Peak ground acceleration assessment of an imaginary site at Hawks Bay near Karachi

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ABSTRACT: *Karachi is located near a triple junction where Arabian, Indian and Eurasian plates are interacting. The plate boundaries are loci of earthquakes. The residential and industrial areas coalesce at many places in Karachi. In this geological and social set up, the determination of antiseismic design parameters are essential. In the present study the maximum credible earthquakes and site specific peak ground acceleration of a sensitive installation like a chemical or a pesticide plant or an oil storage facility have been assessed. For the purpose of this study an imaginary sensitive structure is assumed at Hawks Bay. The methodology adopted is in accordance with IAEA safety guide. No seismites could be recorded in the site vicinity and near regional areas. Surjan Jhimpir fault, Thano Bulla Khan fault zone, Karchat fault and Murray ridge are identified as seismogenic sources on the basis of the historical and instrumental seismicity. The Allah Band fault of Kuch rift zone does not extend through the Kirthar fold and thrust belt and posses no significant seismic risk to Karachi. Intensity V of Mercelli Modified Scale (MMS) is assigned to the large earthquake of the January 2001 after an intensity survey in Karachi. The city area itself is marked by mainly micro seismicity while low to moderate seismicity is associated with seismogenic sources around Karachi. The maximum credible earthquake magnitudes for identified sources have been calculated by the use of regression relationship for 50% rupture of fault length. The Peak Ground Acceleration (PGA) of 0.2 have been assessed by using attenuation relationship. The site specific PGA should be determined for each sensitive installation by following the international criteria.*

INTRODUCTION

Earthquakes and associated phenomena are natural calamities that cause loss of life and property. The plate boundaries are the main zones of seismic activity. The Karachi city is located near a triple junction where three plates are interacting. The industrial and thickly populated urban areas coalesce at places in the city like Gul Bai, Sher Shah and site areas. Under earthquakes loading the industries using toxic or inflammable chemicals and materials may cause more damage to the urban population than the earthquake shocks. Tsunami is another earthquake related threat to the coastal city. The growing industry and urbanization demands that seismotectonic analysis and site-specific peak ground acceleration (PGA) assessment for antiseismic design of important civil structures should be carried out. The pre existing civil structures should be reinforced accordingly.

An imaginary site for a chemical plant is assumed to be located at Hawks Bay (Fig. 1) and site specific PGA is determined by using present state of the art. The work primarily aims to draw attention of professionals and authorities to the importance of seismic hazard assessment and its mitigation.

Geological control on natural hazards: earthquakes and mass movement. Khan, M.A., Abbasi, I.A., & Khattak, G.A. (Eds.). Geological Bulletin, University of Peshawar, (Special Issue), Vol. 35, pp. 27-41, 2002

Fig. 1. TM Image of the Site Vicinity Area

METHODOLOGY

Based upon seismotectonic setting many countries have established regulation, standards and code of practice for important civil structures siting. The International Atomic Energy Agency (IAEA) developed a comprehensive safety guide by combining and consulting guides of different countries for nuclear, chemical and important civil structure siting. The methodology adopted for the present study is in accordance with IAEA safety guide 50 SG. S1- Rev 1.

The IAEA safety guide 50-SG-S1-Rev 1- requires that the database for PGA assessment should be developed at three scales, i.e., regional, near regional and site vicinity. The database is developed by investigating tectonics, structures, neotectonics, historical and instrumental seismicity. The field investigations are supported by remote sensing, geophysical techniques and available geoscientific information.

The regional scale studies are conducted in a radial extent of 150 km around the site. The data source is historical and instrumental seismicity catalogues, specifically processed satellite images, and published information augmented by selected field traverses. The data is presented at scale of 1: 500,000.

The near regional studies extend up to 25 km radius circle around the site. Interpretation of satellite images and field investigations are used to define seismotectonic characteristics of the area and maps are presented at a scale of 1:50,000. The maps of near regional and site vicinity areas are not accompanying the text due to their size. The results are, however, discussed in the text.

The site vicinity scale includes area encircled by 5 km radius. The detailed structural, lithological and neotectonic studies aided by trenching and scraping is required for the site vicinity studies. The data are presented at a scale of 1:5000.

The similarity in deformation styles, stress direction and chronology helps to define tectonic zones. The distribution of seismicity reveals its possible association with a tectonic zone. Fault geometries, epicentral locations, focal depth and focal mechanism are used to relate seismicity with a particular structure or zone which in turn defines a seismotectonic zone. Within a zone seismic sources are determined on the basis of historical / instrumental seismicity, neotectonics and structure. The maximum credible earthquake for each source is calculated and deterministic PGA at specific site is assessed by using attenuation laws.

STRATIGRAPHY

Propagation of seismic waves is greatly influenced by lithological variations. In the area under investigation, Mesozoic rocks composed mainly of limestone, shale and sandstone are exposed in the Mor Range. The Bela ophiolitic mélange occurs in the western Mor Range. The sandstone, shale and limestone sequence of Cretaceous to Eocene age occupies Pab Range and areas to the east of the Pab Range.

