Environmental hazard assessment of Makkah region from seismic microzoning and soil effect responses

تقييم المخاطر البيئية لمنطقة مكة من خلال التمنطق الزلزالي الدقيق واستجابات تأثير التربة.

- **Summary**

Makkah region is the most important one through Saudi Arabia, which is growing rapidly in every aspect, particularly; the major infrastructures, high-rise buildings and new urban communities. The peoples and their beings are constructed along the recently deposited soft soil of Quaternary age. Several ground failure and landslides have been recorded through the populated areas of Makkah region. These ground failure either naturally or artificially reflect the dangerous effect of soft soil-structure interaction. Makkah region was affected by number of strong earthquakes, where it lies close to the seismically active Red Sea and it associated potentially active tectonic structures where Jeddah city was strongly affected by destructive earthquake on 1967. Some of these earthquakes were strongly felt with high seismic intensities through Makkah region. Such a high intensities caused ground failure particularly at the Quaternary soft sediments that significantly amplify the earthquake ground motions. In addition number of instrumental earthquake has been records in Makkah city on 12/4/1431H (Al-Sharai'a earthquake with magnitude 4.1) and 8/8/1426H earthquake (Al-Utaibiya district) having a magnitude of 3.6.

In November 2009, a great damage to buildings and ground failure have been occurred where only about 30% of the Jeddah city was protected against flash-flooding. Eleven wades, at least, converge on the city of Jeddah and flooding is common after rain. About 77 people were killed in intense flooding in Jeddah and nearby areas and about 3,000 vehicles were swept away or damaged, where more than 90 millimetres (3½ inches) of rain fell in Jeddah in just four hours on Wednesday 25 November. The municipality is currently investing around 1 billion riyals (US$270 million) in storm drains, while the cost of a full system is estimated at an additional 3 billion riyals (US$800 million).

The environmental hazard assessment for Makkah region becomes necessary and very important to protect peoples and their being structures. Earthquakes represent one of the natural disasters affecting the environment, so the assessment of their hazard through Makkah region is of utmost importance and critical issue. The detailed and accurate evaluation of the coastal soil responses and the categorizing them according to the values of seismic response is of critical demand for urban developments, safer design of buildings and to the mitigation of the earthquake risk. This will be achieved throughout a comprehensive strategy including collection, analyzing and interpretation of soil-profiles of Makkah region through the application of advanced technologies in the field of environmental hazard assessment. The proposed procedure produces maps that engineers and policy makers can use to mitigate the future environment hazard throughout design an appropriate response to seismic hazards. A better understanding of the Natural hazard resources, including earthquakes hazards and risks is recommended, particularly in Makkah region.

- **Summary (Arabic):**

تعتبر منطقة مكة المكرمة من أهم المناطق في المملكة العربية السعودية، والتي يشهد نموا سريعا في كل جوانب الحياة ، وخصوصا في مجال البنية التحتية الرئيسية والمباني الشاهقة والمجتمعات العمرانية الجديدة لمواجهة الأعداد الهائلة من الحجاج أثناء فترة الحج والعمرة. نظرا لامتداد صخور الدرع العربي الوعرة والصلبة لتغطي مساحات كبيرة من الجزء الغربي من المملكة، فلا يوجد امتدادات أفقية تسمح بإنشاء المنشآت الهامة، وبسبب تلك الظروف فقد تم إنشاء معظم المنشآت الأساسية والحياتية علي تربة هشة ترسبت حديثا داخل الأودية المنتشرة بالمنطقة. وقد تأثرت منطقة مكة بعدد من الزلازل القوية، حيث تقع ملاصقة للبحر الأحمر المعروف بنشاطه الزلزالي وحركاته التكتونية العنيفة الناتجة عن حدوث هذا النشاط الزلزالي، فقد تعرضت مدينة جده لزلزال عنيف ومدمر في عام 1967، والذي تسبب في حدوث انهيارات أرضية شديدة في عدد كبير من الواقع داخل مدينة جده وخارجها، كما شعر به السكان بمدينة مكة المكرمة بقوة . أيضا حدثت بعض الزلازل متوسطة القوة داخل منطقة مكة المكرمة، فقد حدث في12 /4/1431هـ زلزال بقوة 4.1 درجة بمنطقة الشرائع ، وكذلك حدثت هزه أرضية يوم 1426/8/8 هـ شعر بها المواطنين بمنطقة مكة المكرمة فى حي العتيبية بقوة 3.6 درجة على مقياس ريختر. تسببت هذه الزلازل في حدوث انهيارات أرضية ولا سيما في الرواسب اللينة الرباعية التي تعمل على تضخيم للحركات الأرضية المصاحبة للزلزال تصل أحيانا أربعة أضعاف مثيلتها على الأرض الصلبة.

وقد حدث انهيارات أرضية عنيفة والتي أدت لتدمير في المنازل والطرقات والقناطر نتيجة سيول شديدة جدا في يوم الأربعاء الموافق 25 نوفمبر 2009 بمدينة جده وخارجها ، حيث كانت حوالي 30 ٪ فقط من المدينة محمية ضد هذه الفيضانات المدمرة والتي تجمعت من حوالي 12 واديا لتلقي مياهها على مدينة جدة. وقد أدت هذه السيول أيضا لقتل نحو 77 شخصا في أسوأ فيضانات تشهدها المنطقة خلال 27 عاما الأخيرة، وكذلك جرفت هذه السيول ما لا يقل عن 3000 مركبة بعيدا ، فقد بلغ ارتفاع مياه الأمطار أكثر من 90 ملليمتر (3 ½ بوصة) في غضون أربع ساعات فقط.

لقد أصبح من الضروري إجراء تقييم دقيق للمخاطر البيئية بمنطقة مكة المكرمة لحماية المشاعر المقدسة والمواطنين وممتلكاهم. ونظرا لأن الزلازل تمثل أحد المصادر الطبيعية للمخاطر البيئية التي تؤثر على المنطقة ،فإن إجراء تقييم دقيق يبين مدى استجابة التربة السطحية للحركات الزلزالية يمثل أهمية قصوى للتصميم الآمن للمشاريع العمرانية، والى التخفيف من مخاطر الزلازل .وسوف يتحقق ذلك من خلال تطبيق منظومة متكاملة تشتمل على تجميع، تحليل، وتفسير لبيانات قطاعات التربة المختلفة حتي عمق 30 متر بمنطقة مكة باستخدام أحدث الأساليب التكنولوجية المستخدمة عالميا في مجال

تقييم الخطر البيئي الناتج عن حدوث الزلازل. مخرجات هذا المشروع هي عبارة عن قاعدة بيانات رقمية لمجوعة متكاملة من الخرائط التفصيلية لأنواع التربة المختلفة، وخواصها الجيوتقنية، وقوة تحملها للإجهاد، ومدى استجابتها أثناء تعرضها للحركات الأرضية. هذه المخرجات سوف يتم تقديمها للمهندسين المدنيين والإنشائيين والمخططين وواضعي السياسات من أجل استخدامها في التصميم الآمن للمنشآت العامة والخاصة حماية البيئة من مخاطر الزلازل بمنطقة مكة.

INTRODUCTION

Makkah region extends from the Red Sea Coastal plain to the west–central Saudi Arabia into land (Fig. 1). It includes the cities of Jeddah, Makkah Al-Mukarramah and Taif at which all the developmental activities growing fast in recent years. The city of Jeddah is situated on the Red Sea coast, beneath the northern escarpment of the Red Sea rift valley known as the Jabal al-Hejaz, which reaches 600–1,000 metres (1,800–3,000 feet) in the region. The population of the city is about 3.4 million (2009 estimate) in an urban area of 1,765 km^2 (681 sq. mi.), giving a population density of 1,900 hab./km^2 (5,000 hab./sq. mi.). The climate is arid, with most rainfall occurring between November and January, usually as thunderstorms. In addition to that it receives about 5 millions of Muslims for the annual pilgrimage, the *Hajj*, at Makkah Al-Mukarramah (about 80 km east of Jeddah city) and throughout the year for the lesser pilgrimage the *Umrah*. Furthermore, very important structures such as multi-storeyed buildings, flyovers, great industries, and sports centres etc n recent years have been established.

