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Determination of the Volume of Debrisfrom Yingxiu Landslides, Southwest China: Geomorphological and Field Observation Approaches

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Abstract

The May 12th 2008earthquake of magnitude 8.0 on the Richter scale,whichstruck the Yingxiu catchment, southwest China, triggered co-seismic landslides. Of these landslides, 41 were mapped and characterized during fieldwork, based on geomorphology and field observation. The landslide debris became a time bomb for the August 14th 2010 rain-induced debris flow that ravaged the Yingxiu community, leading to death toll of 56 people and destruction of properties worth millions of Chinese Yuan.This research was aimed at determining the volume of materials moved duringthe landslides. This may give an approximate value of the volume of the landslide debrisstill left in the catchment. This indicates the need for the assessment of the potential hazard of the catchment. Theknowledge of the volume of materials moved can also be used in the calibration of landslides or debris flow model, especially in a data poor environment.Based on geomorphological mapping and field observation used, the volume of materials moved during the Yingxiu landslideswas 1,538,475.8 m^3.

Keywords: landslides, geomorphology, debris, hazard, field observation

1. Introduction

The Monday, May 12, 2008, mega-earthquake of magnitude 8.0 that struck the Yingxiu area, southwest China was catastrophic. This high intensive earthquake disturbed the slope bedrock and created an abundance of loose landslide debris on the slopes and gullies and maybe reactivated old landslides. This affects the stability of these slopes for a long period of time.

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The debris (materials moved) later serves as source material for rainfall-induced debris flows as reported by Lin *et al.* (2010) and Tang *et al.* (2011). Landslides are among the hazards on earth that cause the most casualties and damages (Van Asch *et al*., 1999); they come in various types, classified for instance by their type of movement, speed of movement and volume (Varnes, 1978). In steep terrain or mountainous environment, they often occur because of heavy rainfall that triggers ground level rise/fluctuations, leading to lowered cohesion and instability. Therefore, one often sees landslides occurring in parallel with typhoons and hurricanes, or during the monsoon season. A second major trigger can be earthquakes, most especially along fault lines. Human activities such as road constructions, quarrying, building of houses and farming along the foot of mountainous zone may also trigger landslides (Varnes, 1978).

To discern the actual factors that initiate landslides events is often difficult (Crozier, 1986 in Van Beek, 2002); the intrinsic factors change most of the times only gradually over time and can be considered as preparatory factors whereas the extrinsic factors are transient and can be regarded as triggers, that is, the disturbance that initiates slope instability or failure.Van Asch *et al* (1999) discussed some key factors controlling the occurrence and distribution of shallow landslides which can be divided into two categories,namely the static variables and the dynamic variables. For the static variables, they reported that soil properties (thickness or depth, permeability and material cohesion, seepage in the bed rock, topography (elevation), slope, areas of convergence and divergence are the important factors that control the occurrence and distribution of landslides. On the other hand, with respect to the dynamic variables, degree of saturation of soil, cohesion due to the presence of roots and/or partial saturation, and landuse/landcover, control the occurrence and distribution of landslides.

The assessment of the risk due to landslide, including the determination of the volume of materials moved, is critical for the prediction of future hazard events in order to protect people and their property, and to estimate any future losses or damages.

In addition, it forms the basis for risk management which comprises the prevention, preparedness, relief, and recovery of people and property from the hazards (Van Westen, 2010).Determining the volume of landslide materials moved is critical formitigation and prevention, thus, a measure needed to reduce the risk of landslide.Risk is defined as the probability of losses of elements (people or property) vulnerable to hazards and is quantitatively expressed by the equation (Van Westen, 2010):

$$\text{Risk} = \text{Hazard} * \text{Vulnerability} * \text{Elements at risk} \qquad \ldots(1)$$

When the conditional probability of landslides risk is taken into account, equation 1 can be re-written as (Van Westen, 2010):

$$RS = (PT * PS * PR) * V * A \qquad \ldots (2)$$

Where RS is the specific annual risk expressed in monetary values of an element at risk vulnerable to a landslide, PT is the temporal probability of the landslide occurrence, PS is the spatial probability of the landslide occurrence, PR is the conditional probability of run-out with a landslides having a specific type and volume, V is the physical vulnerability of the element at risk to the landslide event and A is the monetary value of the element at risk. (PT * PS * PR) can be described as the hazard component of risk or simply the landslide hazard. Thus, the landslide hazard has a time component and a magnitude component. The time component is the probability or likelihood of landslide occurring at a specific time in the future and is expressed as an annual probability or the chance of an event occurring within a specific return periods like 5, 10 , 50 or 100 years.

Determination of volume of materials moved during the Yingxiu landslides is the focus of this research. This is very pertinent, becauseit gives an approximate idea of the volume of the debris (from the landslides body) still left in the catchment and thus, an indicator for potential future hazard assessment. Moreover, the knowledge of the volume of materials moved can be used in the calibration of landslides or debris flow model, especially in a data poor environment.The evaluation of the volume of materials moved from the landslide scar was based on geomorphological mapping and field observations. Field estimations of landslides volume of materials moved is not entirely a new concept.

