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EXTENDED ABSTRACT

Seismic Hazard Assessment for the NTF by Slip Tendency Analysis based on the Regional Stress Extracted from the Focal Mechanism of Earthquakes and GPS Observables

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1. Introduction

The reactivation of slip on pre-existing planes of weakness is of key interest to many geological phenomena, being implicit for instance in tectonic inversion theory and in the concept of stick slip behavior. The analysis of reactivation is crucial in engineering geology where rock masses must be below the critical stress level needed to initiate sliding and in reservoir geology for selecting safe hydrocarbon traps. It also constitutes a valuable tool in seismic hazard assessment as it provides a means of quantifying the slip potential on mapped or suspected faults in a known or inferred stress field.

The foundations of the fault reactivation theory can be found in Jaeger (1969). He proposed a condition for reactivation based on the frictional resistance to sliding. It is usually assumed that after a shear fracture develops, the rock possesses no cohesion across the fracture plane; so the criterion for reactivation is the Navier–Coulomb for cohesionless faults, expressed as,

$$\tau = \mu(\sigma_n - p_f) \tag{1}$$

Where τ and σ_n are the shear and the normal stresses acting on the fault surface, respectively, μ is the coefficient of the sliding friction and p_f is the pore fluid pressure. In general Eq. (1) applies only in the brittle part of the crust affected by frictional processes.

2. Methodology

In terms of the effective stress $\sigma = \sigma_n - p_f$, which incorporates the effect of the pore fluid pressure (see Eq. (1)), the critical condition for sliding on a pre-existing plane of weakness can be written as

$$\mu = \tau/\sigma \tag{2}$$

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The slip tendency of a surface is defined as the ratio of the shear stress to the normal stress on that surface (Morris et al., 1996),

$$T_s = \tau/\sigma \tag{3}$$

It is therefore clear that the slip tendency equals the coefficient of sliding friction. The fault planes that will more likely slip are those with a high ratio of shear to the normal effective stress, close in value to m. The slip-tendency analysis is based on the fact that the slope of the failure criterion, i.e. the coefficient of friction, may span a range of values limited by the Byerlee's experiments. Generally μ is in the range 0.6-0.85 (Byerlee, 1978). Fixing the stress difference ratio (Mohr's circle diameter), we find a variety of combinations (θ, μ) which make slip viable (Fig. 1). In a region dominated by a particular rock type, the assumption of a specific μ determines the optimum angle θ for sliding (Jaeger, 1969), $2\theta = tan^{-1}(1/\mu)$. This is the most favourable orientation of the fracture plane relative to the direction of maximum compression. In this plane the slip tendency is maximum, i.e. $T_s = T_s^{max}$. A normalized slip tendency varying between 0 and 1 is defined by dividing the slip tendency by its maximum possible value $T_s' = T_s/T_s^{max}$. The normalized slip tendency then ranges from 100% near the ideal fault orientation to 0% in the principal stress directions.

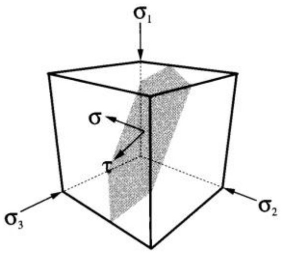

Fig. 1. Normal stress, σ_n, and shear stress, τ, on arbitrarily oriented surface within stress field defined by three principal compressive stresses σ_1, σ_2 and σ_3 (Morris et al., 1996).

3. Results and discussion

Using the map of major active faults of Iran (Hesami et al., 2003), NTF was divided into separate sections based on the change of length so that each section has almost a fixed direction. Finally, 11 sections or branches of the fault were considered for analysis. The considered fault sections are shown in three dimensions in Fig. 2.

