belt, about 400 km wide, in which the sedimentary rocks dip very gently away from the shield outcrops. 2) An interior platform, up to 400 km wide, within which the sedimentary rocks continue to dip regionally away from the shield at low angles. 3) Intra-shelf depressions, found mainly around the interior homocline and interior platform (Fig. 2).

Unfortunately, no locally recorded earthquake data have been used to determine the crustal characteristics of the Arabian platform. The regularly spaced north trending Summan platform, Khurais-Burgan and En Nala-Ghawar anticlines, and Qatar arch in the eastern part of the Arabian plate appear to have formed during the Precambrian Amar Collision about 640-620 million years ago (Ma). This collision occurred along the north trending Amar suture that bisects the Arabian peninsula at about 45 degrees east longitude when the Rayn microplate in the east was fused to the western part of the Arabian craton (Al-Husseini 2000 ; Looseveld et al 1996). The great anticlines are bounded by the northeast trending Wadi Batin fault and northwest trending Abu Jifan fault that converge on the Amar suture. The anticlines intersected deformed metasediments that are dated as syn-collisional. The Amar collision was followed by a widespread extensional collapse of the Arabian-Nubian shield between about 620-530 Ma. The extensional collapse culminated in the regional development of the extensive Najd fault and its complimentary rift basins, Zagros suture, the northeast trending Oman salt basins, Dibba fault, and the Sinai triple junction.

The Sinai triple junction is composed of the Najd fault system, the Egypt rift, the Jordan valley, and Derik rift. During the final extensional stage about 530-570 Ma, the northwest trending Najd fault system dislocated the Arabian shield left-laterally by about 250-300 kilometers. This dislocation appears to compliment the northeast oriented intra-continental rifts in Oman, Zagros mountain, and the Arabian gulf. These rift basins accumulated thick sequences of clastic and carbonate rocks and salt such as the Ara group in Oman, Hormuz series in the Arabian gulf and Zagros mountain (Ziegler 2001). During the extensional collapse, the north trending anticlines probably remained elevated as elongated horst bounded by normal faults. The intervening subsiding grabens accumulated syn-rift sediments including the Hormuz salt, and form an inter-fingering pattern between the great north trending anti-clines. The striking geometric pattern appears to have formed in two tectonic stages. The Precambtian Amar collision between about 640-620 Ma, followed by the development of the Najd rift system between about 570-530 Ma.

In Oman, during the intra-extensional tectonics (rift cycle 1), a series of north-south to northeast –southwest trending basement highs may have developed from north to south. These are the Ghudun-Khasfah high, the Anzaus-Rudhwan Ridge and the Makarem-Mabrouk high, separating different basin segments. The event is also associated with igneous activity which is the formation of the Oman mountains and is followed by a thermal subsidence phase. During this cycle, there may have been widespread rifting of the Abu Mahara group (During the Cambrian to mid-Carboniferous (Rift Cycle 2), the Abu Mahara rift configuration was reactivated. The re-activated eastern angle low-angle bounding fault of the Ghudun-Khasfah high becomes the western margin of the asymmetrical South Oman basin. In the north, the Ghaba salt basin develops as a narrower, deeper and asymmetrical feature with some asymmetry reversals. The

South Oman and Ghaba salt basins are related to the Najd event of rifting and wrenching dated at between 600-540 Ma (Looseveld et al.,1996). Around 110 Ma, the Atlantic ocean started to open, leading to the closure of the Neo-Tethys between the Afro-Arabian and Eurasian plates. A northeasterly dipping intra-oceanic subduction zone developed, accompanied by back-arc spreading. At approximately 93 Ma, this subduction complex collided with the continental crust of Oman. Uplift and partial erosion of the Natih formation and the development of a major hard ground signaled the onset of this event. The initial onset has been described as a mobile or stationary fore-bulge that preceded down-warping of the foreland ahead of the advancing thrust front. During this phase, the Hawasina and Samail Nappes are emplaced, the region south of the nappes are downwarped with local footwall uplift, the Aruma foredeep develops, a dextral transtension along the Fahud fault zone, and a sinistral transtension along the Maradi fault zone occur. In the Eocene-Pliocene second Alpine phase, folding commences in the Oman mountains and shortening overprints extension in the area around Natih, Fahud, and the northern Maradi fault zone (Noweir and Asharhan 2000). The Salakh arch develops, reverse faulting occur in foredeep, the northern portion of the Maradi fault zone is inverted in dextral transpression, and the Fahud main fault is re-activated with a small sinistral component.

