International Journal of Earth Sciences Knowledge and Applications (2022) 4 (1) 19-25

IJESKA contribution to science

International Journal of Earth Sciences Knowledge and Applications
journal homepage: http://www.ijeska.com/index.php/ijeska

Research Article

e-ISSN: 2687-5993

Cracking and Causes of Ground Displacement in Rawat Rawalpindi Pakistan (Causes and Effect Report)

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INFORMATION

Article history
Received 19 March 2021
Revised 11 June 2021
Accepted 12 June 2021

Keywords
Ground displacement
Soil liquefaction
Foundation
Seismicity
Tectonic activity

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ABSTRACT

Numerous fault and fold system are found in Pakistan and its surrounding region which is tectonically active region in entire Asia subcontinent. This research is related to earthquake happened at 24 July 2015 in Islamabad, Pakistan. A policed constabulary building hit by moderate earthquake causes to produce damages at significant level. Their cracking, settlement and ground displacement open the new door of research. This report is generated after field visit under supervision of senior engineering and geologist. Rawat Fault was a sourced which is thrust fault due to Jhelum strike slip fault mechanism. Deep cracking was observed in and outside of wall due to breaking of plaster. Minor level of ground displacement which is about 2 cm to 3 cm was observed during field in the direction of fault lines. Further more intense tectonic area including Rawat Fault which is part of Jhelum Fault is an active fault in the regime. Three numbers of pit were excavated to observe the settlement of sub surface soil. At few places settlement was pointed due to seismic wave propagation and there is no sign of liquefaction of soil. Its mean liquefaction potential at this area is normal and water table is not at shallow depth. Heavy thunder storms accompanied with earthquakes may had triggered the liquefaction of sensitive clays which had resulted in differential settlement in localized areas. The ground shrinkage cracking may have resulted due to suction of water by Eucalyptus trees planted very close to the foundations.

1. Introduction

Pakistan geographically located in the south Asia connected from north east with China eastern border with India. In south western, it makes Iran border and in western side Afghanistan situated with northern edge. In southern part 1.054 km (approx.) coastlines with Arabian sea attached with Pakistan as shown in Fig. 1.

The Pakistan capital Islamabad and attached city Rawalpindi called twin cities are overlain by main boundary thrust (MBT) which produce several kinds of fault like Murree Thrust, Jhelum Fault and Rawat fault. This study is related to visit of the Rawat building of constabulary police department which is much effective due to seismotectonic activity generated by an earthquake on 24 July 2015. The epicentral location of an earthquake is 33.8840, No, 73.2250 E with *Mw* = 5.1km along 19 km focal depth. The site was beneficial for research purpose especially considering the ground movement which can be clear observed and their cracking patches visible as much. A team was constituted under the supervision of director Road Research and Material Testing Institute (RRMTI), Junior research officer, research assistant (Author) and seismologist research scholar for visiting the building site. This report is based on real data from field and taking some data from Nilore Seismic Station which was installed by Pakistan Meteorology Department. The constabulary building was sited at km 170+00 on the left side of G.T. Road south of Rawat Town (Rawalpindi). It lies between latitude 33.25. to 33.28 North and longitude 73.12 to 73.15 East.

The relief of area is generally rolling which is part of Potwar loess plain. It spread from Lawrencepur to Gujar Khan. The soils occur in 2 to 3 % gently sloping part of the loess plain. The average annual rainfall varies from 30 to 40 inch. It generally pours during July to September under high intensity rain storms, however minor percentage of it is received during December and January. There are two pronounced dry seasons spreading from May to June and mid-October to November.

