

MEASURING AND DEPICTING TROUBLE AREAS IN STEREOMODELS

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Landslide detection by applying geology and photo interpretation to photogrammetrically produced highway route investigation and design maps is a continuing policy of the Ohio Department of Highways. Federal Highway Administration funds permitted landslide research and development of an air-photo manual relating to this foundation problem. Stereocompilers, who are trained to detect landslides, can earn their entire career salaries by calling attention to slope instability that, if otherwise undetected, would result in a highway embankment failure. Implementation is based on anomalous contour configuration that contradicts normal topographic expression. One unexpected result of the research was detection of a regional troublemaker with a signature, the Upper Conemaugh red beds. They occur in an arc 100 miles long and 15 to 40 miles wide. As predicted, highway construction provoked numerous back slope slides on the red beds. Further, in the landslide manual, anomalies in the form of bulges were tentatively indicated as potentially more unstable than the visibly sliding slopes. One bulge proved to be the site of one of the worst slides ever involved in a highway cut in Ohio.

•BY the early 1950s, southeastern Ohio had been acknowledged to be an area of landslide prevalence. Condit (2) repeatedly mentions landslides in his assessment of terrain in Ohio. In their study (1), Baker and Chieruzzi rate the region as "severe" with regard to landslides.

Other evaluations have concurred with these opinions, and a study of landslides was initiated because the aerial engineering section of the Ohio Department of Highways had air-photo coverage of numerous route corridors that had been recorded for photogrammetric mapping.

CASE STUDIES

In 1957, a state highway terrain analysis revealed a convergence of evidence that indicated a slope was not stable. The evidence included texture and photograph tones above the existing highway showing that the portion of the field is untillable, fence misalignment indicating slope movement, and topographic position at headward end of drain (Fig. 1).

Field investigation resulted in special highway design to treat this unstable condition. The treatment consisted of cutting a 20-ft wide trench into the existing slope and placing suitable embankment material to backfill to the proposed design grade.

In contrast to the previous unstable condition, this unstable condition was detected and symbolized during highway design mapping.

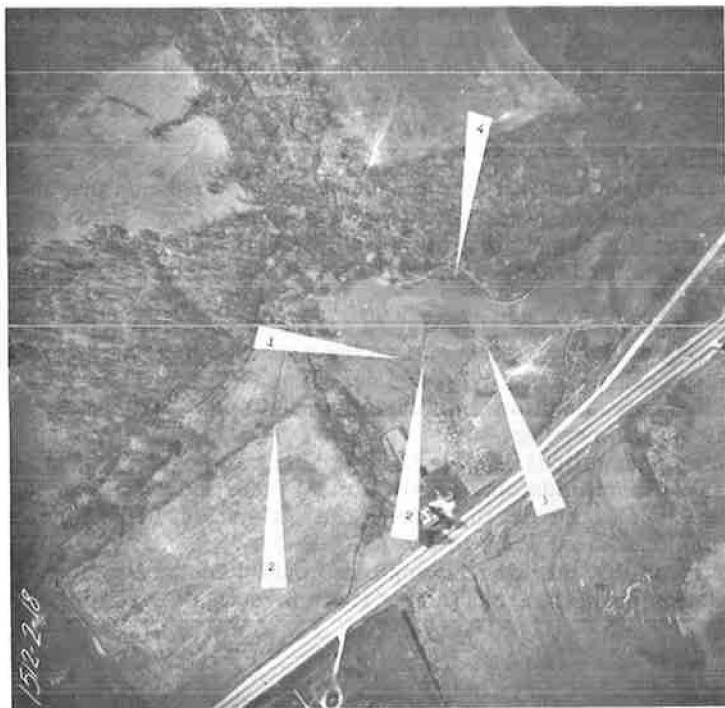
Convergent evidence of unstable conditions include light and dark photograph tones of slope slumping, springs issuing from midslope, small alluvial fans, and an unfarmed wet meadow from the toe of the slope to the run that drains the valley (Fig. 2). An embankment superimposed on this slope failed prior to paving (Fig. 3).

