Evaluation of Uncertainties in the Available Empirical Models and Probabilistic Prediction of Liquefaction Induced Lateral Spreading

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ABSTRACT

Soil liquefaction is known as one of the major causes of ground movement in earthquakes. Liquefaction in slopes might be manifested in the ground surface by lateral spreading which is downward movement of large soil blocks. Liquefaction-induced lateral spreading happens due to successive exceedence of downward seismic stresses from the soil strength while the in-situ static driving stresses may never surpass the deteriorated soil strength. Lateral spreading has caused extensive damage to buried utilities, lifeline networks, and many other underground and surface civil engineering structures. It was reported during some devastating earthquakes including San Francisco, USA 1906, in Prince William Sound, Alaska 1964, Niigata, Japan 1964, and recently Bushehr, Iran 2013 earthquakes. Occurrence and magnitude of lateral spreading depend on the geotechnical characteristics of the liquefiable soil layers, geometry of the ground or the open-face slope, the depth of underground water table, the intensity and duration of the earthquake excitation, the distance from the causative rupture, and site amplification factor. Participation of a large number of factors in this sophisticated phenomenon has encouraged the researchers to develop predictive empirical models (e.g., Hamada et al., 1986, Youd et al., 2002, and Baziar and Ghorbani, 2005, Javadi et al. 2006, Kanibir 2003, and Baziar and Saeedi Azizkandi 2013). The empirical models of Hamada et al. (1986) and Youd et al. (2002) are widely used in the engineering practice.

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1- Introduction

The empirical models of liquefaction-induced lateral spreading were developed through the analysis of field case histories. Geotechnical parameters of the case histories were retrieved through the boring logs available in the sites and distance-dependent averages were employed for the correlations. Therefore, uncertainties involved in the averaging of the geotechnical parameters may lead to undesired errors. Due to variable and epistemic nature of site geology, such uncertainties are likely available in any site under consideration. In this study, the available correlations on the worldwide database of lateral spreading are reviewed in the first step. Then, reliability techniques are employed to account for the variability of effective soil parameters. Site-specific estimation of lateral spreading is presented in terms of probability of exceedence from a predetermined level of displacement.

2- Parametric study of the available empirical models

Available empirical models of lateral spreading were reviewed and the most recent and well known models were selected. A systematic comprehensive study was conducted on the selected models since some models were prone to deficiencies in characterization of geotechnical and seismic parameters. Fig. (1) illustrates variations of lateral displacement with T_{15} which describes cumulative thickness of susceptible layers contributing in displacement. The figure reveals considerable discrepancy among the results of three selected models. Especially, the model proposed by Javadi et al. (2006) suffers significant drawback in parametric study. It seems that the developers mainly
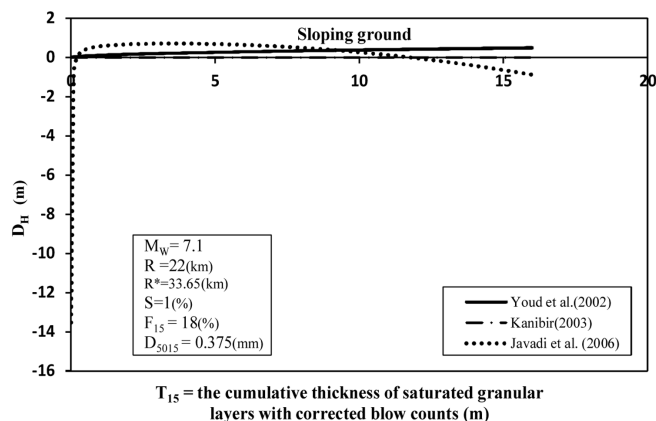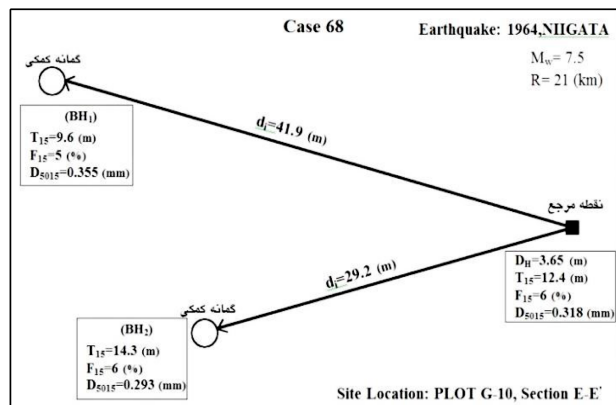

Fig. 2. Schematic demonstration of auxiliary boreholes and lateral spreading observation point
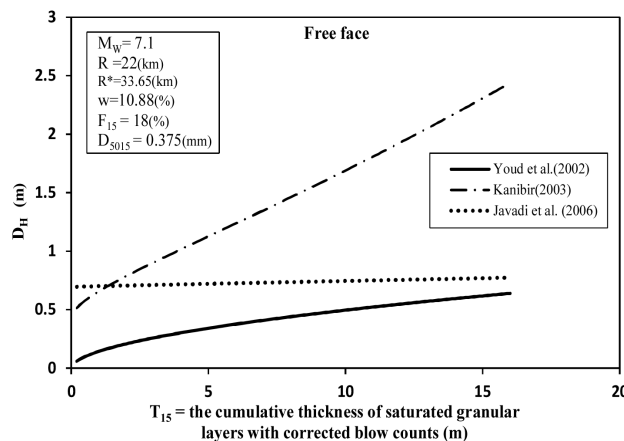
focused on the model precision rather than its physical behavior. In addition to such uncertainties, all of the developed models in the literature were established based on the averaged values of geotechnical parameters from the adjacent boreholes (see Fig. (2)). Some boreholes were located at distances as far as tens meters. Hence, the empirical models may suffer serious uncertainty of input parameters.

