STRUCTURAL MATURITY OF BLIND FAULTS IN ZAFROS FOLD AND THRUST BELT

Nayereh SABOUR
Geological Survey of Iran
n.sabour@gsi.ir

Mohammad Reza GHASSEMI
Research Institute for Earth Sciences, Geological Survey of Iran
ghassemi.mr@gmail.com

Behnam OVEISI
Head of Seismology and Seismotectonic Department, Geological Survey of Iran
ben.oveisi@gmail.com

Keywords: Structural Maturity, Near-field Ground Motion, Zagros, Seismotectonic

ABSTRACT

Structural maturity is a determinant parameter in seismic hazard assessment and is less considered. It is qualified by surface rupture conditions (segmentation, rupture length and displacement value on the rupture), earthquake recurrence pattern and the ground motions produced by earthquake. While surface faulting of earthquakes is extremely rare in the Zagros, therefore in this region, we just used strong ground motion to determine the degree of structural maturity of the faults.

Our study shows that nearly N-S trending faults which are the old faults that govern the structure are the most mature faults. Whereas with change in direction of faults toward NW-SE, the degree of maturity is decreased. Reverse faults have a least degree of maturity and they are the young faults that are govern with structure have a more immature structure in depth.

INTRODUCTION

Active deformation in Iran is caused by the convergence of Arabian- Eurasian plate (Fig. 1) that deforms an area of ~3,000,000 km^2 of continental crust (Allen, 2004). The Iranian plateau accommodates different convergence rates of 35mm yr^{-1} at N-S - N15°E (Berberian, M and Yeats, 1999) to 22± 2mm yr^{-1} at N8±5°E (Vernant et al., 2004). Zagros accommodates an important part of the overall convergence (Allen, 2004).

The present structure of Zagros Folded Belt is qualified by the major thrust fault (fronts) that are parallel to the belt and transfer fault zones or lateral ramps oblique to the belt and Hormoz Salt domes (Sepehr 2005, Berberian, 1995). There are several incompetent layers in the Zagros which cause that earthquakes not be able to rupture the surface in the Zagros (Berberian, 1995). However InSAR studies show that some recent earthquakes ruptured the Competent Group in the lower sedimentary cover (Nissen et al., 2011). In the NW Zagros (west of the Kazerun fault) shortening is accommodated mainly along the Mountain front fault where most of major earthquakes occur. The change in direction and magnitude of velocity vectors occurs across the N-S trending Kazerun and Kerebas faults (Hessami et al., 2006).

The Kazerun Line accommodates some of the shortening between Arabia and central Iran by an elongation of the Zagros Mountains parallel to strike (Baker et al., 1992). GPS measurements suggest that these faults have a combined right-lateral slip-rate of 6±2 mm/ yr on the Kazerun strike-slip fault system, distributed over the Kazerun, Borazjan, Karebas and Sabz-Pushan faults (Walpersdorf et al., 2006). All Earthquakes on the Kazerun fault involve faulting in the metamorphic basement beneath the sedimentary cover that detached from the basement by evaporate horizons (Baker et al., 1992).

The Karebas fault has a total length of 160 km and is located about 65 km east of the Kazerun fault (Fig. 1). It has an N-S trend and in the south turns toward the east and forms the Surmeh thrust fault. The right-lateral strike-slip Sabz-Pushan fault with NNW-SSE trending is located east of the Karebas fault (Fig. 1). The motion on the Karebas fault is about 2 mm/yr and on the Sabz-Pushan fault is almost the same (Walpersdorf et al., 2006).

