Available online at: www.geo-dynamica.com

ISSN 2345 - 4997

Vol. (I) - No. 02- (Special Issue on Intra- Plate Earthquakes) Feb.2014
7th Article- P. 56 to 62

GRIB
Geodynamics Research International Bulletin

Estimating the Hidden Gravity Lineaments Depths by Using Special Function Method and Comparing Them with the Earthquake Focal Depths: A Case Study of Gujarat Province

Mohammad Aryamanesh

Department of Geology, Payam Noor University, Tehran, Iran.

aryamanesh.geo@gmail.com

Article History:	Received: Jan. 22, 2014	Reviewed: Feb. 03, 2014
Revised: Feb. 06, 2014	Accepted: Feb. 07, 2014	Published: Feb. 14, 2014

ABSTRACT

This paper investigates the 2001 Gujarat earthquake, one of the world's most destructive earthquakes, which occurred in western India. The method used in this study was based on gravity data and satellite image processing. The EGM-2008 global gravity model has been used as the reference data. Thus, in the first place, the afore-mentioned gravimetric data was processed by using Oasis Montaj 7.0.1 Software. Then, in order to trace the edge of the buried anomalies in a better way, it was tried to apply the total horizontal gradient filter. Next, to complete the hidden lineaments location, a combination of gravity gradient components was used. Afterwards, Special Function Method (SFM) was used to achieve precise positioning of the depths and the trends of the hidden gravity lineaments. Finally, they were compared with the earthquake focal depths. All the obtained results were compared with earthquakes epicenter using satellite images. The performed analysis and the results of the interpretation of the gravimetric data indicate that there is a significant correlation between focal depths and the depths obtained by this method. Thus, it can be concluded that this method can help us to estimate the depths of the future earthquakes.

Keywords: Gravity Lineaments, Special Function, Earthquakes Depth.

1. INTRODUCTION

A devastating earthquake of magnitude 7.9 (Ms) struck the western part of India on the morning of January 26, 2001(Fig. 1). Although the epicenter is located in a sparsely populated area in western-most part of India, strong shaking was felt over a wide region in India and Pakistan (Rakesh K. Goel, 2001). The afore-mentioned earthquake, which was unprecedented in the last 50 years, took about 20,000 lives (Vijay P. Singh1 &Ramesh P. Singh, 2005).

The earthquake was thought to occur on one of the obvious active faults in the area. The focal mechanism shows a thrust faulting system on E–W trending faults (Negishi et al., 2002). Although the earthquake was shallow, no noticeable surface rupture was seen along the fault (Antolik & Dreger (2003). The lack of primary surface rupture indicates movement along a sightless fault that has been accompanied by wide spread liquefaction (Negishi et al., 2002). The field surveys and the aerial images detected soil liquefaction and associated phenomena in Great Rann, Little Rann, Banni Plains, Kandla River and Gulf of Kuchchh [Hengesh and Lettis, 2001]. On the other hand, the damages were extended up to 400 km from the epicenter, and liquefaction and cracks were observed in a very large region near the epicenter of the event (Antolik, M., and D. S. Dreger ,2003).

All these facts show that study of hidden faults is very important, but unfortunately this subject is overlooked in seismic hazard zonation. Therefore, an effective understanding of seismicity requires suitable information of the nature and dispersal of contemporary stress field in the lithosphere and buried anomalisms in any area.

To obtain a more authentic seismic hazard zonation map, we must consider the role of blind faults geometry and their situations in creating such destructive and calamitous disasters (Aryamanesh, 2014). Geophysical Linear anomalies are very effective to interpret such unknown phenomena and present a more applicable seismic hazard assessment and risk reduction for any region (Aryamanesh, & Zare, 2009).

