An Assessment of the Influence of Earthquake Duration in Inducing Landslides

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Abstract

Earthquake duration is a complex natural phenomenon associated with the sudden energy release induced by fault rupture. The shaking during an earthquake is a result of the primary, secondary and surface waves. This study is aimed at establishing the relationship between earthquake duration and other seismic parameters: magnitude, peak ground acceleration, focal distance, fault length in relation to landslides generated by the major earthquakes. To achieve this objective, we made an intensive review of published data on major earthquakes (Mw ≥ 6.6) that generated landslides between 1998 and 2015 in the world. The results reveal that magnitude, focal length and focal depth times fault length are strong determinants of earthquake duration. However, it is noted that peak ground acceleration (PGA) and focal depth do not necessarily determine the duration of earthquake shaking. It is also observed that duration of an earthquake is moderately correlated to area affected by earthquake induced landslides. Additionally, much as the number of landslides produced during and/or after an earthquake does not necessarily augment with increasing duration majority of the investigated major earthquakes that produced great damage, with respect to landslides, were noticed to have lasted for not more than 60 seconds.

Introduction

Earthquake duration has been defined as the total time of ground shaking from the arrival of seismic waves until the return to ambient conditions [1]. The shaking during of an earthquake is basically a function of the primary waves (P waves), secondary waves (S waves) and surface waves. For the purpose of evaluating seismic response and assessing the potential damage, earthquake duration has been discussed by a number of investigators [2-6], to be 'strong motion duration' due to earthquakes. The duration of strong ground shaking during an earthquake can cause many problems in earthquake engineering [1,4] and for instance; causing slopes failures [7]. The duration of strong earthquake ground motion is one of the main characteristics that influence earthquake's damaging potential [1]. However, duration of ground shaking is not an independent variable. It is basically dependent on earthquake magnitude, length of seismic wave propagation path, the geologic and soil properties along the wave path and frequency of motion [1,2]. A study by Salmon [1] demonstrated that earthquake duration increases with increasing earthquake magnitude and increasing distance from the recording site to the zone of energy release of the causative earthquake and also earthquake duration is greater at soil sites than at rock sites. Majority of studies on earthquake duration have been conducted in relation to response of foundation materials and structures [8-13]. However, this study aims at establishing the relationship between earthquake duration and other seismic parameters: magnitude, peak ground acceleration (PGA), focal depth and fault length in relation to landslides generated during and/after an earthquake. The data to be used ın the study are based on the major earthquakes (Mw>6.6) that occurred between 1998 and 2015 in the world. The established relations among the earthquake parameters and earthquake induced (EI) landslides are presented as relational diagrams.

Objectives

The objectives of the study are:

To document the landslides induced by major earthquakes with moment magnitude Mw ≥ 6.6 that occurred between 1998 and 2015 in the world including the recent 2016 Kaikoura New Zealand earthquake.

To establish the relationship between earthquake duration and other seismic parameters; magnitude, PGA, focal depth and fault length.

To evaluate the impact of earthquake duration on occurrence of EI landslides.

Methodology

Intensive review of data on landslides induced by major earthquakes (Mw ≥ 6.6) that occurred between 1998 and 2015 in the world was made. Data review involved collecting all relevant information on landslides inducing major earthquakes in the world. Reviewed information include; scientific and technical papers, technical reports and technical essays. Valuable data was also obtained from internet sites and relevant books on earthquakes that induced landslides. In the analysis, we have also included some of the minor and major well documented cases like the Aysen Chile [14], Avaj Iran [15], Northridge California, the Finisterre Papua New Guinea and the Loma Prieta USA 1989 respectively and the recent 2016 Kaikoura, New Zealand earthquake in order to consolidate the findings of the study. A quantitative technique of data analysis was applied to correlate variables so as to understand the relationship of earthquake duration and other seismic parameters

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and evaluate its impact in causing landslides during and/or after an earthquake. Microsoft Excel program was applied to analyse the earthquake data and produce; tables and frequency and correlation diagrams.

Review of Definitions of Earthquake Duration

There are a number of definitions of strong motion duration which have been developed by many investigators [1,3,9-16]. The authors elaborated that each of the definitions that have been developed are based on the fact that the damage potential of an earthquake is a function of the energy of the earthquake, and that the majority of the total energy associated with any earthquake is contained in portions of the earthquake time history which is much shorter in time than the total duration. Bommer noted that nearly all of the definitions on duration of strong ground motions can be classified into three generic groups as explained below and some are based on the response of structures to earthquake loading.

Generic definitions of duration

Bracketed duration (Db): According to Bommer, bracketed durations are defined as the total time elapsed between the first and last excursions of a specified level of acceleration (a0) (Figure 1). One disadvantage of this definition is that it considers only the first and last peaks that cross the specified threshold and ignores completely the characteristics of the strong shaking phase, which can result in long durations being estimated for earthquakes with small sub-events occurring after the main shock motion has passed.

Furthermore, definition based on acceleration can be rather unstable if low thresholds for some accelerograms, change from say 0.03 g to 0.02 g and can result in an increase of the bracketed duration by 20 seconds or more.

Uniform duration (D): Uniform durations are also defined by a threshold level of acceleration (a0). But rather than as the interval between the first and final peaks that exceed this level, the duration is defined as the sum of the time intervals during which the acceleration is greater than the threshold.

$$D = \sum_{i}^{n} t_i \tag{1}$$

The concept of "uniform duration" is illustrated in Figure 2. Bommer further explains that the 'D' definition is less sensitive to the

threshold level than the bracketed duration, but it has the disadvantage that it does not define a continuous time window during which the shaking can be considered strong.