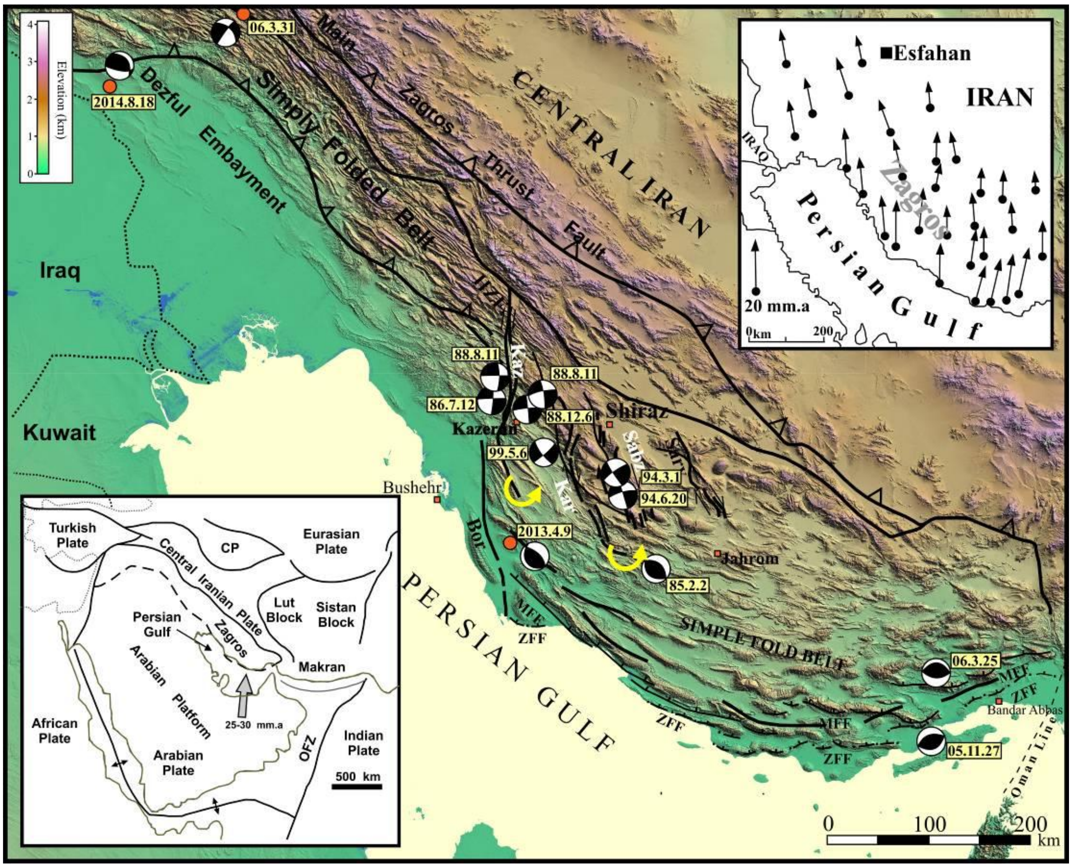

Figure 1. Zagros topography from the SRTM 90 m. Active faults are drawn as black lines. Focal mechanisms of earthquakes from Berberian, 1995, Nissen et al, 2007, Roustaei et al, 2010, Peyret et al, 2008 and IRIS.

METHODS

Source parameters such as earthquake mechanism (normal, reverse and strike-slip), the surface slip associated with earthquakes, regional tectonic setting, long-term slip rate, and structural maturity are the most crucial parameters which play a significant role in the earthquake characteristics like variation in stress drop, slip amplitude, rupture length and magnitude (Manighetti et al., 2007, Radiguet et al., 2009).

Manighetti et al. (2007) and Radiguet et al., (2009) proposed that such variability arises from the number of segments that the fault breaks into. That number depends on the strength of the inter-segment zones, which itself depends on the structural maturity of the faults. They claim fault segmentation should be evoked in earthquake scaling as well as the effect of slip history. They believe it dictates the way earthquakes gaining length, hence strongly governs the relationship(s) between earthquake slip and length. According to this theory, depending on their structural maturity, faults of similar length may produce significantly different amounts of slip. Mature faults obviously break in long ruptures with low slip amplitudes (4–7 m). By contrast, more immature faults break in shorter, yet more energetic ruptures, on which slip as high as 15m may be expected. Hence fault segmentation depends on rupture slip and length (Manighetti et al., 2007) and controls the magnitude effect in source and is a vital parameter in ground-motion prediction equation (GMPEs) (Radiguet et al., 2009).

On the other hand mature faults at the short time scale periods rupture with various magnitudes in multiple events, whereas in long term time scales disrupts as a cluster. In contrast immature faults may have a uniform size distribution of earthquakes (Liu-Zeng et al., 2005). Also the ground motions produced by earthquakes on immature faults are larger than those generated by earthquake on mature faults (Radiguet et al., 2009). These three parameters completely support each other and strong ground motion is the most reasonable and comparable parameter of them (see Sabour et al., 2011). While surface faulting of earthquakes is extremely rare in the Zagros, most information about the active faulting is obtained from earthquakes studies. Therefore in the Zagros region, we just used strong ground motion to determine the degree of structural maturity of the faults.