Wednesday, 25 November 2009 was the first day of the annual four-day Hajj pilgrimage to Islamic holy sites in and around Makkah, for which Jeddah is the main entry point for foreign pilgrims arriving by air or sea. According to the Saudi Interior Ministry, 77 people were killed in intense flooding in Jeddah and nearby areas. However, the main Haramain expressway between King Abdulaziz International Airport and Makkah was closed on 25 November, stranding thousands of pilgrims. Parts of the 80 kilometer (50 mile) highway were reported to have caved in, and the Jamia Bridge in eastern Jeddah partially collapsed. The highway remained closed on 26 November amid fears that the bridge would collapse completely. Rain was unusually heavy in Makkah on 25 November, as well as in nearby Mina, where many pilgrims stay in vast tent cities. The weather had improved by 26 November, and pilgrims had to face “scorching heat” on the plain of Mount Arafat for the second day of the Hajj. The 2009 described by civil defense officials as the worst in 27 years. As of January 3rd, 2010, some 122 people are reported to have been killed, and more than 350 were missing. Some roads were under a meter (three feet) of water on Thursday 26 November, and many of the victims were believed to have drowned in their cars. At least 3,000 vehicles were swept away or damaged. The death toll was expected to rise as flood waters receded, allowing rescuers to reach stranded vehicles. More than 90 millimeters (3½ inches) of rain fell in

Jeddah in just four hours on Wednesday 25 November. This is nearly twice the average for an entire year and the heaviest rainfall in Saudi Arabia in a decade. The flooding came just two days before the expected date of the Eid al-Adha festival and during the annual Hajj pilgrimage to nearby Makkah. Business losses were estimated at a billion riyals (US$270 million). The poorer neighborhoods in the south of Jeddah were particularly hard hit as was the area around King Abdulaziz University. The university was closed for vacation at the time of the floods, preventing even higher casualties.

Western Arabia, including Makkah region, is characterized by their noticeable moderate- high earthquake activities (Fig. 2) (Merghalani et al. 1981; El-Isa and Al-Shanti, 1989; Al-Amri, 1999 and Fnais et al., 2010). Ambraseys et al. (1994) reported several historical earthquakes on 873, 1121; 1269, 1408 and 1426 Ad affected Makkah region. Some of thes events caused small to moderate damage to the long-period structures, such as minarets and pillars surrounding the Holy Mosque. Western part of Saudi Arabia has been indicated to have regional earthquake hazard levels (70-150 gal) of engineering concern (Al-Noury and Ali, 1986; Thenhaus et al., 1989 and GSHAP, 1997). Most of these earthquakes had occurred in this region either along the Red Sea axial trough or within the mainland. Some of these earthquakes affected Makkah region. The amplification of earthquake ground motion by the topmost soil cover becomes an essential component.

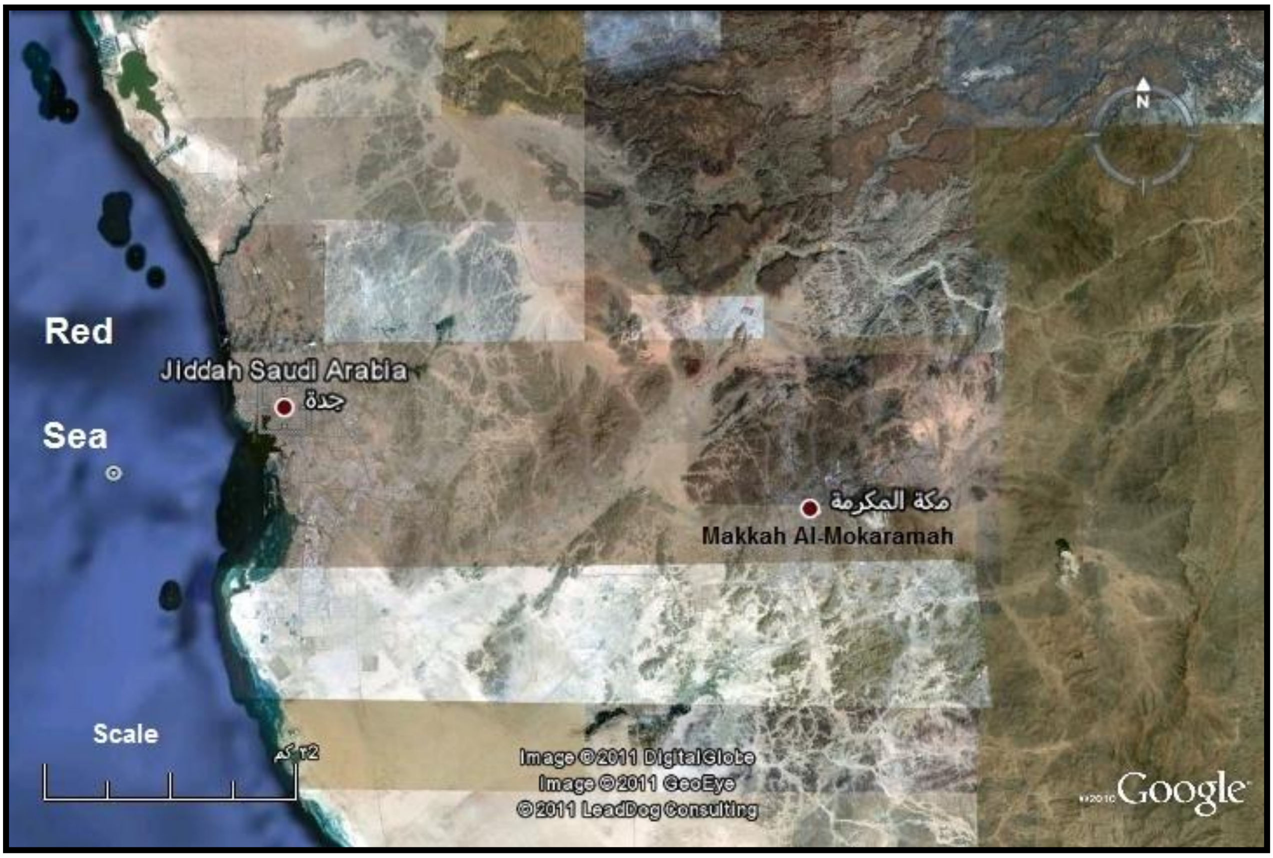


Figure 1. Location map of the Makkah region.

This amplification has long been known, documented, and even quantified, for more than 10 decades. The soil effects can amplify the ground motion levels 2-4 times their bedrock values over sites of thick and/or weak soils. Its disastrous effect in many parts of the world is readily acknowledged and intensively investigated. Soil amplification effects are of especially importance for Makkah region, because the three major cities are mostly situated over the Quaternary alluvial deposits incised into the Precambrian rocks of the Arabian Shield. It is the very condition being situated within the Arabian Shield that should permit the efficient transmission of earthquake body and surface waves due to the lower crustal attenuation as compared to locations where bedrock is of younger, more attenuating sedimentary rock. In addition, it is the condition of soft low velocity soil layers that have a sharp acoustic impedance contrast with a hard, high velocity basement substratum that increase relative amplification of this soil to bedrock ground motion.

Seismic microzonation for urban areas represents the most important step towards a seismic risk analysis and mitigation strategy in densely populated regions. It would like to quantify the spatial variation of the subsurface response on a typical earthquake that can be expected in the area.

