ABANDONED DEEP MINE SUBSIDENCE INVESTIGATION AND REMEDIAL DESIGN, INTERSTATE 70, GUERNSEY COUNTY, OHIO

by

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Abstract. A two thousand linear foot, undermined section of Interstate 70 in Guernsey County, Ohio experienced settlements due to pothole type subsidence events within the travel lanes, shoulders and adjacent right-of-way areas. Potholes measured approximately ten feet in depth and width. The subsidence occurred after the dewatering of the abandoned deep mine during auger mining operations west of the site. A two-phase emergency investigation was undertaken by the Ohio Department of Transportation (ODOT) and Gannett Fleming Corddry & Carpenter (GF). The purpose of the investigation was to assess the immediate danger of potholes occurring in the traveled lanes and paved shoulders, to identify the subsidence mechanisms, and to design a remediation program. Phase one investigations involved the review of existing subsurface data, the advancement of shallow borings and the performance of multiple geophysical surveys including ground penetrating radar, seismic refraction and electromagnetic terrain conductivity. The Phase one investigations did not reveal the presence of subsidence voids. Phase two investigations included borings to the mine level and videotaping of mine conditions. The mine was found to be completely flooded. Based upon the collected data, two mechanisms of failure, localized roof fall and piping of overburden soils into the mine void, were identified. Two remedial alternatives, 1) the filling of the mine void, and 2) the reinforcement of the highway using geotextiles, were evaluated. Filling of the mined interval and grouting of overburden bedrock fractures and voids, within a limited area, were selected. Construction plans, specifications and cost estimates were prepared for bidding and award. During the bidding process, a catastrophic, pothole type failure of the I-70 travel lanes occurred. The interstate was closed and the planned remediation activities were performed as an emergency project. The mine interval was grouted and portions of the highway pavement were replaced. The highway was reopened within 180 calendar days of the failure.

Additional Key Words: grouting, geophysical surveys, deep mine subsidence

Physical Setting

Project Location

The project involves approximately two thousand linear feet of Interstate 70 in Guernsey County, Ohio, approximately four miles east of Cambridge. Guernsey County is in east central Ohio, approximately 90 miles west of Pittsburgh, Pennsylvania and approximately 100 miles east of Columbus, Ohio.

Local Topography

The affected portion of the highway is a flat, tangent section that is approximately nine thousand feet in length, lying within a broad, level valley that ends in steep sloping sides. The valley is drained by Mud Run. Two surface water reservoirs are located up gradient of the Interstate right of way.

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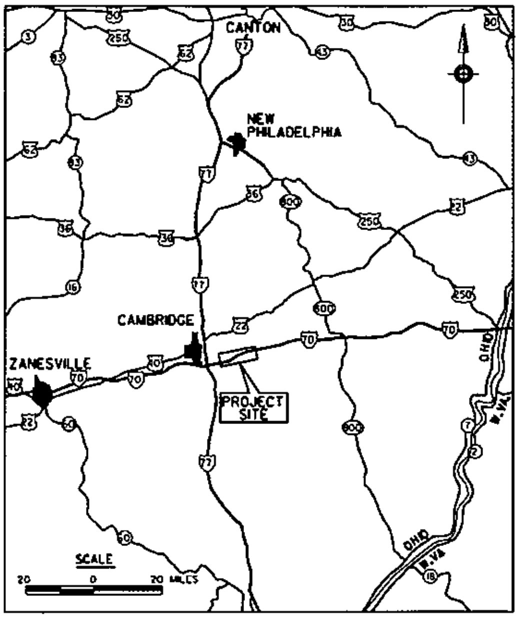


FIGURE 1: PROJECT LOCATION PLAN

Geology

Area Geology

The area is located in the Appalachian Plateau physiographic province. As is typical to this province, this area is characterized by relatively flat or gently sloping sedimentary rocks and gently plunging folds. Formations in this area have been exposed to extensive erosional forces from water and gravity, resulting in well defined valleys and high order river systems. The topography in the plateau is typically narrow valleys with steep, unstable colluvial slopes.

Stratigraphically, the area bedrock is situated in the Conemaugh Group. The Conemaugh is of Pennsylvanian age and is generally divided into two formations: The Casselman and the Glenshaw. Prominent markerbeds in the area include: The Pittsburgh Coal, the lower boundary of the Monongahela Group; the Ames Limestone, the upper boundary of the Glenshaw Formation; and the Upper Freeport Coal, the upper boundary of the Allegheny Group. A geologic map is provided as Figure 2.

Much of the region has been directly and indirectly affected by glaciation. Direct deposit of till by glacial ice flow has occurred over most of Ohio. However, the area discussed herein saw only limited direct glaciatiaton. Instead, much of the area was affected by periglacial erosion and depositional processes. The result is largely stratified deposits caused by glacial outwash, lakes, flooding, frost action and solifluction.

Site Geology

The project site is located approximately 30 miles south and east of the closest termination point of Wisconsinin and Illinoian glaciation. Soils at the site are stratified, with evidence that they were affected by the periglacial processes previously discussed. These soils tended to be clays and silts, with minor lenses of sands and gravels mixed in, especially in the deeper sediments. Many of the sediments were noticeably varved and contained varying amounts of interbedded and intermixed sands and gravels. Most of the site has a thin sand and gravel layer directly on top of bedrock. A generalized subsurface profile is presented as Figure 3.

Stratigraphically, the site is located in the lower Glenshaw Formation of the Conemaugh Group, just above the Upper Freeport Coal. Refer to Figure 4. Bedrock correlates as the Mahoning Sandstone and consisted largely of shale, sandy shale and sandstone. The regional strike is N30E and dip is less than one degree to the southeast.

Coal Geology

A number of prominent coal seams of economic value exist in the area. Most of these coals are referred to locally by a numbering system as well as their common formation name. The most commonly mined seams include: Meigs Creek (No. 9 coal), Pomeroy (No. 8a coal), Pittsburgh (No. 8 coal), Mahoning (No. 7a coal), Upper Freeport (No. 7 coal), Lower Freeport (No. 6a coal), Middle Kittanning (No. 6 coal), Lower Kittanning (No. 5 coal), Clarion (No. 4a coal) and Brookville (No. 4 coal). Locally, the Upper Freeport Coal is mined using surface and deep mining techniques. The Upper Freeport is a good quality, low sulfur coal, but inconsistent in aerial extent due to numerous sand channels that were cut during deposition.

