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Structural and Tectonic Control of Karachi (Pakistan) and the Possibilities of Seismic Hazards

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Abstract

Urban planning becomes an important issue where urban areas expand as a result of an increase in urban population. The objective of urban planning is to reduce the number of conflicts and environmental impacts so that the quality of life and the general welfare of the community are improved. In urban planning geological data are becoming increasingly important for the recognition, control and prevention of natural hazards and disasters. Historically earthquakes are one of the major natural hazards that have caused devastation in terms of high number of human lives, wide spread building and infrastructure failures and sufferings, as remains of an earthquake.

The major transcurrent and transverse faults and also the minor active or dormant faults in different parts of the Karachi city are self explanatory and need careful consideration the selection of sites for civil structures of industries or sky scrapers for human livings. The known active faults are expected toprovide fairly good information for the assessment of possibility of seismic hazards in Karachi area especially with reference to the work of Kukowski et al (2000) who discovered sinistral strike slip fault and named it as Sonne Fault. This obliquely crosses the wedge and continues to abyssal plain of north Arabian Sea and separate the western part of Makran subduction zone from the eastern part. The Ormara plate is considered as a tearing of the Arabian plate along the Sonne Fault. Shahid et al (2003) concluded from their study of seismotectonic and geology of the coastal area of Pakistan that the faults are potential sources of hazards. Karachi lies 150 km east of the triple junction between the Arabian, Indian and Eurasian plates formed by the intersection of Owen fracture zone, the Makran subduction zone and the Ornach-Nal fault. In the light of the historical data and the work done in the recent past, the present location of Karachi and its surrounding areas appear in the zone of severe damage where the intensity of expected shock waves are to be between 6 to9 on Richter scale.

INTRODUCTION

Karachi is one of the world's fastest growing cities with a population over seventeen millions. Structurally, the Karachi region is a part of the folded belt or Karachi Arc of Karachi Embayment. The Karachi region lies on a part of a major synclinorium stretching from Ranpathani River in the east to Mehar and Mol Jabals in the north and sea coast in the south. Within the synclinorium a number of geological structures as Pipri, Gulistan-e- Johar, Pir Mangho and Cape Monze anticlines are exposed and are also dissected by several faults. The presence of concealed synclinal structures under the Malir River Valley, Gadap and Maripur plain can fairly be deduced. Major structural trends and the basin axis strike generally south but with a bulge to the east also centers called Karachi Arc (Bender and Raza, 1995).

The epicenters of many earthquakes have good alignment with many of the active faults in Pakistan (Kazmi, 1979, Ali and Ahmed, 1993). In the western part of the Karachi, a series of transverse faults have displaced the rocks. The relative movement of individual block in relation to adjoining block has been towards northwest. The degree of lateral displacement decreases from west to east. The traces of the Sona Fault, Lal Bakhar Fault, Gulamani Fault, Goth Abdullah Fault and Goth Nek Mohammad Fault etc have been delineated (Hassan and Anisuddin, 1979, Mirza et al, 1984 and Kazmi and Jan, 1997).In addition to the above faults, major active faults around Karachi region are Surjan Fault, Jhimpir Fault, Pab Fault Hab Fault, Rann of Kutch Fault and Allah Bund Fault etc.

