MINE SUBSIDENCE INVESTIGATIONS IN HILLSLOPE/LANDFILL AREAS[1]

by

James W. Mahar PhD/LPG and David A. Berner BSCE/EIT[2]

Abstract. The procedures for carrying out three mine subsidence investigations in damaged homes on and adjacent to slopes and landfills are discussed in this paper. The procedures basically involve a review of the geotechnical/coal mine literature, field studies of the damage to structures and site specific topographic/geologic conditions and instrumentation to monitor ground movement. In cases where the valley is shallow (less than 15 M [50 ft] of re-lief) and bedrock is exposed, precise level line surveys can be carried out on settlement points placed in a profile line from the crest to the floor of the valley. In landfills and deeper valleys where rock is not exposed, bore holes should be rig drilled and settlement points, extensometers and/or inclinometers used to identify the nature of any ground movement. Observations of rock disturbance in the outcrop exposures or in the cores provide an index of potential mine subsidence movement. The absence of such disturbance indicates that the hillslope or landfill is not being affect-ed by failure at mine level. The techniques given in this paper provide a simplified methodology for determination of the cause and origin of damage to structures in complex topographic/geologic settings.

Introduction

Mine subsidence investigations have been performed throughout Illinois by the staff of Geotechnical Consultants Inc (GCI) during the past 24 years. Some of the most complex cases involve damaged structures built on or adjacent to slopes and over landfills. Coal mine subsidence can damage these structures either by direct ground movement in a sag or pit or can induce ground displacement which ultimately causes slope failure that intersects the building.

Procedures have been developed that simplify and allow determination of the cause and origin of damage in areas with abandoned coal mines below hillslopes or landfills. In Illinois as well as many other coal producing areas, the coal often outcrops in the valley and thus is present near the ground surface. Mine subsidence is typically pit or a combination of pit and sag surface expression. Material sampling and geotechnical instrumentation along with the damage pattern are key elements in the investigation to assess the nature of the ground displacements and cause of building distress.

Three cases of damaged structures adjacent to hillslopes and a landfill are discussed in this paper. The cases are listed as follows:

· Case 1: building at crest of shallow valley with rock outcrop in stream bank;

---

[1]Paper presented at the 2001 National Meeting of the American Society for Surface Mining and Reclamation, Albuquerque, New Mexico, June 3-7, 2001. Pub. by ASSMR, 3134 Montavesta Rd., Lexington, KY 40502.

[2]James W. Mahar, Ph.D/LPG is President of Geotechnical Consultants Inc., #4 College Park Court, Savoy, Il. 61874

David A. Berner, BSCE/EIT, is an Engineering Intern at Geotechnical Consultants Inc., #4 College Park Court, Savoy, Il. 61874

Proceedings America Society of Mining and Reclamation, 2001 pp 151-158
DOI: 10.21000/JASMR01010151

https://doi.org/10.21000/JASMR01010151

· Case 2: building on and adjacent to land fill placed to cover abandoned sand and gravel quarry; and

· Case 3: buildings and in-ground pool on and adjacent to a deep and wide river valley.

In each case the overall procedures are similar but are modified based on the site specific details of the particular case.

Basic Concepts

The following general procedures are used in slope/landfill damage investigations:

1) map building damage:

a) record damage and identify the potential center of movement zone (typically we do not expect compression damage in a hillslope area: this is an anomalous condition that requires further investigation);

b) look for and record the nature of any damage in adjacent structures:

1. determine if major damage elements are aligned to delineate the zone of movement.

2) identify and instrument depressions in ground surface;

3) sample and test near-surface soils;

4) examine rock exposures and identify any areas of disturbance;

5) drill holes and install settlement points, extensometers and/or inclinometers in areas of greatest structural damage and along hillslope profile:

a) examine rock core for bedding rotations or disturbed zones;

b) record depths of lost drilling fluid circulation; and

c) install at least one anchor point in rock at bottom of bore hole.

6) record and locate any scarps or offsets in slope:

a) identify springs and hummocky areas at the to of the slope that indicate past or present movement.

7) determine the nature of the land fill materials:

a) look for any obstructions in landfill materials that could cause premature refusal of settlement point installations; and

b) determine whether voids are present in fill that could cause volume changes.