These case studies demonstrated that our stereocompilers could detect, recognize, delineate, and symbolize foundation problem areas during route investigation and highway design mapping.

Figure 1. Evidence of slope instability (1 is uncultivated portion of slope, 2 is fence misalignment, and 3 is topographic position at headward end of drain).



Figure 2. Unstable soil conditions (1 is soil slumping, 2 is springs, 3 is small alluvial fans, and 4 is wet, unfarmed meadow).



The criteria for locating unstable slopes include anomalous contour configuration when contrasted with adjacent stable slopes and the associated visible evidence as seen in the projected stereomodel.

As a result of these findings, Federal Highway Administration funds were granted for researching and developing photograph patterns of potential highway foundation problem areas. These stereopair studies are produced for the compilers who photogrammetrically map route corridors and terrain where highways are to be designed.

Initial research was devoted to landslide conditions, and a manual consisting of appropriate three-dimensional air-photo views and information sheets was developed. The compilers were then given a short course in the research findings. Their knowledge of the appearance of landslides and the associated anomalous contour configuration they observed during compilation enabled them to detect, recognize, and delineate unstable areas.

Figure 4 shows a portion of a highway design map. It was produced prior to the landslide research. Disorientation of the contours on one area of the slope vividly contradicts the adjacent contours where the slope is stable.

A proposed highway centerline traverses the lower portion of the slide area.

To preserve the original appearance of the map no delineation has been done. This enables the viewer to judge the contour anomalies.

After the landslide research had been completed and the compilers trained to recognize unstable conditions, a landslide was detected during highway design mapping (Fig. 5).

Apparently removal of the toe-of-slope material to construct the earthen dam and the associated saturation resulting from the ponded water conjoined to trigger the landslide.

The diagonal line above the landslide is an interceptor ditch that was apparently installed to divert upslope water away from the slide.

Figure 6 shows a portion of the highway design map produced by a stereocompiler using the photography shown in Figure 5.

The limits of instability are indicated by the dashed line shown in Figure 6.

The arrows symbolize the slope movement and its direction.

Contour configuration is anomalous thereby delineating the unstable area and the interceptor ditch.

Special highway design to treat this instability was provided because part of an embankment was to be placed on the landslide.

Implementation of this research is a continuing policy in Ohio. Each compiler has the skill to detect landslides that, if otherwise undetected, could result in a repair cost equivalent to his entire career salary.

THE DESPICABLE UPPER CONEMAUGH RED BEDS

The previous remarks will serve to introduce an interesting chain of events that led to the detection of a regional troublemaker that presented serious highway construction problems.

In 1963, a terrain analysis for an Interstate highway revealed abrupt changes in the slope angles that reflected the rock types within the landforms. More resistant stratigraphic members above and beneath served to bracket about 140 ft of softer strata.

At the northern boundary of this project, the gentle slope occupied a midslope position. The regional trend of the strata along the proposed highway is southward, descending about 30 ft per mile; therefore, at a point 6 miles south along the study area, the lower resistant rocks and the lower part of the softer strata had passed below the point to which erosion had progressed. Figure 7 shows the gentle, unstable slope bracketed between more resistant stratigraphic members.

The findings of this terrain analysis and the subsequent foundation investigation resulted in special highway design relating to the gentle slope because of its persistent indications of instability.

Figure 3. Embankment failure.



Figure 4. Highway design map.

