Void backfill design for a steeply dipping coal-mine void below a highway in Canmore, Alberta,

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ABSTRACT
Four coal seams were mined in the No. 1 coal mine on Canmore Creek, Canmore, Alberta using room-and-pillar-mining methods from the mid-1880s to the mid-1890s. Coal mining was conducted along seams inclined between 45° and 80° from horizontal. Highway 742 - Spray Lakes Road was constructed on top of the No. 1 mine. The depth from highway surface to the coal-mine void is less than 4 m below the highway surface.

Alberta Transportation (AT) is responsible for providing a safe, innovative, and sustainable provincial transportation system in Alberta. AT implemented the geohazard-risk-management program (GRMP) to identify, investigate, instrument, monitor, and, if required, repair geohazard sites. The portion of Highway 742 underlain by the No. 1 mine is referred to as the S012 site. The steeply inclined coal-mine voids in Canmore present a special case in that the potential for brittle collapse of the highway surface is exacerbated beyond what would be expected for flat-lying coal-mine voids.

AT commissioned a series of investigations of the coal-mine void beneath Hwy 742 caused by mining of the No. 2 and No. 3 seams at the No. 1 mine. The results of that work, and a conceptual design of mitigation measures for addressing the coal-mine voids at the S012 site are described in this paper.

RÉSUMÉ
Quatre mines de charbon ont été exploitées dans la mine de charbon n o 1 de Canmore Creek, à Canmore, en Alberta, à l'aide de méthodes d'extraction de pièces et de piliers du milieu des années 1880 au milieu des années 1890. L'extraction du charbon a été effectuée le long des joints inclinés entre 45 ° et 80 ° par rapport à l'horizontale. L'inclinaison abrupte des filons de charbon était due à la perturbation de la séquence sédimentaire du substrat rocheux au cours de la formation des montagnes Rocheuses. La route 742 - Spray Lakes Road a été construite au-dessus de la mine no 1. La profondeur entre la surface de la route et le vide de la mine de charbon est inférieure à 4 m sous la surface de la route.

Alberta Transportation (AT) est responsable de fournir un système de transport provincial sécuritaire, innovateur et durable en Alberta. De nombreux géorisques affectent le réseau routier public de l'Alberta, principalement des glissements de terrain, mais d'autres géorisques ont inclus: les éboulements, l'érosion et les vides souterrains. AT a mis en œuvre le programme de gestion des risques géologiques (GRMP) pour identifier, étudier, instrumenter, surveiller et, si nécessaire, réparer les sites géo-aléatoires. La partie de l'autoroute 742 qui repose sur la mine no 1 est appelée site S012.

Le sujet des risques de subsidence créés par les vides de mines de charbon a fait l'objet de recherches approfondies. Cependant, une grande partie de la recherche est basée sur des vides de mine de charbon relativement plats. Les vides de mine de charbon fortement inclinés à Canmore présentent un cas particulier en ce sens que le risque d'effondrement fragile de la surface de la route est exacerbé au-delà de ce que l'on pourrait attendre des vides de charbon plats.AT a commandé une série d'enquêtes sur le vide de mine de charbon sous la route 742 causé par l'exploitation des filons no 2 et no 3 de la mine no 1. Les résultats de ce travail et la conception des mesures d'atténuation pour combler les vides de mines de charbon sur le site S012 sont décrits dans le présent document.

1 INTRODUCTION

Coal mining in seams inclined between 45° and 80° from horizontal was conducted in the Canmore, Alberta area from 1886 to the 1970s. The steep inclination of the coal seams was due to the disruption of the sedimentary sequence of bedrock during formation of the Rocky Mountains. Four coal seams were mined in the No. 1 coal mine on Canmore Creek using room-and-pillar-mining methods from the mid 1880s to the mid-1890s. Highway 742 - Spray Lakes Road was constructed on top of the No. 1 mine. The depth from highway surface to the coal-mine void is less than 4 m below the highway surface.
Alberta Transportation (AT) is responsible for providing a safe, innovative, and sustainable provincial transportation system in Alberta. Numerous geohazards affect the public

highway system in Alberta, mostly landslides, but other geohazards have included: rockfalls, erosion, and subsurface voids. AT implemented the geohazard-risk-management plan (GRMP) to identify, investigate, instrument, monitor, and, if required, repair geohazard sites. The portion of Highway 742 underlain by the No. 1 mine is referred to as the S012 site.

The work presented in this paper was conducted to assess the nature of the void geohazard present at the S012 site, including assessing if pavement deformation was occurring over the known extent of the void(s), and to design mitigations to reduce the risks posed by the void geohazard to the public travelling on Spray Lakes Road. The three-dimensional nature of the void geohazard and the historical nature of the available background information were addressed by assembling the available background information in a Civil 3D (Autodesk 2016) model. During this work, a risk-rating system for void geohazards was developed based on the existing AT method for assessing risk posed by landslide, rockfall, and erosion geohazards.

2 LOCATION AND GEOLOGIC CONTEXT

2.1 Location

The S012 site is located on Highway 742 in the Town of Canmore between Three Sister's Drive and the Canmore Nordic Centre as shown on Figure 1.

2.2 Geologic Context

The S012 site is located in the southeast end of the Mount Rundle range. Mount Rundle range is oriented southeast-northwest, between Canmore and Banff. Its steep, rocky and bare nature contrasts with the gentle and forested physiography of the Bow valley to the east. The summit of Mount Rundle is at an elevation of 2,948 m, and the Bow valley is between 1,300 m and 1,400 m.

The S012 site is located on the lower mountain slopes on the southwestern side of the Bow River valley. The site topography reflects the underlying northwest to southeast geological trend (EBA 1982A). Thicker bands of steep dipping sandstone form ridges near the site with steep sides creek channel associated with Canmore creek located to the north of the site.

The general site area is underlain by bedrock covered by a thin layer of granular soils. The bedrock is a sequence of interbedded sedimentary bedrock types, that includes sandstone, siltstone, mudstone, and coal. The coal seams and bedding planes of the sedimentary rocks are steeply dipping, being reported to vary between 45° and 85° (EBA 1982A, Norwest 2003). The thickness of the No. 2 coal seam in the No. 1 Mine was reported to be 2.1 m (Riva 2008).

