US-50 Big Horn Sheep Canyon, Fremont County, Colorado
A Rockfall Mitigation Case Study

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ABSTRACT

US-50 extends west to east in Colorado from Grand Junction to Pueblo and beyond through the rugged terrain of the Central Rocky Mountains and is lined with steep natural and constructed rock slopes. A rockfall mitigation analysis and design was requested by the Colorado Department of Transportation (CDOT) for an existing rock slope on US-50 between MP 242.2 and MP 242.6 near Coaldale in Central Colorado. The rock slope ranges in height from 100 to 300 feet and forms blind corners with limited rockfall catchment zones. The Arkansas River parallels the road and rock slope on the north side.

In the spring of 2007, the authors conducted detailed geologic mapping of the rock slope using mountaineering techniques. Based on our mapping and mitigation analysis, blocks of concern and areas of rockfall were identified along the slope and recommendations for mitigation were developed. In conjunction with CDOT, we prepared detailed design plans and specifications for mitigation of the rockfall hazards. Mitigation began in September 2008 to stabilize the areas of concern. Because of the proximity of the Arkansas River, netting was suspended from a crane during scaling to reduce the potential for rockfall into the river. Modified rockfall nets were suspended in gullies and large rock blocks were anchored to the slope. Additionally, a joint team from CDOT and Kleinfelder engineers installed crack monitoring devices along the base and side of a large potentially unstable block to remotely monitor movement because of its size and location on the slope.
INTRODUCTION

Project Description

The project site is an existing rock cut slope on US-50 between MP 242.2 and MP 242.6 (approximately 2,100 feet long) in Central Rocky Mountains near Coaldale, Colorado (Figure 1). The rock cut is on the south side of the highway and forms a blind corner with a limited shoulder and rockfall catchment zone. The rock cut slope ranges in height from about 100 to 300 feet. In addition, the rock cut forms a compound slope with a ledge (bench) approximately midway between the shoulder of the road and the brow of the slope. The ledge dips towards the road and extends the full length of the rock cut. The Arkansas River parallels the road and rock cut on the north side.

Figure 1: Site Vicinity (Image Courtesy of Google Earth)
Local Geology

Along this cut slope section, US-50 exposes Precambrian granodiorite. The regional geological map states that the main body of the granodiorite is characterized as pinkish-gray, massive to foliated, medium to coarse grained hornblende or biotite granodiorite. In localized areas, the granodiorite is altered to granitic gneiss (Scott et al, 1979). During our field investigation, we observed granitic gneiss with some localized areas of schist. The rock cut slope ranges in height from about 100 to 300 feet. The rock slope dips to the north at angles ranging from 60 to 90 degrees and overhanging in some locations. In addition, the rock cut forms a compound slope with a ledge (bench) approximately midway between the shoulder of the road and the brow of the slope. This area is known as Gobbler’s Knob (Figure 2).

Design Challenges

In general, the overall rock quality is good and stabilization design was limited to isolated areas of rock fall or specific rock blocks. Challenges were present with developing a design to satisfy the road and environmental conditions. The roadway consists of two 12-foot wide lanes and minimal shoulders of less than six feet. The limited space reduced the potential for large crane support for rock anchoring. The limited road width and the height of the slope limited the potential design for stabilization of blocks on the upper section of
the slope. Additionally, the proximity of the Arkansas River limited the design and recommendations for extensive scaling or blasting as part of the stabilization.

INVESTIGATION OVERVIEW

*Rock Slope Mapping*

As part of our field reconnaissance at rock cut slope locations, we completed detailed geological and geomechanical mapping (Figure 3). Much of the information collected during our outcrop mapping activities is attendant to the condition of discontinuities within the exposed rock masses including discontinuity information such as dip, dip direction, joint roughness and weathering characteristics. General rock mass information was collected to assess the quality of the rock mass and estimate the rock quality designation (RQD), Rock Mass Rating (Bieniawski, 1989) and Geological Strength Index (Hoek, 1997).

Because of the height and inclination of the existing rock cut slopes, much of our field mapping was completed using mountaineering (climbing and rappelling) techniques (Figure 3).