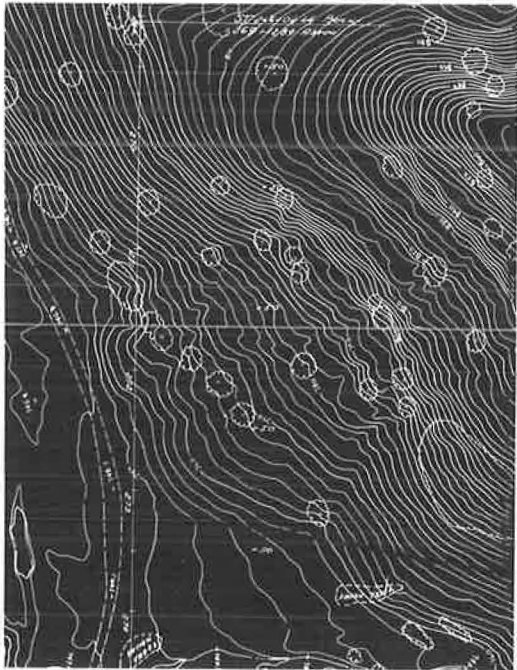


Figure 5. Landslide area (1 is landslide, 2 is interceptor ditch, and 3 is proposed centerline for highway).

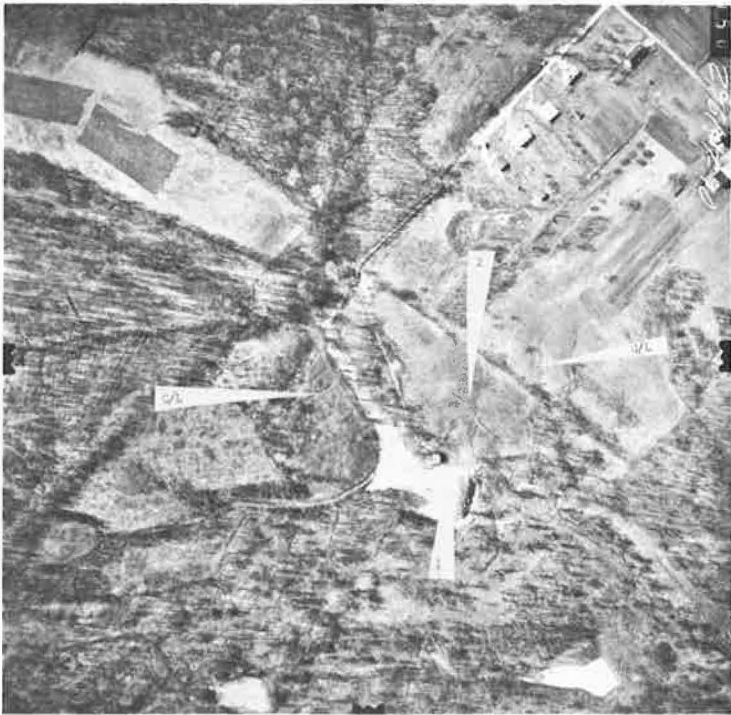


Figure 6. Highway design map produced from Figure 5.



Figure 7. Stereopair showing gentle slope bracketed between resistant rocks.



When the landslide research was initiated in 1965, countless air photographs were studied to select categories and stereopairs for the landslide manual. These had been recorded for photogrammetric work in southeastern Ohio (3). At that time a large percentage of the existing state routes had been photographed. It was during this phase of the research that there evolved the realization of a persistent landform condition in many locations. Recurring views of a gentle, unstable slope bracketed between steeper slopes were found to be common. This was the same type of topography noted during terrain study for the Interstate highway 2 years before.

Further investigation revealed that the capping-resistant rocks are the Monongahela formation and the unstable, gentle slopes are formed on the Upper Conemaugh formation.

Figure 8 shows a classic Upper Conemaugh landform including the steeper Monongahela rocks capping the hill. Note that lower resistant rocks, from the reservoir shore to the Upper Conemaugh red beds, have drainage channels incised into them, but they tend to terminate at the base of the gentle slope.

Following detection of this regional photograph pattern, a section of the manual was devoted to examples from the counties where the Upper Conemaugh red beds outcrop. The slopes shown in Figure 9, photographed 35 miles southwest of the landform shown in Figure 8, make up one of the best stereopairs obtained. The text contained this statement: "Sliding is so prevalent that mapping the areas which are not sliding would greatly simplify the plotter operator's task."