Significant duration: The significant duration is defined as the interval over which some proportion of the total integral is accumulated. This is illustrated for arbitrary limits on a plot of the build-up of Arias intensity (IA), known as a Husid plot [3] (Figure 3).

AI in Figure 3 represents Arias Intensity developed by Arias in 1970. Arias [17] defined Arias Intensity as:

$$AI = \frac{\pi}{2g} \int_{0}^{tr} a^2(t) dt \tag{2}$$

Where a(t) is the acceleration time-history, t is the total duration of the accelerogram and g is the acceleration due to gravity.

The concept of significant duration, according to Bommer, has the advantage that it considers the characteristics of the entire accelerogram and defines a continuous time window in which the motion may be considered as strong. It is worth mentioning at this juncture that the concept of the root-mean-square acceleration, arms which is defined by:

$$a_{rms}^2 = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a^2(t) dt \tag{3}$$

Where t1 and t2 mark the start and end respectively of the time interval under consideration.
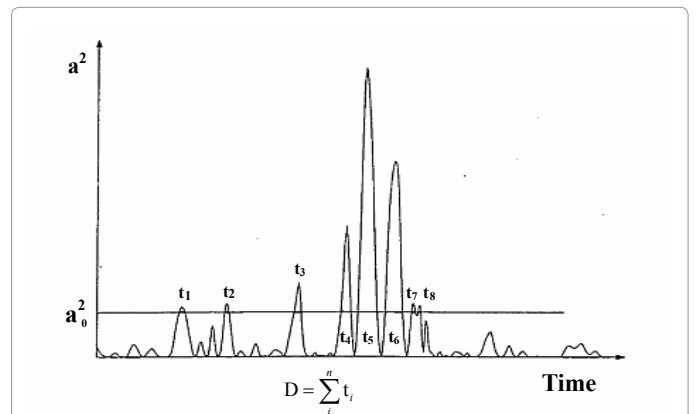

Figure 2: Generic definition of "uniform duration" of an accelerogram (After [3]).
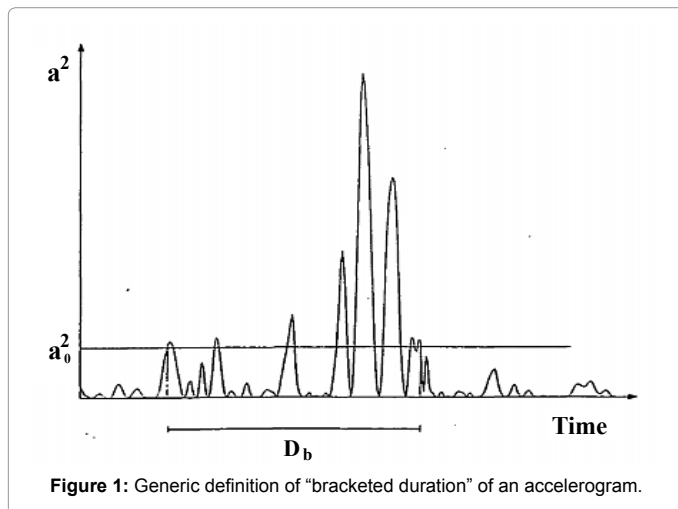

Figure 1: Generic definition of "bracketed duration" of an accelerogram.
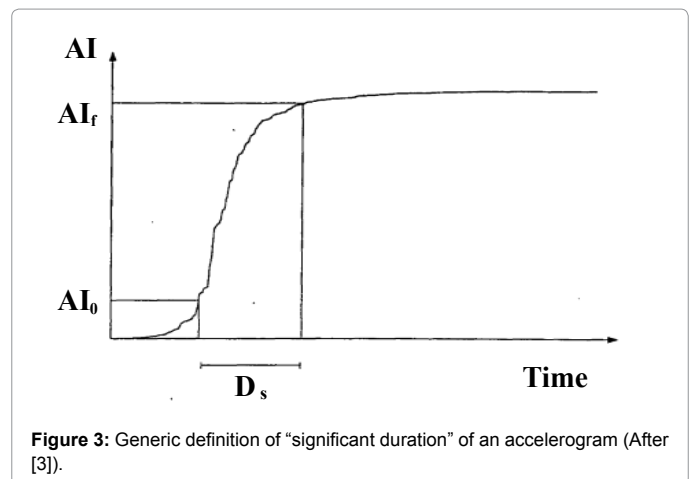

Figure 3: Generic definition of "significant duration" of an accelerogram (After [3]).

Comparison of Equations (2) and (3) shows that a, over a certain interval is in fact directly proportional to the square root of the gradient of this specified interval of the Husid plot [3]. Based on this, Bommer suggested that any definition of duration based on the variation of arms is also regarded as a "significant duration".

However, it is admitted that there is no universally accepted definition for strong motion duration, and reference is frequently made to the duration of earthquake motion without specifying how the duration is defined. A large number of researchers proposed definitions of earthquake strong motion duration over the last three decades [18-33], (Table 1). Due to different definitions developed on duration of ground motion thought it is logical that a further classification is necessary because a number of the definitions that have been proposed are based not on the accelerograms as recorded, but are frequency limited by first processing the records with a narrow pass-band filter.

Classification of duration definitions

Bommer classified the definitions of strong motion duration according to the generic groupings described earlier. Each definition was classified as either frequency-independent or frequency-dependent according to whether the entire accelerogram is employed in the calculation of duration or whether it is first passed through a narrow-band fitter. Furthermore, each definition was also classified according to whether the criteria used to distinguish the strong motion portion of the accelerograms are absolute or their relative values applied to the accelerogram [34-40].