At the Cretaceous-Tertiary boundary, intra-oceanic north-over-south thrusting between the lower and upper nappes of Masirah island occurred, immediately followed in the Paleocene by the oblique obduction of the Masirah complex onto the Arabian continent. Along the east coast of Oman, largely offshore under Masirah bay and Sawqrah bay, a narrow, gently folded foreland basin, the Masirah trough, developed. The western margin is bounded by normal faults reactivating Mesozoic rift related faults. On its eastern margin, a wedge of ophiolitic and probably continental slope sediments is largely under thrusted below the eastern and uplifted part of this foredeep basin.

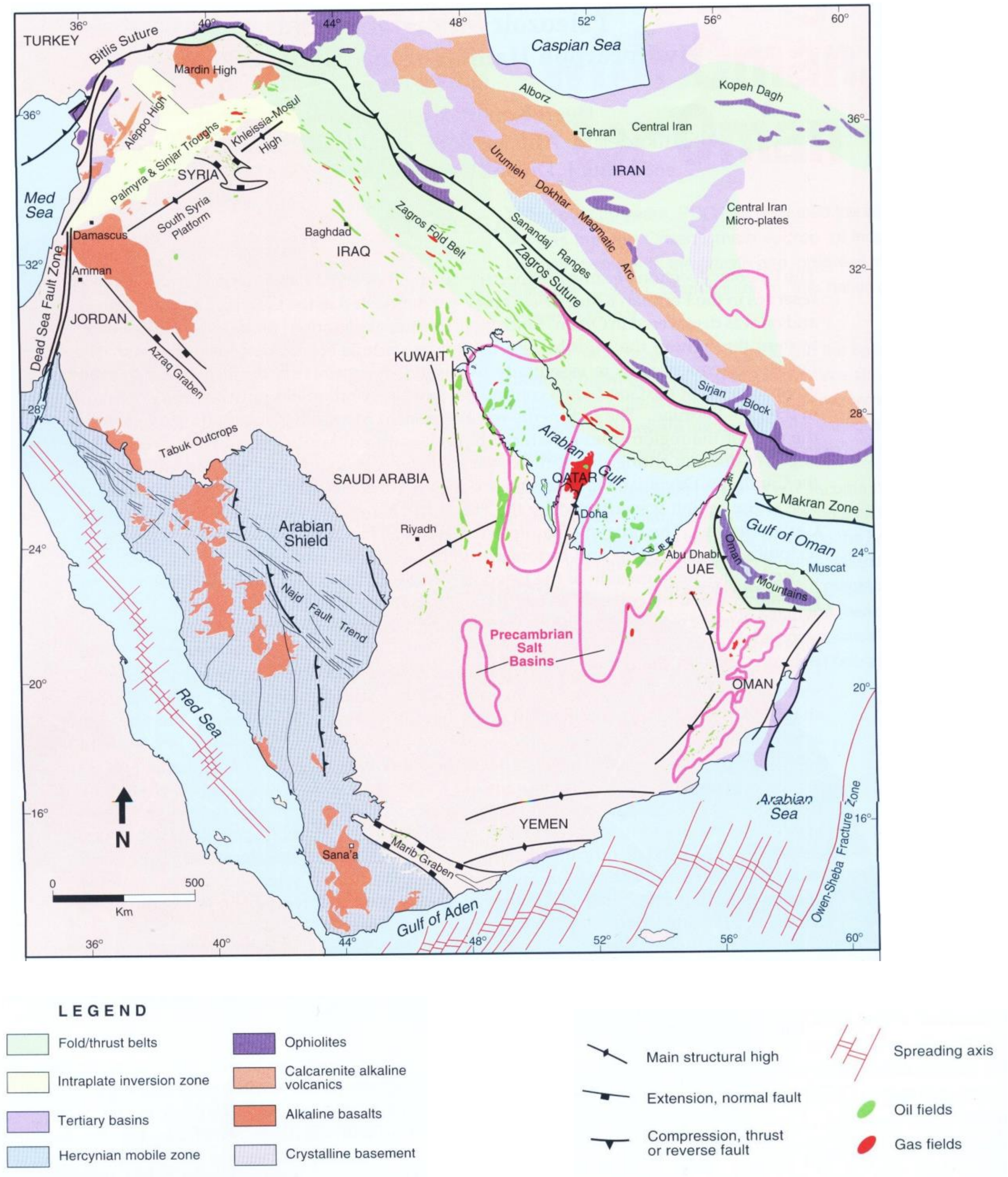

Fig. 2: Location and major tectonic elements of the Arabian plate and Iran. The Makran and Zagros separate the Arabian plate from the microplates of interior Iran.

OBJECTIVES

Although they are not very close, a large earthquake can cause major damage to structures in the eastern region. While the high-frequency components of seismic waves attenuate rapidly with distance, the low-frequency components can travel very far without much attenuation. The low-frequency waves also tend to have very long durations. These are the waves that would be most critical, because they can cause resonant vibrations in tall, flexible structures since these structures will all have very low natural frequencies. The shaking and the panic caused by the M=6.1, 27 November 2005 Southern Iran earthquake have clearly confirmed this. Observations from past earthquakes have shown that, long-period, long-duration shaking created by distant earthquakes cause tall buildings undergo a large number of stress reversals, resulting in strength deteriorations in concrete elements and fatigue failures in steel connections. The impact of an earthquake is not limited to direct losses, such as the loss of life, loss of structures, and business interruptions. Earthquakes also cause indirect losses by producing supply shortages and demand reductions in various economic sectors.

The aim of this project is to help decision makers orient their effort to some areas which need to be processed both intensively and scientifically in order to mitigate any possible approaching disaster on different scales.

Therefore, the objectives of the proposed research is to :

- Investigate historical and instrumental seismicity of the study area
- Characterize sources of seismic zones and ambient noises
- Investigate ground motion characteristics , site effect response, and site amplification
- Assess appropriate attenuation relations for ground motions
