SEISMIC FAULT AND SOIL-RELATED DAMAGE IN THE JUNE 22, 2002, CHANGUREH EARTHQUAKE, IRAN*

Kazuo KONAGAI[1], Takashi AZUMA[2], Hideaki GOTO[3], Assadolah NOORZAD[4], Siamak K. HOOSHIAR[5] and Amir SADR[6]

ABSTRACT: An intense earthquake occurred in western Iran, about 225 km west of Tehran at 7:28 local time, June 22, 2002. Though the moderate moment magnitude of 6.4(ERI, University of Tokyo) – 6.5 (USGS) calculated for this earthquake was not surprisingly large as contrasted with those major earthquakes that ever occurred in this country, a surface fault appeared across the epicenter area along east-west oriented valley in the west of Abegarm, and seriously ravaged villages were found along the fault.

Key Words: surface fault rupture, rockslide, hanging wall,

INTRODUCTION

The dry and barren plateau dominates most of Iran that lies in southwestern Asia. The plateau, lying at height of 900 to 1,500 m above the sea level, has a continental climate, with cold winters and hot summers. An intense earthquake occurred in western Iran, about 225 km west of Tehran at 7:28 local time, June 22, 2002. Though the moderate moment magnitude of 6.4(ERI, University of Tokyo) – 6.5 (USGS) calculated for this earthquake was not surprisingly large as contrasted with those major earthquakes that ever occurred in this country, seriously ravaged villages were found along east-west oriented valley in the west of Abegarm, and 261 people were reportedly killed and 1,300 injured.

On July 5, 2002, Japan Society of Civil Engineers (JSCE) decided that it would dispatch an investigation team to Iran. Though JSCE is composed of researchers having a wide range of expertise, the reconnaissance team, which consisted of 7 experts, had little chance to thoroughly investigate every civil-engineering specialty represented during their short stay (July 22-July 31) in Iran. The preliminary strategy of JSCE team was thus to make a first reconnaissance laying stress on the damage to dwellings etc, to describe the damage in terms of the location with respect to the surface fault rupture, and to discuss with Iranian specialists about possible future collaborations lucrative for both Iranian and Japanese sides.

Among those investigated, this report highlights damage to dwellings and geotechnical problems found along the surface fault rupture.

---

* The greater part of this report was taken from JSCE Provisional Report of the Changureh Earthquake; http://www.jsce-int.org/ .

[1] Professor

[2] Senior Researcher, Active Fault Research Center, National Recearch Institute of Advanced Industrial Science and Technology

[3] Associate Professor, Fukushima University

[4] Visiting Professor (Sept, 2002- Dec., 2002), Associate Professor, Tehran University, Iran

[5] Visiting Researcher (Dec., 2001 - April, 2002),

[6] Graduate student

TECTONIC SETTING AND GEOLOGICAL STRUCTURE

The epicenter and the damaged area are located in a fold and thrust (low-angle reverse fault) belt in the north of Zagros tectonic boundary (**Figure 1**). This belt trends NW-SE direction. Mountain ranges and valleys of about 30 km wide run along the belt. Reverse fault movements have been responsible for large earthquakes including 1962 Ipak (Buin-Zahra) earthquake.

In this barren area, its surface geology is easily observed. Hills are mainly composed of Miocene siltstones with their southern area covered with Quaternary fan deposits. Two deformation lines are recognized in the valley. The northern deformation line is near the main stream of the valley. Bedding of Miocene siltstone dips north, while on the southern deformation line near Abdarreh, siltstone layers dip south The 1:200,000 scale tectonic map of this area shows these deformation lines as thrusts. The topographic feature is consistent with its geologic structure. The Quaternary terraces are deformed along the northern line, and a low land extends behind the hill near the south line.

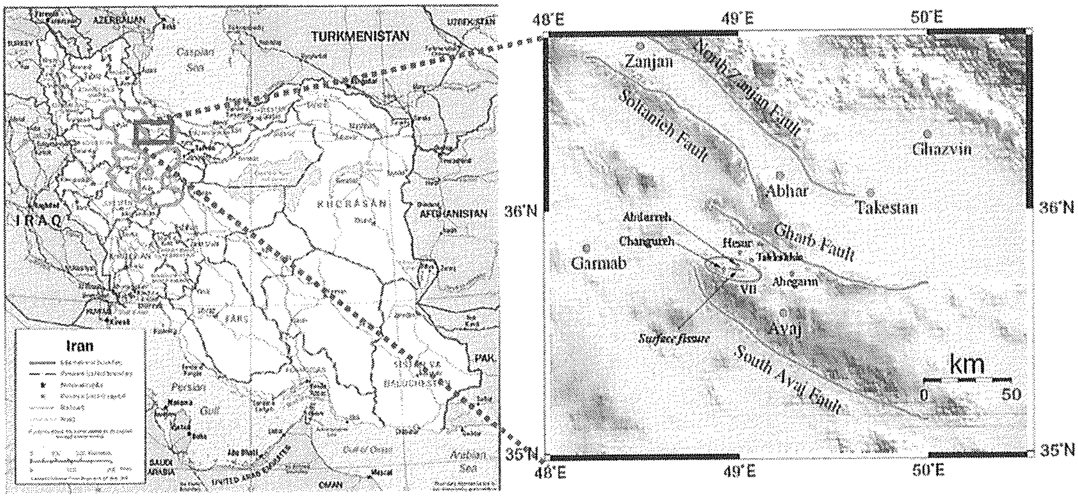


Figure 1 Faults and seismicity of the zone:

★ Epicenter

Magnitude (MW): 6.5
Time: 07:28:21.61 (local)
Location: 35.63N 48.95E
Focal Depth: 10 km
Fault Mechanism: reverse
(Source: USGS, NEIC)

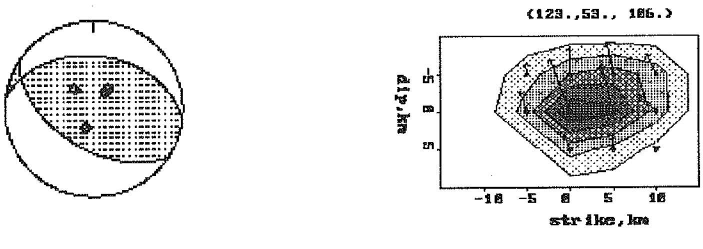


Figure 2 Focal mechanism and slip distribution (Kikuchi and Yamanaka, 2002, ERI)

Kikuchi and Yamanaka, Earthquake Research Institute, University of Tokyo, put up their fault plane solution (**Figure 2**, **http://wwweic.eri.u-tokyo.ac.jp/EIC/EIC_News/020622.html**) that indicates that the main shock occurred on a reverse fault of about NW-SE trend. That mechanism is consistent with the tectonic setting of this area. The Moment Magnitude M_W of 6.4 was calculated for the main shock, while 6.5 was calculated by USGS. The focal depth was about 7 km (ERI, 2002).