In the Illinois Coal Basin, most of the sedimentary rocks are horizontally bedded. The geologic literature should be consulted for bedding orientations in a study area. Bed rotations and disturbed zones are indicative of deep-seated ground movement.

Extensometers are steel rods with anchors placed at different depths and are used to measure vertical displacements. Inclinometers are instruments that are lowered down grooved casings. Measurements are made at right angles along grooves which should be oriented parallel and perpendicular to the slope. The inclinometer is basically a servo accelerometer in which the voltage output changes with changes in the inclination of the casing. Horizontal displacements are determined by differences between initial and subsequent readings. Inclinometers are installed in rig-drilled bore holes. Extensometers can be placed along with the inclinometer casing or can be installed separately in hand-drilled or rig-drilled bore holes.

Part of the initial investigation includes a literature search to determine the following features:

· presence of abandoned mines in area and nature of extraction practices;

· thickness of overburden and rock above abandoned workings;

· coal bed thickness and nature of claystone beneath coal bed; and

· vertical elevation difference between structure and valley floor.

Rainfall records obtained from the nearest weather station are of-ten helpful in evaluating the timing and sequential development of damage.

In areas where mining is deep (e.g. greater that 45 to 60 m [150 to 200 ft]) it may not necessary to drill into the abandoned mine. In such cases settlement points and/or extensometers with anchors installed in rock will be sufficient to determine whether or not any ground movement is deepseated. Vertical ground displacement below the soil/rock contact is indicative that mine subsidence is active and is responsible for the building damage. The drill hole should be cored at least 2.4 to 3 m (8 to 10 ft) into rock to establish that the bore hole is below the soil/rock contact and to check the bedding orientation. Two or more extensometer rods should be installed and grouted in place: one at the bottom of the bore hole and one near the top of rock.

Case 1: Slope Movement Above Shallow Bedrock

The first case involves a multistory home built into the crest of a creek hillside in Catlin, Illinois. The structure has block foundation walls (11-1/2 and 21-blocks high) with the first floor level at the crest of the ridge. The back of the building is near the base of the steep slope. A small perennial stream is located approximately 56 m (185 ft) south of the dwelling. Horizon-tally bedded shale is exposed in the sides of the present creek channel. A flood plain lies between the home and the stream and the foundation was built approximately 5 m (16 ft) above stream level. A scrap with 0.6 m (2 ft) vertical offset and attendant depression were found in the flood plain approximately 20 m (65 ft) from the south wall of the dwelling. Ground water was observed seeping out at the midpoint of the slope near the southwest corner of the home.

The damage in the home consists of outward rotation of the back or downslope wall with horizontal and diagonal cracks along the mortar joints. In the basement, the south wall moved laterally 0.6 to 3.2 cm (1/4 to 1-1/4 in.) and the wall rotated out at the base 1.2 cm (1/2 in.). Racking deformations in north-south door frames were typically 3 to 5 mm/0.6 m (1/8 to 3/16 in./2 ft) and the basement floor sloped 114 mm (4.5 in.) in a downslope direction.

To determine the cause of the damage, a series of settlement points were installed in hand augered bore holes at various points along the ground surface profile (Figs 1 and 2). Because the valley is shallow (10 m [34 ft] from crest to channel) and rock was exposed in the stream banks, settlement point instrumentation was adequate to evaluate the ground movement. One settlement point was driven to refusal and concrete-anchored in the shale exposed in the creek bank (SP-5). There is no indication of bedrock disturbance along the exposed length of the stream valley. Two other settlement points were driven to refusal in bedrock in the depression and on the outside edge of the scarp (SP-4 and SP-3), respectively. The fourth and fifth rods were driven to refusal in the fill slope behind the home and in soil in front of the residence.

If subsidence is responsible for the ground movement and damage to the structure, the center of the movement zone must be located south of the home. In the instrumentation arrangement, the downslope extensometers (SP-3 to SP-5) are used to look for down-ward movement in rock. Since the mode of failure in mine subsidence begins at mine level below the soil/rock contact and progresses upward, the settlement points founded in rock should have significant downward movement if mine collapse is responsible for the damage. In the absence of downward movement in the rock, the settlement points installed in the fill and overburden soils should show upward and downward displacement consistent with moisture content changes and creep in the hillslope soils.

The cause of damage is still under investigation.