UPPER CONEMAUGH RED BEDS INVOLVED IN HIGHWAY CONSTRUCTION

A review of post-construction photography recorded several years after the Interstate highway was opened to traffic substantiated the term "despicable" for the Upper Conemaugh red beds.

At least 33 backslope movements can be detected where cuts were made involving red beds along a 4-mile stretch of Interstate highway.

Although special highway design had been incorporated into the plans to minimize the problems associated with these strata, Figure 10 shows delineations of detectable backslope movements along approximately 9,000 ft of the new highway.

ANOMALOUS BULGES ON UPPER CONEMAUGH SLOPES

It has been established that the Upper Conemaugh red bed can be observed in an area at least 100 miles long and varying between 15 and 40 miles wide. The regional similarity of the landforms and the persistent instability were documented during a 1-year concentrated study of landslides.

The most fascinating contradiction found on the Upper Conemaugh topography was not, however, its persistently visible unstable condition; rather, it was the presence of certain anomalies. For this reason, additional research time was requested because, as was stated in the text accompanying the manual, "On many landforms the sliding can be observed everywhere. On other landforms some segments of the slope reveal a bulge where the slope appears to be stable. These perplexing anomalies may be potentially more unstable than the visibly sliding segments, when involved in construction."

Figure 11 shows that red beds occur from the floodplain up to the Monongahela caps. The lower resistant rocks have dipped below the point to which erosion has progressed. The delineator indicates a bulge that "appears to be stable."

Figure 12 shows the bulge during highway construction. The delineator indicates the scarp of the landslide involving the bulge.

Excerpts from a paper given by Marshall (4) relating to this bulge include the following:

One of the largest slides we have ever had in a cut slope occurred on I-77 . . . in Noble County . . . In January of 1967, a slide occurred in the east slope . . . This slide did not stop at the roadway as is usually the case with a cut slope landslide, but caused a lateral displacement of the cut slope on the west side and a heaving in the embankment south of the cut and displacement of a bridge abutment for a small county road which was to be abandoned . . . The method of treatment consisted of flattening the slope to 2:1 . . . It was thought removal of this large amount of material, approximately 350,000 yards . . . had a reasonable chance to stabilize the slide. However, further major movement occurred during the summer of 1967, and we therefore elected to lay the slope back to 3:1 through the lower 70 feet of the cut . . . This second slope flattening required an additional 150,000 yards

Figure 8. Stereopair showing drainage channels in lower resistant rocks and lack of channels on Upper Conemaugh red beds.



Figure 9. Stereopair showing sliding red bed gentle slopes.

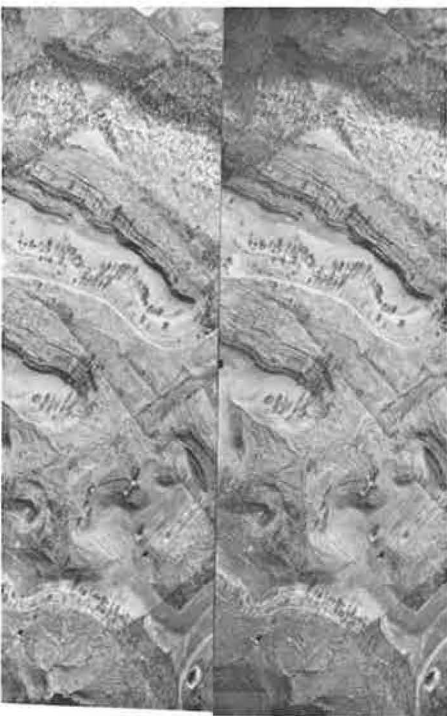


Figure 10. Back slope movements in red beds.

