Vol. 87 Supp. ACTA GEOLOGICA SINICA (English Edition) June 2013
http://www.geojournals.cn/dzxben/ch/index.aspx http://mc.manuscriptcentral.com/ags

WANG Tao, WU Shuren, SHI Jusong, XIN Peng, 2013. Application and Validation of Seismic Landslide Displacement Analysis Based on Newmark Model: A Case Study in Wenchuan Earthquake. *Acta Geologica Sinica* (English Edition), 87(supp.): 393-397.

Application and Validation of Seismic Landslide Displacement Analysis Based on Newmark Model: A Case Study in Wenchuan Earthquake

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1 Introduction

Nowadays, there is no a comprehensive model applicable for regional hazard analysis of all possible seismic landslide types (Miles et al., 2009). While the regional seismic landslide displacement and hazard analysis method based on Newmark permanent displacement model (Newmark, 1965) is proved to be most extensively applied. This method is easier to apply than numerical simulation and provides more useful information of seismic slope performance than pseudostatic analysis (Jibson, 2011). Furthermore, this method has been gradually improved in seismic landslide displacement studies (Jibson, 1993; Jibson et al., 2000; Refice et al., 2002; Jibson, 2011).

2008 Wenchuan M_w 7.9 earthquake induced tens of thousands landslides resulting in more than 20 thousand deaths (Huang, 2009). Studies on seismic landslide displacement and hazard based on Newmark permanent displacement model were carried out after the earthquake (Zhao et al., 2012; Wang et al., 2013). However, the method's validation was scarcely reviewed. Actually, the commonly used seismic landslide displacement analysis method with Newmark model was developed due to 1994 Northridge earthquake (Jibson et al., 2000); such a method maybe not surely quite applicable for other earthquakes. For the reason, this article firstly analyzes seismic landslide displacement in Wenchuan earthquake area with Newmark model, secondly takes 4 typical river basins along the seismic faults in which seismic landslides intensively distribute as examples, precisely interprets landslides with object oriented feature extraction and man-machine interactive methods, finally quantitatively compares the spatial matching extent of seismic landslide displacement analysis results and realistic landslide distribution with Area Under Curve method, further analyzes the applicability and limitation of seismic landslide displacement analysis with Newmark model and provides suggestions.

2 Seismic landslide displacement analysis and precise interpretation

2.1 Seismic landslide displacement analysis with Newmark model

Among various landslide types induced by Wenchuan earthquake, the shallow rock falls and debris slides distribute most widely . Meanwhile the Newmark model is a applicable for permanent displacement analysis of rigid block's translational and rotational sliding under the seismic load (Jibson, 1993). So the displacement analysis method with Newmark model may ensure the reliability of major shallow landslides analysis during Wenchuan earthquake. The procedure of this method consists of 4 basic steps (Fig. 1) (Wang et al., 2013): (1) Calculating regional slope static safety factor F_s with slope geometrical data and physical-mechanical strength parameters of rock-soil mass; (2) Calculating slope critical acceleration a_c under seismic limit equilibrium with F_s and topographic slope; (3) Calculating regional ground motion Arias

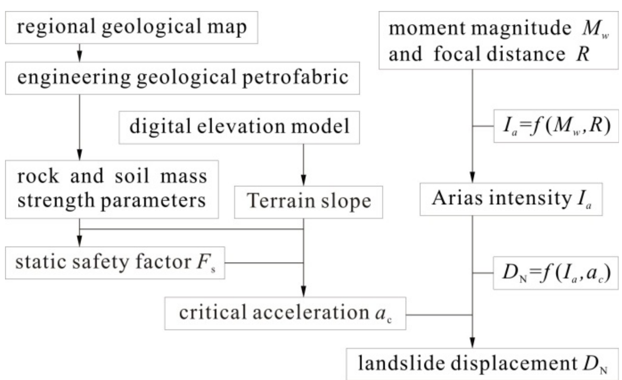

Fig. 1 Flow chart of seismic landslide displacement analysis based on Newmark model in Wenchuan earthquake

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intensity I_a distribution with moment magnitude M_w and hypocenter distance R; (4) Calculating regional slope permanent sliding displacement D_N under seismic load with a_c and I_a, and classifying the landslide hazard level with D_N.

