Arab Gulf Journal of Scientific Research, 22 (3), pp 117-129 (2004)

Original Paper Ref. No 2295

The Need for Seismic Risk and Vulnerability Assessment in Kuwait and Other Arabian Gulf Countries

ضرورة دراسات الخطورة الزلزالية في الكويت ودول الخليج العربية

فريال بوربيع

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Abstract: Strong seismic events along the seismically active Zagros Fold Belt can have damaging effects in Kuwait and other Arabian Gulf countries. A comprehensive seismic risk and vulnerability assessment of infrastructure systems, in particular tall structures and coastal facilities is needed. Evidence is presented which indicates a potential threat from large-magnitude earthquakes originating from the southern part of Zagros, at moderate epicentral distances from Arabian Gulf cities. Observations of seismic paleo-liquefaction features in the Gal-Az-Zor escarpment (Kuwait) are presented and discussed. The historical record of Iranian earthquakes that have caused significant ground motion in the Gulf region is examined, as well as reports of coastal damage from tsunamis. There are specific tasks that give validity to having a Regional Center for Risk Research in the Arabian Gulf countries.

Keywords: Arabian Gulf, Kuwait, Earthquakes, Paleo-liquifaction, Seismic vulnerability, Zagros, Tsunami.

المستخلص: تتأثر دولة الكويت ودول الخليج العربي ببعض الزلازل القوية التي تقع ضمن حزام طيات زاجروس النشط ويؤكد هذا على ضرورة تصميم برنامج شامل لتقييم الخطورة الزلزالية وقابلية المباني للتأثر بالتدمير الزلزالي خصوصاً المباني المرتفعة والمنشآت الساحلية. تم عرض الأدلة على أن هناك مخاطر زلزالية على مدن منطقة الخليج العربي تتمثل في الزلازل القوية التي تحدث في الجزء الجنوبي الغربي من حزام اجرو. تم عرض ومناقشة شواهد جيولوجية عن عمليات تسيل التربة الناتجة عن الزلازل التاريخية في منطقة جال الزور في دولة الكويت. تمت دراسة الزلازل التاريخية والحديثة في جنوب غرب إيران والتي يمكن أن يكون لها تأثيرات متفاوتة على دول الخليج العربية. وتمت دراسة وعرض مخاطر الموجات البحرية الزلزالية (تسونامي) التي تعرضت لها المناطق الساحلية من دول الخليج العربي. في ضوء هذه البيانات والنتائج يؤكد البحث على ضرورة إنشاء مركز إقليمي خليجي عربي لمواجهة الكوارث الطبيعية.

كلمات مدخلية : الخليج العربي، الكويت، الزلازل، تسيل التربة، تسونامي، زاجروس

Introduction

Tectonically, Kuwait is located to the SW of the Zagros Fold Belt, the active collisional plate boundary (Fig. 1) between the Arabian and the Iranian Plates (Fox, 1959; Bou-Rabee, 1986). Strong seismic events along this seismically active belt can have damaging effects in Kuwait (Ni & Barazangi, 1986), especially since the local building codes have no seismic design requirements. According to one published estimate of seismic risk (Nowroozi *et al.*, 1985), an event with a magnitude 7.5 or greater originating in the southwestern part of Zagros Belt, would produce a ground acceleration in Kuwait exceeding 0.1g with a 64% probability in 50 years. However, this estimate is not indicative of the seismic vulnerability of infrastructure systems, especially of tall structures, in Kuwait City and other Arabian Gulf cities such as Abu Dhabi. Among the factors to be accounted for in seismic vulnerability assessment are the local amplification in the soft soils that underlie many areas (in Kuwait and Abu Dhabi in particular) and the relatively slow attenuation with distance of amplitudes of waves with moderate and long periods compared to those with short periods. The main concern is the period range between 1 and 3 seconds, the range of the fundamental periods of many tall buildings. We also summarize historical evidence concerning damage caused by tsunamis in the region. Furthermore the coastal areas have high liquefaction susceptibility and could experience severe damage as a result of an earthquake. The aim of the paper is to point to the need for a comprehensive seismic risk and vulnerability assessment of tall buildings, critical infrastructure systems, and coastal facilities in Kuwait and other Arabian Gulf ountries, in support of important related economic and public safety decisions.

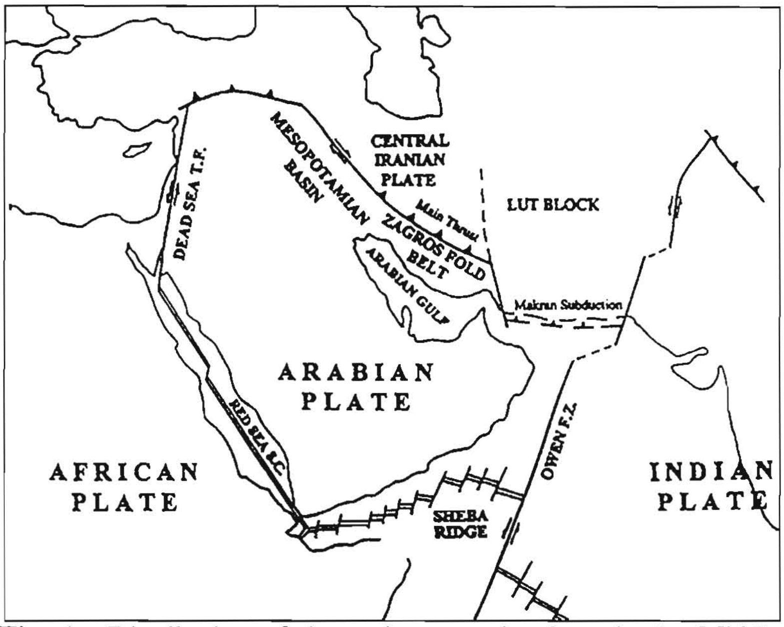

Fig. 1. Distribution of the major tectonic plates in the Middle Eastern region.