Mining History

Deep Mining History

Mining occurred below the site in the Upper Freeport coal seam in the Murray Hill No. 2 Mine. Mining was discontinued in the mine in 1935 and in the adjacent King's Mine in 1927. The Murray Hill No. 2 mine was developed using room and pillar methods and appears to have been designed for secondary (total

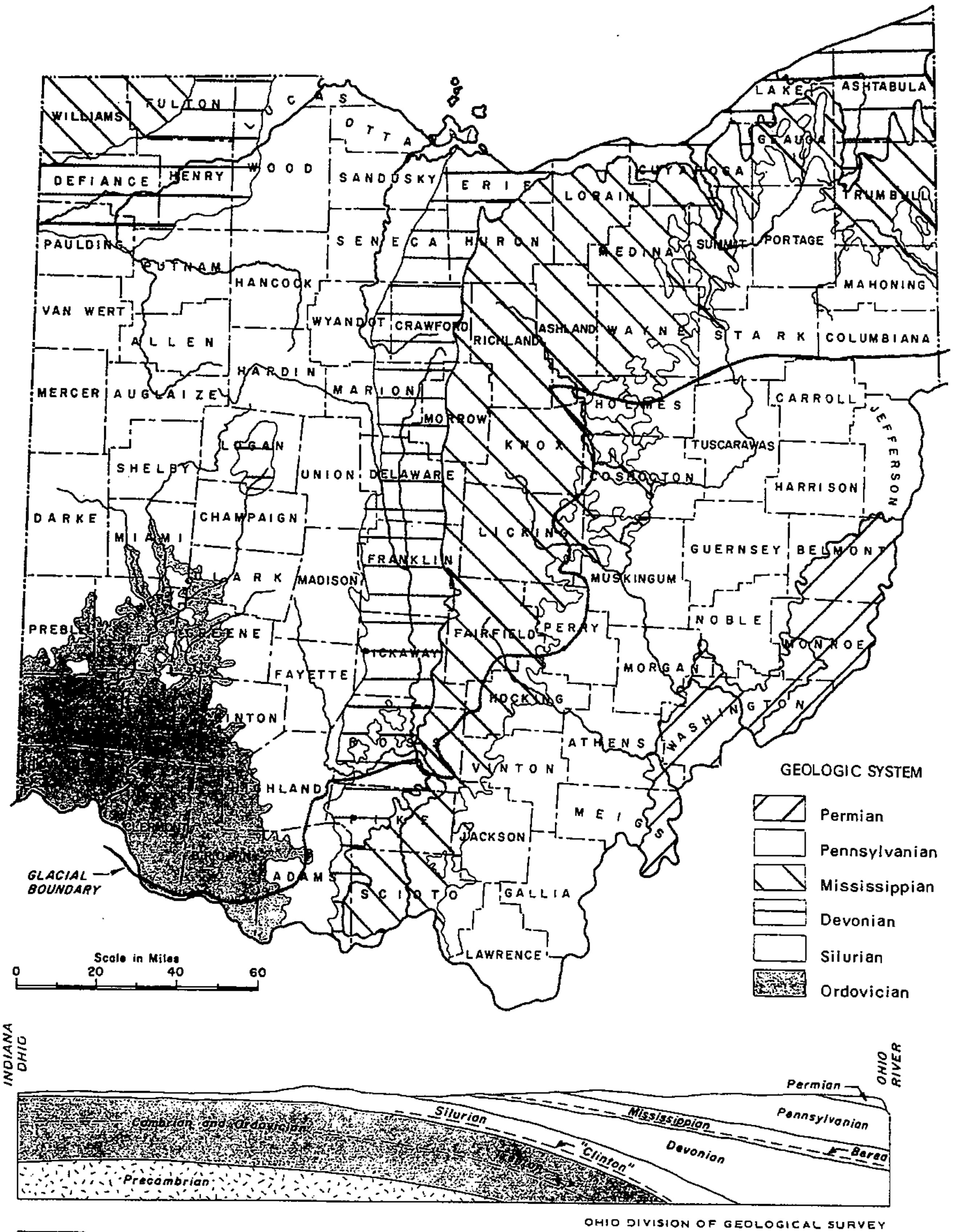


FIGURE 2: GEOLOGIC MAP AND CROSS SECTION

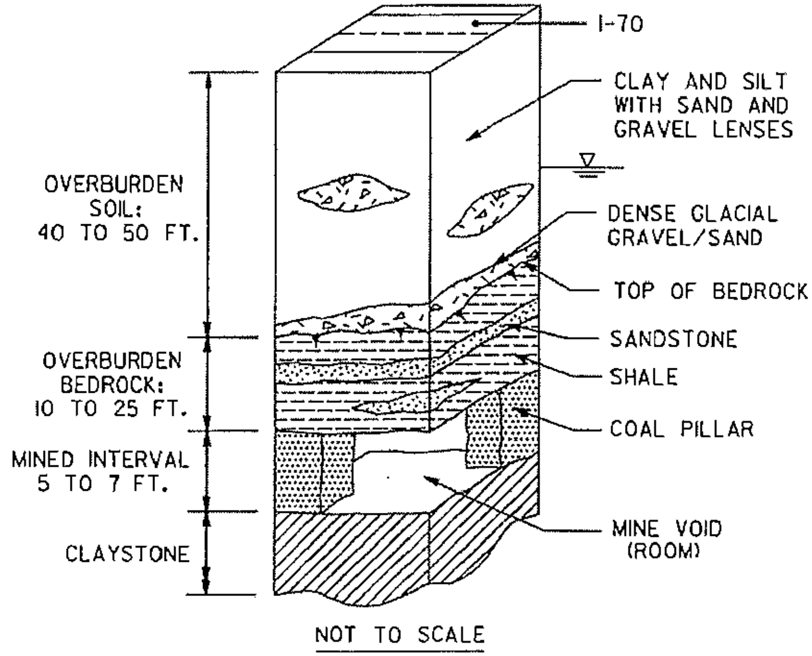


FIGURE 3: GENERALIZED SUBSURFACE PROFILE

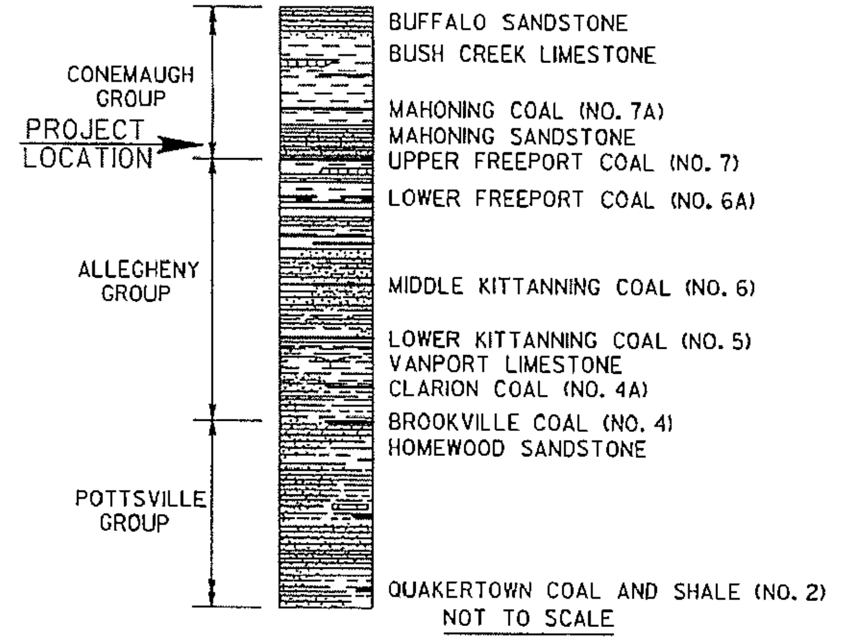
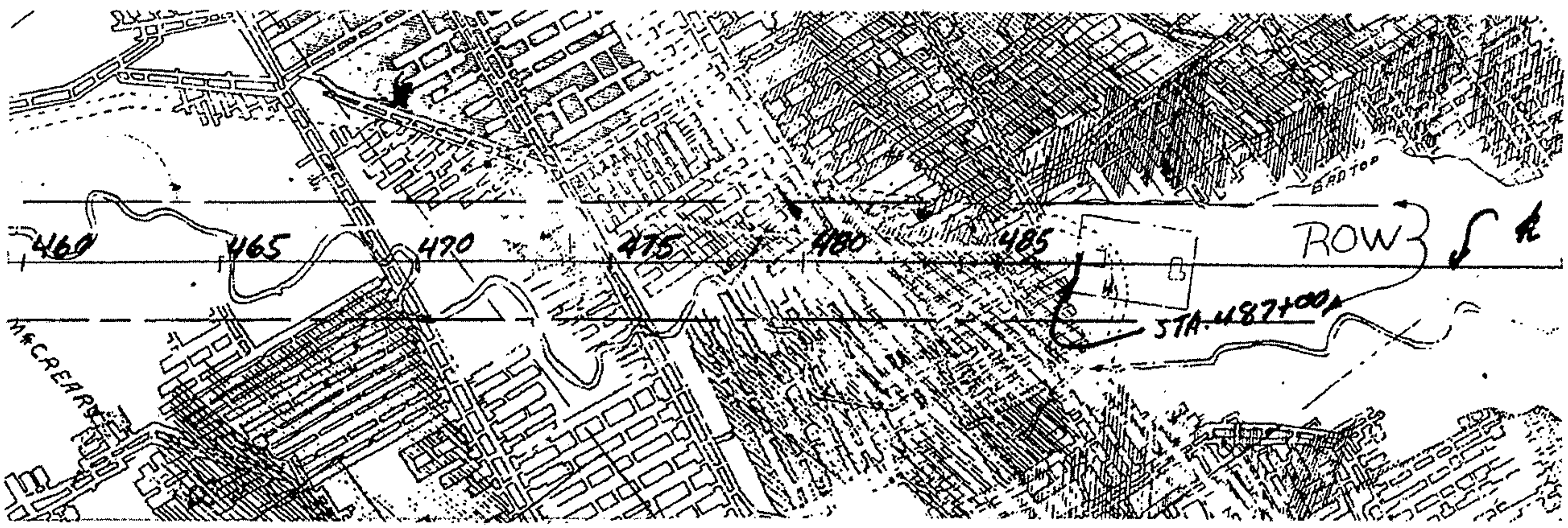


FIGURE 4: STRATIGRAPHIC COLUMN

FIGURE 5: MURRAY HILL NO. 2 MINE MAP



extraction). Main and butt entries were oriented at N11E and N79W, respectively, and were generally spaced like typical room and pillar mines. Refer to Figure 5. However, the mine was not developed as most room and pillar mines are. Because of the inconsistent nature of the Upper Freeport Coal in this area, some entries were cut at odd angles and a few rooms were advanced in directions not typical to total extraction mining.

Mining at the site has occurred approximately between stations 468+00 and 487+00. Up to four entries were advanced through this area. Two of the entries, located near stations 469+00 and 475+00, are main passageways connecting two large sections of the mine. The two entries below the eastern end of the site, near stations 481+00 and 485+00, are not contiguous and appear to have been pushed in from each side of the valley specifically to access rooms.

It is apparent from the mapping that much of this area was prone to roof falls during mining. Parts of the map are labeled "bad top" near the edge of mining. In addition, large blocks of thick, good quality coal were left in place in the valley. It seems likely that the usual mining patterns were used to protect the existing haulage ways, keep the mine open in this area and prevent the mine from flooding.

Surface Mining History

Surface mining, including auger mining, was recently performed adjacent to the site next to workings of the King's Mine. It has been reported by the mine operator and ODOT personnel that abandoned workings were encountered resulting in prolific water flows into the mine's excavation that required constant pumping. The recent subsidence problems along Interstate 70 began shortly after pumping at the surface mine was started. Coal removal at the mine and the subsequent excavation dewatering have ceased and the strip mine has been reclaimed Groundwater and mine water levels, at the time of construction, had returned to the pre-pumped elevations, about 20 feet above the mine roof.