Sinkholes associated with collapse of subsurface coal-mine voids are present to the north and south of the S012 site. The sinkholes are more prominent to the south of the S012 site, and are located on privately owned land.

2.3 Climate

The climate normals come from a weather station located near Kananaskis, about 29 km to the southeast (Environment Canada 2016). The climate of the area can be characterized as continental subarctic. Based on statistical data collected between 1981 and 2010, the average daily temperature ranges between -6.1°C in January and 14.5°C in July. The average daily maximum (i.e., the average daily maximum within a month) ranges between -1.0°C and 22.1°C, while the average daily minimum ranges between -11.7°C and 6.8°C. Extreme maxima and minima can reach + 34.5°C and – 45.6°C during the summer and winter, respectively.

Monthly precipitation ranges between 18.9 mm in December and 119.4 mm in June. Between October and April, the major amount of precipitation consists of snow.

3 BACKGROUND INFORMATION ON COAL MINING

3.1 Mining Method - No.1 Mine, No. 2 Seam

The No. 1 mine operated from 1891 to 1914. Record drawings for the No. 1 mine were available through the work conducted by Norwest and through the Canmore Geoscience Centre. A plan of the No. 2 seam below Spray Lakes Road at the S012 site is shown in Figure 2. A cross section through the No. 1 mine near the S012 site is shown in Figure 3. A photo showing the No. 1 mine infrastructure at the bottom of Canmore Creek is shown in Figure 4 with the No. 2 seam portal circled in red.

The steeply dipping nature of the coal seams was mined by first constructing gently sloping horizontal adits or "levels" along the strike of the coal seam from the bottom of Canmore Creek valley where the No. 2 coal seam daylighted. Mining was then conducted upwards from the adit along the steeply dipping coal seam. Mining was conducted by excavating a grid system of tunnel and rooms within the coal seam, with coal being dropped down to the first level for transport out to the mine buildings in the Canmore Creek valley. The final phase of coal mining was to extract as much of the coal (i.e., pillars) remaining between the rooms and tunnels, leaving pillars to support the mine roof. EBA (1982B) speculated that it was probable that pillars near the surface were not removed during the final stages of mining so that the pillars could support the near surface parts of the mine roof. EBA (1982) reported that the overall extraction from seam No. 2 was 50%, but they also indicated the coal recovery could also have been as high as 100% in some areas.

3.2 Coal-Mine Collapse Mechanism

Coal-mine-roof collapse can involve either collapse of a roof between pillars or due to the failure of pillar(s) of coal. For horizontal or near-horizontal mines, bulking would tend to limit upward void migration if the bedrock above the coal mine was 8 to 12 times the seam thickness (Statham and Treharne 1991). For steeply dipping coal-mine voids like at the S012 site, roof or pillar collapse material could be transported by gravity downslope towards the first level, with no bulking of collapsed material to stabilize the roof. A figure showing the collapse mechanisms for a steeply dipping coal mine property (EBA 1982) is included as Figure 5.

4 COAL-MINE-VOID INVESTIGATIONS

4.1 General

Site investigations were conducted at the S012 site in 2003 (drilling, ground penetrating radar, and downhole camera surveys, Norwest 2004), in 2007 (drilling and downhole camera surveys, AMEC 2007), 2017 (downhole-video-camera surveys and downhole-LiDAR-camera surveys through existing metal capped boreholes installed during the Norwest and AMEC investigations, InSAR monitoring, electrical resistivity and ground penetrating radar surveys, and review of AT pavement LiDAR data, KCB 2017), and 2018 (topographic surveying, drilling and downhole camera surveys in new boreholes drilled during the design phase for coal-mine-void risk mitigation, KCB 2018). The site investigation work was limited to the highway surface and land to the north of the highway owned by the Town of Canmore.

The 2017 work included a site reconnaissance to the base of Canmore Creek near the location of the No. 2 seam portal. The portal is fenced off and could not be accessed or viewed through the dense bushes within the enclosure. A stream of water was observed to be discharging from the toe of the slope and it is believed that the stream is groundwater discharge from the No. 2 seam. A faint pig-manure odour was present at the base of the creek valley near the fencing, indicating that hydrogen sulphide gas may be present in the mine.

4.2 Drilling Investigations

Drilling investigations were conducted using air-rotary-drilling methods. The drilling investigations indicated that there were open voids above a rock fil material within the coal mine void, underlain by intact bedrock. Logging of the boreholes was conducted by monitoring cuttings return, with cuttings return being lost in voids. Collapse material was detected by uneven drilling resistance compared to relatively steady resistance when drilling through the roof material above the void(s).

When multiple boreholes were drilled and left open before backfilling, cuttings and air return were reported to exit adjacent open boreholes. These observations indicted that there was a large, continuous void present beneath the highway surface. The shallowest depth to a coal-mine void was 3.4 m, including 1.0 m of granular overburden soil. The thickness of open voids recorded varied from 0.7 to 5.0 m and the thickness of the collapse material below the open void varied from 1.9 m to 12.9 m.

A hydrogen sulphide gas odour was detected during drilling.

4.3 Downhole-Video-Camera Surveys

Downhole-video-camera surveys were conducted in the 2003 and 2007 investigations; however, AT only has records for the 2003 downhole-video-camera surveys in their files. The downhole-video-camera surveys were conducted through boreholes that were equipped with flush-mounted road-box headboxes. A total of seven such boreholes were equipped with flush-mounted road boxes, but by 2017, all but three of them had collapsed into the mine. The AT operations crews backfilled the borehole holes after the collapses were noted. The three-remaining metal-capped boreholes were surveyed with a downhole video camera in 2017.

Light was observed from adjacent open boreholes drilled in 2003 and 2007 during the video-camera-surveys, indicating that a continuous open void was present below the highway surface.

The 2017 video-camera survey detected what appeared to be either deteriorated bedrock joints, or evidence of cracking in the intact bedrock above the roof that could indicate impending roof collapse. An image from the 2017 downhole-video-camera survey showing the condition of the borehole walls is presented in Figure 6. The resolution of the 2003 downhole-video-camera data was not sufficient to permit comparison and detection of change between the 2003 and 2017 video-camera surveys.