The rock slope mapping was completed along the road level, along the mid-height bench and in vertical traverses spaced across the cut slope. We focused three of the vertical traverses on specific large blocks we observed during our preliminary field visit. Two large blocks start at the bench height and extend 40 to 60 feet down
towards the road (Figures 4 and 5). There are tension fractures present behind these large blocks indicating previous movement.

![Figure 4: Rock Block 1 – Area of Concern](image1)

![Figure 5: Rock Block 2 – Area of Concern](image2)

The third block is on the eastern end of the cut slope near the top of the slope approximately 300 feet above the road (Figure 6). Tension fractures are present along the side and base of this large block.
STABILIZATION DESIGN OVERVIEW

Rock Slope Stabilization Analysis

The development of recommended rock slope stabilization methods was based on three different analyses. These analyses included 1) kinematic evaluation, 2) global stability, and 3) rockfall hazard evaluation. Using the discontinuity data collected, we completed stereonet and Markland kinematic analyses (Watts, 2001) to establish if there is a potential for planar, wedge-, or toppling-type failures from the slope.

The Markland analyses indicated the potential for toppling-type failures from the existing rock slope. Additionally, at the locations of Blocks 1 and 2 described above, there was a potential for planar-type failures. The potential for planar- and wedge-type failures was low in other locations based on the discontinuity data collected.

We completed a global stability analysis of the existing rock slope using the program Slide® by Rocscience. We utilized the Hoek-Brown Criterion (Hoek et al, 1997 and 2002) to estimate parameters for the rock mass. Based on the field mapping, we estimated average rock strength of 50 MPa (7,250 psi) and an average GSI of 60. The global stability analysis estimated a safety factor greater than 1.5 for the existing slope.
The slope stability of Block 1 and Block 2 was evaluated as planar failures from the slope. We assumed cohesion equal to zero because of the presence of tension cracks indicates that movement has occurred. We assumed a factor of safety of 1.0 for our analyses and applied a rock anchor force to achieve a factor of safety of 1.5. We completed hand calculations on the blocks and checked the calculations using the computer program RocPlane V2\textsuperscript{®} by Rocscience. Block 1 and Block 2 are located below the mid-height bench. The slide plane of the blocks is irregular and stepped from vertical to dipping towards the roadway at 55 to 65 degrees. To complete the stability analyses, we assumed a uniform slide plane at the angle observed during the field investigation. Based on our analyses for Blocks 1 and 2, we estimated that 15 to 20 25,000 pound tensioned rock anchors are required to achieve a factor of safety of greater than 1.5.

**Stabilization Recommendations**

Based on our analyses and field observations, we recommended stabilization methods for areas and potentially unstable blocks on the rock slope. Based on existing stationing along the roadway, the location of areas of concern and blocks were recorded and photographs were taken for figures and design specifications. Various potentially unstable rock blocks were observed along the length of the slope. Recommendations for the blocks included scaling and removal of the blocks if feasible and stabilization with rock anchors in scaling was not feasible.

Along the western end of the rock slope, chutes and gullies that extended to the road elevation were present with extensive loose rock. Stabilization recommendations for the chute and gullies included wire mesh drape rockfall system and a modified wire mesh drape system. The modified
system included anchors and cables at the top of the system to hold the top of the drape three to four feet above the slope to allow rockfall to roll under the drape and be contained in the ditch. Additionally, areas of highly fractured rock and blast damaged rock along the western end were recommended to be mitigated with a wire mesh drape system.

Along the eastern end of the rock slope, the mid-height bench slopes towards the roadway. Scaling was recommended along the mid-height bench to reduce the potential for rockfall. For the three large blocks, we provided a recommendation for trim blasting to remove the unstable blocks. Because of the proximity of the Arkansas River, this option was not feasible. Based on the location and height on the slope of Block 3, stabilization or removal was not a feasible option. For Block 3, crack meter telemetry was recommended to monitor potential movement of the block on the rock slope.