Project History

Highway

The subject section of Interstate 70 was designed and constructed in 1961/1962. The construction through the project area included the placement of minor fills of up to eight feet in thickness. Mud Run, flowing to the west, was routed into a rock lined drainage swale (ditch) located south of the traveled lanes. Flow from a tributary stream originating north of the new highway was routed into a rock lined drainage swale located north of the traveled lanes. Drainage swales on both sides of the highway are poorly graded, sloping less than one percent in many areas. A site plan is presented as Figure 6.

The original pavement section of the traveled lanes consisted of reinforced Portland Cement concrete pavement with bituminous concrete shoulders. The highway had a system of pipe underdrains located several feet below finished grade, running parallel to the traveled lanes. In 1989, the original concrete pavement was rubblized and a bituminous overlay was placed. Additionally, shallow underdrains, running parallel with the original underdrains, were installed.

Subsidence Activity and Preliminary Geotechnical Investigations

In undermined areas with relatively thin roof rock, a mine roof collapse can propagate upward without being stemmed by bulking of roof fall materials. Once the collapse reaches the relatively weak overburden soils, the void continues to propagate upward toward the ground surface. This type of pothole subsidence is typically localized and immediate in nature, producing deep, small diameter (less than 20 feet) sinkholes. Adjacent overburden and coal pillars are usually left intact, and the sinkholes typically correspond to significant mine features, such as main entries or haulage ways and intersections of rooms, pillars and haulage ways. In March of 1994, a pothole type subsidence feature was observed within the grassy median of Interstate 70. The hole measured approximately 10 feet in diameter and 10 feet in depth and was located near station 478+25. The hole was immediately filled with rock materials by Ohio Department of Transportation (ODOT) personnel. In April of 1994, ODOT contracted the drilling of four unsampled borings near the subsidence feature.