The rockfill below the open void consisted of cobbles and boulders. Figure 7 taken during the 2017 video-camera survey shows the condition of the collapse material.

4.4 Downhole-LiDAR-Camera Survey

A downhole-LiDAR camera survey was undertaken to assess the extent of the open coal-mine void located beneath the highway. The downhole-LiDAR camera was unable to fully open in one borehole near centerline, limiting the extent of the void surveyed. Although the void is believed to be continuous below the highway, the downhole LiDAR camera data could only confirm the presence of two open voids. The geometry of the surveyed voids is presented in Figure 8.

Electrical resistivity tomography (ERT) Surveys

Electrical resistivity tomography surveys were conducted along three survey lines, as shown in Figure 1. Survey line 03 was located across Hwy 742, along the strike of the mine where the 2003 drilling indicated the shallowest coal-mine voids were present. The interpretation of the geophysical data along the line across Hwy 742 was conducted using the data from the Norwest boreholes and the downhole LiDAR camera survey. The other two survey lines were located on the north and south sides of Hwy 742 and were surveyed to assess if the deeper extents of the coal-mine void could be detected, and to assess if additional coal-mine-roof-collapse features could be detected.

4.5 3-D Modelling

A three-dimensional model was created in Civil 3D with the available background information that could be georeferenced with the topographic survey at the start of the project. The No. 2 seam coal mine crosses Spray Lakes Road on angle, and is oriented at approximately 45 degrees to horizontal. Since mining was completed, roof collapse has caused the roof to migrate upwards towards surface. The geometry of the void is complex, and assessment and design work must be thought of in three dimensions (Stephenson, personal communication).

The Town of Canmore gave KCB and AT LiDAR data collected in 2013 for use in this study. Figure 9 shows an oblique north-facing view of the LiDAR data of the site and surrounding areas collected by the Town of Canmore, including the highway surface and coal-mine-collapse features on privately-owned land to the south of the highway.

The historic coal-mine record drawings and the data collected from the 2003, 2007 and 2017 investigations were assembled in the Civil 3-D model. Sections through the Civil 3D model are shown in Figures 10 and 11.
Figure 10 shows how the floor of the modelled coal-mine and the interpreted open voids and voids backfilled with collapse material generally matches the 2003 and 2007 borehole data. Some variations were noted between the borehole data and the modelled coal-mine void, and drilling is planned to investigate the location of the coal-mine workings at greater depths.

4.6 InSAR Monitoring

Interferometric-synthetic-aperture radar (InSAR) monitoring was conducted on the S012 site from April to October 2017. InSAR was only effective at assessing surface movements in areas with minimal to no vegetation, and only when the area was not covered with snow. The InSAR survey did not detect movement of the pavement surface at the S012 site during the period of survey.

4.7 Pavement-LiDAR Data Review

AT conducts annual data collection on the public highway system that includes LiDAR profiling of highway pavement surfaces. The pavement-LiDAR data is more accurate than the airborne-LiDAR systems that are used to gather LiDAR data over large areas. The pavement-LiDAR data is collected with instrumented vehicles operated by third-party consultants. The available pavement LiDAR data was reviewed to assess if highway subsidence above the coal-mine void occurred at the S012 site.

Pavement-LiDAR data was collected in 2010 and 2013 on Hwy 742:02 at the S012 site. The pavement LiDAR data does not show a change in the pavement profile between 2010 and 2013.

4.8 Assessment of Highway-Collapse Potential

The observation of what appear to be dilating joints in the borehole walls during the 2017 downhole-video-camera survey described in Section 4.3 suggests that the bedrock above the coal-mine void is straining and could indicate that strain associated with ongoing roof collapse could be slowly propagating towards surface. The elevated resistivity below the highway recorded in the ERT survey shown in Figure 10 could also indicate that dilation of bedrock joints associated with strain of the roof over the coal-mine void is occurring.

Notwithstanding observations made during the video-camera survey and in review of the ERT-survey data, if roof collapse is underway, it has not resulted in enough deflection of the pavement to be observed by the AT-pavement-LiDAR surveys in 2010 and 2013, or in the InSAR data collected in 2017, as previously discussed. However, roof collapse affecting the pavement surface could be sudden, and may not be preceded by warning signs, such as deflection of the pavement surface.

5 DESIGN OF COAL-MINE-VOID MITIGATION

A “monitoring-only” strategy should not be used to manage the geohazard posed by the coal-mine void at the S012 site. Various mitigative options were considered and they included either spanning the coal-mine void or backfilling the coal-mine void. AT chose the void backfilling option. The design concept must accommodate highway use and the requirements of the Town of Canmore. Spray Lakes Road at the S012 site is a relatively busy highway with high tourism activity. Therefore, solutions that involve prolonged road closure and surface disruption were not preferred by AT. An in-situ backfilling method through boreholes drilled from the road surface was preferred. However, the backfill material should not be fluid enough to run to the bottom of the coal-mine void, out of concern for release of backfilling materials into Canmore Creek and/or backfilling the entire coal-mine void below Spray Lakes Road and changing the hydrogeology of the S012 site area.

Injected urethane foam was selected by AT to backfill the upper portions of the coal-mine void. The extent of backfilling will be finalised after the next phase of drilling is complete and the Civil 3D model is updated. Urethane foam will be injected into the collapse material, and also into the open voids above the collapse material. Foam injection will create a solid mass of foam and foamed collapse material that will interlock with the surrounding coal-mine void, and resist additional settlement of collapse material into the coal mine void. The foam in the open voids above the collapse material will support the bedrock in the mine roof. A schematic of how the work will be conducted is presented in Figure 12.

Construction of the foam injection repair will be tendered for construction in 2019. Pavement LiDAR data will be collected by AT on an annual basis to provide post-repair ongoing monitoring of the pavement surface.

ACKNOWLEDGMENTS

The authors would like to acknowledge KCB and AT engineering and operations personnel that participated in this project, the Town of Canmore for their cooperation during the field work and in sharing LiDAR data with KCB and AT, Challenger Geomatics Ltd. For topographic surveying and their subcontractor Renishaw Canada Inc. for downhole LiDAR camera surveying, Mr. Mark Bajar of AT for assistance with the pavement-LiDAR data, and Mr. Gerry Stephenson of Terra Incognita who provided much valuable information from his experience working as a mine engineer for Canmore Collieries.