SURFACE FAULT RUPTURE

A surface fault related to this earthquake appeared across the epicenter area of the main shock. According to Sassan, Eshighi, Mehdi Zare and Mohammad R. Mahdavifar, IIEES, surface fissures are continually lined up 3 km straight across the barren terraces between Changureh and Abdareh (**Figure 3**).

The authors traced an about 700m part of the surface fault extending east from Abdareh. The rupture runs straight across the mountain ridges, and is related to the compressional mechanism. The southern hanging wall side has been pushed about 5-10 cm up. This trace of the fissures trends N70°W, and is approximately orthogonal to the axis of the focal solution for this earthquake given by NEIC and Harvard university (2002).

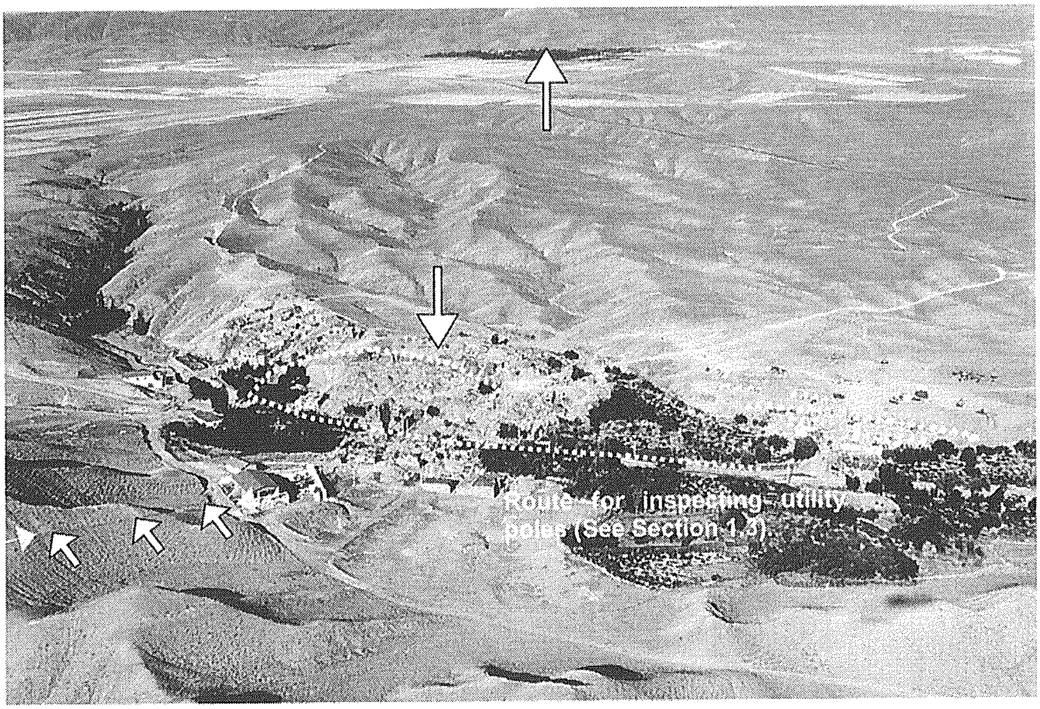


Figure 3. Surface fault trace and affected areas

A trench was excavated at a narrow valley approximately 500 m east of Abdareh (**Figure 4**). The site was chosen in expectation of finding charcoals that would allow dating possible previous events. Since the location was inaccessible by any machines, the trench was dug by hand, and was 3 m wide, 5 m long and about 1.2 m deep with east and west side walls cutting straight in the middle of the valley and along the mountainside (**Figures 5, 6**).

Figure 6 shows a sketch of the east and west walls of the trench. Layer A is the weathered soil covering thin both the mountainside and the valley. Layer B is composed of granule and less matrix. Layer C contains semi-angular pebbles. Layer D is a matrix rich bed. Maximum grain size of 2 cm is reached in this layer. Layer E is a clearly imbricated gravel bed. The average and maximum gravel sizes are about 1 cm and 5 cm, respectively. Layer F is a paleo-soil covering a gravel bed of layer G. Layer H is also a paleo-soil bed, but is overlain by gravels of layer G. Layer I is a gravel bed covered by layer H. Maximum gravel size of layer I is about 5 cm. Layer F, G, H are overlain by layer E with unconformity. The fault found clearly from surface to layer E. It is recognized as open rupture and there is no displacement along the fault. In the layers below layer F, the fault is hardly recognized.

On the west-side wall, layer H and I are considered to be extensions of those on the east wall. The uppermost bed of the valley sediment, layer J, is a sandy soil with much matrix. Layer K is a thin bed of silt or very fine sand. Layers L and M are sand and gravel beds. The matrix is rather rich in layer L than layer M. Layers N and O are paleo-soil and gravel beds overlain by layer I. Though the surface fissures lined up across the valley have clearly proven the presence of the fault at the slope foot, no clear fault dislocation was observed on the west-side wall probably because the strain caused by the faulting has spread over the uncemented soil. Nothing indicating previous fault dislocations was found in the trench.

On the east edge of Abdarreh, surface soil was scraped off to observe the fault trace on a silt rock **(Figure 7)**. The silt rock dips to south. Tufficious fine sand and silt film is caught thin in the silt rock and faulting occurred on its bedding plane. Most southern part of the tufficious sand has developed into clay of 2-3 cm thick probably because of the continual fault dislocations. Siltstone among the thin tufficious sand film has been weakened.

A "bedding plane fault" can be considered as a by-product of folding, and causes a moderate earthquake of M6 class.