The Nari Formation of Oligocene age is widely distributed in the area. It consists of sandstone, shale and subordinate thin beds of limestone. The core of Cap Monze anticline (Allah Bano anticline, Fig. 1) is also constituted by this formation. The Gaj Formation of Miocene age occupies most of the area in and around Karachi, including the site. It is composed of shale, limestone and sandstone. The Manchar Formation of Pliocene to Pleistocene age is mainly comprised of sandstone, shale and conglomerate. This formation is widely distributed in the east of Karachi (Fig. 1).

The Cenozoic rocks are covered by SubRecent and Recent sediments at many places. The sediments are mainly represented by conglomerates, gravel and sand. In the area under investigation the SubRecent and Recent rocks are divided into three units, Upper, Middle and Lower. The lower part consists of subangular to subrounded boulder with fine-matrix and gritty sandstone. It is cemented and lies unconformably over bedrock, making an angle of 8°-15°. The middle unit does not show any lithologic contrast with lower except for the size of boulders. The lower and middle units are of SubRecent age. The upper unit consists of gravel, silt and sand. It is of Recent age (Hunting Survey Corporation, 1960).

TECTONICS

Each year, about 12 million seismic events occur throughout the world. Most of the seismicity is restricted along the plate boundaries. Three lithospheric plates, i.e., India, Eurasia and Arabia are interacting along active plate boundaries in Pakistan. In the south-west, the Arabian plate is subducting under Afghan and Lut blocks of Eurasia along Makran coast. In the off shore region, the Owen fracture zone marks an active boundary between the Arabian and Indian plates (Molnar and Tapponeir, 1975). In the north, the Indus-Zangbo suture is a collision boundary between Eurasia and India (Tahirkheli et al., 1979). The two convergent plate boundaries are connected by sinistral transform fault, called the Chaman-Ornach Nal fault zone. Triple junction is located to the west of Karachi. Permian to Cretaceous rifting from Africa and the northward movement of India with anticlockwise rotation is recorded as rifted features at the western margins. Its subsequent collision with Eurasia and ongoing northward movement resulted in the formation of fold and thrust belts and wrench faults.

The rifted features are represented by horst and graben structures at the western edge of the Indian plate. The EW trending Kuch rift is located in the westernmost limits and separated from NW trending rifted feature by Nager Parker and Allah bund faults. The NW trending Pano Aqil graben with Khairpur high in south and Kandhkot horst in north are dislocated by a dextral fault, from their analogues the Nagar Parkar horst and the Cambay graben (Ahmed & Ahmad, 1991, Fig. 2). The Cretaceous rifting is also recorded by the older sediments in the southern Pakistan.

The Kirthar fold and thrust belt is a consequence of collision of India with Eurasia and its ongoing northward movement. Karachi is located at its southern arcuate termination, named as Karachi arc. The structures in the southern Kirthar are a product of distributive sinistral Cenozoic transpressive wrench faults (Ahmed and Ali, 1991). The Kirthar fault is a major thrust in the frontal part of the range. In north, it is westward dipping fault and its southward extension near Kot Digi consists of foreland dipping fault zone. It can be traced up to Doreji in the south (Fig. 2). The Karachi arc is bounded by Bela-Khuzdar block to the west and Indus foreland to the east. The arc opens up in the Arabian Sea and terminates in Murray ridge area. The wedge-shaped Bela-Khuzdar Block is sandwiched between Ornach Nal Fault in the west and ophiolitic mélange of Mor range to the east (Fig. 2). It is marked by arcuate folds and thrusts in the north, formed due to anticlockwise rotation of the block. The Khuzdar knot is its northern termination (Fig. 2).

The Pab fault is a west-dipping segmented fault zone which loses its throw southwards and dies out in Sonari range near Musa Goth. The ophiolites are thrust over sediments along the More Range fault. The Bela fault, concealed under alluvium bounding the mélanges to the west, probably extends up to Murray ridge in off shore (Ellouz & Lallemont, 2000, Fig. 3).

Surjan fault, located in the frontal part of Kirthar fold and thrust belt (Fig. 2), is a hinterland dipping high angle fault, which extends from Jhampir to Sun area. Some NS trending thrusts along Thano Bulla Khan Ranges collectively constitute Thano Bulla Khan fault zone (Fig 2). A number of strike slip faults with limited aerial extent cut obliquely the strata at

