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Direct and Indirect Influence of Mining Related Subsidence on Structural Damages - A Case Study

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SYNOPSIS

An investigation of causes of damages to a structure located at a toe of a hillside over an undermined area is described. The investigation included a finite element analysis and an analysis of landslide susceptibility of the hillside. Direct and Indirect influence of mining activity appears to be the cause of structural damages.

INTRODUCTION

Due to fast growing needs for energy supplies, a concerted effort is being made to increase the coal production in the United States. Underground mining is an inevitable method for extracting coal resources that are located several hundred feet below the ground surface. One major consequence of Underground mining is the undesirable subsidence (settlements) in the overlying strata and at the ground surface. In fact, it has been estimated that about 2.5 million acres of U.S. land are affected by subsidence due to underground mining. The influence of subsidence can cause damages to houses, sewerage and drainage systems, highways, waterlines, gas lines etc., and hence efforts are being made in minimizing the influence of subsidence by properly planning mining operations and locations of engineering structures. The prediction of influence of mining in hilly terrain becomes a difficult task since there can be indirect influences, in addition to direct influences, that can cause damages to nearby structures. The indirect influence is an important aspect in hilly terrain such as in the Northern Appalachian coal fields. This paper presents a case study that exhibits evidence of direct and indirect influences of mining related subsidence that has caused major structural damages to a building located in Northern West Virginia.

PROBLEM STATEMENT

The one-story building under investigation was located at the toe of a hillside with a slope of 1 in 5 as shown in Figure 1. It was a wood frame structure with a brick veneer built over a concrete basement. There were no problems or any recognizable damage in this building for 17 years following its construction. Suddenly, some cracking in the basement was noticed, and this continued to grow worse, until the structure was abandoned due to excessive damages caused by ground movement. Damages to this structure appeared to have some links with a longwall mining activity in the Lower Kittanning coal seam which is approximately 230 feet below the elevation of the structure. After initiation of mining activity, some horizontal movements on the hillside walls of the house were noticed. This movement has continued and has caused severe damages to the structure in the form of wall and beam cracks. Subsequently, the hillside wall

has collapsed after undergoing about 12 inches of horizontal displacement away from the hillside. This paper presents an investigation that was undertaken to determine the causes of the movements experienced by the aforementioned structure.

INVESTIGATION

The investigation of causes of damages to a structure at the toe of a hillside over an undermined area located in northern West Virginia is described below. In general, the investigation included: (a) detailed visual evaluations of deformations in the structure and surrounding area, (b) estimation of displacements based on photographic records over a three-month period and observation records over nearly six months, (c) observations of changes in the ground water flow patterns down the adjacent hillside, (d) an analysis of the susceptibility of the hillside to development of a landslide, and (e) a finite element analysis of subsidence effects due to underground mining activities. Details of the investigations are given in following sections of the paper. Pertinent information on site geology was obtained from references (3 and 10).

Movements in the Structure

Detailed visual evaluations of deformations in the structure indicated rather substantial cracking in the front side, indicating that it had displaced outward away from the hillside. The nature of crack patterns and displacements show very clearly that the thrust has occurred from the rear of the structure towards the front. This was further evidenced by the subsequent collapse of the rear basement wall which had moved into the building. The horizontal movement in the hillside was clear from the cracks in the masonry retaining wall behind the structure. The horizontal movement in this retaining wall was further confirmed by photographic records over a 3-month period.

Movements of the Hillside Behind the Structure

In addition to the indications of horizontal movement of the hillside behind the structure, which were manifested in cracking and displacements of the structure, there was substantial evidence of movements that was observed in the hillside itself. A severe vertical ground crack was located about 250 feet behind the structure. At most locations, the crack appeared to be open for a substantial depth. Crack widths of as much as two feet were

fact, no older or recent slides are reported on this map close to the site under investigation. Moreover, it should be noted that less than 5% of slides that occurred in West Virginia had a SUMA value as high as that for the slope behind the structure. Therefore, in terms of the statistics of slide occurrence, the probability of a natural slide failure behind the structure is quite low unless some change was introduced in the existing geologic and/or soil conditions to increase the probability of slope failure.

