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CREEP VERSUS SEISMIC SLIP ON THE KORIZAN EARTHQUAKE FAULT: THE ARDEKUL, QA'ENAT (EASTERN IRAN) DESTRUCTIVE EARTHQUAKE OF MAY 10, 1997

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SUMMARY

The Ardekul (Zirkuh) destructive earthquake of May 10, 1997 (Mw7.2), occurred on the eastern margin of the Ferdows Seismotectonic Province, at eastern Iran. The area has already experienced damaging earthquakes in the past seismic history with co-seismic surface ruptures. The 1997 event was associated with 125 km mapped fresh surface rupture in a complex pattern along the Abiz fault system. The maximum displacement reached 2.2 meters at Korizan. The Korizan village, located 300 m far from the reactivated surface rupture, remained intact while the traditional buildings were to week to resist against a strong ground shaking. On of the objectives of this study is to explain this observation on the basis of field evidence.

In this paper, field evidence have been presented to show at least two separatable phases of reactivation along the Korizan fault. The first phase is likely to be associated with a relatively strong shaking, while the second one seems to occure as a fast creep. Source parameters proposed on the basis of waveform modelling and field observations have been compared with the results of close investigation on the Korizan fault.

INTRODUCTION

Iran is a wide zone of distributed continental deformation along the seismically active Alpine-Himalayan orogenic belt. Active Cenozoic deformation is taking place by the counterclockwise rotation of the Arabian schield in the southwest toward Euratian Plate in the north, with a pole of rotation in eastern Syria (Jackson and McKenzie,1984,1988). Central Iran behaves as a rigid continental mass, transferring the accumulated neotectonic stresses into its active boundaries with the surrounding deformable belts. The continental deformation is mainly concentrated in the Zagros fold-thrust belt to the southeast, the Alborz mountain range to the north and the Eastern Iran, with the central part of Iran resisting against deformation. This simple figure has been used to model the continental deformation of Iran, two dimensionally (Sobouti and Arkani-Hamed, 1996).

Several attempts has been made to subdivide the country into the seismotectonic provinces (e.g. Nowroozi, 1976; Nogol-Sadat, 1995). On the basis of geologic, tectonic, morphotectonic, and seismotectonic features as well as the 20th and pre-20th Century seismicity patterns, Naiieri et al. (1996) modified the Nowroozi's figure and proposed 16 seismotectonic provinces (Figure 1).

The Ardekul (Zirkuh) destructive earthquake of May 10, 1997 (Mw7.2), occurred on the eastern margin of the Ferdows Seismotectonic Province (FSP,Figure 1). The FSP is bounded by the Dasht-e Bayaz Fault to the north, the northern extension of the Neh Fault system (Berberian, 1976) to the east, the northern part of the Nayband Fault to the west and the Lut Zone to the south. One of the most outstanding features of the FSP is it's marked seismicity parameters (β=0.23, λ=0.205, Naiieri et al., 1996). In this province, the Nozad earthquake of Jan.10, 1493 (Ms7.0, Ambraseys, 1975; Berberian, 1976), the Dasht-e-Bayaz earthquake of Aug. 31, 1968 (Ms7.4,

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Ambraseys and Tchalenko, 1968; Niazi, 1969, etc.), and the 1979 earthquakes of Nov.14 (Ms6.6) and Nov.27 (Ms7.1) were associated with co-seismic surface ruptures (Figure 2).