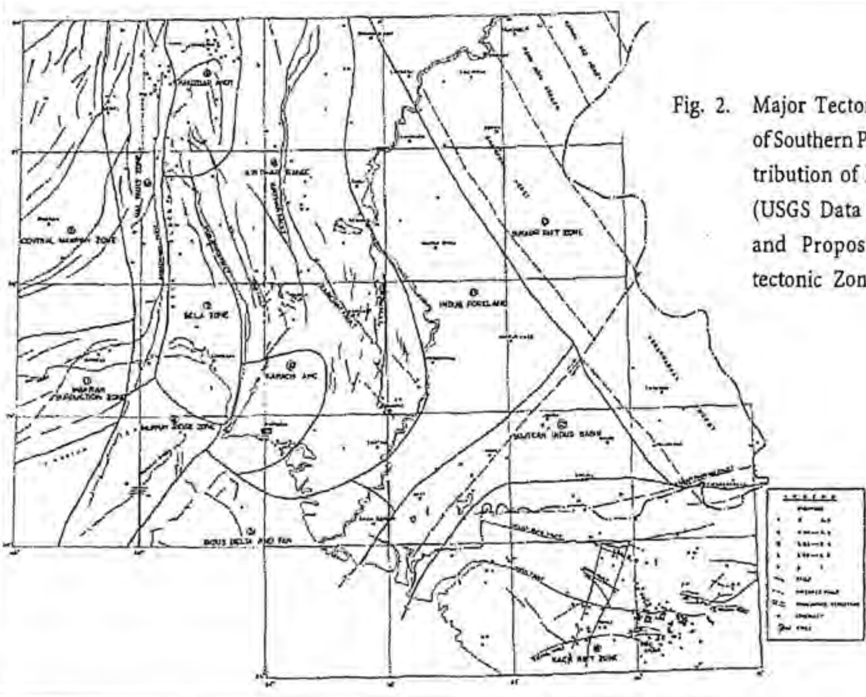

Fig. 2. Major Tectonic Features of Southern Pakistan, Distribution of Earthquakes (USGS Data 1900–2001) and Proposed Seismotectonic Zones.

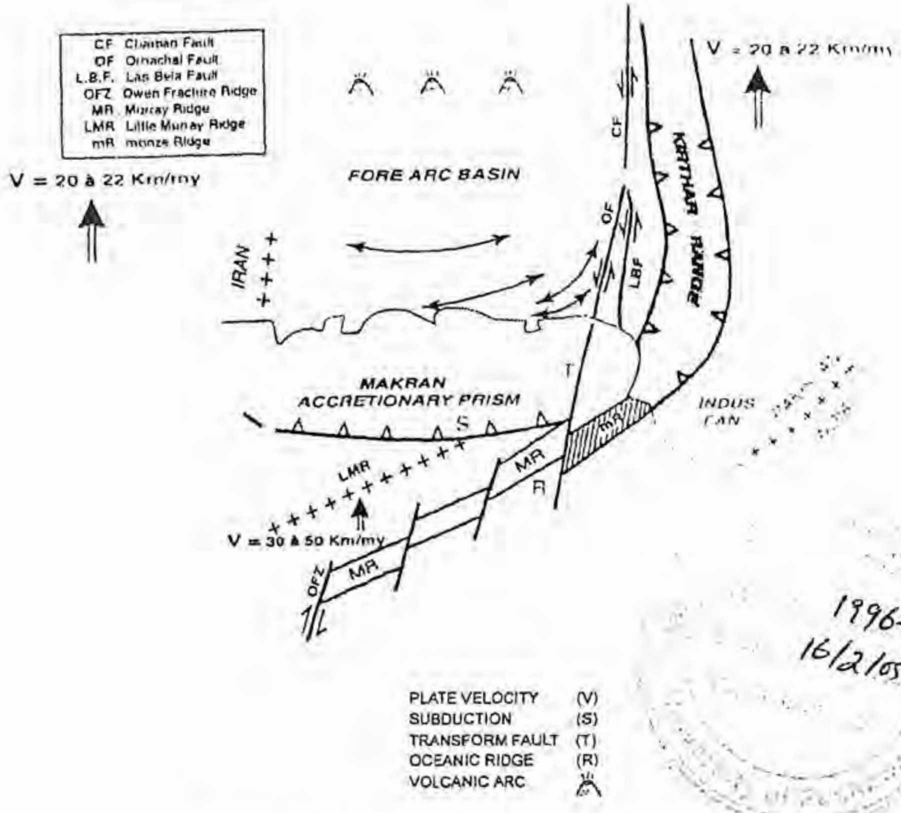

Fig. 3. Major Tectonic Features of South West Pakistan
(After Ellouz & Lallement, 2000)

many places. The northern Kirthar is dominated by NE trending while the southernmost part is dominated more by NW trending strike slip faults.

To the east, the sinistral Ornach-Nal fault constitutes the western boundary of the Indian plate and joins the Murray Ridge in the Arabian Sea (Fig. 2). The Murray Ridge is represented by seamounts with strike slip and normal faulting. The great Rann of Kuch and Bani plain of India are located to the southeast of Karachi (Fig. 2). Low lying marshy land, saltpans and mud flats of Kuch are bounded by EW trending faults. To the north, the Allah Bund and Nagar Parkar faults mark the boundary of great Rann of Kuch (Fig. 2). The EW- trending faults of Rann take a swing to attain NWW trend and seem to be converging in Jati area giving way to the Indus Delta. The dextral fault off setting Sukkur Rift zone is probably the western limit of the Kuch and northwest swing of the Allah Bund fault may be due to drag of the dextral fault. It indicates that the Allah Bund fault does not extend to Karachi area. The Mangupir anticline, NW trending strike slip faults of Sonari and Jhil Range (Fig. 1) and EW trending minor fracture in the Gharo area have been misinterpreted as extension of Allah Bund fault. All these different types of structures cannot represent a single fault.