Case 2: Landfill Settlement

The next case involves a dwelling on a landfill in which deep settlement points were installed to check the ground movement in rock above mine level (see Fig. 3 and 4). The landfill was placed to partially cover a valley which apparently was a former sand and gravel operation. The home is a single story dwelling with a walkout basement. The property is located 20 to 30 m (70 to 100 ft) south of the valley bank. Soil and rubble consisting of tires, concrete blocks and organic debris litter the side slopes of the former pit. Apparently, fill material was used to level out the area for the construction of the home.

The residence is a one-story, wood-frame structure with a full concrete block basement. The damage was concentrated on the east side of the basement where diagonal cracks 3 to 6 mm (1/8 to 1/4 in.) wide were present in the southeast and northeast corners, respectively. The wall tilted out at the top 20 mm/0.6 m (13/16 in./2 ft) and the floor slab had a large crack normal to the east wall. The greatest damage was in the northeast corner of the basement closest to the center of the landfill. Several small depressions were observed in the back yard between the home and the former sand/gravel pit. Abandoned room and pillar mines are located 18 to 21 m (60 to 70 ft) below the ground surface.

Several attempts were made to install settlement points in augered bore holes near the northeast corner in the area of greatest damage (Figs. 3 and 4). Voids were encountered between the ground surface and the obstructions. Each attempt to drive the settlement points was met with premature refusal in which the rods could not be driven below shallow obstructions in the fill. In order to determine whether the damage was caused by mine subsidence or near