Wenchuan earthquake severely afflicted area along Longmenshan seismic faults is chosen as analyzing area, about 1.33×10^4km^2, rectangle shaped (Fig. 2). Regional long axis direction of the area is NE43° which is almost parallel to Longmenshan faults. Regional topographic relief is significant of which elevation varies 505m~5030m. The Longmenshan alpine valley area and alluvial plain respectively takes up 90% and 10% of total area. About 10 river basins are vertically intersect with Longmenshan faults. During Wenchuan earthquake, most of seismic landslides distributed in this area (Huang et al., 2009); meanwhile landslides along major river banks were specially intensive.

In order to analyze seismic landslide displacement, we prepare necessary spatial datum mainly including nearly real-time ground motion parameters, engineering geological petrofabric and digital elevation model etc.. The basic earthquake parameters are obtained from U.S. Geological Survey (USGS) and China Earthquake Administration (CEA) . The moment magnitude of Wenchuan earthquake is M_w 7.9; Linear hypocenter depth is about 15 km below ground surface (Wang, 2010). Engineering geological petrofabrics are digitalized from regional geological map of 1: 50,0000 scale. Regional lithology types are classified into 5 petrofabrics. Physical and mechanical strength parameters of each petrofabric is mainly obtained from empirical values of rock-soil mass basic quality classification handbook and standard (Ministry of water conservancy and hydropower planning and Design Institute et al., 2009; Lin, 1996). Topographic slope data is calculated from digital elevation model (DEM) of 25m×25m resolution ratio. Since the slope less than 10° scarcely form landslide, the displacement of such area is not analyzed. The ground motion Arias intensity is simulated based on empirical equation with moment magnitude M_w and hypocenter distance R (Keefer et al., 1989).

According to procedure of seismic landslide displacement analysis method (Fig. 1), considering combining inducing effects of rainfall and seismic load during Wenchuan earthquake, we calculate sliding displacement of regional shallow saturated slope that greater than or equal to 10° in earthquake area (Fig. 3). In order to ensure the analysis process accurately describe the representative landslide type, The average thickness of

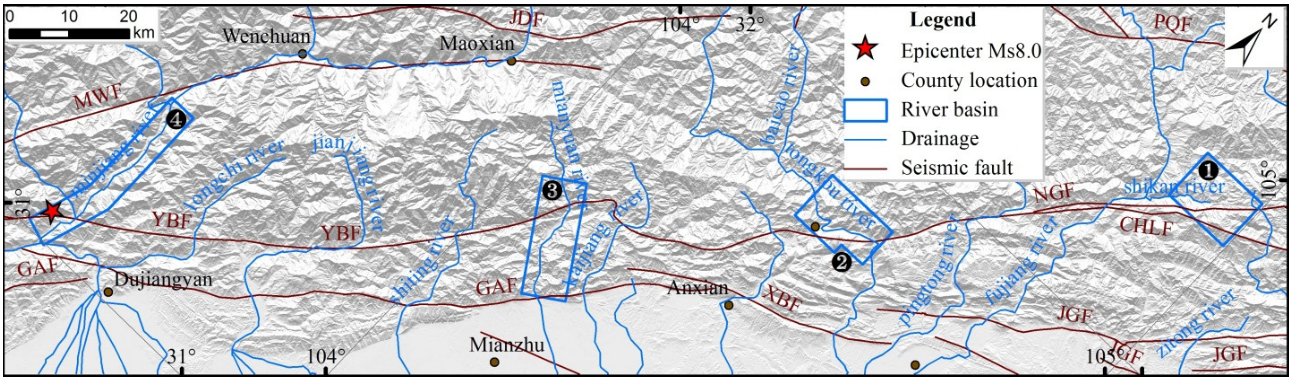

Fig. 2 Seismic faults and typical river basins distribution in Wenchuan earthquake area

Longmenshan front-rang faults: GAF(Guanxian-Anxian fault), XBF(Xiaobachang fault), JGF(Jiangyou-Guangyuan fault); Central faults: YBF(Yingxiu-Beichuan fault), NGF(Nanba-Guanzhuang fault), CHLF(Chaba-Linansi fault); Back-rang faults: MWF(Maoxian-Wenchuan fault), JDF(Jiudingshan fault), PQF(Pingwu-Qingchuan fault).

