Use of Time-Lapse Movie Photography in Landslide Monitoring

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In this paper is described the use of time-lapse movie photography to monitor the Muddy Creek landslide near Paonia, Colorado, during a 7-week period in the spring of 1986. Problems encountered in installation and operation of the equipment are discussed, and improvements in techniques and camera equipment are suggested.

Analysis of landslides by time-lapse photography provides the geoscientist with a unique perspective not apparent to the observer on a day-to-day basis. The method enables the study of the development and evolution of an unstable landmass as they actually take place and provides a useful supplement to traditional surface and subsurface geotechnical instrumentation. Because a camera can be installed quite quickly, the method can be used to provide information during the somewhat longer period required to install conventional observation instrumentation on rapidly moving slides. The quantity of information and the amount of detail obtained far exceed those available from any other method.

The Muddy Creek landslide along CO-133 near Paonia, Colorado, proved to be an excellent candidate for this study. The slide was large and fast moving, attaining a rate of almost 1 ft/hr in its early stages (J. Rold. Muddy Creek Slide Movement, Gunnison County. Unpublished Colorado Department of Natural Resources Memorandum to Governor Richard Lamm, May 1, 1986). The movement threatened not only burial of the highway but closure of the valley of Muddy Creek, with resultant impoundment of the stream flow and a threat to the safety of the Paonia Dam and Reservoir a short distance downstream. The film provided a record not only of the slide movement but also of the activities of the Colorado Department of Highways (CDOH) in preventing closure of the Muddy Creek Valley.

Other important information obtained from study of the film included (a) an estimated rate of landslide movement; (b) amount of total landslide movement; (c) information concerning local topographic changes and the development of dangerous situations not visible to those in the work area; (d) detailed observations of the contractor's operation, including progress in keeping the river channel open and reconstructing the highway embankment; and (e) daily weather conditions.

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MUDDY CREEK SLIDE

The landslide is located in Gunnison County, Colorado, about 10 mi west of McClure Pass between the towns of Redstone and Paonia (Figure 1).

Bedrock of the Muddy Creek area consists of upper Cretaceous sandstones of the Ohio Creek formation unconformably overlain by mudstones, claystones, and shales of the lower Tertiary Wasatch formation. During the late Tertiary, the entire sedimentary sequence was intruded, uplifted, and gently tilted westward by the Ragged Mountain laccolith *(1)*, forming a slope of from 12 to 14 degrees on the eastern side of the valley where the landslide is located.

The Muddy Creek slide is an extremely large complex of individual slides that originated in the sloping beds of the Wasatch formation at the foot of the Ragged Mountains. It is approximately 12,500 ft long by 5,200 ft wide, with an average estimated thickness of nearly 100 ft. The area of failed material is more than 1,500 acres and volumetrically encompasses approximately 140 million cubic yards (B. K. Stover, verbal communication, 1986). The slide is quite old and only minor movements associated with spring runoffs had been reported in historic times. The rapid movement in the spring of 1986 was apparently triggered by abnormally large snowpacks in the Ragged Mountains during the previous three winters. Past movement of the slide has forced the channel of Muddy Creek to the extreme western edge of the valley, where it has cut cliffs more than 100 ft high into the alternating sandstones and shales of the Ohio Creek formation. CO-133 is located along the west side of the stream between the channel and the cliffs. The distance between the slide toe and the cliffs ranges from 60 to 100 ft and the height of the toe from 35 to 40 ft along a 5,000-ft section of the road where the rapid movement of the slide threatened to close the road and dam the valley. It was this area that was photographed with the time-lapse cameras (Figure 2).

The rapid movement of the slide was discovered on April 29, 1986, by CDOH maintenance personnel, and two backhoes were immediately dispatched to the site. Movement of the slide toe had compressed the stream channel against the highway embankment to a width of less than 20 ft. This made it possible for the backhoes to reach across the stream from the road and scale material from the advancing toe into the creek, which carried it away downstream. Four more backhoes were soon added and additional construction equipment was brought in to raise the grade of the embankment, which was being eroded by the stream. Movement of the slide was also raising the grade of the stream, which threatened to flood the roadway. This work