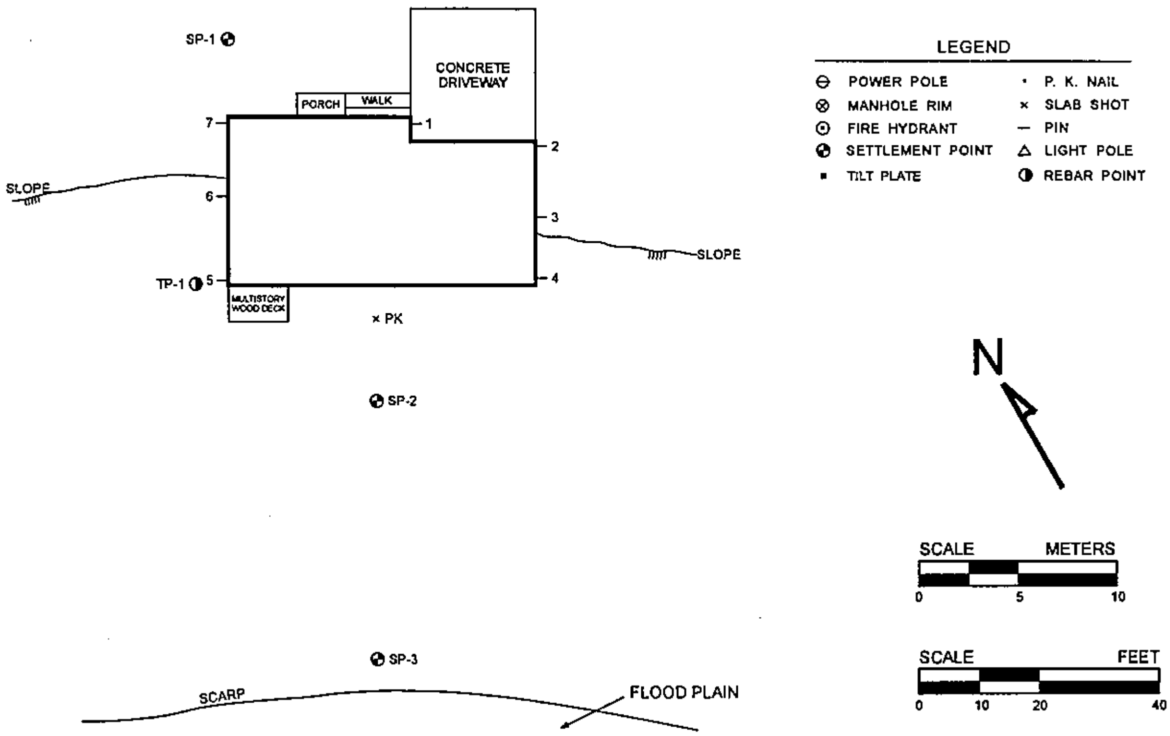

FIG. 1 PLAN MAP SHOWING THE LOCATIONS OF MONITORING POINTS ON AND AROUND THE FIRST CASE - CATLIN, ILLINOIS

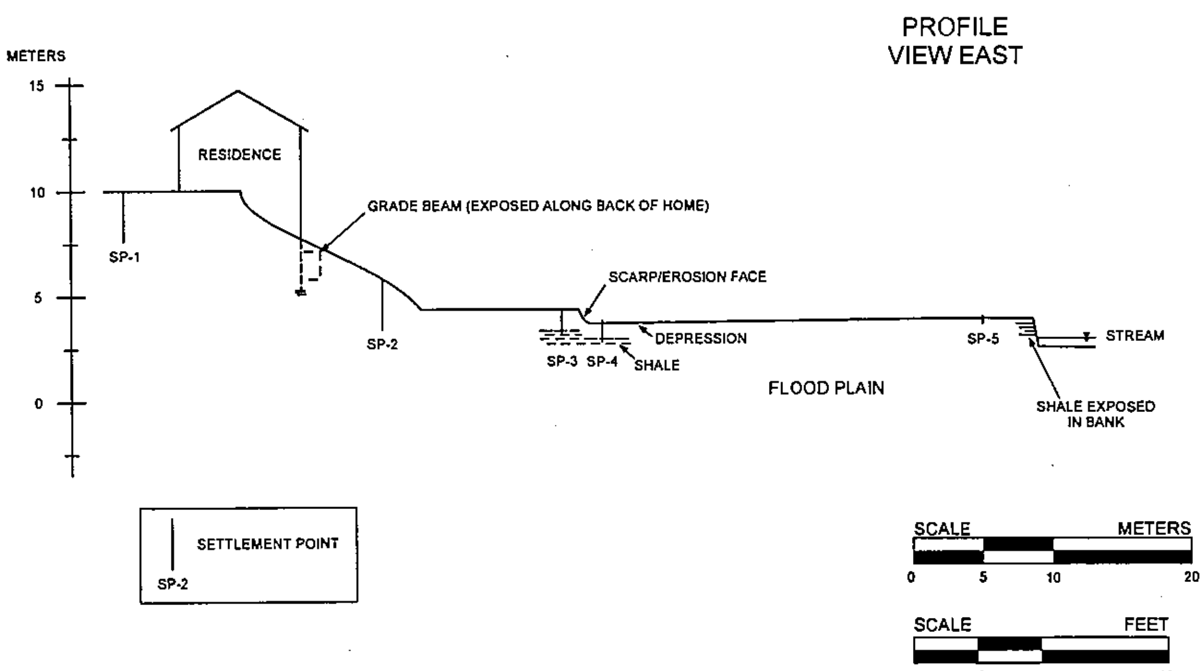

FIG. 2 SLOPE PROFILE SOUTH OF THE FIRST CASE - CATLIN, ILLINOIS

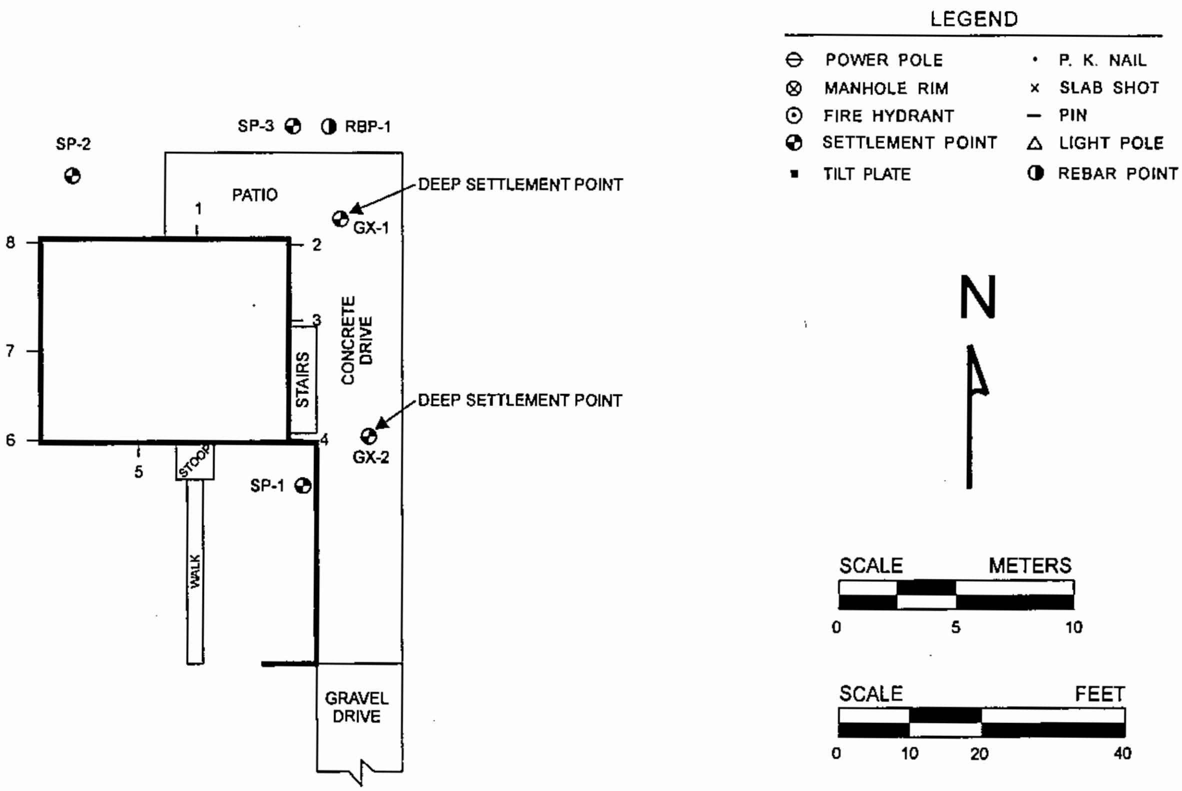

FIG. 3 PLAN MAP SHOWING THE LOCATIONS OF MONITORING POINTS ON AND AROUND THE SECOND CASE - STREATOR, ILLINOIS

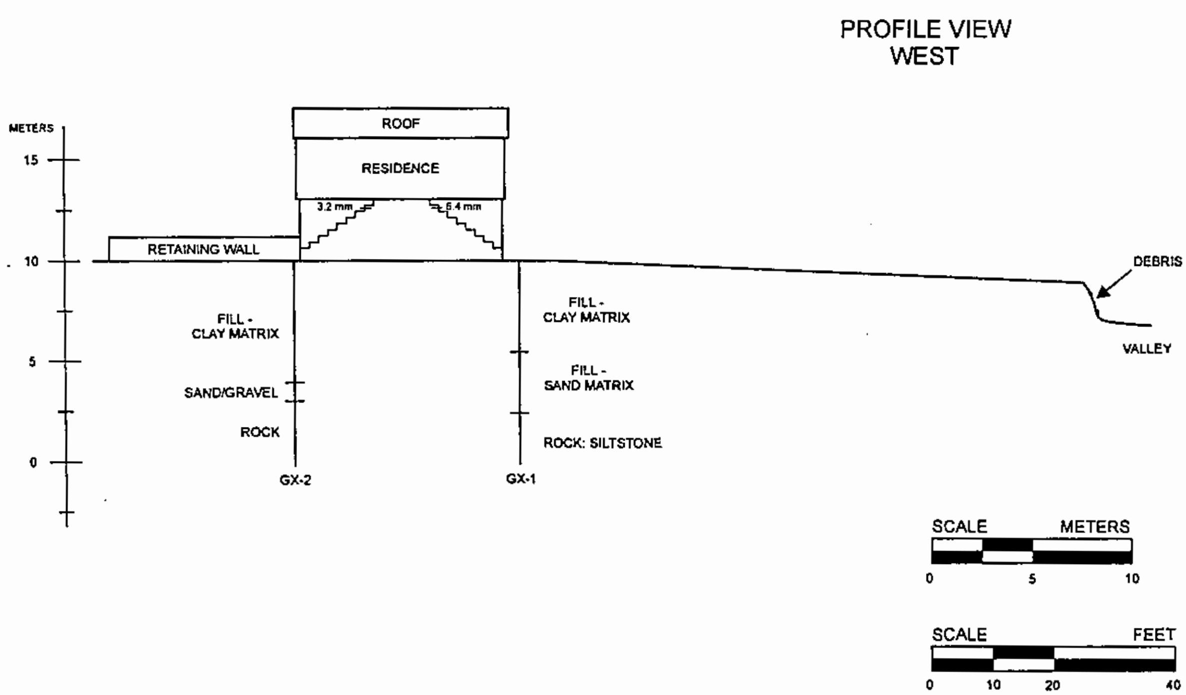

FIG. 4 PROFILE MAP SHOWING THE SECOND CASE - STREATOR, ILLINOIS

surface fill settlement, two deep settlement points were anchored 2.4 m (8 ft) into rock. The settlement points were located near the northeast and southeast corners and were placed in bore holes advanced with a drilling rig. To confirm that the anchor points were founded in rock, cores were taken 2.4 m (8 ft) below the soil/rock contact. Continuous split spoon samples were obtained in the soil profile to establish the thickness of the fill and to determine the nature of the overburden materials. Precise level line surveys were carried out to measure any downward movement in the settlement points as well as in monitoring points placed on the residence. After drilling into the bedrock, a single settlement point rod was grouted in each bore hole at a depth of approximately 10 m (33 ft) below the ground surface. The bore hole results show the presence of 7 to 7.7 m (23 to 25.4 ft) of fill. The fill consists of decomposed brick fragments, coal, glass, asphalt and organic particles/layers in a lean clay or sand matrix. A 0.6 m (2 ft) thick horizon of very