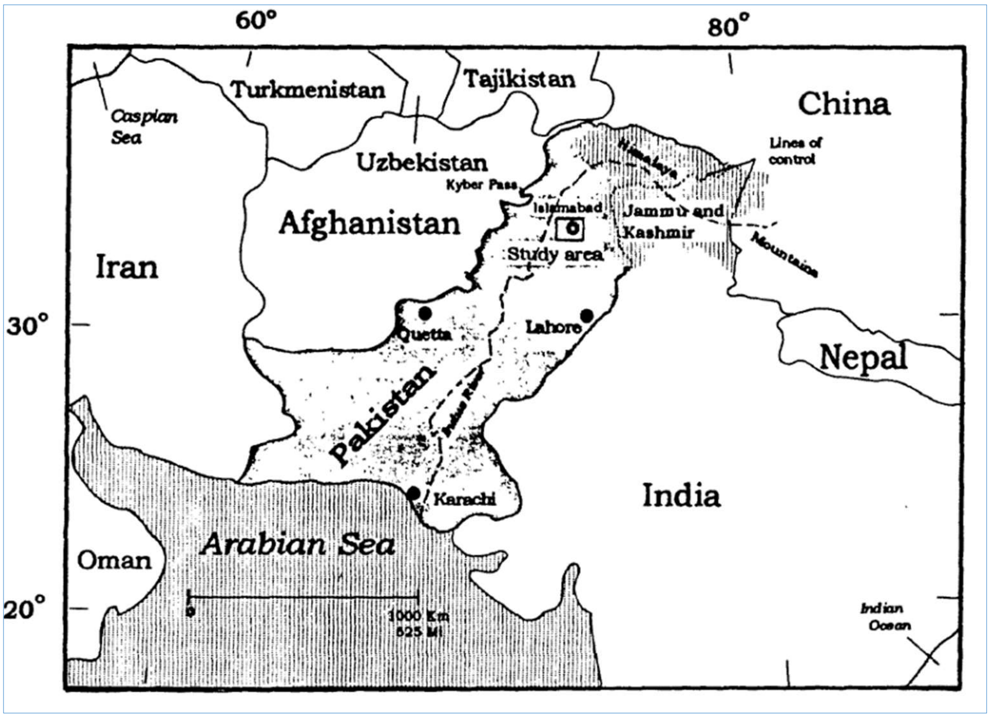

Fig. 1. Geographical map of Pakistan and study location (box) region (modified by William et al., 1990)

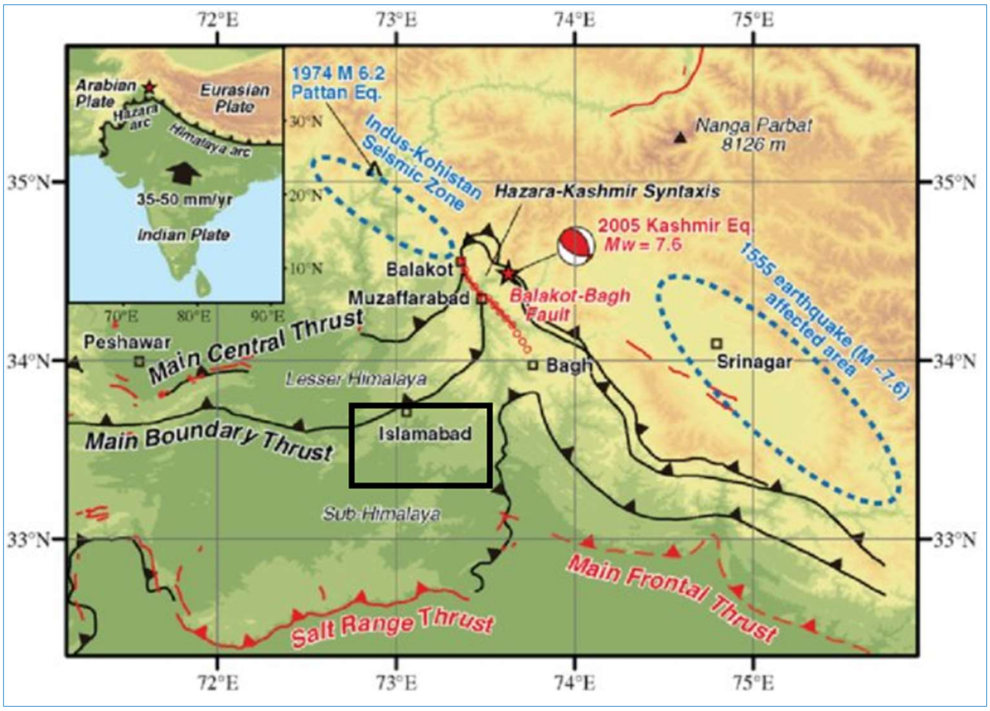

Fig. 1. Location map (Courtesy: Internet and Google Earth Pro)