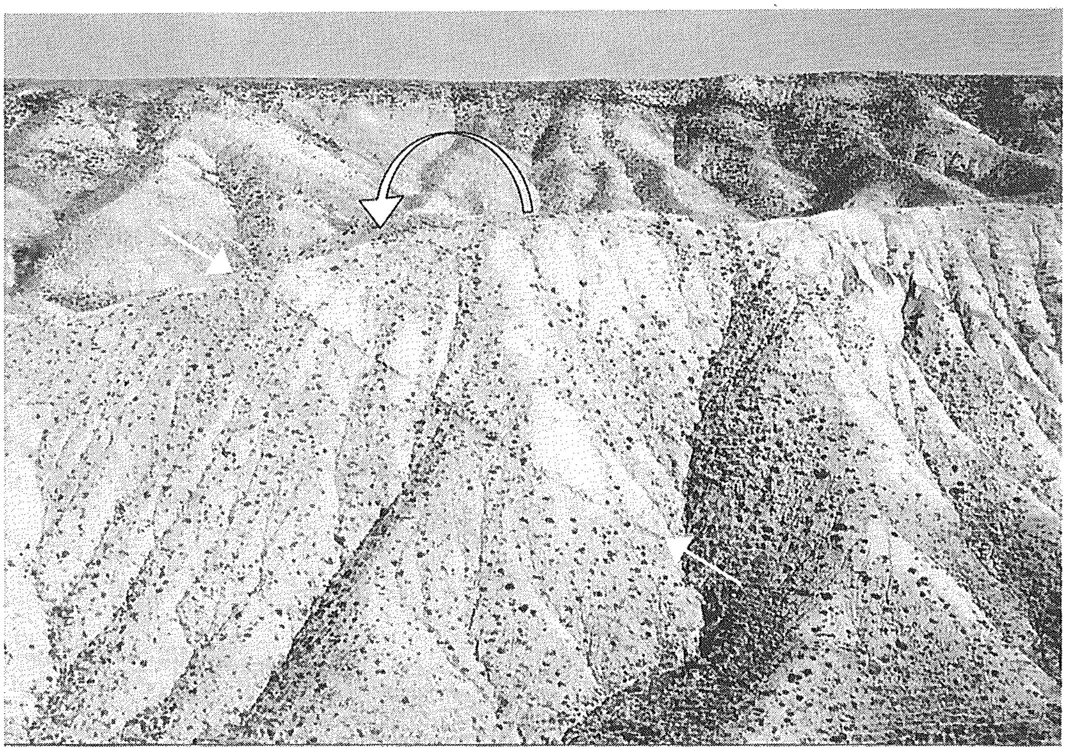


Figure 4. Surface fault trace and location of trench

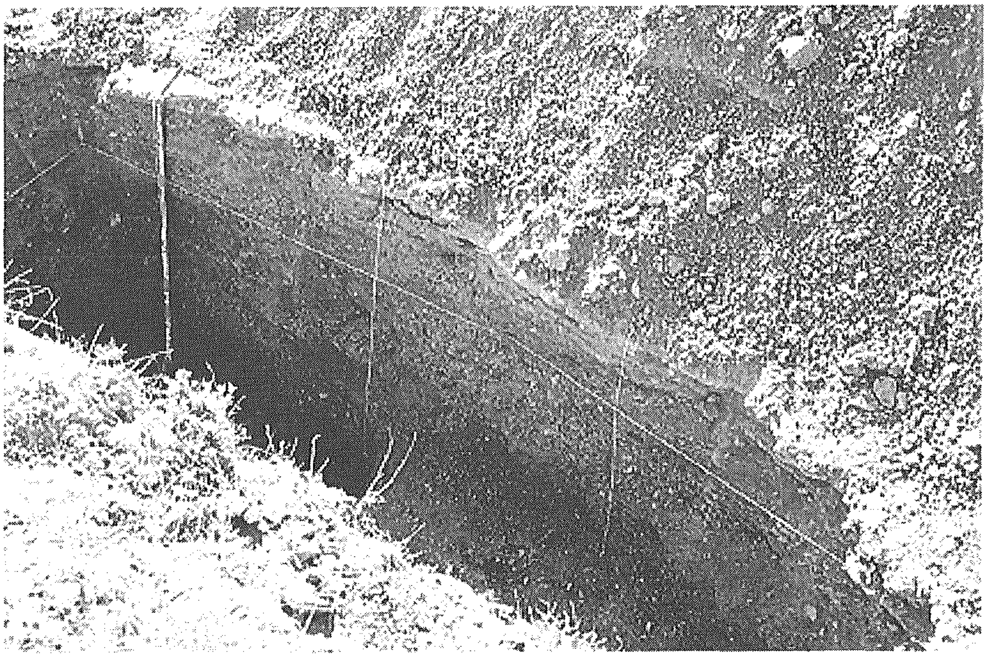


Figure 5. Excavated trench

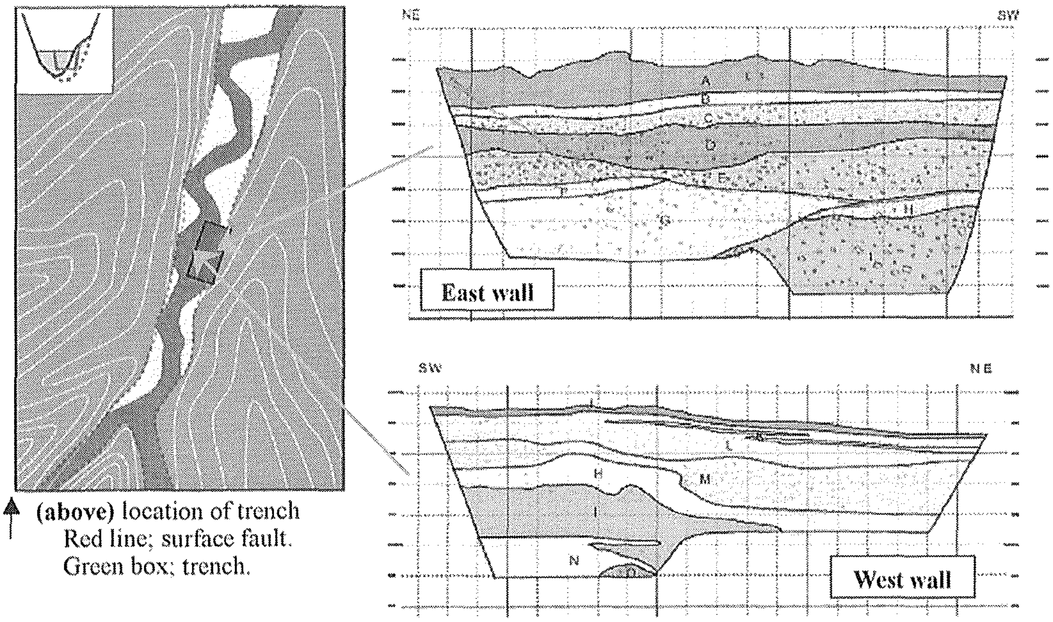


Figure 6. Illustration of trench.