The fact that the slope behind the structure did fail with development of a block glide, described earlier, suggests that some modifications in geologic parameters did occur prior to the initiation of the observed slope movement. The geologic stratification in the hillside, Figure 1, shows the presence of Thornton fire clay (3) at about the basement level of the structure. This stratum represents a relatively weak planar surface along which the sliding could occur. The existence of the vertical crack in the ground surface behind the structure, the observed cracking in the back yard of the structure, and the presence of a potential surface of sliding, suggest that the block glide is in the form shown in Figure 1. It is highly likely that, once the tension crack developed

in the hillside, the redirected ground water coming down the hillside flowed downward into this tension crack to saturate and soften the Thornton fire clay, lowering its shear strength to the point that sliding began. Both the occurrence of the tension crack and the alterations of the ground water flow pattern represent changes in the existing geologic conditions that could have been caused by ground movements associated with subsidence.

Although the block glide behind the structure may have caused major damages to the structure, observations indicate that much of the damage to the structure occurred before the ground movement from the block glide was sufficient to cause any visible ground cracking in the surface. Thus, it can be concluded that the slope instability was not itself the exclusive cause of the damage sustained by the structure.

Direct Influence of Subsidence

The possible influence of the nearby deep mining was investigated by using the Finite Element Method; here, the computer code developed by Siriwardane (7) was used. The thickness of the Lower Kittanning coal seam mined at this location was 5 feet, and the coal was extracted using the longwall method of mining. The width of the two panels closest to the structure are 665 feet and 550 feet, and