In September, 1994, a subsidence feature of similar size was observed in the westbound outside shoulder near station 468+50. This subsidence feature extended beneath the westbound traveled lane and caused the failure of the 6- inch underdrain. In addition to the subsidence feature, several depressions which had developed in the pavement, in both west and eastbound lanes, were noticed. Additional geotechnical investigations and physical site surveys were initiated. ODOT, the U.S. Department of the Interior, Office of Surface Mining Reclamation and Enforcement (OSMRE) and the Ohio Department of Natural Resources (ODNR) worked together to investigate the past deep mining and ongoing auger mining activities. ODOT advanced a total of nine new test borings; performed both conventional and infrared aerial photography; performed non contact profilometer surveys; and, performed detailed topographic surveys of the project area. ODOT also backfilled the shoulder failure with coarse aggregate and leveled the most severe pavement depression at station 483+50, eastbound with an asphalt patch. OSMRE personnel used the boreholes advanced by ODOT to view the overburden bedrock and the mined interval with a downhole video camera.

A total of 13 exploratory borings were advanced by ODOT at the project site as of October, 1994. Ten of the borings were not sampled and three were sampled using Standard Penetration Test (SPT) methods. Soils encountered in the borings ranged from 23 to 53 feet in thickness with most ranging from 40 to 50 feet thick. Soils were generally clays and silts with minor lenses of sands and gravels. Typical bedrock overburden thicknesses were from 10 to 25 feet with the rock type being mostly interbedded sandy shale and sandstone. Coal encountered in the borings was five to seven feet thick and was underlain by soft claystone. The bottom of the coal ranged from 64 to 80 feet below existing grade. Four of the borings encountered in place coal within the mined interval and seven of the borings encountered either voids or collapsed roof rock. The two remaining borings did not penetrate the mined interval.

ODOT initiated visual surveillance of the affected portion of Interstate 70. ODOT personnel visually inspected the pavement conditions at four hour intervals, 24 hours a day, seven days a week. The intent of the surveillance was to spot pavement depressions as they grew and to allow for the closure of the highway if pavement failures were observed.

Geotechnical And Geophysical Investigations

On October 4, 1994, Gannett Fleming Corddry & Carpenter (GF), of Columbus, Ohio, was requested by ODOT to participate in the project. GF's responsibilities included: technical consultation; design and implementation of subsurface investigations; identification of subsidence mechanisms; development of remedial design concepts; and preparation of final plans, specifications and cost estimates. Construction phase services were subsequently added to GF's scope.

The potential for failure of one of the traveled lanes due to deep mine subsidence was the primary concern of the project team. A two phased subsurface investigation program was developed. Phase One concentrated on the conditions of the near surface soils; most importantly, those soils supporting the traveled roadway. Phase Two concentrated on the exploration of the overburden bedrock and the mined interval.

Phase One Investigation

It was theorized that mine roof collapses were propagating upward through the overburden bedrock and soil, ultimately leading to the observed pothole type failures. The primary purpose of the Phase One investigation was to probe the soils supporting the traveled lanes to look for voids working their way up towards the roadway. The Phase One program also was designed and executed to : collect soil type and strength information; determine top of bedrock elevations; attempt to identify conditions affecting subsidence potential such as soil type and soil stratigraphy, and to collect groundwater level data. In addition to roof collapse, it was theorized that movement of overburden soils into the mine interval was creating voids in soil and leading to subsidence events. It was suspected that groundwater was moving vertically downward due to a gradient created by the dewatering of the mined interval at the nearby coal augering operation. The downward movement of the water through the granular soil lenses identified by the ODOT borings, was suspected of carrying soil into the mine.

Borings. A total of ten soil borings were advanced between October 20 and 24, 1994. Each boring was sampled using SPT methods and static water levels were measured in each boring. These borings did not penetrate bedrock. Generally the borings were positioned at or next to subsidence features and depressions, and at locations associated with subsurface anomalies identified by geophysical surveys. Borings were also positioned over main entries of the deep mine.

Geophysical Techniques. Geophysical surveys were conducted to: detect and delineate voids in soil; determine the depth to bedrock; and, to distinguish between generally clayey and sandy subsurface soils beneath the roadway. It was anticipated that such a delineation would be helpful in limiting the required treatment area. GF's geophysics subconsultant, Enviroscan, Inc., of Lancaster, Pennsylvania, utilized ground penetrating radar (GPR), seismic refraction (SR) and electromagnetic terrain conductivity (EM) techniques to perform these surveys. Refer to Figure 7.

Ground Penetrating Radar (GPR) represented the only method with a reasonable likelihood of success for detecting subsurface voids beneath the roadway. Electrical and electromagnetic terrain conductivity/resistivity techniques would have been ineffective for this project due to the presence of the reinforcing mesh and storm and underdrain piping. Seismic techniques exploiting the acoustic resonance of voids would have been difficult to interpret in the expected presence of considerable traffic-related vibration, and interference from high amplitude air blast and ground roll at depths of less than 30 feet.