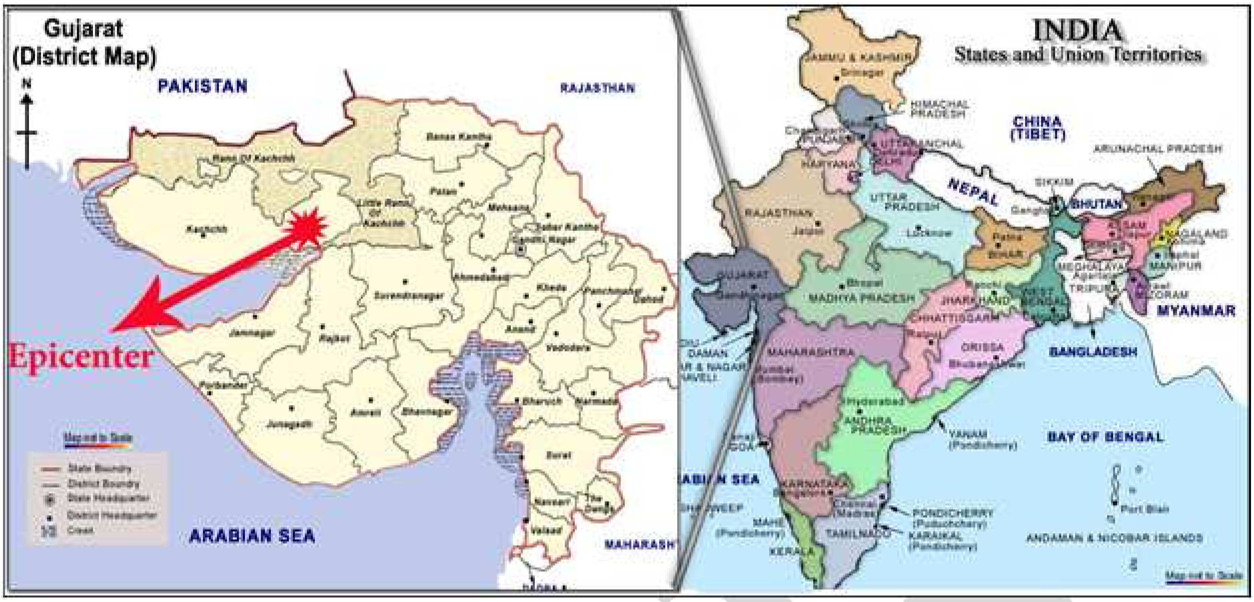

Fig.1 The map of Gujrat State which shows the epicentral location of January 26, 2001 earthquake and major cities in eastern India (Rakesh K. Goel, 2001).

Interpretation of gravity and magnetic data is one of the most applicable methods to detect buried traces, for they indicate some important structural features which we will not be able to follow using morphotectonical tools. Applying these methods can definitely help us present an informative view to study under developed areas and prevent more risks. In this study, it has been tried to show that gravimetric data is an efficient tool to extract hidden lineaments and faults.

2. THE STUDY AREA

Over 100 million years ago India, Australia, South America, Antarctica, South Africa and Madagascar were part of a landmass congregated on the basis of fauna and flora, and were known as the big Gondwanaland. After the separation of the plate which goes back to between 40 and 60 million years ago, India began to collide with Asia to form the Himalayas. The stresses of the continent- continent convergence extend far to the north of the Himalaya plate boundary. Gujarat covered about 400 kilometers of Indian plate boundary and the tectonics regime over it, governed by the effects of continuing continental collision (Carlson et al., 2008). Million years ago, when the Gondwana broke up in the Jurassic times, this area was affected by the rifting phenomenon with west- east trend. Although the stresses of collision lead to shortening, this phenomenon has some other effects on the region, which involves reactivation of the original rift (normal fault) and development of new thrust faults. Therefore, there exist a few folds in central Kutch area. During that period the rift extended from Rajasthan and Kutch into the Narmada Valley, the remnants of which are known as Lake "Nalsarovar" today (Eidinger, 2001). In fact, Kutch, Saurashtra, Cambay and Narmada are four peri-cratonic basins which are parts of Gondwana. On the contrary, the intra-cratonic rift basins are only characterized by rift-fill sediments (Biswas, 1999) (fig 2).

Fig 2. Map of western India which shows rifting along primordial tectonic trend during Gondwana.

The Kutch district is covered by sedimentary rocks. The ages of the rocks are different and range from Jurassic to Eocene. Most rocks contain Shale, Limestone and Sandstone. The Jurassic rocks crop out in three anticlinal ridges trending E-W. Owing to an E-W fault, the whole sequence is repeated (Fig 3) (Eidinger 2001).

