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Evaluating the Applicability of Intensity Prediction Equations for Khash, 2013 Earthquake

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Abstract: The prime focus of the research work presented herein is to investigate the applicability of eight intensity prediction equations to the available dataset for Khash, 2013, earthquake. To this end, data obtained for the earthquake is utilized for comparison with the intensity estimates using the intensity prediction relationships. The data comprises of both subjective as well as instrumental observations. The subjective data used in this study includes a survey conducted in the affected regions, questionnaire surveys through posts, email and telephone and online surveys, while the instrumental data includes the Peak Ground Acceleration (PGA) values recorded through accelerograms. The information gathered from the subjective data is used to estimate the damage which helped in assigning appropriate Modified Mercalli Intensity (MMI). Using Root Mean Square Error (RMSE), the prediction equations are ranked for future use in the seismic hazard assessment procedures. The comparison with the observed intensity has shown that the equations developed for California and Himalaya are in better agreement than the equations developed for Eastern Northern America, Central Eastern United States, Craton and entire India.

Keywords: Ground motion; seismic hazard; earthquake damage; seismic design; Modified Mercalli Intensity

1 INTRODUCTION

For applicability of seismic design and assessment tools or development of pre- or post-disaster mitigation strategies, detailed seismic hazard assessment of a given region is carried out. In order to execute the probabilistic or deterministic seismic hazard assessment reliably, the most suitable Ground Motion Prediction Equation (GMPE) representing the seismotectonic and geological characteristics of the region under study is vital. GMPEs are regression models used to predict various measures of ground motion such as Peak Ground Acceleration (PGA), Peak Ground Velocity (PGV) etc. These GMPEs are a function of the parameters influencing the ground motion measure of interest, such as magnitude of earthquake, depth of earthquake, type of earthquake, site-source distance, site class of the region, fault mechanism of the earthquake, etc. In the last few decades since the availability of recorded ground motions numerous GMPEs have been developed for predicting the ground motion intensity measures due to earthquake events for different regions of the world (Szeliga, *et al.,* 2010). (Atkinson, and Boore, 2003).

Unfortunately, however, there are no GMPEs representing the geology and seismotectonic settings of Pakistan. One of the key reasons for the lack of research on the topic is scarcity of ground motion data for the past earthquake events affecting the country. Resultantly, there is a dire need of research on the topic. While the available data for the past earthquake is still not sufficient to develop an indigenous relationship for the country, the limited data available for the past earthquakes affecting Pakistan can be used for the selection of one or multiple GMPEs that can be used in the hazard assessment in future.

To this end, the relevant data for Khash, 2013, earthquake is obtained from different sources, depending on the availability and other constraints, such as published reports and research work, online surveys, damage data reported in the newspapers and instrumental data. All the data is compiled and consistently converted to intensities and compared with GMPE estimates, and the most suitable GMPEs are selected based on statistical analysis.

2 SEISMIC DATA

Pakistan is located on two tectonic plates namely Indian and Eurasian plate; as a result, the tectonic boundary between the two plates passes through the country. Stresses developed due to relative movement of the plates result in the interplate and intraplate earthquakes within the country and its neighbourhood. Resultantly, numerous earthquakes have occurred within the country and the adjoining regions. However, unfortunately, there is scarcity of the recorded ground motion data to study the seismotectonic and geology of the region extensively, and develop ground motion prediction equations.

A recent large magnitude earthquake event near the Pakistan-Iran border, referred as Khash earthquake as

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well as Gosht (Saravan) Earthquake, provided sufficient data to be explored for the scientific purpose. Khash earthquake, with moment magnitude of 7.8 and focal depth of 82 km, occurred in Iran on 16th April, 2013 at 3:45 pm local time (Data source: USGS). (Zare, and Shahvar, 2013). (Rajaram, and Ramancharla, 2014). The epicentre of the earthquake was located 83 km on the East of Khash in Iran (Data source: USGS). Zare, and Shahvar, 2013). (Rajaram, and Ramancharla, 2014). The effects of earthquake were felt over a large region including Iran, Pakistan and India. In Pakistan, Mashkhel was the nearest populated town within 100 km radial distance from the epicentre near the border of Iran, where maximum intensity was felt (Rafi, *et al.*, 2015). Three different sources were used to collect the data for the above earthquake, as discussed below.