NEOTECTONICS

Regional scale studies

The regional studies were not restricted to 150 km radius but were conducted keeping in view the importance of different geological structures.

Photo 1. Recent alluvium in contact with Eocene Limestone along surjan fault near super highway.

Photo 3. Neotectonic joint in recent sediments near Baran Nai bridge of super highway.

Neotectonics features are associated with Surjan fault, Karchat fault, Thano Bulla Khan and Baran Nai faults.

Along Surjan fault alluvium is in contact with limestone and shale of Laki Formation near Super Highway (Photo 1). In the north of Kalokahar–Jhampir road, sandstone of Laki Formation is in faulted contact with Recent alluvium. The alluvial silt is sheared along the fault. In northern parts of the fault traced tilt and joints were observed in the Recent sediments. All these seismites indicate that the Surjan fault is an active structure.

Active nature of Karchat fault is evident by the tilt in Recent sediments (Photo 2), aligned breaking of pebbles and neotectonic jointing in sub Recent sediments at northern plunge of Thano Bulla Khan syncline. Neotectonic signature of Thano Bulla Khan Range fault is recorded by abrupt truncation of Tertiary rocks against Recent sediments.

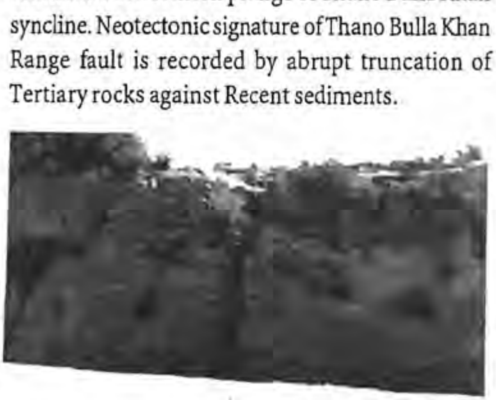

Photo 2. Tilted recent sediments along Karchat fault.

To the southeast of Super Highway bridge at Baran Nai, the neotectonic features are well exhibited along the stream course. The aligned fractures in the Recent sediments, laid down by stream itself, mark the trace of fault (Photo 3). Cracks were also observed in walls of a house built on fault trace. To the northwest the fault joins Karchat fault in the Thano Bulla Khan syncline (Fig. 2).

Neotectonic features have also been reported along Nal fault, Khuzdar knot and Lakhra anticline (Hunting Survey Corporation, 1960; Outerbridge & Khan, 1989; Kazmi and Jan, 1997). East west trending sharp boundary between Rann of Kuch and Tharparkar desert is a geomorphic expression of the Nagar Parkar fault in Recent sediments.

The coastal areas of Karachi were also thoroughly scanned to locate the reported trace of Allah Bund fault. No such fault trace could be located, however, sets of EW trending fractures are present in the south of Gharo area which are not restricted to an area or zone. The overlying Recent sediments do not show any neotectonic deformation.

Near regional scale

The eastern and southern parts of near regional area could not be investigated due to urban population and the sea. The offshore structures have been incorporated from Raza et al., (1990). On land the near regional area is mainly occupied by Cap

Monze (Allah Bano) anticline (Fig. 1) which plunges in Mubarik Village area. Nari Formation of Oligocene lies in the core and Gaj formation of Miocene age is exposed at its limbs. The northern limb of anticline is faulted by the Hab river fault and the fault loses its throw to the west and does not extend beyond Musa Goth. The fault trace is covered by Recent alluvium near Musa Goth and no neotectonic feature could be located along this structure.

The southern limb of the anticline is displaced by NW striking strike slip faults at and near Sona Pass (Fig. 1). The faults were investigated in detail for their neotectonic signature by trenching, scraping, and excavations in the Recent fan material. The Recent strata is intact and there is no sign of neotectonic deformation. Subrecent to Recent sediment, filling the anticline axis, gives an impression of pseudo tilt at the sloping margins of structural lows. No neotectonic deformation is observed in the SubRecent sediment lying over NWW trending faults in Nari Formation near Mubarik Village (Photo 4).

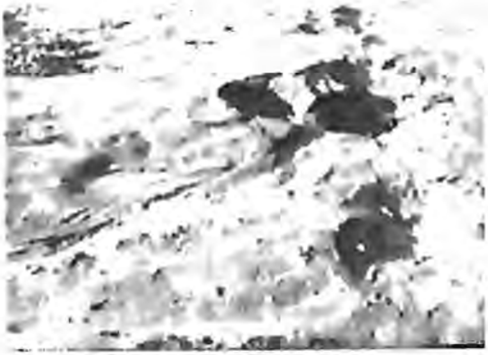

Photo 4. Liquefaction in sandy area near Ali Bandar.

Site vicinity area

The site vicinity area is occupied by peneplained Gaj formation covered by fans. The Gaj Formation is sheared and faulted at many places, however, no deformational feature was observed in the Recent and Subrecent sediments lying over the Gaj Formation. Trenching, scraping and excavations were also made at suspected places, however the Recent sediments were found to be devoid of any neotectonic features (Photo 5,6).