- Delineate seismic microzonation maps to design and evaluate structures
- Implement a geographic information system (GIS) approach, to construct seismic hazard maps by integrating probabilities of ground shaking and local site effects including soil-related amplification, and ground failure effects induced by proximity to fault zones.

METHODOLOGY

Previous seismic hazard assessment studies were restricted to the computation of probabilities of occurrence of ground shaking in a given time period by using probabilistic seismotectonic methods without incorporating local site effects. By using a geographic information system (GIS) approach, we will generate the seismic hazard map for the Arab Gulf area by integrating the probabilities of ground shaking and local site effects including soil-related amplification, soil liquefaction due to shallow underground water, and ground failure effects induced by proximity to fault zones.

King Saud university, King Abdulaziz City for Science & Technology (KACST) and Kuwait seismic networks are the principal resources in the region for characterizing seismic sources and seismic wave propagation. These networks are capable of detecting and locating seismic events with good accuracy in Kuwait and the eastern region of Saudi Arabia and can be used to construct a detailed seismicity map, and to estimate magnitudes, mechanisms and recurrence rates.

There are three major components of seismic hazard assessment and risk mitigation: (1) assessment of seismic hazard, (2) assessment of seismic risk and losses, and (3) development of loss reduction strategies. Assessment of seismic hazard involves determining the expected level of shaking by accounting for seismic sources in the region, past history of earthquakes, and local soil characteristics. Assessment of seismic losses is accomplished by incorporating structural inventory and the associated fragility relationships (i.e., ground shaking versus level of damage curves) into seismic hazard. Loss reduction strategies include retrofit, demolition, land use planning, monitoring systems, training, and education. Ultimate products of a seismic hazard study are a series of digital GIS maps (i.e., seismic hazard maps, site amplification maps, microzonation maps, structural inventory maps, structural damage maps, and loss estimation maps), and a software package to manipulate and modify the maps to assess seismic hazard and risk. This proposal focus on the seismic hazard assessment which includes 3 elements :

- ❖ Probabilistic seismic hazard maps
- ❖ Dynamic Analysis of Borehole Data
- ❖ Site amplification and microzonation maps

