Marina Fire Rockfall Protection: A rapid, practical response

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ABSTRACT

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The Marina Fire (July 2016) resulted in significant increase in rockfall risk to a portion of US 395 in Mono County, California. This corridor is the main north-south transportation artery on the east side of the Sierra Nevada providing access to Yosemite National Park, Mammoth ski area and Southern California. The roadway is cut into a slope comprised of colluvium and interspersed tufa from relict shorelines of Mono Lake.

Due to rockfall events impacting the roadway immediately post-fire, safely keeping the road open to traffic was a priority for Caltrans. A rapid response was executed to assess the hazard and implement a mitigation strategy for this segment of roadway. Working in conjunction with Caltrans, Yeh engineering geologists evaluated the rockfall trajectories impacting the roadway and provided recommendations for installing a temporary flexible rockfall fence.

Two Geobrugg flexible rockfall fences, 2,000 linear feet of GBE 500AR (3m height) and 1,500 linear feet of model GBE 500AR (4m height) were recommended. A significant constraint was the presence of a critical fiber optic utility at the base of the slope, which was installed via horizontal directional drilling. Due to the uncertainty of the precise location of this utility, excavation and drilling to install post support system and ground anchors for the post support were a primary concern.

Design modifications were made to accommodate the site conditions. Of particular note was the design of the post support system. The fence posts did not have the typical concrete foundation type support systems but instead were supported globally by a wire rope support system and locally with number 10 threaded bar, 18 inches in depth. This design did not encroach on the buried utility and facilitated rapid construction, enabling the installation to be completed within a matter of weeks.

INTRODUCTION

Rockfall is a hazard commonly impacting transportation corridors in mountainous terrain. It can originate from natural or cut slopes and the risk of rockfall can be exacerbated by natural events such as intense rainfall and wildfire. In the western United States, dry season wildfire events adjacent to mountain highways can result in an elevated rockfall risk immediately, during, and post-fire. Often, highway managers approach the reality of wildfire-elevated rockfall risk by mitigating the hazard through engineered solutions. Methods that are commonly used include protection systems like wire mesh systems to cover the slopes and flexible fences to prevent rockfall from entering the traveled way.

Advantages of flexible rockfall fences include economic feasibility, expedited analysis, and rapid installation. In use in California since the late 1980s *(1)*, this type of mitigation is now common throughout the world. Comprised of steel posts, wire mesh, and wire rope components, flexible rockfall fences can be manufactured, delivered and installed under an expedited schedule to provide rockfall protection to a site within a timeframe of a few weeks. Of particular interest to geoprofessionals working in transportation corridors with traffic safety and utility constraints, flexible rockfall fence design can be optimized to accommodate site conditions, Figure 1.

Figure 1. Flexible rockfall fence posts installed on US Highway 395, Mono County, California.

Although flexible rockfall fences are now commonplace, a recurrent issue for installation contractors and owners is the post support requirements that are often recommended by designers. Frequently, large excavated foundations are specified that call for a significant quantity of steel reinforced concrete. This translates into a significant portion of the overall cost and a longer construction timeframe for the installation of flexible rockfall fences as compared to other methods of rockfall fence post support.

This paper presents a case study in Mono County, California where temporary, flexible rockfall fences were installed to provide rockfall protection to US 395, Figure 2. A unique aspect of this project was the uncertain location of a critical utility and design modifications that allowed the rapid installation of the fence posts while minimizing risk to the utility.

Figure 2. Project Location on US 395 near Lee Vining, California.

BACKGROUND

US 395 traverses the western margin of Mono Lake and in the project area is cut into slopes comprised of colluvium, alluvium, and interspersed tufa from relict shorelines. Tufa is a precipitated calcium carbonate formation that can be found in proximity to many lakes of the eastern Sierra Nevada. Interestingly, it can precipitate as “tufa towers”, which can be seen in nearshore environments around the lake. Often formed by calcium laden spring water percolating into the alkaline (carbonate) waters of endorheic systems like Mono Lake, these formations are then exposed when lake levels drop, Figure 3.

Figure 5. Tufa towers at Mono Lake. Paoha Island, a volcanic cone, is in the background.

Figure 4. The Marina Fire burning on the slopes above US 395 on June 26, 2016.

The Marina Fire, Figure 4, burned 654 acres of steep slopes between its ignition on June 24, 2016 and its containment on July 7, 2016 *(2)*.The fire was named for its proximity to the nearby old marina on Mono Lake. Prior to the fire, Caltrans had programmed a phased rockfall mitigation project to address rockfall originating from six cut slopes along US 395 from post mile 53.2 to 53.7. Phase 1 of that project had been completed in 2015, with an anchored wire mesh system consisting of cable net with double twist wire mesh backing installed on several cut slopes within the Caltrans right of way where US 395 traverses around Mono Lake. Subsequent to the Marina Fire, this section of roadway experienced rockfall events from source areas outside the Caltrans right of way, and resulted in a need for rapid mitigation of the increased rockfall risk. Phase 2 was temporarily suspended after the fire, until the post fire rockfall risk was mitigated.