Results

Earthquake duration determining factors

Magnitude and earthquake duration: Earthquakes are basically initiated by rupture and slippage along geological faults. Immediately after the rupture and slippage seismic waves are emitted outwards from the focus. As indicated by Salmon, earthquake magnitude has a significant influence on the earthquake duration. The author explains that when an earthquake has a larger magnitude, the dimensions of fault rupture produced by it become larger. Since the dislocation velocity does change significantly with magnitude, the duration of fault rupture generally increases with increasing earthquake magnitude. Based on this theorem, the study attempted to investigate the strength of the correlation between earthquake magnitude and earthquake duration [41-44]. The results of the relationship are presented in Figure 4. It can generally be observed from Figure 4 that duration of earthquakes is directly proportional to the earthquake magnitude in that as magnitude increases so does the earthquake duration. The fitted exponential regression model yielded a coefficient of determination value of $R^2=0.65$ which signifies a strong positive correlation. When the recent 2016 Kaikoura earthquake in New Zealand was plotted in Figure 4, the estimated duration of the ground shaking was noted to be 44 seconds. This will be interesting to compare with the duration values recorded in the aftermath of the earthquake which at the time of writing this paper had not been established [45-48].

Tsirel presented the formula $t_1=10^{0.31M-0.774}$ developed by Antikaev and Shebalin and Schteinberg in 1988 which shows the relationship between duration of vibrations during earthquakes and magnitude. When the equation is plotted using the collected data (Figure 5), a reasonably acceptable relation has been obtained against non-smoothened data [49-53]. The established relation between earthquake duration and magnitude for the major earthquakes that induced landslides between 1998 and 2015 is found to be in close conformity with the Russian's proposed relation. Thus, the outcome ascertains that earthquake duration depends on its magnitude because a comparison of the two approaches in Figure 6 revealed a similar trend with a slight deviation. Additionally, when the 14th Nov, 2016 Kaikoura earthquake in New Zealand was plotted, it plotted well on the magnitude-earthquake duration regression line. This is interesting to note, given the fact that the Kaikoura earthquake data was included in the final stage of compiling this manuscript [54-57].

Definition	Bracketed Rel. Abs.		Uniform Rel. Abs.		Siginificant Rel. Abs.		Structura Rel. Abs.	
Rosenblueth and Bustamente [33]							○	
Housner [6]	●							
Ambraseys and Sarma [32]	●							
Husid					●			
Kobayadu [31]	●							
Page et al. [30]								
Donovan [30]					●			
Bolt [5]	○		○					
Housner [6]					●			
Trifunac and Brady [28]					●			
Hisada nd Ando [29]	●							
Trifunac and Westrmo [28]								
Saragoni [27]								
McGuine and Barnhard [26]	●	●			●			
McCann and Shan [13]					●			
Perez							○	
Vanmarcke and Lai [7]					●			
Zahrah and Hall [25]							○	
Zhou and Xie [22]					●			
Shahabi and Mostaghel [24]					●			
Theolanopoullos and Dralopoulos					●			
Elghadamsi et al.					●			
Xie and Zhang [23]							○	
Mohras and Peng								
Theofanopulos and Watabe					●			
Kawashima and Aizawa [22]	●	●						
Sarma and Casey [20]			●					
Papazachos et al. [19]	●							
Somerville et al. [18]					●			
● Frequency-induced duration			○ Frequency-dependent duration					

Table 1: Classification of definitions of duration of strong motion [3].
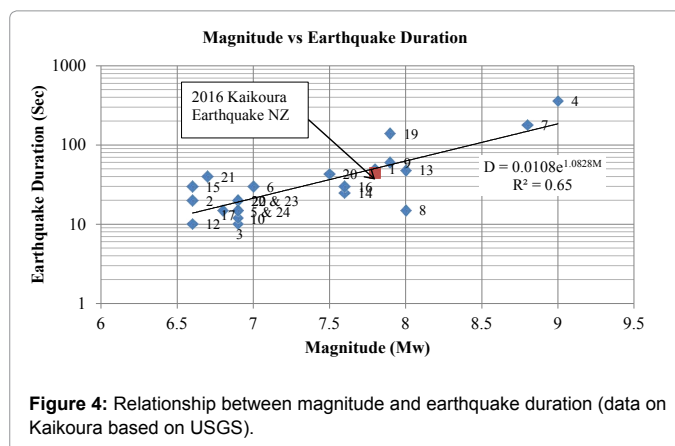