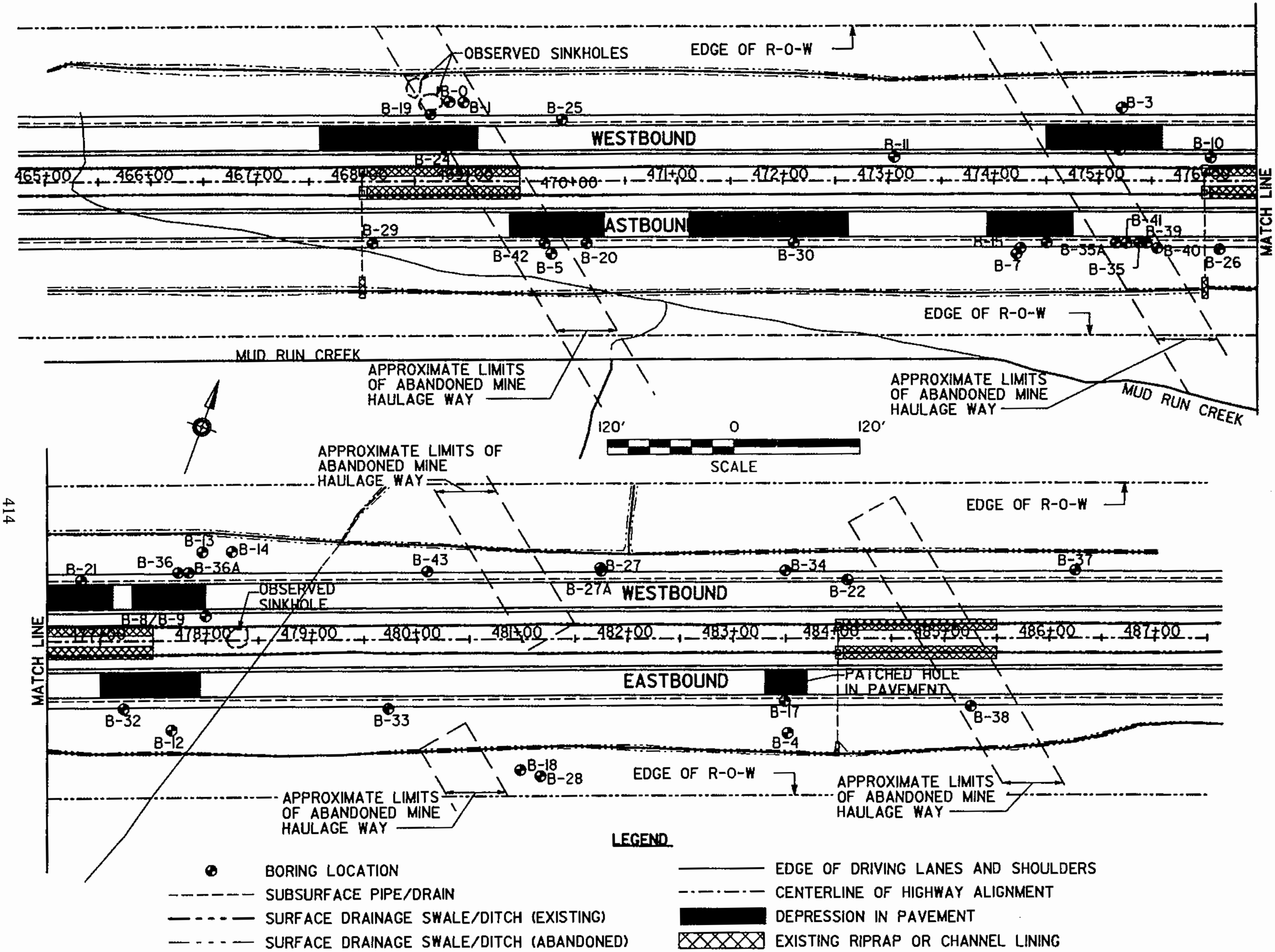


FIGURE 6: SITE PLAN

GROUND PENETRATING RADAR (GPR)

FIGURE 7: GEOPHYSICAL TECHNIQUES

ELECTROMAGNETIC CONDUCTIVITY (EM)

SEISMIC REFRACTION (SR)

GPR systems produce cross sectional images of subsurface features and layers by continuously emitting pulses of radar frequency energy from a scanning antenna as it is towed along a survey profile. The radar pulses are reflected by interfaces between materials with differing dielectric properties. The reflections return to the antenna and can be displayed on a video monitor as a continuous color cross section in real time, with a gradational color scale depicting the amplitudes of reflections as the magnitude of a particular subsurface dielectric contrast. On a color radar profile, the colors are mapped as the amplitude of the reflection (which is proportional to the magnitude of the dielectric contrast at the reflector). Therefore, color radar profiles contain information on the character of subsurface reflectors.

Since the electrical properties of air or water-filled voids are commonly different from most soils and backfill materials, they produce distinct and characteristic reflections. Air-filled voids are particularly distinct due to electromagnetic resonance or "ringing" or reverberation of the void reflection as repeated arrivals continuing vertically downward throughout the record.

In order to detect and delineate suspected potential voids at the Interstate 70 site, Enviroscan performed deep GPR scanning on the unreinforced roadway shoulders and medians using a monostotic 100 megaHertz (mHz) transducer capable of scanning to an estimated maximum depth of 20 to 30 feet. Since the presence of steel reinforcing in the roadway pavement prevented use of the penetrative but relatively low resolution 100 mHz transducer in the traffic lanes, a 500 mHz transducer with lesser penetration (6 to 8 feet maximum) but much better lateral resolution and the ability to penetrate the reinforcing grid was used to scan the traffic lanes. Data were displayed in real time on a color video monitor. The data were recorded on hi-8 video tape with verbal real-time field notes on the audio track.

The GPR field survey was performed on October 15, 1994 and included scanning of two continuous profiles along each of the four travel lanes and four shoulders using the 500 mHz transducer, and two profiles along each shoulder using the 100 mHz transducer.

<u>Seismic refraction</u> (SR) represented the most cost effective means of determining depth to bedrock since GPR could not be expected to penetrate to the necessary depths of up to 50 feet, and GPR and electrical or electromagnetic sounding techniques are difficult to calibrate for absolute depths in the presence of heterogeneous stratigraphy (i.e. fill and interbedded alluvium/colluvium).

Environscan completed a seismic refraction survey on October 28 and 29, 1994. The survey consisted of seismic refraction profiling along three lines - one on each grassy margin and one on the north edge of the median. Seismic refraction generally involves measuring the travel times of shock waves traveling from a surficial source (shot point) to a linear array of ground motion sensors (geophones). At a distance from the shot point, the first arrivals of seismic energy are waves that have been refracted along whatever seismic velocity (i.e. primarily density) contrast or contrasts are present in the subsurface, and the travel times of these arrivals can be used to compute a cross sectional profile of the seismic stratigraphy.

For the Interstate 70 survey, a Geometrics Smartseis S-12 seismograph was used to record seismic travel times at linear arrays or spreads of Mark Products 4.5 Hertz geophones spaced at constant 20 foot intervals along each of the lines. Travel times were recorded for shot points located at each end of each spread to provide multi-fold, reversed seismic data capable of resolving a potentially undulating bedrock surface.

At each shot point, seismic waves were generated by either 300 or 1,000 grain black powder charges set in 18 inch deep shot holes. Where traffic noise was detected in the seismic records, data from repeated charges were summed or stacked to enhance the signal-to-noise ratio.

Processing and interpretation of the seismic refraction data were completed using the SIP package of computer programs developed for the U.S. Geological Survey by Rimrock Geophysical.

<u>Electromagnetic Conductivity</u> (EM) terrain conductivity mapping represented the most cost-effective means of delineating clay versus sandy subsurface soils since clay and sand generally have distinctly different electrical conductivities, but may have similar seismic velocities and gradational contacts or transitions indistinguishable using seismic or GPR methods.

Enviroscan completed an EM terrain conductivity survey of the Interstate 70 site on October 27, 1994 using a Geonics EM-31 instrument. The EM-31 was chosen since it can simultaneously record both subsurface electrical conductivity and an in-phase or metal detector response (for use in identifying areas where the terrain conductivity may be affected by the presence of subsurface or nearby or overhead metallic objects or structures. In addition, the EM-61 provides a good combination of penetration depth insensitivity to shallow interference from surficial debris or shallow, weather-related changes in soil conductivity, and vertical focusing to minimize interference from nearby metallic structures.

The EM survey was completed by collecting vertical dipole mode terrain conductivity and in-phase data at ten foot intervals along seven profiles. The lines were offset 15, 30, and 45 feet off of each outer edge of pavement, and along the center of the median. EM readings were collected by walking the EM-31 along the profiles and pausing to record readings at 10 foot intervals. Accurate stationing was maintained using a precision hip chain which was anchored and zeroed at the beginning of each profile.

In order to remove from the EM terrain conductivity data the effects of possible interference from the metal reinforcing in the roadway, the wire fences, underground metal drain pipes, buried metal debris, etc., the EM in-phase data were filtered to identify stations with a significant in-phase response indicating subsurface of nearby metal within the effective hemisphere of sensitivity of the instrument. These stations were removed from the data set to insure that the remaining terrain conductivities represented only the electrical properties of the subsurface soils.