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Figures

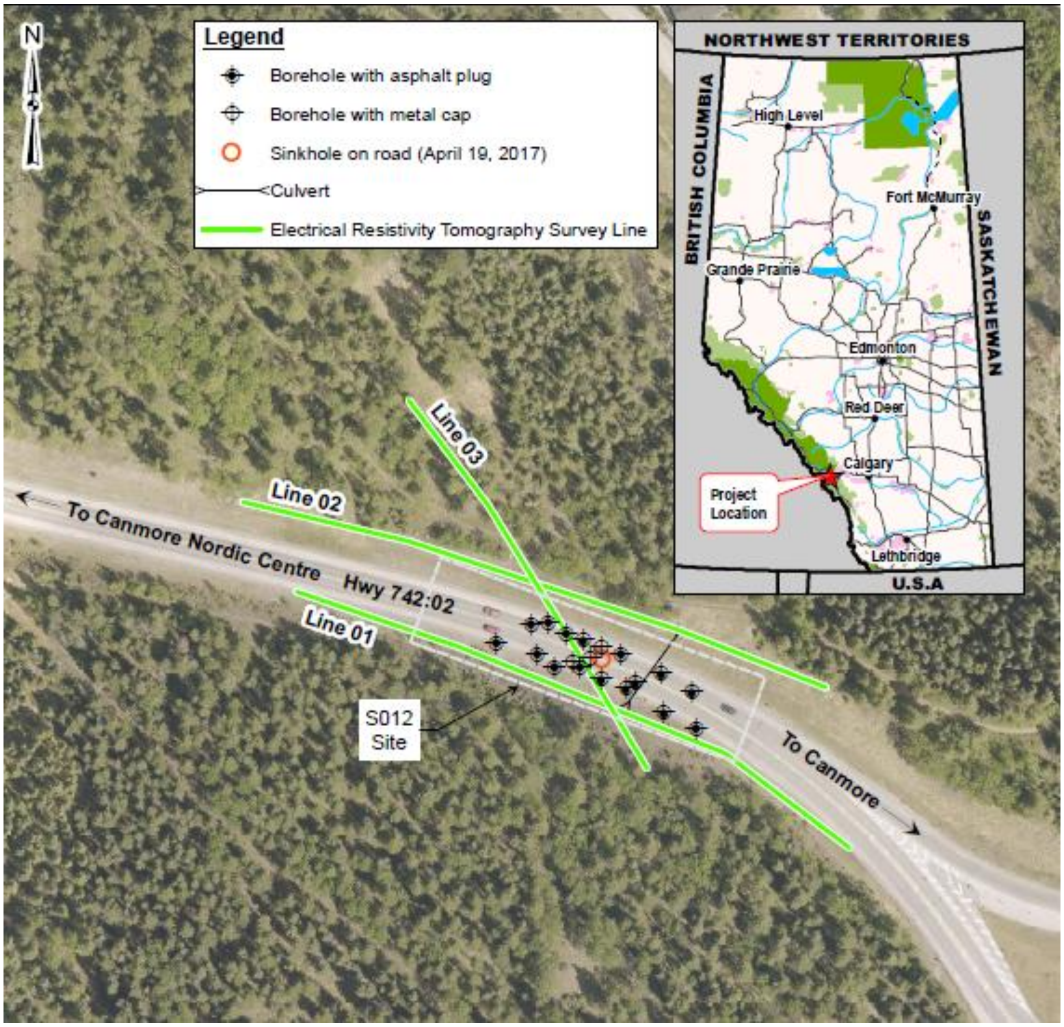

Figure 1. Location of the S012 site

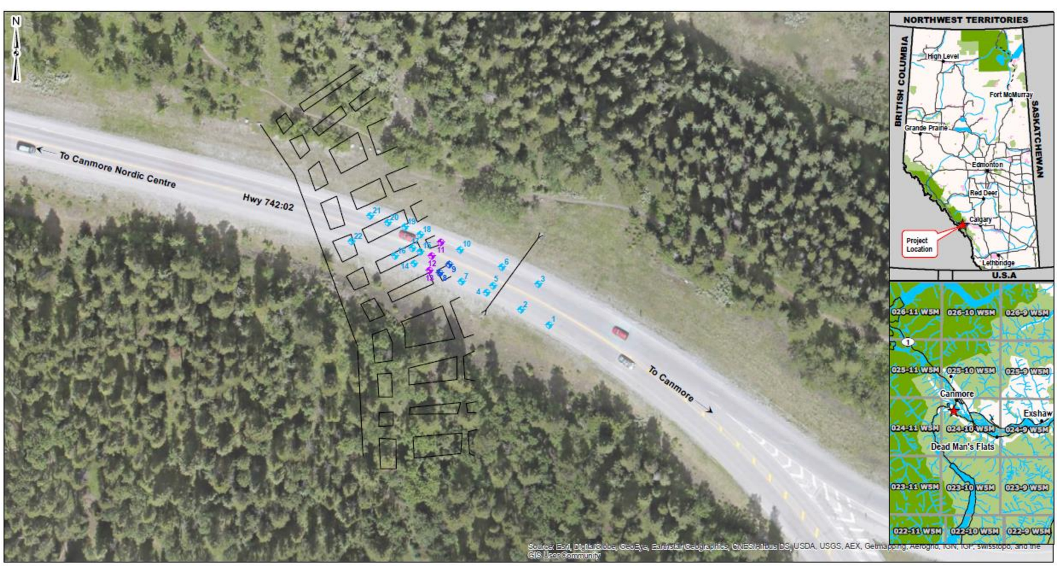

Figure 2. Plan of the No. 2 seam below Spray Lakes Road

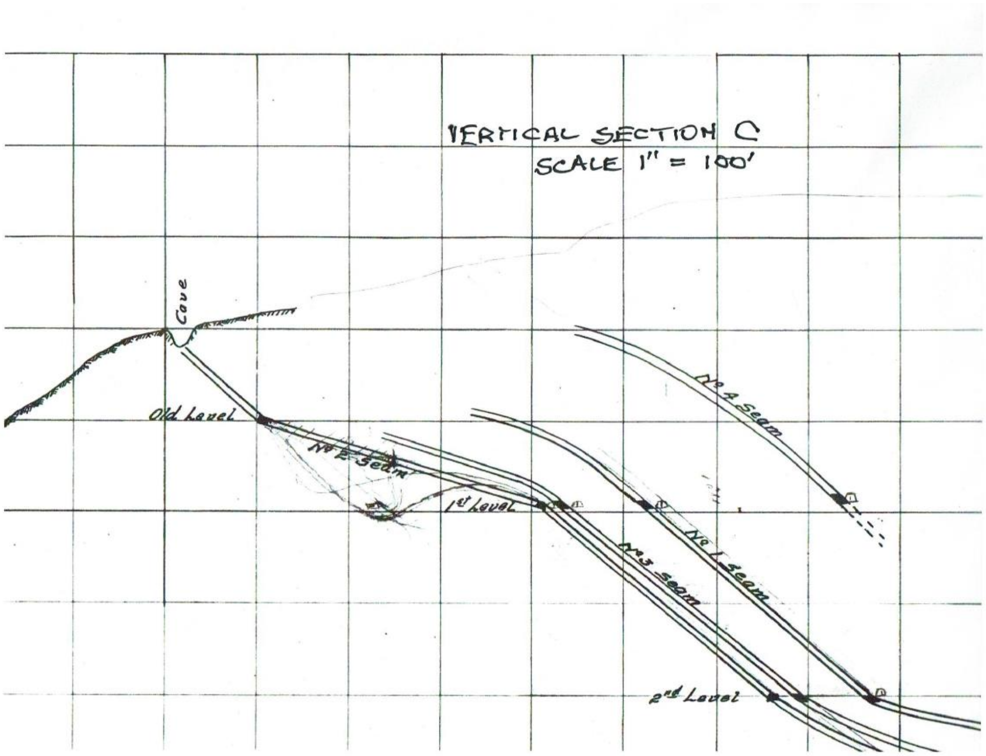

Figure 3. Cross section through No. 1 mine near S012 site


