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Strain analysis of the Darvazeh Quran fault, Zagros Mountains, Iran

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Abstract

The Zagros Fold-and-Thrust Belt is tectonically active and often has active faults with insensible and slow motions. Determining the rate of movement and displacement in these faults requires very precise measurements. One of the measurement methods of fault movements is using geodetic and micro-geodetic studies. This research is focused on one of the active faults in the north of Shiraz city, Fars province called Darvazeh Quran fault in this study. In order to determine the deformation matrix, the local networks are preferred. Deforming area is normally covered by four control points. These points constitute a geodetic network and their location or structure is defined by the topographic and geological parameters. The results show that the obtained displacement vector is from SE to NW with a dextral strike-slip creep. Deformation matrix indicated 4mm±6ppm displacement per year and elongation changes of network have an ascending trend into time.

Keywords: Deformation; earthquake; micro-geodesy; fault; Iran; Zagros

1. Introduction

Perhaps it can be said the dream of any expert or student of Earth sciences, particularly the tectonics branch, would be an opportunity to study in Iran. The great treasure of Eurasia's active tectonics history and young tectonics of the last continent-continent collision and subduction of the Neo-Tethyain oceanic crust in this region of the world has been associated with deformation of the Zagros orogenic belt. On the other hand, this orogenic belt is a live album from all structures that are important for the tectonics researcher.

Collision between the Indian-Eurasian-Arabian plates [1] is the main activity in this region. Crustal shortening and formation compression structures led to the combination of dip-slip and strike-slip faulting in the Zagros Orogeny [2] and this shortening does not include the southern border of the collision zone. Young tectonics structures showed a collision at the late Eocene in the south of Iran [3].

The Zagros is part of the Alpian-Himalayan orogenic belt [4] which includes the area from east of Turkey to the Minab Fault Zone in the south of Iran [5]. It lies on the northern margin of the Arabian plate [6, 7]. This is the result of the Neo-Tethys Sea closing [8]. Intense seismic activity is an indicator for Zagros Thrusting [9, 10, 1]. This structure zone has caused Zagros to divide into three zones including: The High Zagros, Fold-and-Thrust belt of Zagros and the Khuzestan plain, which is part of the Simply Folded Belt [9].

Nowadays, not only in crustal deformation studies, but also in engineering studies, dam construction, applications of the large constructions and industrial equipment, complicated projects and even in archaeological and architectural applications there is a need to achieve high precision. Conventional geodetic techniques have lost their importance in many application areas with the wide spread usage of the satellite techniques. Thus, for a small area or faulted areas based on the large scale studies micro-geodetic networks need to be optimized and designed.

Measuring the movement of continents on a global, regional and local scale is done by the relative strain analysis methods, geodetic and micro-geodetic studies in scattered parts of the faults and in points with uniform coverage in the level area [11]. By using this method, one can determine the position of points where the tectonics pressure is increasing [12]. In general, geodetic and micro-geodetic studies, alongside the geological, seismological and geophysical studies can open a new horizon in determining the activities of active faults for researchers.

2. Tectonics and geological settings

Studied region with 7.145 km^2 area lies between

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52°33'48" and 52°33'52" northern longitude and 29°38'04" to 29°38'09" eastern latitude in the Fars province, southwestern Iran in the north east of Shiraz in the Esfahan path gate, which is part of the high Zagros [13]. Andalibi et. al. suggested that the Shiraz region was divided into two tectonics subzones which include intermediate tectonics subzone and transitional tectonics subzone based on the Shiraz seismotectonics behavior, geological and structural studies. Therefore, this region is part of the intermediate tectonics subzone. Asymmetrical folds and the traces of young thrusting indicators exit in this range [13]. There are Jahrom (Eocene), Asmari (Oligocene-Miocene) and Razak formations in it. The lithology of these formations consists mainly of limestone and marl (Fig. 1).