2.1 DATA SOURCE – 1: SURVEY

The intensity distribution data was gathered with the aid of physical survey as well as questionnaire survey conducted using various communication means. The physical survey was conducted for the city of Mashkhel by a reconnaissance team from the Department of Earthquake Engineering of NED University of Engineering and Technology (Rafi, *et al.*, 2015).Twelve different areas of Mashkhel city were surveyed by the team including the FC Headquarter. Considering the damage caused to various structures in the surveyed city, average MMI was assigned to the city. In addition, 200 survey forms consisting of questionnaires to evaluate MMI for various cities were filled through email, posts and telephonic means. Due to the large area of Karachi, it was divided into seven different zones and intensity for each zone was obtained separately. In cases when multiple observations were available for a city or town, the most repeated (mode) MMI value was assigned. The questionnaires with incomplete information or the conflicting information were exempted. Combined intensities from both the surveys are plotted against epicentral distance, as shown in **(Fig. 1(a)).**

2.2 DATA SOURCE – 2: 'DID YOU FEEL IT' PROGRAM

Did You Feel It (DYFI)' program launched by USGS encourages the internet users all over the world to share their experience after occurrence of an earthquake event. Based on the experiences of various users, the Modified Mercalli Intensity (MMI) is assigned to various locations that lead to development of Isoseismal Maps for a given earthquake. Therefore, it has been considered for the collection of data for every earthquake in this study. The data collected for Khash, Iran earthquake, from the DYFI is presented in graphical form against epicentral distance in **(Fig. 1(b))**. It may be noted that there exists very large variability in the intensity distribution data.

2.3 DATA SOURCE-3: PUBLISHED LITERATURE

The earthquake ground motion data for the Khash earthquake was recorded by 33 strong motion instruments installed in various locations in Iran. However, in the report presented by Zare *et al.*, (2013) the strong motion data for six stations is presented, and therefore used in the study presented herein. The observed accelerations for the six stations are converted to MMI values using (Wald *et al.,* 1999). The data obtained from the three data sources is presented in **(Fig. 1(c))** in the form of MMI versus epicentral distance. It may be noted that the data presented in the figures is restricted to epicentral distance of 500 km considering that beyond this distance earthquakes do not produce shaking higher than that to be considered important for the engineering applications.

3. GROUND MOTION PREDICTION EQUATIONS

The equations for prediction of intensities include (Szeliga *et al.* 2010), Bakun and Wentworth (1997), (Bakun *et al.* 2003), (Ambraseys and Douglas 2004) and (Atkinson and Wald 2007). The first four prediction equations have the following form, as shown in Equation 1.

$$I = a + b M_W + c R + d \log R \tag{1}$$

In the above equation, M_w and R represent moment magnitude and hypocentral distance respectively; a, b, c and d are the regression coefficients. (Szeliga *et al.* (2010) proposed different set of coefficients for entire India, Craton and Himalaya as shown in **(Table 1).** The coefficients proposed by Ambraseys and Douglas (2004) for Northern India, (Bakun and Wentworth 1997) for (California and Bakun *et al.* 2003) for Eastern North America are shown in **(Table 2).**

The prediction equation proposed by Atkinson and Wald (2007) is shown in Equation 2. The coefficients used for the equation are provided in **(Table 3).**

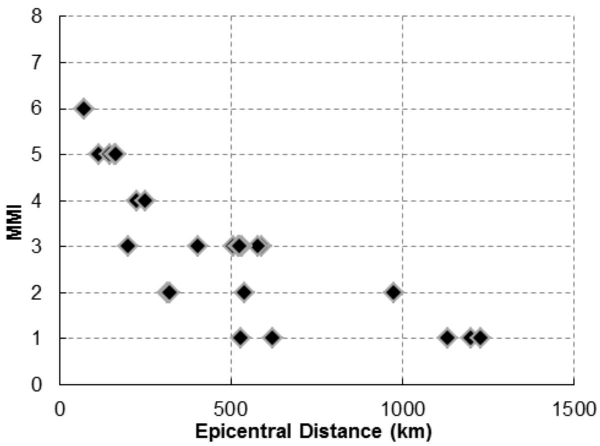
$$MMI = C_1 + C_2 \left(M - 6\right) + C_3\left(M - 6\right)^2 + C_4 \log R \ldots \ldots$$

