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DEFORMATION OF LANDSLIDE SURFACES AS INDICATORS OF MOVEMENT PROCESSES

Abstract: FLEMING R.W., BAUM R.L. & JOHNSON A.M., *Deformation of landslide surfaces as indicators of movement processes* (IT ISSN 0391-9838, 1993).

Deformation that occurs at the surface of a moving landslide can provide insight into landslide kinematics and stability analysis. The deformational data, combined with subsurface information on geometry and pore pressures, can lead to different strategies for remedial treatment depending on the size and geometry of the driving and resisting elements of the landslide. Displacement of points on the surface of the landslide can be measured using an analytical stereoplotter and different sets of aerial photography. The scalar magnitudes of the displacement vector are used to draw contour map of the displacement. Changes in displacement can be used to compute average one-dimensional strain at the landslide surface. Examples from the Twin Lake landslide are discussed. The observed pattern of deformation shows large extensional strain in the upper part and large compressive strain at the toe. A neutral area separates driving from resisting parts of the landslide.

KEY WORDS: Stress-strain analysis, Landslide.

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Le deformazioni che avvengono sulla superficie delle frane possono fornire indicazioni sulla loro cinematica e stabilità. I dati delle deformazioni combinati con le informazioni sulla geometria del sottosuolo e della pressione neutra, possono portare a differenti strategie per gli interventi a seconda della misura e geometria degli elementi che hanno guidato la frana. Monitorando le fratture e le faglie e misurando gli spostamenti dei punti sulla superficie delle frane si ottengono informazioni circa i processi di movimento. Gli spostamenti della superficie delle frane possono essere misurati usando apparecchi fotorestitutori analitici e differenti sets di foto aeree. I valori scalari dei vettori spostamento sono usati per disegnare le mappe degli spostamenti. I cambiamenti nello spostamento possono essere usati per misurare la deformazione media della superficie della frana.

Sono illustrati gli esempi della frana del Lago Twin. Le osservazioni sulle deformazioni mostrano un'elevata deformazione distensiva nella parte alta e un'elevata deformazione compressiva nell'unghia della frana. Un'area neutra separa le parti spingenti da quelle resistenti.

TERMINI CHIAVE: Analisi sforzo-deformazione, Frana.

Studies of the deformation that occurs at the surface of a moving landslide can provide insight into landslide kinematics and stability analysis. The types of deformation that are useful to monitor include (1) cause, distribution, and growth of individual cracks and faults, (2) displacement of points on landslide surfaces, and (3) point measurement of strain on landslide surface (BAUM, JOHNSON & FLEMING, 1988; FLEMING & JOHNSON, 1989; BAUM, FLEMING & ELLEN, 1989). One example of measurements and observations is summarized here to illustrate applications of specific methods.

DEFORMATION AT THE TWIN LAKE LANDSLIDE, UTAH

The Twin Lake landslide is in Twelvemile Canyon, about 9 km east of the small town of Mayfield, Utah. The landslide, a reactivation of old landslide debris, began moving during the spring of 1983. Movement was initially rapid (as much as 10 m per day) through May and June, and amounts of movement locally exceeded 45 m. Movement stopped during the summer of 1983 but began again during the spring of 1984. Since 1984, the landslide has been dormant.

The Twin Lake landslide is about 450 m wide and 900 m long. Based on a thickness of 30 m determined by one boring, the volume is about 12 million m^3. During the period of rapid movement, the ground surface was relatively dry and brittle. As a result of movement, the ground was broken by a myriad of fractures, including faults and

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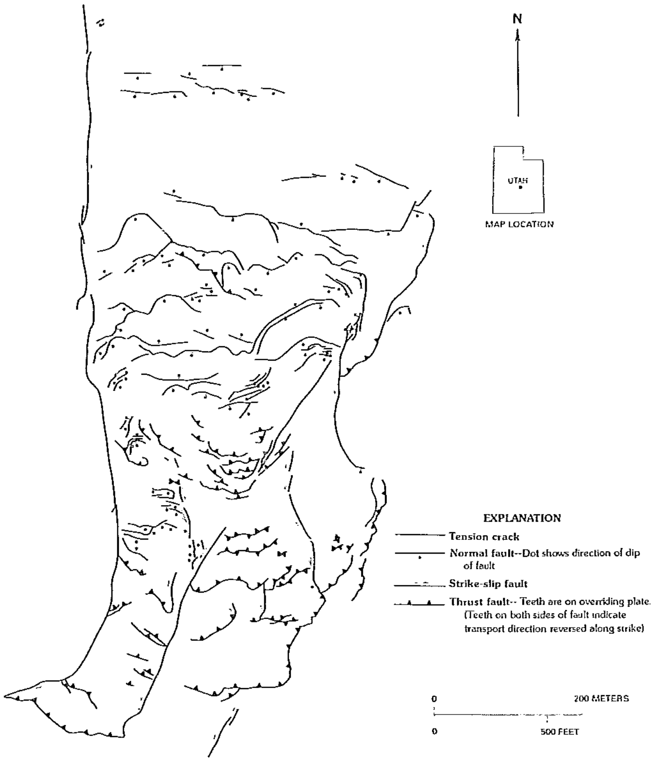