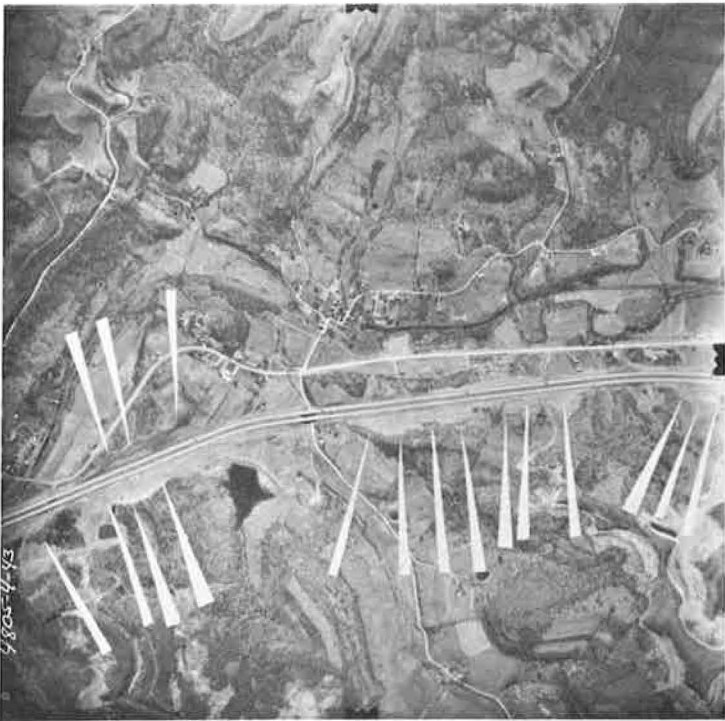


Figure 11. Occurrence of red beds.

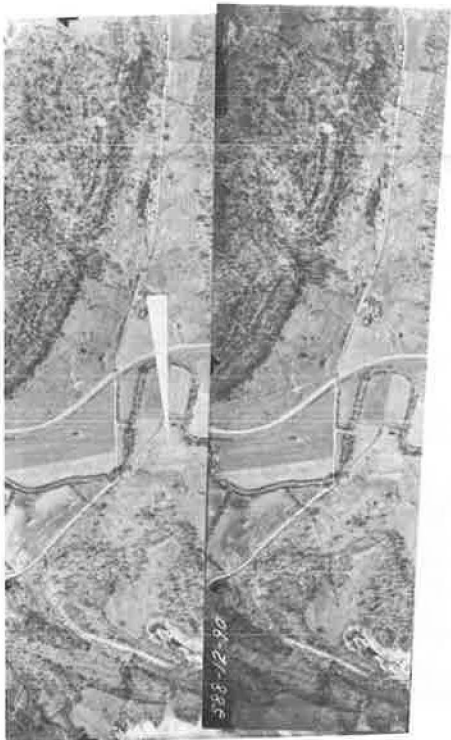


Figure 12. Bulge during highway construction.



Figure 13. Red bed performance on east-west Interstate highway (1 is back slope slide during construction, 2 is closed ramp, and 3 is location where westbound lanes were closed).