1. Probabilistic seismic hazard maps

The probabilistic assessment of seismic hazard involves calculation of the expected value of ground shaking for a specified probability of exceedance within a specified time period (e.g., peak ground acceleration that has a 10-perecent probability of being exceeded within the next 50 years). Figure 3 presents schematically the steps of probabilistic hazard assessment. To calculate seismic hazard, we will utilize the methodology recently developed by the USGS (Frankel, et al., 1996). This methodology has been reviewed extensively by the scientific and the users communities in several workshops convened by the USGS, the Building Seismic Safety Council, and the Applied Technology Council in the United States. The seismic hazard and design maps that resulted from this methodology have now officially been published by FEMA as National Earthquake Hazard Reduction Program Recommended Provisions for Seismic Regulations for New Buildings in the United States (FEMA, 1997).

The USGS methodology for the probabilistic assessment of seismic hazard includes the following steps:

- ❖ Produce comprehensive earthquake catalogue with uniform magnitude scale.
- ❖ Produce database of active faults with slip rates, estimated recurrence times, and estimated maximum magnitudes.
- ❖ Assess appropriate attenuation relations for ground motions as a function
- ❖ Integrate (1)-(3) into probabilistic calculation of seismic hazard curves with uncertainties.

The calculations give the numerical values of various ground motion parameters (e.g., peak acceleration, peak velocity, root-mean-square acceleration, response spectra, spectral intensity, etc.) for any given probability of exceedance or return period.