Photo 5- Undisturbed cover sediments lying over sheared / fractured sandstone of Gaj Formation near imaginary site.

Photo 6. No joints extend into the sediments (photo after excavation)

SEISMICITY

The Karachi area is marked by only micro and low seismicity. Occasional low magnitude earthquakes (<4) have occurred in the area like other stable regions of the world. The tectonic elements around Karachi, however, have remained active since historical and geological times.

Historical record

Oldham (1882), compiled an earthquake catalogue of the Indian Subcontinent covering the period of 25 AD to 1882. The magnitudes of the events are ascertained by the intensities based upon the felt reports.

BHAMBHORE, 13th CENTURY: Bhambhore town located to the east of Karachi was affected. Epicentral location is not known, the event might be associated with the faults of Kuch Rift.

SHAH BANDAR, MAY 2, 1668: The event of the estimated magnitude 7 to 7.6 occurred somewhere near 24° North, 68° East and caused destruction in Shah Bandar area. The historical record does not indicate destruction in old town of Thatha. It is inferred that the epicenter was located somewhere in the western Kuch Rift and Shah Bandar was effected by shocks and permanent ground displacement.

SHAH BANDAR, MAY, 1688: Details of the event are not documented, it probably occurred in the same area where the event of 1668 was felt.

RAS KUCHARI, 1765: The event was probably associated with eastern terminus of the Makran subduction zone.

RANN OF KUCHH, JUNE 16, 1819: The earthquake of magnitude 7 to 7.8 and intensity XI occurred about 50 km northeast of Bhuj town. The biggest event of Kuch was felt over wide swathe of Indian subcontinent, surface faulting and subsequent subsidence of epicentral area is documented. An east-west trending, 4.5 m to 7 m high fault scarp was formed which dammed Shatadro stream. The fault, having about 90 km length, was named as "Allah Band" (mound of God) (Oldham 1926). Isoseismal map shows intensity VI in Karachi (Mirza et al., 1984).

BHUJ, 1820: Severe shocks with loud noise were felt in Bhuj. It was the after shock of 1819 event.

BHUJ, 1828: Event again occurred in the same area, causing panic.

SHEHWAN-PHOULJEE, FEBRUARY 2, 1851: Other than ground shaking, no detail of the event is available. Keeping in view its location, it can be postulated that the event was associated with frontal fault system of Kirthar (Quittmeyer and Jacob, 1979).

UTHAL-BELA, April 22, 1891: Karachi was effected by the tremor that was probably related to thrusts of Khuzdar Bela Block or Bela fault (Quittmeyer and Jacob, 1979).

Instrumental Seismicity

The catalogue of instrumentally recorded seismic events between 65° to 71° E and 23° to 28° N is compiled from NEIC (National Earthquake Investigation Center) of the United States Geologic Survey, Quittmeyer & Jacob, (1979) and Malik et al., (2000). The catalogue is complete after 1972, however, recording of micro seismicity of the area is lacking due to absence of high magnification seismic network. About 275 numbers of event occurred in the area. The epicentral location and magnitudes are depicted in Fig. 2. Only two events of Kuch had magnitude > 7, while five moderate events occurred near Shahdad Kot, Jabri and Kuch region of India. Only three percent of total earthquakes were moderate to large and thirteen percent were small. Khuzdar area is seismically very active as manifested by clustering of the epicenters. The earthquakes were generally small. Seven moderate earthquakes associated with Nal fault occurred in Nal-Jabri areas. Some epicenters located near Bela were probably related to Bela fault. The epicenters located near Dadu were associated with the frontal fault system of Kirthar while small earthquakes near Sehwan and Jhampir were associated with the northern and southern terminus of Surjan fault, respectively. The epicenters near Karchat and Thano Bulla Khan can be related with Karchat fault and the faults along Thano Bulla Khan Range.

Majority of the earthquakes of the region occurred in the great Rann of Kuch and Banni Plains of India. The event of Jan 14, 1903, with magnitude 6, was felt in Karachi. The Anjar earthquake of January 21, 1956, was widely felt in southern Pakistan, however, no severe damage was reported. The Recent earthquake (January 26 2001), of magnitude 7.7 with focal depth of 10 km, occurred 40 km to the north of Bhuj city. Intensity was above X in the epicentral area while intensity V is estimated for Karachi area. No damage was caused in Karachi. A Poorly constructed building in Hyderabad and shed of Mirza sugar mill near Badin were damaged. The two boundary walls in Badin town also collapsed. Liquefactions occurred in Kadhan, Ali Bandar and in Rann of Kuch near Nagar Parker. No liquefaction or damage occurred to the west of Badin.

The epicentral location of October 26, 1921, seismic event of magnitude 5.5, was located at 68°E and 26° N, near Jhampir. The event was probably related to the Surjan fault. The earthquake of magnitude 6 occurred near Shahdad Kot at 69 and 28° N on May 15, 1935. It might be associated with frontal fault system of Kirthar Range.

