THE
TORONTO SECTION:
A STUDY OF
SLOPE STABILITY

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Northwest view of cut slope along State Route 7, between Toronto and Empire, Ohio. (Stations 1490 to 1505)

Author, standing on Upper Freeport Coal, measuring a dislodged block of Mahoning Sandstone. (At station 1479)
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INTRODUCTION

It was brought to my attention by a geologist employed in the Highway Department that during the construction of the new State Route 7, north of Toronto, Ohio, movement had possibly occurred in the cut slope. The evidence for this suspicion was that the plotting of spot elevations from consecutive aerial surveys of the construction site had shown a downward progression of points at the crest of the slope, in areas untouched by actual excavation, termed original ground. I might add that the use of photogrammetry methods of surveying during excavation of road cuts is unusual; however, due to the height and steepness of the slope, normal hand surveying methods were impractical and almost impossible. Such a complete aerial survey afforded an excellent opportunity to study the stability of this particular slope during excavation.

The purpose of this study is to prove whether slope movement actually occurred, to measure the extent of movement, and to investigate possible causes if movement did indeed occur.

The data used in the study were obtained through personal investigation at the site, including measurement of geologic sections, photographs of geologic features exposed in the road cut, and inspection of the slope for features indicative of slope movement; topographic maps, plans of the project, aerial photographs, and numerical survey data were obtained from the Division of Aerial
Engineering of the Ohio Highway Department; details of the local geologic features were obtained from the Ohio Geological Survey Bulletins; details of geologic features exposed in road cut were obtained from the roadguide, published by the West Virginia Geologic and Economic Survey; maps of the mines were obtained from the Ohio Division of Mines.

The numerical data were assimilated and processed using an IBM 360-50 computer and the results were plotted as a contour profile, showing slope movement. This profile was then the basis for the analysis of slope stability with respect to geologic features.
MAJOR GEOLOGIC AND GEOMORPHIC FEATURES

The road cut which was studied is located along State Route 7, adjacent to the Ohio River, between Toronto and Empire, Knox Township, Jefferson County, Ohio. (See Figures 1, 2, and 3.)

The area under study is further divided into stations, a term used by the Ohio State Highway Department to designate planes, extending perpendicular from the center line of a highway. The numbers by which stations are called are measurements of the distance in feet along the center line from the southern boundary of the county. The stations under study are numbers 1450+00 to 1505+00, meaning 145,000 feet to 150,500 feet along the center line of Route 7, from the southern border of Jefferson County. The figures in this report are labeled according to this convention.

Jefferson County is located in the physiographic province known as the Appalachian Plateau, which in Ohio is referred to as the unglaciated plateau. A plateau region is generally considered to be a broad highland, bordered by escarpments and distinctly higher than the surrounding regions. In Jefferson County, distinct features of a plateau have been destroyed by stream dissection, with the result that the county is very hilly with relief increasing toward the east.

The plateau region is underlain by thin to medium bedded shales, limestones, and sandstones of Mississippian, Pennsylvanian, and Permian ages. The upland terrain soils are thin with greatest depth of
weathering and accumulation of residual material occurring on steep slopes, particularly those which face in a northerly direction.

The short, high gradient streams of Jefferson County empty directly into the major water course of the region, the Ohio River. Broad continuous valley plains have not developed along the Ohio River and the tributary streams join the river from steep-sided ravines. The cities and industries in the Ohio Valley are located on the concave side of broad meander curves where plains, one-half mile wide, have been cut by the river. Highways and railroads linking the populated valley flats are crowded in narrow corridors along the bank of the river on narrow flood plains or are benched into the base of the adjacent hill slope, as is this particular section of highway under study.