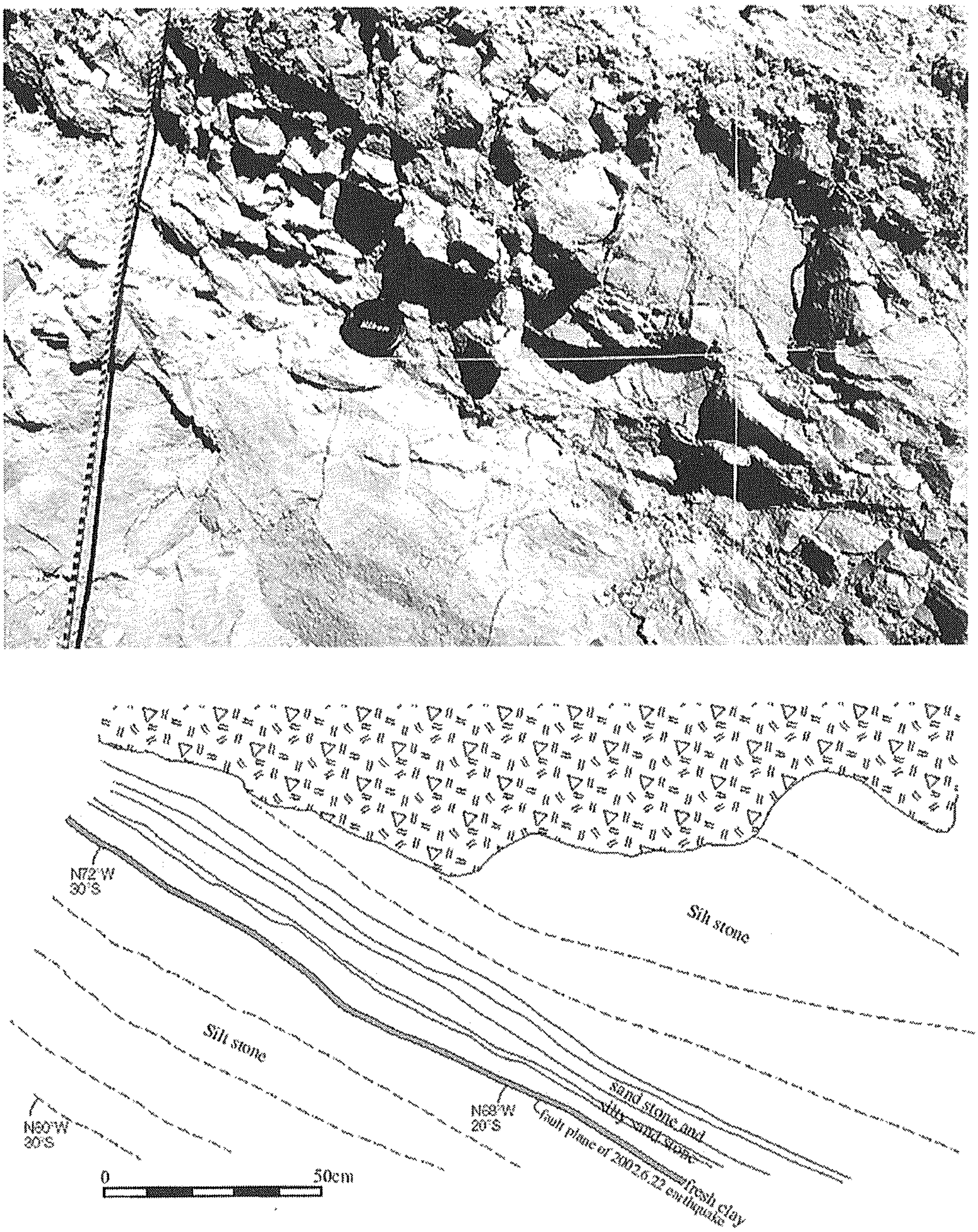


Figure 7. Exposed surface of silt rock

FAULT AND DAMAGE TO ABDARREH

Abdarreh was one of the hardest hit villages by this earthquake. A gentle ridge, the northeast extension of a sand rock terrace rising behind, dips gently towards its northeast lowland. This ridge is densely covered with adobe dwellings, and most of them were flattened in the earthquake.

Distribution of cracked utility poles is considered to be a good index for estimating possible spatial distribution of intense ground motions. Observed crack intensities on total 28 utility poles were roughly classified into the following 5 groups:

Group 1: no visible crack. **(White)**
Group 2: with hair cracks (>0.1 mm, **Light yellow)**
Group 3: with cracks (0.1-0.2 mm, **Yellow)**
Group 4: with cracks (0.2-0.3 mm, **Dark yellow)**
Group 5: with cracks (<0.3 mm, **Brown)** that can be seen at a distance of about 2m

Figure 1.8 shows the observed distribution of crack intensities. In this figure, the route taken for the inspection is lined up with the utility poles (colored circles). The route goes straight from right to left along a valley, and turns sharply up towards the ridge when it reaches the southern edge of the village. Then it comes slightly back along the ridge. Several arrows near the bend of the route indicate the inferred directions of strong ground motions. The other line of dark sphere marks is the fault trace. It goes across another mountain ridge that rises east of the village, and meets the route. It is noted that the fault trace seemingly divides the utility poles into two groups; cracked poles on the hanging wall side and less damaged on the foot wall side. This clear contrast suggests that the shake on the hanging wall side must have been more intense than that on the foot wall, and thus must have been responsible for serious destruction of the village. The arrows show that the motion was intense in the normal direction to the fault trace.