Cardinali*et al*. (2002) estimated landslides volume from field observation based on landslides type, intensity and expected velocity. The volume of the materials moved or generated for this study wasconducted using the formula adopted from Ayonghe and Ntasin (2008).

2. Geology and Geography of the Study Area

The Yingxiu catchment is located in the Sichuan Province, Southwest China(Figure1). The catchment has an area of 5.35 km^2, length of 3.55 km. The area is underlain by granitic rocks, which are deeply fractured and highly weathered. In Figure 1, the areas affected by landslides are shown in white; while the green represents vegetation and the red thin line shows the catchment boundary.The geological structure and the strike of the rock strata show a NE–SW orientation. Tang *et al*. (2011) reported that the Yingxiu-Beichuan faults ruptured during the Wenchuan earthquake and runs through the study area. The area is situated in the typical humid subtropical, monsoon climate zone with an annual average temperature of 12.9°C. The annual average precipitation over a period of 30 years is 1,253 mm, with a highest recorded annual precipitation of 1,688 mm in 1964.The maximum recorded rainfall intensity was 269.8mm/day in 1964 (Tang *et al.,* 2011). The rainfall is largely concentrated in the period from June to September. On the average, 70% of the annual precipitation falls during this period. The catchment has a very steep slope and rugged terrain. The highest point on the catchment is over 2,200m above sea level, while the lowest point at the valley floor is about 800m above sea level. The area has a uniform vegetation cover except for areas where the landslides have distorted the vegetation.

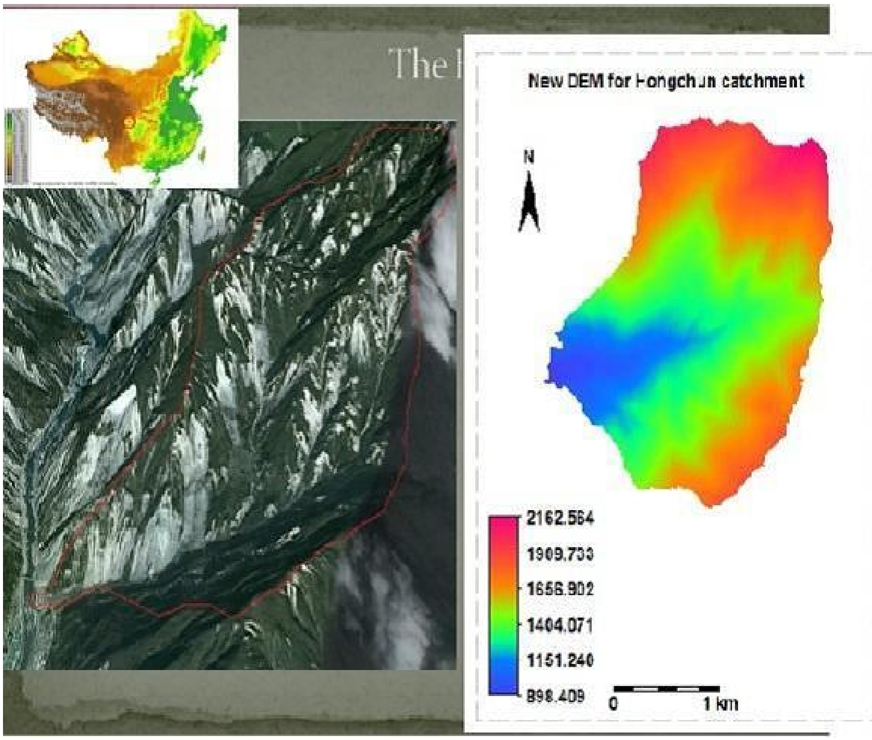

Figure 1: Satellite Imageand Digital Elevation Modelof the Yingxiucatchment, South West China

3. Methodology

The method of investigation consisted of fieldwork and geomorphological mapping.An intensive fieldwork was carried out for two weeks at Yingxiu, China. During the period, information on the co-seismic landslides were mapped and characterized. Geomorphological mapping of the area was carried out to determine the geological and environmental factors that must have caused the landslides. Attention was paid on the rock type, fractures, degree of slope and determination of the volume of materials moved during the landslides.

In the determination of the volume of materials moved in a landslide, one approach is to subtract the prior Digital Elevation Model (DEM) of the landslides from the DEM after the landslides using appropriate Software.

However, the approach used in this research was prompted by lack of digital elevation models (DEM) after the landslides. But, the results of this method gave a good idea of the volume of debris resulting from the earthquake induced landslides. In a data poor environment it may be a very useful tool.In calculating the volume of materials moved during the landslides, the width, heightand lengthof landslides scar were determined using measuring tape in accessible areas of the catchment. However, visual estimation was used in inaccessible areas. The average of each of the measured parameters were then determined and used for calculation. The volume of the materials moved or generated was obtained using the formula adopted from Ayonghe and Ntasin (2008) in which:

$$V= 1/6\pi \ (H *W*L) \qquad \dots (3)$$

Where V = volume of the materials generated from the landslides, Π = pie (3.142), H= height of the landslides scar, W= width of the landslides scar, L= length of the landslides scar

4. Results and Discussion

4.1 Field Observation

The materials from the landslide were made up of large to small debris/fragments of the rocks (Figure 2 and 3) which were mainly granite. Granitic rock characterizes the Yingxiu catchment, which may have accounted for the uniform texture of soil found in the catchment. The soil composed mainly of sandy-loamy soil with pockets of clay found in the lower part of the catchment. The clay may have been formed from the weathering product of the feldspar component of the graniticrocks. Flakes of shiny minerals, suspected to be micacomponents of the granitic rocks were seen scattered all over the place. The materials were deposited along the sliding path and the size of the materials decreases from top to bottom.

