

INTERNATIONAL SOCIETY FOR SOIL MECHANICS AND GEOTECHNICAL ENGINEERING



This paper was downloaded from the Online Library of the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE). The library is available here:

<https://www.issmge.org/publications/online-library>

This is an open-access database that archives thousands of papers published under the Auspices of the ISSMGE and maintained by the Innovation and Development Committee of ISSMGE.

The paper was published in the proceedings of the 7th International Symposium on Geotechnical Safety and Risk (ISGSR 2019) and was edited by Jianye Ching, Dian-Qing Li and Jie Zhang. The conference was held in Taipei, Taiwan 11-13 December 2019.

A Study on the Relationship between Arias Intensity and Earthquake-Induced Slope Displacement

Chih-Hsuan Liu¹, Hsuan-Ho Wang², and Ching Hung³

¹Department of Civil Engineering, National Cheng Kung University, No.1, University Road, Tainan City 701, Taiwan. E-mail: n68071504@mail.ncku.edu.tw

²Department of Civil Engineering, National Cheng Kung University, No.1, University Road, Tainan City 701, Taiwan. E-mail: N66054344@mail.ncku.edu.tw

³Department of Civil Engineering, National Cheng Kung University, No.1, University Road, Tainan City 701, Taiwan. E-mail: ChingHung@gs.ncku.edu.tw

Abstract: Earthquake-induced landslides have great impact to safety, property, and the environment. In order to evaluate the risk associated with slope failure, a better understanding of slope movements induced by earthquake is pivotal. Acknowledging both the energy-based Arias Intensity as a reliable parameter to describe earthquake shaking and the finite element analysis as a practical and effective alternative to conduct the dynamic analysis, this study utilized a series of seismic records and performed numerical investigations to study the relationship between Arias Intensity and earthquake-induced displacement. To further observe the relationship between Arias Intensity and earthquake-induced displacement, several landslide models with slope angles of 20°, 30°, and 45° were evaluated. Our results demonstrate the potential of using Arias intensity and finite element analysis to acquire the empirical relationship and provides preliminary investigation of using Arias intensity to assess the seismic hazards.

Keywords: Earthquake-induced landslide; Arias intensity; Finite element analysis; seismic hazard.

1 Introduction

Taiwan is located at the boundary between the Philippine Sea Plate to the East and the Eurasian Plate to the West. Due to the collision of two plates, seismic activities and subsequent landslides (e.g. Tsaoling landslide) occur frequently in Taiwan. The frequent seismic activities occurred in Taiwan aroused the interest in research of seismic response, and furthermore, the prevention of seismic-induced damage or landslide mitigation. Many researchers have utilized seismic hazard analysis and proposed several strong ground motion empirical relationships (Joyner and Boore 1981; Campbell and Borzongnia 2003) to mitigate damages.

In seismic hazard analysis, the most common parameter representing seismic shaking intensity is the Peak Ground Acceleration (PGA). Even with many research works applying the peak ground acceleration, some studies have different opinions about PGA to describe the severity of seismic shaking. PGA is only a single point in an acceleration-time history and is a raw measure of shaking intensity (Evernden 1975; Jibson 1993). For earthquake with short duration, even with higher peak acceleration, the destructive capability is relatively low, and the margin of safety is high. Wilson (1993) stated the peak ground acceleration is strongly affected by high frequency components. From the results, to describe the severity of seismic shaking more precisely, the duration and the frequency should be considered. Arias intensity (Arias 1970), an energy-based measure, incorporates duration and frequency. Thus, the estimation of the Arias intensity expected on landslide prone slopes may be useful for a preliminary delimitation of areas that may be affected by earthquake-induced mass movements (Chousianitis et al. 2014).

Acknowledging finite element analysis as a practical and effective alternative to conduct the dynamic analysis (Hung et al. 2017; Lin et al. 2017; Hung et al. 2018), in-depth numerical analyses can be carried out to investigate the relationship between Arias intensity and earthquake-induced displacement to help assess seismic landslide hazards.

2 Finite Element Procedure

In the procedure, slopes were modeled by 15-node triangular solid elements, which provide a fourth order interpolation for displacements and a numerical integration involves 12 Gauss points. For the dynamic analysis, in order to avoid the seismic wave causing unrealistic vibrations in the model, the artificial boundary must be set up on the boundaries. In this study, viscous boundary conditions were used to ensure the precision of simulation results. The calculations of the numerical analysis were formulated in terms of the Mohr-Coulomb failure criterion with an angle of internal friction and a cohesion. Details of the finite element procedure can be found in Hung et al. (2017) and Lin et al. (2017).