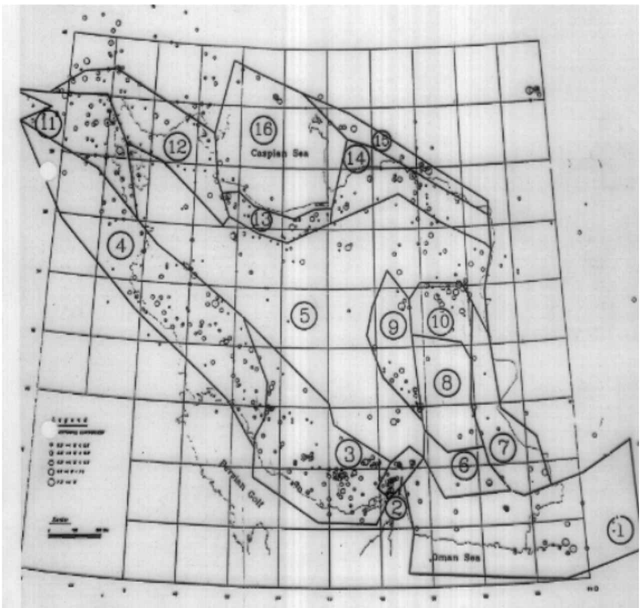

Figure 1. Seismotectonic provinces of Iran (Naiieri et al., 1996). 10 mark the Ferdows Province.

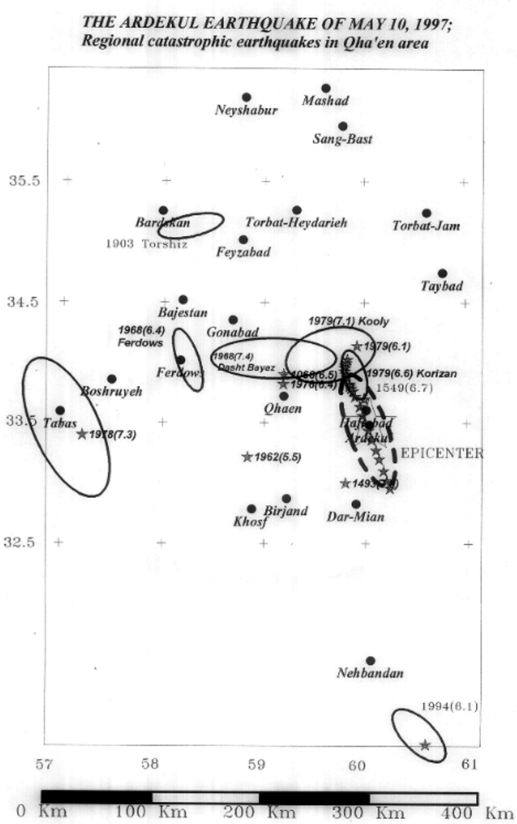

Figure 2. Regional destructive earthquakes in Qa'enat area. The meizoseismal area of the Ardekul earthquake marked by dashed ellipse.

Crustal shortening is generally taking place in a NNE direction within Iran. On the basis of the spatial variation of the style of strain rates indicated by earthquakes (Jackson et al., 1995), the velocity field within the concerned area has recently been estimated to be in the same direction (Berberian et al., 1999). However, the magnitude of the velocity vector here is less than 4mm/year, i.e., less than 10% of a typical value in Iran. This may suggest either the long recurrence interval of large earthquake clusters in the region, or the reduced crustal deformation rate, assuming that the main events in pre-20th Century, which contribute to the strain rate calculations, have been fully identified. Typically, the mechanism of faulting is right-lateral faulting on north-south trending and left-lateral faulting on east-west oriented wrench faults. The north-northwest trending co-seismic fault of the 1997 event had a right-lateral strike slip mechanism, following the mentioned geometrical rule.

Co-seismic and post-seismic surface ruptures

The earthquake was associated with more than 120km long complex fresh surface rupture along the Abiz active fault system (Figure 3). The Abiz fault is a NNW trending segmented wrench fault with dominant right-lateral strike slip mechanism. The surface ruptures follow the pre-existing fault-related geomorphic features (Berberian et al., 1999). To the north, the fault extends towards the Dasht-e Bayaz east-west trending left-lateral wrench fault and joins the Korizan earthquake fault.

