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# Geometry and Focal Mechanism of Active Faults in Ardal Area (High Zagros) Using the Movement Potential Evaluation

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## ABSTRACT

The studied area is located in the structural divisions of Iran in the High Zagros zone.The Ardal fault (Southwest fragment of the MRF) with the northwest-southeastern trend is the youngest structure in the area of the case studie. So that the evidence of kinematic (fault plane and Scratch slip) in the region, it represents the motion of the right strike slip fault. In this paper a theoretical model has been presented for evaluation of Fault Movement Potential (FMP) based on the relation between geometric characteristic of faults and the regional tectonic stress field in Ardal active fault zones.This model provides ratio of possible movements for all the active faults of a range on current tectonic regime (CTR). The result of the present method is compatible with the historical seismic records and recently micro seismic activities of the zone. This theoretical model is based on the relations between geometric characteristics of the faults and the regional tectonic stress field. The structural data were collected to find the direction of axials certain stress in wide range of study area. This was used from application equations of the pattern in 15 station on study area. Finally we obtained the direction of maximum mainly stress for each section separately by using inversion method which are applied in equations.

**Keywords** High Zagros, Maximum mainly stress, Movement potential, Regional tectonic stress field.

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## INTRODUCTION

Iran is one of the most active areas of the world in terms of tectonic activities in the Alps-Himalayas belt. One of the characteristics of this belt includes the presence of thrust faults and associated folds along with the general trend of the belt- northwest - southeast as well as transverse faults with north, northwest - south southeast trend (Alipoor *et al.* 2012). Folded - Thrust Zagros as a part of the Alpine - Himalayan orogenic belt and one of the youngest and most active continental collision zones on earth, with a length of about 1500 km extending from the Tarsus Mountains in northeast Turkey to Minabfault in the northeast of Hormoz Island in southern Iran. The High Zagros is a folded-thrust belt of Zagros in the southwest Iran with the width of 80 km. This area is bounded on the north by the Main Zagros Reverse Fault (MZTF) and on the south by the High Zagros Fault (HZF) (Alipoor *et al.* 2012).

According to Alipoor *et al.*(2012), the formation of this area is related to the continuous convergence movement of the Arabian plate in the southwest and the subcontinent of central Iran in the northeast, which is itself the result of a movement to the northeast of the African-Arabic plate to Eurasia. Ardel area, located in the southern part of Chaharmahalva Bakhtiari province and is part of the Zagros structural zone in terms of structural land division, extends along a general northwest-southeast direction. The study area is part of the Zagros zone, the oldest geological unit in the study area, which is related to the Khanekat Formation, followed by the Neiriz Formation, Sarmah Formation and the Darian Formation. The study area is located at 51´ 31 ° -50 °16´ Eastern longitude and 32 °,9'-31 ° 18' North latitude in southwestern Iran and south of Chaharmahalva Bakhtiari province with active faults with significant seismic background. It ranges from northwest to Abbas Abad village to the southeast to the village of Sartang Hana Ali. Quaternary faults have a direct relationship with the seismicity of the area and as a variable, it can be useful to quantify fault movement potential (FMP) to quantify earthquake hazard along active Ardal faults. Therefore, it has been used to assess earthquake hazard along active fault zone. Fault movement potential, or FMP, is a new parameter to quantify earthquake risk for Quaternary and active faults in the region. This parameter as described by Lee *et al.* (1997) has been applied to evaluate the movement of major faults in Hong Kong. The results are consistent with historical seismic records and current seismic activity in that area. Therefore, taking into account considerations, it can also be applied to Iran- faults. Abbassi and Farbod (2009) believe that fault movement potential calculated based on fault geometrical features and regional tectonic stress field, is a useful tool for potential movement classification of the Quaternary and active fault movement. In this paper, the method of Lee *et al.* (1997) has been used to evaluate the activity of active fault in Ardal due to the mechanical relationships between fault geometry and tectonic stress field.