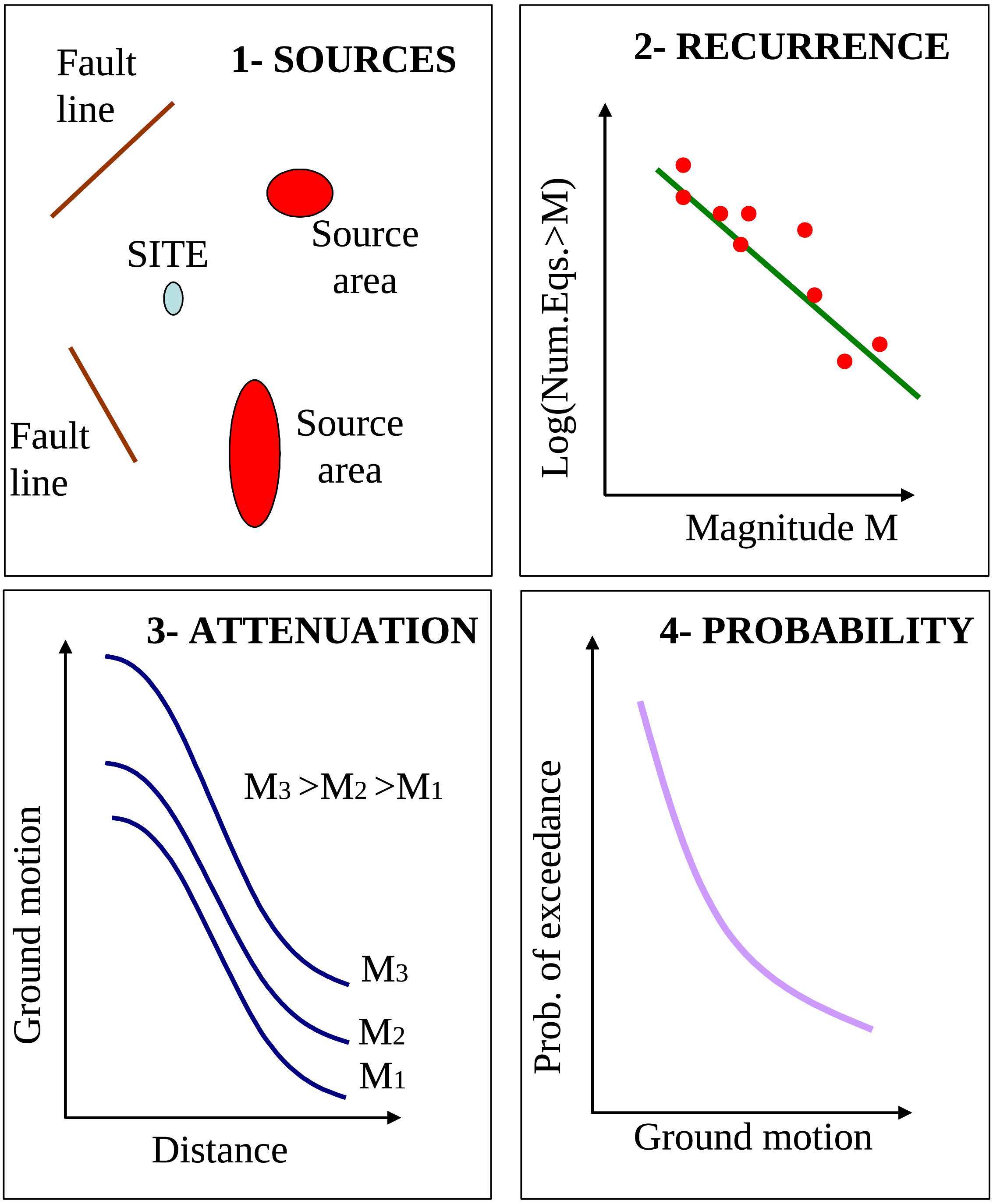

Fig.3- Steps of probabilistic seismic hazard analysis for a given site: (1) definition of earthquake sources, (2) earthquake recurrence characteristics for each source, (3) attenuation of ground motions with magnitude and distance, and (4) ground motions for specified probability of exceedance levels (calculated by summing probabilities over all the sources, magnitudes, and distances).

The data needed for the calculations include the catalogue of past earthquakes, location and the size of seismic source zones and active faults, and the attenuation equations (i.e., the equations describing the variation of ground motion parameters with magnitude and distance). We will utilize the published reports and maps, and seismic data.

The products from this task will be a set of probabilistic seismic hazard maps showing peak ground accelerations and pseudo-acceleration response spectra at 0.2, 1.0, 2.0, and 4.0-sec. periods for 10% probability in 50 , 100 and 250 years. The maps will be presented in a digital format compatible with commonly used GIS software packages.

2. Dynamic Analysis of Borehole Data

This task involves dynamic analysis of all existing borehole data. We will develop a software package that will read the borehole data from the Geobase system and calculate soil amplification factors for each borehole location by using nonlinear soil column analysis. The software developed for nonlinear analysis will be compatible with the existing database system such that it can be incorporated as an additional module into Geobase.

One of the key parameters needed for calculating site amplification from borehole data is the shear wave velocities of each geologic layer in the borehole log. We will initially assign shear wave velocities by using international data bases on shear wave velocities for similar geologic materials. We will then calibrate the shear wave velocities by matching the site characteristics determined from the analysis of ambient noise data collected using portable instruments.

This task will provide five products. The first two products will be a geologic map and a shear wave velocity map of sub-surface layers in Dammam and Alkhobar. The next product will be a site amplification map calculated from borehole logs and calibrated by ambient noise analysis. The last two products will be the shear wave velocities of each geologic unit found in the two cities, and a software package to calculate site amplification for a given borehole log.

3. Site amplification and Microzonation

The term "site amplification" refers to the increase in the amplitudes of seismic waves as they propagate through the soft geologic layers near the surface of the earth. Site amplification is a critical factor influencing the damage in structures during earthquakes. Soft soil layers can cause five to ten fold increase in the amplitudes of seismic waves. The probabilistic seismic hazard maps, discussed above, are developed for a generic soil type. To determine the actual ground shaking at a specific location, the shaking values given in seismic hazard maps should be multiplied with the local site amplification factors. The resulting maps are known as Microzonation Maps. These are the maps that are used to design and evaluate structures because they represent the actual ground shaking in that location.

The most accurate way to determine site amplification factors is to use field measurements. We propose to determine site amplification factors by recording ambient ground noise with portable instruments. In an urban area like Dammam and Alkhobar, there are a lot of sources that generate ground vibrations, such as the wind-induced motions of tall buildings that are transmitted to ground through their foundations, vibrations induced by machinery and moving vehicles on ground surface, and microtremeors.