The major transcurrent and transverse faults and also the minor active or dormant faults in different parts of the Karachi city are self explanatory and need careful consideration for the selection of sites for civil structures of industries or sky scrapers for human livings. The known active faults are expected to provide fairly good information for the assessment of possibility of seismic hazards in Karachi area especially with reference to the work of Kukowski et al (2000) who discovered sinistral strike slip fault and named it as Sonne Fault. This obliquely crosses the wedge and continues to abyssal plain of north Arabian Sea and separate the western part of Makran subduction zone from the eastern part. The Ormara plate is considered as a tearing of the Arabian plate along the Sonne Fault. Shahid et al (2003) concluded from their study of seismotectonic and geology of the coastal area of Pakistan that the faults are potential sources of hazards. Carayannis (2006) concluded that large destructive tsunamigenic earthquake can occur similar to November 1945 earthquake along major faults in the east Makran region as well as along the western end of the subduction zone. Karachi lies 150 km east of the triple junction between the Arabian, Indian and Eurasian plates formed by the intersection of Owen fracture zone, the Makran subduction zone and the Ornach-Nal fault. In the light of the historical data and the work done in the recent past, the present location of Karachi and its surrounding areas appear in the zone of severe damage where the intensity of expected shock waves are to be between 6 to 9 on Richter scale.

A Brief Historical Background of Earthquakes in and around Karachi Region

A review of the known historical data prior to 1800 AD on earthquakes within 500 km of the city of Karachi is limited and unreliable. The catalogue of earthquakes in Indus delta of 1893 and 1894 shows that the historical town of Debal was destroyed by earthquake shocks. The epicenter of this earthquake was not in India but in Armenia, Europe where substantial evidences point to the occurrence of large earthquake (Oldham 1883, Ambraseys and Melville 1982).

Oldham (1883) also mentioned that the earthquake might have been associated with the port Debal which is not far from Indus delta. The parts of the well known city of Bhambore at a distance of 189 km from Karachi are also considered to be ruined with Debal.

Carayannis, (2006) concluded from the tsunami of November 1945 generated by earthquake on the Makran coast as the cause of severe damages and death of 4000 people in southern Pakistan. A great loss of lives and devastation also took place along the coast of Iran and Oman. He further concluded that large destructive tsunamigenic earthquake can occur similar to 1945 along major faults in the east Makran region near Karachi as well as along the western end of the subduction zone.

Structural and Tectonic Framework of Karachi Region

The structural framework of Karachi region is a result of the rifting during Triassic,oblique collision of the Indo-Pakistan plate with the Afghan blocks durng the Late-Cretaceous and Palaeogene and by post collision deformation during Neogene and Quarternary periods(Bender and Raza,1995).

Ornach, Rann of Kutch, Sona Pass, Lal Bakhar, Ghulamani and the subsurface faults which have been described briefly for better understanding of the possible hazards that could occur in the area.

At present Karachi area appears to be unfortunate of being in many seismic gaps along the fault zones which may be expected to be active any time. Karachi lies approximately 150 km east of the triple junction between the Arabian, Indian and Asian plates, (Fig 1). According to Apel et al (2006), the western and north trending arms of the triple junction sustain convergent and transcurrent movement rates of 35.5 and 42 mm/year respectively. The recently discovered active fault known as Sonne Fault indicates that the Arabian plate has been fragmented across the south western corner of the triple junction. The Ormara plate whose velocity is related to Arabian plate increases the subduction below by few mm/year as compared to the rate in the west (Kukowski et al, 2000). Two other active structural zones also have produced damaging earthquake that have been felt in the city in the year 2000. The residents of Karachi felt shocks also from earthquakes of Makran, 1945 and Bhuj, 2001, which produced documented damages. The thrust and fold belt extending northward parallel to the transform fault separate India from west Asia with anticlockwise rotation of the Indian plate.

Active Faults system in and around Karachi

The information related to some of the following known faults and their activities in Karachi city provide fairly good information so far as the assessment of the possibilities of seismic hazards in the area is concerned.

Major Active Faults

The major important active faults related to triple junction and their possible activities are briefly described to assess the possibilities of seismic hazards in Karachi area. Ornach Nal Fault is active and is considered to be the offshoot of Chaman Fault by some of the geoscientists. However according to Jacob and Quittmeyer (1979), and Kazmi (1997),the seismic evidences have been directly traced to this fault upto this time, but the probability of large earthquake event in Karachi may be possible in future.