SEISMOTECTONIC ZONING

Quittmeyer et al., (1979), have divided southern Pakistan into six seismotectonic zones i.e, Makran, Murray ridge, coastal region of Karachi, Ornach Nal fault and Indus Basin. This broader seismotectonic zoning have been subdivided by the authors, based upon Recent developments in tectonics, instrumental data and neotectonics (Fig. 2).

I. *Makran subduction zone:* The zone covers offshore and coastal areas of Makran. All the seismic events of the zone are related to the thrusts of the subduction zone. The zone is seismically active, and historic event of Ras Kucharri occurred in its eastern part. It is about 100 km to the west of the site and may affect the site by shocks and tsunami in case of large events.

II. *Murray Ridge:* The northeast trending Murray ridge is located to the south of Sonmiani bay in the offshore region (Fig. 2). It is marked by the shallow depth earthquakes of magnitude up to 6. Being an active plate boundary it can generate shallow moderate earthquakes. An earthquake of magnitude 4.6 occurred on September 29, 1998, in the northern part of the ridge. The epicenter was about 50 km from the Karachi, but it was not felt in Karachi. The event of Murray Ridge can generate tsunami.

III. *Indus delta and fan:* Indus delta and submarine fan zone is bounded by Murray Ridge in the east, Karachi arc and Indus foreland in the north and Kuch zone in the east. Some of the faults in the zone follow the trend of Murray Ridge (Raza et al., 1990). The east west trending faults of Kuch Rift does not extend into the zone. The zone poses no significant threat to the site.

IV. *Kuch Rift Zone:* This 250 km long and 150 km wide zone is flanked by Nagar Parkar fault in the north and Kathiawar fault in the south. Katrol, Kuch, Banni and Allah Bund faults are major east west trending active faults. The Kuch zone experienced many episodes of earth movement along these faults throughout the Cenozoic time (Malik et al., 2000).

Frequent seismic events of shallow focal depths are associated with normal faulting with some exception of high angle reverse faults. To the west the Kuch rift is terminated by a north-east trending dextral fault concealed under Sind plains (Ahmed and Ahmad, 1991). The seismicity of Kuch also does not extend westward beyond the fault.

Some low to moderate events are also associated with Nagar Parkar fault and western termination of Kuch Rift zone. The source zone is more than 150 km from the site and poses no significant threat to the site. Keeping in view the tectonic setup, the possibility of moderate and occasional large earthquakes in the region cannot be rule out.

Intensity level VI have been assessed in Karachi area for the large events of 1819 and 2001, however the historic events of Shah Bandar area indicate that any large event in the westernmost Kuch Rift zone may cause some higher level of intensity in Karachi.

V. *Central Makran:* The zone marked by sparse seismicity represents hind part of Makran accrenationary prism. Few epicenters are located in the east where thrust of Makran obliquely joins Nal fault zone. Two epicenters occur in the west, which are associated with basal detachment as indicated by focal depths.

VI. *Ornach-Nal Fault Zone:* A number of shallow epicenters are located along 300 km long Ornach-Nal fault zone. Majority of the epicenters occurred around the northern terminus of the fault near Jebri – Nal. The zone lies more than 80 to 130 km away from the site.

VII. *Bela Zone:* Southern Baluchistan fold and thrust belt and Bela fault constitute the zone where 15 seismic events of magnitude up to 5 have occurred in the last century. Four epicenters are located near Sonmiani. A relationship of seismicity with Bela fault could not be established due to lack of sufficient data. For the sake of safety it has been treated as floating.

VIII. *Khuzdar Knot Zone:* It includes northern Baluchistan folds and thrust belt marked by arcuate thrusts and folds. The northern segment of the Pab fault, Gazan fault and Nal fault bound the zone in the east, north and west respectively. The zone is highly active as manifested by a cluster of epicenters with magnitude up to 6. The zone poses no potential seismic risk to the site.

IX. *Kirthar Range zone:* The Kirthar fold and thrust belt constitutes the zone. It can be divided into eastern frontal and western hinterland parts. In the western parts NS striking hinterland-dipping thrusts are segmented and at places these are joined by oblique strike slip faults. Occasional low seismicity is associated with northern fault segments while the southern faults are devoid of seismicity and neotectonic features.

In the eastern foreland part of Kirthar fold and thrust belt, the Kirthar fault and associated structures are important seismogenic sources. The Kirthar fault is foreland dipping and seismic events of magnitude up to 6 are associated with it. The southern terminus of fault is about 100 km to the NNE of the site.

A number of neotectonic features are associated with different structures in the frontal part of Kirthar fold and thrust belt, recent uplift of Lakhra anticline (Outerbridge and Khan, 1989) growing folds of duplex geometry (Branks and Warburton, 1986). Seismic events of magnitude up to 5 are associated with the structures.

Seismicity and neotectonic features are also associated with Surjan Jhimpir fault, Karchat fault and Baran Nai fault. The Karchat fault is southward extension of regional fault parallel to Kirthar fault and Baran Nai fault is also its splay.

X. *Karachi Arc Zone:* The Karachi arc is comprised of southern arcuate terminus of Kirthar fold and thrust belt. No neotectonic features are associated with Mangopir anticline, Sona Pass faults and southern extension of Pab fault.