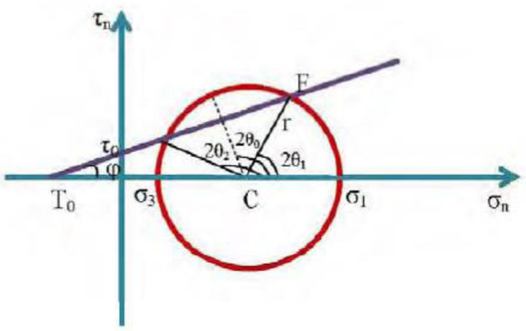


**Fig. 1**. Moore circle indicating the stress state during the fault slip, Adapted from Lee *et al.* (1997).

**Active faults of the region**

There are 14 active faults in the study area Zard Kuh Fault, Kordan Fault, Ghareh Fault, Dopolan Fault, Kermani Fault, Massan Fault, Bazuft Fault, Dena Fault, Sabzeh Kuh Fault, Ardal Fault, MZRF Fault, Heydarabad Fault, Mourchegan Fault, Semirom Fault. Using the kinematic evidence, we can evaluate the mechanism and activation of faults. The faults crossing different formations along their route have left fault surfaces with different movement signs. Stairs and fault scratches are among these signs, if there are different generations of fault scratches, using cutting base (fault scratches crossing the younger generation fault scratches that are younger in terms of age) and we can define their priority and delay and the mechanism of the youngest movement on the fault plane. Ardel fault as the youngest fault in the study area is the southwestern part of the current Zagros fault in the study area, which is approximately 70 km long. It joints the Sabzekuh Fault (fragments of the Kazeroon Fault) to the northwest after passing the north west of Ardal city in the proximity of Naghan city. In the study area, the formations of Cretaceous (Darian-Fahlian, Kazhdumi, SarvakIlam) formations, Bakhtiari formation (Late Pliocene) and Quaternary sediments are affected by the movement of this fault. By traversing the Ardal Fault in three areas of the north of Kaj Village, Tang Dereksh-Varkesh (northeast of Ardal City) and the northwestern limestone mines of Naghan city, fault surface related to this fault is taken at 129 stations. The stereogram and contour diagrams are derived from the polarization density of the fault surfaces in three zones for the Ardel fault (Figs. 1- 4). The stereographic image of the fault plates and their strike slides in the Ardal fault zone as well as the Ardal fault rose diagrams

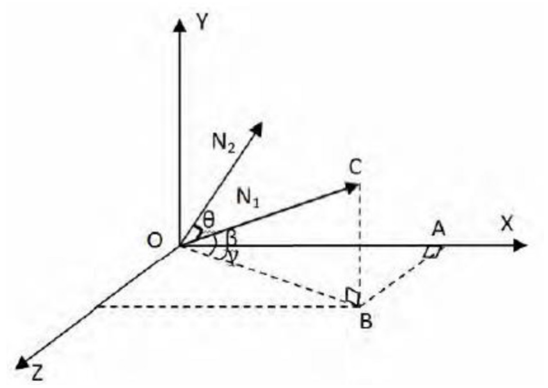


**Fig. 2.** A straight line in three dimensions and the image on the screen, adapted from Lee *et al.* (1997).

with approximate trends at 129 stations southwest ward are shown. The fault surfaces taken in all three zones have different generations of fault scratches. In their study, based on the young fault scratches with rake near the horizon (due to the cuttingbase), the mechanism of the youngest movement of Ardal fault of right strike is proposed. The Main Zagros Reverse Fault is observed in the northeast and southeast of the study. The Main Zagros Reverse Fault in the northeast of the study area is a imbricate thrust system with a width of about 500 m with thrustfaults to the slope to the northeast of the Sanandaj-Sirjan Zone in the northeast and the folded-thrust belt of the Zagros in the southwest (Alipoor *et al.* 2012). The faults of this zone have a gradient of 2 to 5 degrees northwest. In this imbricate thrust system, thrust sheets are of various genera including lime, igneous rocks, slit and red sandstones as observed.

## Theoretical model for fault movement potential analysis

Fault movement potential (FMP) is dependent on tectonic stress (σ), fault plate geometry (G) and physical properties of the inner and side of the fault (P). FMP is a function of these factors:

$$FMP=f(\sigma, G, P) \tag{1}$$

Although a geological environment is usually heterogeneous and very complicated, it can be considered statistically homogeneous and isotropic. Based on this problem and to simplify the theoretical model, the geological environment of the faults is considered