Therefore the accelerometer network data (Building and Housing Research Center) for 15 earthquakes in Zagros are examined, and acceleration response spectra for horizontal motion of the ground in seismic periods of 0.1-2 sec are calculated respectively. Horizontal accelerated motion of the ground regarding the magnitude and distance from the epicenter of the earthquake in every station on each earthquake are calculated as well according to Boore et al. (1997) equation. The mean value of 0.1-2 seconds determined for the acceleration at various stations as the basis for maturity of fault and response spectrum of any earthquake normalized to the mean value (Fig. 2). Increase or decrease of the response spectrum from mean level determines immaturity or maturity of the fault (Table 1).

Table 1. Maturity of the faults that studied in this research

No.	Fault Name	Earthquake Name	Date (dd/mm/yyyy)	Mw	Depth (Km)	Style of Faulting	Maturity	Reference
1	Unknown	SE Gir	02/02/1985	5.6	11	T	Mature	1
2	Kazerun		12/07/1986	5.5	7	R	Mature	2,3
3	Kazerun		11/08/1988	5.5	7	R	Mature	2
4	Kazerun		11/08/1988	5.8	9	R	Mature	2
5	Kazerun		06/12/1988	5.6	10	R	Mature	2
6	Sabz-Poushan	Mook	01/03/1994	5.9	13	S	Mature	1
7	Sabz-Poushan		20/06/1994	5.8	9	S	Mature	1
8	Karebas	Kouhmareh-Sorkhi	06/05/1999	6.1	7	S	Mature	1
9	Karebas	Kouhmareh-Sorkhi	06/05/1999	5.7			Mature	4
10	Unknown	Qeshm	27/11/2005	6	4-8	T	Mature	5
11	MRF	Chalan-Choulan	31/03/2006	6.1	6	S	Mature	6
12	Unknown	Fin	25/03/2006	5.7	8±3	T	Mature	7
13	Karebas		27/09/2010	5.6	16		Mature	8
14	Unknown	Shonbeh	09/04/2013	6.3	10	T	Mature	4
15	Unknown	Murmuri	18/08/2014	6.2	10	T	Mature	4,9

(1) Talebian and Jackson, 2004; (2) Baker et al., 1992; (3) Berberian, 1995; (4) USGS (5) Nissen et al., 2007; (6) Peyret et al., 2008; (7) Roustaei et al., 2010; (8) Nissen et al., 2011; (9) IRIS.

DISCUSSION

To investigate the fault structural maturity of Kazerun fault, seismogram of 4 earthquakes with magnitudes of Mw= 5.5 to 5.8 occurred between 1986 to 1988 are used. During the 2 years, 4 earthquakes have occurred on the Kazerun fault. The last destructive historical earthquakes event that is likely to be linked with Kazerun fault are two 1824 and 1891 earthquakes (Berberian, 1995), therefore it may provide some evidence of the clustering behavior in seismicity of Kazerun fault. Earthquake magnitude and focal depth of the earthquake in all 4 events are different, but the mean curve extracted from seismic stations seismograms located below the Boore’s base line (Fig. 2) calming that the fault is mature. Locating in the east of Kazerun fault 160 km long north to north west trending Karebas fault within about 10 years have had 4 events greater than 5.2 Mw, which reveals fault's cluster activity. Apart from these 4 events there was no other record of seismic activity on the fault. In Three events 06/05/1999, 06/05/1999 and 27/09/2010 the calculated average line of motion, are located below the Boore's base line (Fig. 4), and claim the maturity of fault.

Located in the east of Karebas fault, the NW-SE trending strike-slip Sabz-Pushan Fault has experienced two major earthquakes (Mw= 5.8 and 5.9) over a year. But no other seismic activity associated with the Sabz-Pushan fault has been yet documented, although the meizoseismal region of the north western Shiraz earthquake of 1824.06.25 is elongated parallel to the north-western extension of the Sabz-Pushan fault (Berberian, 1995). The March 1994 earthquake known as Mook, has only one seismogram recorded that is not reliable enough, but the 20 June 1994 earthquake that occurred on this fault was recorded by 10 stations less than 80 km far. The recorded accelerograms suggest the structural maturity for the Sabz-Pushan fault. The notable issue is the deviation of three earthquakes average line of motion from the Boore' base line (Fig. 2). In this area in the Kazerun fault in western part, the maximum deviation is observed whereas to east in the Karebas and the Sabz-Pushan the deviation from the Boore' baseline is decreasing (Fig. 2). An increase in slip rate on the Karebas fault (5.5 mm/yr by Hatzfeld et al., 2010) relative to the Kazerun fault (northern segment also known as the Dena fault), 3.1- 4.7 mmy^{-1} and the middle segment (Kazerun fault), 3.2-5.1 mmy^{-1} by Hatzfeld et al., 2010), confirm the increase of immaturity of the faults from the kazerun to the Karebas faults. In Qeshm, Fin, Murmuri and Shonbeh earthquakes that occurred as a result of reverse faulting, average lines of motion calculation suggest that the causative faults are mature (Fig. 2) but have a least degree of maturity and nearest place to Boore’s base line (Fig. 2).