$$+ C_5 R + C_6 B + C_7 M \log R \tag{2}$$

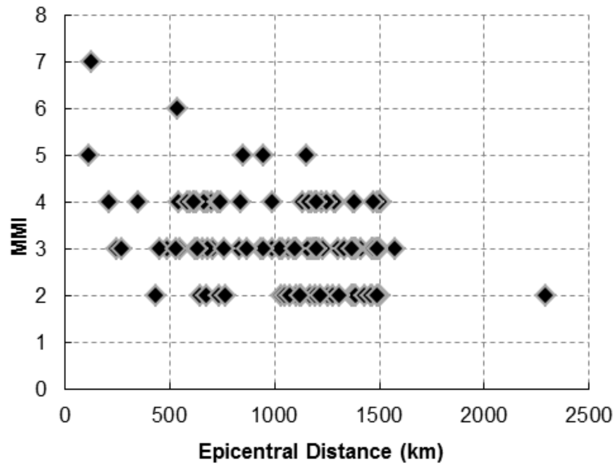
In the above equation, M represents moment magnitude; R and B are given by Equation 3 and 4 respectively; and C_1, C_2, C_3, C_4, C_5, C_6 and C_7 are the coefficients provided in Table 3 for California, and Central and Eastern United States.

$$R = \sqrt{D^2 + h^2} \tag{3}$$

$$B = \begin{cases} 0 & \text{for } R \le R_t \\ \log \frac{R}{R_t} & \text{for } R > R_t \end{cases} \tag{4}$$



(a)



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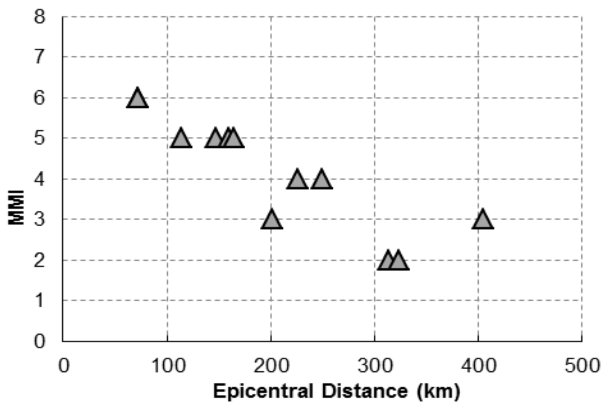
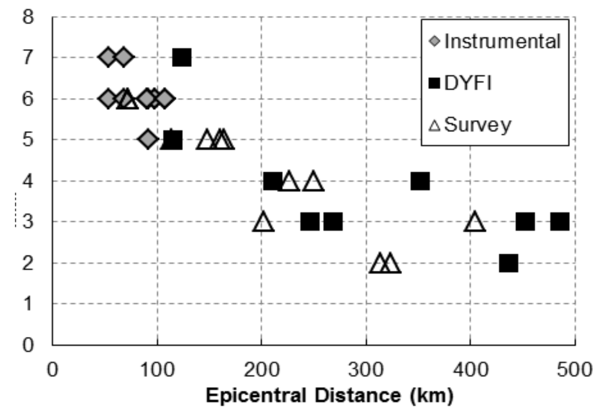


(c)



(d)

Fig. 1 a) MMI recorded from the questionnaire and physical surveys shown against the epicentral distance; b) MMI obtained from DYFI shown against the epicentral distance; c) MMI obtained from instrumental data shown against the epicentral distance; d) MMI obtained from all three sources of data shown against the epicentral distance less than 500 km.