Figure 4: Relationship between magnitude and earthquake duration (data on Kaikoura based on USGS).
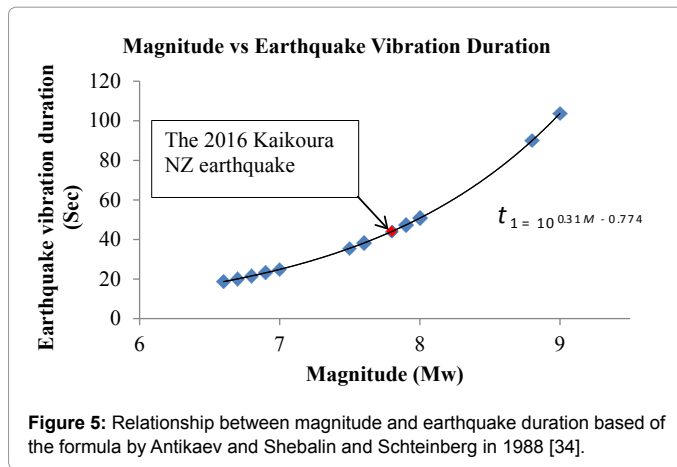
Figure 5: Relationship between magnitude and earthquake duration based of the formula by Antikaev and Shebalin and Schteinberg in 1988 [34].
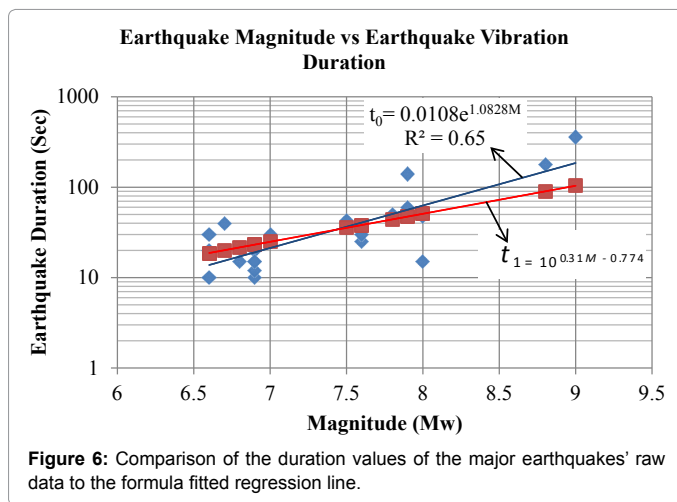

Figure 6: Comparison of the duration values of the major earthquakes' raw data to the formula fitted regression line.
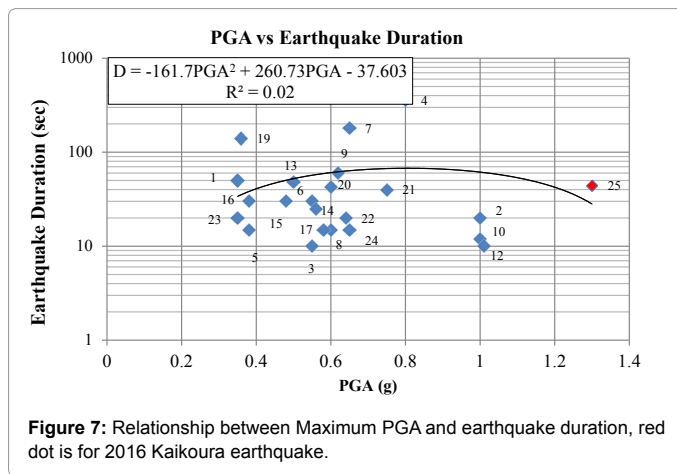

Figure 7: Relationship between Maximum PGA and earthquake duration, red dot is for 2016 Kaikoura earthquake.

PGA and earthquake duration: PGA can as well be considered to have a significant impact on the duration of strong earthquake ground motion. In this study, efforts were made to establish the relationship between PGA and earthquake duration. The statistical analysis between PGA and duration of studied earthquakes is shown in Figure 7. The relationship indicates that there is no correlation between PGA and duration of earthquake. Thus, it is suggested that a good relationship of the two variables may be obtained if comparisons are made in the

same geological settings since earthquake duration is also affected by geological materials [58,59].

Fault length and earthquake duration: Within the scope of the study, we investigated the influence of fault length on duration of earthquakes. The established relationship between the fault length and the duration of the studied earthquakes is presented in Figure 8. It was established that fault length correlates positively to earthquake duration as evidenced by the value of coefficient of determination (R^2) after running a regression analysis. The regression analysis result gave a high coefficient of determination value of 0.81 (Figure 8).

Focal depth and earthquake duration: Focal depth is one of the crucial parameters in earthquake engineering studies. The extent of the shaking due to earthquakes depends on whether the earthquake is shallow or deep seated. From this background, the study attempted to assess the impact of focal depth on earthquake duration. The analysis conducted revealed that there is an extremely low correlation between focal depth and earthquake duration with a coefficient of determination at $R^2=0.03$ (Figure 9).

Focal depth times fault length and earthquake duration: According to Salmon et al., earthquake duration increases with increasing distance from the recording site to the zone of energy release (focus) of the causative earthquake, substantiated that this phenomenon is due to the presence of slowly propagating surface waves arriving from long distance as well as of late time indirect body wave arrivals due to increased numbers of refractions, reflections, and scatterings of body waves over the longer travel path. Based on
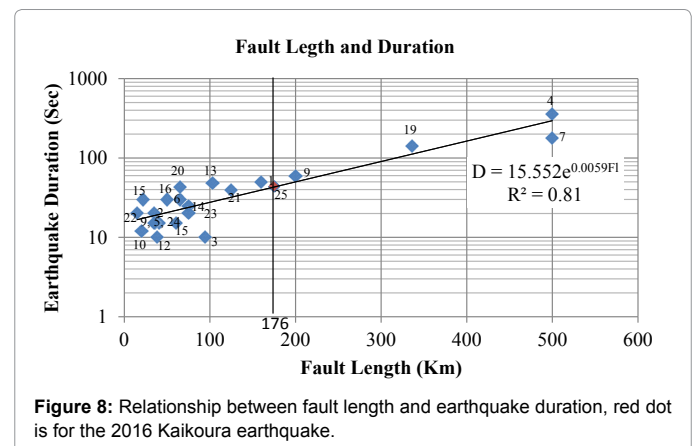

