University of Tabriz

Journal of Civil and Environmental Engineering
Volume 52 (2022), Issue 1 (Spring), 67-80

EXTENDED ABSTRACT

Determination of Appropriate Geodetic Observational regions to Monitor the Mechanical behavior of NTF by Sensitivity Analysis of Okada Model Using HDMR Method

Asghar Rastbood *, Babak Shahanden, Mehdi Mohammad-Zadeh

Civil Engineering Faculty, University of Tabriz, Tabriz, Iran

Received: 06 December 2021; **Accepted:** 17 January 2022

Keywords:
Sensitivity Analysis, Mechanical Optimization, Geodynamic Network, North Tabriz Fault.

1. Introduction

The faulting phenomenon involves different variables. Some of these variables are determined more accurately than others using non-modeling approaches. The main subject of this paper is to investigate the influence of both individual geometrical and physical input parameters involved in the Earth surface displacement models. For different physical and geometrical parameters, it is recommended to use sensitivity analysis on parameters that are determined from a field study with less accuracy. Both slip rate and locking depth of the fault are major parameters, in this aspect.

In this paper, the role of all faulting parameters on surface displacement data has been investigated. To do this analysis, the elastic half-space model of Okada (1985) was used. As a case study, the surface displacements model was applied to the North Tabriz Fault. The medium is composed of an elastic half-space. Sensitivity analysis was conducted on all geometrical and physical parameters. Finally, the regions of the most appropriate surface displacements were determined to obtain the most accurate values for the studied parameters. According to the obtained results, the model parameters, i.e., locking depth and slip rate, could be determined more effectively in the regions near and away from the fault trace, respectively.

2. Methodology

2.1. Okada model

The 3D dislocation that occurs at point i is stated by (Okada, 1985) as follows, for the Green function $u_j^i(x_1.x_2.x_3)$ from a rectangular field Σ half-space isotropic, the deformation due to dislocation is $\Delta u_j(\xi_1.\xi_2.\xi_3)$ centered on a point $(\xi_1.\xi_2.\xi_3)$ with j direction.

$$u_i = \frac{1}{F}\iint_{\Sigma} \Delta u_j \left[\lambda\delta_{jk}\frac{\partial u_i^n}{\partial \xi_n} + \mu\left(\frac{\partial u_i^j}{\partial \xi_k} + \frac{\partial u_i^k}{\partial \xi_j}\right)\right]\nu_k d\Sigma \tag{1}$$

where λ and μ are Lame constants, δ_{jk} is delta Kronecker and ν_k is normal cosines w.r.t $d\Sigma$.

2.2. High Dimensional Model Representation (HDMR)

Sensitivity analysis in general tries to reveal the relationship between the model inputs and the model outputs. The high dimensional model representation (HDMR) method introduced by Rabitz et al. (1999) can dramatically reduce the computational effort needed for the mapping and was mainly developed to express the input-output relationship of a complex model with a large number of input parameters.

---

* Corresponding Author

E-mail addresses: arastbood@tabrizu.ac.ir (Asghar Rastbood), babak.shahandeh95@ms.tabrizu.ac.ir (Babak Shahandeh), m.mohammadzadeh96@ms.tabrizu.ac.ir (Mehdi Mohammad-Zadeh).

HDMR is an expansion with a hierarchical form in terms of the input parameters (Rabitz et al. 1999, Rabitz & Ali§ 1999, Li et al. 2000). The mapping between the input parameters $x_1 \ldots . x_n$ and the output $f(x) = f(x_1 \ldots . x_n)$ in the domain K^n can be written in the following form:

$$f(x) \approx f_0 + \sum_{i=1}^{n} f_i(x_i) + \sum_{1\leq i<j\leq n} f_{ij}(x_i . x_j) + \cdots + f_{12\cdots n}(x_1 . x_2 . \ldots . x_n) \tag{2}$$

Here f_0 denotes the mean effect (zeroth-order), which is a constant. The function $f_i(x_i)$ is a first-order term giving the effect of parameter x_i acting independently (although generally non-linearly) upon the output $f(x)$. The function $f_{ij}(x_i . x_j)$ is a second-order term describing the cooperative effects of the parameters x_i and x_j upon the output $f(x)$. The higher-order terms reflect the cooperative effects of increasing numbers of input parameters acting together to influence the output $f(x)$. *If* there is no interaction between the input parameters, then only the zeroth-order term f_0 and the first-order terms $f_i(x_i)$ will appear in the HDMR expansion.