The filtered terrain conductivity data were contoured using the statistical kriging routine in SURFER by Golden Software.

Results of Phase One Investigations

Borings

The stratigraphy identified by the ODOT borings was generally confirmed by the Phase One borings. Additionally, the borings showed no voids were present in the overburden soils at the locations drilled at the time of the Phase One investigation. Static water level data showed that groundwater tended to be in either the upper 30 feet of the soil strata (above elevation 800 ±) or within 20 feet of the top of the coal (below elevation 780 ±). This demonstrated the presence of two water regimes at the site representing apparent perched water conditions in the overburden soils and flooded conditions in the mine.

Geophysical Techniques

The GPR identified anomalies within its effective penetration depth (20 to 30 ft) that were interpreted to be small voids or subsidence zones beneath the highway. Most appeared to be associated with previously identified sinks or depressions. Verification borings did not reveal subsurface voids at any anomaly locations. The GPR accurately identified the locations of the steel reinforcing mesh within the concrete pavement and the locations of cross pipes and underdrains.

The SR survey detected three velocity layers corresponding with roadway embankment materials, natural soils, and bedrock. The top of bedrock elevations determined by the SR were consistent with those measured in confirmation borings; generally corresponding within four feet. The SR also detected a constant low velocity zone along the top of bedrock over a 200 foot length of roadway. This was interpreted as bedrock that is more weathered or that has been fractured due to roof fall in the deep mines.

The EM survey showed an apparent clay content increase eastward across the site. The conductivities, however, were somewhat higher than expected for sand and clay soils and may have been affected by de-icing salt runoff.

Phase Two Investigative Methods

The goals of the Phase Two investigation included: sampling and classification of overburden soil, bedrock, and the mined interval; examination of the mined interval and the overburden bedrock using downhole video cameras; and verification of the SR top of bedrock profile.

Borings. A total of 26 additional borings were advanced between November 28 and December 13, 1994. Each boring was sampled using SPT and NQ wireline, double tube, split inner barrel rock coring techniques. Static water levels were measured in each boring. The borings were advanced to investigate the following features: partially and fully extracted mine entries; partially and fully extracted room and pillar sections of the mine; apparent unmined areas; and surface deformations including sags, pavement depressions, and subsidence features.

Downhole Video Camera. Borehole video logging and video logging of the mined interval was performed. The logging revealed that the overburden bedrock was fractured, but that large discontinuities occurred only within three feet of the roof of the mine. Above that level, the bedrock was very competent with only minor horizontal and infrequent high angle fracturing.

Results of Phase Two Investigations

Borings

Soils encountered in the borings ranged in thickness from 23 to 53 feet with most ranging from 40 to 50 feet thick. Soils generally tended to be clays and silts, with minor interbedded lenses of sands and gravels. The upper 5 to 15 feet of soil below the highway consisted of soft to stiff clay and silt fill with rock fragments. Generally, below this layer, soft to stiff silt and clay with sand and gravel, up to 10 to 20 feet deep, was encountered. Blow counts in these upper layers averaged

8 to 12 blows per foot (bpf) with some as low as two or three bpf. Below these layers, a medium stiff to stiff layer of silt and clay with sand and gravel was often encountered down to the top of bedrock. This layer was noticeably varved (cyclic layering) and contained varying amounts of interbedded and intermixed sands and gravels. These varved sediments are typical of a lake environment. Most of the site, specifically the southwestern two-thirds, has a thin sand and gravel layer directly on top of bedrock. This layer, like most of the coarse sediments encountered in the borings, showed sub-rounded to sub-angular sediments composed of various rock types including sandstones, shales and coal. These sands and gravels were most likely randomly placed by either debris flows or ice rafts. Most of the interbedded gravel layers, especially the deeper ones, were very dense, almost having the appearance of glacial till. A 19 foot thick layer of this material was also encountered in boring B-38 at the northeast edge of the site. Some of the borings encountered a thin layer of residual soil.

Bedrock at the site consisted largely of sandy shale, shaley sandstone, coal and claystone. Bedrock overburden thicknesses above the coal ranged from nine feet at the western end of the site to 42 feet at the eastern end, with the rock thickening towards the east end of the site. However, typical bedrock overburden thicknesses were more in the range of 10 feet to 25 feet with the rock type mostly being interbedded sandy shale and sandstone. Overall, the bedrock was of good quality. Coal at the site was five to 7 feet thick and was underlain by soft claystone. The depth from the ground surface to the bottom of coal ranged from 65 to 80 feet across the site. In addition, the bottom of coal shows a sharp localized dip across the highway to the southeast of five to six degrees in places.

Water level observations were measured in all of the borings performed by GF and in the borings left open by ODOT. Water levels were collected immediately upon completion of the borehole and, when possible, a minimum of 24 hours after completion. As with the Phase One investigations, static water levels showed that a perched water condition exists in the overburden soils and that the mine interval is flooded.

Before construction of Interstate 70, all of the surface water runoff from the site flowed directly into Mud Run. Drainage from the ponds located north of the right-of-way drained to a channel that previously crossed the alignment. Now, since construction of Interstate 70, a large amount of surface flow from the watershed drains into the channel on the north side of the highway and is carried along the highway for up to a mile. Additionally, runoff from the highway itself is discharged into the swale to the south of the highway and is carried the same distance. These swales are poorly graded, sloping less than one percent in many areas. This poor drainage has produced soft, marshy areas in many places.

Identification of Subsidence Mechanisms

Based upon the data collected, two main mechanisms were identified as the most likely sources of the ground settlements, or subsidence features, observed at the project site. These mechanisms are mine roof failure and piping of soil into the mine void.

Mine Roof Failures

Dewatering of the mined interval and the reduction of static water levels in overburden soils, due to the adjacent auger mining operations, is suspected to be the direct cause of the mine roof failures. In addition to the removal of buoyant forces on the overlying soils and bedrock, lateral restraining hydrostatic pressures were removed from the coal pillars. Combined with the weakening of the coal due to exposure to air, these changes in the state of stress of the coal pillars are believed to have lead directly to the failure of coal pillars, the mine roof and the overburden soils.

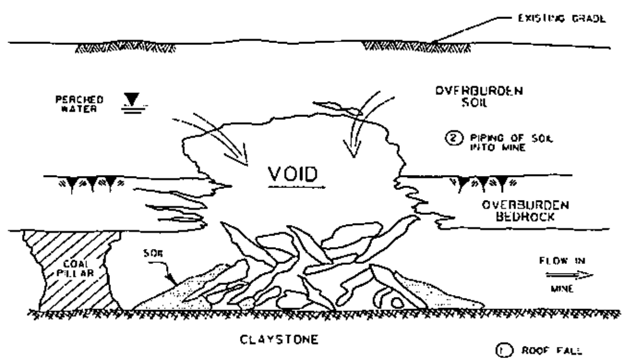


FIGURE 8: SUBSIDENCE MECHANISMS

Piping of Soils into the Mine Void

Phase One and Two boring data indicate that: the mine was flooded; overburden soils were saturated to approximately elevation 800 ±; and the bedrock was acting as an aquiclude. As the mine pool was drawn down by the auger mining operations and failures of roof rock occurred, a downward gradient between the soil and the mine interval was created. This downward flow of water within the overburden soils is believed to have carried soil into the mined interval, through the roof collapses. In addition, downward flow within subsidence features is expected due to the disturbed and potentially loose nature of the soils within subsidence features. Thus, subsidence features became larger and provide a mechanism for continued settlement. Figure 8 Illustrates the suspected mechanisms of subsidence.