Figure 8: Relationship between fault length and earthquake duration, red dot is for the 2016 Kaikoura earthquake.
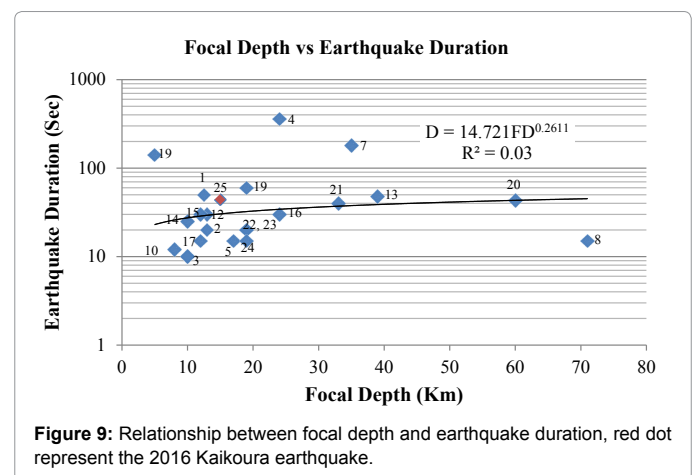

Figure 9: Relationship between focal depth and earthquake duration, red dot represent the 2016 Kaikoura earthquake.

this discussion, efforts were made to establish the impact of the focal distance multiplied by fault length, on earthquake duration. It can be observed in Figure 10 that there is a moderately strong relationship between focal depth times fault length and duration of earthquake ground motion. The correlation value obtained from the relationship is R^2=0.61 which shows a significant influence.

Earthquake duration and landslides: Earthquakes are among the most destructive natural hazards on Earth. Normally when an earthquake occurs, assessment of the extent of its damage is in relation to fatalities, displacement of people and structures. But, earthquakes can also cause a slope to become unstable by the inertial loading it imposes or by causing a loss of strength in the slope materials thereby inducing failures. In this regard, we investigated into the influence of earthquake duration on landslides induced by the major earthquakes.

Earthquake duration and reported number of landslides: In the preceding section, it has been found that duration of strong ground motion increases with increasing magnitudes (Figure 1). Corollary, it could be anticipated that the number of landslides generated by an earthquake should be proportional to the duration of the ground motion. However, the results presented in Figure 10 indicate that number of landslides produced during and/or after an earthquake do not necessarily increase with increasing duration. In fact, majority of the devastating earthquakes occurred in a short period with a great deal of damage. Most investigated landslides inducing earthquakes between 1998 and 2015 lasted for ≤ 60 seconds (Figure 11). This trend leads us to a conclusion that the build-up power from the earthquake attenuates with time.

Earthquake duration and area affected by landslides: In the scope of this study, a special attention was given to the influence of duration of strong earthquake ground motions on surface response to rupture and damage in relation to landslides. This is a shift from studies that have extensively researched on and acknowledged the influence of duration of strong earthquake ground motion on structural response. The results on the relationship are presented in Figure 12. It can be observed in Figure 12 that there is a moderately strong positive correlation obtained between duration of earthquake ground motion and square root of the area affected by EI landslides. The correlation value of R^2=0.61 indicates that area affected by landslides is to some extend determined by earthquake duration. Another observation to draw from the outcome is that most earthquakes do not last long but their impacts are enormous.

Discussion

In this study, data for major earthquakes (Mw ≥ 6.6) that induced landslides between 1998-2015 in the world were investigated. The study came up with relationships between earthquake duration and other seismic parameters: magnitude, peak ground acceleration, focal depth, fault length and focal depth times fault length in relation to the number and area affected by landslides generated during and/after the earthquakes.

It has been established from the analysis that the duration of earthquakes is directly proportional to the earthquake magnitude in the sense that an earthquake with a higher magnitude tends to have a long duration of strong ground motion. This substantiates and validates the findings of Trifunac and Salmon et al. Additionally, the relation established between the earthquake duration and magnitude for the major earthquakes is noted to be in agreement with Antikaev and Shebalin and Schteinberg's equation in the sense that the trend of the relations are conformable (Figure 5). Given the fact that earthquake duration is anticipated to vary in distinctive areas, regardless of equal magnitude, due to; different local site conditions and propagation path of waves, the positive correlation between the two variables proffers a conclusive indication of the influence of magnitude on earthquake duration. However, the results for PGA against earthquake duration indicate that there is no proportional correlation between the two variables. It has been noted that earthquakes that registered a high PGA do not have a reciprocal high duration. This outcome emanates from the choice of the representative PGA of the earthquake shaking in which only the peak value was taken into consideration. Thus, the PGA value does not provide the total acceleration content of the record to
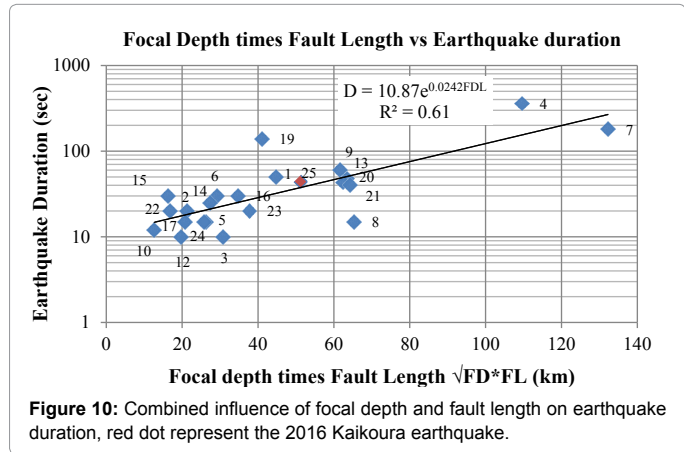