The propagation of ground motion through the subsurface is particularly affected by the local geology and the geotechnical ground conditions. Large amplification of the seismic signals generally occurs in areas where layers of low seismic velocity overlie material with high seismic velocity, i.e. where soft sediments cover bedrock or more stiff soils. Therefore, essential here is to obtain a good understanding of the local subsurface conditions. This poses already a problem in most areas, particularly in developing countries. Availability of borehole data, geophysical surveys and laboratory tests are often very limited. Subsequently, seismic microzonation is often carried out by dividing the project area in rather large sub-areas where the geological model and ground conditions are considered to be homogeneous. For each sub-area, the seismic response is calculated and assumed to be representative for this entire area.

The soil shear wave velocity (Vs) structure, which is an essential component of site-response estimates of possible shaking has proved to be an important indicator of surficial horizontal acceleration and amplification produced in varying geologic units by strong ground motions Produced by earthquakes (Tinsley and Fumal, 1985; Borcherdt et al., 1991; BSSC, 1998 and Glassmoyer, 1992; AIJ, 1993; Anderson et al., 1996 and Kramer, 1996). Recently, the average shear wave velocity to depth of 30m (Vs30) has become a widely used parameter for classifying sites to predict their potential to amplify seismic shaking and is now adopted in recent building codes (Dobry et al., 2000 and BSSC, 2001) and in loss estimation. The site classes estimated from shallow shear-wave velocity models are also important in deriving strong motion prediction equations (Boore et al., 1997), in construction of maps of hazard reduction on a national scale, e.g. the US National Earthquake Hazard Reduction Program (NEHRP) in classes (Wills et al., 2000) and in applications of building codes to specific sites. Because of the robustness of Vs30, it has been accepted by the US National Earthquake Hazard Reduction Program (NEHRP) as the standard for characterizing soils in seismic hazard analysis. The NEHRP soil profile categories are also part of the International Building Code adapted in 2001 (IBC, 2002). Several field and lab. techniques have been devised to either directly measure or indirectly obtain soil Vs. These include standard Penetration Testing (SPT), Cone penetration testing (CPT), seismic cone penetration testing (SCPT), P-S logging, suspension logging, cross-hole, seismic refraction and reflection techniques are either costly, intrusive (require boring), laborious, time-consuming, or not urban-friendly.

The use of penetration tests has always been one of the convenient ways to identify subsurface soil profiles. The Standard Penetration test (SPT) has been widely used to investigate deposits consisting of cohesionless soils or relatively stiff soils, while the Cone Penetration Test (CPT) has been used to identify soil properties in soft soil deposits (Lune et al., 1997). In the SPT, in addition to soil identification based on soil sampling, the blow count, N-value, is obtained. Deriving Vs information from SPT, N-value based on empirical formulas has long been in use in seismic hazard and engineering applications, despite their known inaccuracies. These formulas are derived based on standardized derilling and testing practices in soils of specific areas of the world. Some of the most commonly used such formulas for various types of soils and soil ages were reported by Imai and Yoshima (1970); Ohba and Toriumi (1970); Ohta and Goto (1978) and Okamoto et al. (1989).

The need for rapid, accurate, non-invasive, and inexpensive assessment of earthquake hazard at large numbers of sites has led to the development of several geophysical testing methods that do not require drilling and are less laborious. The Spectral Analysis of Surface Waves (SASW) and microtremor array techniques both use surface-wave phase information to interpret shear-velocity or rigidity profiles. The SASW technique, sometimes referred to as "CXW" (Boore and Brown, 1998), first introduced by Nazarian and Stokoe (1984) uses an active source of seismic energy, recorded repeatedly by a pair of 1 Hz seismometers at small (1m) to large (500m) distances (Nazarian and Desai, 1993). The seismometers are vertical particle velocity sensors, so shear-velocity profiles are analyzed on the basis of Rayleigh-wave phase velocities interpreted from the recordings. In response to the shortcomings of SASW in the presence of noise, the Multichannel Analysis of Surface Waves (MASW) technique (Park et al., 1999) was developed. The simultaneous recording of 12 or more receivers at short (1-2 m) to long (50-100m) distances from an impulsive or vibratory source gives statistical redundancy to measurements of phase.

Over the last two decades, emerged the passive (not requiring seismic sources) seismic techniques utilizing ambient vibration (microtremor) measurements. Ambient vibration techniques are much cheaper than classical geophysical site investigations and, thus, have the potential to significantly contribute to effective seismic risk mitigation, particularly in urban areas, where the risk is the largest and keeps growing. That is why their use is rapidly spreading world- wide, especially again in urban areas. Among these techniques, the horizontal- to- vertical spectral ratio (H/V) technique, widely known as the "Nakamura's" technique, has gained wide acceptance and has been widely applied all over the world in site-response studies for seismic hazard assessment. Being essentially a noise recordings and analysis method, it works successfully inside buildings, over pavements, on roads and highways with exceptional ease. As such, it can provide for rapid, cost-effective spatial coverage, and it should work best in seismically noisy urban areas, as traffic and other vehicles, and possibly the wind responses of trees, buildings, and utility standards provide the surface waves this method analyses.

As soil amplification of ground motion is a frequency-dependent process, the most complete description of this process is, therefore, possible only if relative amplification is expressed as a function of frequency. The shear wave velocity profiles were, therefore, input to a one-dimensional (ID) spectral soil response modelling routine to obtain the fundamental resonance frequency and the corresponding maximum relative amplification. Further, the modelled amplification and frequency were compared at selected sites with measurements carried out using the microtremor spectral ratio (H/V) technique. The site response will obtained from ambient vibration recordings at two monitoring stations simultaneously recording at a rock and soil site will hampered by the bedrock site having a site response of its own. Once the site response functions are determined, it became possible to compute uniform hazard site-specific acceleration spectra with a 10% probability of exceedence during an exposure time of 50 years and a damping ratio of 5%. In this project the geotechnical, geomorphological and geological information will be the main input parameters in a seismic response modelling program - such as the widely used software SHAKE - a more accurate spatial variation of the seismic response can be modelled, which will provide an improved seismic microzonating maps in terms of amplification characteristics and fundamental frequencies at each of the measured sites through Makkah region.