2. Tectonic Setting of Rawat site of Rawalpindi-Islamabad

The area under discussion is part of the northeastern Potwar Plateau. It comprises of Siwalik rocks altering sand and shale/mud stone deposits and Potwar loessic deposits. The geological structure occurring in the area which has developed in response to Himalayan tectonic compression stresses as shown in Fig. 2 for Rawalpindi and Islamabad tectonic setting. It is structural flexure encountered south of Rawalpindi. it is a flat-bottomed southwest plunging fold with a steep northwestern flank and a shallower southeastern flank Fig. 1. The axis of the syncline lies a little south and is roughly parallel to the Soan River (Verma, 1991). The eastern part of the syncline is a simple axis bounded on the northwest by a complex, faulted, severely. Compressed anticline in the Murree beds and on the south east by a strike fault of great throw i-e Rawat Fault. The strata in the central part of Soan syncline have undergone very little internal deformation. Seismic lines north of the Soan River shows that the broad folds within the Soan syncline give way at depth to north dipping imbricate stack.

The sedimentary sequence is tilted steeply southward and the base of the section is marked by north dipping decollement. Geomorphological structure "Butter (Mankiala Anticline)" was there at site. Its orientation is NE trending fold developed northeast of Rawat Fault and across Mandra structural saddle. It preserves Soan Formation overlaying Dhok-Pathan sand stone on its western flank. It is truncated in the northeast by Kahuta Fault (Rafi, 2012).

South of the Soan Syncline, the first major brittle structure is the Rawat Fault. Interpreted to be an out of sequence. Out of syncline thrust. This fault is a southward verging thrust that juxtaposes lower and middle Siwalik deposits. It is a good example of thrust fault dwindling in throw and merging into an overturned fold.

The footwall in the south of Rawat had more probably sheared. Geologically Rawat Fault in Pakistan which spread through Rawat Punjab, Islamabad to Kashmir. This fault and Himalayan Salt range is generated by Indian and Eurasian tectonic plates collision. According to the English deputy commissioner this fault line of boulders stated as Rawalpindi Gazetteer in 1893-94 as dogs' teeth (Fig. 3a and b) in Rawat Rawalpindi for their elevation.

3. Seismicity

The Himalayas represents the most extensive active collision zone in the world active foreland thrusting is occurring on a continental scale as the Indian shield is being overridden by its own northern margin in a series of south verging thrust. This active tectonic set up of Pakistan is responsible for the accumulation of stresses and consequently the high seismicity ranging from micro earthquake to major earthquake occur in this area (Seeber et al., 1981). The tectonic earthquake, by mechanism is related with the fault, which become active through accumulation of stresses over geologic time.

