Interpretation of Slope Failure Distribution Triggered by the Northern Pakistan Earthquake on 8 October 2005 using SPOT5 Stereo-imageries

by

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ABSTRACT

This paper presents distribution of slope failures triggered by the northern Pakistan earthquake using 2.5m resolution SPOT5 (System pour l'Observation de la Terre 5) images. The stereo-images taken on October 20 and 27, 2005 were interpreted, as a result, 2,424 slope failures were detected. According to field survey, most of the slope failures were shallow slides. Over the one-third of the detected slope failures occurred within one kilometer of the active faults. Form this study, it was found that remote sensing is effective tool to estimate the damages in wide area, and it is important to know the existence and location of active fault to prevent earthquake disasters in advance.

KEYWORDS: SPOT5, Pakistan, earthquake, interpretation, active fault

1. INTRODUCTION

Northern Pakistan earthquake (Mw7.6) of October 8, 2005 occurred in the Kashmir region in the northwestern part of the Himalayas. The epicenter is north-northeast direction and 105 km away from Islamabad.

The crustal deformation was spatially mapped with Synthetic Aperture Radar (SAR) data from the European Space Agency's ENVISAT [1], and it was found that the newly deformed area occupies a 90-kilometer-long northwest-southeast trending strip. Heavily damaged area north of Muzaffarabad has the maximum deformation up to six-meter uplift as observed by the satellite.

There are known active faults (Muzaffarabad and Tanda faults) stretching to the northwest and southeast near the epicenter [2], which reveal some uplift (on the northern side) and dextral (right-lateral) strike-slip activities. The detected crustal deformation was along these active faults and all observations were consistent with previously known directions of past fault movements.

According to Pakistan Government, 87,350 were dead as of November 8, 2005. The earthquake occurred in mountain and in distant area from the capital city, it was difficult to know the earthquake disaster immediately. It is important to collect the slope failures location for restoration activities and taking measures against secondary disaster.

2. METHODS

2.1 SPOT5 image interpretation

After the earthquake, SPOT5 (System pour l'Observation de la Terre 5) panchromatic images were taken on October 20 and 27, 2005. The incident angle of October 20 and 27 images is at the left side of 26.4 degree and at the right side of 30.4 degree, respectively.

As shown in Fig. 2, these images make stereoscopic vision, and through the stereo-images slope failures were interpreted and delineated on the images. Fig. 2 shows north area of Muzaffarabad. In the figure the circle #5 shows not slope failures but the flexure cliff along the surface rupture of the earthquake fault. Slope failures were interpreted as white-bright slope, especially the right side of the river. In delineating such the slope failure, each slope failure was divided as considering unit slope. However, the interpreted area contains high mountain areas covered with snow, and it was difficult to interpret slope failures in

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such the area. In the case the slope failures were not interpreted.

2.2 Methods of slope failures delineation

2.2.1 Preparation of ortho-images

To delineate the interpreted slope failures, in advance, orthographic (ortho-) images were prepared, namely, to overlay the map, SPOT5 images were geometrically corrected using ground control points (GCPs). The 34 mountain summits' location and elevation, whose data were gathered from 90m-resolution SRTM (Shuttle Radar Topography Mission), were used as the GCPs.

After the geometric correction calculation, root mean square errors at the 34 GCPs showed c.a. 72m at east-west direction, c.a. 62.3m at north-south direction, respectively. This error indicates the location of ortho-image randomly shifts not more than one grid of SRTM data.

2.2.2 Comparison of interpreted slope failures with pre-earthquake SPOT5 image

The interpreted slope failures may contain the slope failures occurred before the earthquake. To remove such the slope failures, the interpreted slope failures were superimposed on the orthography of SPOT5 image taken on March 2, 2004. Finally, the interpreted area is the overlap between before and after earthquake images, 55km by 51 km in area except high mountain area covered with snow.