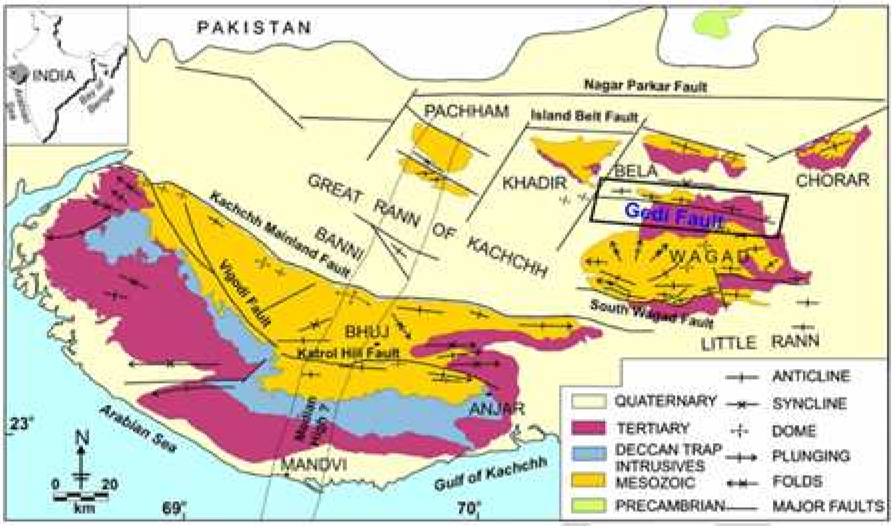

Fig 3. Geology of Kutch, a part of the Study area (Maurya et. Al 2013)

The shoreline of Kutch is covered by Quaternary sediments. If we move along the south to the north, we can find the regular sequence of Tertiary rocks as a thin band surrounded by Deccan traps on the north. The northern part of the Kutch peninsula is covered by recent marine deposits on which Jurassic rocks form outcrops. This area seems to be undergoing some marine recession. A major paleo- rift valley lied along the E-W direction passing through the Kutch region.

3. MATERIAL AND METHODS

Linear anomalies are important in the interpretation of gravity data and in active tectonics studies, because they indicate some important structural features and contacts. The use of gravity gradient (GG) data in exploration is becoming more common. However, interpretation of gravity gradient data is not as easy as the familiar vertical gravity data for burden density contact. Various combinations of the gravity gradient components can be used to simplify their complex pattern and to further enhance and facilitate the interpretation of the data. In this study, two methods of combined gradient gravity (GG) products were used, both of which are useful in simplifying and focusing on the complex pattern of anomalies over their source. These two methods provide more enhancements for the high-frequency part of anomalies to compensate for shallow sources, so that we can obtain a reasonable interpretation.

In this study, it was tried to detect hidden faults and some lineaments (faults, dikes, and anything that can be active and deform the crust) which cause earthquake. These hidden faults were detected via gravity data and some filters. Then, they were compared with the epicenter of all the earthquakes which occurred in Kutch region. It was found that all the epicenters overlaid the afore-mentioned lineaments .Thus some filters had to be used to detect the edge of the contacts. One of the best filters for this purpose was horizontal gradient (HG) which could be directly used as an edge-detector, but another filter which is a combination of Total Horizontal gradient and gradient component was used in this study to obtain better results. Then, lineaments were extracted from these grids. These methods are explained in the following part.

3. 1. TOTAL HORIZONTAL GRADIENT

The horizontal-gradient of gravity is contoured and the lines are drawn or calculated along the contour ridges (Blakely & Simpson, 1986). These results mark the top edges of gravity or density boundaries. Thus, the maximum value of the horizontal gradient anomalies is placed on top of the sources and can be an offset from a position directly over the edges of several anomalies. However, offsets occur when edges are not vertical or when several anomalies are close together. Many other factors cause offsets as well, but they are less straightforward and are usually significant only in local studies. The biggest advantage of the horizontal gradient method is its low sensitivity to the noise in the data, because it only requires calculations of the two first-order horizontal derivatives of the field. The horizontal gradient of the potential field is the sum of the following equation:

$$HG(x,y)=\left[\left(\frac{\partial F}{\partial x}\right)^2+\left(\frac{\partial F}{\partial y}\right)^2\right]^{1/2}$$

Where F is the potential field (gravity or magnetic) and "∂x" and "∂y" are directional derivative of Field. Figure (4) show the Horizontal gradient of gravity field of Gujarat Province.