soft and wet fill was encountered between depths of 2.7 to 4 m (9 to 13 ft). The fill matrix coarsened from south to north toward the former sand and gravel pit. Rock was encountered roughly 7.6 m (25 ft) below the ground surface. The rock is a light to medium gray siltstone. The upper 0.6 to 0.8 m (2 to 2.5 ft) of rock below the contact is weathered. Core recovery and RQD values in rock are 83 to 90% and 63 to 69%, respectively. Bedding is horizontal and the core showed no evidence of disturbance. However, it was necessary to monitor the ground movement because the core results alone are not completely conclusive. Moreover, mine subsidence could take place by downward movement of the roof primarily as a unit with little or no bedding disturbance or rotation.

The settlement data along with the bore hole and damage studies clearly showed that the damage to the structure was not caused by mine subsidence. Moreover there was no consistent downward movement of the settlement/monitoring points that would be indicative of mine subsidence (Fig. 5). Clearly the damage was caused by settlement of the soft and organic rich layers in the fill and possibly downward migration of the finer soil particles (piping) into the fill voids.

Case 3: Slope Movement Above Deep River Valley

The third case involves a home on the top of a ridge in Spring Valley, Illinois (see Figs. 6 and 7). The ridge is approximately 30 m (100 ft) vertically above the Illinois River channel. The home has an inground pool and several outbuildings at the top of the slope. The initial inspection