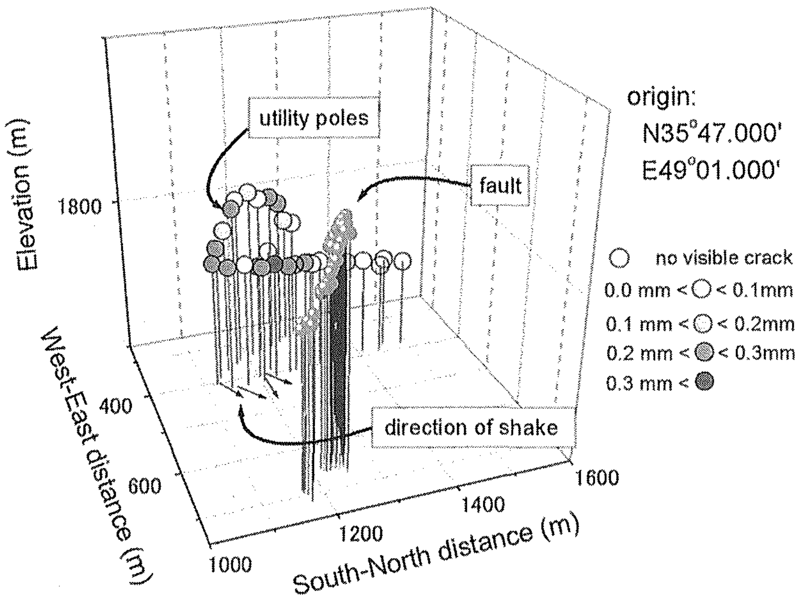


Figure 8. Locations of cracked utility poles

ROCKSLIDE

Several gorges cut deep in a terrace of silt rock, and Changureh village that has been flattened in this earthquake spreads along a rim of the terrace. On the other side of the gorge, a thin mountain ridge dips gently towards north. A rockslide took place on its west slope (**Figure 9**). The stratified silt rock mass with a cap rock covering its top dips about 25-28 degrees S40°W as shown in **Figure 9**, and the slide seemingly took place along layer boundaries.

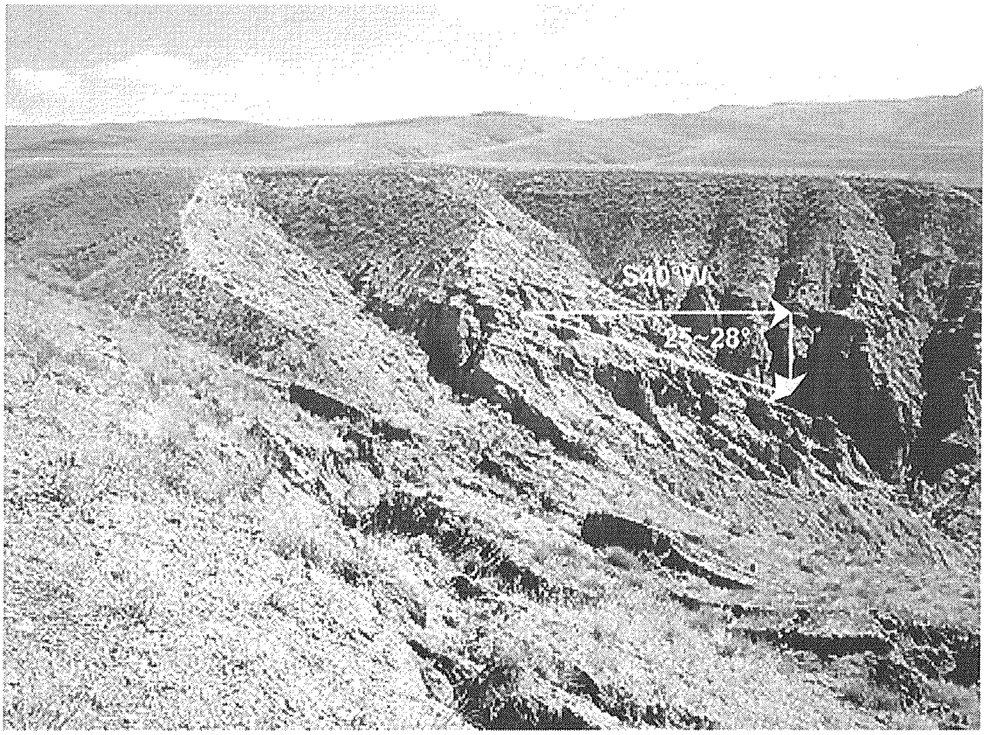
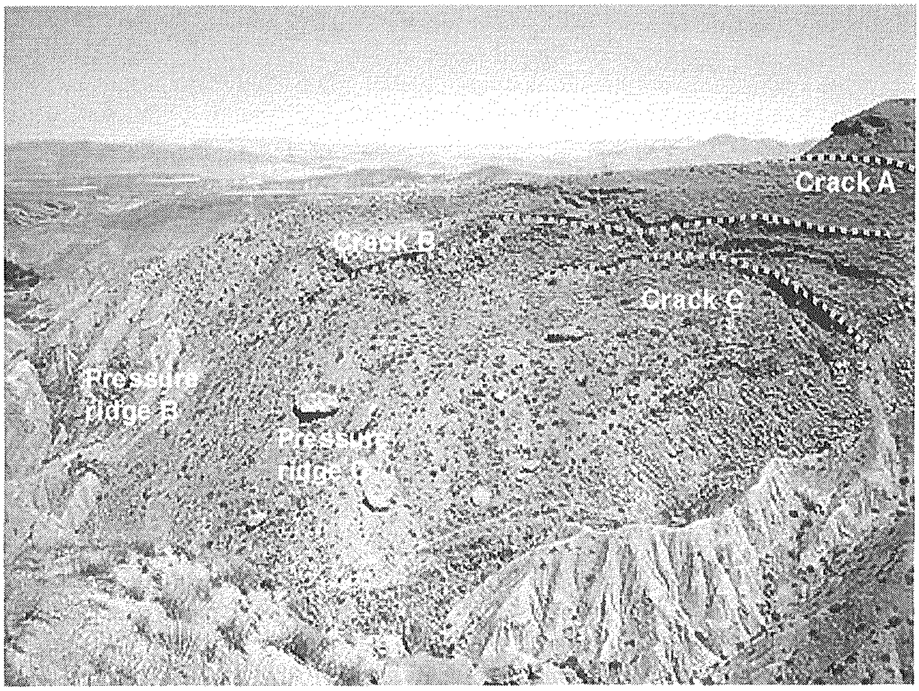