Rann of Kutch Fault is well known fault in Kutch Area of India at the eastern border of Pakistan; and is marked as a probable source of future, major to moderate earthquakes in the city of Karachi. It indicates that the hazard lies due to the faults present in and around the city of Karachi and are described in chapter- 1 of the present thesis.

A violent earthquake of magnitude 7.8 occurred in Kutch area of India on July 1689 in and affected the towns of Bhuj and Ajmer of India. The shocks of this earthquake were also felt as far as Calcutta in the east at a distance of about 2000 km. In the west river courses were changed, the loss of life was very high and Allah Band geomorphic feature appeared as dyke in eastern part of Pakistan due to heap of earth reef. Similar earthquake occurred in 1956 at Anjar in western part of India and caused significant death and destruction in the city of Ahmadabad and Gujarat of India and also in Thar-Parkar and Indus delta of Pakistan (Mirza et al, 1984).

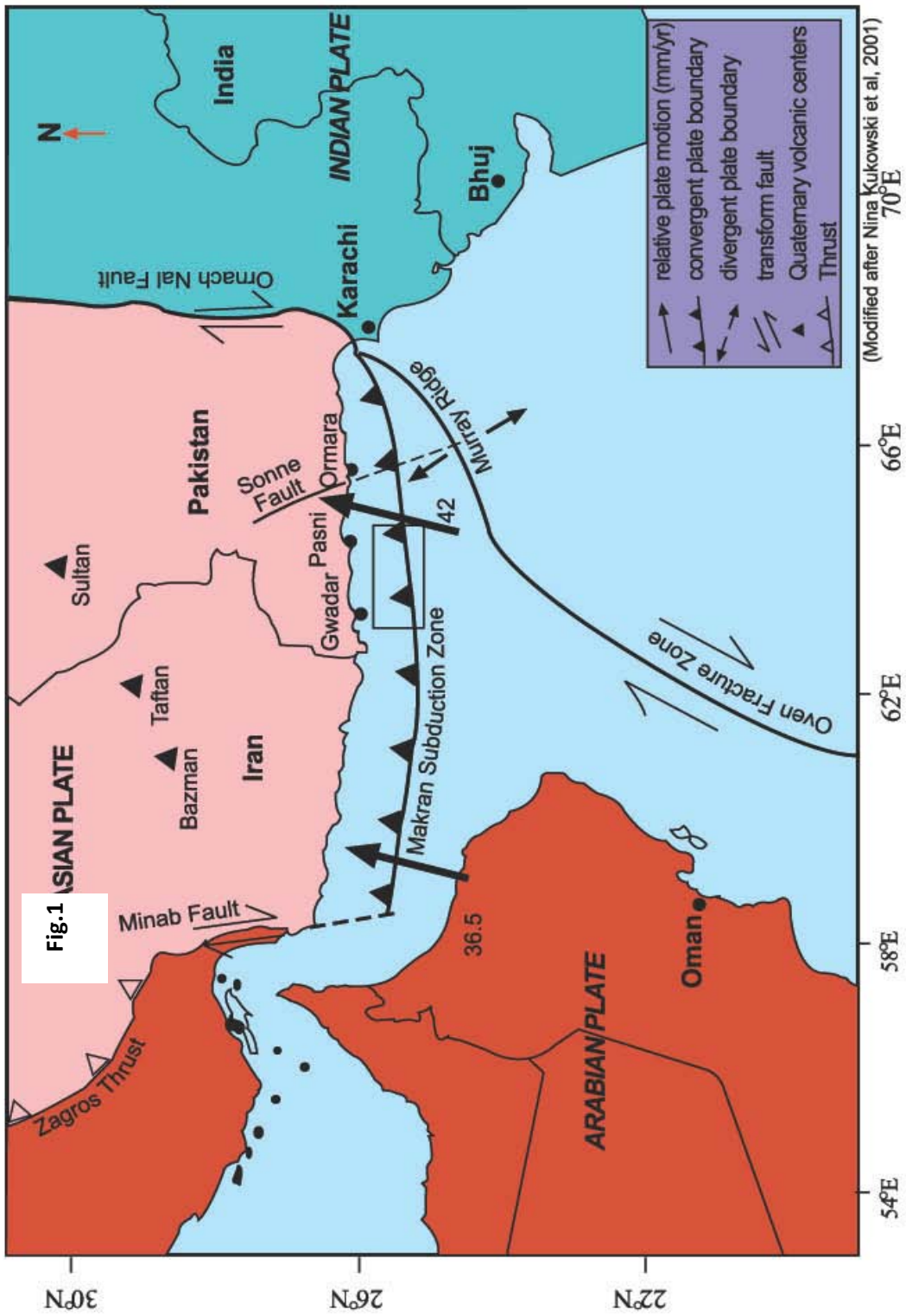

Fig. 2.2 Schematic map showing present - day plate tectonic frame work of Arabian - Indian - Eurasian Convergence Zone

Fig.1

The city of Karachi is near to a plate boundary of triple junction and within the reach of earth-quakes due to the presence of several tectonically active faults like

The Allah Band fault is more than 230 km away in south-east of Karachi. The area between Allahband and Karachi is cut across by 18 km width of mud, marsh and tidal lagoon of the Indus. The Rann of Kutch Fault and its possibilities to continue toward Karachi as an active fault need to be ascertained as yet.

Minor Active Faults

In addition to major faults, a brief description of the minor active faults and the subsurface faults in different parts of Karachi also appear relevant parameters

to be evaluated for over all tectonic control assessment of Karachi area (Fig 1.4).

A series of transform faults have displaced the rocks in western part of Karachi. The general displacement is in northward direction. The lateral displacement decreases from west to east. Hassan and Anessuddin (1979), Mirza et al (1984) and Kazmi and Jan (1997) have traced and delineated faults within Karachi city limits. The well known active faults like Sonapass, Lalbakhar, Gulamani, MoachKoh, Surjani and Hub are not far from the city of Karachi and need thorough investigations for the possible seismic hazards in future. At present these faults are characterized as tele-seismic events of shallow focal length with magnitude 3 to 6 on Richter scale. The detailed information related to these faults is also needed to consider the possible impact on planning and development of the ever-expanding Karachi city in respect of population and industries. Most of these faults in general exhibit parallel orientation in northwest- southeast direction.

