Geology of Salt Range and seismic risk analysis

Géologie de Salt Range et analyse du risque sismique

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SYNOPSIS The region of Pakistan represents a most interesting seismic geology setting where boundaries of interacting plates and micro plates are present. Some of these are characterized by active faults. This paper discusses the recent studies carried out in the Salt Range, which has occupied the interest of various researchers; however, its seismic geology and its engineering implications may not have been clearly understood.

In recent years a substantial amount of data has been gathered by means of telemetered seismic networks, seismic profiling and deep drilling. In the light of this background the Quaternary Geology of the Salt Range has been examined which has revealed that the Salt Range represents a major thrust along a salt lubricated decollement. The frontal face is also characterized by active strike-slip faults such as the Kalabagh Fault. Several exposures representing movement in alluvial deposits have been detected and it has been concluded that various faults in the Salt Range are capable of generating large earthquakes.

The historic record does not indicate occurrence of any major catastrophic earthquake associated with this frontal zone, whereas the seismic geology indicate the potential of ground rupture and consequent major earthquakes. The design of major engineering structure in this area therefore poses a major proposition of engineering judgement.

GEODYNAMIC SETTING OF PAKISTAN

A study of tectonic pattern of the globe shows that the tectonic mechanism within the earth's crust are primarily confined to the narrow zones associated with edges of the crustal plates. Therefore the level of seismicity for a region will depend upon its location with respect to the boundaries of the plates and also on mechanism of movement of plate boundary. (Abul Farah et al, 1979). The mountanious regions of Pakistan are the result of collision of continental parts of Indian and Eurasian plates.

About 40 million years ago in Late Eocene to early Oligocene period, continental collision between the Indian and Eurasian plates started and with that began the formation of the Himalayan ranges (Powel et al, 1973). The Himalayan orogeny reached its most voilent stage during middle Miocene age when the great granitic masses were intruded into the Himalayas. The other mountains in northern Pakistan, like Hazara, Salt Range, Sulaiman Range, and Kirthar Range have also resulted from the collision of the continental portions of Indian and Eurasian plates. The northern region of Pakistan which is a zone of convergence depicts extensive folding and thrusting. Some recent studies (Seeber et al, 1977) indicate the development of extensive decollement surfaces. The Salt Range forms the southern most portion of the Himalayan mountain system where the lower most sedimentary formation is exposed while the basement rocks are exposed just 50 km south of these ranges.

TECTONIC OF SALT RANGE

The Salt Range comprises a narrow zone of intense deformation resulting in tight folding faulting and uplift in the west.

The uplifted block of the Salt Range is interpretted as the upthrown block of a low-angle thrust fault, along the Precambrian salt formation and the basement rocks. It may in fact be a decollement between two formations with a great contrast in its strength. The seismic survey carried out in this region indicate P-wave velocity changes from 3.0 km/sec. in the sediment to 6.5 km/sec. in the basement. Salt Range is relatively young, since Siwalik group of Miocene to Pliestocene age have been fully involved in its deformation.

QUATERNARY GEOLOGY OF SALT RANGE

Salt Range has occupied the interest of geologists since the early part of this century, but the emphasis has been more on understanding its structure and stratigraphy. The authors have studied the Quaternary tectonics in order to evaluate its engineering significance. The importance of geological studies for evaluating seismic risk has been realized in recent years and analysis of earthquake record of countries like China, Japan and Turkey have shown that Active faults having potential for creating large earthquakes, can go through a quiet period of several thousand years (Allen, 1975). Therefore historical record of earthquakes is not usually long enough to carry out a realistic analysis of the seismic hazard. Hence it becomes imperative to study the tectonics of the region and to investigate for any possible indication of recent movements along the faults. Active faults can be evaluated for their maximum capability to generate earthquake through a synthesis of the local geologic and seismic history and worldwide relationships between fault dimension and earthquakes (Slemmons, 1977). Several well known fault length-magnitude relationship have been developed by different authors which are being used worldwide to assess the earthquake potential of faults.