The HDMR expansion is computationally very efficient if higher-order input parameter effects are weak and can therefore be neglected. For many systems a HDMR expression up to second-order already provides satisfactory results and a good approximation of $f(x)$ (Li et al. 2001b). Therefore, the main focus in this work will be on an up to second-order HDMR expansion.

$$f(x) \approx f_0 + \sum_{i=1}^{n} f_i(x_i) + \sum_{1\leq i<j\leq n} f_{ij}(x_i . x_j) \tag{3}$$

There are two commonly used HDMR expansions: cut-HDMR, which depends on the value of f(x) at a specific reference point *x* as described in the next section, and RS-HDMR, which depends on the average value of $f(x)$ over the whole domain.

3. Results and discussion

Since the Okada model is for half-space media, so the NTF region becomes a half-space using a map projection. Because the whole area of the North Tabriz Fault is located within zone 38 of the UTM map projection, so the same map projection was used for the entire of the study area. Then a network included 200,000 nodes with 10 KMs distance between them was applied to the whole model with 400 * 500 square kilometers area. Then modeling was done for the reference values of the North Tabriz Fault. To determine the range of geometric parameters of the reference fault, including locking depth and slip rate, the error range was considered according to various studies (Haji-Aghajany, et al. 2019). For the Young modulus and the Poisson's ratio, the minimum and maximum possible values known for the Earth's crust were considered. Then, assuming a Normal distribution for all parameters, random sampling was performed by the Monte Carlo method with a sample size of 1023 for each parameter. Okada model was performed for all samples and displacements were calculated in all nodes of the network. To do the sensitivity analysis, the HDMR meta-model was used up to second order. Between the two common and efficient HDMR expansions, the RS-HDMR method was used to calculate the sensitivity indices based on variance. Input parameters of the model, together with the displacements, are entered into the RS-HDMR expansion, and its component functions were calculated. After obtaining the RS-HDMR expansion component functions, the partial and total variances were calculated. Then the first, second and total order sensitivity indices were obtained using partial and total variances. Parameters with a higher value of first-order and total sensitivity indices have the greatest effect on the output (i.e. displacement). This was done for 200,000 grid nodes on all input parameters of the Okada model and the first, second and total sensitivity indices were calculated for all parameters. Interpolation was performed between the obtained sensitivity indices to determine which input parameter is more sensitive to displacements in each node. It is recommended that to perform geodetic observations (GPS or InSAR) in regions where the displacements are more sensitive to the input parameter and use it as a constraint to solve the inverse problem to achieve a more accurate value for the considered parameter. Very small values were obtained for the second-order sensitivity indices. This caused the difference between the first-order and total sensitivity indices to be very small and negligible. It is evidence for no interaction among the reference fault parameters. The results of the analysis for fault locking depth and slip rate are shown in Fig. 1 and 2 for the total sensitivity index using contours. The trace of the fault is marked in green.

According to Fig. 1, the total sensitivity index related to the fault locking depth around the fault is observed with high values. Therefore, it is suggested to determine the locking depth of the North Tabriz Fault using the Okada analytical model by geodetic observations around it.

According to Fig. 2, the total sensitivity index related to the slip rate parameter is observed in areas far from the fault with values greater than 0.8. So, the use of geodetic observations in regions far from the fault to monitor or solve the inverse problem using the Okada analytical model is strongly recommended to determine the fault slip rate.

In modeling, it must be noted that the results of modeling, i.e. displacements, must be in a range that could be measured. If the results of the modeling be so small and less than the precision of the measurements, the interpretation of the results will not be usable despite of the increase in the sensitivity index. So, in order to determine the appropriate regions for geodetic observations, in addition to the sensitivity index, the amplitude of surface displacements related to the reference fault should be considered.