The subsurface geological and structural details of Karachi urban area need to be investigated in detail to find out the faults in addition to major and minor structures below the recent and sub-recent sediments which are being considered as foundation material of civil structures of variable sizes (Fig. 1.4). Since the depth of the soil in different parts of the city are variable in addition to their geotechnical characteristics like porosity, permeability, mineralogical composition, stress-strain characteristics and Atterberg limits coupled with variable moisture content.

Risk of Liquefaction in Karachi

There is a great possibility of liquefaction of the foundation material in Karachi. In case of earthquake shocks the process of liquefaction will be enhanced due to leakage and seepage of water supply lines, sewerage lines and the use of septic tanks especially in low income areas of the city.

According to Waltham (2002), the drainage reduces pore pressure and thixotropic recovery of the strength. During seismic conditions strong shaking produces liquefaction in the fine sand/silt. In such a situation the mineral grains are settled and the interstial water is expelled to the surface. If the pore water rises to the level approaching the weight of overlying soil, the soil behave as viscous liquid rather than as solid and collapse of civil structure takes place. The possibility of liquefaction is great in the area where groundwater lies within 10 m of the ground (Hussain et al, 2004). The above mechanism of liquefaction indicates great possibility of this process to occur in Karachi area because of the disturbance in soil-moisture density relationship in the foundation of soil of Karachi due to seepage and leakage of water from sewage and water supply lines and the common presence of septic tanks etc in different parts of city. The liquefaction may cause ground cracking and surface settlement which can be evidenced in settling of overlying structure or floating of underground structure due to oversaturation of soil with water. Liquefaction is extremely damaging agent to civil structures. It has already caused destruction in Alaska and San-Francisco (Pinty, 2003). Similar effects of minor scales have been observed in DHA locality of Karachi. The ground failure due to liquefaction has also been observed in New Madrid in Spain, Bhuj in India and Hazara and Kashmir areas of Pakistan due to earthquake which caused 3 ft vertical and 6 ft to 33 ft lateral displacement (Tuttle, 2001). It appears relevant to describe that the liquefaction features caused by earthquakes were also observed in Nagar Parker and Badin districts of Pakistan at distances of about 350km and 70km in southeast of Karachi.