In this valley corridor, the Ohio River lies at a mean elevation of just below 600 feet. The old Ohio Route 7 lies 50 feet from the river bank on the flood plain of the river, at an elevation approximately 5-10 feet above water level. The flood plain extends 200 feet where it meets the steep valley wall. The Pennsylvania Railroad right-of-way lies approximately 25 feet above the flood plain, benched into the slope of the valley. The new State Route 7 lies in a deep side-hill cut, rising from an elevation of 700 feet to 800 feet at its crest. The road cut is approximately one and one-fourth miles in length, oriented north-northwest - south-southeast; its approximate southern boundary is Croxton Run and the approximate northern boundary is Jeremy Run. The limit of the slope extends horizontally as much
as 700 feet from the center line of the highway and reaches a maximum
elevation of 1175 feet. Four hundred feet of middle Allegheny to
middle Conemaugh rocks are exposed. Several deep ravines dissect
the face of the road cut. Abandoned coal and clay mines give evi-
dence of extensive previous mining in this particular slope.
GEOLOGIC FORMATIONS

Rocks of the middle Allegheny to middle Conemaugh Series are exposed in the Toronto Section. The following is the description of the members displayed in Figures 4, 5, 6:

Allegheny Series

1) Clarion Coal and Clay
   a. Underlie the roadcut at the elevation of the Ohio River.
   b. Do not crop out, location known from mine records.
   c. Clay is 9-12 feet thick; coal is approximately 1 foot thick.
   d. Clay is of plastic variety.
   e. Clay was mined at the southern limits of the roadcut, at the former site of the town of Calumet.

2) Lower Kittanning Coal and Clay
   a. Beds crop out slightly above the railroad in the northern end of area.
   b. Clay averages 9 feet in thickness.
   c. Clay is arenaceous and plastic.
   d. Mined extensively by the American Sewer Pipe Company and the Minor Firebrick Company, before 1912. (See Figure 7.)

3) Middle Kittanning Coal and Clay
   a. Clay crops out above the railroad but is covered by surface debris.
   b. Clay averages 7 feet in thickness; coal averages 1 foot in thickness.
   c. Clay is arenaceous and low in plasticity.
   d. Coal is shaly and impure.

4) Washingtonville Shale
   a. Located several feet above middle Kittanning Coal.
   b. Only a few inches thick.

5) Lower Freeport Sandstone
   a. Material in which pavement of S.R. 7 was laid in northern 500 feet of the roadcut.
   b. Approximately 40 feet thick but variable.
   c. Heavy-bedded, course-grained. Some interbedding of arenaceous shales.
GEOLOGIC MAP OF OHIO AND
MAP OF KNOX TOWNSHIP (Jefferson County)

FIGURE 1
TOPOGRAPHIC MAP
Showing area of study between Toronto and Empire, Jefferson County, Ohio. Contour interval is 20 feet (some contours omitted)

FIGURE 2
6) Lower Freeport Clay and Coal  
a. Elevation is approximately 750 feet at the south, rising to 775 feet at the northern end of the roadcut.  
b. Coal and clay together are approximately 7 feet thick.  
c. Coal was mined and used for firing of clay products.

7) Upper Freeport Sandstone  
a. Exposed at an elevation of 800 feet at the northern end of the section. Grades into shale to the south.  
b. Greatest thickness is 75 feet.  
c. Cross-bedded, poorly cemented, coarse-grained, micaceous.

8) Upper Freeport Limestone  
a. Occurs at an elevation of 800 feet, immediately below the Upper Freeport Coal, in the southern half of the roadcut.  
b. The greatest thickness is approximately 4 feet.  
c. Fossiliferous, fresh or brackish water deposit.

9) Upper Freeport Coal and Clay  
a. Occurs at elevation of crest of highway (800 feet). Rises, northerly, to an elevation of 840 feet.  
b. Clay is plastic and arenaceous.  
c. Coal is the uppermost member of the Allegheny Series.  
d. Coal is approximately 3 feet thick and has been mined in a few places.

Conemaugh Series

1) Above the Upper Freeport Coal is arenaceous shale of variable thickness. In the central portion of the roadcut, this shale has been replaced by the Upper Mahoning Sandstone, at the same elevation. At the base of the Upper Mahoning Sandstone is a scourbottom conglomerate, which is a surface of unconformity. The Upper Mahoning Sandstone has a maximum thickness of 40 feet and grades laterally into arenaceous shale. The sandstone is coarse-grained and micaceous. Within the sandstone is an abandoned channel fill of shale, located between stations 1483 to 1487, at an elevation of 850 feet. (See Figure 4.)