Design and Construction Drawings and Specifications

Design and construction drawing specifications were prepared for the slope stabilization. The construction drawings package contained overview photographs of the slope with areas requiring stabilization highlighted (Figure 7). The photographs provided the contractor with a general picture and stationing of where the various stabilization methods would be installed. Details on the drawings summarized the rock anchor locations, quantities, geometries, loading requirements and testing requirements. Additionally, details summarized the wire mesh drape rockfall system installation specifications, wire mesh anchor installation, and approximate wire mesh quantities.
CONSTRUCTION OVERVIEW

Construction began in September 2008 at the close of summer to avoid the heavy use period of the Arkansas River. Slope stabilization was performed by AIS Construction. As described above, stabilization included slope scaling in select areas, wire mesh and modified wire mesh installation, rock anchor installation, crack telemetry installation.

Slope stabilization included environmental and technical construction challenges to the contractor. Slope scaling was closely monitored and a wire mesh was hung from a crane to reduce the potential for rockfall into the adjacent Arkansas River. To allow for traffic flow to continue, the road had to be cleared of debris and field work stopped on 20 to 30 minute intervals. Weather became a challenge as construction pushed into the late fall season in the Central Rocky Mountains. Because of safety concerns, icy roads often slowed construction. In addition, the
steep inclination and height of the rock slope provided technical challenges. Stabilization efforts were completed with rope access or from a basket on the crane. Wire mesh placement was completed with the assistance of a helicopter (Figure 8).

Slope stabilization progressed in phases. Phase 1 was slope scaling. Slope scaling was completed in specific areas of the slope and not the entire slope. Scaling was primarily completed on the western end of the rock slope where gullies were present and where more loose rock and blast damage was observed.

Phases 2 and 3 included wire mesh installation. During Phase 2, anchors to suspend the wire mesh were installed on the slope. Anchors were primarily installed using hand drilling methods with the contractor on rope access (Figure 9). Two types of wire mesh were used: a lightweight, stretchable mesh for temporary protection and a heavier, more rigid mesh for permanent reinforcement.

Figure 8: Wire Mesh Installation with Helicopter Support

Figure 9: Wire Mesh Anchor Installation
mesh were installed to reduce rockfall onto the roadway. The standard wire mesh drape rockfall system was installed over areas with rockfall potential (Figure 10). A modified wire mesh drape rockfall system was installed in gullies and areas where rockfall may occur further up the slope. The modified system included anchors and cables at the top of the system to hold the top of the drape three to four feet above the slope to allow rockfall to roll under the drape and be contained (Figure 11). CDOT has utilized the modified wire mesh drape system in various locations in Colorado with success in containing rockfall.

Phase 4 of the slope stabilization was the installation of rock anchors in the unstable rock blocks identified during our field mapping and analyses. Rock anchors were installed from a basket supported by the crane; also by a drill rig installed on the boom of the crane with the driller.
supported with ropes using mountaineering techniques. Rock anchors installed and tensioned to 25,000 pounds. Lengths ranged from 10 to 20 feet.

For Phase 5, telemetry was installed on Block 3 to remotely monitor movement of the block. Based on the location and height on the slope of Block 3, stabilization or removal was not a feasible option. In a joint effort with CDOT and Kleinfelder, three crack meters were installed at various locations along the tension crack behind Block 3 (Figure 12). CDOT and Kleinfelder used mountaineering techniques (rappelling and climbing) to set-up at the desired locations. Hand drills were employed to install the anchors for the crack meters across the tension crack (Figure 13). The crack meters are connected to a remote power source and can be monitored remotely. With real-time monitoring, the crack meters will detect the slightest movement in Block 3. If movement occurs, a signal will be transmitted to CDOT who will be able to close the road to protect the travelling public.

**CONCLUSIONS**
The CDOT Rockfall Hazard Classification System identified a 2,100-foot long slope along US-50 in Central Colorado because of blind corners, limited rockfall catchment, high traffic volumes, and multiple objective hazards. Through discussions with CDOT, geologic mapping of the rock slope, and stability analyses, Kleinfelder provided a range of recommendations for stabilization and mitigation of rockfall hazards from the rock slope. During construction, Kleinfelder worked closely with CDOT to monitor construction and provide field engineering consultation where necessary.

REFERENCES


RocScience Inc. Toronto, Canada.