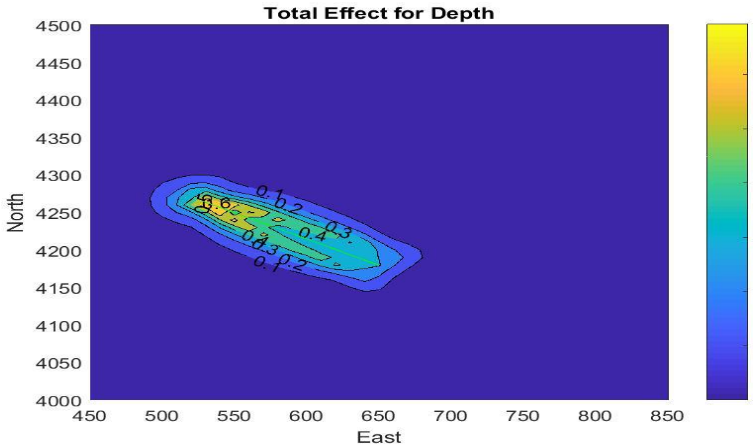

Fig. 1. Total sensitivity index for the locking depth parameter that is observed with significant values around the North Tabriz Fault

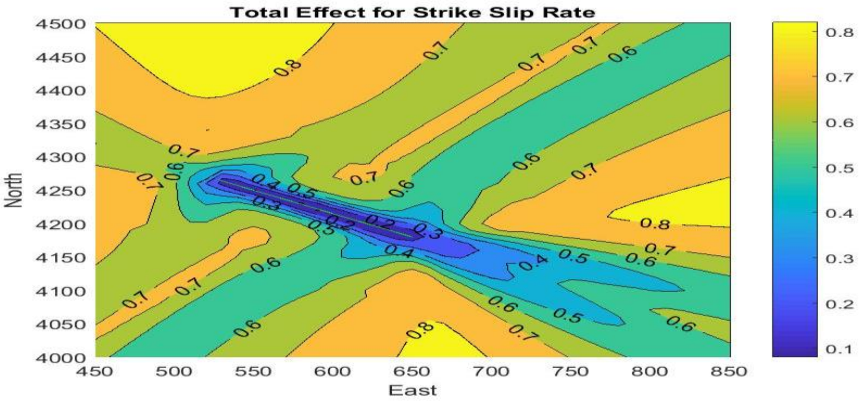

Fig. 2. Total sensitivity index for the fault slip rate parameter, the value of the index in areas away from the fault reaches more than 0.8

4. Conclusions

In this paper, we developed a more practical new method for the optimal design of geodetic monitoring schemes. This method can be used to estimate the fault-model parameters, such as slip rate and locking depth, with high accuracy. The simulation was done to model the real-world state. The stations should not be located in the distances far away from the studied fault trace; otherwise, they may be affected by other tectonic activities rather than the fault of interest. The position of the geodetic stations is important to estimate fault model parameters. The model parameters locking depth and slip rate can be determined more effectively at the locations near and away from the fault trace, respectively. Limiting factors such as topography, installation cost, support of stations and etc., could be considered at this stage. In this study, sensitivity analysis for surface displacements resulted from the Okada elastic half-space model was done. This analysis is recommended for surface displacements caused by symmetric and asymmetric spherical as well as for the viscoelastic half-space Earth model.

5. References

Haji-Aghajany S, Voosoghi B, Yazdian, A, “Estimating the slip rate on the north Tabriz fault (Iran) from InSAR measurements with tropospheric correction using 3D ray tracing technique”, Advances in Space Research, 2019, 64, 2199-2208.

Li G, Wang S-H, Rabitz H, “High Dimensional Model Representations (HDMR): Concepts and Applications”, IMA Workshop: Atmospheric Modeling, 2000.

Okada Y, “Surface Deformation Due to Shear and Tensile Faults in a Half-Space”, Bulletin of the Seismological Society of America, 1985, 75 (4), 1135-1154.