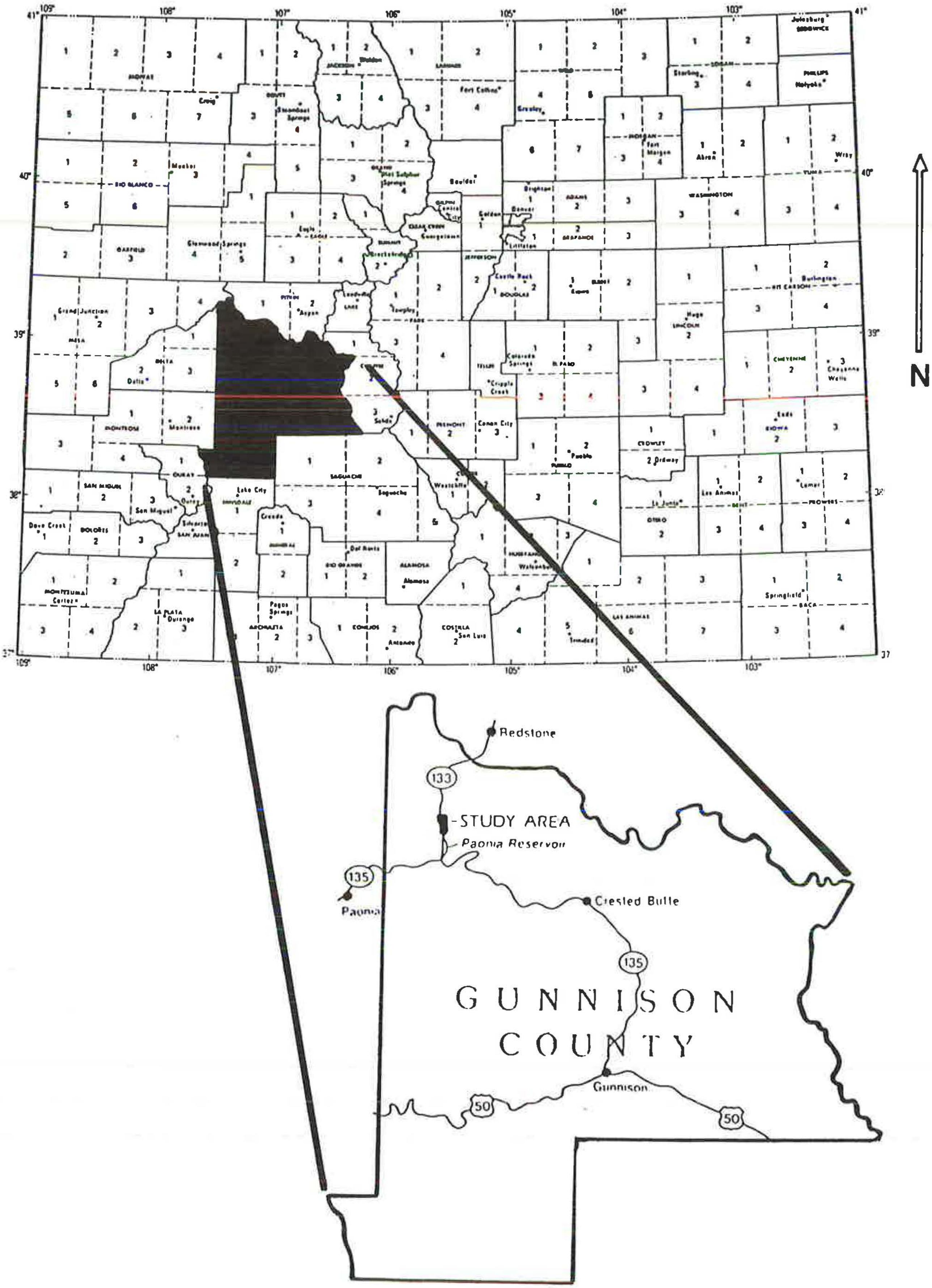

FIGURE 1 Location of study area.