3. RESULTS AND DISCUSSION

The interpreted slope failures were overlaid on the SRTM data, and shown in Fig. 3. The total count of the slope failures was 2,424. Comparing Fig. 3 with Fig. 1, most of them occurred on the hanging wall side. Furthermore, many slope failures occurred along Muzaffarabad fault and Tanda fault. Fig. 4 shows relation between slope failures and distance from these active faults. It was found that over the one-third of them occurred within one kilometer from the active fault.

To fit area size of the slope failures for SRTM resolution, the large-scale slope failures at the size of 100m by 100m (1 ha in area) and more, namely, 207 counts, were selected. Furthermore, the relation between large-scale slope failures and slope calculated from SRTM was investigated. The result is shown in Fig. 5. The minimum and maximum slope was 8.4 degree and 52.3 degree, respectively. The most failures, 44 counts, occurred at the slope of 30-35 degree, 87 counts failures occurred at the slope of 35 degree and more, and 76 counts occurred at the slope of less than 30 degree. There is a slight tendency that more large-scale slope failures occurred at steeper slope than at gentler slope.

Fig. 6 shows relation of 207 counts failures between slope (degree) and distance from the active faults. It infers that large-scale failures occurred not only at steep slope but also at gentle slope in the near area from the active faults, slope failures of 10-15km from the faults occurred at steeper slope (43.4 - 46.3 degree). However, at the distance of c.a. 18km or further, large-scale slope failures also occurred at the gentler slope (less than 30 degree). It is not concluded that large-scale slope failures occurred at steeper slope when they located at further distance from the active faults.

Fig. 7 shows vertical curvature frequency distribution of 207 counts failures. The vertical curvature [3] was calculated from SRTM. It is the index which shows plus and higher values when cross section of topography is more convex, minus and lower values when more concave. Vertical curvature is zero, it means linear slope. The most failures occurred at the curvature of +0.1 - +0.2, 37 counts, 128 counts occurred at the curvature of more than zero (at convex slope), and 79 counts occurred at the curvature of less than zero (at concave slope). Form Fig. 7, there is the tendency that more large-scale slope failures occurred at the convex slope than at the concave slope.

4. CONCLUSIONS

By interpreting slope failures using SPOT5 stereo-images, characteristics of slope failures were revealed as mentioned before. In the monsoon season heavily rain may cause secondary slope failures, and many residents who live on the slope may suffer from the secondary damage of slope failure. To prevent and mitigate such the damage, further monitoring may be important. The interpreted slope failures data will help such disaster prevention measures.

5. REFERENCES

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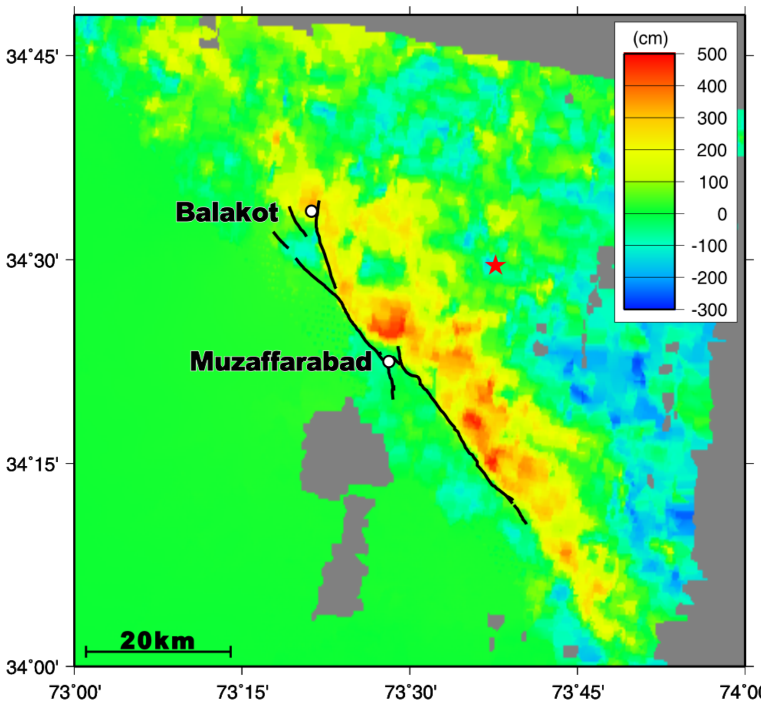

Fig.1 Detected crustal deformation using ENVISAT/SAR data (wavelength of 5.6 cm, C-Band) [1]. Positive values indicate the movement toward the SAR satellite in the line-of-sight direction (upward and/or E-SE displacement). Solid black lines show Muzaffarabad and Tanda faults [2] and star mark is the epicenter.