Geologically, Kuwait lies at the edge of the Arabian foreland where the northeast dipping monocline passes into the geosyncline of the Arabian Gulf and Iraq Valley (Cox, 1932). The interaction of the Arabian and Zagros folds is apparent in the submarine topography of the Arabian Gulf (Kassler, 1973), as well as in the subsurface structures of Kuwait (Al-Sarawi, 1980 and 1982; Fox, 1959; Davis, 1965 and Milton, 1967). The topography of Kuwait is controlled by the intense folding of the Zagros Orogeny in a NW to SE trend (Bou-Rabee, 1999). The Quaternary sediments show evidence for the continuation of the uplifting movements which formed the large anticlines of the Great Burgan Oil Field and other oil fields in Kuwait during the Cretaceous period (Al-Sarawi *et al.*, 1993). The relatively shallow depth (<3m deep) of the water table over most of Kuwait areas and the presence of widespread thick clean sand deposits at shallow depths has provided an excellent opportunity for paleoliquefaction features to form in response to earthquake shaking throughout Neogene and Quaternary in Kuwait and other Arabian Gulf countries. Al-Sarawi *et al.*, (1993) studied the local fluctuations at sea level at the southern coastal areas of Kuwait during the Holocene and late Pleistocene eras, and related these fluctuations to Neotectonic movements which must have affected many parts of the Arabian Gulf, as it lies along a collision zone between two continental plates.

Bou-Rabee, (1999) describes the Kuwait National Seismic Network (KNSN) (established at the Kuwait Institute for Scientific Research (KISR)), extensive studies in support of the Network's design and the siting of the field stations. In operation since March 1997, the Network has recorded many regional earthquakes originating along the Zagros fold belt as well as some local events. The seismicity map of Kuwait (see Fig. 2) reveals two main clusters of events: the first cluster is around the Minagish - Umm Gudair oil field zone and the second is around the Raudhatain-Sabriya oil field zone. The spatial correlation between earthquake locations and oil fields suggests that these seismic activities might be induced by oil production (Bou-Rabee 1994 a,b; Bou-Rabee and Nur, 2002). These moderate earthquake activities in Kuwait's seismic zones, suggest a potential source of large earthquakes. The northern part of the Arabian Gulf shows some moderate earthquake activity and the event nearest to Kuwait was located east of Bubyan Island.

Geology and Tectonics of Kuwait

The Zagros mountains are a folded belt that extends for a distance of about 1500km in a NW-SE direction along the western part of Iran and northeast Iraq, from Oman in the southeast to the Turkish border in the northwest. The folded belt probably started to form during the Upper Miocene - Lower Pliocene era and is still active, being considered one of the currently most active orogenic belts on earth (Barazangi, 1983). The simple folded belt, which is a zone about 250km in width, consists of some fourteen asymmetric folds. Their intensity of deformation and amplitudes increase toward the interior of Iran. New folds are being formed along the southwestern margin of Zagros in the Arabian Gulf and in the Mesopotamian foredeep in Iraq. The initiation of the major episode of deformation in the Zagros closely corresponds to the most recent phase of the separation of the Arabian from the African plate along the Red Sea rift zone. The main Zagros thrust has undergone a major episode of thrusting and uplift since the Miocene time (Barazangi, 1983). The only region where an oceanic lithosphere continues to be subducted beneath Iran is located in the Makran region of southern Iran, where the apparently oceanic lithosphere of the Gulf of Oman is being subducted beneath the coastal ranges of Makran. An active volcanic belt is associated with this subduction zone. The earthquakes in the Zagros province define a zone about 200km wide that runs parallel to the folded belt. The majority of earthquakes occur in the crustal part of the Arabian plate that underlies the Zagros folded belt (Barazangi, 1983).

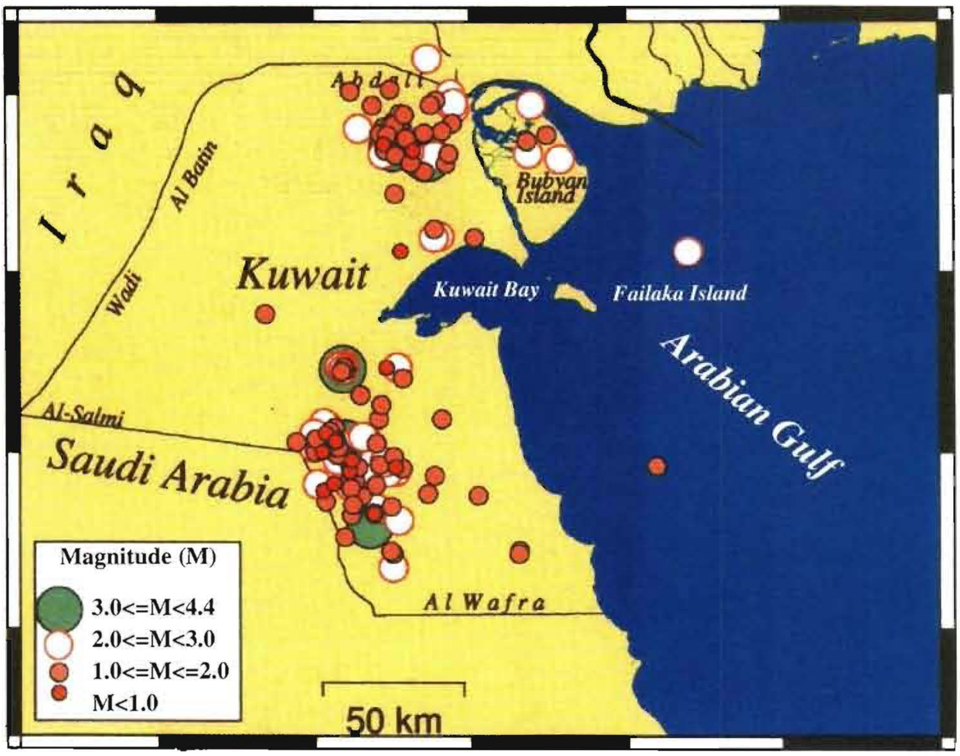

Fig. 2. Seismicity Map of Kuwait (1997 - 2003).

Seismic Paleo-Liquefaction Features in Kuwait

Earthquake-induced paleoliquifaction features in Holocene sediments in the eastern sector of Jal-Az-Zor escarpment (Fig. 3) are evidence of strong shaking in the recent prehistoric past in an area where only infrequent, low magnitude earthquakes have occurred recently.

Earthquake-induced paleoliquefaction studies began for the first time in Kuwait during 2003. The research has been mainly conducted at the Jal-Az-Zor escarpment area, which lies a few kilometers inland from the northwest and north shore of Kuwait Bay (Fig. 3). It has a remarkably straight trend, and is formed of two sectors; The western sector extends for 50km with a N40°E trend, and the eastern sector extends for 30km in a N35°W direction.