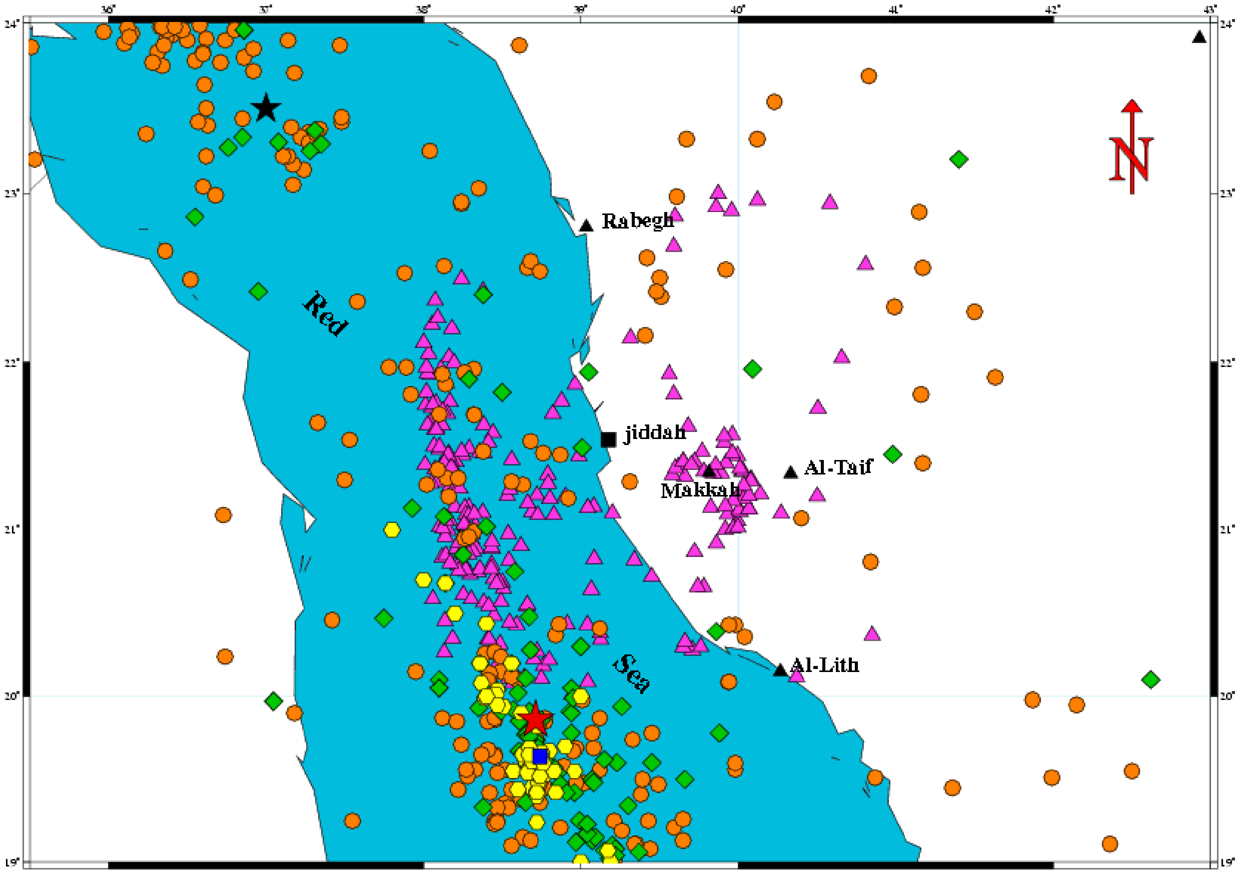


Figure 2: Seismicity of Makkah region.

1.2 GEOLOGICAL SETTING OF MAKKAH REGION

Topographically, Makkah region has great variety of geomorphological features; the flat area of the coastal plains of Red Sea constituted by alluvial sand, sabkha soil and coralline reef rocks; hilly and mountains consist of metamorphosed rocks and intrusive batholiths encountered to the east of the region. These topographic features resulted from the uplifting associated with Red Sea rifting. The elevations vary mainly between 300 and 980 meters above sea level. Elevation increase in the middle of the mapped area while the topography tends to be rugged and high massive mountains of weakly deformed and slightly weathered rocks dominate, and then drains into Wadi Fatimah graben in the extreme northwestern part with NE – SW trending. To the southeast of Wadi Fatimah, moderately high mountains with elongated shapes and some hills are separated by small wadis. In the middle part, the relief becomes more rugged as the elevations increase between 610 and 980 msl.

Geologically, Makkah region lies on the western margin of the Arabian Shield (Skiba et al., (1977); Moore and Al-Rehaili (1989) (Fig. 3). It is dominated by different types of igneous, metamorphic and sedimentary rocks of Precambrian and lower Palaeozoic era (Greenwood *et al.* 1976). In addition, there are subordinate sedimentary rocks and basaltic lava flow of Tertiary and Quaternary age (Sonbul, 1995). The coralline limestone is approximately 7 km wide and may reach more than 40 m in thickness. Small occurrences of the limestone are found as small mounds in disseminated areas. The limestone was also observed close to the ground surface east of Jeddah, which is possibly because of faulting and uplifting. Al-Haddad et al., (2001) investigate the resistant design of the western coast of Saudi Arabia and concluded that the soil profiles in Jeddah can be classified as soft soil. Under this soil class the liquefaction phenomenon can be occurred.

Makkah region has been studied in terms of geology, tectonic, volcanic activity and earthquakes during the past four decades (McKenzie et al. 1970; Moore 1979; Stern et al. 1984; Moore and Al-Rehaili 1989; Camp and Roobol 1991a, b; Abdelsalam and Stern 1996; Al-Amri 1998 & 1999; Bosworth et al. 2005; and Al-Saud, 2008). The area affected - to a large extent – different geological structures and these structures covered with volcanic lava and sedimentary rocks that formed during the Quaternary. The surface area is covered with recent sediments, which stretches north and south along the coastal plain of the Red Sea, and east to the holy city of Makkah. Structurally, it is also notable that the southern region of the study area affected by Ad Damm fault which extends towards the northeast, one of the seismically active sources that experienced a series of earthquakes in recent times, in addition to that there is fault of Wadi Fatima, which passes the central region of the study area (Fig. 3).

The coralline limestone is often filled with alluvial sand, shell fragments or marly material (Al solami et al., 2006). The alluvial sand consists of brown silty sand and terraced sand. The brown silty sand is a major soil unit in Jiddah that covers most of the alluvial coastal plain. This sand is found east of the coralline limestone and locally underlies it or interfingers with it in the subsurface. This sand consists of sand, silt and a clay binder. Clay and gravel lenses are sometimes seen embedded in the silty sand unit. The terraced sand is found in the alluvial fans where the main wadis flowing from the east discharge into the alluvial plain. It is also found between wadi courses in south Jiddah. This unit consists of gravel, sand, and small percentage of fines. The sabkha soil is located in small depressions near the coastline in the low relief areas or in depressions within the coralline limestone. They are mainly of silty nature with seems and pockets of cohesive soils. These soils grade in color from dark gray to brownish gray and becoming grayish white in some locations.

Two of major different tectonic trends oriented NE-SW and NW-SE are clearly identified through the area NE – SW fault trends occupying an area of approximately 600 km along the Red Sea coast, extending from Al-Lith to Yanbu and 150 km inland, the trend of these lineaments as well as the lithostratigraphic belts attain NE direction. There are three of major faults (e.g. Ad Damm and wadi Fatima faults to the south of Jiddah and Bir Um Buq fault to the north) are well documented in the area. Whereas, NW-SE faults dissected the area into different structural troughs. These structural trends reflect the major phases of Precambrian deformation and Tertiary faulting.