Figure 4. Canmore No. 1 mine in Canmore Creek. Photo provided by Canmore Museum and Geoscience Centre. Portal to No. 2 seam circled in red.

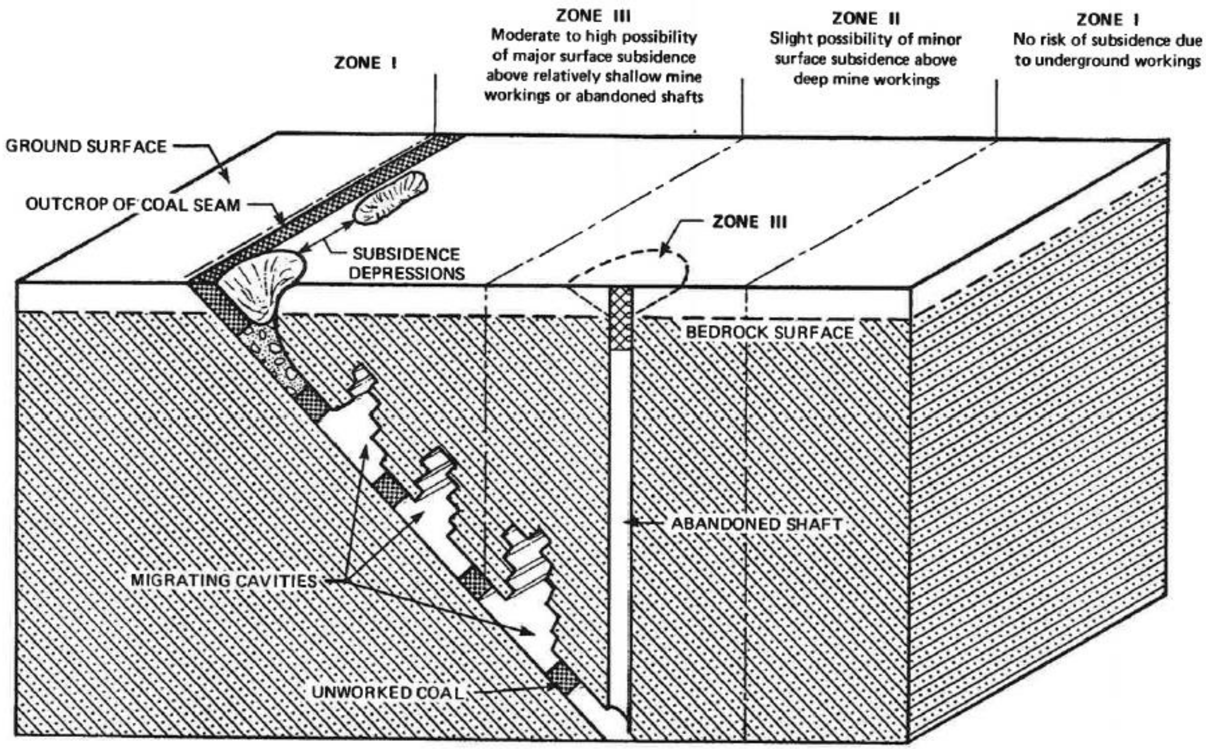

Figure 5. Schematic diagram showing collapse mechanisms for steeply dipping coal mine (after EBA 1982)