The Korizan fault is a right-lateral strike-slip fault with a curved trace in plane, which ruptured in a length of about 20 km from Estend to north of Korizan during the Korizan earthquake (Ms6.6) of Nov. 14, 1979. During that event, both horizontal and vertical displacements along the fault reached about one meter. The villages of Korizan, Bohnabad and Estend were totally destroyed and a large damage was induced to the Zirkuh area (Ambraseys and Melville, 1982).

The 1997 event caused reactivation of the Korizan active fault. The maximum horizontal displacement reached 2.20 meters as measured near Korizan few days after the earthquake (Naderzadeh and Khademi,1997). There, the gravelled road to the Korizan village was offset right-laterally (Figure 4). It is worth noting that, similar to the 1979 event, the longest undisturbed segment of the surface rupture along the Abiz fault was about 20 km (Berberian et al., 1999). This may have a suggestion on the upper bound of the surface rupture length along the Abiz fault system, including the Korizan fault, although more detail information is required to draw a reliable conclusion.

Field evidence reveals some details about the sense and the phases of movement along the Korizan fault during the May 1997 event. A key section of the NNW trending Korizan fault at Estend, representing the characteristics of the latest phases of movement alongside the fault, has already been identified and reported (Naiieri, 1997). AT this section, a fault-controled north-south trending ridge has been developed. Along the ridge, the eroded Late-Quaternary fault scarps, with the successively older scarps at the southern parts have been exposed (Figure 5). Ancient southern scarps afford evidence of fault growth during successive episodes of movement in Late Quaternary time. A comparison of the ridge length with the average displacement of the 1997 event shows more than 10 times of similar reactivation phases during the past movements.