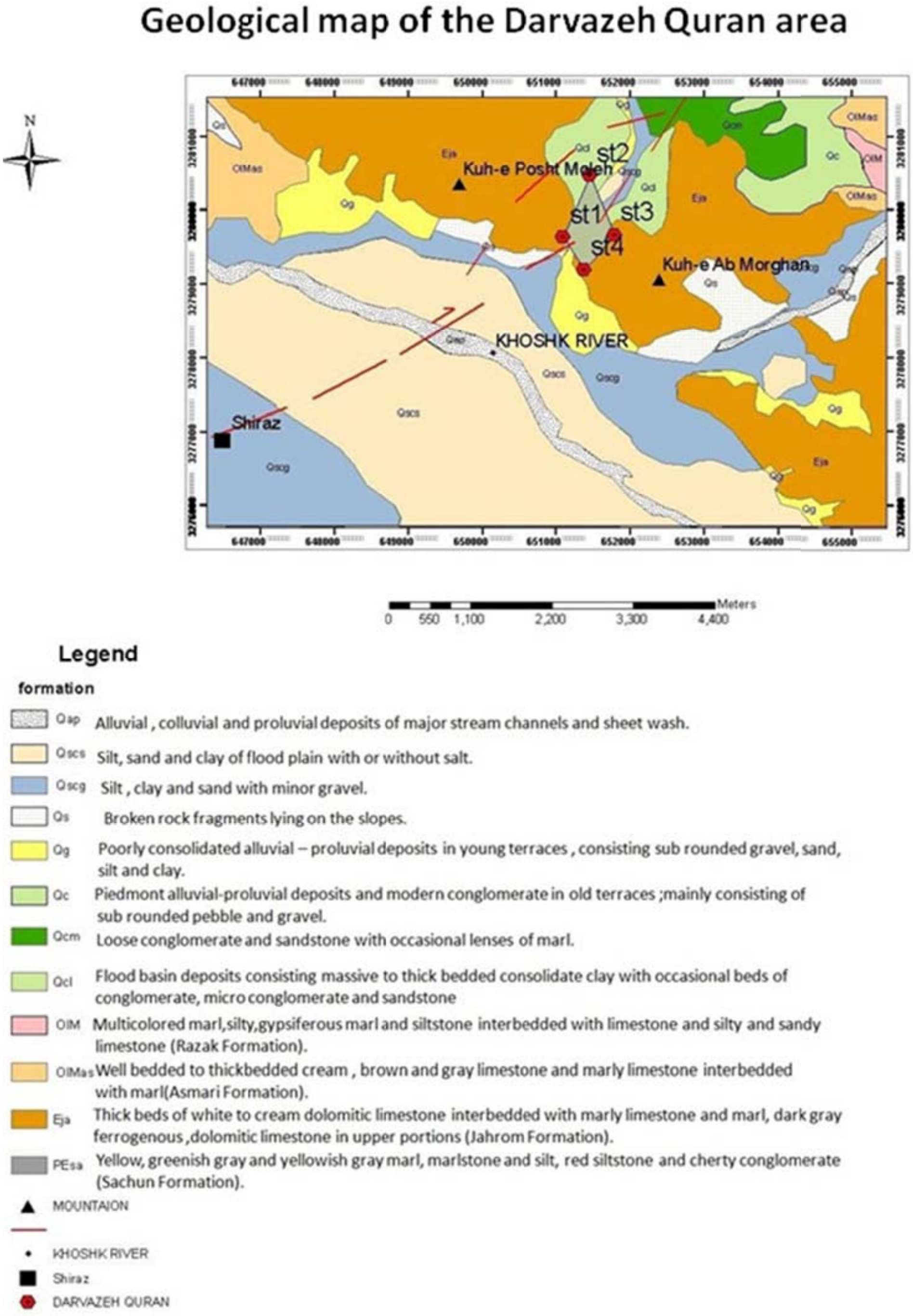


Fig. 1. Map showing regional geology map and position of network derived from 1:100,000 scale of the Shiraz map

This range is active from the point of tectonics [13]. Sabz-pushan basement fault is established in the southwest side of the studied area. There are three active faults; these faults are the Saadi thrust fault zone, Bamo fault zone in the north and the Soltan fault in the south [13]. This region is surrounded by Ab Morghan syncline and Bajgah Mountains (Fig. 1), these faults follow the structural trend of the Zagros Fold-Thrust Belt striking NW-SE along Zagros Thrust System.

3. Microgeodesy Studies

Observation techniques, selected equipment and surveying interval of any project have to be optimized in terms of some parameters. These optimizations, in general, are realized to achieve a desired precision. Besides, reliability is also as important as precision. One should trust not only the results, but also the reliability of a network which can be expressed as mathematical relations. The precision, reliability and economical parameters in a geodetic network can be arranged in order to achieve the optimum solution which is defined as the optimization of geodetic networks [14].