Seismic Zonation of Karachi Region

In this connection the epicenters of the earth-quakes occurred regularly in different parts of Pakistan have been integrated and plotted on the map by the GSP in 2006 with the title of Seismic Hazard Zones of Pakistan (Fig 2). The map explains the different zones in which the intensity of seismic hazards ranging from 9 to 6 have been plotted and shown as zones. This map appears as a good reference map to asses and evaluate the possibilities of seismic hazards in different parts of the country in general and Karachi in particular.

On this map the location of Karachi and the surrounding area appear in the zones of severe and minor to severe damages where the intensity of shock waves were noted between 7.5 and 9 on Richter's scale.

These seismic zonations especially in Karachi urban and its surrounding area need to be considered in terms of the submarine Oven Fracture Zone and its continuation which passes through Murray Ridge and ultimately joins Ornach Nal Transform fault in Axial belt. The other element is of subduction zone of Makran which also meets the Axial belt zone at the triple junction in the west of Karachi.

The presence of seismic zone of Bhuj at the western border of India but not far from Rann of Kutch of Pakistan should be taken in account during the assessment of possible seismic hazards that could contribute hazards in Karachi and its surrounding areas. The 2001 earthquake of Bhuj of fairly high intensity (7.5) was felt in different parts of Karachi, like Malir, North Nazimabad and Gulshan-e-Iqbal Towns. The indication of seismic effects as cracks in building can still be observed in the towns mentioned above. Allah Band geomorphic structure developed due to liquefaction effects of past seismic activities in Gujrat of India is still a historical moment in this regard. The seismic shocks of 6.3 on Richter scale felt in the month of Feb: 2011 which occurred in the upper northern part of Dalbandin, Baluchistan area of Pakistan was very much felt in different parts of Karachi city.