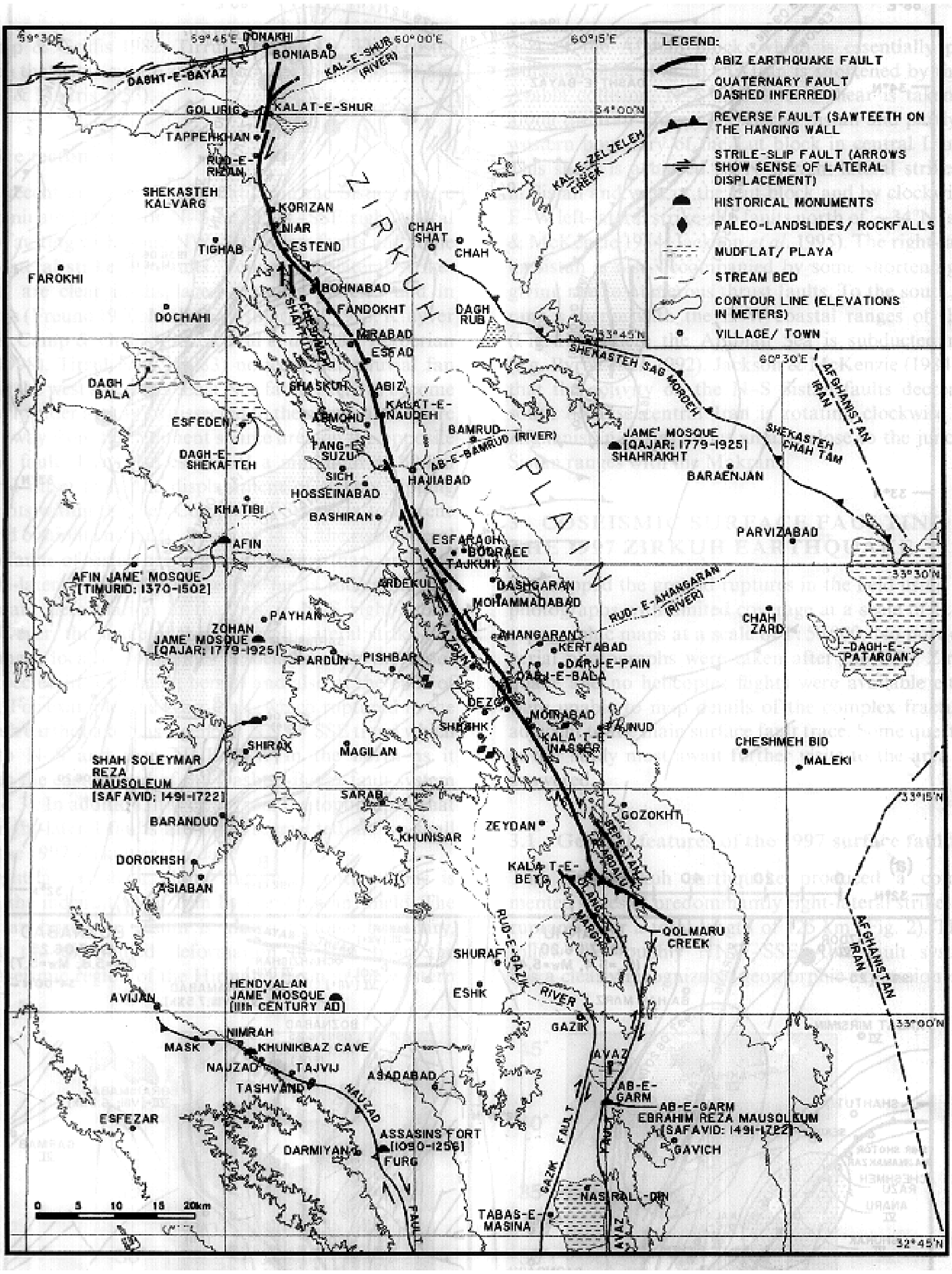

Figure 3. The causative fault of the Ardekul destructive earthquake (After Berberian et al., 1999)

Figure 4. Scarplet developed on a furrow along with the eastern side of the Korizan access road (looking west). (Reproduced after Naderzadeh and Khademi, 1997, with permission).

Figure 5. Vertical fault scarp along the Korizan fault at Estend (looking north). The exposed triangular geomorphic feature at the centre of the photo appeared during the renewed movement along the fault on May, 1997 (Naiieri, 1997).

Outstanding exposure of the rejuvenated steep fault scarp about 6 m high and more than 4 m wide (at the top) has been formed at the northernmost part of the ridge (centre of Figure 5). Dip angle of the smooth fault plane is about 80 degrees towards west. The smooth fresh fault plane here is covered by a thin layer of sun-dried reddish clay originated from the shearing of the footwall against the hanging wall (Figure 6). This gravitationally metastable standing steep clayey cover indicates that no strong horizontal ground shaking was experienced during and after the process of its exposure, since otherwise it would easily collapse.

Figure 6. Close up of the central part of the triangular feature at Figure 5, showing the smooth surface of the exposed fault plane with fresh horizontal slickensides (look at the pen in the center of the figure). The surface is covered with a soft sun-dried redish clay.

Both subhorizontal fresh slickensides on the fault plane (Figure 6) and the morphology of the scarp (Figure 5) clearly indicate almost horizontal slip along this section of the Korizan fault during the last movement in May 1997. Nearby offsets within the agricultural area close to and parallel with the fault scarp (Figure 7) show a reduced magnitude of slip. This is because the slip here is much more spatially distributed and the maximum displacement measured here is 1.9 m.

Figure 7. A longitudinally cut and offset tree at Estend aggricultural area. The horizontal displacement here is 1.5 m.

There is a neotectonic saddle as a narrow fault-controlled valley just to the north of the fault scarp, with evidences of ancient ground deformations representative of strong earthquakes (Naiieri,1997). These geomorphic features indicate the strong ground shakings during the past seismic history of the region. Rock falls at the foot of the reletively older and eroded southern part of the fault scarp (Figure 5, bottom), as well as slope failures within the agricultural area, show a phase of strong ground shaking resulted from the 1997 main shock.