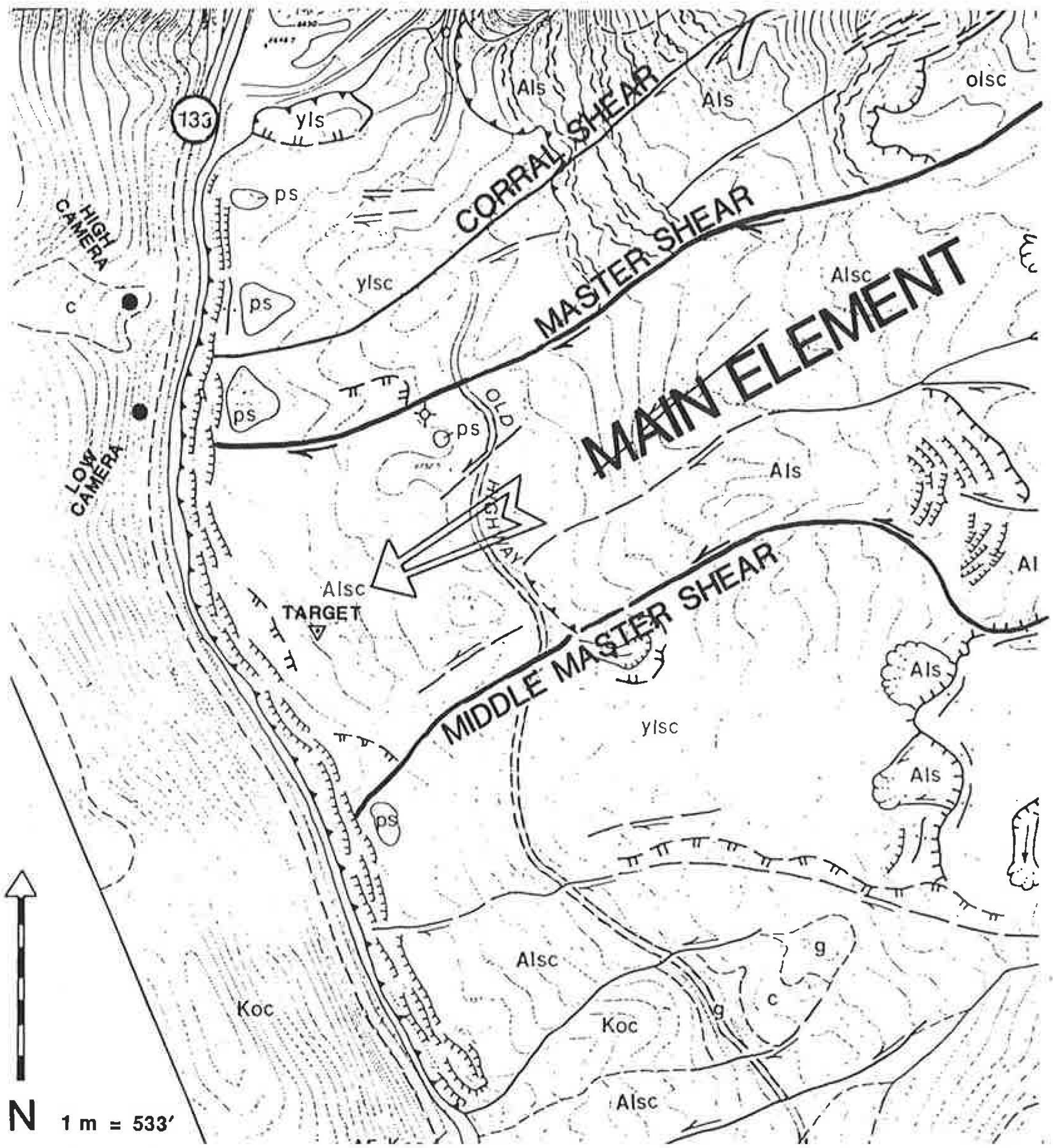

FIGURE 2 Study area showing locations of cameras and target.

continued on a 24-hr basis until June 23, at which time the grade had been raised approximately 40 ft and the slide movement had essentially stopped.

CAMERA SYSTEM

Two Kodak Analyst Super 8 time-lapse movie cameras were used in this study. The cameras, which are no longer manufactured, had been acquired at a government surplus outlet approximately 3 months before their installation on this project. Markings on the boxes indicated that the cost of the cameras in 1973 was $175. Both came equipped with soundproof and weatherproof covers (Figure 3).