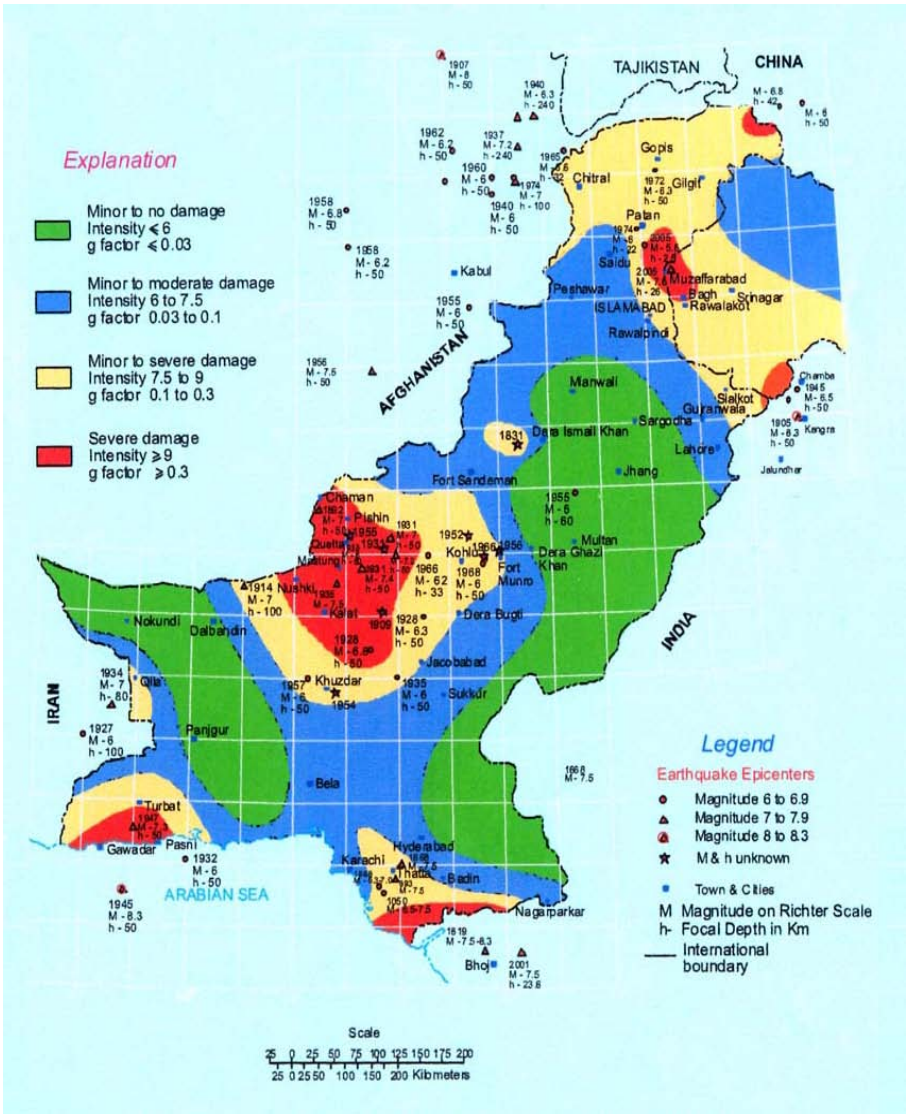

Fig 2. Seismic Hazard Zones of Pakistan
(After Geological Survey of Pakistan, 2006)

CONCLUSIONS AND RECOMMENDATIONS

It is significant to note that Kutch region is about 300 km away from active plate boundaries but showed displacements of the structures. It is therefore reasonable for the scientists, working for the assessment of possible hazards in Karachi to take into account the active plate boundaries of triple junction at a distance of 150 km from Karachi, and also consider the recent active zones of seismic activity that may jolt the region anytime and bring disaster of lives and properties.

In Karachi area, the foundation soils are of varying types in respect of texture, amount of clays and non-clay minerals, silt fractions and to some extent the organic constituents in different parts of the city. In coastal areas uniformly graded, coarse grained, poorly packed, relatively poor density soils are common. The reclaimed soils representing to fills areas are also being developed to settle the incoming population in the city. In this type of locality great care is needed during ground improvement for civil structure because in such types of foundation material settlements do take place for a longer period.

Some of the text books examples of ground fill indicate a period of about 25 years for the ground to be stable for civil structures (Sower, 1979). However the choice of architectural designs of the civil structures may reduce the time period for the utilization of ground and can survive the earthquake shocks upto 7 on Richter scale.

According to Bilham et al (2007), Karachi is closed to an active plate boundary and is literally surrounded by known active and subsurface faults. They equate Karachi city with the

well known mega cities of Los Angeles and California of USA. They also described that Karachi has not experienced any significant damaging earthquake in the past 150 years. If the faults start moving significantly the hazard in Karachi would be compound and more disastrous due to non-availability of building codes which need to be improved for safety of civil structures and demographic safety to the people.

Keeping in view the deadly Kashmir earthquake (2005), the government of Pakistan has to develop new hazard map of the country to update the expected seismicity areas in general and the southern part of the country including Karachi in particular which may be subjected to serious seismic hazards in the years to come.

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