Figure 9 Rockslide in the foreground and Stratified structure of the rock



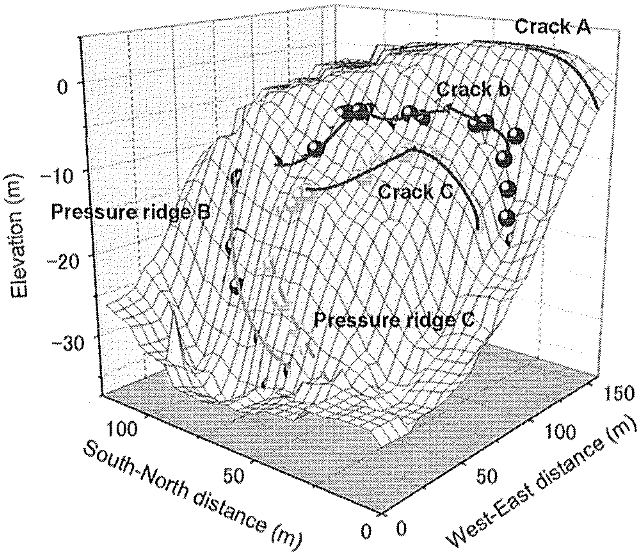


Figure 10. Slipped rockmass

The slid rock mass of about 150m long, 100m wide and 30m high is barely caught on the slope, and its configuration was measured by using a laser theodolite (**Figure 10**). The upper part of the rock mass was cracked along the perimeter of the slipped mass, and major cracks were mapped on **Figure 10**. The opening of cracks became wider as we came closer to the top, and the maximum opening and depth of 3.5-4 m and 5m were reached at **Point A** on Crack **A** (see **Figure 11** showing the plan of Crack **A**). It is noted in **Figure 11** that there was little difference between elevations of both sides of this crack; this fact suggests that the failure surface geometry could be planar.

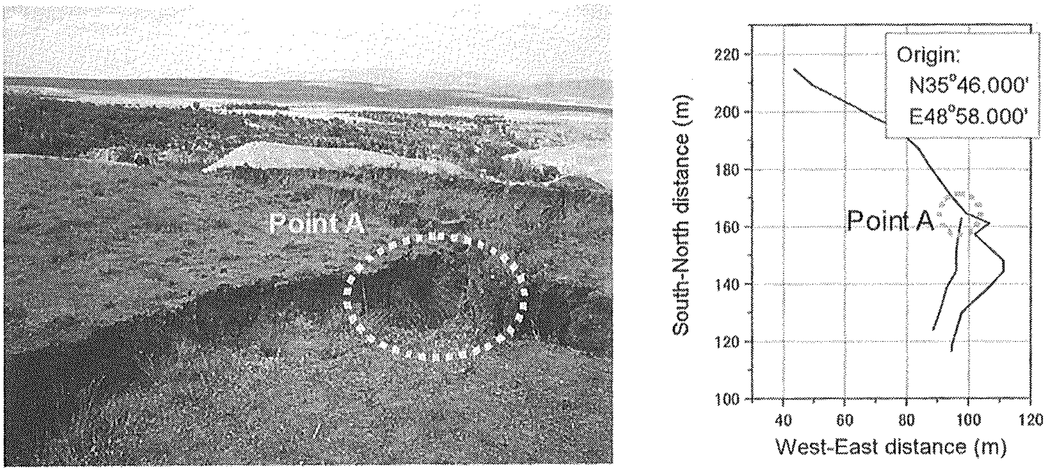


Figure 11. Crack A and its plan

LIQUEFACTION

Hesar, about 5km north of Abdarreh, lies in the middle of a valley of about 15km wide extending in NW-SE direction. A liquefaction took place in a flat area of a little grassy land about 2 km northwest of Hesar (**Figure 12**). **Figure 13** shows the traces of liquefied sand. The bunch of cracks appearing across the area seems to be winding along a small river trace, which is dried up in hot weather. Soils along the crack at Point **A** are covered 5-10 cm thick with fine sand (about 0.5 mm in diameter, **Figure 12**), while gravels were found at Point **B** (**Figure 14a**). The flat mass of gravel stopped there was cut upright (**Figure 14b**) to discuss its possible sedimentation process. The bottom part was full of middle size grains of about 3-5 mm diameter, which was then covered thick with finer sand. And lastly, a number of bigger grains (5-15 mm) were found all over the sand mass. This fact suggests that the liquefied matter was forcibly spouted twice.

A trench was excavated at Point C, where the surface soil was covered thick with fine sand (0.5 mm in diameter). Several cracks were found almost upright on a stiff clay wall of the trench through which liquefied sands forced their ways up (**Figure 15**). There were several cracks appearing upright on the clay wall of the trench, through which liquefied sands forced their ways up. The clay layer was 2m thick lying over the completely wet sand layer.