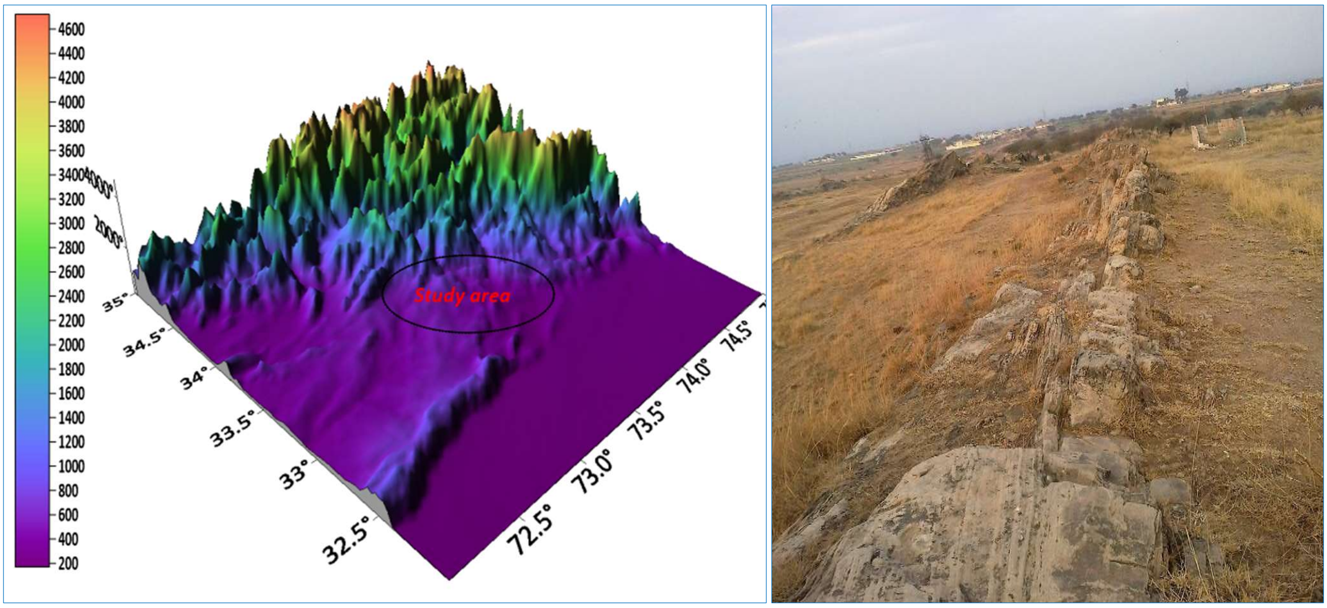

Fig. 3. a) Hill shade view of the study site near Rawalpindi-Islamabad city and b) Rawat Fault line across the Rawalpindi like dog teeth

The seismicity map of Pakistan and its surrounding region can be seen in (Fig. 4) in which red box showing the study area. Rawalpindi and Islamabad Cities captured by Jhelum and Rawat Fault lines and the seismicity around these two cities are moderate to severe. The highest earth around the Jhelum Fault shown (Fig. 2) can be seen near Balakot. When these stresses in the fault zone over frictional forces, a displacement or rupturing take place. Larger the frictional force major is the earthquake. Active fault and lineament were marked in Pakistan by (Kazmi and Jan, 1997). Some of them are considered seismically very active because the epicenters of many earthquakes have good alignment with them. However various epicenters do not appear to have any relation with fault (Khalid et al., 2016). It is must be borne in mind that micro earthquakes may not well define a major dipping fault plane but may occur on numerous small fault blocks either side of it. Since some continental earthquakes have focal depths between 5 and 20 km. The apparent lack of earthquake on fault does not necessarily mean that the fault is inactive.

The significant of such fault in any way is much more connected with their proximity to major fault and possible activation in response to nearby large earthquake (Khalid et al., 2020). The creep, movement too slow to radiate seismic energy have been observed on faults of all scales in many parts of the world and may occurs before or after major earthquake. In the Himalayan Mountain system, the seismic moment release can account for less than half the overall Indo Pak plate northward into the Eurasia (Farid et al., 2018).

In Rawalpindi earthquake of magnitude ranging from 4.5 to 5.0 on the MM scale have occurred in since 1904. On February 14 1977 a magnitude 5.8 MM scale earthquake occurred in Rawalpindi area having an epicenter seven-kilometer northeast of Rawalpindi and another earthquake happened in July 2015 have same impact. It was widely felt in the region and it caused considerable damage in the epicenter area near Nilore.

The geometry of the rupture plane related to this earthquake was determined by accurately locating about 50 aftershocks. The dip of plane was 450 to southeast (Seeber and Armbruster, 1979; Seeber et al., 1981). The hypo central location was determined in the same vicinity. Two out of four earthquakes were found aligned with Rawat Fault in Rawalpindi Kahuta Area. Rawalpindi Islamabad fell in moderate seismic hazard zone with intensity VII of MM scale. The g value factor for Islamabad Rawalpindi was worked out to be 0.2 to 0.3 (Lisa et al., 1997).

Pakistan atomic energy commission is vigorously investigation seismic tectonic of the area for safety of their projects. Effect of earthquakes whether moderate or intense is shown as under:

On Ground:
- ✓ Fissure
- ✓ Settlement
- ✓ Landslide
- ✓ Liquefaction
- ✓ Earth pressure

On Man Made Structures
- ✓ Cracking
- ✓ Sliding
- ✓ Overturning
- ✓ Buckling
- ✓ Collapse