Proceedings of the 7th International Symposium on Geotechnical Safety and Risk (ISGSR)

Editors: Jianye Ching, Dian-Qing Li and Jie Zhang

Copyright © ISGSR 2019 Editors. All rights reserved.

Published by Research Publishing, Singapore.

ISBN: 978-981-11-2725-0; doi:10.3850/978-981-11-2725-0_IS11-4-cd

3 Finite Element Models

The objective of this study is to clarify the relationship between Arias intensity and earthquake-induced displacement. To this end, simple models were analyzed. According to Chan et al. (2015), approximately 75% of the landslides in Taiwan occurred on slopes with angles from 20° to 50° (Table 1). Simple landslide models with three different angles of 20°, 30° and 45° were thus considered (Fig. 1). To avoid the effect of the material properties, the material properties of the simple landslide models are control to be the same. The geomaterial assumed in the simple models is sandstone, and its parameters are shown in Table 2.

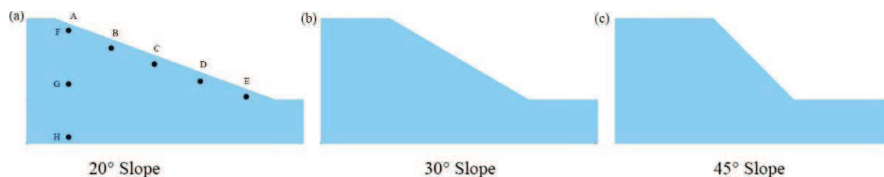


Figure 1. Analysis model from three different slopes.

Table 1. Recent landslide in Taiwan (after Chan et al. 2015).

Slope Angle	Total	Percentage (%)
<20°	23	12.7
20°-30°	53	29.3
30°-40°	58	32.0
40°-50°	24	13.3
>50°	23	12.7

Table 2. Model parameters for simple models (after Lin et al. 2017).

Cohesion (kPa)	Friction Angle (Degree)	E (kPa)	γ_t (kN/m ³)	ν
700	40	5×10^6	20	0.17

In finite element analyses, altogether 20 strong ground motions were employed, in which, 10 were taken from the records of the 1999 Chi-Chi Earthquake, and the other 10 were from those of the 1979 Imperial Valley Earthquake. In this study, the distances of the seismic stations to the source area are all under 30 km. In order to be comparable, all the seismic records were scaled to PGA=70, 100, and 200 gals, respectively. The seismic records applied in this study are shown in Table 3.

4 Results and Discussion

In the simulation, seven monitoring points were set up to investigate the displacement varying with time (Fig. 1a). Five monitoring points were located near the surface of the slope, and the other three are located on the vertical line extended from the highest of the slope. To understand the effect of the range of Arias intensity, the seismic records were scaled to PGA=70, 100, 200 gals, resulting the Arias intensity to be in the range of 0.01 to 0.25, 0.01 to 0.4 and 0.3 to 2.0 m/s, respectively. The linear regression method was chosen to present the relationships between Arias Intensity and earthquake-induced displacement, because linear regression methods was usually used in the relationship between Arias intensity and displacement (Jibson1993; Hsieh and Lee 2010; Chousianitis et al. 2014). To facilitate comparisons between the results, the resultant earthquake-induced slope displacements were sorted out by using a normalization method called Min-Max normalization, which mapped the entire range of the displacement results to the range 0 to 1. The definition of the Min-Max normalization is shown below:

$$X^* = \frac{X - X_{min}}{X_{max} - X_{min}} \tag{1}$$

Table 3. Seismic records used in the analyses.