Figure 4 shows a schematic of such excitation sources. If the objective were to locate earthquake sources, such noise would be detrimental, because it interferes with waves generated by the earthquake. That is why seismologists do not want to locate their instruments in urban areas. However, when the objective is to determine site amplification factors, such noise are very useful because they incorporate a lot of information on the characteristics of sub-surface soil layers. It can be shown that by proper analysis we can extract site amplification factors from ambient ground vibrations (Safak, 2006).

We propose to use 8 sets of portable broadband seismic recorders with built-in three-component sensors. We plan to divide the study area into four regions, deploy all the instruments in a region for one month, record ground noise continuously, and then move to the next region to do the same. In six months, we will complete a database of ambient noise recordings for the entire area. We will start analyzing the data from each region as soon as the instruments are moved to the next region. The site amplification factors determined from noise measurements will be used to check and calibrate the analytical models developed from the geotechnical boring logs. The results will be presented in the form of a site amplification map and microzonation maps for probabilistic seismic hazard, all in standard GIS format.

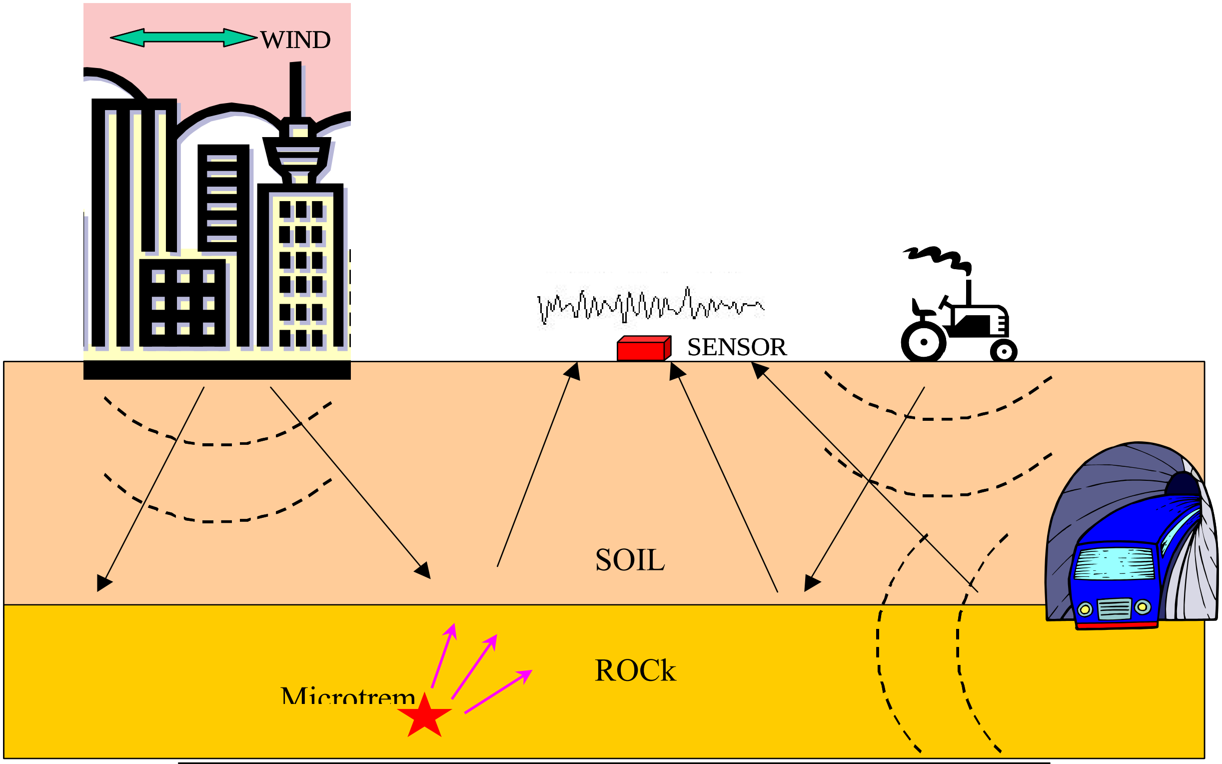

Fig. 4 - Sources for ambient ground vibrations.