Remedial Alternatives Analyses

ODOT and GF developed several remedial alternatives for consideration. The criteria for these alternatives required that the alternative eliminate the risk of catastrophic roadway failures and be constructable while maintaining two way traffic through the work zone on alternate sides of Interstate 70.

Potential Treatment Intervals/Locations

Six potential locations at which some remedial treatment could be applied, either independently or in concert, were identified. These potential locations included:

The Adjacent Auger Mine. To remove the catalyst of the mine roof failures and subsidence events, the permanent sealing of the adjacent auger mine was identified as a potential remedial alternative. In addition, the coordination of ODNR and ODOT in the review of future surface mining permit applications within the Murray Hill No. 2 Mine was recommended.

The Mined Interval. To remove the possibility of future roof rock collapses into mine voids, the elimination of the voids was identified as a remedial alternative. This would be accomplished by filling the mine voids entirely with a bulk material, such as fly ash.

The Overburden Bedrock. Because the transport of soil downward through the bedrock was considered to be a potential subsidence mechanism, the consolidation grouting of joints, bedding planes and fractures within the bedrock was identified as a remedial alternative.

The Overburden Soils. Soil improvement was considered as a remedial alternative. Methods considered included: compaction grouting; chemical grouting; jet grouting; and impact densification.

The Highway. Another potential remedial alternative involved the excavation of the existing pavement section, median and drainage system to a depth of approximately six feet below grade; the placement of four layers of geogrid reinforcement ; and the replacement of the drainage system, median and pavement. This alternative would not reduce the likelihood of deep mine subsidence, but it would allow the highway to function by bridging, or spanning, subsidence features.

The Drainage Swales. To reduce the infiltration of surface water into the overburden soils and, thereby, reduce the downward flow of water through the soils, the lining of the drainage swales adjacent to the highway with an impermeable clay liner was identified as a remedial alternative.

One other alternative was proposed by a general contractor. This alternative involved the total excavation of the highway, overburden soil, overburden bedrock, and the remaining pillars and mine gob and the replacement of the soils and rock and the construction of a new highway. This alternative option was ruled out due to the requirement to maintain limited traffic, the cost, the time required to perform the work and the fact that much of the excavated soil material would be too wet to be used as backfill, and the problems associated with dewatering the entire Murray Hill No. 2 mine.

Final Treatments

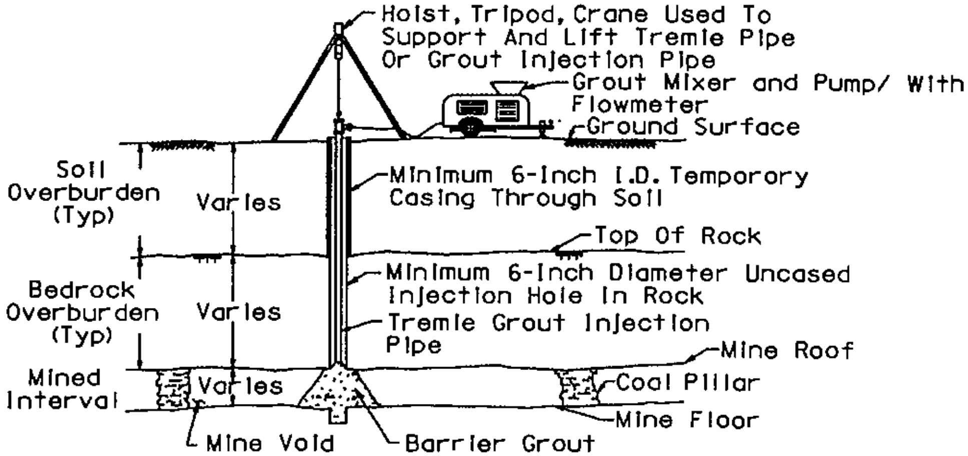
Following an evaluation of cost and potential future risk, the following remedial alternatives were selected for final design (refer to Figure 9):

- Construction of a permanent seal at the adjacent auger mine and monitoring of future surface mining permits.
- Complete filling of the mined interval with a grout mixture consisting of fly ash, cement and sand.
- Consolidation grouting of the overburden bedrock.
- Tremie grouting of the overburden soil (boreholes and any voids encountered) with grout.
- Lining of the drainage swales with an impermeable liner.

Remedial Design Features and Limits

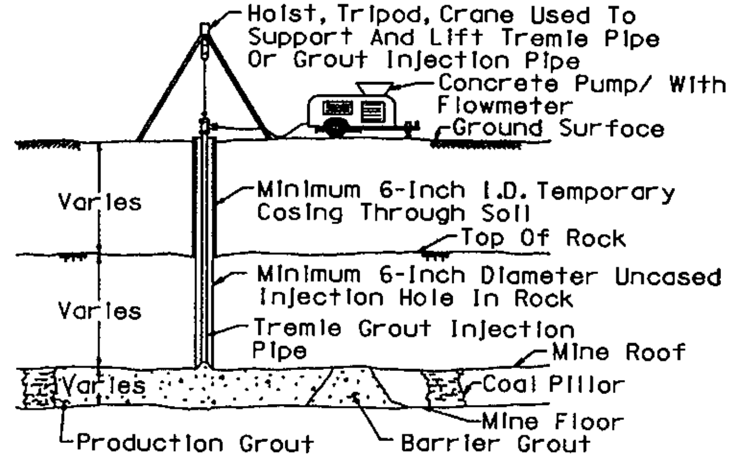
Treatment Limits

Although the highway is underlain by abandoned mine workings over a distance of approximately 1,800 linear feet, final design limits included only the westernmost 1,200 linear feet of the undermined area. Additionally, the width of the treatment was limited such that only the traveled lanes and median were fully protected from subsidence. The treatment area was limited because: nearly all of the observed subsidence features and surface sags and depressions were located within the treatment area (with one notable exception); The borings, SR survey and mine maps showed that the bedrock was least competent and most fractured within the treatment limits; the borings revealed that overburden soils became more dense and thicker and the bedrock thickness increased towards the eastern end of the undermined area; and because surface water drainage conditions were much better at the eastern end of the area.