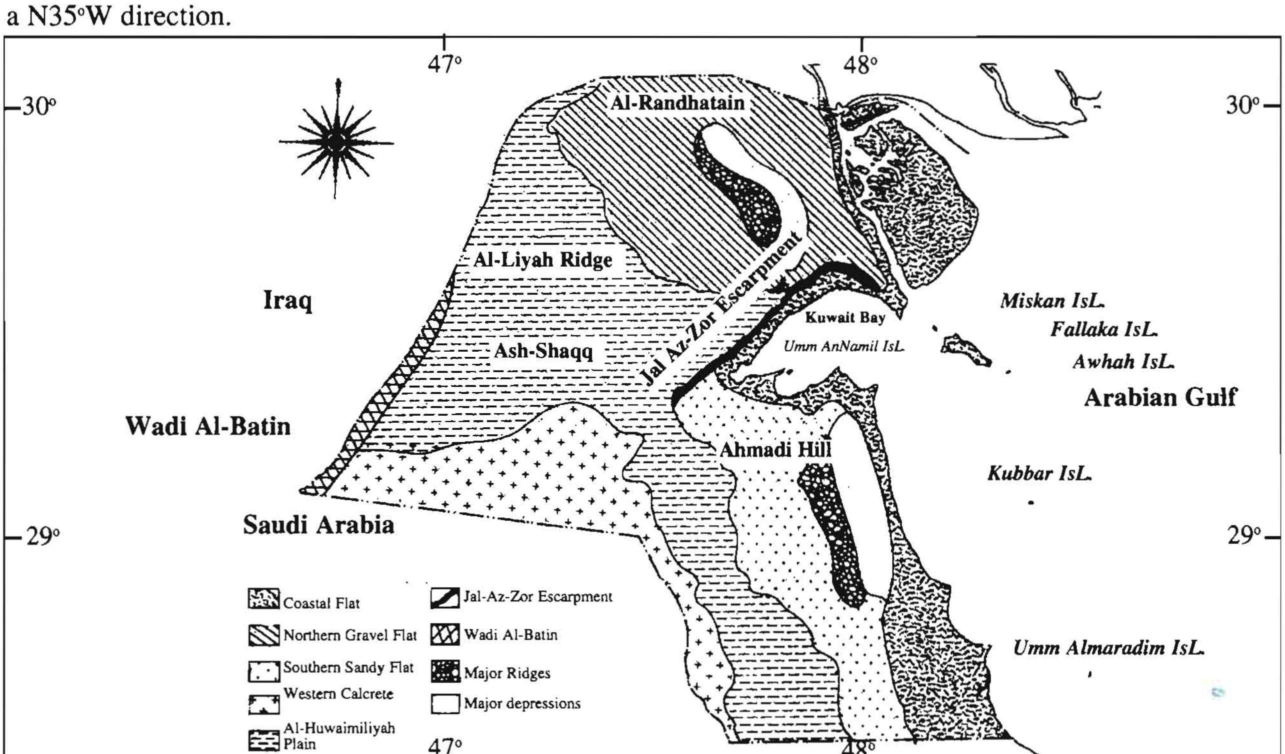

Fig. 3. The distribution of major geomorphic features of Kuwait including Jal-Az-Zor escarpment.

Virtually all features that we interpreted as having a seismically induced liquefaction origin are located and distributed in the eastern sector of the Jal-Az-Zor escarpment. The features are sand and gravel filled dikes that are nearly vertical and connect to a sediment source at depth (Fig. 4).

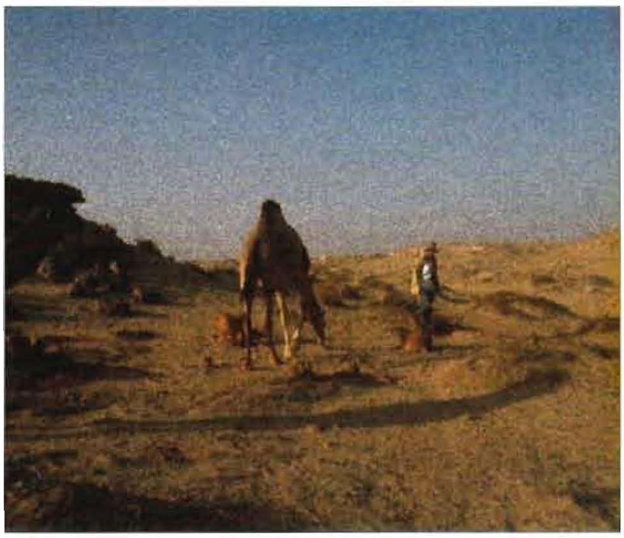

Fig. 4. Cemented sand liquefaction column or pipe. A system of these cylindrical dikes and sand blow was observed in the eastern sector of Jal-Az-Zor escarpment.

Sediment has vented from the dikes at many places to form sand blows, but many of them were eroded. Dikes are linear in plan view and exhibit strong parallel alignment, of a NNE-SSW direction, in local areas. The size and abundance of the dikes along the eastern sector of Gal-Az-Zor escarpment, generally decrease with increasing distance from a central region of large dikes. An interesting observation is that dike widths exceed 20cm at five sites and exceed 30cm at four sites, the maximum observed width being 1.5m. The grain size of an individual dike or blow filling can vary in size: silty fine sand, sand, sand with a small amount of gravel and calcareous sand. Dibdibba formation is the source strata that provides sediments which flow into the dikes. This formation can be divided into two members:

The Lower Member of Mio-Pliocene age, and

The Upper Member of Plio-Pleistocene age (Al-Sulaimi *et al.*, 2000).

The dikes cut through the low-permeability cap that overlies the thick source strata, they are of Pleisto-Holocene age and composed of boulders of calcareous grits with finer detritus covered by residual gravel deposits (a mixture of gravel, sand, silt and clay).

This area, as in most of the Kuwait zone, has a high liquefaction susceptibility because of shallow ground water and sandy, poorly consolidated deposits. Certain residential parts of the Arabian Gulf countries, some industrial structures, and ports are situated predominantly within high liquefaction susceptibility zones.