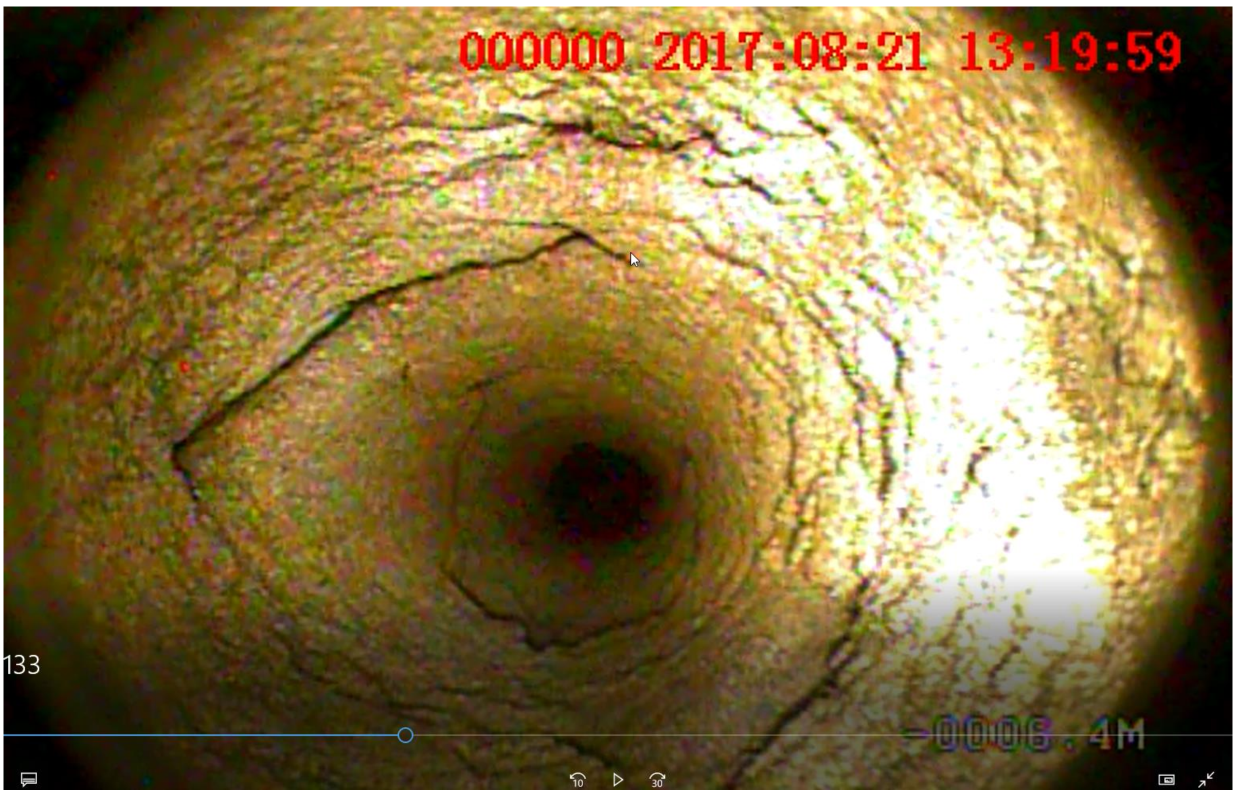

Figure 6. Image from 2017 downhole-video-camera survey of metal-capped borehole

Figure 7. Image from 2017 downhole-video-camera survey of metal-capped borehole. Note roof collapse material.