FIG. 1 - Map showing the pattern of deformation on the surface of the Twin Lake landslide. In general, the deformation is stretching in the upper part and shortening or compression in the lower part of the landslide.

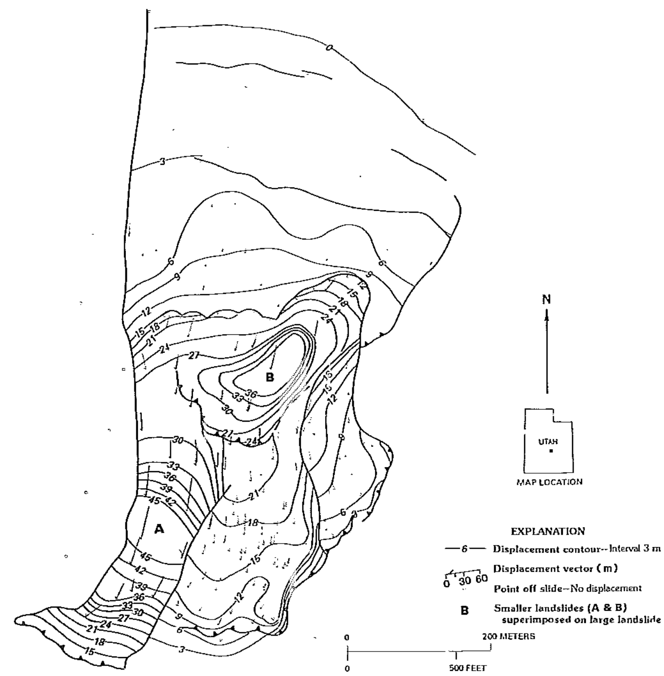

FIG. 2 - Contours of displacement and displacement vectors on the Twin Lake landslide. Displacement measured from aerial photographs.

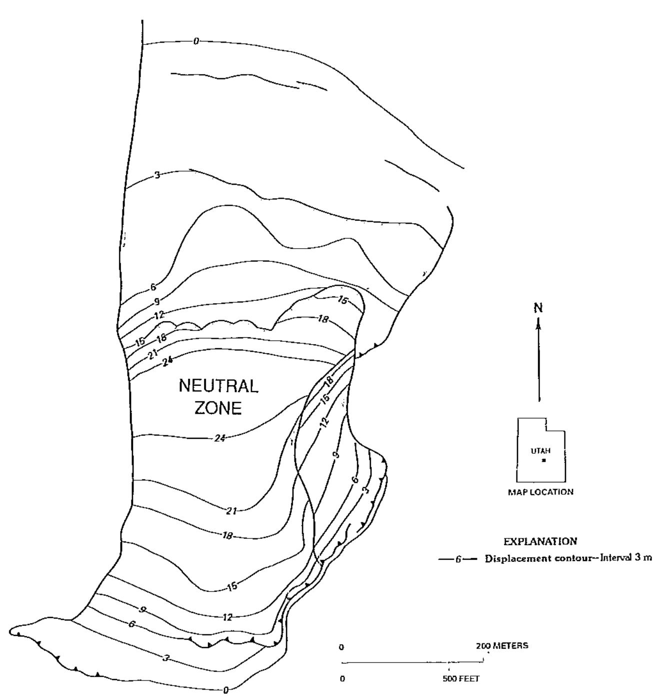

FIG. 3 - Simplified displacement contours determined by removing the displacement of the superimposed landslides shown on Fig. 2. Shaded area is the general position of the Neutral Zone of the main body of the landslide.

open cracks. The landslide is bounded on the west by strike-slip faults and on the east by a complex of strike-slip, normal, and thrust faults. The head of the landslide is north, and movement was toward the south.

Aerial photographs (scale 1:6,000) of the landslide were taken at three times in May, 1983, just after movement had begun; in June 1983, after about three-fourths of the total movement had occurred; and in June 1984, after movement had ceased. Detailed maps of cracks and faults were prepared using photo enlargements and plane-table maps as bases. Figure 1 is a simplified map of the principal cracks and faults.