The narrow zone of deformation formed by the Salt Range has been studied through ERTS Imagery, aerial photographs, air reconnaissance and field verification of suspected features. The Salt Range can be sub-divided into three main sections: (i) The frontal bulge, (ii) The syntaxial bend, (iii) The arcuate Trans-Indus Ranges. The major faults which govern the seismicity of this region are described below:

i) Salt Range Thrust:

The frontal bulge of the Salt Range has been studied between Khewra and Musakhel (Fig. 1) and several exposures have been examined. There is abundant evidence of older rocks of Permian and Cambrian age thrust over fan deposits. In various areas along the frontal face alluvium has been found to be tilted. At Katha an exposure was examined extending for more than one kilometer where alluvial deposits of silt with occasional layers of subrounded gravels are seen along the frontal face. Here the Salt Range formation (the oldest sedimentary formation) could be seen thrust over alluvium, the contact could be more than 400 meters.

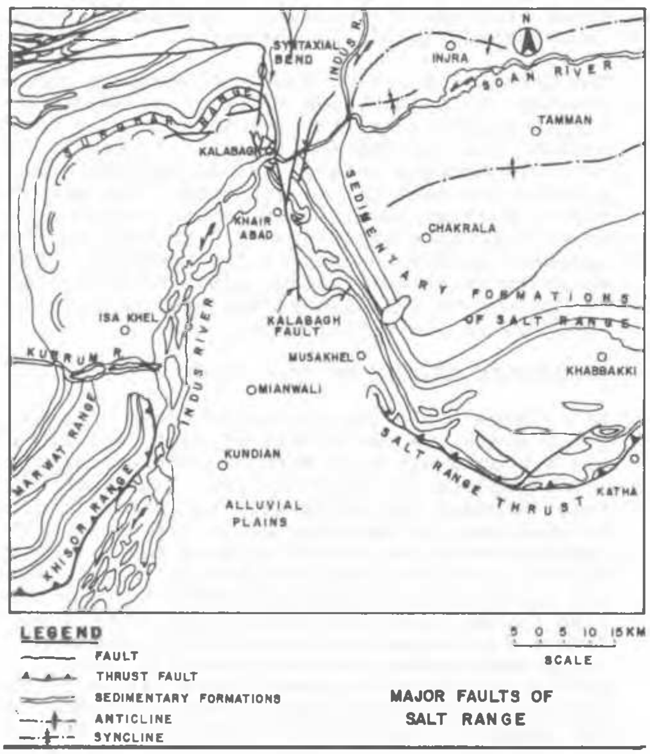

Fig.1 The Major faults of Salt Range

ii) The Syntaxial Bend:

The syntaxial bend is characterized by a major strike-slip fault referred to as the Kalabagh fault. The tectonics in this area are extremely complicated, here Salt diapirism is taking place as well as recent tectonic movements are noted in terraces and fan gravels.

Some of the most remarkable exposures of recent tectonic activity along the Kalabagh fault are found between the Kalabagh Town and Khairabad village area in the south. Thrust faulting involving bedrock over alluvium as well as thrusting of alluvial gravels is found as seen in Fig. 2.

Near Khairabad, faults are seen in terrace gravels and alluvial fan deposits shown in Fig. 3.

Fig. 2 Faulting in terrace deposits near Kalabagh Fault

Fig. 3 Faulting in Fan-gravels near Khairabad

iii) Arcuate Trans Indus Ranges:

The Trans-Indus Salt Range comprises the Surghar, Shinghar and Khisor Range (Fig. 1). These Ranges have been studied and evidence of tectonic activity is found along the frontal face of Khisor Range.

Khisor Range is the southern most of the arcuate ranges. Faulting is present along portions of the front of this Range where evidence of recent movements has been found at several locations along the fault.

SEISMICITY AND RISK ANALYSIS

The three major faults associated with the frontal face of Salt Range have been studied and analysed. Evidence of movements in the alluvium overlying these faults indicate that these features are active and capable of generating large seismic events of the order of Magnitude 7.

Available instrumental record in the Salt Range area shows that maximum earthquake was of magnitude 5. In addition some events of magnitude 4 and a number of micro-seismic events have also been recorded. Evaluation of the micro-seismic data suggests that the micro events are not aligned along any particular pattern but are occurring randomly, and this situation would be understandable in the seismo-tectonic setting of the Indian Plate which is active.