Features of this camera include a variable focal length 13 mm to 28 mm f/1.9 zoom lens, which permits latitude in selection of the field of view. Power can be supplied by 110-volt household current through an accessory transformer or, for

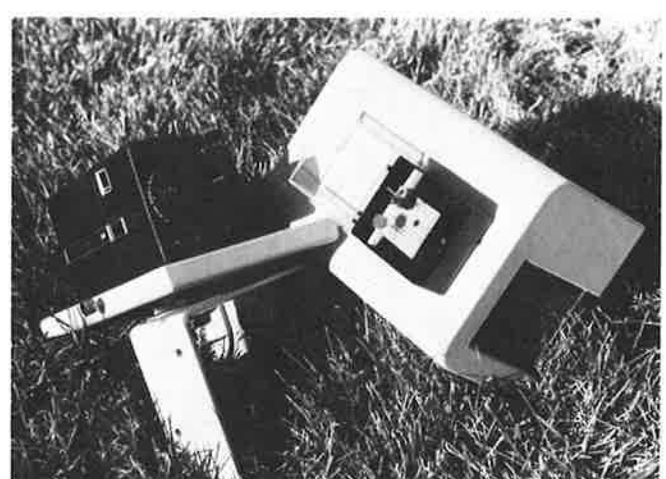

FIGURE 3 Camera, mounting platform, and protective cover.

remote operation, by four size AA 1.5-volt dry cells. Three of the cells power the film advancement motor and the fourth cell operates the automatic exposure control system. The camera is also equipped with a manual focusing adjustment, an end-of-film indicator lamp, an exposed-film indicator window, and a slide for adjusting the field of view through the reflex viewfinder. Rate of operation ranges from one frame every $1^1/_4$ sec to a maximum of one frame every 90 sec. The camera is designed to accept a standard Super 8-mm film cartridge containing 100 ft of film, but, because these are no longer available, 50-ft rolls were used. Depending on the frame rate selected, these permit continuous operation for periods ranging from $1^1/_4$ to 90 hr. The cameras used in the study are equipped with a mounting bracket that includes a gimbal, which permits the cameras to be adjusted horizontally or vertically. The upper part of the bracket contains a threaded socket hole for standard tripod installation, and the lower part has four holes to allow attachment to a mount with nails or screws.

The cameras use Kodachrome Super 8 ASA 40 or Ektachrome ASA 160 Type G Super 8 color film, both of which in the Denver area cost $9 per roll. Processing charges are approximately $5 per roll. Kodachrome requires shipping to a Kodak Regional Center for processing whereas Ektachrome can usually be developed locally.

CAMERA INSTALLATION

To obtain an adequate field of view, it was necessary to locate the cameras above and at some distance from the portion of the slide being photographed. Two sites were selected on the cliff west of the highway, which had previously been cut and benched north of the area where the roadway grade was being raised. One camera was positioned on one of the cut benches and the other was placed several hundred feet west and higher on the slope. Both were pointed south, which avoided problems with the rising or setting sun, and both were centered on the same scene with the high camera providing a wider field of view than the lower one (Figure 4).

At the time of installation, both cameras were thought to be well outside the area of construction although this later proved to be incorrect in the case of the low camera.

Because the cameras were installed on quite short notice there was no time to prepare field mounts ahead of time, and it became necessary to improvise these on the job using survey lath, duct tape, and steel reinforcing bars. The resulting mounts appeared to be reasonably stable (Figure 5), but an unanticipated problem, described in the next section, was discovered during examination of the early pictures.

FIGURE 4 Field of view from high camera location; protective box is visible in lower right corner.