Earthquake	Station Name	Epicenter Distance	Component	PGA	Ia(70)	Ia (100)	Ia (200)
1999 Chi-Chi	CHY024	23.76	U	141.4	0.1301	0.2655	1.0622
		23.76	N	162.16	0.1664	0.3395	1.3581
		23.76	E	276.34	0.0969	0.1978	0.7913
1999 Chi-Chi	CHY028	32.3	U	335.5	0.0408	0.0832	0.333
		32.3	N	749.9	0.0498	0.1016	0.4062
		32.3	E	624.16	0.0639	0.1304	0.5215
1999 Chi-Chi	CHY080	10.6	U	715.919	0.0175	0.0357	0.1428
		10.6	N	841.53	0.0432	0.0882	0.3526
		3.1	E	792.362	0.0664	0.1355	0.5419
1999 Chi-Chi	TCU067	28.15	U	230.58	0.0588	0.1201	0.4803
		28.15	N	312.66	0.112	0.2285	0.9141
		28.15	E	488.86	0.0598	0.122	0.4878
1999 Chi-Chi	TCU071	15.07	U	415.54	0.0661	0.135	0.5399
		15.07	N	639	0.09	0.1837	0.7348
		15.07	E	517.82	0.1219	0.2487	0.9947
1999 Chi-Chi	TCU075	20.06	U	223.88	0.0696	0.1421	0.5686
		20.06	N	257.32	0.0582	0.1187	0.4747
		20.06	E	325.34	0.0897	0.132	0.7326
1999 Chi-Chi	TCU076	15.53	U	275.38	0.0876	0.1787	0.715
		15.53	N	420.02	0.0847	0.1728	0.6914
		15.53	E	340.1	0.1243	0.2538	1.0151
1999 Chi-Chi	TCU078	5.53	U	171	0.1019	0.2079	0.8318
		5.53	N	302.48	0.1222	0.2494	0.9975
		5.53	E	439.7	0.1157	0.2362	0.9448
1999 Chi-Chi	TCU079	8.14	U	382.32	0.0601	0.1227	0.491
		8.14	N	416.96	0.0959	0.1957	0.7828
		8.14	E	579.78	0.1062	0.2168	0.8671
1999 Chi-Chi	TCU084	9.23	U	311.76	0.0739	0.1509	0.6035
		9.23	N	422.82	0.0559	0.1141	0.4566
		9.23	E	989.22	0.0644	0.1315	0.5261
1979 Imperial	USGS 5054	6	UP	321.1	0.0475	0.097	0.3881
		6	S40E	583.9	0.0516	0.1052	0.4209
		6	S50W	762.9	0.043	0.0877	0.3507
1979 Imperial	USGS 5053	15	UP	171	0.0649	0.1325	0.53
		15	S45W	267.8	0.0491	0.1003	0.4011
		15	N45W	197.6	0.0626	0.1277	0.5109
1979 Imperial	USGS 5055	20	UP	205	0.0404	0.0825	0.3299
		20	S45W	243	0.0642	0.131	0.5239
		20	N45W	209.4	0.0822	0.1678	0.6711
1979 Imperial	USGS 5054	7	VERT	347.7	0.0428	0.0874	0.3495
		7	230	770.4	0.044	0.0898	0.3593
		7	140	575.7	0.0534	0.109	0.4361
1979 Imperial	USGS 5053	17	VERT	179.1	0.0665	0.0516	0.5425
		17	225	272.5	0.0486	0.0243	0.3968
		17	315	200.4	0.0758	0.0518	0.6191
1979 Imperial	USGS 5055	20	VERT	223.7	0.0564	0.1152	0.4607
		20	225	254.1	0.0624	0.1273	0.5093
		20	315	245.3	0.0797	0.1626	0.6502
1979 Imperial	USGS 0955	27	UP	204.4	0.0306	0.0625	0.2501
		27	S50W	349.2	0.0367	0.075	0.3
		27	S40E	480.8	0.027	0.0551	0.2204
1979 Imperial	USGS 0412	27	UP	98.9	0.0526	0.1073	0.4293
		27	N40W	226.6	0.0563	0.1149	0.4597
		27	N50E	166.1	0.0905	0.1846	0.7384
1979 Imperial	USGS 0958	27	UP	349.3	0.0296	0.0604	0.2414
		27	S40E	599.7	0.0204	0.0416	0.1666
		27	S50W	438.1	0.0363	0.0741	0.2963
1979 Imperial	USGS 5165	26	UP	454.9	0.0235	0.0479	0.1917
		26	WEST	339.3	0.0697	0.1423	0.5693
		26	NORTH	473.6	0.0439	0.0895	0.3581

The resultant earthquake-induced slope displacements under different range of Arias intensities are normalized separately, and the results of the relationship between Arias intensity and normalized slope

displacement are shown in Fig. 3. As shown in Fig. 3, the results for the five monitoring points near the surface under earthquake are very similar. On the other hand, the results of the other three monitoring points show that the fit-line for the monitoring points in the sliding zone had bigger slopes than the points outside the sliding zone, but still, the results are still quite similar, and the main focus of this study should be in the sliding area. To prevent the flow chart from becoming too complicated, the displacement of the toe of the slope (monitoring point E), where most houses situate, are used for further discussion. The results of monitoring point E are shown in Fig. 4. As shown in Fig. 4, the effect of the range of Arias intensity on the relationship fit curve is obvious. When the range of the Arias intensity increases, the slope of the relationship fit-line curve decreases. In the smaller ranges of the Arias intensities, the increasing rate is much higher than those in the bigger ranges. According to Ravichandran and Arulchelvan (2017), the use of a fitted curve beyond the range of the observed data is referred as extrapolation and is subject to a degree of uncertainty since it may reflect the method used to construct the curve as much as it reflects the observed data.