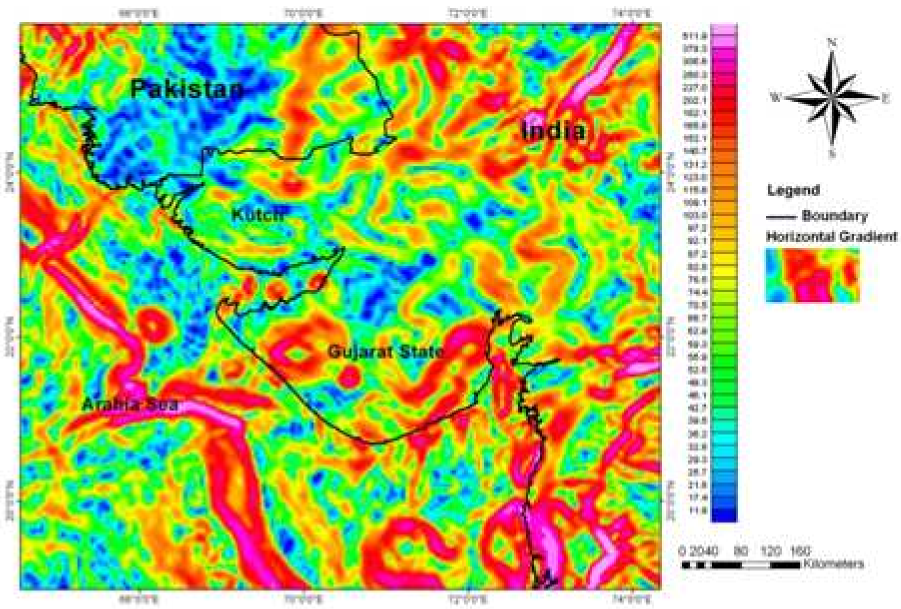

Fig 4. Horizontal gradient of gravity field of Gujarat Province.

3. 2. TOTAL HORIZONTAL GRADIENT AND GRADIENT COMPONENT

The total gradient of F is computed from combination of the elements of the gravity gradient tensor $\left(\left(\frac{\partial F}{\partial x}\right)^2, \left(\frac{\partial F}{\partial y}\right)^2, \left(\frac{\partial F}{\partial Z}\right)^2\right)$, which is obtained by the following equation:

$$TG(x, y) = \left[\left(\frac{\partial F}{\partial x}\right)^2 + \left(\frac{\partial F}{\partial y}\right)^2 + \left(\frac{\partial F}{\partial Z}\right)^2\right]^{1/2}$$

Total Horizontal gradient and gradient component shown in figure (4), are obtained in 4 steps:

(1) Fourier transform of gravity data to frequency domain.

(2) Computation of the total gradient grid and the related derivative grids containing total gradient grid file, , horizontal gradient grid file, x(east)-derivative grid file, y(north)-derivative grid file, z(vertical)-derivative grid file, (vertical gradients are computed from the horizontal gradients using Hilbert transform components).

(3) combination of the results of the second step and the order of initializing polynomial for plugging horizontal derivative grids and the number of minimum curvature iterations for plugging horizontal derivative grids.

(4) Inverse Fourier transform to space domain.

The result of these steps is shown in figure (5). The result shows the edge structure better than the horizontal gradient.