In order to determine the deformation, local networks are preferred. Deforming area is generally covered by four control points. These control points constitute geodetic network and their location or structure which is defined by the topographic and geological parameters. The number of points is directly related to the deforming object and the deformation accepted in the area. The ideal approach is an interdisciplinary study to define the number of points and locations for these “control networks”. Kuang (1996) suggested three sets of control points for deformation monitoring which are deformation points, reference points and orientation points.

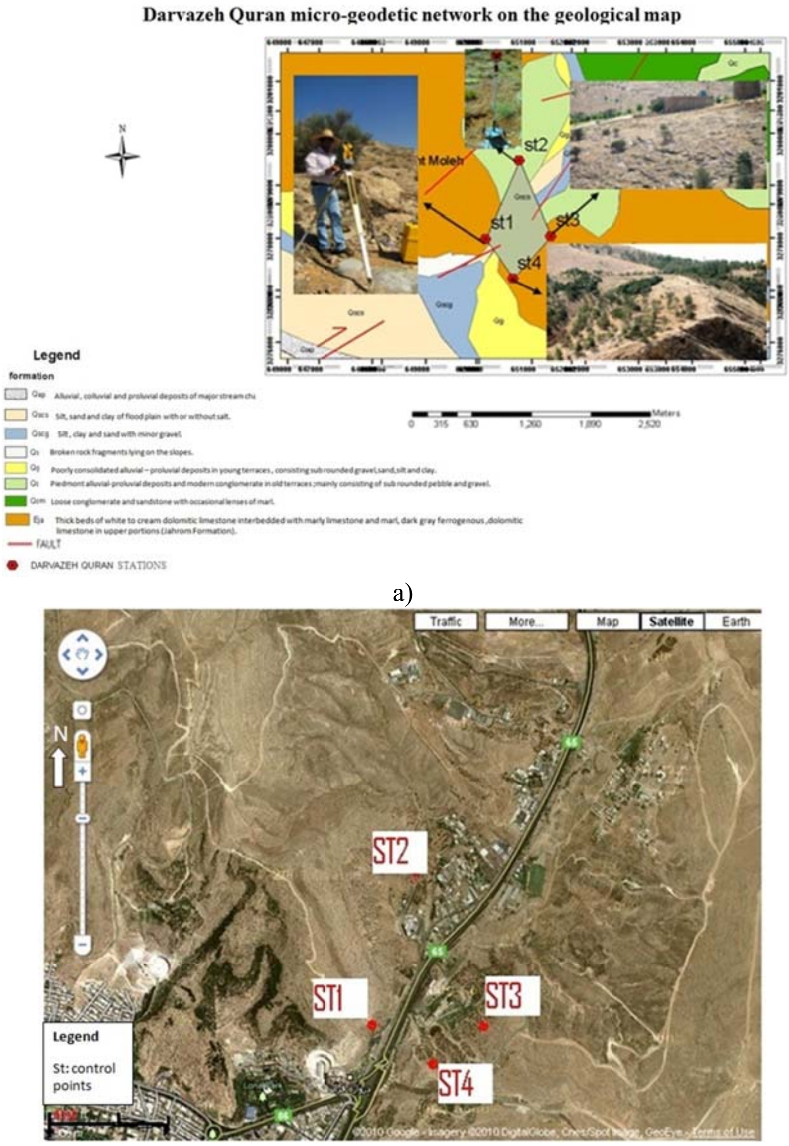
There are several mathematical models to describe the relationship between observations and unknown parameters [14]. The parametric model is used in this study so that observations are as a function of the unknown parameters. The following condition was added to the parametric model to consider the accuracy and value of the observations for determining answers. (formula1)

$$V+L=AX \tag{1}$$

Where V is the residual vector, A is the coefficients matrix, X is unknowns and L is observations. Residual vectors cause the heavy weight observation to be less correct. The advantage of parametric models is these models can be prepared easily in the form of computer programs and the unknown parameters can be obtained directly. The least square as an adjustment method is the most common method in the parametric models.

In order to design a monitoring network along Darvazeh Quran Fault, some pre-studies were performed. Finally, the Darvazeh Quran micro-geodetic network is introduced according to the suggestions of several Earth scientists and experimentists. The general plan for the network design was performed on several parameters which are the available data collected from local resources, the topographic and economic situations, and equipment which is going to be used and the fault geometry. The outputs of these parameters are the approximate locations of the geodetic control points, the number of stations, and the observation and processing strategies.