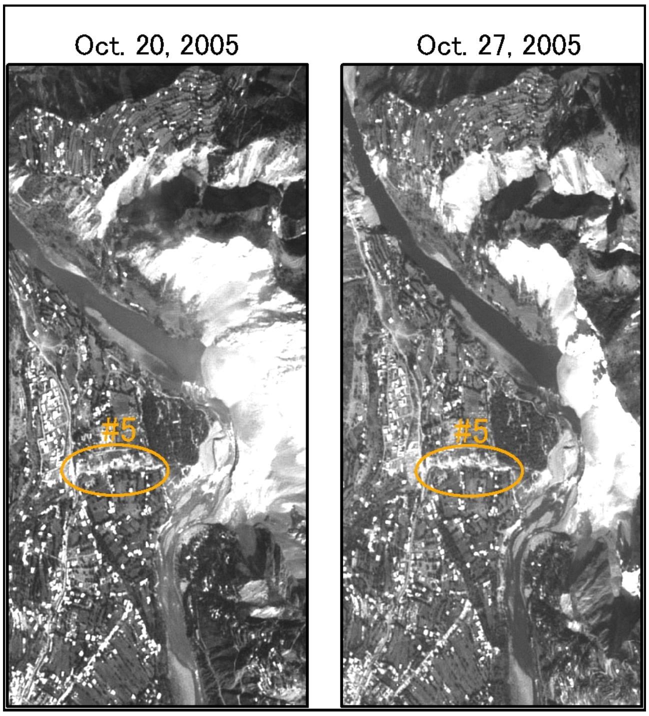

Fig.2 SPOT5 stereo-imagery in the damaged area of north Muzaffarabad

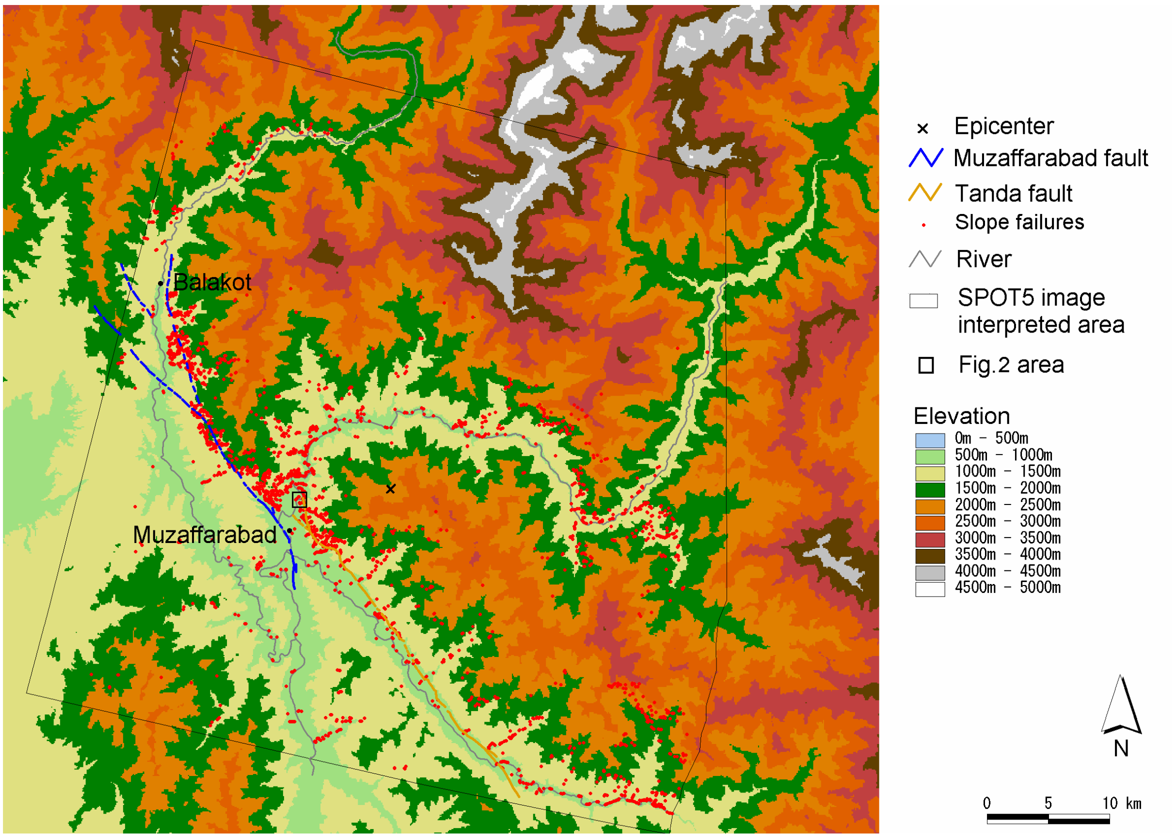

Fig. 3 Distribution of slope failures triggered by the earthquake. Elevation data are based on SRTM.