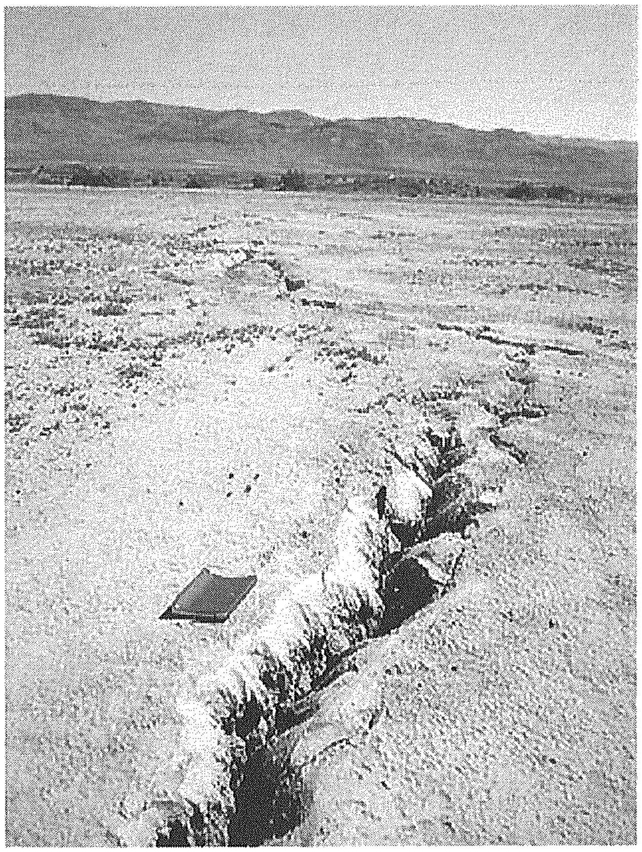


Figure 12. Liquefied sand at Point **A**

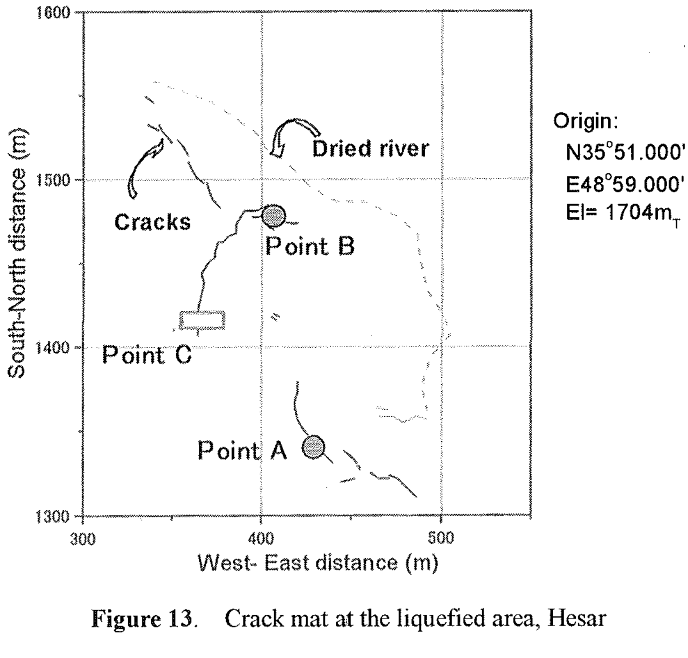
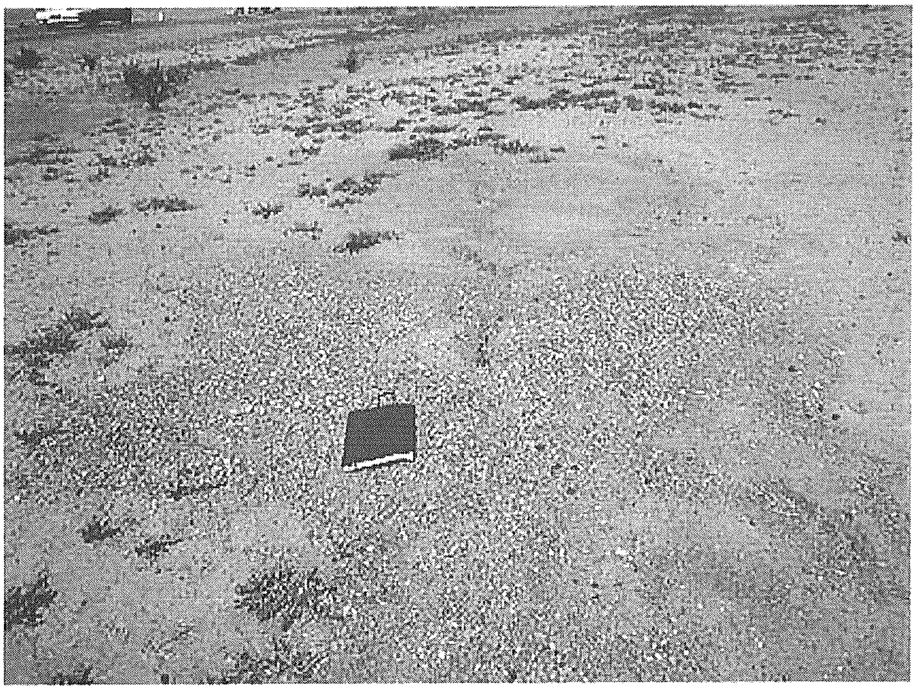
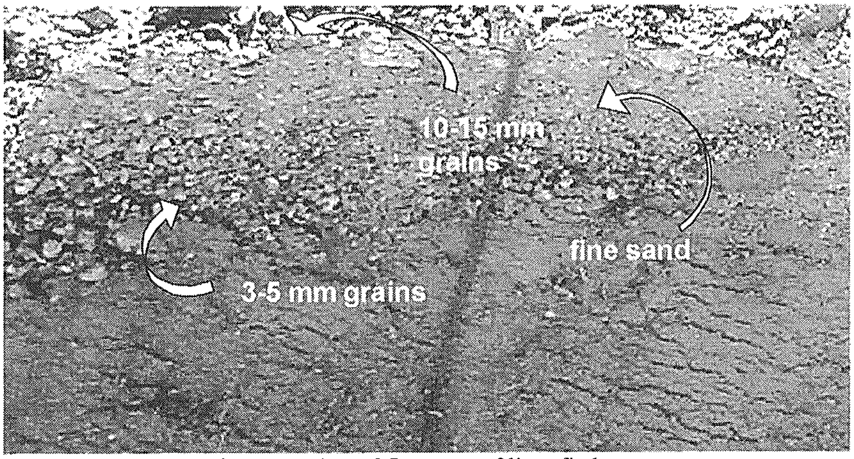