The Karachi arc is marked by micro seismicity only (Zaigham et al., 2000). The epicentral locations and focal depths of microseismic events are not available, so it cannot be related to any specific structure. The stable crustal parts experience occasional microseismic events caused by defused seismicity and Karachi appears to be such a case.

XI. *Indus Foreland Zone:* The Indus foreland zone is comprised of Sind alluvial plains lying over relatively less deformed Tertiary sequence. Only one seismic event is located in the zone, which is probably related with foreland dipping fault of Kirthar Range.

XII. *Southern Indus Basin Zone:* The southern Indus foreland close to Kuch Basin has an important subsurface dextral strike slip fault which offsets Sukker Rift zone. Six earthquakes of magnitude up to 6 roughly following the fault trend are located in this zone. More subsurface data is, however, required to relate the events with the fault.

XIII. *Sukker Rift Zone:* The Sukker Rift zone is marked by twelve seismic events of magnitude up to 6. Most of the epicenters are located in the northern and southern extremes of the zone where it is interacting with other tectonic elements.

SEISMIC RISK EVALUATION

I. *Seismic Sources for the site:* Surjan fault and Kirthar fault are the thrusts resulting from transpression. The Karchat and Baran Nai faults are located close to the Surjan fault and Kirthar fault. Maximum credible earthquake associated with these faults are comparable, so Karchat and Baran Nai sources have not been dealt separately.

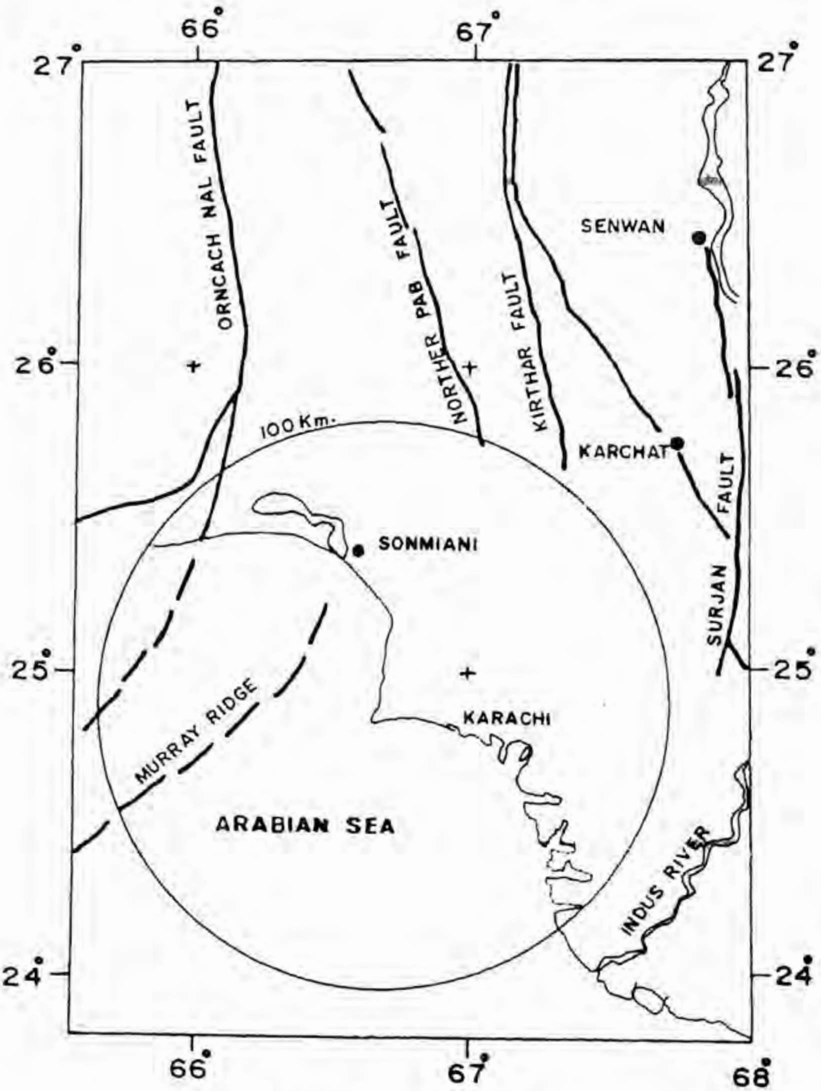

Fig. 4. Seismic Sources Around the Site.

Northern segment of Pab fault is a thrust while Ornach - Nal fault shows predominately strike slip motion. Murray Ridge source is the nearest source marked with strike slip and normal faulting. All these sources are line sources. The Sonmiani area has been considered as a zone of diffused seismicity and floating earthquake have been assessed by using seismic parameters of the zone (Fig. 4).

II. *Maximum Credible Earthquake:* The maximum earthquake generating capability of a source is determined on the basis of seismological and geological data, including historical and instrumental seismicity, neotectonics, rupture length and type of the source. The maximum credible earthquake of each seismic source is given in the Table 1.