An earthquake-induced paleoliquefaction origin for the dikes and sand blows of Jal-Az-Zor eastern sector is interpreted because of the following aspects, when considered together:

1. This area, as in most of the Kuwait zone, has a high liquefaction susceptibility because of shallow groundwater and sandy, poorly consolidated deposits.
2. The discovered dikes widen downward or have walls that are parallel and cut across the layered sedimentary rocks. Some are concentric layered and others look like craters filled with sand finer in size than the surrounding rock.
3. Dikes are linear in plan view and exhibit strong parallel alignment, the trend of these features are NNE-SSE direction in local areas.
4. The dikes have vented large quantities of sandy sediment to the surface as sand blows.
5. The size and abundance of the dikes along the eastern sector of Jal-Az-Zor escarpment generally decrease with increasing distance from a central region of large dikes.

All of these features indicate that the ground water setting of this area was suddenly affected by strong hydraulic forces of short duration which could not be reasonably expected, except from earthquake-induced paleoliquefaction.

The presence of seismically induced features such as sand dikes, cylinders, sand blows or sand volcanos, indicates that the strength of shaking was high enough to have caused damage to man-made facilities. The threshold magnitude for inducing liquefaction is about M5.5. Consideration of dike sizes and distribution throughout the eastern sector of Jal-Az-Zor escarpment, in conjunction with the local geologic and hydrologic setting, indicates the earthquake source zone is most probably located in that sector. These also might suggest that it was a single earthquake source. On the basis of over 100 data points, Ambraseys (1988) found that the moment magnitude M for any earthquake was related to the maximum epicentral distance Rc, measured from the adopted epicenter to the most distant site, there was clear evidence of liquefaction-induced ground failure. He found the relation

$$M = -0.31 + 2.65 \times 10-8\ Rc + 0.99\ (\log Rc)$$

Where Rc in centimeters represented the upper limit for Rc as a function of M. The liquefaction feature farthest from the energy center (site of the largest dike) was found in the eastern sector of Gal-Az-Zor escarpment, about 10km to the north-northeast. Using this distance with Ambraseys's relation yields M ~ 5.6.

Archaeological studies in Jal-Az-Zor showed that a stretch of the coastline of Kuwait, now deserted, supported a cosmopolitan and industrious community seven thousand years ago, in a site known as H3 As-Sabiya (Carter, *et al.* 2001). The site of H3 is a low mound on the northern, inland edge of a peninsula, which stretches into mudflats on the northern side of Kuwait Bay. The peninsula is known as Jazirat Dubaij (Fig. 5).

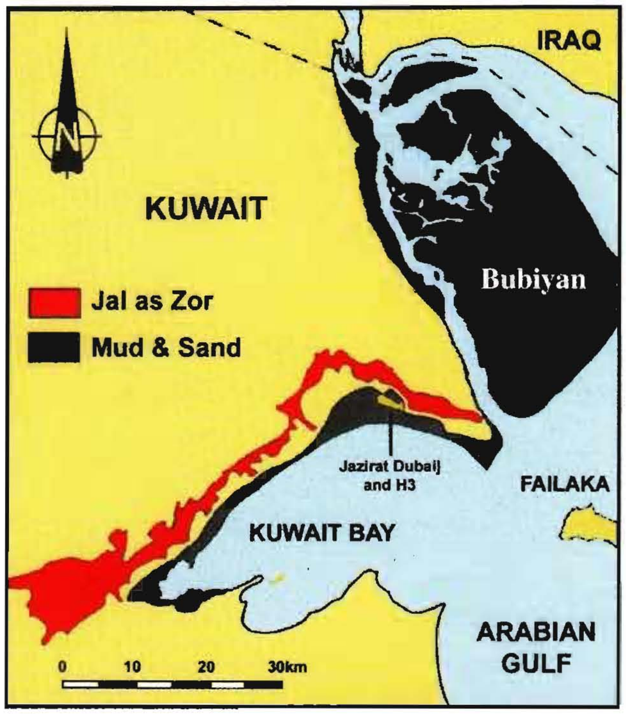

Fig. 5: The location of Jazirat Dubaij and H3 site.

The seismicity map of Kuwait (see Fig. 2) shows some small size earthquake activity located at Jal-Az-Zor escarpment. The presence of seismic paleo-liquefaction features in the same zone indicate a long history of high level seismic activity. It is believed that the H3 As-Sabiya site, its culture and community were damaged or completely destroyed due to the earthquake activity in that area about seven thousand years ago.

Effects in the Arabian Gulf Countries from Earthquakes in Zagros Active Zone

Table 1 lists the parameters of recent southwestern Iran earthquakes documented to have been felt in Kuwait. The earthquake of Dec. 14, 1996 in the northern part of the Arabian Gulf was felt by many all over the coastal areas of Kuwait, awakening some people as it occurred close to midnight. Its intensity ranged between III and IV on the MSK scale (Medvedev, *et al.* 1965) along the Kuwaiti coast. The southern Iran event of March 4, 1999 was felt in Kuwait, 900km from the epicenter, and in the United Arab Emirates. Many people in high-rise buildings in Kuwait and Abu-Dhabi (UAE) also felt this event, whose MSK intensity was estimated in the range from III to IV. There were reports of hanging objects swinging and of rattling windows, doors, and dishes, especially on the upper floors of buildings. On March 11, 2002, at midnight, the Fujairah Masafi region in the UAE was shaken by an earthquake of shallow depth and local magnitude M = 5.1 on the Richter Scale. The earthquake occurred in Dibba fault in the UAE with the epicenter of the earthquake 20km NW of Fujairha city. The focal depth was just 10km. The earthquake was felt in most parts of the northern emirates: Dubai, Sharjah, Ajman, Ras Al-Khaima, and Um-Qwain. The "main shock" was followed in the following weeks by more than twenty-five earthquakes with a local magnitude ranging from M = 4 to M = 4.8. The location of these earthquakes was along the Zagros Reverse Faulting System on the Iranian side of the Arabian Gulf, opposite to the shores of the UAE. Most of these earthquakes were shallow and were actually felt by people (Al-Homoud, 2003).