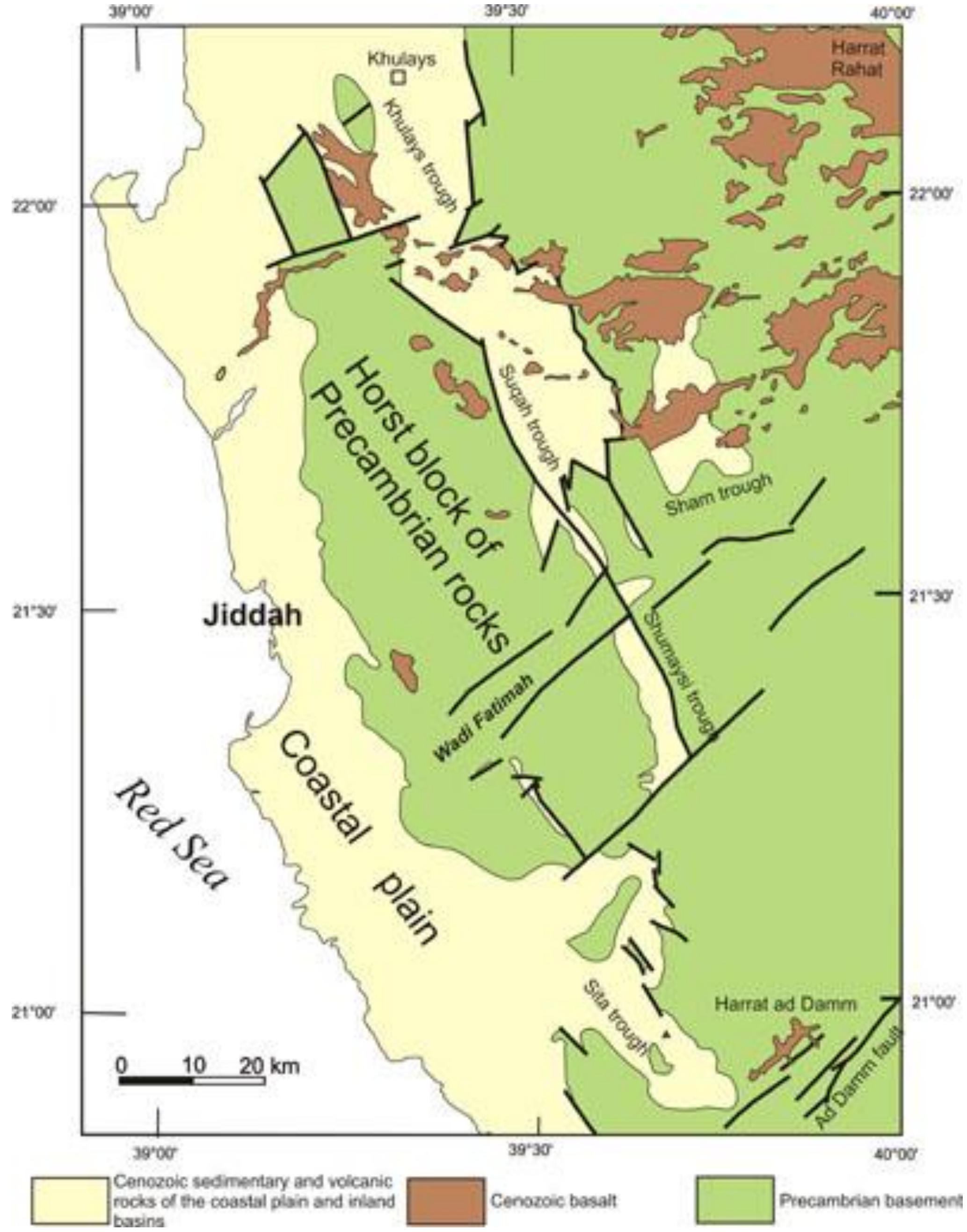


Figure 3: Geological map of Makkah region.

2. PROJECT OBJECTIVES

Earthquake can cause panic to structures and environment in the epicentral area of 100 km around the epicenter (Ambraseys, 2005). The impact of an earthquake, on the environment 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. This Project aims to mitigate the destructive effects of earthquakes on the urban area in Makkah region. The results of this project will support the decision makers with some residential 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 are to quantify the environmental hazard of the coastal soil through;

- Soil classification (Vs30) maps according to NEHRP-IBC. Due to the wide variety of soil – profile types and the overlying structures and residential buildings through Makkah region, the geotechnical properties and thicknesses of these soil-types should be, more precisely, evaluated. Furthermore, the soil capacity and soil-structure interaction should be quantified as well. MASW technology will be used in this project to fulfil the main tasks.
- Site response estimation. The advanced technologies used to assess the environmental hazard from earthquake occurrences will be applied through this project. 1D shear- wave velocity (Vs30) modelling and microtremor measurements are the main approaches of worldwide application.
- Determination of Peak Ground Acceleration (PGA) and response spectra: It will be achieved through the application of deterministic and probabilistic hazard approaches. PGA distribution values through Makkah region with 10% probability of exceedence during an exposure times of 50,100, 250 years and damping ratio of 5% will be mapped.
- Seismic Microzonation of Makkah region Using Geographic Information System (GIS) technology: It will based on the identified soils according to their own responses 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.

3. LITERATURE REVIEW

The local geology and topography effects control the distribution of damages due to strong earthquakes. The amplification of earthquake ground motion by local site conditions has important implications in urban planning and development. In areas characterized by soft sediments, the amplification of the ground motion is common and lead to enhanced seismic hazard and risk**.** Local site response may be evaluated by empirical and theoretical methods. The theoretical methods allow detailed analysis of the parameters used in the evaluation; however, they require detailed geo-technical information about the materials through which the seismic waves propagate to the surface. The analytical response of plane SV waves impinging on a single layer overlying a half-space is well known and widely used (Burridge, 1980; Shearer, 1987; Lermo and Chávez-García, 1993). Empirical methods are based on seismic records on sites; thus, dominant frequency and amplification are determined directly. Empirical methods can be separated in two categories: those that use two sites and those that use only one site. Borcherdt (1970) introduced the sediment-to-bedrock ratio (the most common approach) that consists of dividing the spectrum of the measured earthquake motions at a site by that of a nearby reference site (rock site). If the two sites have similar source and path effects, and if the reference site has a negligible site response, then the resulting spectral ratio constitutes an estimate of the site response. This approach identifies, in most cases, the fundamental resonant frequency and is considered to be the most reliable (Rogers et al., 1984, Singh et al., 1988, Jarpe et al., Darragh and Shakal 1991, Borcherdt and Glassmoyer 1992, Gutierrez and Singh, S. K., 1992, Satoh, et al., 1995; Aguirre and Irikura, 1997; Su, et al., 1998; Beresnev, et al., 1998; Hartzell, 1998; Reinoso and Ordaz, 1999). Many investigators, among them Tucker and King (1984), McGatt et al. (1991), Field et al. 1992, Jongmans and Campillo (1993), Liu et al. (1992), Gagnepain-Beyneix et al. (1995Carver and Hartzell (1996), Hartzell et al. (1996), Zaslavsky et al. (2000) evaluated site response function from moderate to weak motions of earthquake. However, this technique requires a number of earthquake records. In regions with relatively low seismicity, it would be necessary to wait for a significant period of time to obtain a usable data set.

Several studies (e.g., Otha et. Al., Yamanaka et al., 1994) applied the Borcherdt’s approach, using ambient seismic noise instead of earthquake. For frequencies smaller than 0.5 Hz, seismic noise is categorized as microseisms and, for higher frequencies, as microtremors. The main advantage given by this approach is the fact that the spectral characteristics of microtremors have been recognized to be associated with the site conditions (Kanai and Tanaka, 1961; Katz, 1976; Katz and Bellon, 1978, Kagami et al., 1986; Gutierrez and Singh, 1992). It has been shown that with microtremors it is possible to identify the fundamental resonance frequency of nears surface soil deposits (see among others Otha et. Al., 1978; Lermo et al., 1988; Hough et al., 1991, 1992).

Nakamura (1989) proposed a method that requires only one recording station. Nakamura hypothesized that site response could be estimated from the horizontal-to-vertical ratio of microtremors. This technique was tested, experimentally and theoretically, at many sites all over the world, by different authors (Ochamachi et al., 1991; Lermo and Chavez-Garcia, 1993, 1994; Lachet and Bard, 1994; Field and Jacob, 1995; Zaslavsky et al., 1995, 1998, 2000; Malagnini et al., 1996; Seekins et al., 1996; Gitterman et al., 1996, Teves-Costa et al., 1996; Theodulidis et al., 1996; Konno and Ohamachi, 1998; Mucciarelli, 1998). Results obtained by implementing Nakamura's technique support such use of microtremors measurements for estimating the site response of surface deposits. Lermo and Chávez-García (1993) applied Nakamura's technique to seismic recordings of earthquakes and concluded that this approach is able to reliably estimate the frequency of the fundamental resonant mode and correctly predict the amplification level. This technique, known as the receiver function technique, is also applied to studies of the Earth's interior from teleseismic waves (Langston, 1979; Ammon, 1991). Receiver functions were introduced by Langston (1979) to determine the velocity structure of the crust and upper mantle from teleseisms

Field and Jacob (1995); Bonilla et al. (1997); Horike et al. (2001) and Satoh et al. (2001) also indicated that estimates of Horizontal –Vertical Spectral Ratio (HVSR) frequency of predominant peaks are similar to those obtained from traditional sediment –to- bedrock spectral ratio of earthquake records (Borchedt, 1970), however, the absolute level of site amplification does not correlate with the amplification obtained from this method. Based on measurements of explosives, earthquakes and ambient noise by reference and non-reference techniques, Malagnini et al. (1996) showed that the use of the HVSR failed to identify both the resonance frequency and its amplification. Nevertheless, Seekins et al. (1996) showed that HVSR obtained from mirotremors agreed better with sediment-bedrock spectral ration from S-wave than the microtremor ratio with respect to a reference site. Coutel and Mora (1998) used a theatrical approach, using synthetic data of modelled incident and SV waves to compare four site-response estimation techniques. The first two techniques were reference techniques, involving dividing the spectrum of the horizontal motion at a site by that of a reference site using incident shear waves and microtremors. The latter was unable to reveal either the resonant frequencies or peak amplitudes in any cases. The two other techniques were HVSR also using shear waves and microtremors.