2) Above the Upper Mahoning Sandstone is an interval of shale. The lower beds of the shale intertongue with the sandstone. The shale is quite variable in thickness. It is present in the section except between stations 1489 to 1495, where it has been replaced by the Buffalo Sandstone.

3) The Brush Creek Coal occurs in three segments above the shale in the northern portion of the roadcut. Its thickness does not exceed 2 feet.
4) The Brush Creek Limestone occurs as a remnant at an elevation of 900 feet, between stations 1466 to 1470. Its thickness is no more than 3 feet.

5) Both the Brush Creek Coal and Limestone have been cut off by an unconformity.

6) The Buffalo Sandstone was deposited over the unconformity. A conglomerate occurs at the base of the sandstone, and is particularly noticeable in the channel bottom located at station 1490, at an elevation of 875 feet. The sandstone is medium to coarse-grained, micaceous, and is composed of quartz sand and altered feldspar. It is light greenish-gray in color. The thickness of the unit varies from a maximum of 100 feet, at station 1489, to a minimum of 5 feet, at station 1497. The variable thickness is due to cross-bedding and build-up of thickness during deposition in a channel environment.

7) The Buffalo Sandstone intertongues with the extensive shale unit above it. Shale extends up beyond the slope limit. The shale is thin bedded, green in color, and on its surface, weathers into flaggy material. At station 1501, core samples showed that the shale was jointed and slickensided at its base.

8) Within the shale, at an elevation just below 1000 feet, is a thin coal bed, called the Wilgus Coal. A thin bed of limestone occurs directly above this bed.
PREVIOUS MINING IN AREA

This area was an early center for clay products and Toronto and Empire grew from this industry. In 1869, the Minor Firebrick Company was established one mile south of Empire, which is the area under study. The company mined Lower Kittanning Clay and used in the manufacture of firebricks. Plants numbered 13 and 14 of the American Sewer Pipe Company were established in this area in 1873. The company mined the Clarion Clay and the Lower Kittanning Clay to produce bricks, sewer pipes, flue linings, stove pipes, etc. This company also mined the Mahoning and Lower Freeport (Roger) Coals for use in firing the kilns. The bed of the Mahoning Coal, like the remnants of the Brush Creek coal we see in the face of the cliff today, was probably truncated by the unconformity, and thus was of limited extent. No evidence of the Mahoning Coal was seen in the face of the roadcut; however, it was mined at an elevation of 860 feet and reported to have a thickness of four and one-half feet.

The mines have long been abandoned due to the exhaustion of the coal or a thinning of the bed, before 1915. The extent of mining of the two companies was quite extensive, as shown in Figure 7. The shafts were an average of ten feet high. The Minor Firebrick Company shafts extended 2,500 feet westward into the hill, between stations 1500 to 1510. The American Sewer Pipe Company shafts extended 1,000 feet westward into the hill, between stations 1480 to 1495.
GEOLOGIC SECTION
Station 1501 +00

ARENACEOUS SHALE
FRACTURED, JOINTED* and WEATHERED

JOINTED*SLICKENSIDED
Buffalo Sandstone
Brush Creek Coal

Upper Mahoning Sandstone

ARENACEOUS SHALE
JOINTED* and BROKEN
Upper Freeport Coal

Upper Freeport Sandstone

Lower Freeport Coal

-1050
-1000
-950
-900
-850
-800
-750 (Base)

* Diagonal lines indicate jointed zone

FIGURE 5
Mine Map
Showing location of abandoned mines adjacent to S. R. 7
(BETWEEN STATIONS 1480 and 1505)

Scale: Feet

Mine Locations

FIGURE 7
DATA CHARACTERISTICS

This study utilized four aerial surveys, done over a period of two years for detection of movement on the slope. Date of the first aerial survey was August 8, 1967, which was before construction was begun. The two intermediate surveys were made during construction. The final survey was made after completion of the highway, November 22, 1969.

The aerial surveys yielded aerial photographs which were used to determine elevations of points on the ground along the right-of-way of the highway. The points were measured to the left and right of the center line, along station lines which were at fifty foot intervals. Approximately thirty points to the left of the center line (westerly) were taken at each of these station lines, out beyond the slope limit to the original ground.