NOT TO SCALE

BARRIER GROUT PLACEMENT



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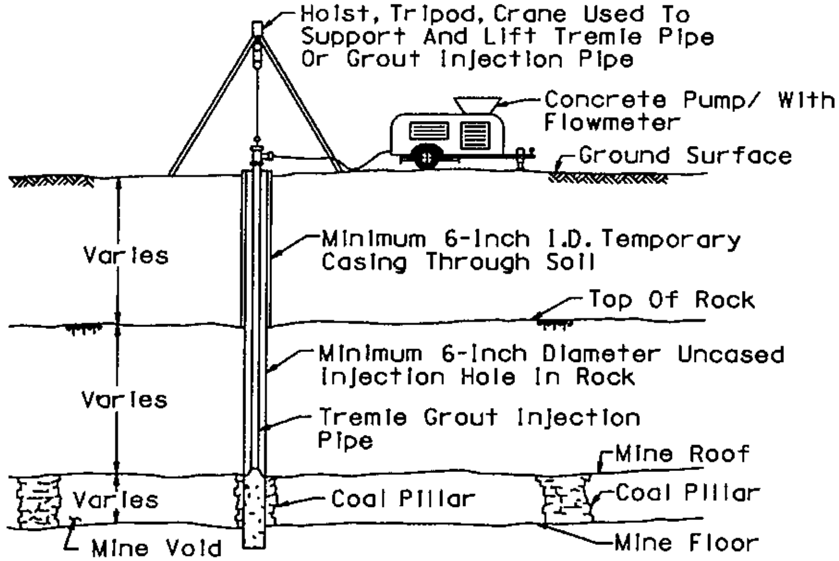
PRODUCTION GROUT PLACEMENT



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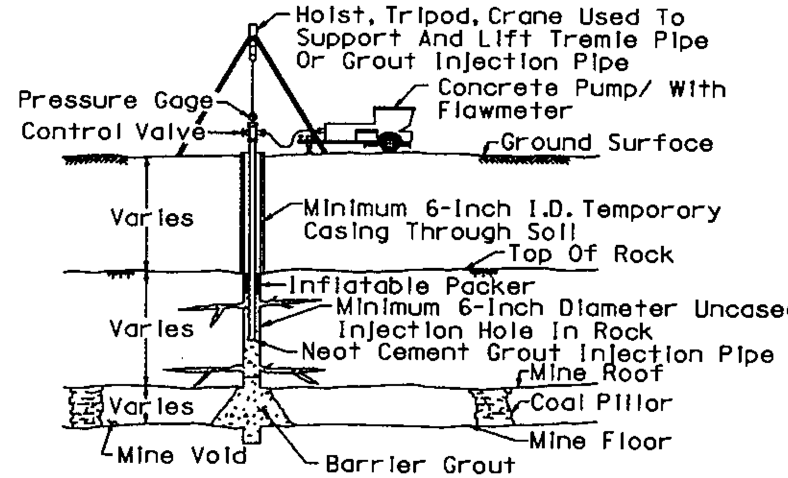
COAL PILLAR GROUTING



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OVERBURDEN ROCK GROUTING

FIGURE 9: REMEDIAL TREATMENTS

The pavement depression at station 483+50, eastbound, first noticed and patched by ODOT in September, 1994, was the only known area of distress located beyond the final design treatment limits. Final plans include a special treatment involving placement of barrier, production, consolidation and borehole grout for this area.

Treatment Descriptions

Auger Mine Seal. The auger mine was reclaimed in February, 1995. At the time of reclamation, the mine pool water levels were significantly below final grades in the auger mined area and no surface flow was visible. Therefore, no seal was designed for the auger mine. ODOT and ODNR have arranged to monitor strip mine permit applications for the Murray Hill No. 2 mine in the project area.

Filling of Deep Mine With Grout. The grouting of the deep mine included the placement low strength fly ash, cement and sand grout in the mined interval. First, a barrier grout material is placed within the mined interval around the perimeter of the treatment area. This barrier serves to restrict the flow of a production grout material. The purpose of the production grout is to fill the existing mine void within the limits of the previously placed barrier. Both production and barrier grouts are tremie injected, through drilled borings, under static pressures.

Consolidation Grouting of the Overburden Bedrock. Upon completion of the barrier and production grouting operations, the overburden bedrock is consolidation grouted under pressure using neat cement grout.

Tremie Grouting of Overburden Soils. Boreholes in the overburden soils are grouted under static heads with production grout materials. If voids are encountered during drilling, they are filled during borehole grouting. The specifications allowed for the pressure grouting of overburden soils as required.

Lining Drainage Swales. The drainage swales adjacent to the highway are lined with a Geocomposite Clay Liner.

The grout mixes are tested before use in the construction. A test construction program is performed by the contractor. The test construction involves the construction of a barrier, using the contractor proposed mix design and placement equipment, both on the ground surface and underwater. Production grout mixes are pumped. The purpose of the test is to evaluate the ability of the proposed grout mixes to build barriers or to flow freely, as required. Based upon the results of the test construction, proposed grout mix designs are adjusted.

Epilogue

On Saturday, March 4, 1995, the area of patched pavement at eastbound station 483+50 failed catastrophically. Four vehicles hit the resulting hole, and one person was injured. The eastbound lanes of Interstate 70 was closed immediately by ODOT between the Cambridge and Old Washington exits. Traffic was detoured onto Interstate 77 and U.S. 40.

Because of the failure, the design team met in an emergency session. The purpose of the meeting was to: evaluate the appropriateness of the treatment limits; to review the expected effectiveness of the designed treatments and to evaluate the safety of the remaining portions of the undermined highway. Ultimately, ODOT found the entire undermined highway to be potentially unstable and closed the westbound lanes. Additionally, the treatment limits were extended to include the entire undermined length of the highway.

The plans, specifications and cost estimate were completed and the project was bid on Wednesday, March 22, 1995. The contract was awarded on March 23 and Nicholson Construction Company of Pittsburgh, PA, began operations on the site Friday, March 24, 1995.

A total of 1,800 bore holes were drilled for a total of approximately 125,000 linear feet of drilling using 80,000 linear feet of steel drill casing in soil. 22,000 cubic yards of flyash/cement grout were pumped through the bore holes into the mined interval. The construction took place 20 hours per day, seven days per week. Drilling was performed at an overall rate of 1,350 linear feet per day. Grout was injected at an overall rate of 240 cubic yards per day.

In addition to the drilling and grouting, two heavily reinforced, 14 inch thick concrete slabs were constructed beneath portions of the pavement within the treatment areas. They were constructed over areas where the drilling and grouting program encountered high concentrations of caved and broken materials within the mined interval. One slab was 700 feet in length and the second was 110 feet long.

The remediated portions of the highway were instrumented with piezometers and settlement plates. Water levels have remained steady and no settlements have been reported since completion of construction.

The eastbound travel lanes were re-opened to traffic on June 24, 1995, a total of 92 calendar days after the start of construction operations. The total cost of the construction, including the reinforced concrete slabs, was $3,600,000. The initial cost estimate was $3,300,000.

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