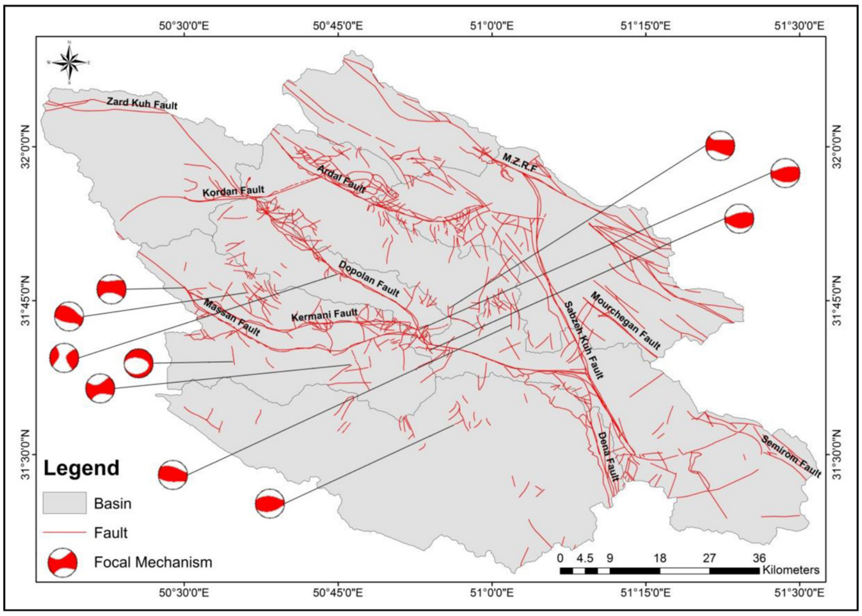


**Fig. 3.** Focal mechanism map of the active fault in the study area.

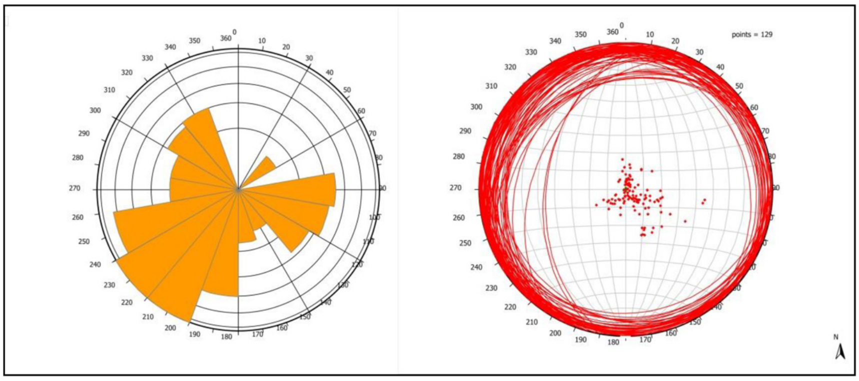


**Fig. 4**. Stereographic image of the Ardal fault zone and silican sides of the Ardal fault zone and its rose diagram using the Move software.

as a homogeneous, isotropic and elastic material. Thus, FMP can be simplified as follows.

$$FMP = f(\sigma, G) \qquad (2)$$

To consider the effect of tectonic stress orientation and fault geometry on fault seismicity, Dehbozorgi *et al.* (2010) conducted experiments using block models. The results show that changing the slope of the fault causes significant changes in the time intervals of re-occurrence of seismic events, independent of the amount of seismic energy. For some slope values, the seismic activity of the fault disappears and to prove the results of these experiments, Ritz *et al*. (2012) conducted a theoretical analysis and showed that the faults can slip when the angles are between 20 and 70 degrees in the orientation of the maximum compressive stress and along the fault. However, there are some exceptions to this model for real fault systems. These exceptions are due to the limitation of two-dimensional investigations. In fact, fault plates are not always vertical and the orientation of the maximum compressive stress is not always horizontal. In this method, this problem is considered using the Moore's stress circle.

**Theoretical model**

Mechanically, the most important factors that influence the onset of slip movement on a pre-existing fault (compressive stress is positive) are:

1. Difference of the maximum principal stress ($\sigma_1$) and minimum ($\sigma_3$ ): ($\sigma_1$ - $\sigma_3$), which determines the diameter of the circle of Mohr.

2. The sum of the main maximum and minimum stresses: ($\sigma_1 + \sigma_3$ ), which determines the location of the Mohr circle.