revealed a severely buckled 2.4 m (8 ft) high foundation wall of the outbuilding adjacent to the slope with small scarps and depressions in the alley behind the buildings. The alley adjoining the buildings is supported by a 0.9 m (3 ft) high timber retaining wall which runs parallel with the ridge. The timber wall is bowed out 0.6 m (2 ft) at the top. Dwellings are present on the slope below the alley.

The slope down to the river does not have any rock outcrops or obvious scarps indicative of hillside movement. To determine whether the damage was induced by mine subsidence or is being caused by slope creep/bearing failure, a 30.3 m (99.4 ft) bore hole was drilled with a rig in the alley adjacent to the damaged structure (see Figs. 6 and 7). Split spoon sampling and coring were carried out to a depth of 23.5 m (77.2 ft) in the soil. Rock cores were obtained below 23.5 m down to a depth of 30.3 m (99.4 ft). A deep extensometer rod was installed in bedrock at the bottom of the hole. A second extensometer rod was installed 2 m (6 ft) below the rock/soil contact. The inclinometer casing was placed at a depth of 10 m (33 ft) in the upper part of the soil. The bore hole results show 2.3 m (7.5 ft) of loess above glacial till. The majority of the wind-blown deposit is a soft, moist to wet lean clay with fine sand. The underlying till is stiff to hard lean clay to clayey sand. A perched ground water table was found 3.2 m (10.5 ft) below the alley surface. The rock is a gray to olive green shale interbedded with limestone. The bedding in the core samples is horizontal.