In Afra et al. (2017), earthquake focal mechanisms were used to estimate regional stress with two methods: multiple inverse (Yamaji, 2000) and iterative joint inversion (Vavrycuk, 2014). Also, in this research, using the GPS horizontal velocity field from the reference of Jamour et al. (2011) in the study area, the main values of the stress tensor that have the best fit to the study area were calculated using the least squares method. For this purpose, first the displacement gradient tensor, then the strain rate tensor, and finally the stress rate tensor is calculated using the generalized Hook law. The results for regional stresses are presented in Table 1.

Table 1. Results of three methods for regional stress extraction

Method	σ_1(º)		σ_2(º)		σ_3(º)		
	Trend	Plunge	Trend	Plunge	Trend	Plunge	φ
Multiple inverse method	134	1	235	85	44	5	0.28
Iterative joint inversion	142	2	238	73	51	17	0.07
Horizontal GPS Observables	165.1	0.0	165.1	-90.0	75.1	0.0	0.45

Using the Cauchy's law, the normal and shear components of regional stress in the plane of different sections of NTF in all three stress states were calculated, and using the ratio of shear to normal stress, the amount of slip tendency was calculated for each fault section. According to Fig. 3, in case of using multiple inverse method to determine the regional stress, in the branches of the northwestern part of the NTF, the values of slip tendency are above 50% and towards the southeastern part of the fault, its value is reduced to less than 50%.

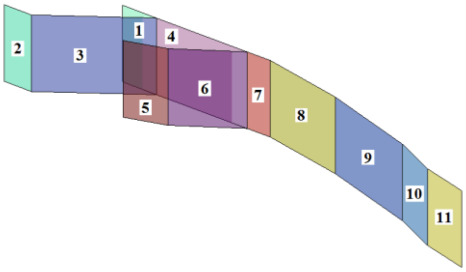

Fig. 2. Three-dimensional geometry of different parts of NTF. For better identification, the page of each section is shown with a separate number and color.

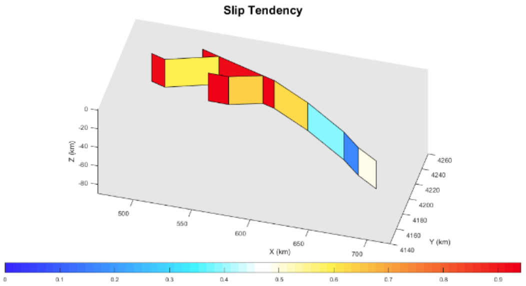

Fig. 3. Three-dimensional geometry of different parts of the NTF, which is shown in color between zero and one in terms of the amount of slip tendency with the stress extracted by the multiple inverse method.

According to Fig. 4, in the case of iterative joint inversion method to determine the regional stress in all branches of the fault, the slip tendency is above 50% so that from the northwest of the fault to the southeast, its value is gradually reduced, but does not fall below 50%. According to Fig. 5, in the case of GPS horizontal observations to determine the regional stress in all fault branches, the tendency to slip is above 50% so that from the northwest of the fault to the southeast, its value gradually increases and it is generally above 50%.

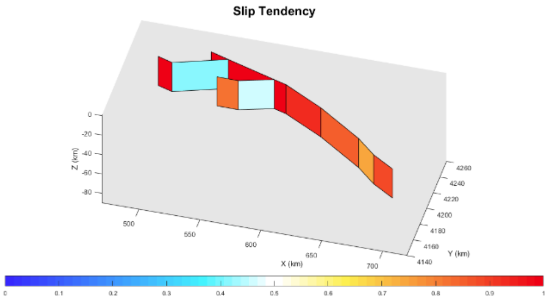

Fig. 4. Three-dimensional geometry of different parts of the NTF, which is shown in color between zero and one in terms of the amount of slip tendency with stress extracted from the iterative joint inversion method.