Bour et al. (1998) compared HVSR responses with 1D equivalent –linear model (Schnabel et al., 1972) and showed that the fundamental frequencies obtained by the two techniques were in good agreement, but that the amplitudes obtained by the two techniques were sometimes different. Meneroud et al., (2000) reported that HVSR from microtremor measurements was very successful and gave the same results than more expensive and time consuming methods. Dimitriu (2002) even indicated that the HVSR technique successfully revealed nonlinear site responses induced by the 1994 Northridge earthquake. He also favoured it to the SSR which required a suitable reference site that is rarely available. Faeh et al. (2001) was successful in inverting HVSR site response to obtain Vs soil profile. Panou et al. (2005) compared soil response extracted from the HVSR technique at 250 sites with geological and geotechnical studies, as well as with macroseismic data of a magnitude 6.5 earthquake and found good correlation.

Pratt and Brocher (2006) indicated that response estimates for three earthquakes at 47 sites using SSR and HVSR showed that the latter site response exhibited less spectral decay than the SSR responses, but obtained many of the same resonance peaks. They hypothesized that the HVSR yielded flatter response across the frequency spectrum than SSR because the HVSR reference signal (vertical component of the shear wave arrivals) had undergone a degree of attenuation similar to the horizontal component recordings. Correcting the SSR site responses for attenuation with the basins by removing the spectral decay improved agreement between SSR and HVSR estimates. Sokolov et al. (2007) evaluated the characteristics of amplification of rock sites of NEHRP-class "B" using the HVSR of S-wave phase from recorded earthquakes. The applicability of the technique was also checked for a few stiff and soft soil sites (NEHPR- classes D and E). Based on extensive field measurements and numerical modelling, Bonnefoy-Claudet et al. (2006a) concluded that HVSR was mainly controlled by local surface sources and mainly due to the ellipticity of the fundamental Rayleigh waves. They concluded, therefore, that while the HVSR can provide information on the fundamental resonance frequency of a site, its peak amplitude was not able to give a good estimate of the site amplification factor.

The ability of site response obtained by the HVSR technique to match actual site response obtained from actual SSR is, therefore, still widely controversial. There is a general agreement, however, that for simple geology, this technique is reliable in detecting the resonance frequency of a soil site, but not as reliable in determining the amplification level. Bonnefoy-Caudet et al. (2006) presented an extensive review of publications concerning this technique, its origin, applications, and state – of-the- art development. Their review spanned the period from the 19th Century till 2006. Since the site response functions are, by definition, equivalent to the spectral ratio of surface motion with respect to that on a reference site located on bedrock, a most comprehensive assessment of site response would be to use a hybrid approach in which 1D numerical site response models are compared and complemented with the findings of one or more field observation techniques. In an endeavour to perform a comprehensive assessment of soil response in Makkah region, this strategy will be achieved in the present research. 1D numerical site response models were first obtained; they will then compare with site responses obtained using the HVSR, PSR techniques that will be conducted at the selected sites through Makkah region.

4. DESCRIPTION OF THE PROPOSED WORK

4.1 Approach, tasks and phases:

1- Evaluate the subsoil properties using available data or conducting field geotechnical experiments. The site characterizing for the study area has to be carried out at local scale of 1:20:000 or less using geotechnical and shallow subsurface geophysical data. Site characterization should include an evaluation of subsurface features, subsurface material types, subsurface material properties and buried/hollow structures to determine whether the site safe against earthquake effects. Site characterization should provide data on the following:

  - Geotechnical data
  - Soil conditions
  - Geological data
  - SPT data
  - MASW data
  - Hydrogeology/ground water data
  - Aquifer or permeable characteristics

2- Local site effects and ground response analysis. The site response studies for microzonation are carried out using one-dimensional ground response analysis and experimental method of microtremor. Site response analysis aims at determining the response of a soil deposit to the motion of the bedrock immediately beneath it. The overburden plays a very important role in determining the characteristics of the ground surface motion thus emphasizing the need for ground response analysis. A number of techniques have been developed for ground response analysis. These techniques can be grouped as one-, two, and three dimensional analyses according to the dimensionality of the problems they can address. Site response studies mainly deal with the determination of peak frequency of soft soil, amplification and the nature of response curve defining the transfer function at the site which forms an important input for evaluating and characterizing the ground motion for seismic hazard quantification. Peak frequency or predominant frequency can be determined using microtremors.

3- Evaluation of the expected input motion using deterministic and/or probabilistic seismic hazard assessment.
   a. Deterministic seismic hazard analysis (DSHA) through; 1) Source characterization which includes identification and characterization of all earthquake sources that may cause significant ground motion in the study area, 2) Selection of the shortest distance between the source and the site of interest, 3)Selection of controlling earthquake i.e. the earthquake that is expected to produce the strongest level of shaking. Controlling earthquake has been evaluated based on the past earthquake data and assumed subsurface fault rupture length, and 4) Defining the hazard at the site formally in terms of ground motions produced at the site by the controlling earthquake.
   b. Probabilistic seismic hazard analysis (PSHA)

4- Preparing of microzonation maps using GIS technique.

APPROACH UTILIZED FOR ACHIEVING OBJECTIVES

Objective	Approach of achieving the objective
Soil classification	MASW and boring approaches
Site response estimation	Microtremors measurements (HVSR) and PSR approaches
Determination of Peak Ground Acceleration (PGA) and response spectra	Deterministic and Probabilistic seismic hazard approaches
Seismic Microzonation	GIS technology approach

MAPPING OF PHASES AND TASKS TO ACHIEVE OBJECTIVES

Objectives	Phases	Tasks
The Soil classification (Vs30) maps according to NEHRP-IBC building codes.	Evaluate the soil-profile types using the available data or conducting field geotechnical experiments.	▪ Collection of the available boring data and Vs30 estimation. ▪ MASW-based shear wave velocity modeling.
soil response estimation.	Local site effects and ground response analysis.	• 1D site response modeling technique. • Soil response maps of the fundamental resonance frequency and corresponding maximum relative amplification. • The HVSR –based site response. • The PSR – based site response.
Peak Ground Acceleration (PGA) and response spectra**.**	Determination of the expected input motion (PGA) using deterministic and/or probabilistic seismic hazard assessment**.**	• Source characterization which includes identification and characterization of all earthquake sources that may cause significant ground motion in the study area, • Selection of the shortest distance between the source and the site of interest, • Selection of controlling earthquake i.e. the earthquake that is expected to produce the strongest level of shaking. • Defining the hazard at the site formally in terms of ground motions produced at the site by the controlling earthquake.
Microzoning of Makkah region	Implementation of Geographic Information System (GIS) technology and Microzoning of Makkah region	1- Installation of GIS technology and its relevant software packages. 2- Preparing of the Vs30 – based soil classification map; 3- Preparing depth-to-basement maps; 4- Soil fundamental resonance frequency map; 5- Site amplification factor map; 6- Ultimate Bearing capacity map 7- Peak Ground Acceleration (PGA) map.