There are two types of micro-geodetic network. One is absolute network and the other is relative network [14] each of which has different applications. Darvazeh Quran network is a relative micro-geodetic network based on study aims. According to the optimization strategies, performed experiments and collected information stated above, a geodetic network was designed and interpretation strategies are discussed in order to monitor this fault and its vicinity. Network was designed on the information of existing control points and the fault trace geometry. Stations were established in February, 2009 in order to define the slip rate of the fault trace and its strain matrix. Some stations are located on the alluvium so to solve this problem, drilling was used to reach bed rock and to establish these stations on the bed rock. In conclusion, the locations of the stations points of micro-geodetic network were distributed to both sides of the Darvazeh Quran fault. Finally, this network (Fig. 2) was ready for surveying. Measuring was done alternatively, over 15 months in 6 periods at the same times. Results were adjusted by the least square method, and errors, defects, and wrong data were deleted. Additionally, it was shown that this fault branch has about 4mm±6ppm dextral strike-slip fault movement in each year in the North West to South East direction. (For more details refer to Quanbari and et.al, (2010) which was presented in the Geological Symposium in August 2010 [15])



a)

Fig. 2. Locations of the sites of Darvazeh Quran micro-geodetic network on the geological map (a) and the satellite image (b)

4. Strain matrix

Displacement field is a function that shows amount of displacement of points [16]. This function is stated as a 2*2 matrix. The rate of change of this field into the location of points is called strain [17]. Mathematical relation of this aspect has been indicated in the following formula 2. Where d is displacement matrix, r is the location of survived points and E is strain matrix.

$$d=\begin{bmatrix}\Delta x(x,y)\\ \Delta y(x,y)\end{bmatrix} \qquad r=\begin{bmatrix}x\\ y\end{bmatrix}$$

$$E=\frac{\partial(\Delta x,\Delta y)}{\partial(x,y)}=\frac{\partial d}{\partial r}=\begin{bmatrix}\frac{\partial\Delta x}{\partial x} & \frac{\partial\Delta x}{\partial y}\\ \frac{\partial\Delta y}{\partial x} & \frac{\partial\Delta y}{\partial y}\end{bmatrix}_{2\times2}=\begin{bmatrix}e_{xx} & e_{xy}\\ e_{yx} & e_{yy}\end{bmatrix}_{2\times2} \qquad (2)$$

D is displacement matrix, r is the location of survived points and E is strain matrix.

This matrix stated all of the motions and deformation of one object. Each strain can be written as the sum of one symmetric matrix(S) and asymmetric matrix (A). The symmetric part of it is strain tensor, (formula2). Symmetric matrix indicates rotation (ω, radian) (formula3).

$$E=\frac{1}{2}\left(E+E^{T}\right)+\frac{1}{2}\left(E-E^{T}\right)=S+A$$

$$S=\frac{1}{2}\left(E+E^{T}\right)=\begin{bmatrix} e_{xx} & \dfrac{e_{xy}+e_{yx}}{2} \\ \dfrac{e_{xy+yx}}{2} & e_{yy} \end{bmatrix}$$

$$A=\frac{1}{2}\left(E-E^{T}\right)=\begin{bmatrix} 0 & \frac{1}{2}\left(e_{xy}-e_{yx}\right) \\ \frac{1}{2}\left(e_{yx}-e_{xy}\right) & 0 \end{bmatrix} \tag{3}$$

$$\omega=\frac{1}{2}\left(e_{xy}-e_{yx}\right)$$

Strain tensor can be written as the sum of three matrixes (formula4).

$$S=\begin{bmatrix} \underbrace{\frac{1}{2}\left(e_{xx}+e_{yy}\right)}_{\sigma} & 0 \\ 0 & \frac{1}{2}\left(e_{xx}+e_{yy}\right) \end{bmatrix}+\begin{bmatrix} \underbrace{\frac{1}{2}\left(e_{xx}-e_{yy}\right)}_{\tau} & 0 \\ 0 & \frac{1}{2}\left(e_{yy}-e_{xx}\right) \end{bmatrix}+ +\begin{bmatrix} 0 & \underbrace{\frac{1}{2}\left(e_{xx}+e_{yx}\right)}_{\gamma} \\ \frac{1}{2}\left(e_{yx}+e_{xy}\right) & 0 \end{bmatrix}$$

$$\sigma=\frac{1}{2}\left(e_{xx}+e_{yy}\right),\ \tau=\frac{1}{2}\left(e_{xx}-e_{yy}\right) \tag{4}$$

In this formula δ is dilation strain,τ is pure shear strain and γ is total shear strain (formula4).