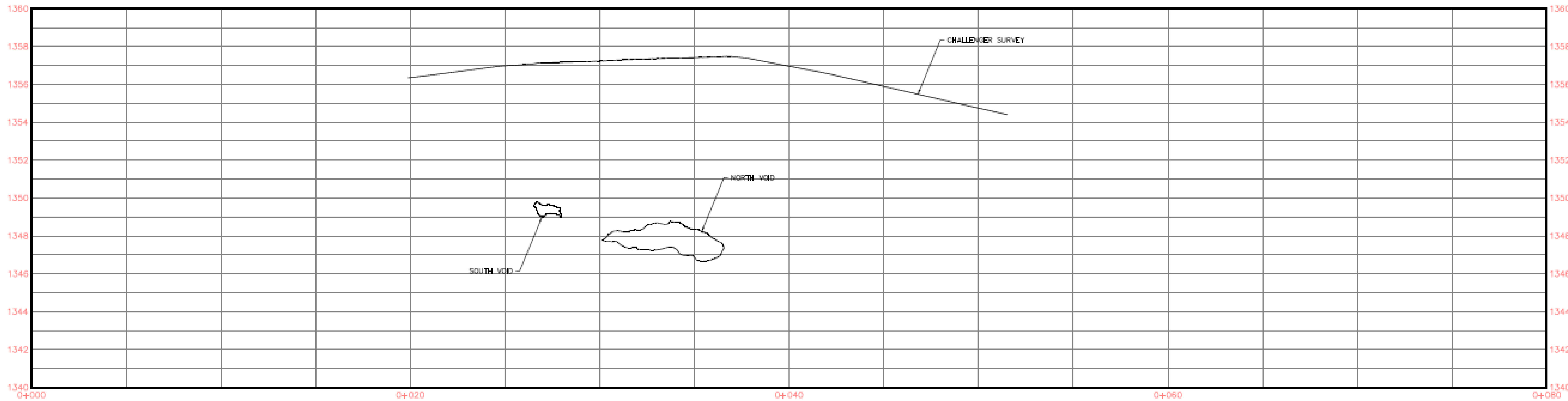

Figure 8. Geometry of surveyed voids from downhole-LiDAR-camera survey

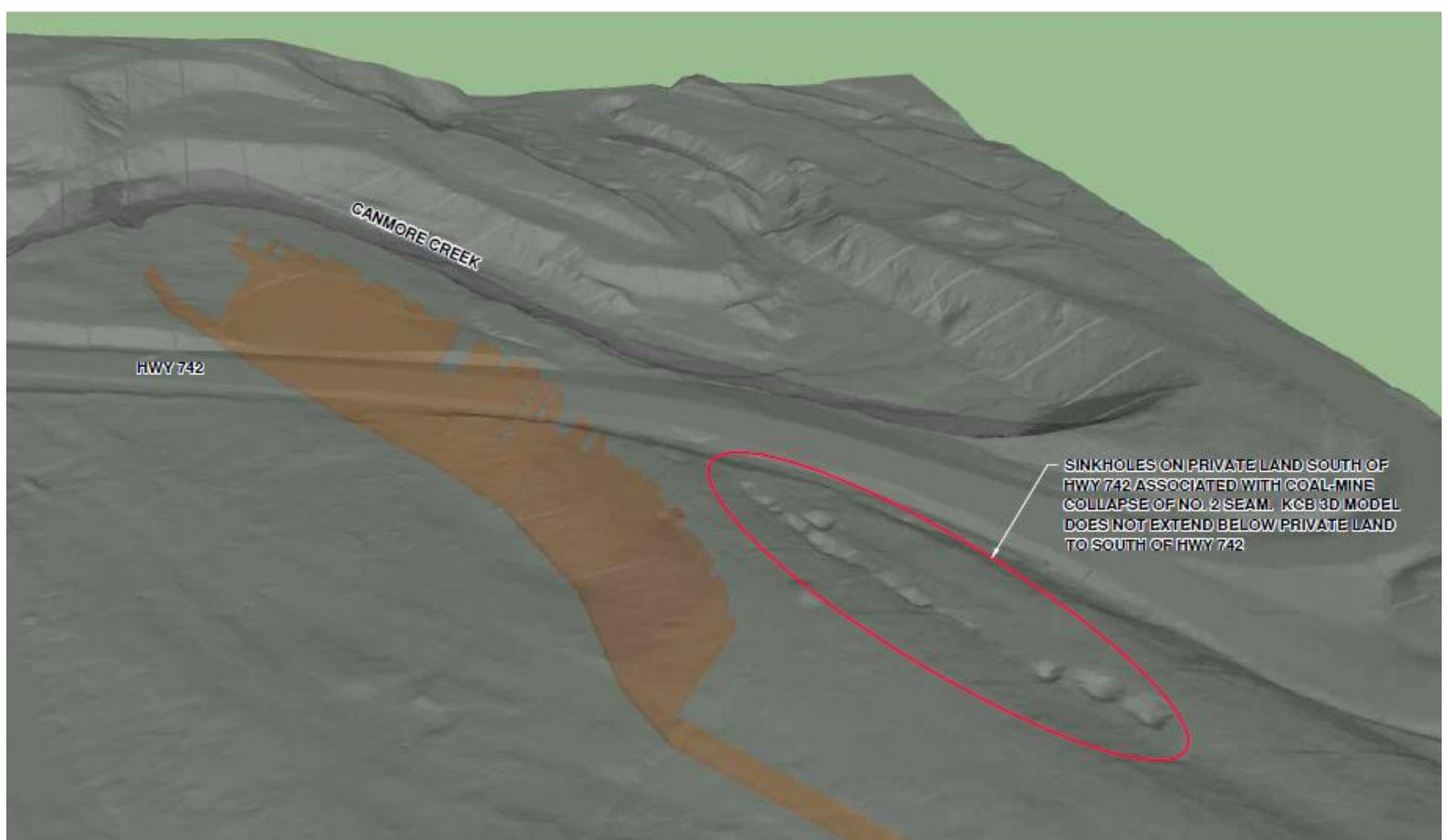

Figure 9. Oblique north-facing view of the S012 site and surrounding areas using 2013 LiDAR data.