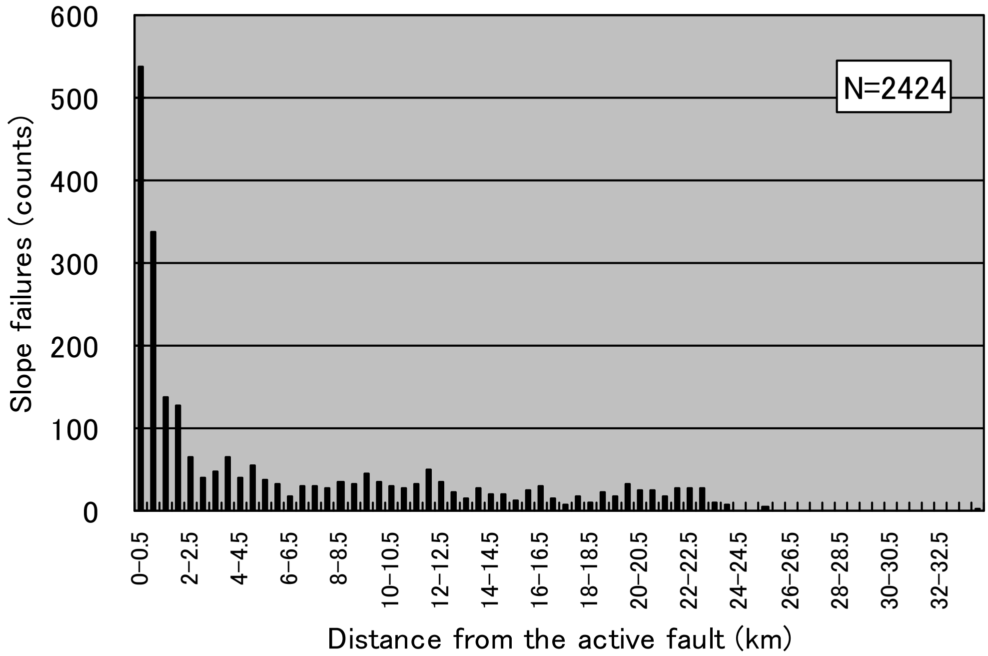

Fig. 4 Slope failures frequency distribution on distance from the active fault

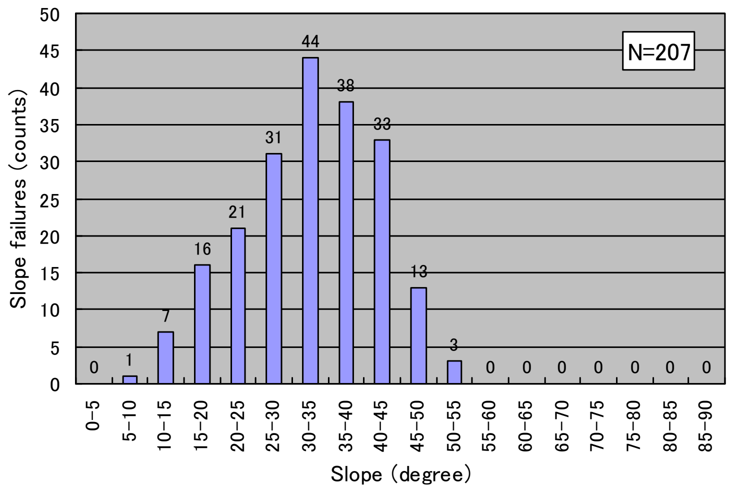

Fig. 5 Large-scale slope failure frequency distribution on slope (degree)