In formula4, ∂ is Mean Strain, λ is total strain, λ_1 and λ_2 are components of strain tensor ellipsoid. Total shear strain (γ) is calculated by formula 5, where τ is pure shear strain and v is simple shear strain.

$$\partial=\frac{1}{2}\left(\lambda_1+\lambda_2\right),\ \lambda=\sqrt{\lambda_1^2+\lambda_2^2} \tag{5}$$

$$\gamma=\sqrt{\tau^2+\nu^2}\ ,\nu=\frac{1}{2}\left(e_{xy}+e_{yx}\right) \tag{6}$$

There are two types of shear strain matrixes including pure shear strain matrix (τ) and simple shear strain matrix (v), each of which has been stated in formula 7 and 8, respectively (Fig. 3a, b)

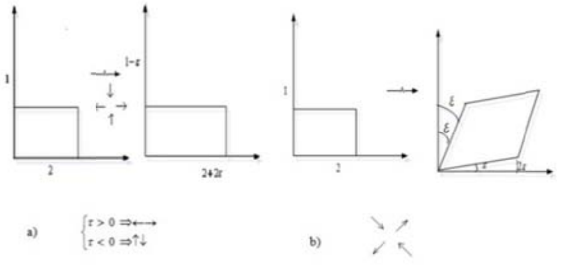


Fig. 3. (a) Operation of the pure shear strain matrix on object, (b) Operation of the simple shear strain matrix on object

$$\tau=\begin{bmatrix} 1+\tau & 0 \\ 0 & 1-\tau \end{bmatrix}=I+\begin{bmatrix} \tau & 0 \\ 0 & -\tau \end{bmatrix},$$

$$I=\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} S=\begin{bmatrix} \lambda & 0 \\ 0 & \lambda \end{bmatrix}=\lambda.I\ ,$$

$$\omega=\begin{bmatrix} 1 & \omega \\ -\omega & 1 \end{bmatrix}=I+\begin{bmatrix} 0 & \omega \\ -\omega & 0 \end{bmatrix} \tag{7}$$

I, S and ω indicate Identity matrix that keeps figure, scale matrix and rotation matrix, respectively (formula 6).

$$\nu=\begin{bmatrix} 1 & \nu \\ \nu & 1 \end{bmatrix}=I+\begin{bmatrix} 0 & \nu \\ \nu & 0 \end{bmatrix} \tag{8}$$

It is essential to create a displacement model for determining strain matrix so this model was used (formula 8). Our movement is very small so the higher degrees of polynomials were not used.

$$\begin{cases} \Delta x=a_0+a_1x+a_2y \\ \Delta y=b_0+b_1x+b_2y \end{cases} \tag{9}$$

$\{a_0,b_0\}$ indicates body movement is, in which $\{a_1,a_2,b_1,b_2\}$ are the elements of strain matrix and indicates rotation and deformation (formula9, 10,11and12).

There are two methods [17] for determining the strain matrix including finite difference, which was obtained for each point of the network from one of the stated displacement models (formula 10), and finite element which was obtained for each triangle of network from one of the stated displacement models (formula 11).

$$\text{a)}\begin{cases} \Delta x_i=a_0+a_1\left(x_i-x_p\right)+a_2\left(y_i-y_p\right) \\ \Delta y_i=b_0+b_1\left(x_i-x_p\right)+b_2\left(y_i-y_p\right) \end{cases}$$

$$\text{b)}\begin{cases} \Delta x_i=\Delta x_p+a_1\left(x_i-x_p\right)+a_2\left(y_i-y_p\right) \\ \Delta y_i=\Delta y_p+b_1\left(x_i-x_p\right)+b_2\left(y_i-y_p\right) \end{cases} \tag{10}$$

I points are the points connected to P point, which is the selected point for calculating strain matrix. Finally, the strain matrix is obtained as formula 12.