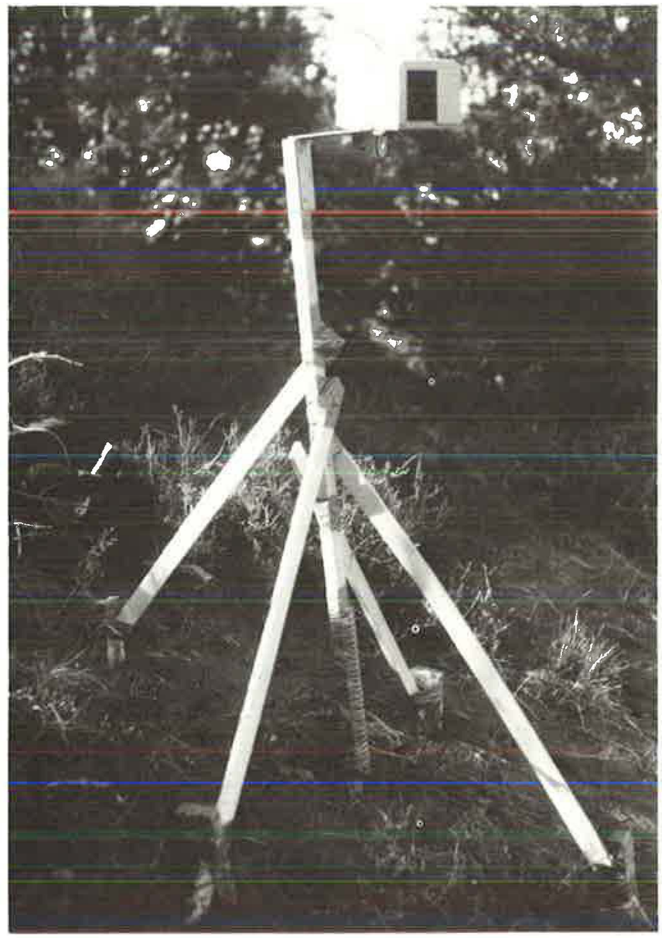

FIGURE 5 High camera installation showing wooden mount.

After the cameras had been mounted, the shutter rate was set at one frame every 90 sec. The rate was then checked for accuracy with a watch to ensure that the rate was not actually faster than indicated, which would mean that the film might run out before the camera was serviced. Both cameras were found to be operating somewhat more slowly than indicated, with between-frame intervals of 99 sec and 105 sec, respectively. Because a 50-ft roll of film provides a run time of 99 hr at the rate of one frame every 99 sec, this allowed an interval of 4 days between film changes. This time interval allowed most of the film in the cartridges to be used yet provided a moderate margin of safety. The manufacturer's instructions stated that a fresh set of batteries would last through two 100-ft rolls of film, but it was decided that a battery change with each film change would provide inexpensive insurance against loss of coverage.

To provide an easily identifiable reference point in the pictures, a target consisting of an orange safety vest strung between two survey laths was driven into the ground at the location shown in Figure 2, near the toe of the main element of the landslide. This was unfortunately removed by construction activity early in the project, but during its brief existence it provided the marker that was later used in determining the rate of movement of the slide.

FILM RECORD

Features

Filming was started on May 4 and continued with a few minor interruptions through June 24, producing an essentially continuous record of both slide movement and construction activity throughout the 52-day period. The 13 rolls of film that were obtained from each camera were edited and spliced together in chronological order for analysis. An attempt was made to copy the low camera record on videotape, but the results were considered unsatisfactory because of poor color rendition and loss of definition. The film was later transferred to 16-mm format for more effective presentation.

Examination of the film shows that both cameras performed remarkably well in spite of changing weather, temperature, and lighting conditions. Color rendition and exposure were good and image definition was as sharp as could be expected from the type of equipment used. Mist or frost on the lens in a few of the early morning sequences degraded the image quality but dissipated rapidly as the sun rose.

Several interesting features of both the landslide and the associated construction activity were recorded on the film. The orange target vest could be observed to change position through the day during the first few weeks of filming, and trees, boulders, and large pieces of landslide material could be seen falling into the creek as the slide advanced. A few days after the beginning of construction activity, two bulldozers were set to work on the east side of Muddy Creek, scraping material from the surface of the slide toe and pushing it into the stream. As the cleared area increased in size, a pattern of small concentric cracks appeared in the bare ground near the edge of the toe and continued to expand in size and complexity for several days until obliterated by the equipment. Two small ranch ponds noted close to the edge of the toe were judged to pose hazards to the construction if they should suddenly breach into Muddy Creek, and the bulldozers were used to cut trenches to drain them into the stream. The film shows the construction of the trenches, and a rapid flow of water from one of them is briefly visible. Another, rather odd, sequence shows a small tree on the side of the pond opposite the camera actually moving past the pond. Although not apparent on the film, a longitudinal crack separating two lobes of the slide was present between the pond and the tree, and the lobe carrying the tree was moving at a faster rate. This shear is designated "Master Shear" in Figure 2.

The roadway construction activity is shown in interesting detail. Lifts of embankment material advance rapidly down the roadway ahead of the equipment, and the increase in embankment height can be measured by comparing the daily changes in vertical distance between the grade and fixed objects on the adjacent canyon wall. At a curve in the stream, the portion of the channel visible to the camera can be seen to alternately constrict and widen as the slide advances and the backhoes remove additional material. At one point, because of topography and camera perspective, the channel appears to close completely as the backhoes fall behind schedule. The nighttime sequences show stationary construction lamps and moving vehicle headlights and include a brief interval about halfway through each night when all of the headlights stop simultaneously while the crews eat lunch. The amount of detail shown and the possibility of correlating this detail with given days and even times of day suggest that the method could also be an effective tool for construction monitoring. A record of this type could be extremely useful in resolving owner-contractor disputes and avoiding expensive litigation.