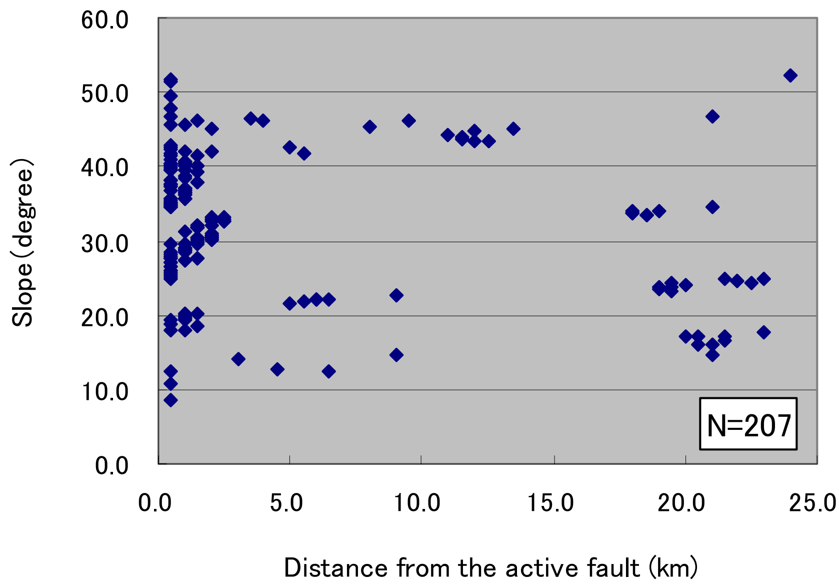

Fig. 6 Relation between distance from the active fault and slope (degree)

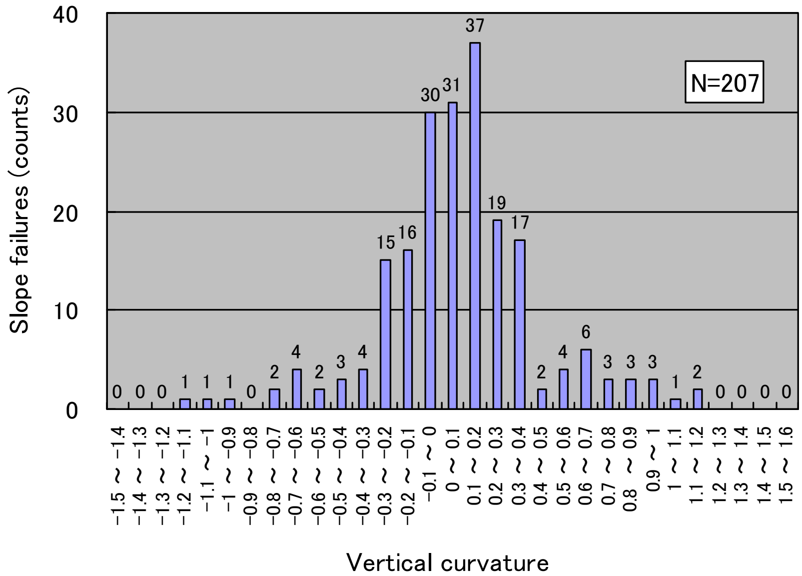

Fig. 7 Large-scale slope failures frequency distribution on vertical curvature