Installation of the inclinometer will allow measurement of the near surface horizontal slope movement which may be responsible for the damage. The extensometers will be used to measure any vertical elevation change in the rock. If mine subsidence is causing the damage, both extensometer rods will undergo downward displacement with the deepest anchor showing the greatest movement.

The cause of damage in Case 3 is still under investigation.

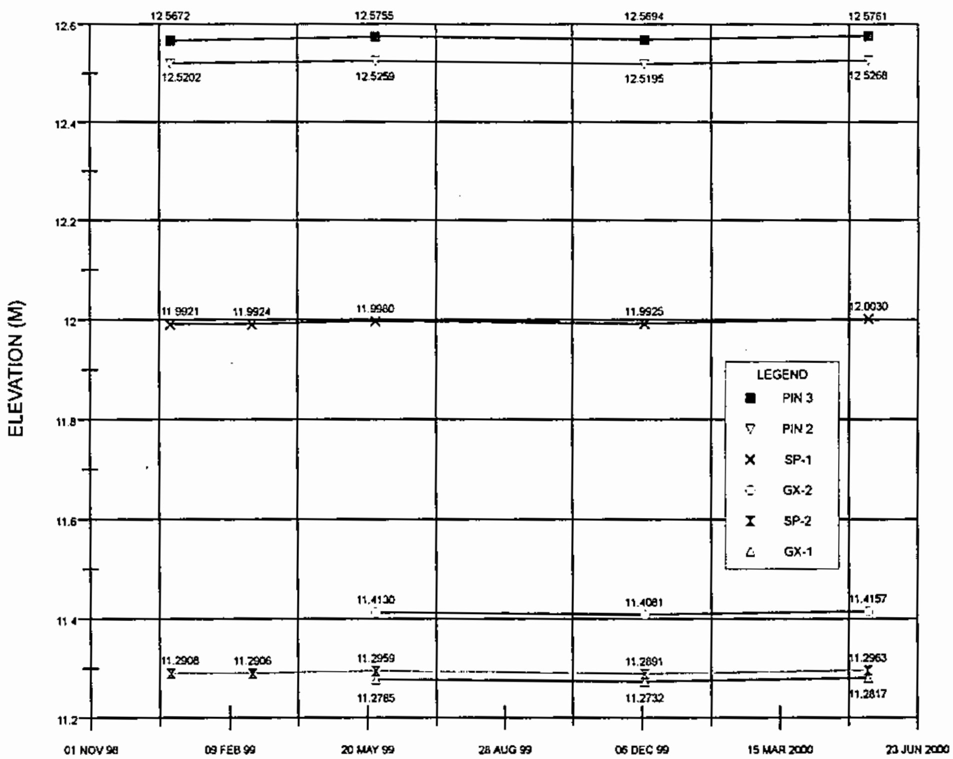

FIG. 5 PLOT OF ELEVATIONS ALONG THE PROFILE VIEW OVER TIME

TIME (DATE)