4. Field Measurements

The deployment pool will consist of (8) Broad band accelerograph consisting of Q330, Baler and Episensor (Figures. 5 and 6). The deployment pool will 100% compatible with the existing seismic network. The Q330 family of instruments represents Quanterra's fourth-generation of high-resolution data-loggers. The Q330 product family physically splits the functions of digitization, timing, telemetry, and sensor control from later downstream functions such as recording. The main components of the family are the Q330 Data Engine™, or simply Q330, and a Packet Baler™, an intelligent low power network-aware recording companion. One of the fundamental design criteria of the Q330 + Packet Baler was to adhere to the open architecture concept. The Packet Baler™ is low-power local deep buffering unit. It can be connected locally or remotely to the Q330 through the Ethernet or serial links for data packaging, recording, or additional real-time processing.

Fig. 5. Advanced Very Broad Band Digitizer, IP-Aware, Very Low Power Consumption Quanterra Q330 System.

Fig. 6. The Packet Baler™ is low-power local deep buffering unit.

The Q330 + Packet Baler solution offers the following advantages:

- Low power consumption: approximately 1.1 Watt
- High dynamic range: greater than 135 dB
- High precision timing: 0.1 ms
- Ease of installation: The Q330 + Baler will start recording data as
- soon as it is turn on.
- Provision for connection to telemetry links: The Q330 + Baler
- comes standard with the appropriate interfaces (Ethernet and
- Serial) for connection to any type of telemetry links.
- Robust: The Q330 + Baler has been designed to operate in rough
- environment and under strong shakings
- Low Total-Cost-of-Ownership: Some COTS elements of our
- solution (i.e. hard disk) are subject to the same limited life span
- inherent in all computing technologies. However, by physically
- separating the digitizer and the data storage unit, we could easily
- redesign the data storage unit to take advantage of future
- technological changes and ensure the support of the product over
- its lifecycle.
- After sales support: The personnel at our office in Switzerland are
- fully trained to provide after sales services

Work Plan

The project will proceed along the following outline over a period of 24 months which will be implemented in four phases as follows:

Phase I (Six months)

1. **Characterization of seismicity**

   The first step in a hazard assessment is to map the occurrence of earthquakes within and adjacent to the eastern region. The following questions about earthquakes must be answered:

   - ❖ Where do earthquakes occur? How deep do they occur?
   - ❖ What causes the earthquakes (e.g. identify faults) and what types of earthquakes occur (for example, strike-slip, dip-slip)? Knowledge of the type and orientation of the earthquakes permits and estimate of how and in what direction seismic energy is projected from an earthquakes source.
   - ❖ What is the largest magnitude earthquake that can occurs on each identified source of earthquakes (e.g. faults)?
   - ❖ What is the recurrence interval, i.e. the expected time interval between earthquakes of particular magnitudes?

Phase II (Six months)

2. Estimation of attenuation rates

The second step in a hazard assessment is to find a good attenuation model for seismic wave propagation. The seismic waves generated by earthquakes lose strength as they travel away from the earthquake source. With the major exception if site effects (described below), the further a city is from an earthquake, the less severe the strong ground motion from that earthquake will be. The amount that seismic waves diminish as they propagate from the earthquake source depends very much on the geologic conditions along the path from the source to the city. Since seismic waves travel through the crust and upper mantle, the rate at which seismic energy is absorbed in the crust and mantle (the attenuation rate) is an important factor for calculating the strength of seismic waves at a specified distance form the source.

The attenuation rate is best estimated using strong-motion recordings of moderate to large earthquakes. Since we do not have history of strong motion recording, two alternatives can be used. We can use the recordings of weak motion from local events and events of the near Zagros to bound attenuation, and can apply the principal of geophysical analogy to import strong motion attenuation estimates from other parts of the world with similar conditions.

Phase III (Six months)

3. Site response estimation

The response of any particular site to excitation from a passing seismic wave is strongly a function of the local geologic conditions at the site. Soft soils and sediments can amplify the ground motion in certain period bands by factors of two or more. The site response is controlled by the type of soil or rock that structures are built upon and by several other factors, such as:

- degree of water saturation,
- soil shear strength,
- thickness of soils above solid rock,
- effects of waves reverberating in sedimentary basins.

To estimate site response, geologists must map these characteristics across the eastern region. The spatial characteristics and physical properties of the soils are most conveniently stored as layers in a modern GIS system, which facilitates probabilistic hazard assessment.