In the lower (south) part of the landslide, there are two prominent left-lateral strike-slip faults that divide the landslide toe into three separate elements. These strike-slip faults are boundaries between landslide elements. Deformational patterns are different in each element. In the westernmost element, there are both normal and thrust faults. In the middle element, the entire lower part of the landslide is comprised of a series of subparallel thrust faults indicating that the landslide debris is being compressed throughout. The eastern element of the landslide toe also contains internal thrust faults, small buckle folds, and numerous discontinuous left-lateral faults that individually contain small displacements. Overall, the deformational pattern in the eastern element is compression and shearing.

Farther upslope, there is an area of thrust faults with most arranged arcuately across the mid-part of the landslide (fig. 1). Toward the west side, the thrust faults are intermingled with subparallel normal faults in a pattern that indicates both stretching and shortening are occurring in the same place. In the upper half of the landslide, the features are almost exclusively normal faults.

Displacement of the surface of the landslide was measured for about 150 point using an analytical stereoplotter and the three sets of aerial photography. Coordinates of photo-identifiable points were computed and displacement plotted as vectors on figure 2. Points off the slide are shown as open circles; measurement of these stable point revealed that displacements on the moving ground are accurate to about ± 1 m.

The scalar magnitudes of the displacement vectors have been used to draw a contour map of the displacement (fig. 2). Large offsets in displacement occur along the major internal boundaries in the toe. For example, note that there was about 30 m of differential displacement along the left-lateral fault just east of «A» in the shaded part of figure 2. Displacement in the shaded area represented by «A» increased from about 27 to 45 m and then decreased to zero at the toe. Similarly, in the shaded area «B» on figure 2, the displacement increases from a background value of about 12 m at the upslope end to a maximum of 36 m. Farther downslope, displacement decreased to 24-27 m at the thrust fault at the downslope end of «B».

These two shaded areas shown as «A» and «B» contain similar patterns of cracks and faults (fig. 1) as well as distinctive displacement patterns. Within each shaded area, extension occurs in the upper part and compression in the lower part. This deformation and crack pattern, together with the displacement record, identifies each area as s smaller landslide within the boundaries of the larger Twin Lake landslide.

The displacement pattern for the larger landslide can be isolated by removing the displacements of the smaller landslides. The amounts of displacement outside the shaded areas show consistent increases from the upslope end to the heads of the smaller landslides (fig. 2). Furthermore, there is consistent shortening in the area when displacement decreases from 21 to 0 m in the middle element of the toe. Extending the trends of these displacement contours of the larger Twin Lake landslide across the shaded areas in effect subtracts the additional displacement due to superimposed movement within the shaded areas «A» and «B» and greatly simplifies the displacement pattern (fig. 3). The amount of displacement of the Twin Lake landslide increased from 0 to about 24 m; then it decreased to 0 m at the toe.

Additional information about landslide kinematics can be extracted from the maps by comparison of the different data in figures 1, 2 and 3. For example, most displcement vectors are oriented normal to the scalar displacement contours. In these areas where the contours are at right angles to the displacement vectors, the distortion of the landslide debris is pure stretching or shortening.

The structures associated with stretching are tension cracks and normal faults that are common in the upper part of the landslide. Thrust faults and buckle folds characterize the shortening or compression evident in the landslide toes. In a few other parts of the landslide, particularly along the east flank of the landslide near the toe, displacement vectors are oblique to the displacement contours. These areas are characterized by shearing in addition to shortening.

The changes in displacement can be used to compute average one-dimensional strain at the landslide surface. The extensional strain in the upper part of the landslide increases from about 2 percent near the uppermost cracks to about 20 percent in the region of extensive normal faulting (fig. 1) between the 21- and 24-m displacement contours. Near the toe, the compressional strains range up to about 33 percent while farther upslope, near the 24-m displacement contour compressional strains are about 4 percent. A neutral zone occurs between the 24-m contours (fig. 3) where strains change from extensional to compressional.

DISCUSSION

Careful mapping of positions and kinds (tension, compression, shear) of features on moving landslides leads to identification of different elements within a landslide and accurate depiction of landslide boundaries. When deformational features are combined with spatial data on displacement, the distribution of deformation can be related to strain on the surface of the landslide. The pattern of deformation on the Twin Lake landslide is large extensional strain in the upper part and large compressive strain at the toe. The neutral area, where the type of deformation changes from stretching to shortening, may separate driving from resisting parts of the landslide. The area of shortening generally resists sliding movement while areas characterized by stretching or nondeformation are the driving elements of the landslide (Baum & Fleming, 1991). These deformational data, combined with subsurface information on geometry and pre pressures, can lead to different strategies for remedial treatment depending on the size and geometry of the driving and resisting elements of the landslide.

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