Table 1: Coefficients proposed by Szeliga et al., 2010 for intensity predictions for India, Craton and Himalaya region

Region	A	B	c	D
India	5.57	1.06	-0.0010	-3.37
Craton	3.67	1.28	-0.0017	-2.83
Himalaya	6.05	1.11	-0.0006	-3.91

Table 2: Regression coefficients for intensity prediction proposed by Bakun and Wentworth (1997) [8], Bakun et al. (2003) [9] and Ambraseys and Douglas (2004)

Reference	a	b	C	d
Bakun and Wentworth (1997) [8]	3.67	1.17	0	-3.19
Bakun et al. (2003) [9]	1.41	1.68	-0.00345	-2.08
Ambraseys and Douglas (2004) [10]	0.46	1.54	-0.004	-2.54

Table 3: Regression coefficients for intensity prediction equation proposed by Atkinson and Wald (2007)

Coefficients	California	Central and Eastern United States
C_1	12.27	11.72
C_2	2.270	2.36
C_3	0.1304	0.1155
C_4	-1.30	-0.44
C_5	-0.0007070	-0.002044
C_6	1.95	2.31
C_7	-0.577	-0.479
h	14.0	17.0
R_t	30.0	80.0

Table 4: Root Mean Square Error (RMSE) for different equations in comparison with the observed intensities

GMPE	RSME
Szeliga et al. (2010) -India	1.72
Szeliga et al. (2010) - Craton	2.53
Szeliga et al. (2010) - Himalaya	1.49
Bakun and Wentworth (1997)	1.36
Bakun et al. (2003)	4.65
Ambraseys and Douglas (2004)	1.60
Atkinson and Wald (2007) - California	0.92
Atkinson and Wald (2007) - CEUS	2.90