The points were then plotted and the elevations measured by State Highway Department personnel using a Kelah Sterographic Plotter. Many of the points coincided geographically in two or more of the four surveys, providing an opportunity to compare elevations at the coinciding points, thus determining elevation changes occurring between surveys.
COMPUTER PROCESSING

An IBM 360-50 computer was used for convenience and expediency. The following information was typed on IBM cards:

1) The survey number.
2) The station number.
3) The point location (distance along the center line and distance perpendicular from the center line).
4) The corresponding elevation to the point.

This procedure was followed for each of the twenty-nine stations between 1491+100 to 1505+100, with approximately thirty points per station, and for all four surveys.

A computer program was written to read in the data cards. The order was to read the data of all four surveys, one station at a time. The program then sorted between two consecutive surveys, those points which coincided in location and determined the vertical displacement at these points, from one survey to the next. This was repeated for the three consecutive pairs of surveys, 1-2, 2-3, 3-4, and the results printed out. This process was repeated for each of the twenty-nine stations.

The results of the above program, as printed out by the computer, were as follows:

1) The station number.
2) The consecutive pair of surveys being considered.
3) The elevations and numerical displacement of the coinciding points.
A set of cards for each of the three consecutive pairs of surveys was then punched out by the computer. The information on the cards consisted of the locations of the geographically coinciding points and their associated displacement, for all the stations.

At this step, the program eliminated all the coinciding points with displacement greater than ten feet in order to eliminate data concerning displacement obviously due to excavation.

The remaining points were used in a second IBM 360-50 computer program to produce plotting commands for use with the IBM 7094 computer and a Calcomp Model 563 digital incremental plotter. The purpose of this step was to produce a display of the numerical results in the form of a contour map.
RESULTS OF DATA PROCESSING

The computer program ran as required and printed the desired information. It found a total of five hundred and forty coinciding points, or spot elevations, with two hundred and seventy-two coinciding points found in comparing surveys 1-2, eighty-six coinciding points found between surveys 2-3, and one hundred and eighty-two coinciding points found between surveys 3-4. Vertical displacement ranged from minus six feet to plus five feet, including many points showing zero displacement.

These points and the associated displacement were then plotted and contoured on a profile of the slope. (See Figure 8.) The profile map was used for easy reference to the geologic profile for analysis.

The plotting of the profile was done on the digital plotter; however, the results were not satisfactory and could not be used for meaningful interpretation. The failure occurred in the sub-routine which is a part of the system's library, and which contoured the points. Despite several attempts to rectify the problem through changes in the program, no satisfactory results could be obtained. Therefore, the plotting and contouring of points was done manually.
ANALYSIS AND DISCUSSION

Positive displacement of points is interpreted as shear failure along one or several surfaces, causing lateral movement along the face of the slope. Negative displacement of points is interpreted as slump or subsidence. Further interpretation is made taking into account the geologic structure and rock type.

A significant displacement or movement occurred between the third and fourth surveys. Up to the time of the third survey, excavation had not progressed deep into the side hill cut. Between the third and fourth surveys, the final depth of excavation had been reached. The resulting pattern of apparent movement is in the contour profile, Figure 8.

Negative displacement, signifying slump or subsidence occurred between stations 1494 to 1497, at elevations above 900 feet. This is an extensive area covering approximately 10,000 square yards on the face of the slope.

Positive displacement, signifying apparent lateral movement, occurred between stations 1499 to 1505, at elevations above 800 feet. This, too is an extensive area, covering approximately 10,000 square yards on the face of the slope. In each case, the greatest displacement occurred at the highest elevations. An anomaly appears between stations 1502 to 1504, at the elevation of 950 feet, at the limits of the cut slope, in which zero displacement occurred. An investigation of the topography shows that these points are located above the crest.
of the slope, in a flat area. The type of movement which occurred on the sloping ground in this area would not result in elevation change of the flat area.

Two hypotheses, to account for the negative displacement between stations 1494 to 1497, may be considered. The hypothesis that slump had occurred would indicate that movement was produced along an internal slip surface. It would be assumed that the internal slip surface was concave upward, as has been found in the majority of slump movement studied. Visual evidence for such movement would be bulging at the foot of the surface of rupture and some evidence of a main scarp at the crown of the slide; associated with main scarp, tensional fractures are occasionally found above the crown.