Phase IV (six months)

4. Probabilistic hazard assessment

The final step in a hazard assessment is to construct a probabilistic ground-shaking hazard map of the eastern region. This map will provide an estimate of the level of ground shaking at all sites expected from earthquake sources throughout the region (both local and regional). The calculated seismic hazard will be site-specific because it will incorporate site amplification factors, which will be determined from the ambient ground vibration records collected by portable seismic instruments deployed throughout the two cities.

The map integrates the seismicity, attenuation and sit response factors described above, in a GIS (Arc Info software) environment. Spatial analysis of the data in a GIS environment requires building topologies (polygons), overlaying datasets, and manipulation (e.g. buffering) of overlaid data sets.

In most modern approaches, seismic hazard is described in terms of probability that ground motion will exceed a specified acceleration (fraction of one gravity) in a specified time interval (e.g.50 years-the useful life of an ordinary building, as prescribed in most modern building codes). Urban planners can use maps of this so-called probability of exceedance to determine whether restrictions on building may apply at particular sites, based on the known response of different kinds of structures to different levels of ground acceleration. Usually the ground motion is specified in terms of peak acceleration, or sustained (sinusoidal) acceleration in each of several period bands.

Schedule of Work Plan

PHASES	ACTIVITY	MONTHS			
		6	12	18	24
ONE	❖ Literature review ❖ Data collection from SNSN, KSUSN and Kuwait Networks ❖ Construct maps of seismicity ❖ Construct GIS plate form ❖ Reconnaissance geological field trips				
TWO	❖ Estimation of attenuation rates ❖ Characterize seismic sources ❖ Deployment of Portable Seismic Stations ❖ Interim Report				
THREE	❖ Estimation of site response ❖ Dynamic Analysis of Borehole Data ❖ Site Amplification Estimates ❖ Microzonation				
FOUR	❖ Probabilistic hazard assessment ❖ Construction of hazard maps in GIS system ❖ Final report				

Utilization

The results of this research will lead to a more accurate and complete earthquake catalog and lead to more accurate assessments of seismic hazard. Our expected crustal velocity models can be used in seismic investigations pertaining to attenuation measurements in the crust. These measurements are also required in studies related to seismic hazard assessment. A thorough understanding of the seismic structure and wave propagation characteristics of the region must be established before we can proceed to assess seismic hazard.

Together these analyses will result in a unified model of the structure and physical state of the lithosphere beneath the Arabian Gulf region and provide important information concerning the tectonic evolution of the Arabian Plate. The proposed research will provide valuable data for use by policy makers and urban planners to improve building codes and prevent loss of life.

This project will help decision makers orient their effort to some areas which need to be processed both intensively and scientifically in order to mitigate any possible approaching disaster on different scales.

DELIVERABLES

The following table identifies the products and the equipment to be delivered by Dept. of Geology, King Saud University for this project.

	Hazard Assessment products	Quantity Lot
	1. Instrumental and Historical seismicity maps. 2. Probabilistic seismic hazard maps for Dammam and Alkhobar cities. The probabilistic maps will be 10% in 50 years and 2% in 2500 years probability levels, and maps of peak ground acceleration, peak ground velocity, and spectral accelerations at 0.2, 1.0, 2.0, and 4.0 seconds for each probability level will be given . 3. GIS Software package for Probabilistic seismic hazard maps . 4. A site amplification map. Collection and processing of site noise including sites preparation. 5. Dynamic Analysis of Borehole Data 6. Fence diagrams (3D borehole diagram) of geotechnical logs. 7. Microzonation maps (i.e., hazard maps + site amplification map) 8. GIS Software package for Microzonation maps 9. Interim and Final reports.	
	Equipment for Site Survey	**8**
	Ultra-Low-Power High Resolution Network-Aware Seismic Data Acquisition System (3-ch), includes: * 24 bit A/D Converter * 8 Mbyte RAM * GPS with 5 meter cable	
	Baler 14 Field Ruggedized version with * 20Gbyte memory disk * Rated for –20C to +75C * Operating shock tolerance of 100G/11ms	
	Surface Triaxial Force balance Accelerometer with single +12 VDC input power option	
	Cable, Q330-Episensor analog, pwr, & control. 25 ft	
	12 VDC power System	

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