The slope failures on one hand and the standing steep metastable sun-dried clay cover over the Korizan fault plane, on the other hand, suggest at least two separate phases of ground motion at Estend. The first phase should be a strong seismic event on an asperity along the Abiz fault system, most probably near the Ardekul village. This phase occurred before the exposure of the renewed fault scarp at Estend and caused rock fall and slope failures along older eroded topography at Estend. The second phase seams to be a fast creeping reactivation phase along the Korizan fault, which made exposed the steep undisturbed fault scarp at Estend.

Further north in a distance of 5 km from Estend, the Korizan village which was destroyed during the 1979 (Mw6.6) shock, remained intact in the 1997 event. The traditional houses in the village are typically built with sun dried mud-brick, with low resistance against strong horizontal shakings. It is worth noting that Korizan is located on alluvial deposits in a very short distance (300 m) to the Korizan fault rupture. It is the same section of the fault which showed maximum horizontal displacement as much as 2.20 m. Such a site condition normally enhances the base acceleration to higher peak and duration values. The withstanding of traditional houses at Korizan strongly indicates that ground shakings experienced in the village were too week to cause any damage. This point which is of prime interest from engineering seismology point of view, supports the idea of creeping along this segment of the Korizan fault.

Comparison with seismological data

Very recently, source parameters of the 1997 main shock has been studied by (Berberian et al., 1999) using routine waveform modeling techniques (e.g. Nabelek, 1984; Taymaz et al., 1991). They constrained the source to be a double-couple, which is a reasonable assumption on the basis of our field evidence on strike-slip wrench faulting . The results have been presented in Table 1.

Table 1. Source parameters of the Ardekul (Zirkuh) main shock (after Berberian et al., 1999)

Source	Strike	Dip	Rake	Depth (km)	M0*	Mw
Subevent 1	170	88	178	9	21.9	6.8
Subevent 2	150	71	127	10	6.4	6.5
Subevent 3	335	84	169	10	38.9	7.0
Subevent 4	120	20	90	10	3.5	6.3

* Seismic moment in units of 10**18 N m.

As summarised in Table 1, in their source model the main shock consists of four subevents. They assumed the first subevent (Mw6.8) was nucleated near Korizan and propagated north. The focal depth of this event was resolved to be 9km. They then held this subevent fixed and located the second, third and fourth subevents further to the SSE along the complex surface rupture at a fixed depth of 10km.

The first subevent (Mw6.8, M0=21.9e18 N m) was the second large subevent of the multiple main shock, and the most strong nearby event for the villages of Korizan and Estend. In a simple approach, if we consider the first subevent as a single shallow (9 km) point source in a horizontal distance as short as 300 m (measured from the rejuvenated surface rupture) to Korizan, the predicted strong ground motion at the surface would be underestimated with respect to a realistic distributed propagating line source with pronounced directivity effect. In that simplified case, the induced horizontal acceleration at Korizan would be in a range from 0.38g to 0.56g, using the Campbell's (1997) 50% (mean) and 84% (mean + one standard deviation) values for a strike-slip mechanism and an alluvium or firm soil site condition. Such accelerations are too high to be experienced by the traditional houses at Korizan while leaving them intact. In this sense, the source model suggested by (Berberian et al., 1999) although adequately reconstructs the details of the far field P and SH waveforms, does not reasonably explain the low level of induced damage to the traditional buildings at Korizan, as discussed above.

ACKNOWLEDGEMENTS

This study was conducted with the technical assistance and finantial support of Lar Consulting Engineers. The fieldwork was organized short time after the earthquake by the Iranian National Committee on Large Dams (IRCOLD). Dr. James Jackson kindly provided the author with the results of his very recent study (Berberian et al., 1999) on the source parameters of the main shock, when the first manuscript of this paper was almost finished, and caused the author to add a discussion on this respect. Mr. A. Amid had helpful contribution in preparing images from the field slides and photographs for which the author is thankful.

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