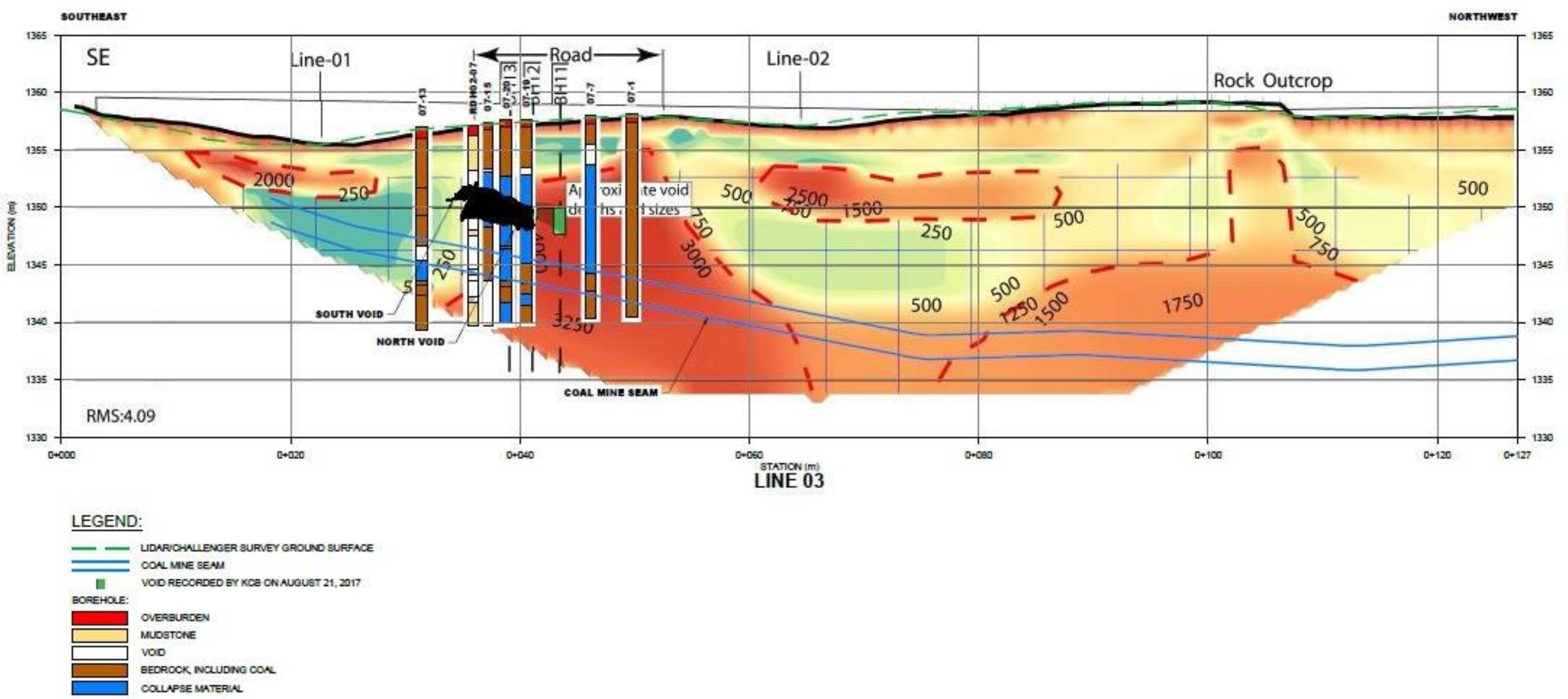

Figure 10. Cross section through Civil 3D model along Line 03

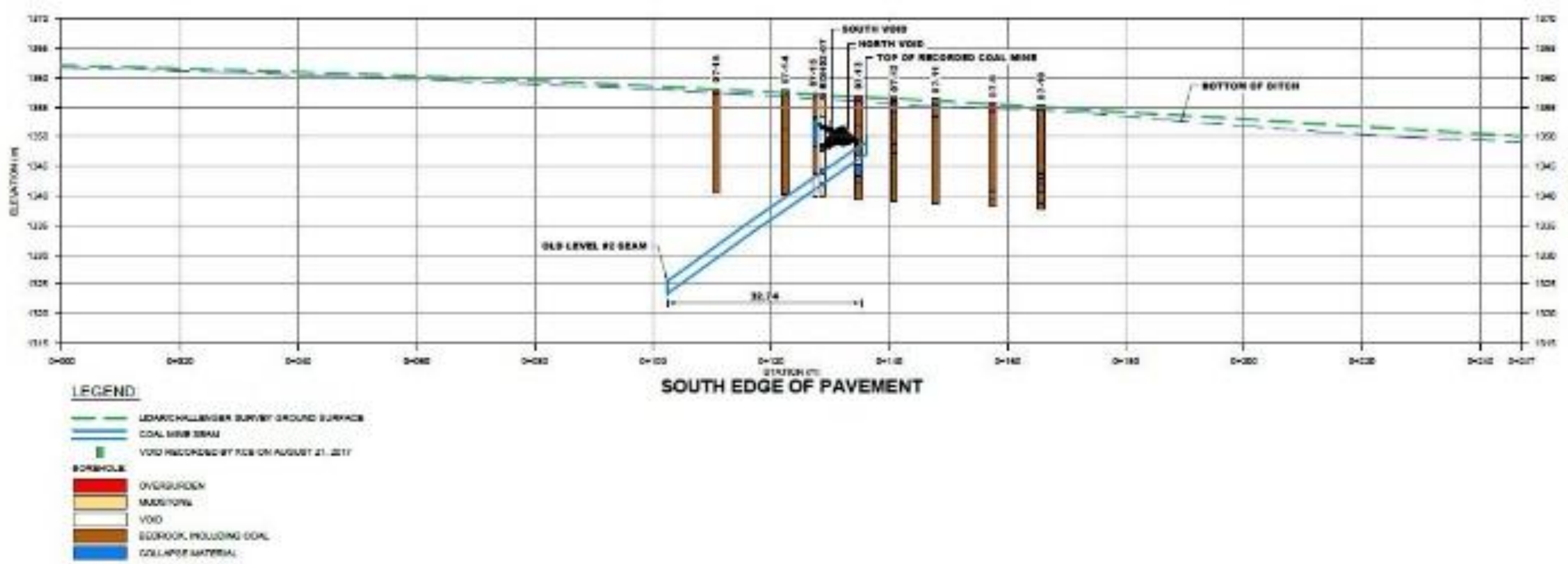

Figure 11. Cross section through Civil 3D model along Line 01 (south edge of pavement)

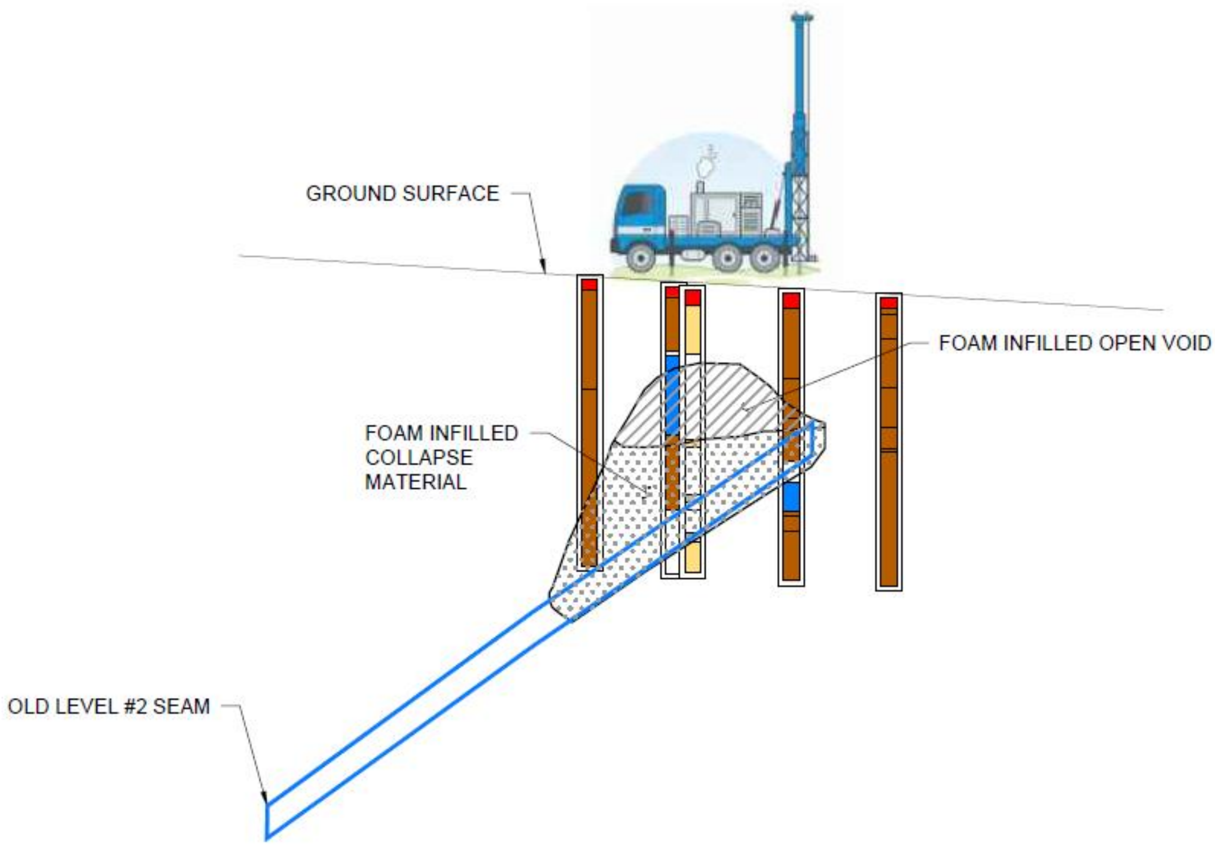

Figure 12. Schematic of coal-mine-void mitigation with foam injection