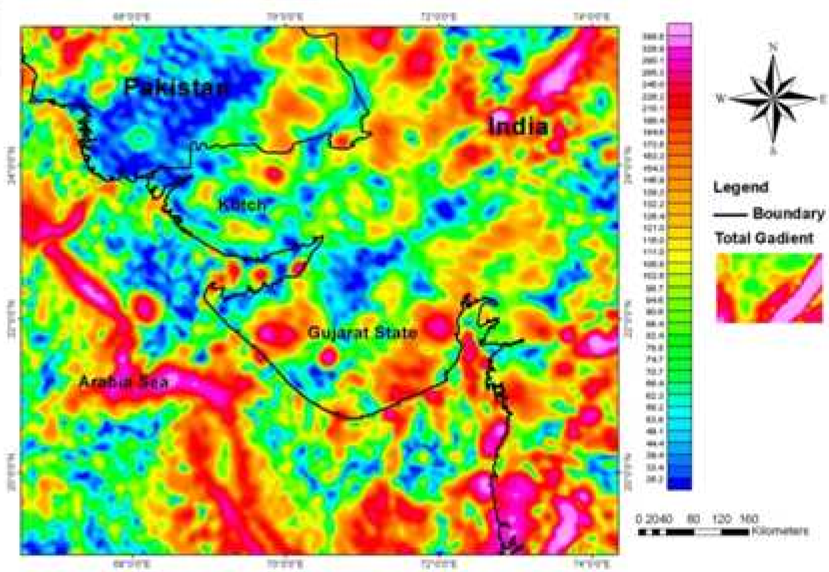

Fig 5. Total gradient of gravity field of Gujarat Province

3- 3. SPECIAL FUNCTION

In image processing, edge detection is a process which attempts to detect significant features from the result of total gradient component. The main idea of edge-detection technique is to detect the geological features for gravity-data processing and interpretation. It is difficult to design a general edge-detection algorithm which performs well in many contexts. In the case of a low noise level, gradient estimations are classical methods which give satisfactory results. In gravity interpretation, the edges come in many forms and shapes. They might be in the form of faults, contacts, and various structural boundaries. The gradient extreme of anomalies usually correspond to the boundaries of these anomalies and have been used to approximate edges of source bodies or to analyze lineaments (Blakely and Simpson, 1986).

In image processing, lineaments are obtained by an automatic method (Special Function). Then, all lineaments correspond to active tectonic indices (surface deformation and other phenomena) and earthquake focal mechanism. Initially, lineaments were extracted from gradient component grid by automatic lineament tracing method. To extract automatic lineaments Special Function Method was used. The results of this method are shown in Figure (6).