Assessment of Peak Ground Acceleration (PGA)

The peak ground acceleration and shape of spectrum at the site is dependent on the magnitude, epicentral / hypo central distance, intervening medium and the local site conditions. The PGA is usually estimated using the empirical attenuation relations developed from actual records of strong motion. As sufficient strong ground motion data is not available for Pakistan, it was not possible to derive the site-specific empirical relation. As such attenuation relations developed for different regions of the world were studied and most suitable ones rich in database were used.

The site accelerations from different seismogenic structures/ faults have been estimated using the attenuation relations of Campbell (1997) and Sadigh et al., (1997).

Campbell (1997)

The equation developed by Campbell (1997) is applicable for:

i. The larger horizontal component of peak acceleration should be at least 0.02g.

ii. Moment magnitude should be equal or greater than 5.0.

TABLE 1

MAXIMUM CREDIBLE EARTHQUAKE MAGNITUDES FOR VARIOUS SEISMIC ZONES IN THE REGION

Fault Zones	Known Length S (km)	Magnitudes Corresponding 50% Rupture		Max. Earthquake Magnitudes		
				Doc.	Rec.	Cred.
The Rann of Kutch	225	7.8	7.7	IX-X (7-7-7)	6.13	7.8
The Surjan-Jhimpir	165	7.4	7.4	IX-X (7-7-7)	5.6	7.7
The Sonmiani	55	7.1	6.9		5.1	7.1
The Ornach-Nal	33	7.6	7.6		5.9	7.6
The Pab	110	7.3	7.2		6.4	7.3
The Murray Ridge	400	7.7	7.7		5.9	7.7
The Makran Thrust	225	7.7	7.7		8.3	8.3

1. Bonilla et al (1984)
2. Slemmons et al (1989)

iii. Near field earthquakes (less than 60 km)

iv. Focal depth is less than 25 km.

v. Accounts for soil, soft rock and hard rock.

vi. Style of faulting – strike slip reverse & thrust.

$$\ln(A_H) = -3.512+0.904\,M$$
$$-1.328\ln\sqrt{R_{SEIS}^2 + [0.149\exp(0.697M)]^2}$$
$$+[1.125-0.112\ln(R_{SEIS}) -0.0957M]\,F$$
$$+[0.440-0.171\ln(R_{SEIS})]S_{SR}$$
$$+[0.405-0.222\ln(R_{SEIS})]S_{HR} + \in$$

Where A_H has units of g, $\in$ is standard deviation, R_{SEIS} is shortest distance (km) to the zone of seismogenic rupture, M is moment magnitude, F=0 for strike Slip, = 1 for reverse/ thrust faults, S_{SR}=1 & S_{HR}= 0 for soft rock.

Sadigh et al., (1997)

The equation developed by Sadigh is applicable to:

i. Shallow crystal earthquakes (20-25 km)

ii. Soils and rock sites

iii. Strike slip and reverse faulting earthquakes

iv. Earthquakes of moment magnitude M 4 to 8+

v. Distances up to 100 Km.

$$\ln(y) = C_1 + C_2M + C_3(8.5M)^{2.5} + C_4\ln(R\,rup + \exp(C_5 + C_6M) + C_7\ln(R\,rup + 2)$$

Where Y is peak horizontal acceleration, M is moment magnitude, R rup is the closest distance to rupture surface and values of C1, C2, C3, C4, C5, C6, C7 and standard deviation are given in [SSA]

The estimated 'g' values (mean + 1 SD) at Site are shown in Table for the different seismogenic structures and vary from 0.05 g to 0.21 g, and by adding further safety the 0.21 g, is proposed as the SSE value for imaginary site of chemical plant (Table 2).

TABLE 2

PEAK GROUND ACCELERATION

Seismogenic Zones / Provinces	Maximum Recorded	Maximum Credible	Closest Distance	Acceleration (g)	
				Sadigh	Campbell
Surjan/Jhimpir (Reverse)	5.6	7.6	110	.06	.05
Sonmiani (Diffused)	5.1	6.1	40	.08	.08
North Pab (Thrust)	6.4	7.4	105	.06	.05
Kirthar (Thrust)	6.8	7.8	110	.07	.06
Murray Ridge (Strike slip / normal)	5.9	8.0	50	.20	.21
Ornach Nal (Strike slip)	5.9	7.9	90	.08	.09
Floating	5.1	6.1	20	0.21	0.19

CONCLUSIONS AND RECOMMENDATIONS

The imaginary site is located in the southern arcuate terminus of the Kirthar fold and thrust belt and eastern frontal part of he the belt is being actively deformed and seismically active. The proposed site is located in relatively stable part of the fold and thrust belt. The cover sediments in the site vicinity area are devoid of any neotectonic features indicating that the area remained stable in the Holocene times.

- Kuch fault and Allah Band fault of the Kuch Rift zone do not extend in to Karachi area.
- Peak Ground Acceleration (PGA) up to 0.21 g has been assessed for the imaginary site.
- PGA for all existing and future sensitive civil structures in the city should be determined and pre existing structures should be reinforced
- Sensitive civil structure should be planned distant to the residential areas.
- A regulatory body should be constituted in the country which should define a uniform criteria and minimum requirement for determination of PGA. The regulatory body should have constitutional powers, to enforce its recommendations.

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