CONCLUSION

Our study shows that nearlly N-S trending faults, subparallel to shortening direction, are the most mature faults (e.g. the Kazerun fault) that have a long term activity and several events are recorded on them. These faults are the old faults that govern the structure. Whereas with change in direction of faults toward NW-SE, the degree of maturity is decreased (e.g. causative faults of 2006 Chalan-Chulan earthquake). In central Zagros, from Kazerun fault toward Sabz-Pushan fault with change in direction, the structural maturity is decreased. Hatzfeld et al., (2010) in their study on fault slip rates in western Zagros point the migration of seismic activity on the faults and suggest that it seems the motion is transfered from main recent fault to Dena and Kazerun faults, jumps to the Krebas fault and distribute slightly on the high Zagros and Sabz-Pushan faults. It seems that the motion moves from the more mature Kazerun fault toward the Karebas and Sabz-Pushan younger faults with less degree of maturity. Reverse faults (e.g. causative faults of the 2006 Fin earthquake, 2014 Murmuri, 2013 Shonbeh), have a least degree of maturity and they are the young faults that are govern with structure and don't have many activity background and have a more immature structure in depth.

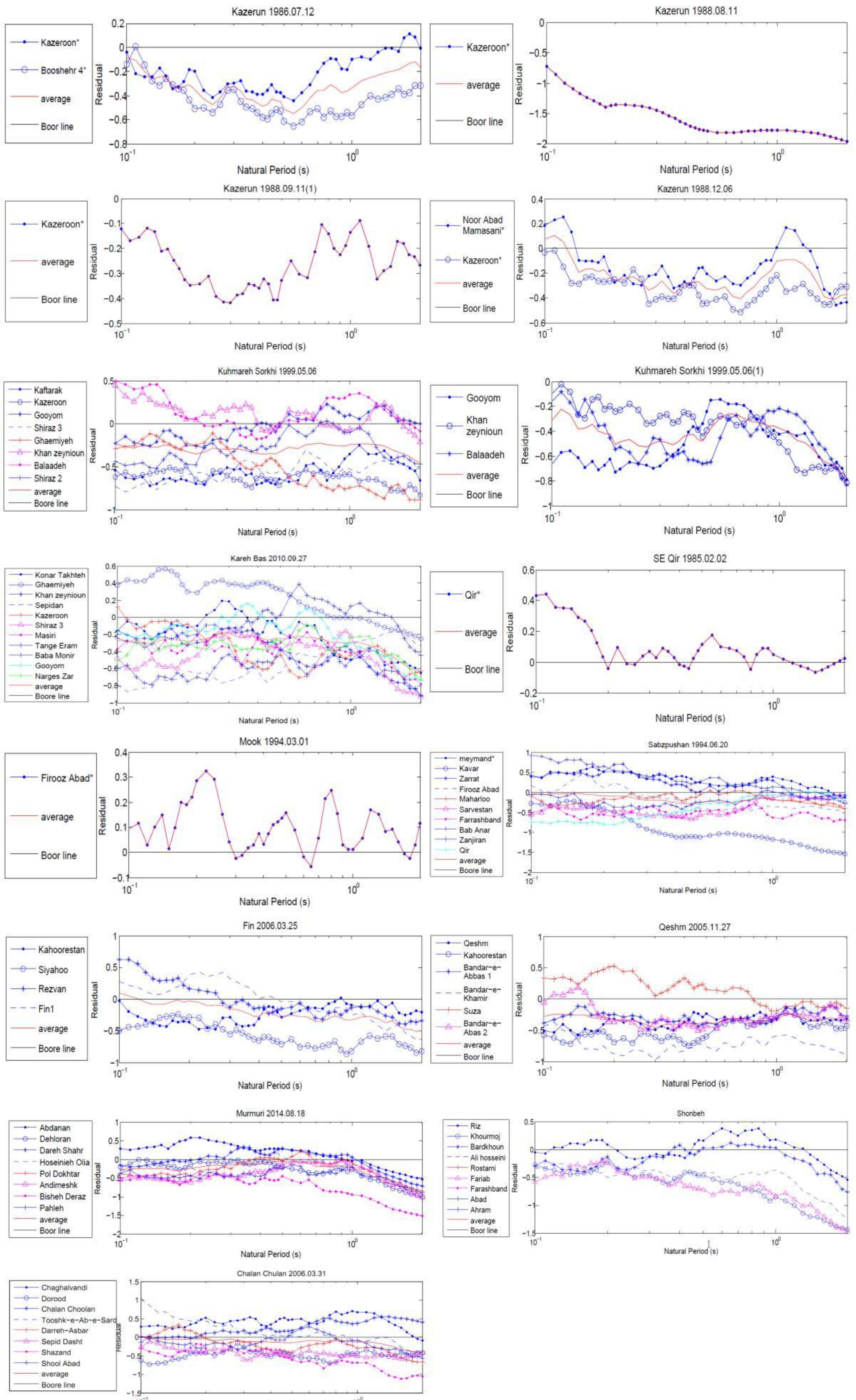

Figure 2. Ratio of response spectra for near field horizontal motions of some earthquakes in Zagros that compared with ones resulted from the experimental model presented by Boore et al (1997). The name of recording stations is showed in the legend.

REFERENCES

Baker C, Jackson J and Priestly K (1993) Earthquakes on the Kazerun line in the Zagros mountains of Iran: strike-slip faulting within a fold-and-thrust belt, *Geophys. J. Int. 115, 41-61*

Beberian M (1995) Master "blind" thrust fault hidden under the Zagros folds: active basement tectonics and surface morphotectonics, *Tectonophysics 241 (1995) 193-224*

Boore DM, Joyner WB and Fumal TE (1997) Equations for estimating horizontal response spectra and peak acceleration from western North American earthquakes: a summary of recent work, *Seism. Res. Lett*