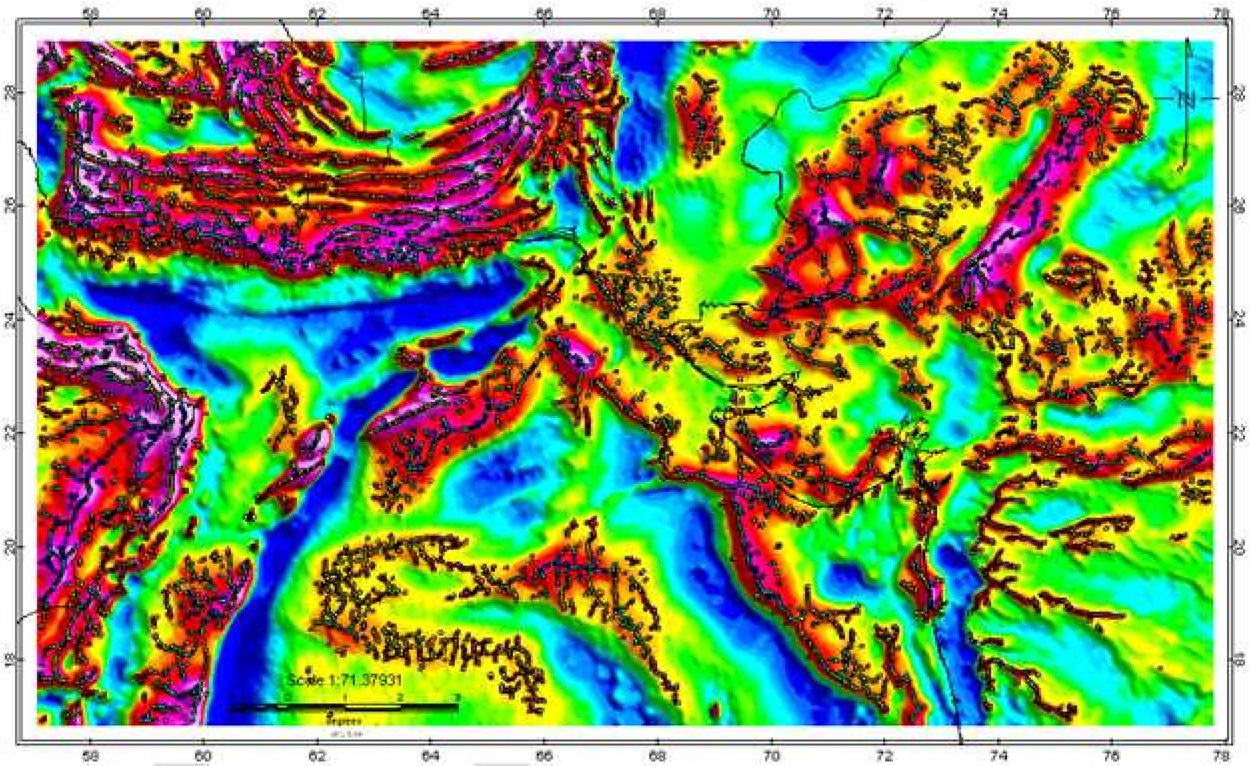

Fig 6. Lineaments magnetic field of the extraction Special Function method

4. RESULTS AND DISCUSSIONS

In the following section, the results obtained by Special Function Method have been investigated to determine if they correspond with the focal mechanisms of the earthquakes which have occurred in the last 13 years (fig 7). Then, the study area is divided into 32 sections and focal depths were compared with the depths obtained by Special Function Method in each region.

In order to assess the correspondence of the data obtained for the two variables, namely the depths of the Special Function Method and earthquakes' focal depths, the correlation between them was computed using SPSS software (version 18), the results of which are shown in Table (1) .

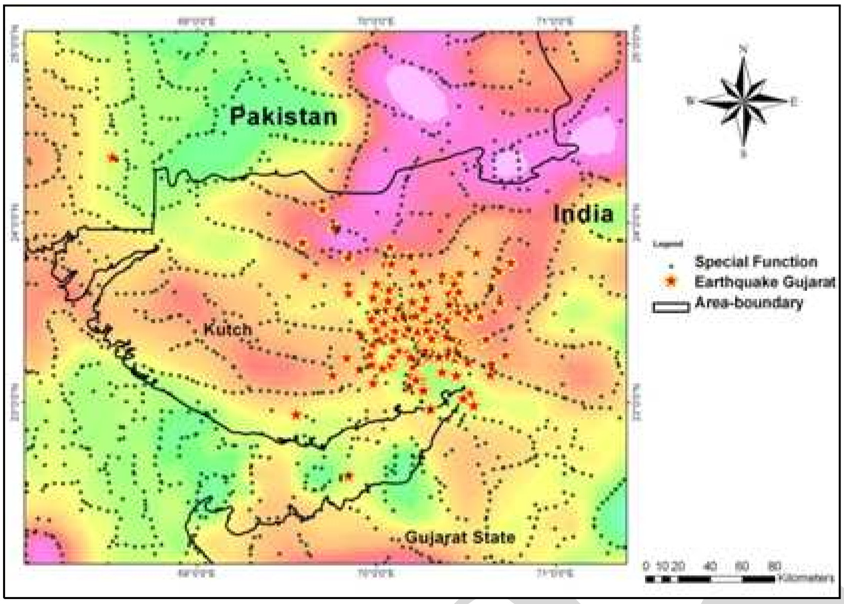

Fig 7. Lineaments of special function and earthquakes

Table 1. The results of the Correlation between Depths of SF method and the Earthquakes' Focal Depths

Depths obtained by		SF	Earthquake
Depths obtained by SF Method	Pearson Correlation	1	.504**
	Sig. (2-tailed)		.004
	N	31	31
Earthquakes' Focal Depths	Pearson Correlation	.504**	1
	Sig. (2-tailed)	.004	
	N	31	31

**. Correlation is significant at the 0.01 level (2-tailed).

As it is manifest in the table, the two variables were significantly correlated, $r(29) = .5$, $p < .05$.

5. CONCLUSION

Nowadays underdeveloped overpopulated areas need to be reinvestigated in terms of seismicity. Morphotectonic methods alone are not able to present a clear picture of seismicity of the areas. Different earthquakes such as 2003 Bam earthquake and 1968 Tabas earthquake in Iran prove this fact.

Geophysical data, particularly gravimetric and magnetic data can help us detect hidden hazardous phenomena. By detecting these hidden anomalies, we can get a clear picture of the seismicity of the area. This data can even help us predict foreshocks. Thus, we will be able to take the necessary actions to alleviate the destructive effects of the earthquakes.

In this study, it was tried to extract the lineaments from two grids via Special Function Method. These grids include Total Horizontal Gradient (THG) and a combination of THG and other gradients. The lineaments obtained by the second method have a better distribution and correspond more with earthquake focal mechanisms. Moreover, the depths obtained by Special Function Method are significantly correlated with the earthquakes' focal depths ($r = .5$, $p < .05$). This is indicative of the fact that in case of shallow earthquakes, this method is capable of detecting the sources of the earthquakes quite well.