3- The proposed empirical model

The most recent database of liquefaction-induced lateral ground displacement was compiled based on the uncertainties of the distant boreholes and the following formulas were developed as new empirical models for gently sloping and free-face grounds:

Free face :

$$\log D_H = -17.95 + (1.605 M_W) - (1.8673 \log R^*)$$
$$- (\log(R+20))^{(-3.3836)} + (0.5471 \log W) + \qquad (1)$$
$$(0.4431 \log T_{15}) + (4.1873 \log(100 - F_{15})) -$$
$$(0.7666 \log(D_{5015} + 0.1))$$

Fig. 1. Parametric study of the available empirical models for T_{15}

Sloping ground :

$$\log D_H = -19.63 + \left(2.0137 M\right) - \left(2.6124 \log R^*\right) -$$
$$\left(\log\left(R+20\right)\right)^{(-2.7004)} + \left(0.3147 \log S\right) + \quad (2)$$
$$\left(0.6985 \log T_{15}\right) + \left(4.1954 \log\left(100 - F_{15}\right)\right) -$$
$$\left(0.6772 \log\left(D_{5015} + 0.1\right)\right)$$

where M, R^*, S, W, T_{15}, F_{15}, D_{5015} characterize earthquake magnitude, source–to–site distance, ground slope, free face ratio, cumulative liquefaction prone depths, fines content, mean grains diameter, respectively. Table (1) compares coefficient of determination and root mean squared error (RMSE) of the proposed model with the selected available empirical models. It is seen that the proposed model represents superior performance and obtains the required precision. Note that the new model was completely evaluated by parametric study and variations of the input parameters are in agreement with our current knowledge on the physical behavior of lateral spreading phenomenon.

4- Probabilistic estimation

The new empirical model was developed based on the refined database of lateral ground displacement in which some criteria was adopted to remove very far boreholes. It was shown that such refinement has improved performance of the empirical model, despite the fact that a simple regression technique was employed rather than the complicated artificial intelligent approaches. Uncertainty of all geotechnical parameters was considered by Monte Carlo simulation and the results for the new empirical model are shown in Fig. (3) as instance. Fig. (3) illustrates probability of displacement exceedence from 0.3 m and 0.7 m versus variations of S and W respectively for sloping

Table 1. Comparison of the proposed model with the available ones

Empirical model	R^2	RMSE (m)
Hamada et al. (1986)	13.2 %	–
Bardet et al. (1999)	69 %	1.4
Youd et al. (2002)	71.2 %	1.4
Kanibir (2003)	74.51 %	–
Al Bawwab (2005)	80.1 %	–
Javadi et al. (2006)-GP	81.6 %	1.3
Baziar et al. (2013)-GP	88.6 %	0.8
Current study	90 %	0.92

and free-face grounds. The Monte Carlo simulations were analyzed for two standard deviations as shown by solid and dashed curves. These curves can estimate seismic performance of slopes in liquefaction condition considering the effects of geotechnical parameters uncertainties.

5- References

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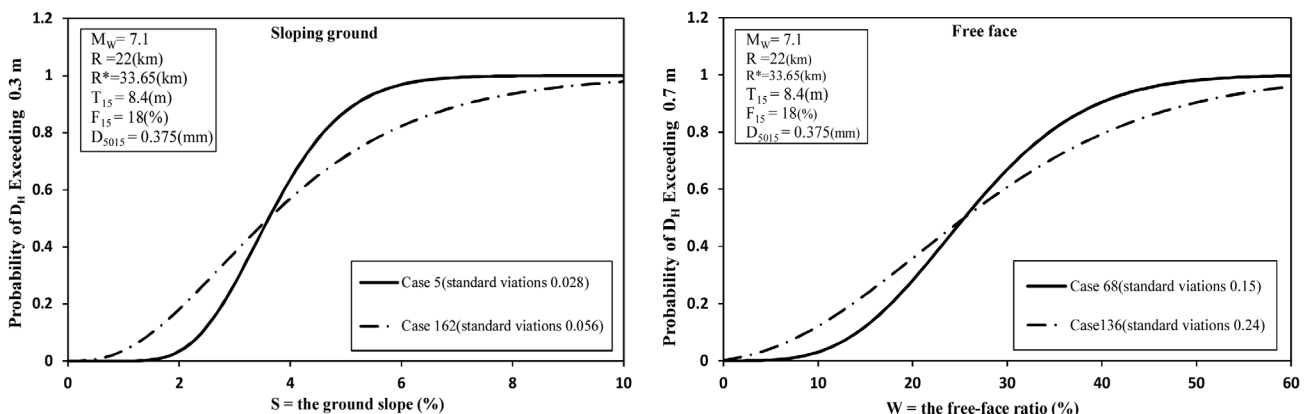

Fig. 3. Probability of lateral spreading occurrence based on the new correlations: (a) sloping ground; (b) free-face slope

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