Figure 10: Combined influence of focal depth and fault length on earthquake duration, red dot represent the 2016 Kaikoura earthquake.
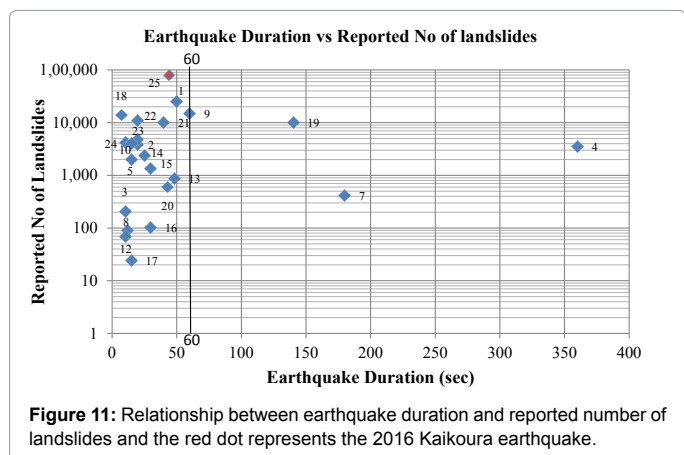

Figure 11: Relationship between earthquake duration and reported number of landslides and the red dot represents the 2016 Kaikoura earthquake.
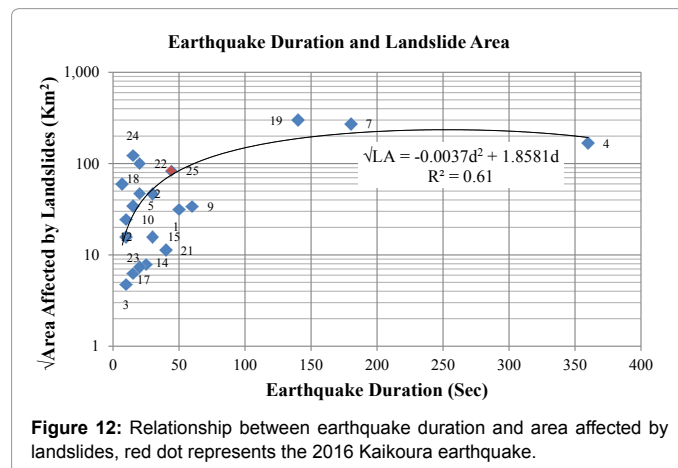

Figure 12: Relationship between earthquake duration and area affected by landslides, red dot represents the 2016 Kaikoura earthquake.

give a complete characterisation of the shaking energy during the time of an earthquake in relation to its impact of inducing landslides. In this regard, it is suggested that a good relationship of the two variables may be achieved if comparisons are made in the same environment settings of earthquake occurrence.

It was also established that fault length correlates positively to earthquake duration. Major earthquakes which had extended fault length registered longer duration of earthquake ground motion. This is arguably, a direct consequence of energy attenuation which tends to slow the rate of travel of the seismic waves as they get dissipated through the rupture. However, it came out that earthquake duration is not essentially affected by focal depth as it could be anticipated although the earthquakes at greater depth have somewhat high duration. Nevertheless, the combined effect of focal depth and fault length was found to be positively correlated to duration of earthquake.

An assessment of the influence of duration of strong earthquake ground motion on land sliding revealed that number of landslides produced during and/or after earthquakes do not necessarily augment proportionally to earthquake duration. This could be attributable to the influence of other causative factors, such as geology and relief, which play key roles in inducing landslides during and/or after an earthquake. Nonetheless, majority of the investigated earthquakes that triggered landslides between 1998 and 2015 lasted for ≤ 60 seconds and caused enormous damage. The extent of damage by EI landslides when evaluated using a relationship between earthquake duration and area affected by landslides gave a moderately strong positive correlation with a coefficient of determination of $R^2=0.61$. This indicates that the extent of the damage by the resulting landslides after and/or during an earthquake is somewhat influenced by earthquake duration. This is to say that elongated ground shaking culminates into perpetual weakening of the slopes over relatively a large area. When the movement of the loose materials is finally triggered the scale of coverage gets correspondingly large. For instance, after the Chi-Chi earthquake some affected parts did not cause imminent landslides but the shaking impact as a function of time caused slopes to become unstable thereby acting as a catalyst to landslides during the subsequent heavy rains brought by typhoon Toraji. It is also fascinating to note that the reconnaissance results on the area affected by the landslides after the Kaikoura New Zealand earthquake, which is 7,000 km², falls close to the regression line of the parametric relation after taking the root value thereby validating the relationship.

Conclusion

This review paper, unlike majority of the studies which extensively researched on the impact of duration of strong earthquake ground motion on structural response, deviated from the norm by focussing on the influence of duration of earthquake ground motion on slope stability in relation to landslides. The following points have been drawn from the study:

Magnitude and fault length have a strong positive correlation with earthquake duration.

PGA and focal depth have a negligible correlation with earthquake duration.

The relationship between focal depth times fault length and duration of earthquake ground motion yielded a moderately strong positive correlation.

Reported number of landslides produced during and/or after an earthquake do not necessarily augment with increasing duration, however most of the landslides occurred at an earthquake duration of ≤ 60 seconds.

Duration of earthquake ground motion yielded a moderately strong positive correlation against square root of the area affected by EI landslides.

Most of the seismic parameters of the recent Kaikoura earthquake, New Zealand: PGA 1.3, Mw 7.8, intensity of IX, focal depth 15 km and estimated seismic shaking of 44 sec, have surely contributed to the multiple landslides (80,000-100,000) that have enormously affected the Kaikoura area (see Appendix).