Where, $\theta$ is the angle between the normal to the fault plane and the maximum principal stress ($\sigma_1$). The upper and lower limits $\theta$ are shown in the slip fault denoted by $\theta_2$, $\theta_1$, $\theta_0$ indicates the eigenvalue of $\theta_0$ in fault slip most likely, $\phi$ is the angle of internal friction of the fault, $\tau_0$ the internal cohesion of the fault and $T_0$ is the location at which the tensile fracture occurs. First, the angle ( $\theta_0$ ) at which the fault is most likely to slip is calculated. Based on the sinus theorem and Fig. 1, we have:

$$\frac{\sigma_1 - \sigma_3}{\sigma_1 + \sigma_3 + 2\,\tau_0\, ctg\,\phi} = \frac{\sin\phi}{\sin(2\theta - \phi)} \qquad (3)$$

By deriving the stress ($\sigma$) to the angle $\theta$ and considering the derivative as equal to zero, we have:

$$\cos(2\theta - \varphi) = 0,\ \theta_0 = 45^0 + \varphi/2 \qquad (4)$$

Then, the lower and upper limits of the angle $\theta$ are calculated for possible fault slip. From equation (3) we have:

$$\sin(2\theta - \phi) = \frac{\sigma_1 + \sigma_3 + 2\tau_0 \operatorname{ctg} \phi}{\sigma_1 - \sigma_3} \sin \phi \qquad (5)$$

In Fig.1, $\sigma_1+\sigma_3+2\tau_0 \operatorname{ctg} \phi \rightarrow \sigma_1-\sigma_3$, $\sigma_3 \rightarrow T_0$, $\theta$ is maximal, so we have :

$$\sin(2\theta - \phi) = \sin \phi \qquad (6)$$

$$\theta_1 \rightarrow \phi,\ \theta_2 \rightarrow \pi/2 \qquad (7)$$

On a brittle fracture surface, the friction factor is usually between 0.5 and 0.8 (Wang *et al*. 1979), related to the following angles :

$$\varphi = 27^0 - 39^0$$

For simplicity of calculation, $\phi$ is considered equal to 30 degrees. Therefore :

$$\theta = \begin{cases} \theta_0 = 60^0 \\ \theta_1 = \varphi \\ \theta_2 = \pi/2 \end{cases} \qquad (8)$$

This means that the fault can slip at $30^0 < \theta < 90^0$,. When $\theta = 60^0$, the fault slips easily. If $\theta \leq 30^0$ or $\theta \geq 90^0$, the fault cannot slip.

To quantify the relationship between fault movement potential (FMP) and angle $\theta$, FMP is defined as a normalized factor as follows:

$$FMP = \begin{cases} 0 & ,\ \theta \in [0^0, 30^0] \\ \dfrac{\theta - 30^0}{30^0} & ,\ \theta \in [30^0, 60^0] \\ 1 = \dfrac{\theta - 60^0}{30^0} & ,\ \theta \in [60^0, 90^0] \end{cases}$$

**Calculate angle** $\theta$

If the direction perpendicular ($\gamma_1$) to the fault plane and its inclination angle ($\beta_1$) and the maximum principal stress orientation ($\gamma_2$) and its inclination angle ($\beta_2$) are known, then their geometrical relations can be calculated (Fig. 2).

If $\gamma$ is the azimuth of a straight line and $\beta$ its inclination angle, the straight line can be defined as follows:

$$\begin{aligned} l &= OA = \cos\beta \cos\gamma \\ m &= CB = \sin\beta \\ n &= AB = \cos\beta \sin\gamma \end{aligned} \qquad (10)$$

And the vector $N = [l, m, n]$ is the direct line direction. Therefore, the angle between two straight lines can be calculated as follows:

$$\cos\theta = \cos\beta_1 \cos\beta_2 \cos(\gamma_1 - \gamma_2) + \sin\beta_1 \sin\beta_2 \qquad (11)$$

However, if the axis $_{1\sigma}$ is upward, $\beta_2$ becomes negative.

**The orientation of regional tectonic stress**

Tectonic stress is a stress added to the lithostatic stress condition. In other words, the deviated part is dedicated to the lithostatic stress. The analysis of the depth mechanism of earthquakes is one of the most common methods in studying contemporary tectonic stress field. However, the main compressive stress orientation maximally obtained from the analysis of the deep mechanism of a strong earthquake represents the characterization of a large regional tectonic stress field. Some analyzes of the deep mechanism of large earthquakes reveal the complex conditions of deep structures and the view of stress. The stress view means that the exceptional stress field in the instantaneous focal process is added to the regional tectonic stress field in the process of earthquake creation and the analysis of the depth mechanism of a single small earthquake has a random shape. Fortunately, analyzes of the artificial depth mechanism of many small earthquakes may determine the condition of regional tectonic stress. Thus, both the analysis of the depth mechanism of large earthquakes and the average analysis of small earthquakes can be used to obtain the overall composition of the regional stress situation.