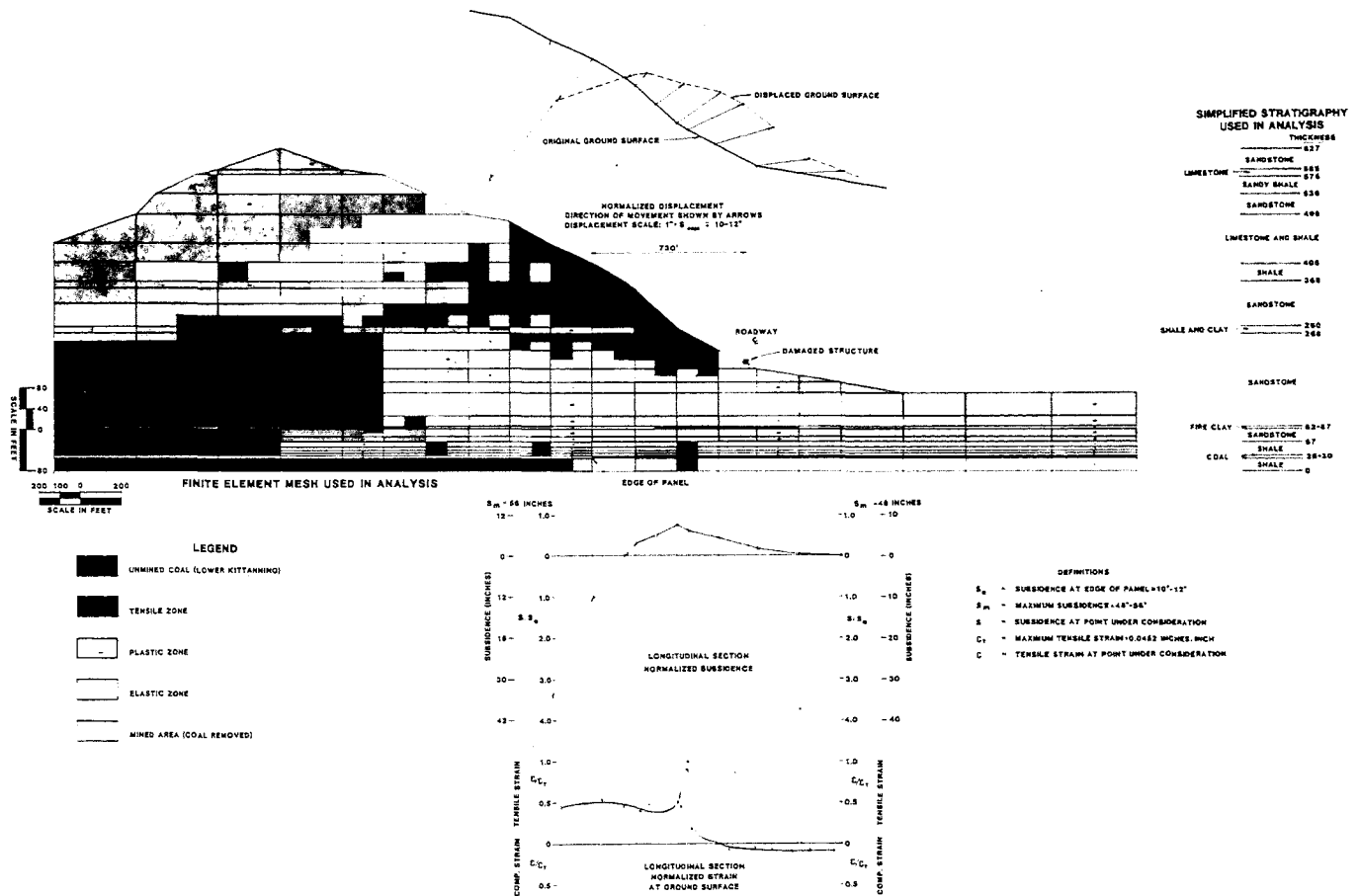


Figure 2. Finite Element Mesh Used in the Analysis, and Predicted Subsidence Profile and Tensile Zones in the Hillside.

the average length of the panels was taken as 5295 feet based on the available mine maps. The location of the structure relative to the mine panels is shown in Figure 2. The idealized geologic profile and the finite element mesh used in the analysis are shown in Figure 2. The overburden height at the edge of the mine is about 400 feet. The material properties used in the analysis are given in Ref. (8). These properties for each material are based on average properties reported by several researchers, as presented by Siriwardane and Amanat (8). Details of the analysis are also presented in reference (8), and only the results from the analysis of the longitudinal section are presented herein. The longitudinal analysis was carried out in three sequences (mining stages) in order to account for material nonlinearities. This incremental analysis provided information on the propagation of plastic and tensile zones in addition to providing displacements and stresses. The computed normalized subsidence profile is shown in Figure 2. The subsidence profile was normalized with respect to the vertical subsidence, S_{edge} , at the ground surface right above the edge of the mine, in order to display the relative deformations elsewhere with respect to a point at which there is obviously direct influence of the mining operation. The magnitude of the maximum subsidence over the mine area was estimated as 48 to 56 inches based on the information given in references (5 and 9). Thus, the subsidence at the edge of the mine could be expected to be 10 to 12 inches. The subsidence profile shown in Figure 2 indicates that there would be about 2 inches of heave at the location of the damaged structure. The predicted resultant of vertical and horizontal displacements is shown in Figure 2. Unlike the situation that can be expected with a horizontal ground surface, the predictions show large horizontal displacements, in excess of 12 inches near the location of the structure.

The developments of plastic and tensile zones resulting from the mining activity are also shown in Figure 2. It can be seen that a large tensile zone is developed behind the location of the structure. The tensile strain profile, Fig. 2, at the ground surface indicated that a very large tensile strain is developed at about 250 to 300 feet behind the structure. It is significant that this is also the approximate location of the large vertical crack that was observed in the hillside behind the structure.

The results of the finite element analysis of mining effects show very clearly that the location of the structure has been subjected to heaving and relatively large horizontal displacements as a result of the nearby long-wall mining operation. These horizontal ground movements explain the structural damages that were observed even before noticing any ground cracking. The sliding movement (block glide) behind the structure caused increased structural damages. The data would suggest that it was the tensile crack that triggered the block glide by permitting the hillside seepage to flow into the crack, lubricating the Thornton fire clay and resulting in the sliding movement.

CONCLUSIONS

Based on the investigation described above, it was concluded that the severe damages to the structure were a direct result of subsidence effects produced by nearby mining operations. Most of the early damages appear to have been caused by the large horizontal movement that resulted from mining activity. These subsidence movements also produced two additional effects of major importance: (a) changes in ground water flow pattern and

(b) development of large tensile strains and resultant cracking in the hillside behind the structure. The water flowing down the hillside from new ground water paths flowed into the cracks lubricating the fire clay layer underneath and triggering a block glide type slope failure which can be considered an indirect influence of subsidence. Additional horizontal displacements caused by the slope failure further damaged the structure.

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