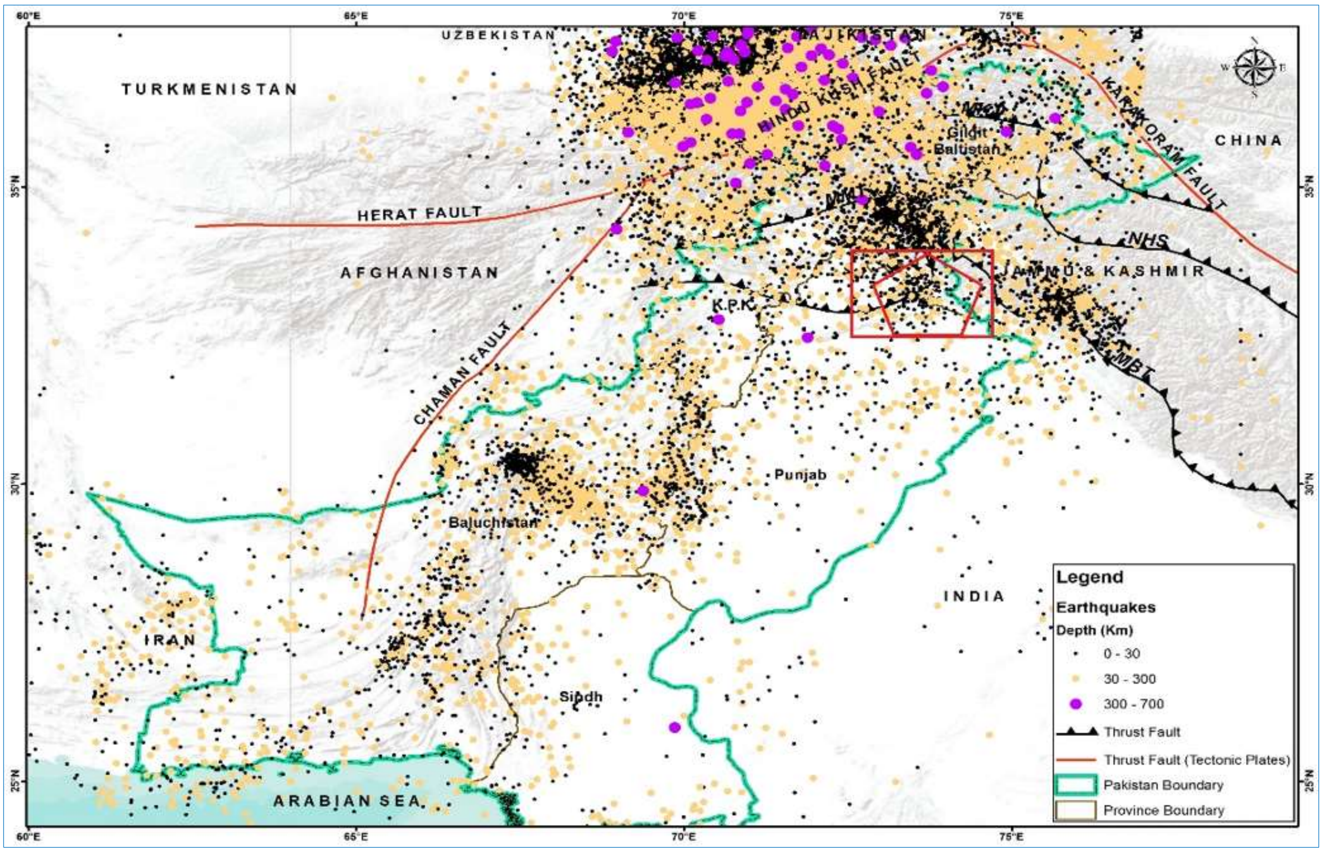

Fig. 4. Seismotectonic map of Islamabad and Rawalpindi Regions

4. Soil Profile

The soils at the site are a part of Potwar Loess deposit. These soils had developed in late Pleistocene. The difference in soil characteristics was attributed to variation in relief. Climate and age of the surface. These soils were deposited over the structural surface developed by the folding/faulting of middle and upper Siwaliks (sand stones and mud stone rocks with minor gravel). Under the influence of Himalayan Mountain building forces. The loess material is calcareous, which occupies level to nearly broken land sloping 2 % to 3 % southward in this case where infiltration is relatively high (Hassan, 1972). As a result of leaching its profile had been decalcified to the depth of 1.75 feet to 3.25 feet. Clay has moved from surface to the sub soil. Moreover, some primary soil mineral particles had decomposed to form clays. The soil profile of police barracks and inspector's residence was comprised of lean clay CL. Lean clay with sand to sandy lean clay from natural surface level (NSL) to 15-16 feet depth. Soil corrosion potential may determine for new construction in near future for better understanding of soil nature (Khurram et al., 2020). Otherwise, liquefaction potential can be estimated on subsurface parameters.