Historically, owing to the sparse population before 1950 and a general lack of public awareness about earthquakes, few seismic events are documented to have been felt in Kuwait and other Arabian Gulf countries. Al-Hatem (1980) mentioned an earthquake in 1879 felt in Kuwait during the birthday of Sheikh Yousif El-Kenaie, a well known religious scientist who became a member of the Shura Council in Kuwait, 1938. This event could be the one ascribed to Behbahan (southwest Iran) where it was reported strongly felt (Sirjani 1983), or it could have been one of the local earthquakes of Kuwait.

Various earthquake catalogs (Al-Suyuti, 1983; Ambraseys & Melville, 1982; Berberian, 1994 & Seismicity Catalogs of US NOAA and NEIC) were examined in searching for events in the Zagros folded belt that might have caused significant ground motion in Arabian Gulf countries. Ambraseys & Melville (1982) studied the history of Persian earthquakes in the area delineated by the 24th and 40th degrees of north latitude and the 44th and 66th degrees of east longitude. Utilizing all the macroseismic data available to them, they list the largest earthquakes, those most informative to earth scientists and earthquake engineers, up to 1979.

Berberian (1994) summarized and interpreted the information about the pre-historic and historical (pre-1900) seismicity and seismotectonics of Iran, seeking to associate seismic sources with historical events, which provide insight into the physical and chronological relationships between faults and earthquakes and helps predict the future behavior of the active faults and folds.

The epicenters of the events (Table 1) have been added to the map (Fig. 6) presented by Ambraseys & Melville (1982), showing the association of earthquake activity during the last thirteen centuries with active tectonics.

Figure 6 shows the major faults of the Quaternary age (solid lines), faults of late Tertiary age (dashed lines), and dotted areas showing zones affected by destructive earthquakes with intensity from 1 to 3 on the Ambraseys & Melville (1982) intensity scale [which ranges from 1 = catastrophic to 5 = non-damaging]. From the fact that the 5.1 magnitude Bushehr earthquake of Sept. 24, 1999 was widely felt in Kuwait, we infer that most interplate earthquakes from the southern part of the Zagros belt with magnitude five and higher could produce significant ground motion in Kuwait and the other Arabian Gulf countries.

Major intraplate events in the Eastern Iranian zone are also felt in Kuwait and other Arabian Gulf countries, as was the event of March 4, 1999 with M = 6.2 (Table 1) and epicentral distance 900 km from Kuwait, where it was felt with intensity III - IV.

Table 1. The Iranian plate earthquakes which affected Kuwait recently

Date	Origin time G.M.T.	Location Lat.°N	Long.°E	Ms	I At Kuwait MSK	Dist. from Kuwait City in km.	Region
1996 Dec. 14	19hr 49min 55sec	28°55′	49°57′	4.5	III-IV	150	Arabian Gulf
1999 March 04	05hr 38min 26sec	28°31′	57°17′	6.2	III-IV	900	Southwestern Iran
1999 Sept. 24	19hr 17min 13sec	28°89′	51°13′	5.1	III-IV	330	Bushehr
2003 Dec. 11	16hr 28min 17sec	32°03′	49°36′	4.9	III-IV	240	Ahvaz

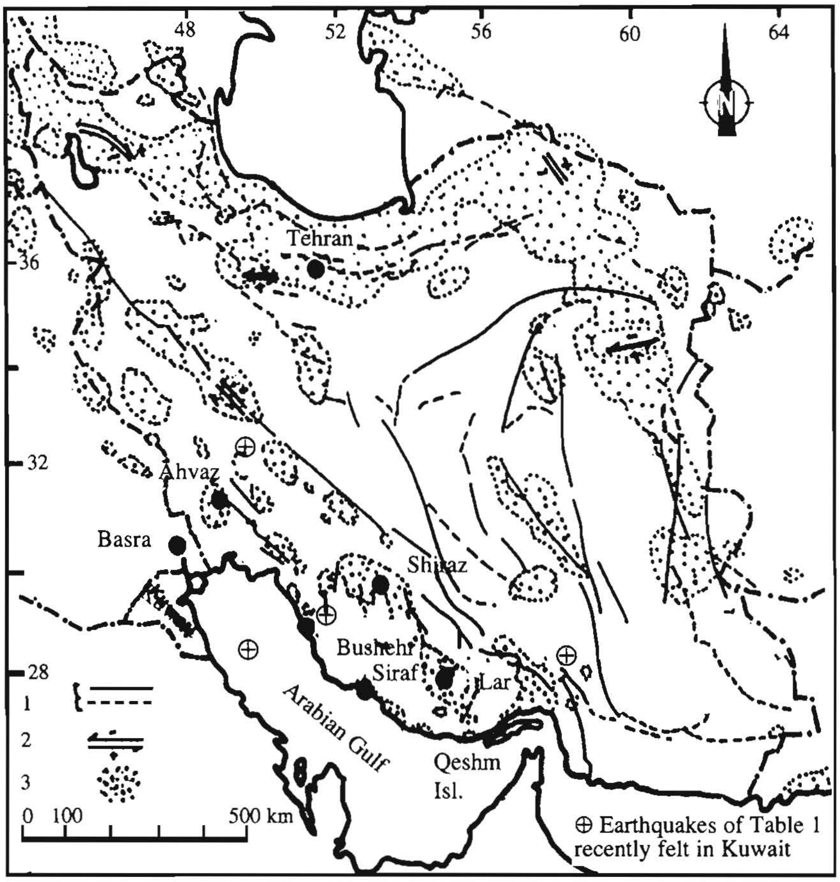

Fig. 6. Association of earthquake activity during the last thirteen centuries with active tectonics and recent Iranian earthquakes felt in Kuwait.

1: Solid lines show major faults of Quaternary age, dashed lines show faults of late Tertiary age

2: Location, extent and sense of displacements of faulting associated with events since AD 700, superimposed on

3: Areas affected by destructive earthquakes. (After Ambraseys & Melville 1982.)

Generally, this can be explained in terms of:

1. source directivity, i.e., the directional aspects of the fault rupture causing more energy to be released in a particular direction
2. regional (variability in) attenuation
3. local site amplification in areas covered by poorly consolidated soils with low shear wave velocities, increasing the amplitudes of seismic waves over what would be experienced on solid rock.