Hatzfeld D, Authemayou C, Van Der Beek P, Bellier O, Lave L, Oveisi B, Tatar M, Tavakoli F, Walpersdorf A and Yamini- Fard F (2010) The Kinematics of Zagros Mountains (Iran), *Geological Society, London, Special Publications, No. 330, 19-42*

Liu-Zeng J, Heaton T and DiCaprio Ch (2005) the effect of slip variability on earthquake slip-length scaling, *Geophys. J. Int. 162, 841-849*

Manighetti I, Campill M, Bouley S, Cotton F (2007) Earthquake scaling, fault segmentation, and structural maturity, *Earth and plantary science letters 253, 429-438*

Nissen E, Ghorashi M, Jackson J, Parsons B and Talebian M (2007) The 2005 Qeshm Island earthquake (Iran)- a link between buried reverse faulting and surface folding in the Zagros Simply Folded Belt?, *Geophys. J. Int*. 171, 326-338

Nissen E, Tatar M, Jackson J and Allen MB (2011) New views on earthquake faulting in the Zagros fold-and-thrust belt of Iran, Geophys, J. Int. 186, 928-944

Peyret M, Rolandone F, Dominguez S, Djamour Y and Meyer B (2008) Source model for the Mw 6.1, 31 March 2006, Chalan-Chulan earthquake (Iran) from InSAR, *Terra Nova, Vol 20, No. 2, 126-133*

Radiguet M, Cotton F, Manighetti M, Campillo M and Douglas J (2009) Dependency of Near Field Ground Motions on the Structural Maturity of the Ruptured Faults, *Bulletin of Seismological Society of America*, Vol. 99, No. 4

Roustaei M, Nissen E, Abbassi M, Gholamzadeh A, Ghorashi M, Tatar M, Yamini-Fard F, Bergman E, Jackson J and Parsons B (2010) The 2006 March 25 Fin earthquake (Iran)- insights into the vertical extents of faulting in the Zagros Simply Folded Belt, *Geophys. J. Int. doi: 10.1111/j.1365-246X.2010.04601.x*

Saboor N, Ghassemi MR, Eskandary M, Oveisi B and Talebian M (2011) Influence of structural maturity of active faults in eastern Iran on the strong ground motion, *6th International conference on Seismology and Earthquake Enggineering*

Talebian M and Jackson J (2004) A reappraisal of earthquake focal mechanisms and active shortening in the Zagros mountains of Iran, *Geophys. J. Int. 156, 506-526*

Walpersdorf A, Hatzfeld D, Nankali H, Tavakoli F, Nilforoushan F, Tatar M, Vernant P, Chery J and Masson F (2006) Difference in the GPS deformation pattern of North and Central Zagros (Iran), *Geophys. J. Int*. 167, 1077-1088