To investigate the effect of angle on the relationship between Arias intensity and normalized slope displacement, different angles with same PGA were put in same figures (Fig. 5). As shown in Fig. 5, the relationships between Arias Intensity and normalized displacement are very similar, a possible reason is that all three simple landslide models have same properties. While the original displacement may be different, empirical relationships with normalized displacements show similar characteristic. This discover may have benefit for future usages of empirical relationships, in which, cases with similar properties may lead to similar empirical relationships.

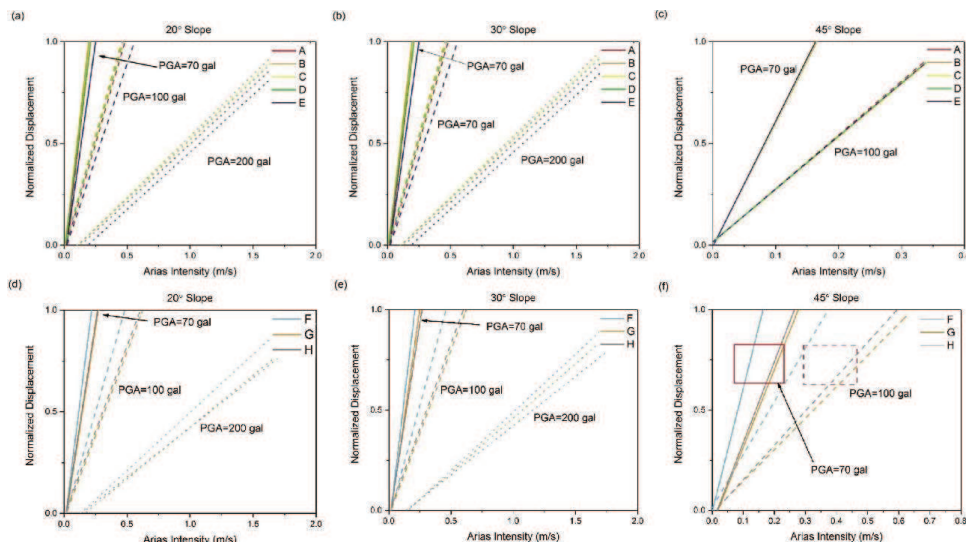


Figure 3. Relationship between Arias Intensity and normalized displacement for monitoring points (same slope angle with different PGA).

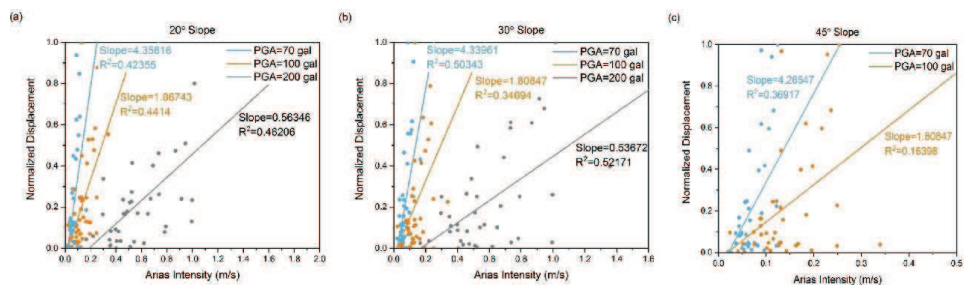


Figure 4. Relationship between Arias Intensity and displacement for monitoring points E (same slope angle with different PGA).

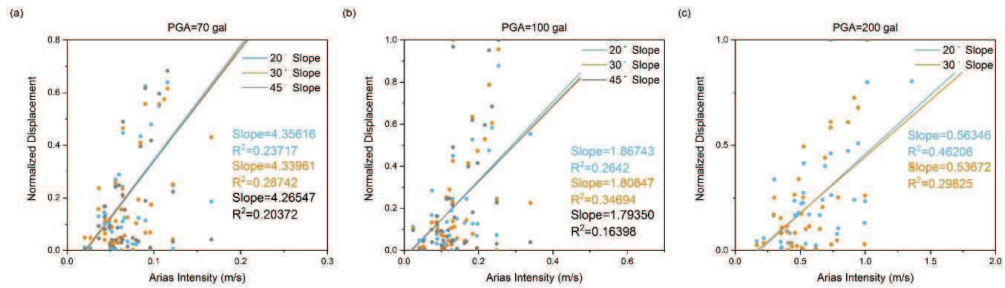


Figure 5. Relationship between Arias Intensity and normalized displacement (same PGA with different slope angle).