Table 1. Cracking observation during field visit

Degree of damages	Description of typical damage	Approximately cracks width	Building
Severe cracks in walls diagonally starting from roof slab toward damped proof course (DPC) (Fig. 5)	Window and door frames of residential barracks distorted. Floor sloping noticeably. Walls leaning or bulging. Service pipes may be disputed. Movement at the interface of long wall and DPC	15-25 mm. it also depends on number of cracks	Barracks
Very sever. Cracks starting from roof slab diagonally toward DPC with secondary shear cracks this can be seen in Fig.7	Walls lean badly toward southeast direction windows with distortion	Normally more than 25 mm but depends on number of cracks	Commandant Office

The soil column for the site of residence of constable/dafti/Naib Qasid from NSL to drilled depth was constituted by altering strata of lean clay CL, highly plastic clay CH and silty sand SM. An appreciable lateral movement/displacement up to one-inch of wall was observed at the DPC brick wall interface in one residential barrack.

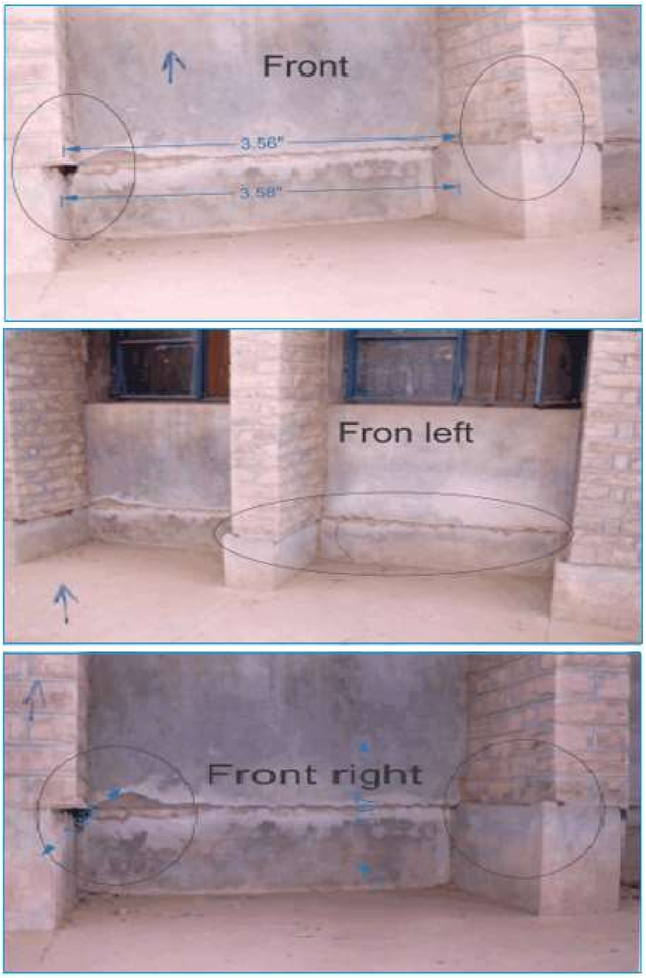

Fig. 5. Ground displacement of building after earthquake

Whereas severe lateral movement/ displacement [1 inch to 3 inches] was observed in commandant office building. There was no cracking in cross walls of barracks neither in the long walls of Mess which are parallel to cross walls of barracks. In case of commandant office, all the walls showed primary distortion and secondary shear cracks initiating from roof slab downward to DPC. Transverse crack on the road at one place was visible which was in line to the cracks in the wall of barracks on both sides.

5. Results and Discussion

During an earthquake, a structure is subjected to a forced vibration imposed upon it by the movement of its foundation. The inertia of structure tends to resist the movement of the foundation. Therefore, at the foundation there is a shearing force/base shear imparted to the structure in order to make it move and displaced the ground as shown in (Fig. 5). The ground movement left to right indicate the strike slip fault in thrust regime.

This structure will be stable. In case of more than one tenth of acceleration of gravity (g value), the structure may not be safe. The g value ranging from 0.2 to 0.3 has been recommended by (Lisa et al., 1997) for thin area. The movement of a foundation during an earthquake are continually reversing and changing. Therefore, the forces are also continually reversing and changing.