Figure 2: Large to small debris in Yingxiu Catchment

The materials might have been sorted during the transportation of the materials and thus have a coarsening up sequence. The materials that were moved to the foot of the hill were deposited in the then existing river valley and banks. Some of the debris in the catchment occurs as landslide bodies. During the field mapping, it was observed that large amounts of the landslide debris were still lying in the channels in the catchment. Some of the check dams constructed in the catchment as a mitigation measure to reduce the materials from further causing harm were overtopped by the debris. Human activity like farming no longer takes place in the catchment at the moment as a safety measure. This was in line with the directive issued from the Chinese Government after the earthquake triggered landslide struck in what is known as multi-hazard scenario, thus producing a domino effect.

Field evidence indicated that the rock in the catchment is mainly granitic. The rocks were highly fractured. The deep and penetrating fractures in the rocks must have brought about gradual weathering which resulted in the slow but steady decrease in the strength of the materials thus increasing the likelihood of sliding. However, the earthquake triggered the landslides in the catchment but with the other precursor actively acting in the catchment, led to the landslides that occurred. Water from the antecedent rainfall saturated the landslide bodies and also acted as a lubricant for the materials to move downslopes.

Figure 3:DebrisintheYingxiu Catchment

4.2 Morphological Factor

Slope and topography are seen as the morphological precursor that aided the co-seismic landslides ofYingxiu catchment (Figure 4). Field measurements indicated that the area is characterized by steep slope ranging from 10° to 27°, deep valleys and generally rugged relief. This type of slope angle greatly affects the relative magnitude of the driving force on slopes. As the angle of potential slip plain increases, the driving force also increases, assuming that, other landslide causing factors to be constant, landslides should be most frequent on steep slopes. A study of landslides that occurred during the two raining seasons in California's San Francisco Bay area established that 75 to 80 percent of landslides activities is closely associated with urban areas on slopes greater than 15% or 8.5 (Nilson*et al,*1976).

Figure 4:Steep Slopes that Aided Movement of Materials During theYingxiu Landslide

4.3 Determination of Materials Moved

In calculating the volume of materials moved during the landslides, the average width of 8m, average length of 548.8m and average height of 16.32m were determined using measuring tapes and visual estimation of inaccessible area of the catchment. Thus the volume of the materials moved using the equation 3 is given by

$$\text{Volume, } V = 1/6\pi\ (H * W * L)$$
$$= 0.5237(16.32*8*548.8)\ m^3 = 37523.8m^3.$$

Therefore, the total volume of materials moved or generated from the 41 landslides was37523.8 *41= **1,538,475 m^3**

This value gives a rough idea of the volume of the landslide materials moved and indicates potential for future landslide hazard assessment. The evaluation of the landslides volume was based on field observation of the deposit volume, detachment area, deposit height, deposit base, morphology and geometry.

The total estimated volume of the landslides materialsmoved from the field observation did not agree with the figure got from the field interview with Mr. Wang, the chief supervisor of the HUADI Construction Company at the Yingxiu catchment site on 2nd October, 2011 at 2pm. According to him, 2.25 million cubic metreof landslide materials were determined for the catchment. This accounted for a difference of 711,524 cubic metre. This may be due to differences in approaches and the methods used in the estimation of the materials moved. However, the method used by the HUADI Construction Company to determine the volume of materials was not disclosed to the researcher and thus unknown.

In addition, the approach used in this research was prompted by lack of a “good”Digital elevation model (DEM) after the earthquake. This is because, the subtraction of Digital elevation model (DEM) prior to and after the landslide would have given an idea of the volume of debris generated and thus, the volume of materials moved during the landslides would have been determined. However, the geomorphological and field mapping approaches gave at least, a rough idea of the volume of debris resulting from the earthquake induced landslides. In a data poor environment, the knowledge of the volume of materials moved can be used in the calibration of modelling of landslides or debris flow.

5. Conclusion

The volume of landslide materials moved from the landslide scar has been determined based on geomorphological mapping and field observation of the deposit volume, detachment area, deposit height, deposit base, morphology and geometry. The volume of materials moved by the landslide was **1,538,475** m^3.Thus,this put the catchment at risk for future debris flow. The results of this method give a rough indication of the volume of debris resulting from the earthquake induced landslides. In a data poor environment where post DEM data is lacking, it may be a very useful tool.It also can be used in theCalibration of landslides or debris flow model.

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