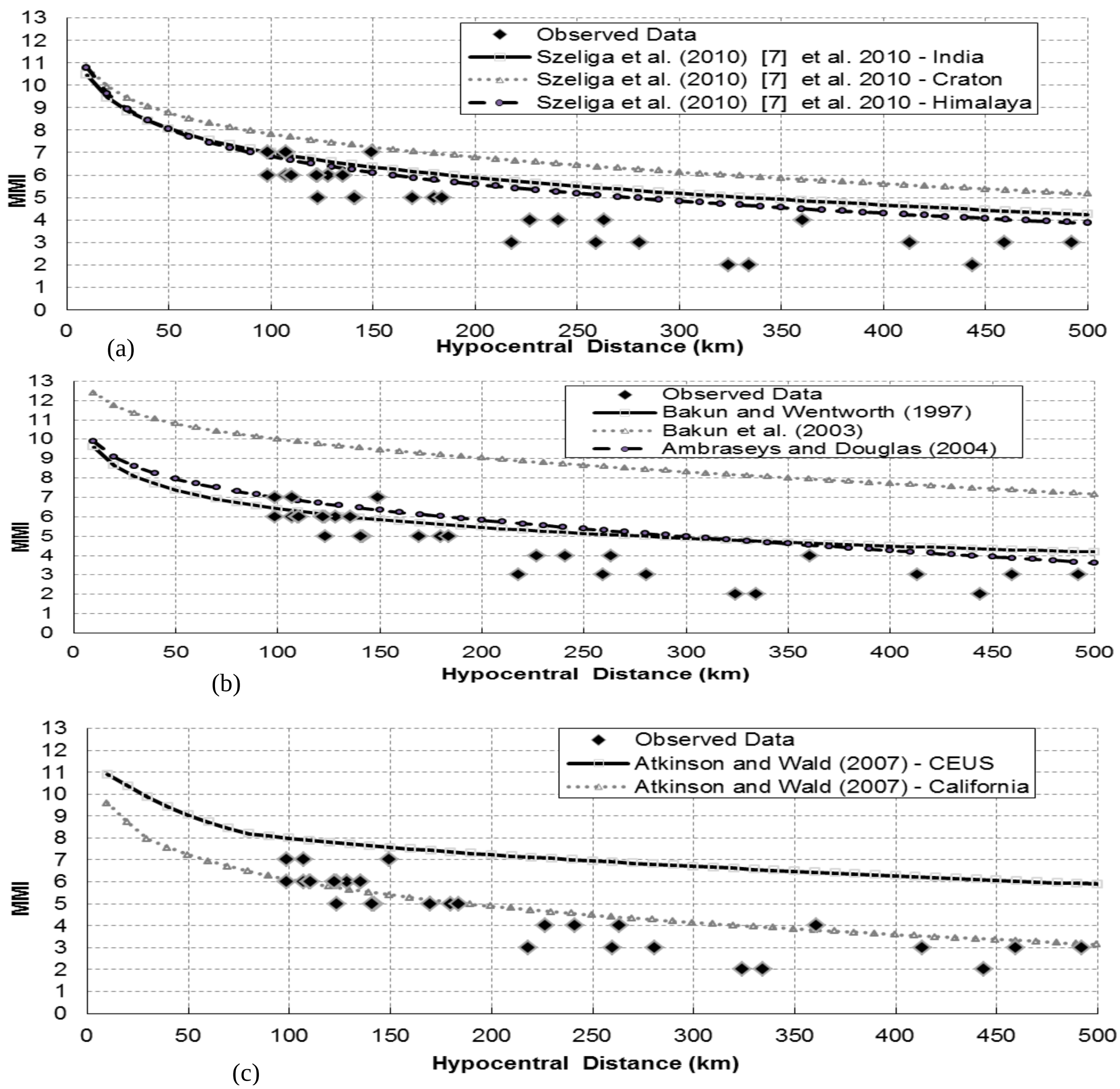


Fig.2 Comparison of observed MMI values for Khash earthquake with prediction of: a) Szeliga et al. (2010) equations for India, Craton and Himalaya; b) Bakun and Wentworth (1997) , Bakun et al. (2003) and Ambraseys and Douglas (2004) c) Atkinson and Wald (2007) for California and Central Eastern United States

In the above two equations, D represents distance from a given fault (in this study it is considered as the hypocentral distance); h is the effective depth term provided in Table 3; and R_t is the transition distance in the attenuation shape given in Table 4.

4 COMPARISON AND RANKING

The aforementioned ground motion prediction equations for intensity are compared with the recorded intensities obtained from three different sources. **(Fig. 2(a))** demonstrates the comparison of observed intensities with estimates of three ground motion prediction equations developed for the entire India, Craton and Himalaya region. It may be observed from the comparison that the equation proposed for the entire India severely overestimates the intensities for all distances. Among the three equations, the intensity estimated by the equation proposed for Himalaya region is relatively better than the remaining two equations. **(Fig. 2(b))** shows the comparison of the observed intensities with intensities estimated by Bakun and Wentworth (1997), (Bakun *et al.* 2003), (Ambraseys and Douglas 2004). It is observed that Bakun *et al.* (2003) equation proposed for Eastern Northern America significantly over predicts the intensities; whereas the other two equations show relatively better agreement. **(Fig. 2(c))** shows comparison of the observed intensities with the equations proposed by Atkinson and Wald (2007) for California and Central Eastern United States. It is observed that the equation for California is in much better agreement, whereas the equation proposed for Central Eastern United States over predicts the intensities significantly.

To quantify the comparison, root mean square error (RMSE) is calculated using the observed intensity and corresponding predicted intensity for a given hypocentral distance for each equation, as provided in Table 7. Based on RMSE values, it may be deduced that among all the prediction equations (Atkinson and Wald (2007) equation for California has superior agreement with the observed intensities sequentially followed by Bakun and Wentworth (1997) for (California and Szeliga *et al.* 2010) for Himalaya.

5 CONCLUSION

The work presented herein aimed to evaluate the applicability of various ground motion prediction equations developed for India and other parts of the world on the intensity data for Khash, (2013), earthquake. The intensity data recorded using instruments; physical and questionnaire surveys and DYFI program were obtained for the locations where the earthquake was felt. The comparison with multiple prediction equation has shown that the intensity prediction relationships developed by Atkinson and Wald (2007) for California is in superior agreement with the observed data with RMSE noted as 0.92. In general, it is noted that the equations developed for California and Himalaya are in good agreement with the observed data; whereas the equations developed for Eastern Northern America and Central and Eastern United States show very poor comparison with the observed data.

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