## MATERIALS AND METHODS

In this study, we investigate the active fault of Ardal area using Move, Arc GIS software and integration of software data with calculated fault movement data and integration with device earthquakes to identify tectonic active areas are. In order to analyze the movement potential of active faults in Ardal area, shear surfaces with slip lineaments and their associated fault plates were measured and finally stress changes in rock units were calculated.

The inversion method was used to determine the principal axes of stress in order to obtain the active potentials of wide fault faults and at all sections, the principal stresses of the area were calculated by Tectonic FP software. In this method, it is assumed that , the lines on the plate show the maximum shear stress fault.

Finally, the angle between the normal vector of the plate to the maximum stress was measured and plotted in the equations (Table 1) and the potential movement of the active faults at each section was obtained.

## RESULTS AND DISCUSSION

The focal map of the active fault mechanism in the study area (Fig. 3) and the focal mechanism of earthquakes plotted along the Zagros present fault in the Ardal area (Nazari *et al*. 2011) show that most of the faults are of the reverse strike-slip type. According to the calculations of movement potentials of active fault zones, according to Lee *et al.* (1997) method, the regional stress at each section is solved separately using equation 9 (Table 1) which shows the southern terminal of the Ardel fault in Cheshmepahanwith the highest probability of seismic event in the future. Following the calculations, the results of Lee *et al.* (1997) method of solving the equation based on regional stress show that the south of the study area and around the Ardel fault has high potential rate in terms of earthquake recurrence.

## CONCLUSION

According to the calculations of the fault potential at each section of the study area, it was found that the southern terminal of the Ardal fault in each section of the studied region has the highest movement potential compared to the other strike-slip faults. As shown in Rose diagram and stereographic image for this fault, it was shown that the layers extend to the southwest, and are consistent with field data, the Ardal right strike-slip fault has been introduced as the youngest structure in the area, revealing young silican sides. Due to the dispersed device earthquakes, it was found that most of the events are sporadic and irregular, while medium to large scale earthquakes occurred near the Ardal fault and south of the area. The results of calculating the potential of fault movement in each plot show good match with the frequency of earthquakes, so it is suggested that in Darebid of Duplan, Duplan fault with the strike-slip movement

**Table 1.** The movement potential calculations of Ardal active faults using regional stresses.

| FMP | θ | Fault plain | (σ1) | Fault name | Section name |
|---|---|---|---|---|---|
| 0/7 | 51 | 354/10 | 50/45 | Zard Kuh fault | Abbas Abad |
| 0/8 | 54 | 12/16 | 50/45 | Kordan fault | Kordan |
| 0/2 | 36 | 314/25 | 50/45 | Ghareh fault | Landy |
| 0/2 | 84 | 332/31 | 50/45 | Dopolan fault | Dopolan Bid Valley |
| 0/3 | 40 | 170/22 | 50/45 | Kermani fault | Sarkhon |
| 0/5 | 74 | 163/13 | 50/45 | Massan fault | Sarmazeh |
| 0/7 | 52 | 25/17 | 50/45 | Bazuft fault | GelehShur |
| 0/6 | 48 | 286/11 | 50/45 | Dena fault | Chalgav |
| 0/4 | 42 | 291/18 | 50/45 | Sabzehkuh fault | Shams Abad |
| 0/9 | 61 | 342/12 | 50/45 | Ardal fault | CheshmehPahn |
| 0/5 | 73 | 150/23 | 50/45 | MZRF fault | Bid Valley |
| 0/8 | 66 | 325/10 | 50/45 | Heydarabad fault | Heydarabad |
| 0/8 | 66 | 320/08 | 50/45 | Mourchegan fault | Mourchegan |
| 0/5 | 75 | 298/15 | 50/45 | Mourchegan fault | Darmeh |
| 0/8 | 64 | 326/12 | 50/45 | Semirom fault | Sartang Hana Ali |

is considered as active fault in pre-seismic phase. Most of the movement potentials after Ardal fault are related to these three faults and the Kordan fault in the northwest. Zardkuhfault in Abbas Abad section with high rate of movement potential is introduced as a significant and active fault from the perspective of the study area.

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