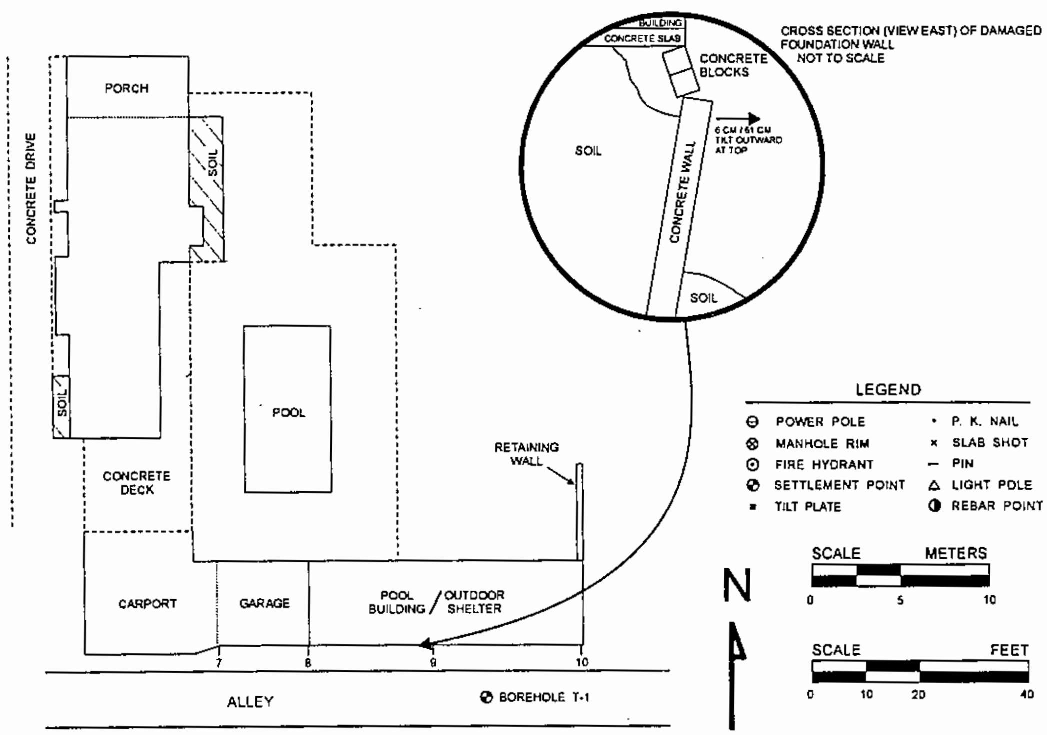

FIG. 6 PLAN MAP SHOWING THE LOCATIONS OF MONITORING POINTS ON AND AROUND THE THIRD CASE - SPRING VALLEY, ILLINOIS

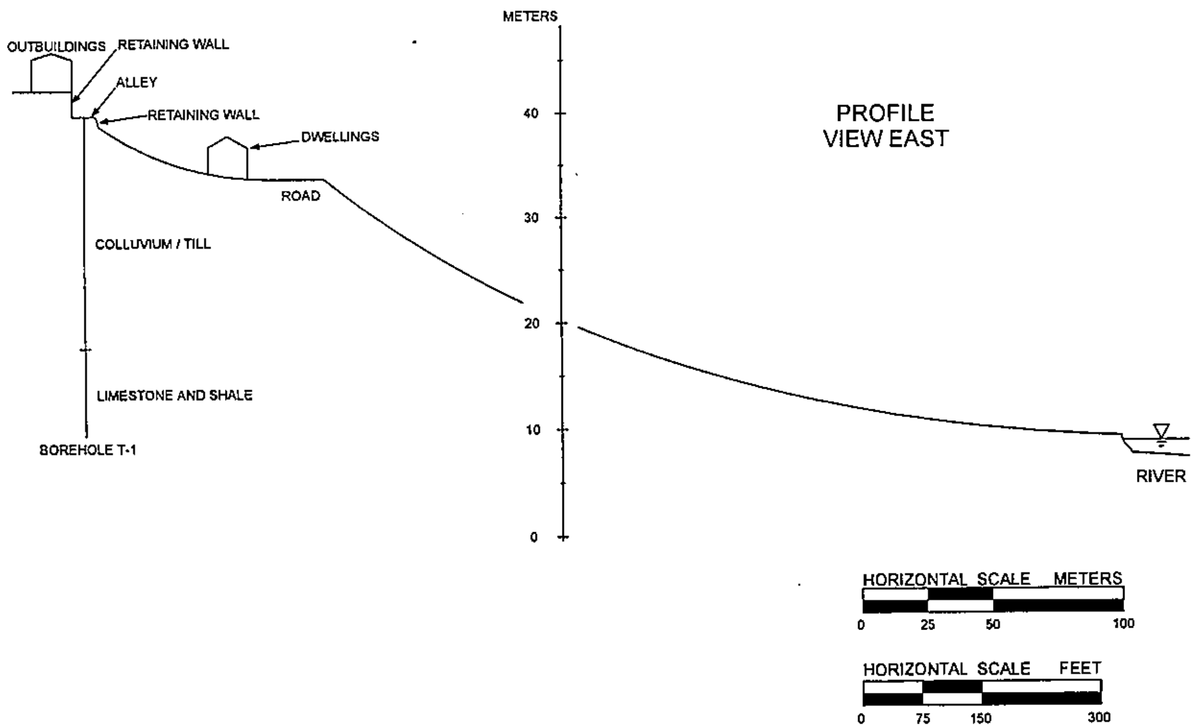

FIG. 7 SLOPE PROFILE SOUTH OF THE THIRD CASE - SPRING VALLEY, ILLINOIS