Local weather conditions at the site were recorded as part of the daily photographic record and included snow, rain, early morning mist, wind, and passing clouds. Effects of precipitation were not apparent in the day-to-day behavior of the landslide and its rate of advancement, probably because of the relatively small amount of moisture and the time required for precipitation to penetrate to the slip zone and generate a noticeable reaction. The films do show that precipitation decreased during late May and June, which probably helped slow the movement of the landslide during this period.

During examination of the daily positions of the vest on the film, it was noted that these occasionally showed retrograde, or uphill, motion. After reviewing several possibilities to account for this unlikely behavior, it was noticed that the aberration appeared to occur during and after periods of stormy weather. This suggested that the wooden survey laths of which the mount was constructed might be warping as they underwent periods of wetting and drying. Comparison of the position of a stable reference point on the cliff face relative to the edge of the picture confirmed that the camera was undergoing slow, periodic, side-to-side movements after each storm. It was soon discovered that small misalignments of the camera were also resulting from removal and replacement of the cameras when the film was changed.

Rate-of-Movement Determination

After the first rolls of film had been viewed, it was decided to use the orange target vest to attempt a determination of the rate of slide movement. This was done by projecting the film onto a cardboard screen and marking the starting position of the orange vest on the screen with a pencil. The position of the stable point on the cliff was also marked on the screen. As the film progressed and the vest moved across the screen, a new pencil mark was added at the dawn positions of both observation points for each subsequent day. To compensate for camera movement, the horizontal and vertical components of the apparent daily movement of both points were measured and the true movement of the vest determined by algebraically adding the apparent movement of the stable point components to the respective components for the vest. The scale in the field of view near the vest was determined from the known length of nearby heavy equipment.

As can be seen in Figure 6, plots of the movement determined by this method show close agreement with similar plots of optical measurements taken by the Colorado Geological Survey. The fairly consistent discrepancy separating the rate curves is believed to result from error in scale determination of the photography or from camera perspective angle (the line of sight of the camera was not precisely perpendicular to the direction of slide movement).

An estimate of the total cumulative distance moved was not possible from the low camera film record because the camera location was changed twice to accommodate construction. Each movement changed the field of view and, along with it, the location of the reference point. The high camera was not moved, however, and a total horizontal movement of 125 ft during the 52 days was estimated from this record. This value was judged to be fairly accurate compared with a known distance scaled from recent aerial photographs of the area.

PROBLEMS AND SUGGESTED SOLUTIONS

Although time-lapse photography provides a number of obvious benefits, the system and methods used on the Muddy Creek project were found to have some disadvantages. All appear to be easily correctable.

Camera Problems

One inconvenience is the lack of an automatic feature to turn the camera on and off at appropriate times. Because of the remote location of the Muddy Creek slide, daily visits to the camera sites were not practical, and the cameras were allowed to operate 24 hr per day. This increased film consumption by approximately 40 percent and necessitated editing the nighttime sequences from the finished film.

To eliminate the need for an additional power source to operate a timer at remote locations, a simple photoelectric switch powered by the batteries in the cameras was developed by the CDOH Physical Research Section. A circuit diagram is shown in Figure 7. The switch, which consists of a cadmium sulfide photocell, a resistor, and a thyristor, was assembled from components obtained from Radio Shack at a cost of approximately $2.50. A variety of CdS cells is available to provide sensitivity to various intensities of light.

Although not a problem on the Muddy Creek project, the maximum delay of 90 sec between frames could be a limitation