In summary, the Zagros fold belt in the collision zone is responsible for most of the seismicity in the region: magnitude 5 earthquakes in the Zagros are frequent and magnitude 6 events may occur several times yearly. The Zagros Mountains pose the primary seismic hazard for the Arabian Gulf countries, while local (in-country, intraplate) earthquakes occur in areas such as Minagish, where these may be associated with oil and gas withdrawal (Bou-Rabee, 1994; 1999). Ambraseys & Melville (1982) stated that "to the west of the Zagros, in the Arabian Plate, there is no evidence of significant intraplate activity", but the database and world seismicity maps of the U.S. National Earthquake Information Center include an intraplate event of surface wave magnitude 6.4 on July 9, 1953 located 100km northwest of Rafha (Saudi Arabia), located at 30°N latitude and 42.5° E longitude.

Table 2, contains data taken mainly from Berberian (1994). It is a summary of the pre-instrumental earthquakes in Iran that might have been associated with significant ground motion in Kuwait and other Arabian Gulf countries. The hypothetical recurrence of the historical earthquakes of Bushehr (Bishapur), Basra, Ahwaz and Shiraz with a magnitude M >5 may yield varied losses and damage in present-day Kuwait and other countries of the Arabian Gulf. Also, the recurrence of the large-magnitude earthquakes of Hurmoz (Makran), Lar and Qeshm might cause damage in the States of Bahrain, Qatar, United Arab Emirates and Oman.

Table 3 was compiled from catalogs of Ambraseys & Melville (1982), the U.S. National Oceanic Atmospheric Administration (NOAA) and the database of the U.S. National Earthquake Information Center (NEIC. The table lists the locations and magnitudes of historical and instrumentally recorded earthquakes pertinent to engineering seismic risk assessment in Kuwait and other Arabian Gulf countries. Figure (7) shows the location of the earthquakes listed in Table 2 and 3.

Table 2. Historical (Pre-instrumental) earthquakes in Iran which might have affected Kuwait and other Arabian Gulf countries. Selected from Berberian (1994).

Date	Local time	Macroseismic Epicenter °N - °E	I_o MMI	r⁻	M_s	People killed	Location
0293-0302	-	29.30 - 51.51	-		-	-	Kazirun
0531-0579	-	29.30 - 51.51	-		-	-	Kazirun
0658	-	30.50- 47.80	(nondamaging)		-	-	Basra
0840	-	31.23 - 48.67	VIII		6.5	-	Ahwaz
10th Cent.	-	29.30 - 51.51	-		-	-	Kazirun
0978.06.17	-	27.68 - 52.37	VII		5.3	>2000	Siraf (Taheri)
1008 Spring	-	27.68 - 52.37	VIII		6.5	K	Siraf
1085.05.00	-	30.60 - 50.30	>VII		5.8	-	Bahbahan
1361.00.00	-	26.81 - 55.91	VII		5.3	-	Qeshm Island
1400.00.00	-	27.66 - 54.33	VII		5.3	-	Lar
1483.02.18	-	25.70 - 57.30	VIII	800	7.7	-	Hurmoz-Makran
1497.00.00	-	27.18 - 56.18	VIII	-	6.5	-	Hurmoz-Bandar Abbas
1593.09.00	-	27.70 - 54.30	VIII	-	6.3	3000	Lar
1623.00.00		29.85 - 52.85	>VII	-	>5.5	-	Marvdasht
1666.00.00		32.10 - 50.50	VIII	300	6.5	-	Ardal
1677.08.00		27.97 - 54.12	VIII	260	6.4	-	NW Lar
1806.00.00		29.00 - 50.80	-	-	-	-	Bushehr
1824.06.02		29.70 - 51.50	VIII	140	>6.0	-	Kazirun
1824.06.25	04:50	29.75 - 52.40	VIII	250	6.4	-	NW Shiraz
1853.05.05	12:00	29.60 - 52.50	VIII	200	6.2	9000	Shiraz
1853.06.05		31.30 - 51.90	VII	110	5.5	-	Izadkhast
1862.12.21	10:00	29.50 - 52.50	VIII	250	6.2	-	Shiraz
1871.09.06		-	-	-	-	-	Bushehr
1875.03.20	15:00	30.50 - 50.50	(Destructive)	119	5.7	-	Behbahan
1880.00.00		32.02 - 50.65	>VII	120	>5.3	-	N. Siraf
1883.10.16	Night	27.74 - 52.20	VII	210	5.8	-	Kangan
1884.05.19		26.81 - 55.91	>VII	120	>5.3	218	Hurmoz
1890.03.25		28.78 - 53.65	VIII	250	6.4		S. Shiraz
1891.12.14		29.90 - 51.58	>VII	100	>5.3		Kazirun
1892.08.15		29.10 - 52.70	VII	-	>5.3		South Kazirun
1894.02.26	Evening	29.50 - 53.30	VII+	180	5.9		S. Shiraz
1897.01.10	23:30	26.95 - 56.26	VIII	250	6.1	1600	Qeshm Island

Notes on Table 2:

Local time: The time (when given) is Tehran civil time for the historic period. Tehran local time minus 2h:30m equals coordinated universal time (UTC or G.M.T). At present this difference is 3h : 30m.

$\mathbf{I_o}$: Highest epicentral intensity, mainly in the Modified Mercalli Intensity Scale (MMI).

r⁻ : Mean distance at which the shock was felt with an intensity of IV (MMI).

K : Indicates an unspecified number of fatalities.

Table 3. The instrumentally recorded Iranian earthquakes that could have affected Kuwait and other Arabian Gulf countries