$$\begin{cases} \Delta x_i=a_0+a_1x_i+a_2y_i \\ \Delta y_i=b_0+b_1x_i+b_2y_i \\ \\ \Delta x_j=a_0+a_1x_j+a_2y_j \\ \Delta y_j=a_0+a_1x_j+a_2y_j \\ \\ \Delta x_k=a_0+a_1x_k+a_2y_k \\ \Delta y_k=b_0+b_1x_k+b_2y_k \end{cases} \quad or \quad \begin{cases} \Delta x_i=a_0+a_1\left(x_i-x_c\right)+a_2\left(y_i-y_c\right) \\ \Delta y_i=b_0+b_1\left(x_i-x_c\right)+b_2\left(y_i-y_c\right) \\ \\ \Delta x_j=a_0+a_1\left(x_i-x_c\right)+a_2\left(y_i-y_c\right) \\ \Delta y_j=b_0+b_1\left(x_j-x_c\right)+b_2\left(y_j-y_c\right) \\ \\ \Delta x_k=a_0+a_1\left(x_k-x_c\right)+a_2\left(y_k-y_c\right) \\ \Delta y_k=b_0+b_1\left(x_k-x_c\right)+b_2\left(y_k-y_c\right) \end{cases} \tag{11}$$

There are 6 equations and 6 unknowns in finite element method (formula 11) without any degrees of freedom. Finally, the obtained strain matrix is as shown in formula 12.

$$E = \begin{bmatrix} a_1 & a_2 \\ b_1 & b_2 \end{bmatrix} \qquad (12)$$

This study focused on the idea of dealing with a strain matrix determining project by using geodetic techniques. Moreover, this study tried to form interactions between Earth sciences and geodesy in terms of deformation monitoring projects. Geological and geophysical evidence is incorporated in order to form these interactions and detailed tectonics of the region is introduced. The importance of the region is underlined by adding the tectonics of the region by introducing its relationships with adjacent tectonics phenomenon.

Results were adjusted by the least square method, and errors, defects, and wrong data were deleted. Additionally, the strain components (Table 1) and deformation matrix (Table 2 and 3) were calculated. To eliminate the effect of other faults the weighted constraint model was used in the network design stage.

Table1. The components of σ, λ, γ, τ, υ, ω, for any point (a) and triangle of network (b) δ is Mean dilation strain, λ is total strain , γ is total shear strain, where τ is pure shear strain and υ is simple shear strain. Rotation has been shown by (ω, radian)

The number of points	Sigma(σ)	Lambda(λ)	Gamma(γ)	Tau(τ)	Nu(v)	Omega(ω)
1	0.0000	0.0452	0.0319	-0.0319	0.0009	-0.0023
2	0.0001	0.0854	0.0604	-0.0603	0.0015	0.0261
3	-0.0290	0.1055	0.0687	-0.0630	-0.0275	0.0282
4	-0.0191	0.0693	0.0451	-0.0414	-0.0180	0.0068

(a)

The number of triangle	Sigma(σ)	Lambda(λ)	Gamma(γ)	Tau(τ)	Nu(v)	Omega(ω)
124	-0.0290	0.1055	0.0687	-0.0630	-0.0275	0.0282
123	-0.0191	0.0693	0.0451	-0.0414	-0.0180	0.0068
342	0.0000	0.0452	0.0319	-0.0319	0.0009	-0.0023
134	0.0001	0.0854	0.0604	-0.0603	0.0015	0.0261

(b)