Acknowledgements

References

1. Michael WS, Steven AS, Robert PK (1992) Strong Motion Duration and Earthquake Magnitude Relationships. Carlifornia: Ijwrence Livermore National Laboratory.

2. Trifunac MD, Todorovska MI (2012) Duration of strong ground motion during Northridge, California, earthquake of January 17, 1994. Soil Dynamics and Earthquake Engineering 38: 119-127.

3. Bommer JJ, Martinez-Pereira A (1999) The effective duration of earthquake strong motion. Journal of Earthquake Engineering 3: 127-172.

4. Trifunac MD, Brady AG (1975) A study on the duration of strong earthquake ground motion. Bulletin of the Seismological Society of America 65: 581-626.

5. Bolt BA (1973) Duration of strong ground motion. Proceedings from the World Conference on Earthquake Engineering 5: 1304.

6. Housner GW (1965) Intensity of earthquake ground shaking near the causative fault. Proceedings from the World Conference of Earthquake Engineering 3.

7. Vanmarcke EH, Lai SSP (1980) A measure of duration of strong ground motion. Proceedings from the World Conference of Earthquake Engineering 7: 537.

8. Lee J (2015) Strong Ground Motion Durations of Directivity Motions. 6th International Conference on Earthquake Geotechnical Engineering. Christchurch, New Zealand.

9. Raghunandan M, Liel AB (2013) Effect of ground motion duration on earthquake-induced structural collapse. Structural Safety 41: 119-133.

10. Snaebjornsson JT, Sigbjornsson R (2008) The duration characteristics of earthquake ground. World Conference on Earthquake Engineering.

11. Hernandez B, Cotton F (2000) Empirical determination of the ground shaking duration due to an earthquake using strong motion accelerograms for engineering applications. The World Conference on Earthquake Engineering 2254.

12. Reinoso E, Ordaz M, Guerrero R (2000) Influence of strong ground motion duration in seismic design of structures. 12th World Conference on Earthquake Engineering 1151.

13. Mccann JM, Shah H (1979) Determining strong-motion duration of earthquakes. Bulletin of the Seismological Society of America 69: 1253-1265.

14. Sepúlveda SA, Serey A, Lara M, Pavez A, Rebolledo S (2010) Landslides induced by the April 2007 Aysén Fjord earthquake, Chilean Patagonia. Landslides 7: 483-492.

15. Mahdavifar MR, Solaymani S, Jafari MK (2006) Landslides triggered by the Avaj, Iran earthquake of June 22, 2002. Engineering Geology 86: 166-182.

16. Taflampas IM, Spyrakos CC, Koutromanos IA (2009) A new definition of strong motion duration and related parameters affectingthe response of medium-long period structures. Soil Dynamics and Earthquake Engineering 29: 752-763.

17. Arias A (1970) A measure of earthquake intensity. Seismic Design for Nuclear Power Plant, Hansen RJ (ed.) MIT Press: Cambridge.

18. Somerville PG, Smith NF, Graves RW, Abrahamson NA (1997) Modification of empirical strong ground motion attenuation relations to include the amplitude

and duration effects of rupture directivity. Seismological Research Letters 68: 199-222.

19. Papazachos BC, Papaiannou CA, Margaris VN, Theodulidis NP (I992) Seismic hazard assessment in Greece based on strong motion duration. Proceedings Tenth World Conference on Earthquake Engineering 2: 425-430.

20. Sarma SK, Casey BJ (I990) Duration of strong motion earthquakes. Proceedings Ninth European Conftmmx on Eadquake Engineering 1: 174-183.

21. Mohraz B, Peng MH (I989) The use of low-pass filter in determining the duration of strong ground-motion. Journal Pressure Vessels and Piping Division ASCE 182: 197-200.

22. Kawashima K, Aizawa K (19891) Bracketed and normalized duration of earthquake ground acceleration. Earthaquake Engeneerin and Structural Dynamics 18: 1041-1051.

23. Xie LL, Zhang X (I988) Engineering duration of strong-motion and its effect on seismic damage. Proceedings Ninth World Conjerence on Earthquake Engineering, Tokyo-Kyoto 2: 307-312.

24. Zhou Y, Katayama T (1985) Effects of magnitude, epicentral distance and site conditions on the duration of strong ground motion. Seisan Kentyu 37: 1-13.

25. Shahabi M, Mostaghel N (1984) Strong ground motion duration and effective cyclic acceleration. Proceedings Eighth World Conference on Earthquake Engineering 2: San Francisco, 843-850.

26. Zahrah T, Hall WJ (1984) Earthquake energy absorption in SDOF structures. Journal of Structural Engineering Division 110: 1757-1772.

27. McGuire RK, Barnhard TP (1979) The usefulness of ground motion duration in prediction of severity of seismic shaking. Proceedings Second US National Conference on Earthquake Engineering, Stanford 713-722.

28. Saragoni GR (1977) The α β γ method for the characterization of earthquake accelerograms. Proceedings Sixth World Confemce on Earthquake Engineering, New Dehli 357-362.

29. Trifunac MD, Westermo B (1977) A note on the correlation of frequency-dependent duration of strong earthquake ground motion with the Modified Mercalli intensity and the geologic conditions at the recording stations. Bullettin of Seismological Society of America 67: 917-927.

30. Hisada T, Ando H (1976) Relation between duration of earthquake ground motion and magnitude. Kajima ICT, Japan.

31. Donovan NC (1972) Earthquake hazards for buildings. Building Science Series 46: 82-111.

32. Kobaydu Y (1971) Effects of earthquakes on ground. Journal of Physical Earth 19: 231-241.

33. Ambraseys NN, Sanna SK (1967) Response of earth dams to strong earthquakes. Ge'otechnique 17: 181-283.

34. Rosenblueth E, Bustamante JI (1962) Distribution of structural response to earthquakes. Journal Engineering and Mechnic Division 88: 75-106.