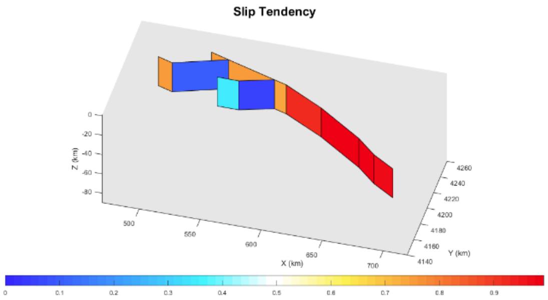

Fig. 5. Three-dimensional geometry of different parts of NTF, which is shown in color between zero and one in terms of the amount of slip tendency with stress extracted from horizontal GPS observations.

4. Conclusions

Slip tendency analysis is a valuable tool in fault reactivation evaluation and seismic hazard assessment as it provides a means of quantifying the slip potential on mapped or suspected faults in a known or inferred stress field. In addition to identifying the faults most prone to reactivation, it’s possible to compute and plot synthetic focal mechanisms from the direction and sense of likely slip. This allows compatibility between focal mechanisms and geological structures to be verified. The potential for slip depends on the prevailing stress field, the fault surface orientation and the coefficient of friction. Due to the location of Tabriz metropolis near the NTF, the study of seismic potential in this fault is of particular importance for seismic hazard analysis in this city. In this study, the geometric information of the fault was selected from various sources and assumed to be constant. Then, the regional stress that has the best fit to the study area was collected and also calculated using GPS observables. Then the stress was decomposed using the Cauchy's law in the shear and normal directions of different parts of the fault and the slip potential for them was calculated by considering the ratio of shear stress to normal. A noticeable point in the results is the slip tendency above 50% for the fault branch passing through the north of Tabriz metropolis, which shows the potential for earthquakes in this region. Different states of regional stress have different results for the slip tendency analysis. In the case of using multiple inverse method to determine the regional stress, the values of slip tendency in the branches of the northwestern part of the fault are above 50% and towards the southeastern part of the fault, its value is reduced to less than 50%. In the case that the regional stress is determined by the iterative joint inversion, in all branches of the fault, the slip tendency is above 50%, such that from the northwest of the fault to the southeast, its value is gradually reduced but does not reach below 50%. In the case of using GPS observables to determine regional stress, in all branches of the fault, the slip tendency is above 50%, so that from the northwest of the fault to the southeast, its value gradually increases and is generally above 50%. A noticeable point in the calculations is the slip tendency above 50% for the fault branch passing through the north of Tabriz metropolis, which shows the potential for rupture and the occurrence of earthquakes in this section. A noticeable point in the results is the slip tendency above 50% for the fault branch passing through the north of Tabriz metropolis, which shows the potential for rupture and the occurrence of earthquakes in this area.

5. References

Afra M, Moradi A, Pakzad M, “Stress regimes in the northwest of Iran from stress inversion of earthquake focal mechanisms”, Journal of Geodynamics, 2017, 111, 50-60.

Byerlee JD, “Friction of rocks”, Pure and Applied Geophysics”, 1978, 102, 453-475.

Djamour Y, Vernant P, Nankali HR, Tavakoli F, “NW Iran-Eastern Turkey Present-Day Kinematics: Results from the Iranian Permanent Gps Network”, Earth and Planetary Science Letters, 2011, 307, 1-2, 27-34.

Hesami K, Jamali F, Tabassi H, “Map of Major Active Faults of Iran” Published by International Institute of Earthquake Engineering and Seismology, Available from: www. iiees. ac. ir/Seismology/ActiveFault. pdf, 2003.

Jaeger JC, “Elasticity, Fracture and Flow with Engineering and Geological Applications”, first ed. Methuen and Co. Ltd., London, 268 pp, 1969.

Morris A, Ferrill, DA, Henderson DB, “Slip-tendency analysis and fault reactivation”, Geology, 1996, 24, 3, 275-278.

Vavrycuk V, “Iterative joint inversion for stress and fault orientations from focal mechanisms”, Geophysical Journal International, 2014, 199, 69-77.

Yamaji A, “The multiple inverse method: a new technique to separate stresses from heterogeneous fault-slip data”, Journal of Structral Geology, 2000, 22, 7, 441-452.