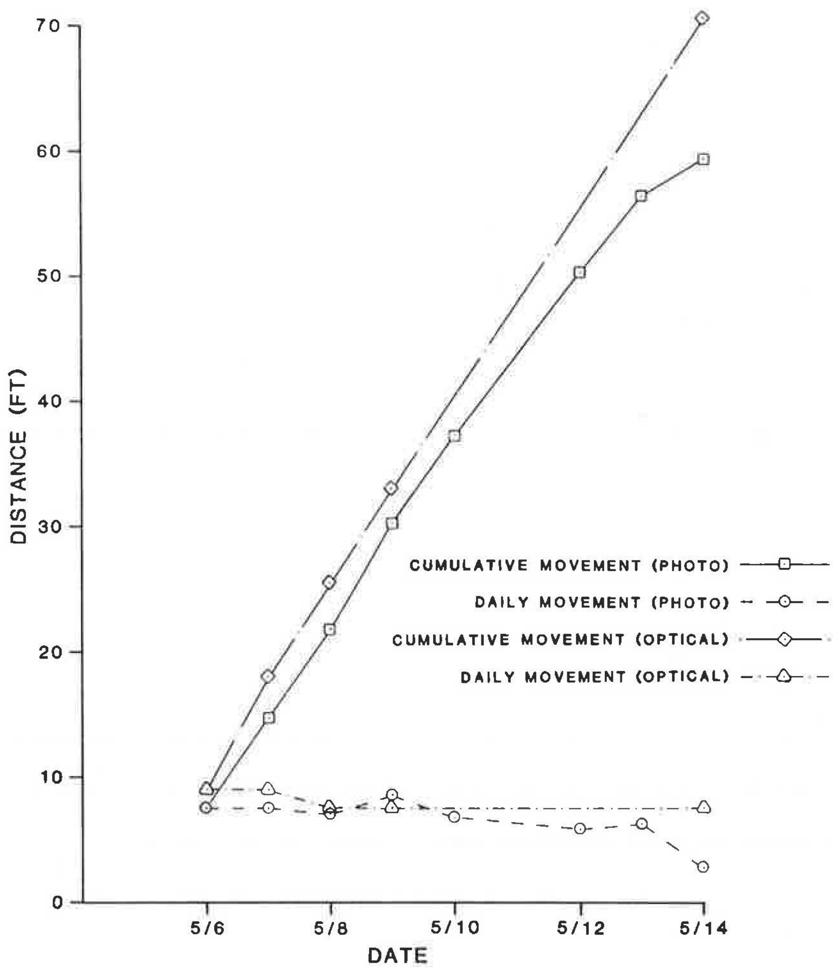

FIGURE 6 Comparison of rate-of-movement aeterminations from time-lapse photography and optical monitoring: Muddy Crreek slide, May 1986.

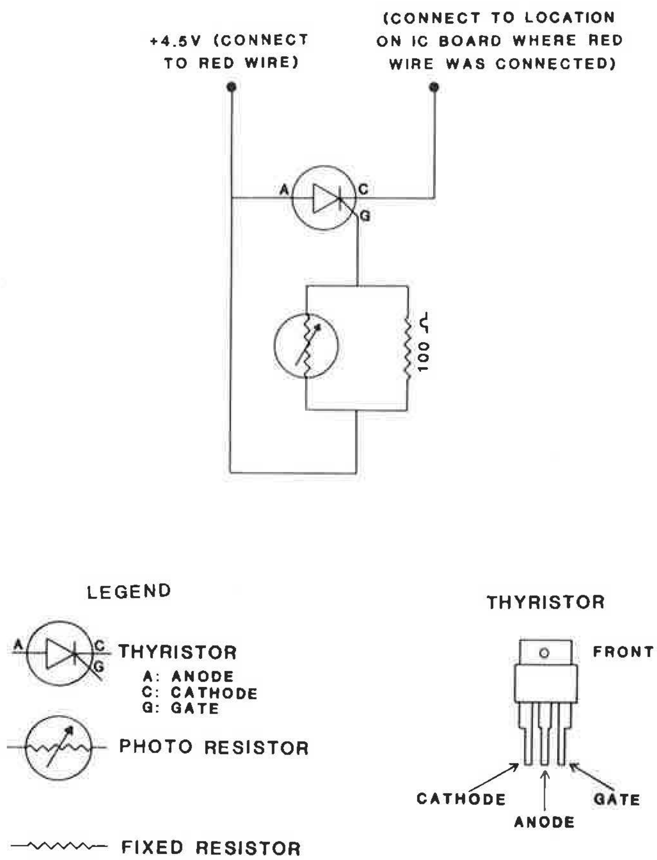

FIGURE 7 Circuit diagram of photoelectric switch.

on other slides. Delays of as much as 15 min would be beneficial in extending the coverage obtained on each roll of film and would give additional flexibility in photographing other long-term events that might be adequately recorded with fewer frames per day.