Date Y	M	D	Origin time G.M.T. h	m	Location Lat.°N	Long.°E	Ms	mb	Region
1902	07	09	03	38	27.00	56.00	6.4		Hurmoz
1907	07	04	09	12	27.00	55.00	5.7	6.0	Souoth Lar
1913	03	24	10	34	27.60	53.91	5.8		Lar
1924	06	30	03	41	27.50	53.80	5.8		Lar
1925	12	18	05	53	28.50	51.20	5.5		South Bushehr
1927	11	12	14	46	32.39	47.97	5.6	6.0	N. Basra
1929	07	15	07	44	32.06	49.60	6.2	6.3	N. Basra
1931	07	05	17	57	29.90	48.50		4.8	Arabian Gulf
1938	01	23	09	26	27.22	53.28	5.5		Siraf
1939	11	04	10	15	32.60	49.02	5.7	6.0	Ahwaz
1945	01	15	17	21	27.04	54.85	5.5		Lar
1946	03	12	02	21	29.72	51.72	5.7	5.7	NE Bushehr
1954	08	20	15	30	27.50	52.00	5.0		Arabian Gulf
1956	10	31	14	03	27.21	54.39	6.3	5.9	Lar
1960	04	24	12	14	27.72	54.44	5.8	6.0	Lar
1961	06	11	05	10	27.90	54.53	6.5	6.4	Lar
1964	08	19	09	33	28.21	52.63	5.5	5.3	N. Siraf
1968	06	23	09	16	29.80	51.20	5.3		N. Bushehr
1971	04	06	06	49	29.80	51.90	5.2		NE Bushehr
1972	04	10	02	07	28.40	52.80	7.1		Jahrum
1972	07	02	12	56	30.10	50.90	5.4		Behbahan
1973	02	24			28.60	52.60	5.2		Jahrum
1973	11	11	07	14	30.60	52.90	5.5		N. Shiraz
1976	01	02	04	30	28.62	48.95		4.1	Arabian Gulf
1976	04	22	17	03	28.71	52.12	5.7	6.0	N. Siraf
1976	09	26	00	12	29.54	46.76		3.2	Kuwait
1976	06	05	02	23	28.88	48.19		3.8	Arabian Gulf
1978	12	14	07	05	32.14	49.65	6.1	5.9	Jahrum
1985	02	02	20	53	28.40	53.00	5.3		Jahrum
1986	07	12	07	54	29.90	52.60	6.2		N. Shiraz
1986	12	20	09	13	30.00	51.60	5.4		Kaziriun
1987	11	03	14	26	28.42	50.44		4.6	Arabian Gulf
1988	08	11	16	05	30.00	51.60	6.1		Kazirun
1989	05	27	09	13	30.10	50.90	6.0		Behbahan
1991	11	04	01	50	30.70	50.20	5.4		Behbahan
1992	09	08	00	38	29.10	52.20	5.2		S. Kazirun
1993	01	06	22	52	29.00	52.10	5.3		S. Kazirun
1993	06	02	22	01	28.94	47.61		4.8	Kuwait
1994	06	20	09	09	29.00	52.60	5.9		Shiraz
1995	05	31	20	44	28.20	53.30	5.0		Jahrum
1996	03	31	15	12	29.66	50.62		4.3	Arabian Gulf
1996	09	25	16	22	27.96	51.25		4.4	Arabian Gulf
1996	12	14	19	49	28.45	49.63		4.5	Arabian Gulf
1997	05	05	15	11	27.10	53.88	5.1		Lar
1997	09	18	20	24	28.99	47.44		4.6	Kuwait
1997	12	30	18	18	28.78	47.50		4.4	Kuwait
1998	11	13	13	01	27.79	53.61	5.4		Siraf
1999	09	25	19	19	28.71	51.21	4.9		Bushehr
1999	09	24	19	17	28.67	51.32		5.2	
1999	10	31	15	09	29.41	51.81		5.0	
2000	03	01	20	06	28.42	52.88		5.2	
2000	03	05	09	40	27.97	56.49		5.6	
2000	05	03	09	01	29.74	50.88		5.1	

contd. ↳

Date Y	M	D	Origin time G.M.T. h	m	Location Lat.°N	Long.°E	Ms	mb	Region
2000	06	23	06	15	30.10	51.68		5.1	
2000	09	13	13	09	27.82	51.70		5.1	
2000	12	21	10	39	26.66	55.83		4.2	
2001	02	21	19	32	29.87	49.30		4.2	
2001	02	22	03	19	29.41	51.69		5.0	
2001	03	28	16	34	29.88	51.05		5.0	
2001	04	22	01	41	30.11	47.59		3.5	
2001	08	25	09	45	30.98	47.99		4.5	
2001	11	05	05	19	25.99	54.73		4.4	
2001	12	08	14	48	26.92	55.35		3.9	
2002	02	11	00	15	28.02	49.14		3.7	
2002	02	17	13	03	28.47	51.86		5.1	
2002	03	11	20	06	25.24	56.15		5.0	
2002	09	25	22	28	32.26	49.18		5.4	
2002	10	12	06	28	28.66	49.69		3.6	
2002	11	09	04	31	27.10	50.53		4.0	
2003	07	10	17	06	28.40	52.20		5.9	
2003	07	10	17	40	28.40	54.00		5.6	
2003	10	24	05	58	28.30	54.00		5.5	
2003	11	05	07	58	28.30	55.60		5.3	
2003	12	11	16	28	32.00	49.40		4.9	

Historical and Recent Tsunamis in the Arabian Gulf and Arabian Sea

Seismotectonic studies in Iran show that the Iranian coastal areas (Makran, Arabian Gulf) have been tectonically and seismically active, and large magnitude earthquakes have affected the entire coastal areas in the past (Berberian 1981, 1983a).

The Makran and Arabian Gulf coasts have experienced at least the following tsunamis:

In 978 (A.D.) June 17, the ancient Siraf port (the present Taheri) was shaken by an earthquake. Most of the houses in the town were damaged and more than 2000 people were killed (Ambraseys & Melville 1982). The shock was associated with a tsunami, that sank a number of ships and flooded the coastal plain (Berberian, 1994). Al-Suyuti (1983) located this earthquake to be in Baghdad, but the editor corrected it to Siraf.

In the spring of 1008 (A.D.) there was an earthquake at Siraf along the coast of the Arabian Gulf. Many people were killed and a number of ships were sunk probably by tsunami (Ambraseys and Melville 1982). Parts of Siraf port were submerged (Berberian and Tchalenko, 1976a). Al-Suyuti (1983) located this event in Shiraz which the editor, again, corrected it to Siraf.

In September 1871, most of the Kuwaiti trading ships were sunk in the Arabian Gulf and the Arabian Sea due to very strong unexpected sea waves associated with flooding in the coastal zones (Al-Saidan, 1970; Al-Resheid, 1978 and Al-Kenaei, 1987). High windstorms were not known or expected during those times. Kuwaiti people called this event "Al-Tabah", meaning the event in which most of Kuwaiti ships were sunk. Most probably it was a tsunami caused by an earthquake at Bushehr of the same date.