4.2 Research methodology:

There are several methods proposed to investigate the behaviour of soft sedimentary structure to the excitation of seismic waves. The most common procedure, introduced by Borcherdt (1970), and applied by numerous researchers, is to compare the spectra of seismograms of earthquakes with the ones obtained at a nearby reference station located on competent bedrock. The factors of epicentral distance and source radiation, therefore, are practically the same for both neighboring sites and the differences in the response can be ascribed to the local geological or topographical characteristics of the site. This technique needs the occurrence of earthquakes and to assume that the radiation pattern and epicentral distances for both the sites are similar. Besides it is needed to deploy instruments at all the sites of interest.

Nakamura (1989) developed a simple technique based on the ratio of the spectra of the horizontal to the vertical components of ground motion generated by microtremors or ambient noise. Lermo and Chavez-Garcia (1994) indicate that the method assumes that the surface layers do not amplify the ‘vertical tremor’. Besides it is assumed that, for a wide range of frequencies, the ratio of the horizontal to the vertical spectrum at the base of the system has a value near unity. According to them, this later assumption was experimentally verified by Nakamura using microtremors recorded in a borehole. Thus, Nakamura concluded that the spectral ratio between the horizontal and vertical component of motion in the same site can be used as an estimate of site effects for internal waves. Despite the apparent appeal of Nakamura’s method (source, radiation patterns, directivity and path effects are discarded), the validity of its results and assumptions has not yet been established, especially with complex and deep soft layered structures. Field and Jacob (1993) worked a 3D model in a simpler layer on a half space with microtremors under a random distribution in space and time of forces applied in selected points on top of the layer. By using Green functions, the horizontal and vertical amplitudes were evaluated and compared with the response spectrum at the surface for the incident SH waves to vertical plane.

The peak frequency in both the cases was coincident with the resonance natural frequency of the layer for shear waves vertically incident. Lachet and Bard (1995) concluded that Nakamura’s technique may be used to determine the natural resonance frequency of a soft layer, but it fails to predict the amplification of surface waves. Moreover, they showed that the natural frequency of the layer obtained with Nakamura’s technique and ambient noise simulations is independent of the excitation source, dependent of Poisson’s ratio and controlled by the polarization curve of the Rayleigh waves. However, the method based on the assumption, not always fulfilled, that the propagation of the vertical component of motion is not perturbed by the uppermost surface layers, and can therefore be used to remove source and path effects from the horizontal components. This method produced some unsatisfactory results, as verified in recent severe earthquakes.

As a matter of fact, instead of waiting for data accumulation, either based on the computation of the spectral ratio between the signal recorded at soft soil and nearby bedrock site, or generation of microtremors of ambient noise to be used for H/V ratio technique, it is more wiser to apply the preventive tool given by realistic modeling, based on computer codes developed from the knowledge of the seismic source and of the propagation of seismic waves associated with the given earthquake scenario. With such approach, source, path and site effect are all taken into account and a detailed study of wave field that propagates at large distances from the epicenter is possible. Actually, the realistic modeling of ground motion requires simultaneous knowledge of the geotechnical, lithological, geophysical parameters and topography of the medium, on one side, and tectonic, historical, palaeoseismological, seismotectonic models, on the other, for the best possible definition of the probable seismic source. The initial stage of the realistic modeling is thus devoted to the collection of all available data concerning the shallow geology, and the construction of a three-dimensional structural model to be used in the numerical simulation of ground motion.

A powerful hybrid technique has been developed by Fäh et al., 1993a and 1993b which combines the modal summation (Panza, 1985; Panza and Suhadolc, 1987; Florsch et al., 1991; Panza el al., 2001) and Finite-difference scheme (Virieux, 1984; 1986), exploiting both the methods to their best. However, the most fundamental data like geotechnical information, S-wave velocity structure at a site where a prediction of ground motion is required, are generally insufficient, therefore, the reliability of the modeling of strong ground motion due to 2D/3D structure is highly dependent on the structure of shallow geology over the bed rock. There are several exploration technique used to obtain the S-velocity structure but the conventional seismic methods are difficult or impossible to implement in urban areas or environmental sensitive areas. To overcome this difficulty, recently very popular technique of “Microtremor Array Observation” is being applied which makes use of microtremors (ambient noise) found in abundance anywhere in the surface of the earth.

Nakamura H/V ratio technique for resonance frequency

The other most popular technique of Nakamura (1989) is very widely used to obtain quick Microzonation map of any large urban area with the use of microtremor measurements for the estimation of resonance frequency and site-effects. However, the site amplification obtained by this technique is questionable, as reported in many papers. Kanai et al. (1954) was the first paper to use microtremor recordings with the objective of studying site effects. They thought that the source of microtremors was white noise and that they were mostly body waves. This technique has been described in several papers and is based on the assumptions for the fundamental characteristics of microtremors. However, considering the great contribution of Rayleigh wave propagation for the ambient noise, it will be necessary to convert the ratio HS/HB, in order to estimate a transfer function for microtremor measurements. Figure 4 shows the simple model used by Nakamura. The Nakamura technique is based on the assumption that:

(1) Microtremors are composed mainly of Rayleigh waves, propagating in soft surface layers overlaying an half-space;

(2) The vertical motions are not affected by the soft soils.

(3) The microtremors are originated by local surface sources (traffic and industrial noise) and they have no contribution from deep sources;

(4) he amplification of the vertical component is exclusively associated with the depth dependence of the surface (Rayleigh) waves motion.

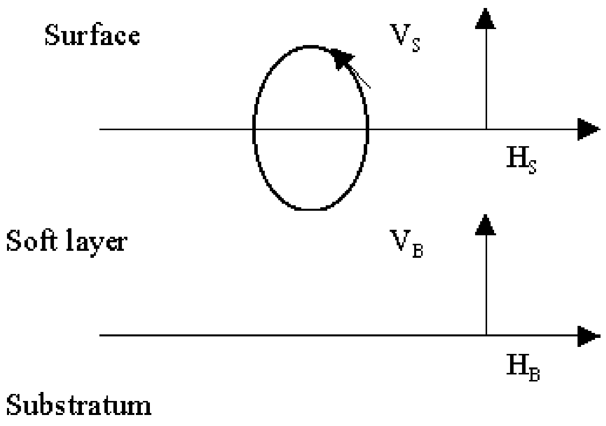


Figure 4. Simple model assumed by Nakamura (1989) to interpret microtremor measurements.

According to Nakamura, the transfer function (i.e., the site response function) for Rayleigh waves, and compensated for the source spectrum is:

$$S_M = \frac{Zs}{Zb}$$

Where Zs= Hs/Vs and Zb=Hb/Vb. Under the prescribed assumptions, the vertical component is not amplified by the surface layer, i.e.,

$$\frac{Vs}{Vb} \sim 1$$

we obtain

$$S_M = \frac{Hs}{Vs}$$

i.e. the vertical component of microtremors on the surface retain the characteristics of horizontal component of the hard rock.