None of these features was found at the site; however, the indicated displacement was so small, that a large main scarp would not be produced. A small scarp could easily be masked by the soil and debris at the crest of the slope. If this was a slump movement, its magnitude suggests that the surface of rupture which occurred would have been large enough to produce bulging at or below the level of excavation, below 850 feet. As the surface of rupture would have extended deep below the level of excavation, the excavation would have removed the evidence of bulging. As can be seen on the geologic profile, the entire area where movement occurred is composed of shales, which are amenable to slumping. The reasons for this are that shales are poorly consolidated and friable. Below the shales are the plastic clays which yield to movement by a type of plastic flow. The thick sequences of
lower Freeport and Mahoning Sandstones are competent layers and would tend to act as barriers to deep seated movement. The presence of these sandstones casts doubt on the slump hypothesis.

The second hypothesis is that the negative displacement was caused by subsidence due to compaction of the shales or settlement over abandoned mining areas. Subsidence is defined as movement in which there is no surface of rupture and material is displaced vertically downward with little or no horizontal movement. The pattern of movement shown through visual inspection of the site and in the contour profile conforms to movement of subsidence type.

Further support for this hypothesis is the fact that the abandoned mine shafts of the American Sewer Pipe Company are directly below the area of movement, as verified by Figure 7. Within the mines, void areas are present in the form of open rooms and galleries. Roof collapse and failure of supporting pillars would probably cause instability of the overlying materials. Shales and jointed sandstones, such as the Lower Freeport and Upper Mahoning Sandstones, are particularly susceptible to collapse at these unstable areas.

Further support for the subsidence hypothesis is that as a result of excavations such as this, there is usually a lowering of the water table in the adjacent slope. The draining of shales, such as the shale in this case, may result in compaction of the shales, due to the withdrawal of liquids from pore spaces in the sediments.

Between stations 1499 to 1505, positive displacement occurred, which is interpreted as shear failure along one or more surfaces, causing
lateral movement. This kind of movement is generally a result of removal of supporting material from the base of the slope or surcharge pressure applied above the crest of the slope. Such pressure could be the result of depositing excavated materials above the slope. In this case, the excavation certainly did remove material from the base of the slope. Failure very likely occurred along a shear plane, such as the jointed slickensided zone at the base of the shale unit, immediately above the Buffalo Sandstone. Or, it may have occurred along the jointed and broken shale, immediately above the Upper Freeport Coal. Both these zones were found during study of the preliminary drill cores. Slickensides are evidence of movement along the zone in which they are found. These zones are known to be incompetent because they had previously yielded to natural stresses imposed upon them.

Loading above the crest of the slope was done at the southern portion of the roadcut, stations 1454 to 1468, resulting in actual landslides. This is outside the area initially suspected of movement. The Ohio Highway Department then ordered the ceasing of dumping of waste materials above the crest of the slope. Thus, there was no loading above the crest of the slope north of station 1468+100.
CONTOUR PROFILE

Showing changes in elevations of points on the cut slope of S.R.7, between stations 1491 and 1505. Annotations are changes in feet (+ or -)
SUMMARY

This study was undertaken with the purpose of determining whether movement had actually occurred on the slope of the road cut, resulting from construction of State Route 7, north of Toronto, Ohio. The data from four aerial surveys were processed, using an IBM 360-50 computer, and a contoured profile map made. Detailed geologic data for the area were compiled. Reasonable evidence for movement was found through the data resulting in the contoured profile map and an analysis of the movement was made using the geologic data, represented by the detailed geologic profile.
CONCLUSION

Although this study showed that movements had occurred along the road cut, the movements were not great enough to be considered serious. No visual evidence of movement was found upon investigation of the site, other than minor surface rockfalls due to active weathering processes on the face of the slope.

Since all of the beds which compose the cut slope are horizontal in attitude, there does not seem to be an immediate threat that the movement already recorded will result in further mass movement. At present, the slope appears stable.
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