Mounting Problems

The slight changes in camera alignment, which occurred during film changes, would not constitute a problem if the only purpose of the surveillance was to provide a visual record of slide activity, although the resulting pictures would not transition smoothly between rolls. However, if rate-of-movement curves are to be plotted from the film record, misalignments will cause inaccuracies in recording daily target positions, which must be compensated by the method previously described. To maintain a more consistent alignment between film changes, CDOH is considering a simple gunsight arrangement consisting of two vertical wires attached to the front and rear of the protective case parallel to the optical axis of the camera. The sight would be aligned on a fixed point at the start of filming and realigned on the same point after every film change. A considerably more accurate system would consist of mounting an inexpensive low-power telescopic rifle sight on the case.

Changes in camera alignment resulting from warping of the frame can also be compensated in the manner described, but only if the fixed reference point remains within the field of view. To eliminate this problem, CDOH plans to use a length of steel pipe mounted in a concrete-filled hole for future installations. This should provide a stable mount that can be readily installed. A small platform welded to a pipe connector will be fitted with suitable connections for mounting the protective box. The platform and fitting can then be easily removed for reuse at other locations while the pipe standard remains in place.

A problem encountered on this project, which would probably occur only rarely but which should nonetheless be considered, is stability of camera location. When the cameras were placed on the Muddy Creek project, project personnel provided assurances that the locations would not be disturbed by construction. However, it was shortly decided that the area in which one of the cameras was located would be a good place to obtain additional embankment material for the roadway grade change. This required moving the camera. A few days later additional material was needed, so the camera was moved a second time. Although the cameras were realigned to approximately the same orientation after each move, the change in angle of aspect caused noticeable and disconcerting changes in the continuity of the finished film. In the interest of obtaining a smoothly continuous film record and avoiding the extra labor of moving the equipment, it is important to select camera locations that are the least likely to be disturbed by later changes in plans by persons not involved in the photography.

Other Problems

A vital aspect of using photography as a measuring tool is determination of image scale. This was not considered at the outset of the Muddy Creek project although the need became apparent as soon as the idea of constructing a rate-of-movement graph was conceived. Fortunately, the construction equipment visible on the film provided objects of known dimensions whose images could be measured on the projection screen, but this would not necessarily be the case in all situations in which the method might be used. For future projects, CDOH is planning to use targets made of plywood sheets of known dimensions painted fluorescent orange. To provide backup in case of removal of a target, as happened on this project, it is planned to install a series of two or more targets spaced at measured intervals along a line crossing the field of view of the cameras. The well-defined edges of this type of target should increase the accuracy of scale determinations made from the photographs.

A potential problem, which was not encountered on this project but which appears to be a likely possibility in the future, is the effect of cold weather operation on the dry cell power supply of the cameras. No record of the temperatures encountered during the May–June duration of the filming was available, but, given the elevation at the camera locations (6,700 ft), it is likely that the temperature dropped slightly below freezing for at least a few hours during some nights in early May. The film has not been analyzed in detail for the effects of the lower-temperature episodes, but there are some indications that the filming rate may have decreased. It is thought that an external power source would be advisable if the cameras are to be operated for extended periods in temperatures below freezing.

The department is considering use of a 6-volt motorcycle battery equipped with a voltage divider to provide a higher ampere-hour source. Another advantage of the motorcycle battery would be its ability to be recharged, which would eliminate the expense of replacing the camera dry cells with every film change as was done on this project.

Another potential problem that will undoubtedly be encountered sooner or later is security. The cameras would be a tempting target for thieves or vandals and need to be either carefully concealed or located in places difficult to access. Tall poles have been used with success although ladders are required to service the cameras. Hard shelters can be considered although these would not be completely safe from determined persons even if access were difficult. No problems were experienced on the Muddy Creek project because of the clifftop locations of the cameras and the general remoteness of the area, but these will not be the conditions in all areas where the cameras will be used.

CONCLUSIONS

Experience gained with the use of time-lapse camera equipment on the Muddy Creek slide has shown that the technique can provide an effective, economical observational tool that can be used to measure rates of movement of relatively fast-moving landslides. In addition to providing an amount of detailed information not furnished by any other method, it also provides a permanent, minute-by-minute record of all events occurring within the field of camera view over extended periods of time. Observation of the details of the roadway construction filmed during the Muddy Creek project suggests that the method could be of value in construction monitoring as well.

REFERENCE

1. R. C. Johnson and F. May. *A Study of the Cretaceous-Tertiary Unconformity in the Piceance Creek Basin, Colorado.* Bulletin 1482-B. U.S. Geological Survey, 1980.

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