5 Conclusion

This study is aimed at studying the relationships between Arias Intensity and earthquake-induced slope displacement. In this study, a series of seismic records were utilized, and finite element analyses were performed. The effect of (a) the ranges of Arias Intensity and (b) the angles of slopes were revealed. Conclusions are drawn as follows:

1. The range of the Arias Intensity has an obvious effect on the relationships between Arias Intensity and the normalized earthquake-induced slope displacement. With the increase of the range of the Arias Intensity, the slope of the fit-line curve of the relationships decreases. The results are also the same in the verification models obtained from previous research.
2. The angles of the slopes for three simple landslide models show very small influence on the relationships between Arias Intensity and the normalized earthquake-induced slope displacement. A possible reason is that the three simple landslide models exhibited the same material properties.

Acknowledgments

The authors gratefully acknowledge financial support from the Ministry of Science and Technology (MOST) in Taiwan: 107-2636-E-006-003. Special thanks go to the Young Scholar Fellowship Program by the Ministry of Science and Technology in Taiwan (The Pilot Directions for MOST Grant for the Columbus Program).

References

- Arias, A. (1970). A measure of earthquake intensity. Hansen, R.J. (Ed.), *Seismic Design for Nuclear Power Plants*. Massachusetts Institute of Technology Press, Cambridge, MA, 438–483.
- Campbell, K.W. and Bozorgnia, Y. (2003). Updated near-source ground-motion (attenuation) relations for the horizontal and vertical components of peak ground acceleration and acceleration response spectra. *Bulletin of the Seismological Society of America*, 93(1), 314–331.
- Chousianitis, K., Gaudio, V.D., Kalogeras, I., and Ganas, A. (2014). Predictive model of Arias intensity and Newmark displacement for regional scale evaluation of earthquake-induced landslide hazard in Greece. *Soil Dynamics and Earthquake Engineering*, 65, 11–29.
- Chan, H.C., Chang, C.C., Chen, S.C., Wei, Y.S., Wang, Z.B., and Lee, T.S. (2015). Investigation and analysis of the characteristic of shallow landslides in mountainous areas of Taiwan (in Chinese). *Journal of Chinese Soil and Water Conservation*, 46(1), 19–28.
- Everden, J.F. (1975). Seismic intensities, "size" of earthquakes, and related phenomena. *Bulletin of the Seismological Society of America*, 65, 1287–1315.
- Hsieh, S.Y. and Lee, C.T. (2011). Empirical estimation of the Newmark displacement from the Arias intensity and critical acceleration. *Engineering Geology*, 122, 34–42.
- Hung, C., Lin, G.W., Syu, H.S., Chen, C.W., and Yen, H.Y. (2017). Analysis of the Aso-bridge landslide during the 2016 Kumamoto earthquakes in Japan. *Bulletin of Engineering Geology and the Environment*, 77(4), 1439–1449.
- Hung, C., Liu, C.H., Lin, G.W., and Leshchinsky, B. (2018). The Aso-Bridge coseismic landslide: a numerical investigation using finite and discrete element methods. *Bulletin of Engineering Geology and the Environment*, 78(4), 2459–2472.
- Joyner, W.B. and Boore, D.M. (1981). Peak horizontal acceleration and velocity from strong motion records including records from the 1979 Imperial Valley, California, earthquake. *Bulletin of the Seismological Society of America*, 71(6), 2011–2038.
- Jibson, R. (1993). Predicting earthquake-induced landslide displacement using Newmark's sliding block analysis. *Transportation Research Record*, 1411, 9–17.
- Lin, G.W., Hung, C., and Syu, H.S. (2017). Evaluation of an enhanced FS method for finding the initiation time of earthquake-induced landslides. *Bulletin of Engineering Geology and the Environment*, 78(1), 497–506.
- Plaxis (2016). *Reference and Material Models Manual*, Plaxis BV, Netherlands.

- Ravichandran, K. and Arulchelvan, S. (2017). The curve fitting model analyzed the survey of crime news awareness in India. *2017 Second International Conference on Recent Trends and Challenges in Computational Models*, 191-195.
- Wilson, R.C. (1993). *Relation of Arias Intensity to Magnitude and Distance in California*, U.S. Department of the Interior U.S. Geological Survey.