If the system had a very small mass (m) and very short rigid strong foundation, its period of vibration would be small. During an earthquake with a long period, this system would move practically with ground. The lateral forces in this case would be equal to the mass of structure multiplied by the acceleration of earthquake g. If the rigidity of the system should gradually have diminished either through liquefaction or creep of the underlying clayey soil. Its natural period of vibration increased approaching to that of earthquake period.

The amplitude of motion at top would magnify as it synchronized with earthquake motion. The crack initiation and distortion of the buildings seems to be well agreeable to the above analogy. Since the project under discussion is located south of Rawat town [located on rock out crop]. The Rawat Fault plain shear zone may pass through or close to this site. Another influencing geological structure of area is the Mankiala anticline. Which also plunges south east of Rawat Fault and constabulary site. the fissure and cracking portion of building can be seen in the (Fig. 6).

Many soft slightly plastic silts to highly sensitive clays [sensitivity more than 16] develop quick conditions [liquefaction] under effects of seismic disturbances. Seismic waves propagating through rocks are attenuated when enter in alluvial material but the amplitude of these waves is increased 3 to 4 times than those in the rocks.

Fig. 6. Fissure and cracking on the wall after earthquake impact

Fig. 7. Open pit settlement behavior of subsurface soil

Stresses propagating south east which may have been supplemented by liquefaction of sensitive clays with sand parting may have led to the shear deflection of residential barracks and leaning/distortion of commandant's office in south east direction. Various researchers had documented the seasonal shrinkage of clay soils under shallow foundations of structures as a result of vegetation growth. It had been pointed that large tree like Elm. Poplar and eucalyptus willow with their deep root system and huge water demand are capable of effecting the shrinkage of sub surface clay soils during summer/draught when the amount of water used by trees during transpiration exceeds the amount of rainfall with in the area of ground containing the tree roots. During period of draught, trees in particular lower the water content of localized pockets of soils resulting in a differential shrinkage of clayey foundation soils and cracking in the proximity of the trees. Skemption reported a case study where foundation failure occurred due to shrinkage of soil caused by Polar Trees (Salena, 2016). Serious cracking was noticed in a shallow founded brick wall of a theater after 14 years of its construction. The roots were founded up to 10 feet depth and settlement was of reasonable nature specially during dry period and growing season. Settlement of this earthquake impact can be seen in three pits in Fig. 7. These pits excavated up to depth 2 to 3 feet for measuring the cracking and settlement behavior in sub surface. In this case it has been observed that Eucalyptus have been planted very close to the foundation. Where the trees are excessive in number with thick trunks, sagging was observed which may have further aggravated the situation.

5. Conclusion

Rawalpindi Islamabad called joint cities of Pakistan which fall on the Himalayan Fold and thrust belt. Tectonically, Jhelum Fault passes beneath these cities which is active part of MBT. From the field observations, seismo-tectonic setting and nature of soil profile, Local seismotectonic control over geological structures and teleseismic activities have their due share toward the share deflection and distortion of the buildings. Elevation of the study area is not much higher comparatively towards North. High peaks in the region describe the more vulnerability of natural disaster. Heavy thunder storms accompanied with earthquakes may had triggered the liquefaction of sensitive clays which had resulted in differential settlement in localized areas. The ground shrinkage cracking may have resulted due to suction of water by Eucalyptus Trees planted very close to the foundations. During structural designing of the buildings, earthquake factor may have not been given proper considerations neither foundation is laid to suitable depths to mitigate the lateral earth movements of all types.

6. Recommendations

Following general recommendations are offered for detailed study for the causes of failure.

- ✓ Seismotectonic study of the area may be conducted. Since Pakistan Atomic Energy Commission has engaged its experts for this study in the area. So, it will be more appropriate to request this organization to include this project in their detailed study.
- ✓ Some suitable geologists of the department may also be attached with this study for transfer of knowhow for the planning of such projects.

Acknowledgement

I special thanks to Dr. Muhammad Munawar Iqbal Gondal Ex. Director RRMTI who gave me this case study data for publication purpose. I am also thankful to Syed Atif Ali who encourage me during proof reading. I also specially gratitude to Dr. Perveiz Khalid who is my supervisor of PhD, his comments for proof reading were very important and meaningful for betterment of publication.

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