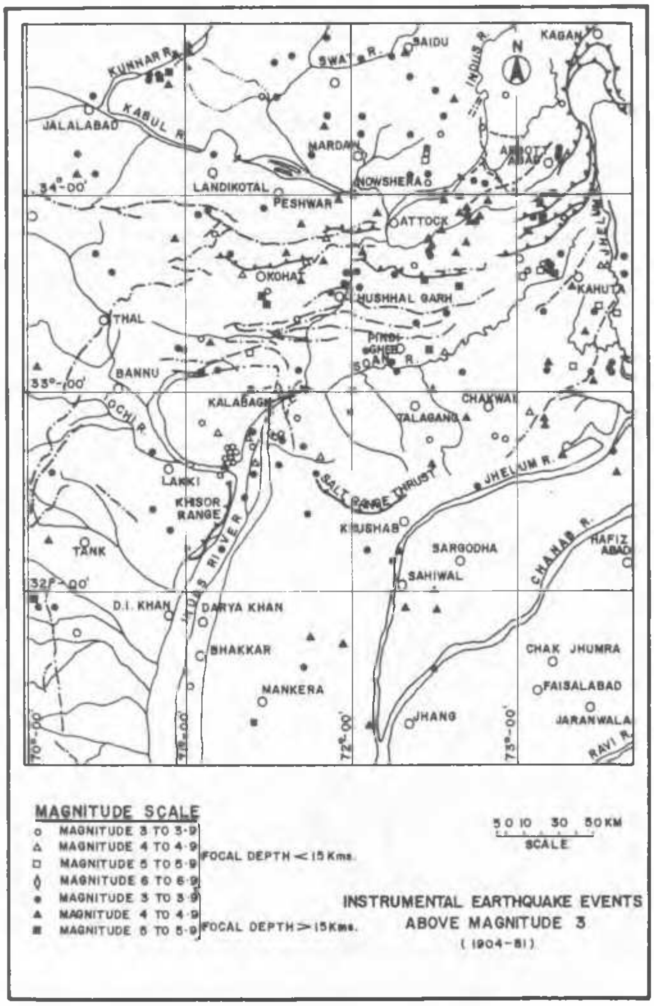

Fig. 4. Instrumental Earthquake events above magnitude 3.

Historic record of a number of events of intensities VII to X have been found associated with the Hazara Thrust system which is about 100 km north of the Salt Range, but there is a significant lack of any historically recorded felt intensities in Salt Range area. This may be due to a comparative scanty population.

The historical and instrumental seismicity indicate the absence of any major event in the vicinity of Salt-Range. The instrumental data reflects few scattered events of Magnitude 4+. The Quaternary geology however show ample evidence of tectonic movements within gravel terraces and fan deposits. For assessment of seismic risk, the Salt Range presents a peculiar situation where the earthquake potential appear to be far greater than what is reflected by the recorded siesmicity of the region.

The existing seismic maps are based on historic record and therefore show this area within a very low seismic zone of the country. However, the seismo-tectonic and geologic studies done in the recent past have picked up evidences, which indicate that the large faults in the Salt Range area have moved in recent geologic time and should be considered active. Therefore these deterministic features cannot be ignored while designing major civil engineering structure in this area. To what extent the structure built in this area should be safeguarded against a potential seismic hazard which may be caused by movement of the capable fault is a matter of engineering judgement, coupled with cost economics depending on the risk which owners are willing to take for possible damage to the structures. Engineering judgement based on all the facts would probably be the most important factor. All those structures, failure of which can cause major hazard to life and property, would have to be designed against conservative estimates of seismic factor. On the other hand, ordinary buildings or structures, where only property damage is involved, it would be un-economical or probably even unwise to design on very conservative factors. The concept of Maximum Credible Earthquake and Operational Basis Earthquake could be very useful in the decision making process. Maximum Credible Earthquake (MCE) could be based on "deterministic" geologic feature like rupture potential of the nearby faults and corresponding estimate of ground motion using appropriate attentuation laws. It should be ensured that major structure like big Dams, Power Plants etc. to be designed in the area may get damaged during the MCE, but would not fail so that they would cause catastrophic loss of life. The Operational Basis Earthquake (OBE), which will represent a lower design earthquake could be selected for each type of structure depending upon its importance and hazard potential. The OBE could be based on a "probablistic" and statistical approach. The structures should be designed to remain fully functional during the OBE.

CONCLUSIONS

1. Geologic and seismotectonic studies carried out recently in the Salt Range area of northern Pakistan have shown existence of Active faults, with high earthquake potential. The available historic and instrumental record, however, do not produce evidence of any large earthquake experienced in the area.

2. The Authors recommend that all major structures to be built in the Salt Range area should be subjected to detailed seismo-tectonics studies, coupled with cost and risk analysis,

3. The concept of Maximum Credible Earthquake and Operational Basis Earthquake would probably provide a satisfactory solution in selecting the earthquake design parameters for each type of structure to be built in the area.

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