This study showed that there is a significant relationship between the depths of the detected lineaments and the earthquakes' focal depths of Gujarat Province in eastern India. This finding is a beneficial result for natural disaster management in such areas.

REFERENCES

Antolik, M., & Dreger, D.S. (2003) Rupture Process of the 26 January 2001Mw7.6 Bhuj, India, Earthquake from Teleseismic Broadband Data. *Bulletin of the Seismological Society of America* 93, 1235–1248.

Aryamanesh, M. (2014) *Seismotectonics and Seismic Hazard Analyses*, (The Book Under Press), Fundamental Sciences Press, Tehran, Iran.

Aryamanesh, M., & Zare, M. (2009) Aeromagnetic Interpretation Data to Locate Buried Faults, A Case Study of Tabas Region, Eastern Iran. *Quarterly Journal of The Earth, 4 (3), 1-8.*

Biswas, S.K. (1999) A Review on the Evolution of Rift Basin in India During Gondwana with Special Preference to Western Indian Basins and Their Hydrocarbon Prospects. *Proceedings of the Indian National Science Academy*, 65A (3), 261-283.

Blakely, R.J. & Simpson, R.W. (1986) Approximating Edges of Source Bodies from Magnetic or Gravity Anomalies. *Geophysics*, 51, 1494–1498.

Carlson, D.H., Plummer, C.C. & Mc-Geary, D. (2008) *Physical Geology*: Earth Revealed, 7, Illustrated, Publisher, Mc-Graw-Hill Education, ISBN, 0071102191, 9780071102193.

Eidinger, M.J. (2001) *Gujarat (Kutch) India M7.7 Earthquake of January 26, 2001 and Napa M5.2 Earthquake of Sept. 3, 2000*. Lifeline Performance, Issue 19 of Monograph (American Society of Civil Engineers. Technical Council on Lifeline Earthquake Engineering),Issue 19 of Monograph Series, Volume 19 of Monograph: Technical Council on Lifeline Earthquake Engineering, Issue 19 of Technical Council on Lifeline Earthquake Engineering monograph, ISBN 0784475067, 9780784475065, 166 pages.

Goel, KR. (2001) *A Quick Report on January 26, 2001 Earthquake in INDIA (Estimated Magnitude 7.9 Ms)*. Department of Civil & Environmental Engineering California Polytechnic State University San Luis Obispo, CA 93407.

Hengesh, J.V. and Lettis, W.R. (2001) Liquefaction and Related Effects from the Mw 7.7 Republic Day earthquake, *India, Seismological Society of America (Abstracts Online).*

Kayal, J.R., Zhao, D., Mishra, O.P., De, R. & Singh, P.O. (2002) The 2001 Bhuj earthquake: Tomographic evidence for fluids at the hypocenter and its implications for rupture nucleation. [Online] *Geophysical Research Letters*, 29 (24), 2152. Available from: doi: 10.1029/ 2002 GL 015177.

Maurya, D.M., Chouksey, V., Joshi, P.N. & Chamyal, L.S. (2013) Application of GPR for delineating the Neotectonic Setting and Shallow Subsurface Nature of the Seismically Active Gedi Fault, Kachchh, Western India. [online] *Journal of Geophysics and Engineering*, 10 (3). Available from: doi: 10.1088/1742-2132/10/3/034006.

Nabighian, M.N. (1984) Toward a Three-Dimensional Automatic Interpretation of Potential Field Data Via Generalized Hilbert Transforms: Fundamental Relations. *Geophysics*, 49 (6), 780-786.

Negishi, H., Mori, J., Singh, T.R., Kumar, S. & Hirata, N. (2002) Size and Orientation Sato of the Fault Plane for the 2001 Gujarat, India Earthquake (Mw 7.7) from Aftershock Observations: A high Stress Drop Event. *Geophysical Research Letters*, 29 (20).

Singh, P.V. & Singh, P.R., (2005) Changes In Stress Pattern Around Epicentral Region of Bhuj Earthquake of 26 January 2001. [Online] *Geophysical Research Letters*, 32 (L24309). Available from: doi:10.1029/ 2005 GL 023912.