ROCKFALL INVESTIGATION

At the request of Caltrans, Yeh engineering geologists performed a field investigation on July 19 and 20, 2016 to evaluate the rockfall conditions at the site and to provide recommendations for temporary rockfall mitigation. Yeh personnel walked the alignment within the project limits to document the site conditions, measure the catchment width, slope angles, and interview construction and maintenance personnel to obtain verbal accounts of rockfall activity post-fire. At the time of the field investigation, Caltrans was in the process of placing concrete K-rails along the edge-of-traveled way on the southbound lane of the highway as an immediate response to rockfall events at the site.

Yeh engineering geologists observed rockfall in the catchment area, Figure 5, and evidence of rockfall impacts to the K-rail along the fog line and to the pavement in the traveled way. Caltrans maintenance personnel reported that a rockfall event had occurred that spalled concrete from the top of the K-rail and crossed into the highway.

Figure 5. Largest rockfall observed in catchment area during field investigation on July 19, 2016.

ANALYSIS AND DESIGN

Based upon the field investigation and meetings with Caltrans personnel to understand the project constraints, a temporary, flexible rockfall fence was recommended to mitigate the increased risk of rockfall for a 3,500 linear feet (lf) portion of the highway. The temporary mitigation was requested to have a service life of up to 5 years and was required to have no impacts to a critical fiber optic utility line that was installed via horizontal directional drilling along the southbound shoulder of the highway. Yeh engineering geologists evaluated rockfall trajectories at the site to provide recommendations for the flexible rockfall fence energy rating and height.

The potential energy equation can be used to calculate the maximum possible energy that could result from a design rockfall event.

$$P.E. = mgh$$

$$where\ m = mass\ of\ rock, g = gravitational\ acceleration\ (32.17\ ft\ (9.80\ m) per\ S^2),$$

$$and\ h = vertical\ height\ of\ rock$$

As a part of the analysis, the natural slopes above the highway were evaluated for rockfall potential. Given the slope heights and geometries, the maximum vertical height for potential rockfall to impact the roadway was estimated at 200 feet. The vertical height was used to calculate the maximum potential energy that could result from rockfall originating at this height and impacting a flexible rockfall fence along the highway.

The largest boulder observed by Yeh engineering geologists in the catchment area within the project limits was a blocky-shaped granodiorite boulder with dimensions 2-ft x 2-ft x 1-ft, Figure 5. The design rock used in this analysis had dimensions 3-ft x 3-ft x 1-ft and was based on rocks observed in the rockfall source areas at the site. The design rock was igneous (granodiorite) and was assumed to have a unit weight of 160 pcf. The weight of the design rock was estimated to be 1,500 lbs. Utilizing the potential energy equation, the maximum potential energy that could be expected from the design rockfall event is approximately 150 ft-tons (408 kJ).

Given this maximum potential energy, a 185 ft-tons (500 kJ) rockfall fence was recommended. Although the maximum potential energy was calculated to be 150 ft-tons, the maximum kinetic energy that could impact the fence in the design rockfall event would be much less due to energy losses as the rock travels from the source area towards the catchment *(3)*.

The slope inclinations along the alignment were measured at 31 degrees or flatter. On slopes flatter than 38 degrees, the rockfall trajectory will be a rolling motion on the ground *(4)*. To provide a design height recommendation for the rockfall fence, the Rockfall Catchment Area Design Guideline (RCADG) *(5)* and the Ritchie Criteria *(6)* were used.

By measuring the heights, slope angles, and catchment area along the project alignment, and using these parameters as input to the RCADG and Ritchie Criteria, a percent retention can be developed for rockfall originating from a particular slope configuration. Using these methods and a 95% retention criteria, fence heights were recommended for the project area. The southern portion of the project (2000 lf) had overall flatter slopes and wider catchment and a 10 ft (3m) fence height was recommended. The slopes on the northern end (1500 lf) were steeper and required a 13 ft (4m) height to fulfill the retention criteria.

Due to the emergency nature of the project, and the presence of the poorly located underground fiber optic utility, it was necessary to avoid excavating large foundations for the rockfall fence posts. By recommending a commercially available rockfall fence, the manufacturing timeframe could be minimized. Working with the contractor, the Geobrugg GBE series rockfall fence was selected for the project, and recommended design modifications were coordinated with the manufacturer to optimize the functionality and feasibility of installation at the site.

The GBE A model rockfall fence post design is a hinged post and baseplate configuration supported by upslope and lateral wire ropes, while the GBE AR model rockfall fence posts consist of a braced post design welded to a baseplate, without support ropes. For this project, the braced post design was modified, for global support, to accommodate a post base support wire rope, Figure 6, and upslope and lateral support wire ropes. The post base wire rope is attached to the base of the post and attached to a ground anchor installed at the base of the slope. The intent is to prevent the post from kicking out upon impact. The upslope and lateral wire rope supports were installed in typical fashion. For local stability, threaded bars were grouted 18 inches into the ground. The post baseplate was placed on the bar and secured with a nut. While not commonplace today, this type of rockfall fence post support has been in use in California since the early 1990s.