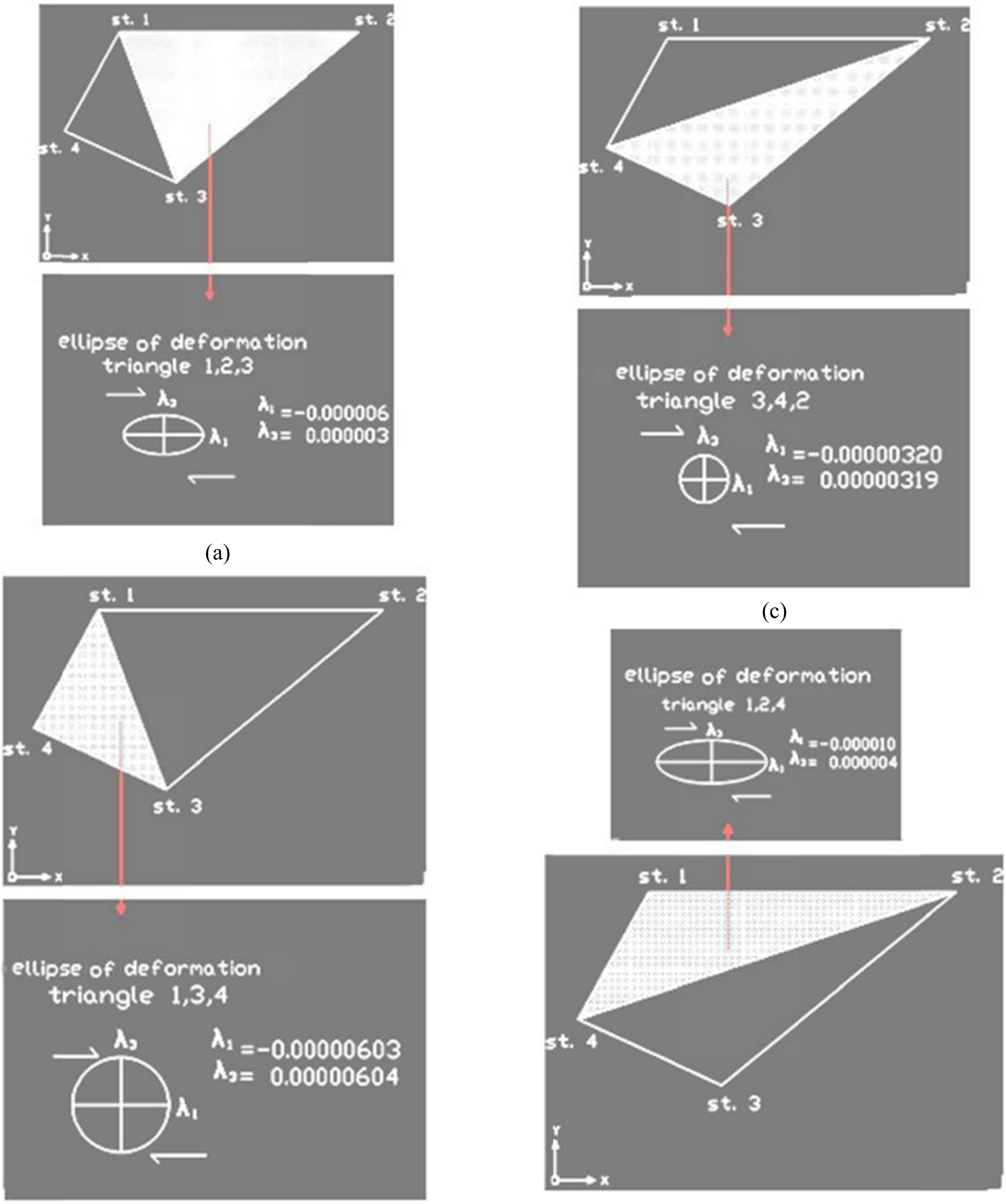
Table 2. The strain matrix for any triangle of network

Triangle	124		123		342		134	
Strain	-0.0000092	0.0000001	-0.0000060	-0.0000011	-0.0000032	-0.0000001	-0.0000060	0.0000028
matrix	-0.0000056	0.0000034	-0.0000025	0.0000022	0.0000003	0.0000032	-0.0000026	0.0000060

Table 3. The amount of ω (radian) and φ (degree) for any triangle of network

The number of triangle	ω(Radian)	φ(Degree)
1	0.0000028	3.93004495
2	0.0000007	2.582289804
3	-0.0000002	1.827115771
4	0.0000026	3.456465917

The strain ellipsoid was drawn for any triangle of network (Fig. 4) and strain changes were investigated with time, which showed these changes had an ascending trend with overtime (Fig. 5, Table 4).