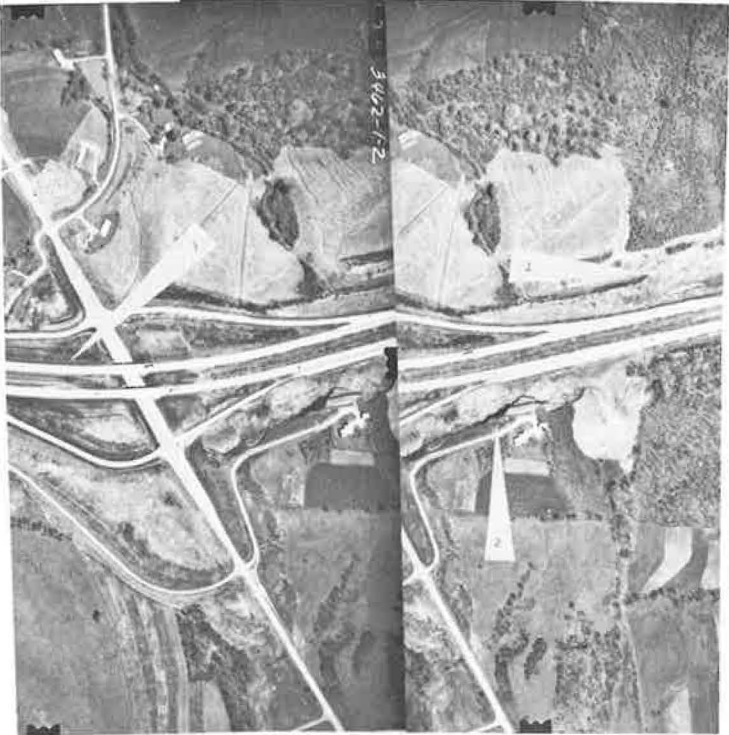
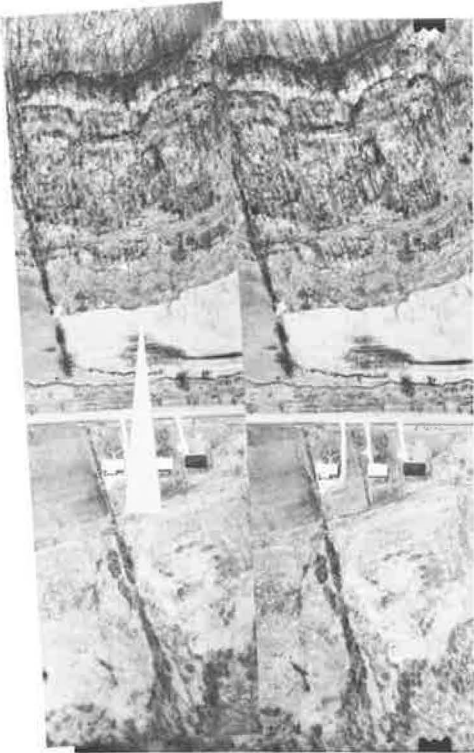


Figure 14. Spoil slide bulldozed to red bed slope.



of excavation; however, it too turned out to be not enough and late in the fall there was further movement in the cut slope and upheaval in the bench and subgrade area for the northbound lanes. An upward revision of the grade for the northbound lanes only . . . provided enough surcharge to establish a temporary balance from July 1968 until January of 1969, during which time the pavement and shoulders were completed and the road opened to traffic . . . In all, we have removed about one-half million yards more material from this cut than the plan quantity. This is not the end; however, in the past month further movement has occurred in the slope with resultant heaving in the paved shoulder and in the outside lane . . .

Miles away the red beds also outcropped along this east-west Interstate highway (Fig. 13).

Figure 13 shows the location of back slope slides that occurred during highway construction and the location where the westbound lanes were closed during the summer of 1971 due to slope instability. Also shown is a closed on-ramp. Today the entire back slope has been flattened, and the residence has been moved.

MINING PROBLEMS ASSOCIATED WITH UPPER CONEMAUGH RED BED TOPOGRAPHY

The basal member of the capping Monongahela formation is the Pittsburgh No. 8 coal. Bedded approximately 30 ft above is the position of the Redstone 8a (Pomeroy) coal.

Where these seams are of minable thickness, abandoned drift mines continue to collect landform water. Particularly in the down-dip portion of the mine, constant saturation of the Conemaugh slopes goes on, aggravating the deformation of the plastic soil that formed on the red beds.

Where strip-mining has been done, the spoil piles have been piled on the slope, in essence loading the slope. When they slide they virtually bulldoze the soil that formed on the red beds into piles lower on the slope. Although the natural slope instability cannot be seen from air photographs, knowledge of the regional instability of this stratigraphic group permits inferred evaluation based on its past performance.

Figure 14 shows a spoil slide that has carried with it trees and slope soil. It is encroaching into a portion of a cultivated field as delineated.

REFERENCES

1. Baker, R. F., and Chieruzzi, R. Regional Concept of Landslide Occurrence. Eng. Exp. Sta., Ohio State Univ., 1958.
2. Condit, D. D. Conemaugh Formation in Ohio. Ohio Geological Survey, Bull. 17, 1912.
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4. Marshall, H. Landslide Recognition and Control on Ohio Highways. Presented at Ohio State University, 1969.