Typical river basins: ❶(Shikan river basion), ❷(Tongkou river basion), ❸(Mianyuan river basion), ❹(Minjiang river basion)

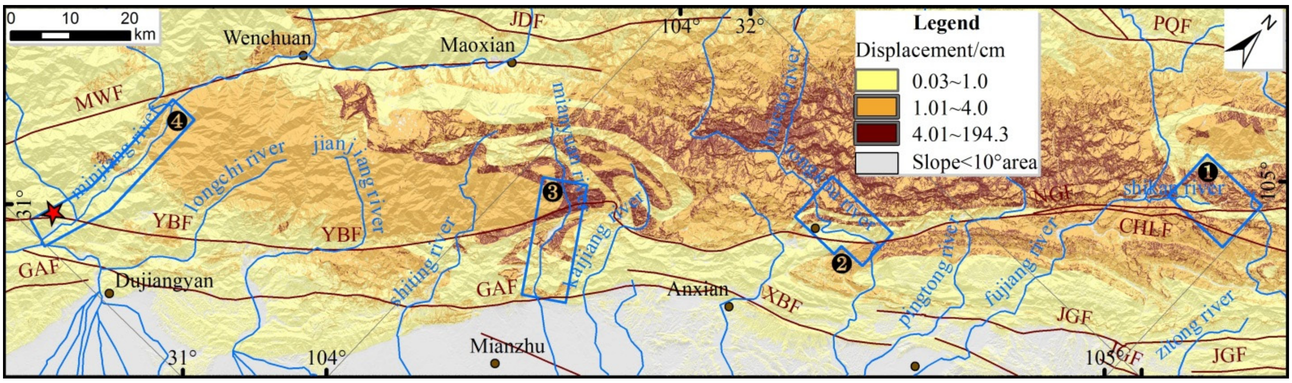

Fig. 3 Regional seismic landslide displacement analysis result based on Newmark model in Wenchuan earthquake area

sliding mass is assumed as 5m. Regional seismic landslide displacement can be classified into 3 levels: low hazard 0.03~1.0cm, moderate hazard 1.01~4.0cm, high hazard 4.01~194.3cm. Although the absolute displacement value may not be accurate comparing with physical truth, its relative large or small can be taken as important basis for hazard level grading. Analysis result indicates that moderate~high hazard area of seismic landslide mainly distribute along hanging wall of Longmenshan central faults. Moreover, in regional scale, the field surveying most catastrophic landslides and the most intensive landslide distribution area both are corresponding to moderate~high hazard area. However, it is ambiguous whether the analysis result in river basin scale is reliable or not.

2.2 Landslide interpretation with object oriented feature extraction and man-machine interactive methods

Comparing with conventional landslide interpreting methods such as supervised classification, unsupervised classification etc., object oriented feature extraction technique is able to ensure both interpreting accuracy and efficiency. This image interpreting method flow generally consists of 2 steps: object recognition and classification extraction. Taking Shikan river basin as an example, post-earthquake timely SPOT5 remote sensing image of 2.5m resolution ratio was shot (Fig. 4A). Through interpreting, surface features with distinct spatial and spectral characteristics are classified out as seismic landslide, forest land, farm land, water and cloud. On this basis, combing field survey and experience, seismic landslides are further revised with man-machine interactive method. Finally, seismic landslide area in Shikan river basin is revealed as 12.7km^2 taking 10.7% of total basin area (Fig. 4B). Obviously, seismic landslides mainly concentrate on right bank of Shikan river and its NE extension area, that is the hanging wall area of Nanba-Guanzhuang faults (Fig. 3).

For verifying reliability of landslide displacement analysis in Shikan river basin, we clip the river basin area from regional analysis result (Fig. 4C). Comparing with the realistic seismic landslide distribution (Fig. 4A, 4B), it can be roughly judged that SE part of analysis result is more dangerous than physical truth, while the other part is approximately matching with realistic landslide distribution. However, the quantitative verification still need to be further done. For ensuring the verification is effective, landslides in other 3 river basins are also interpreted by object oriented feature extraction and man-machine interactive methods (Fig. 3, Table 1).