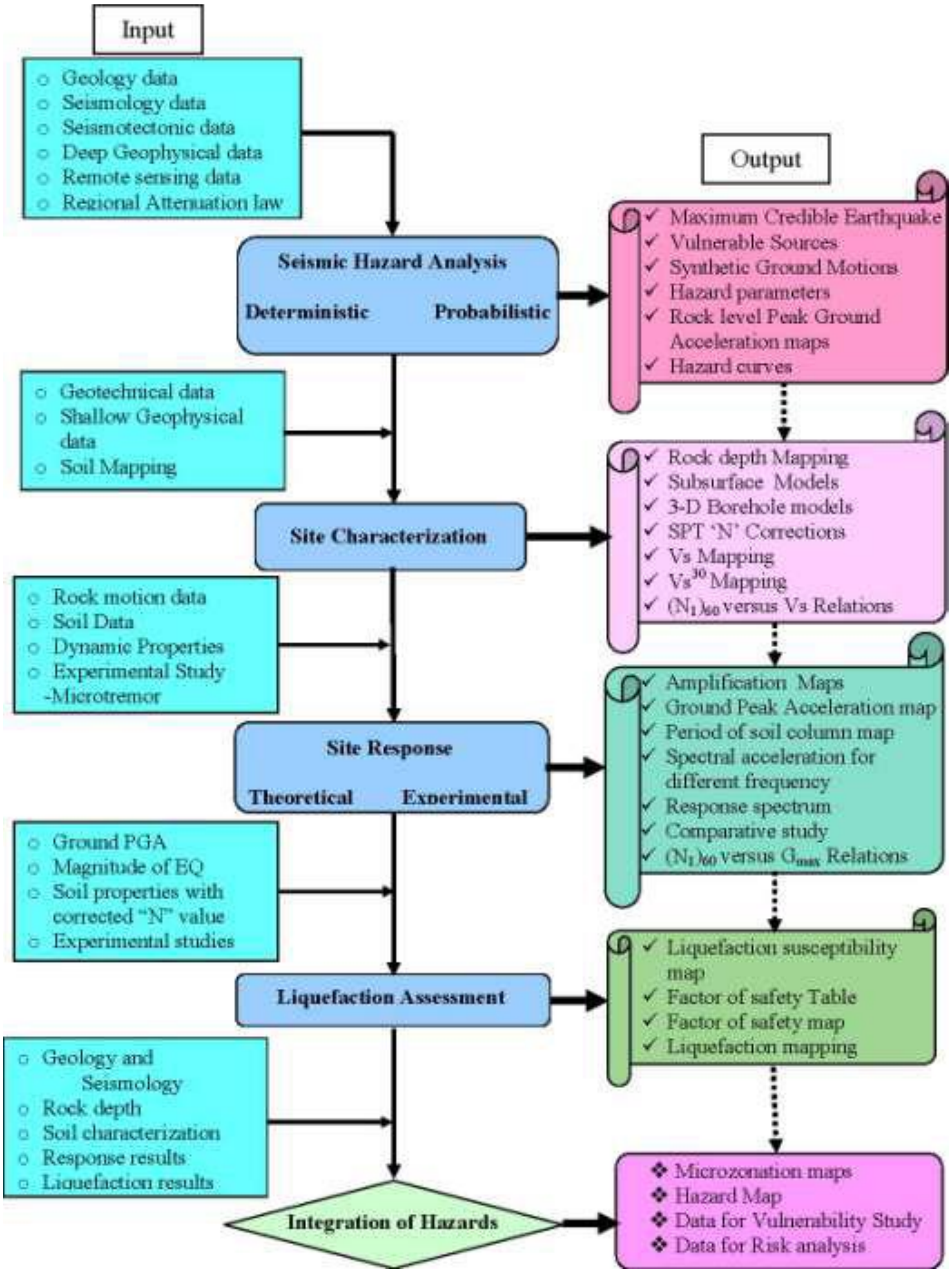
It has been demonstrated (Bard, 1998) that microtremors are about 70% surface waves. At long periods (below 0.3 to 0.5 Hz) they are caused by oceanic waves at large distances and it is possible to find good correlation of microtremors in those periods with large scale meteorological conditions in the sea. For intermediate periods (between 0.3-0.5 Hz and 1 Hz or less) the microtremors are generated by waves from near coasts and from the sea, so their stability is significantly smaller than those of long periods. For short periods (frequencies larger than 1 Hz) the sources of microtremors are due to human activities. Also the noise spectrum will have several peaks related to different frequencies, in other words it is not flat. Traditionally, the noise of natural origin (frequencies smaller than 1 Hz), which is called microseisms, is different from the noise caused by human activity (frequencies bigger than 1 Hz) called microtremors.

As a final condition it is assumed that for all frequencies of interest Thus, an estimate of the transfer function is given by the spectral ratio between the horizontal and the vertical components of the motion at the surface Some of the above conditions were already tested, experimentally and theoretically by different authors (Jensen, 2000; Bour et al., 1998; Teves-Costa et al., 1995; Lerno and Chavez-Gacia, 1994; Nakamura, 1989 etc.).

Numerical Simulation of Strong Ground Motion:

Fäh et al., (1993a, 1993b) developed a hybrid method that combines the modal summation technique, valid for laterally homogeneous anelastic media, with finite difference that include the lateral heterogeneity of the 2-D subsurface geological structure and optimizes the use of the advantage of both methods. The modal summation technique is applied to simulate propagation from the source position to the sedimentary basin or the local irregular feature of interest and the finite difference method is used in the laterally heterogeneous part of the structural model, which contains the sedimentary basin. This hybrid approach allows us to calculate the local wave field from a seismic event, both for small (a few kilometers) and large (a few hundreds of kilometers) epicentral distances. The use of the mode summation method helps to include an extended source, which can be modelled by a sum of point sources appropriately distributed in time and space. This allows the simulation of a realistic rupture process of the fault. The path from the source position to the sedimentary basin or the local heterogeneity can be approximated by a structure composed of flat 1-D homogeneous layers.

The finite difference method applied to treat wave propagation in the sedimentary basin, permits to modelling of wave propagation in complicated and rapidly varying 2-D velocity structures. The coupling of the two methods is carried out by introducing the resulting time series obtained with the mode summation method into the finite-difference computations. The ground motion time series computed for the 1-D modal contain all possible body waves and surface waves consistent with the pre-assigned phase velocity and frequency interval. To excite the finite-difference grid, ground motion time series are computed at adjacent points lying on one side of the 2-D part of the model and sampling different depths along two vertical lines that belong to the regular grid used for discretization of the medium (Fäh et al., 1990). In this way the seismic wavefield generated and propagated in the 1-D medium is used to excite the 2-D part of the structural model.


Input
Geology data
Seismology data
Seismotectonic data
Deep Geophysical data
Remote sensing data
Regional Attenuation law
Seismic Hazard Analysis
Deterministic
Probabilistic
Output
Maximum Credible Earthquake
Vulnerable Sources
Synthetic Ground Motions
Hazard parameters
Rock level Peak Ground Acceleration maps
Hazard curves
Geotechnical data
Shallow Geophysical data
Soil Mapping
Site Characterization
Rock depth Mapping
Subsurface Models
3-D Borehole models
SPT 'N' Corrections
Vs Mapping
Vs^{30} Mapping
$(N_1)_{60}$ versus Vs Relations
Rock motion data
Soil Data
Dynamic Properties
Experimental Study -Microtremor
Site Response
Theoretical
Experimental
Amplification Maps
Ground Peak Acceleration map
Period of soil column map
Spectral acceleration for different frequency
Response spectrum
Comparative study
$(N_1)_{60}$ versus G_{max} Relations
Ground PGA
Magnitude of EQ
Soil properties with corrected "N" value
Experimental studies
Liquefaction Assessment
Liquefaction susceptibility map
Factor of safety Table
Factor of safety map
Liquefaction mapping
Geology and Seismology
Rock depth
Soil characterization
Response results
Liquefaction results
Integration of Hazards
Microzonation maps
Hazard Map
Data for Vulnerability Study
Data for Risk analysis

5. VALUE TO THE KINGDOM

The expected results and outputs of 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 both the ministries and national bodies as follows;

- National Commission for the Saudi Building Code.
- Ministry of Interior and Civil Defence.
- Municipalities of Makaah, Jeddah and Al-Taif cities.
- Ministry of Municipal and Rural Affairs.
- Urban planners and developers.
- Engineering consulting offices, and
- other relevant authorities

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