Figure 13. Crack mat at the liquefied area, Hesar



(**a**) Liquefied gravels



(**b**) Cross-section of flat mass of liquefied matters

Figure 14. Gravels liquefied at **Point B**

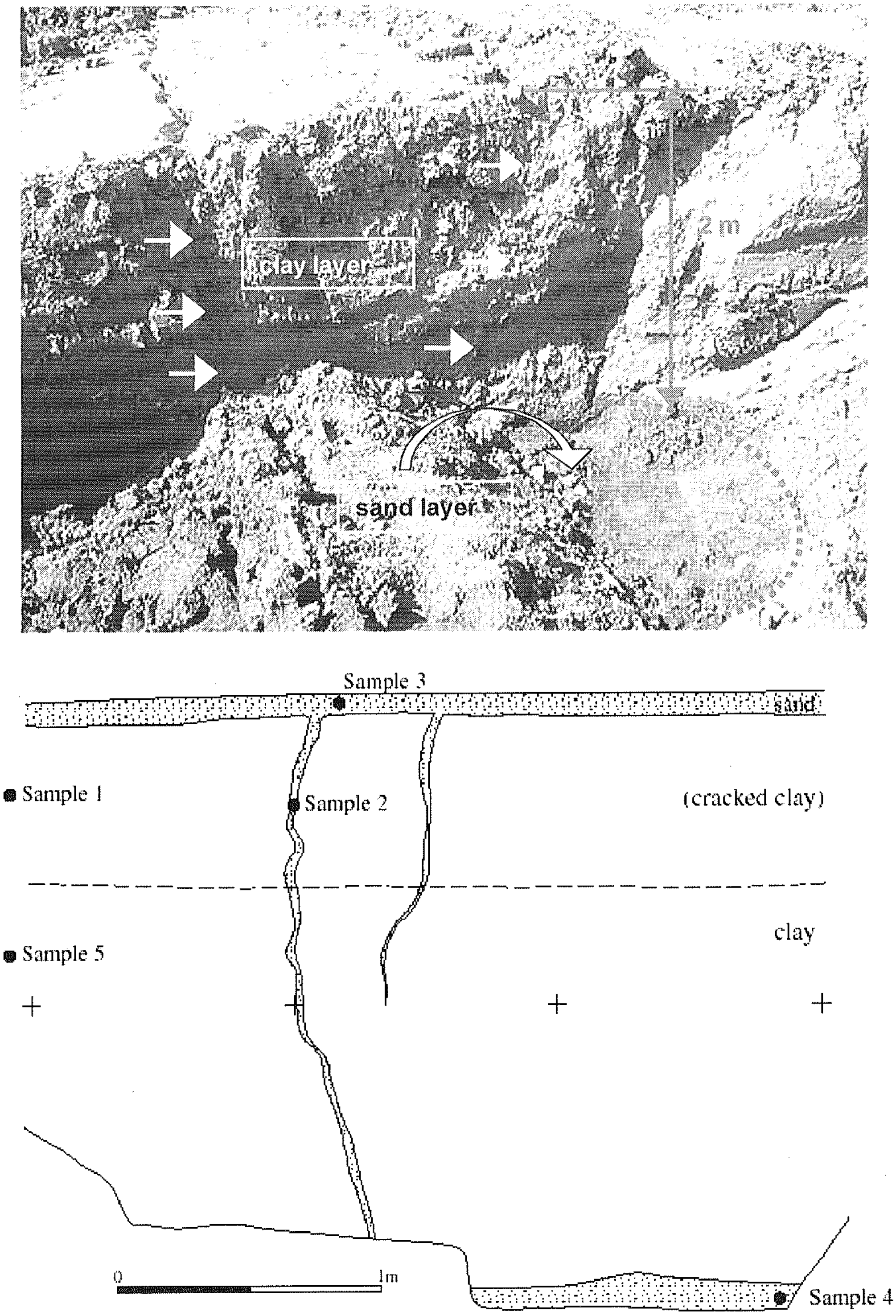


Figure 15. Liquefied sand channels through clay layer

SUMMARY

Though the moderate moment magnitude of 6.4(ERI, University of Tokyo) – 6.5 (USGS) calculated for the Changureh earthquake was not surprisingly large as contrasted with those major earthquakes that ever occurred in Iran, seriously ravaged villages were found along east-west oriented valley in the west of Abegarm, and 261 people were reportedly killed and 1,300 injured.

An about 700m part of the surface fault extending east from Abdareh was traced. The rupture runs straight across the mountain ridges, and its southern hanging wall side has been pushed about 5-10 cm up. This trace of the fissures trends N70°W, and is approximately orthogonal to the axis of the focal solution for this earthquake.

Even though almost all adobe dwellings were flattened in Abdarreh, ground motion seems to have been more intense on the hanging-wall side judging from the distribution of cracks that appeared on utility poles.

The intense shake triggered a rockslide near Changureh village, which was also seriously damaged in this earthquake. The stratified silt rock mass with a cap rock covering its top dips about 25-28 degrees S40°W, and the slide seemingly took place along layer boundaries.

Even on the footwall side, the shake was strong enough to cause a liquefaction in Hesar. A trench was excavated where the surface soil was covered thick with fine sand (0.5 mm in diameter). Several cracks were found almost upright on a stiff clay wall of the trench through which liquefied sands forced their ways up. The clay layer was 2m thick lying over the completely wet sand layer. Even gravels were found at a particular point. The bottom part of the liquefied matter stopped there was full of middle size grains of about 3-5 mm diameter, which was then covered thick with finer sand. And lastly, a number of bigger grains (5-15 mm) were found all over the sand mass. This fact suggests that the liquefied matter was forcibly spouted twice.

ACKNOWLEDGMENT

The members are grateful to many experts from Tehran University and CEST for their valuable suggestions and numerous discussions during the survey. The team was was fully briefed on the entire scope of the earthquake-related damage by Dr. Alaghebandian, R., Earthquake Engineering Research Center, Tehran University. Dr. Rahimian, Vice-Chancellor of Tehran University, together with Dr. Alaghebandian, Dr. Noorzad, A. and Dr. Ghalandarzadeh, A. kindly made every arrangement for the team's reconnaissance trip, coordinating the schedules of specialists and officials in charge in such authorities as the Ministry of Interior Affairs, Center of Earthquake & Environmental Studies of Tehran (CEST), etc. The team members wish to further collaborate with Iranian specialists for possible countermeasures, e.g., reconstruction of damaged structures, retrofitting of existing structures and reducing earthquake hazards.

Finally all the team members would like to express hereby their sincere sympathy to the people affected by the devastating earthquake.

REFERENCES

JSCE Reconnaissance team (2002). Provisional Report of the June 22, 2002, Changureh (Avaji) Earthquake, Iran, **http://www.jsce-int.org/**

Earthquake Research Institute (2002), **http://www.eri.u-tokyo.ac.jp/EIC/ERI_News/020622.gif**

Zare, M. (2002). The Changureh (Avaj, Iran) Earthquake of 22 June 2002; Mw6.3; A Geological-seismological Overview, 1-15

Farzaneghan, E., Mirzaee A., H. (2002). "Investigation of seismic and accelerogram data of Changureh-Avaj earthquake." *Proc., Lessons learned from Changureh-Avaj Earthquake of June 22, 2002*, Building and Housing Research Center (BHRC), Iran, July 23, 29-33.