3 Quantitative verification of landslide displacement analysis results

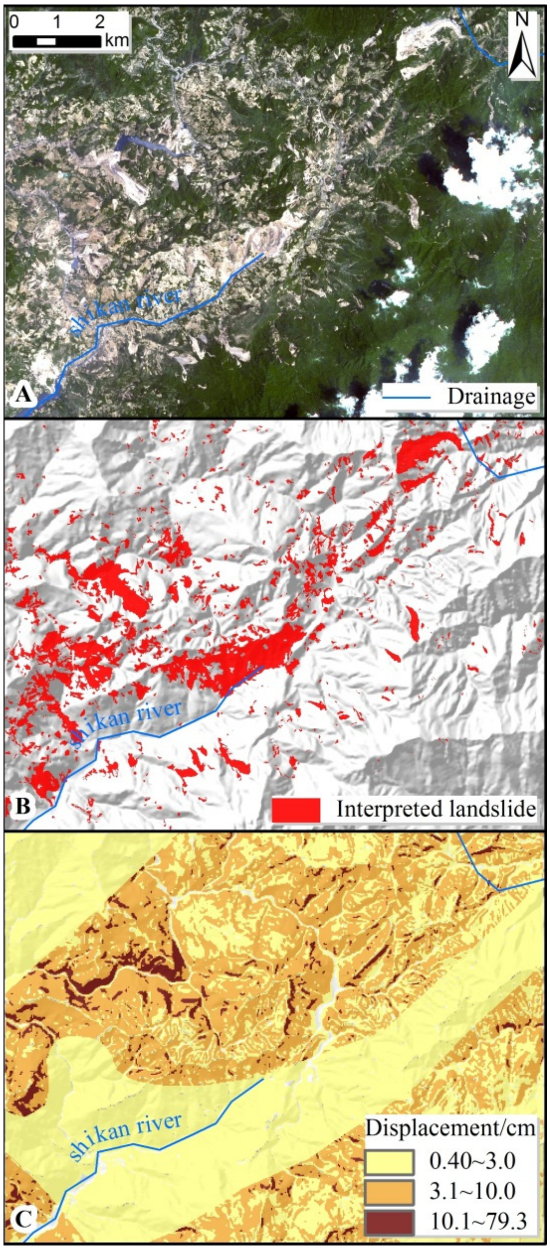

Fig. 4 Comparison of (A) remote sensing image, (B) interpreted seismic landslide and (C) landslide displacement analysis result in Shikan river basin

Based on displacement analysis and accurate interpreting results of seismic landslides in 4 typical river basins mentioned above, Area Under Curve (AUC) method is applied to compare the matching extent of both. It is drawn in the plane rectangular coordinate system, of which vertical axis stands for realistic accumulated landslide proportion, horizontal axis stands for river basin accumulated area proportion (Fig. 5). Through comparing area under the curve, the matching extent between seismic landslide displacement analysis and accurate interpreting results can be quantitatively evaluated. AUC value interval

Table 1 Seismic landslides interpreting results of 4 typical river basins

Sequence number	River basins	Image resolution ratio (m)	Basin area (km^2)	Landslide area (km^2)	Most intensive area of landslide distribution
1	Shikan river	2.5	119	12.7	Nearby hanging wall of Nanba-Guanzhuang fault, right bank of Shikan river and Xinping village areas
2	Tongkou river	1.0	119	16.0	Nearby hanging wall of Yingxiu-Beichuan fault, right bank of Tonkou river, Tangjiashan landslide and barrier lake areas
3	Mianyuan river	5.0	150	33.8	Nearby fault block between Yingxiu-Beichuan fault and Guanxian-Anxian fault, left bank of Mianyuan river, Wenjiagou debris avalanche areas
4	Minjiang river	5.0	162	50.6	Nearby Yingxiu-Beichuan fault, right bank of Minjiang river, Zaojiaotuo-Chediguan landslide cluster areas