In the early hours of Nov. 28, 1945 the Makran region was shaken by one of the largest earthquakes of this century (Ms = 8.1). A part of the port and the town of Pansi (on the Arabian Sea) was affected in a submarine slide that submerged a zone along the shore, which today is about 100 meters inland (Ambraseys & Melville, 1982). The event caused a tsunami that added significantly to the overall damage caused by the main shock, as sea waves reportedly reached five to ten meters in height on shore. At Karachi, 360 kilometers away, the waves had a height of about 1.5 meters. The tsunami waves in Bombay harbor, more than 1100 km from Pansi, reached heights of up to two meters. At Muscat (Oman), the shock was accompanied by a very high tide. There is no information about the effects of the waves in the Arabian Gulf, but in the Arabian Sea at least one dhow was sunk with casualties. Aftershocks continued for some time. On January 1946, Pansi was again damaged, and on 5 August 1947 another shock in the evening ruined many houses at Pansi. On the morning after the main shock, the leading theory in Muscat was that it had been caused by British experiments with atomic bombs in the Arabian Sea (Ambrasey & Melville, 1982).

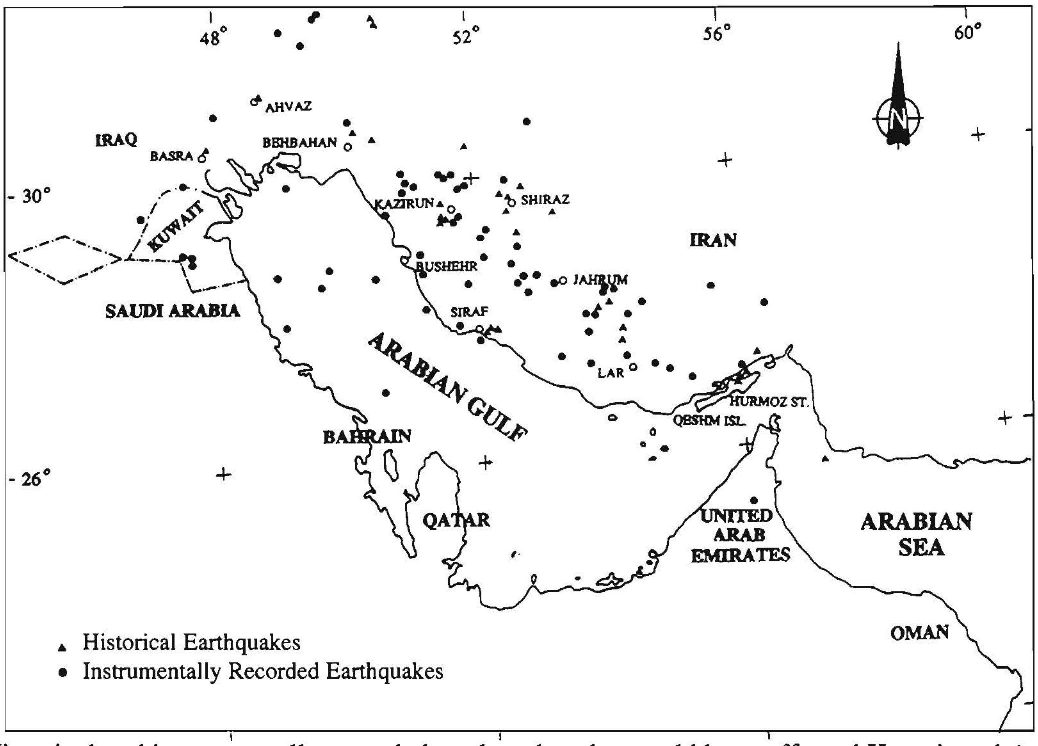

Fig. 7. Historical and instrumentally recorded earthquakes that could have affected Kuwait and Arabian Gulf Countries.

Need for Seismic Risk and Vulnerability Assessments

Risk assessment can uniquely offer support for decisions about appropriate levels of protection, for instance, by a city, against catastrophic hazards like earthquakes. What level of seismic building code offers the best balance between added expenditure for protection (greater initial cost of infrastructure) and reduced losses in case damaging earthquakes occur? Certain classes of structures may require added protection because of the types of earthquakes (and the frequency content of the ground motions they cause) that dominate the local seismic risk profile, or because of local soil amplification. In particular, tall buildings in Kuwait City and other Arabian Gulf cities such as Abu Dhabi may experience significant shaking during large-magnitude earthquakes in the Zagros fold belt at moderate source-to-site distances. Large-magnitude earthquakes tend to be rich in low-frequency waves that attenuate relatively slowly in intraplate regions. Hence, the greater threat to tall buildings that have low natural frequencies of vibration. Other factors to be accounted for in the seismic vulnerability assessment are the potential for soil amplification, possible soil-structure interaction, and the chance of liquefaction in the sandy soil in many areas.

On the eastern side of the Arabian Gulf, Iran is planning to establish nuclear power plant structures in some seismically active zones such as Ahvaz, Shiraz and Bushehr (Fig. 8).

Fig. 8. Iranian Nuclear Structures.

These structures, systems and components should be designed to withstand the effects of natural phenomena, such as earthquakes, tsunami and seiches without loss of capability to perform their safety functions. The geologic, seismic and engineering characteristics of the sites selected to establish these structures, should be investigated in sufficient scope and detail to provide reasonable assurance that they are sufficiently well understood to permit an adequate evaluation of the proposed sites and their environs, plus a safety review at multiple levels. In a lighter vein it could be said that a Nuclear Power Plant should be the safest place to stay during an earthquake event.

Only a comprehensive analysis of the seismic hazard to tall buildings in Kuwait and other cities in the region, combined with a methodology of risk-based decision analysis, will clarify the advisability of (more or less stringent) seismic design provisions in the local building code. Such a study may also lead, for instance, to recommendations for strengthening the supports or attachments of appendages (e.g., water tanks) to tall buildings, an inexpensive mitigation measure. A multi-hazard risk assessment for both wind and earthquakes should clarify to what extent existing design procedures for wind loads suffice to cover the threat from lateral loads due to earthquakes. In addition, the risk of tsunamis needs to be evaluated in support of decisions about proper protection of coastal facilities. The tasks just mentioned, and similar assessments of natural and technological hazards to population and industrial centers in Kuwait and other Gulf states, constitute the research priorities of a Joint Center for Research on Complexity and Risk for a long-term cooperative project.

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Received, 7th Feb. 2004; in revised form; 6th June 2004