35. Tsirel SV, Zuev BY, Pavlovich AA (2012) The Influence of Earthquakes on Open-pit Slope Stability. International Journal of Geosciences 3: 799-808.

36. Aydan O, Ulusay R (2015) A quick report on the 2015 Gorkhan (Nepal) Earthquake and its geo-engineering aspects. International Association for Engineering Geology and the Environment 10: 25-35.

37. Tang C, Ma G, Chang M, Li W, Zhang D, et al. (2015b) Landslides triggered by the 20 April 2013 Lushan earthquake, Sichuan, Engineering Geology 187: 45-55.

38. Chakraborty I, Ghosh S, Bhattacharya D, Bora A (2011) Earthquake induced landslides in the Sikkim-Darjeeling Himalayas - An aftermath of the 18th September 2011 Sikkim earthquake. Soil Dynamics and Eartquake Engineering 7: 1-8.

39. Hashmoto M, Fukushima Y, Takada Y (2012) Coseismic deformations of the 2011 Tohoku, Japan, earthquake and triggered events derived from Alos/Palsar. Disaster Prevention Research Institute 661, 5-9. Fringe 2011 Workshop.

40. Xu C, Xu X (2014a) Statistical analysis of landslides caused by the Mw 6.9 Yushu, China, earthquake of April 14, 2010. Natural Hazards 72: 871-893.

41. Gorum T, van Westen CJ, Korup O, van der Meijde M, Fan X, et al. (2013) Complex rupture mechanism and topography control symmetry of mass-wasting pattern, 2010 Haiti earthquake. Geomorphology 184: 127-138.

42. Delgado J, Garrido J, López-casado C, Martino S, Peláez JA (2011) On far field occurrence of seismically induced landslides. Engineering Geology 123: 204-213.

43. Umar Z, Pradhan B, Ahmad A, Neamah M, Shafapour M (2014) Earthquake induced landslide susceptibility mapping using an integrated ensemble frequency ratio and logistic regression models in West Sumatera Province, Indonesia. Catena 118: 124-135.

44. Qi S, Xu Q, Lan H, Zhang B, Liu J (2010a) Spatial distribution analysis of landslides triggered by 2008. 5 . 12 Wenchuan. Engineering Geology 116: 95-108.

45. Yagi H, Sato G, Higaki D, Yam M (2009) Distribution and characteristics of landslides induced by the Iwate-Miyagi Nairiku Earthquake in 2008 in Tohoku District, Northeast Japan. Landslides (2009). Landslides 6: 335-344.

46. Collins BD, Kayen R, Tanaka Y (2012) Spatial distribution of landslides triggered from the 2007 Niigata Chuetsu - Oki Japan Earthquake. Engineering Geology 127: 14-26.

47. Wartman J, Cox B, Meneses J, Moreno V, Olcese M (2008) Landslides triggered by the 15 August 2007 M8 . 0 Pisco, Peru earthquake. Geophysical Research Abstracts 10.

48. Harp BEL, Crone AJ (2006) Landslides triggered by the October 8, 2005, Pakistan. Earthquake and associated landslide-dammed reservoirs. Geomorphology 94: 1-9

49. Kieffer DS, Eeri M, Jibson R, Eeri M, Rathje EM, et al. (2006) Landslides Triggered by the 2004 Niigata Ken Chuetsu, Japan, Earthquake. Earthquake Spectra 22: 47-73.

50. Keefer DK, Wartman J, Navarro C, Rodriguez-marek A, Wieczorek GF (2006) Landslides caused by the M 7.6 Tecomán, Mexico Earthquake. Engineering Geology 86: 183-197.

51. Bouhadad Y (2010) Earthquakes-induced landslides in Algeria: The Laalam, March 20th, 2006 earthquake. Earthquake Engineering Center 12: 5-9.

52. Jibson RW, Harp EL, Schulz W, Keefer DK (2004) Landslides triggered by the 2002 Denali fault, Alaska, earthquake and the inferred nature of the strong shaking. Earthquake Spectra 20: 669-691.

53. Garc-Rodriguez MJ (2010) Assessment of earthquake-triggered landslide susceptibility in El Salvador based on an Artificial Neural Network model. Natural Hazards and Earth System Science 10: 1307-1315.

54. Khazai B, Sitar N (2003) Evaluation of factors controlling earthquake-induced landslides caused by Chi-Chi earthquake and comparison with the Northridge and Loma Prieta events. Engineering Geology 71: 79-95.

55. Parise M, Jibson RW (2000) A seismic landslide susceptibility rating of geologic units based on analysis of characteristics of landslides triggered by the 17 January, 1994 Northridge, California earthquake. Engineering Geology 58: 251-270.

56. Meunier P, Hovius N, Haines AJ (2007) Regional patterns of earthquake-triggered landslides and their relation to ground motion. Geophysical research letters 34: 1-5.

57. Keefer DK (2000) Statistical analysis of an earthquake induced landslides distribution - the 1989 Loma Prieta , California event. Geology Enginnering 58: 231-249.

58. Lin CW, Liu SH, Lee SY, Lin CC (2006) Impacts of the Chi-Chi Earthquake on subsequent raifall-induced landslides in central Taiwan. Engineering Geology 89: 87-101.

59. Geological Nuclear Science (GNS) (2016).

60. USGS (2016).