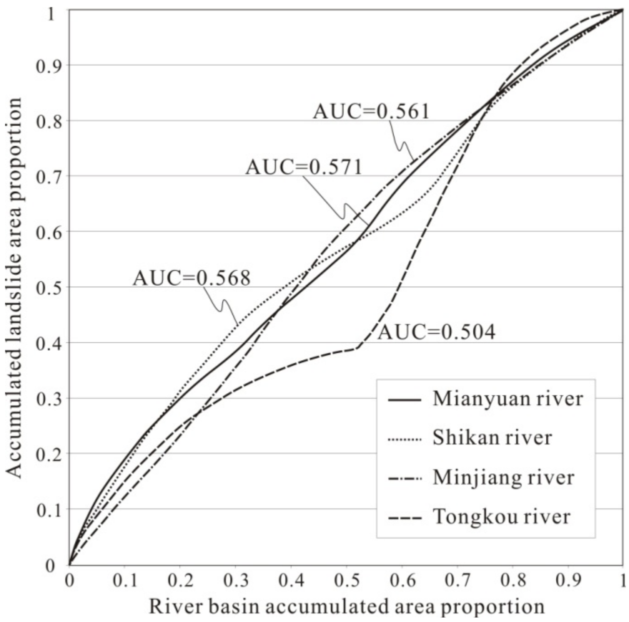

Fig. 5 AUCs of seismic landslide displacement analysis results and realistic distribution in 4 typical river basins, Wenchuan earthquake area

is (0, 1). The larger of the area, the better of the matching extent, and vice versa. The AUC values of 4 typical basins vary 0.5~0.6. Ranking the matching extent of landslide displacement analysis result and realistic landslide distribution in river basins from good to poor as Mianyuan river, Shikan river, Minjiang river, Tongkou river. Such values suggest that seismic landslide displacement analysis results do not matching well with the realistic landslide distribution in typical river basins. However, Jibson et al. developed this seismic landslide displacement analysis method based on Newmark model; it performed ideal on seismic landslide study in 1994 Northridge earthquake (Jibson et al., 2000).

4 Discussion

In regional scale, although landslide displacement analysis result is roughly corresponding with the most intensive landslide distribution area, the result underestimates landslide developing intensity somewhere such as Yingxiu town surrounding area nearby the epicenter. In river basin scale, landslide displacement analysis performs much worse than the application in 1994 Northridge earthquake. The reason why seismic landslide displacement analysis method based on Newmark model performs poor here mainly owe to 4 aspects.

(1) Regional lithology data is of low spatial accuracy. Engineering geological petrofabric merging makes rock-soil mass types further simplified. Moreover, seismic landslides induced by Wenchuan earthquake mainly formed in the shallow weathering rock mass of which the physical and mechanical parameters are different from fresh rock mass. Even so, we can neither obtain the detailed geological data as the Northridge earthquake case of 1: 24, 000 scale nowadays nor physical and mechanical parameters of site rock-soil mass.

(2) Although the relative accurate DEM of 25m is available, more and more engineering slope cutting activities have been significantly changing the local topography. These changes generally cannot be timely updated in DEM. Consequently landslide displacement analysis will underestimates the realistic landslide developing intensity, especially in alpine and valley area.

(3) Referring to seismic landslide study inland, the ground motion Arias intensity is not commonly used as Peak Ground Acceleration (PGA). Arias intensity is generally analyzed by empirical equation; the site effect of ground motion propagation is neglected. However, this site effect is complicated and not be well revealed in the alpine and valley area nowadays.

(4) Morphological and structural characteristics of various seismic landslide types are quite different. For instance, the sliding mass thickness, landslide type and volume vary from different lithological area, so cannot be described with consistent parameters in landslide displacement analysis.

5 Conclusions

Through the application and validation study in Wenchuan earthquake area and river basins, it can be concluded that landslide displacement and hazard analysis based Newmark model is applicable for seismic landslide rapid assessment in regional scale. Although the absolute landslide displacement value may not be quite accurate, its relative large or small of displacement can be taken as important basis for hazard level grading. The analysis result may be served as decision-making reference during earthquake emergency response step.

While in the river basin scale, only if detailed rock-soil mass physical and mechanical parameters, reliable topographic and ground motion datum are available, this displacement analysis method can be applied for accurate landslide assessment; or else, the analysis result will not be ideal. To be noted, trying to make the seismic landslide displacement analysis simultaneously meet both accuracy and efficiency targets still needs more time.

Considering the limitations of landslide displacement analysis based Newmark model in Wenchuan earthquake case study, some issues should be concentrated in the future such as spatial database constructing of regional rock-soil mass physical and mechanical strengthen parameters, timely update of topography data and site effect study of ground motion propagation. Even more, all of relevant basic geological and topographic spatial data set should be gradually shared and released to public, so as to improve seismic landslide study.

6 Acknowledgement

This study is jointly funded by National Natural Science Fund (41102165), National Science and Technology Support Program (2011BAK12B09, 2012BAK10B02), Geological Survey Project (1212011220144).

Key words: Seismic landslide, displacement, Newmark model, Validation, Wenchuan earthquake

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