(a)

(b)

(c)

(d)

Fig. 4. Strain ellipsoid in any triangle of network

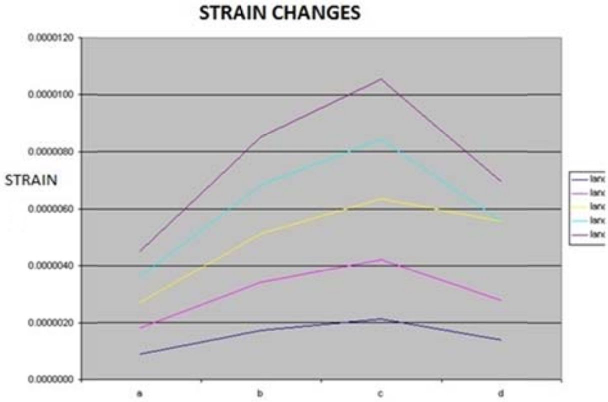


Fig. 5. Strain changes in any triangle

Table 4. The strain changes for any triangle of network

Lambda	Lambda3	Lambda6	Lambda9	Lambda12	Lambda15
A	0.0000009	0.0000018	0.0000027	0.0000036	0.0000045
B	0.0000017	0.0000034	0.0000051	0.0000068	0.0000085
C	0.0000021	0.0000042	0.0000063	0.0000084	0.0000105
D	0.0000014	0.0000028	0.0000055	0.0000055	0.0000069

5. Conclusion

The result of every epoch indicated a permanent slip with an almost constant rate during surveying in the region. This showed that the Darvazeh Quran fault is permanently active. This permanent slip caused energy discharge due to strain exerted on the plain. Investigation of the drawn adjusted networks, which were drawn in AutoCAD software 2008, showed the amount of displacement is the same as the obtained amount with MATLAB software. This displacement vector is from SE to NW with a dextral strike-slip creep (Fig. 6).

Obtained deformation matrix indicated 4 mm±6ppm displacements (Fig. 6). We used relative geodetic network. The amount of displacements was assumed constant in one side so that it showed cumulatively in the other side.

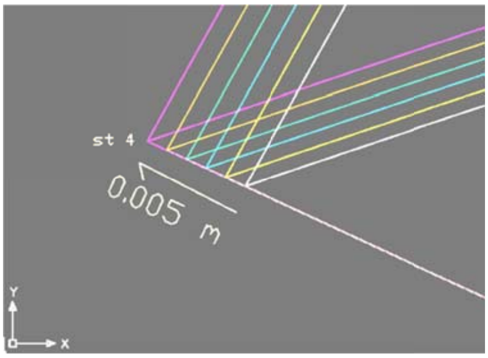


Fig. 6. Total displacement vector in station 4

Elongation changes of network investigated during the survey. The results showed these changes have an ascending trend into time (Fig. 7, Table 5). Network has shortening in the direction of line 1-3.

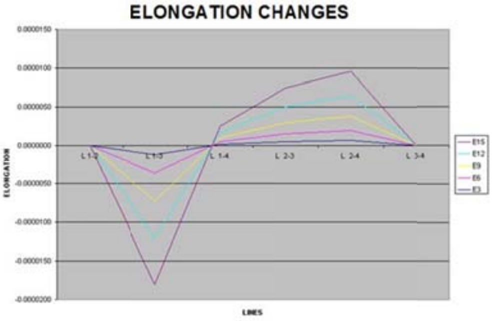


Fig. 7. Elongation strain changes with overtime

Table 5. The elongation strain changes of network

	$L_{1\text{-}2}$	$L_{1\text{-}3}$	$L_{1\text{-}4}$	$L_{2\text{-}3}$	$L_{2\text{-}4}$	$L_{3\text{-}4}$
E_3	0.0000000	-0.0000012	0.0000002	0.0000005	0.0000006	0.0000000
E_6	0.0000000	-0.0000024	0.0000003	0.0000010	0.0000013	0.0000000
E_9	0.0000000	-0.0000036	0.0000005	0.0000015	0.0000019	0.0000000
E_{12}	0.0000000	-0.0000048	0.0000007	0.0000020	0.0000026	0.0000000
E_{15}	0.0000000	-0.0000060	0.0000008	0.0000025	0.0000032	0.0000000

Finally using this method suggested for determining the activity amount of fault displacement, the movements of fold due to faulting, diapirism movements and other movements are due to other activities related to structural deformation. This fault has passed from a dense and highly populated old urban area so that its rapid creep can destroy old and un-resistant buildings in this region. This creep has an effect on Shiraz Grand hotel, so to prevent destruction it should be monitored by permanent surveying.

Creating several networks on the active faults, controlling and recording its permanent movement can be useful for providing geodynamic maps, which show points are ready for an occurring earthquake. In addition, it can be used on hazard faults for finding locking points on it. These locking points can be controlled by other pre-earthquake indicators in order to predict earthquake.

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