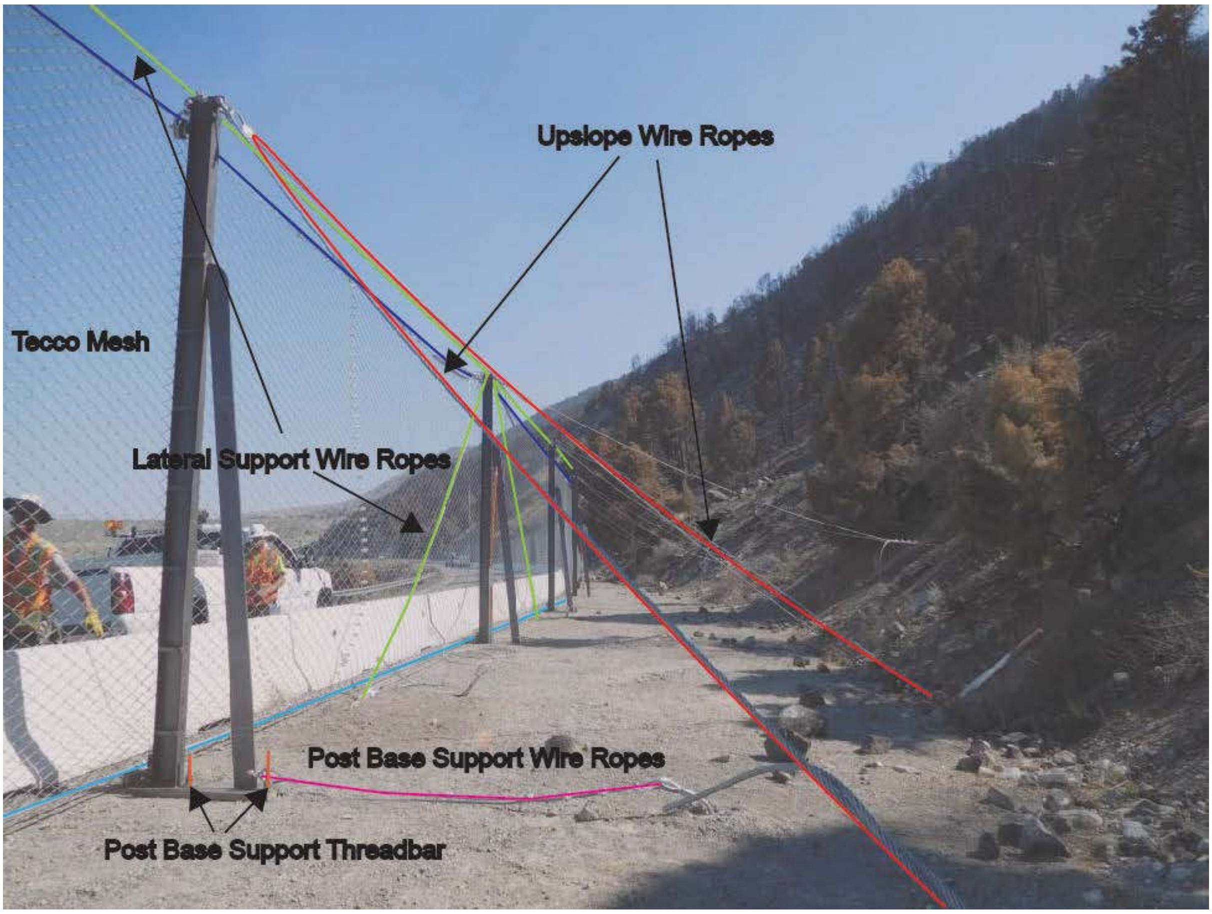

Figure 6. GBE 500AR temporary rockfall fence with upslope and lateral support wire ropes and threaded bar post support.

CONSTRUCTION

Caltrans directed the contractor that was performing the phased anchored mesh installation to install the temporary fence system. Since they were already on site, layout of the temporary, flexible rockfall fence was conducted on July 20, 2016 and consisted of 30 ft. post spacing, with upslope and lateral anchors marked out per the manufacturer's recommendations to facilitate rapid drilling and installation.

Geobrugg provided upslope and lateral support rope ground anchor loads required for the 500 kJ-rockfall flexible fence system. These loads were used to estimate anchor embedment depths to provide the required pull out resistance. The contractor proposed to drill 4-inch diameter, 6-feet deep holes for the ground anchors. In lieu of testing production anchors, the contractor installed sacrificial anchors along the project alignment and pulled to failure, to verify that the bond strength and pullout capacities were sufficient to withstand the loads that could be transferred to the anchors in a rockfall event.

The construction sequence involved drilling holes for the wire rope anchors and post support threadbar, grouting the anchors and threadbar in place, testing the sacrificial anchors to verify pull out strength, and assembly of the fence components. Using air rotary drilling methods with an excavator mounted drill, the anchor holes were rapidly advanced into the subgrade. Delivery of the wire rope anchors began the first week, and the first posts were fabricated and delivered to the site within a week of ordering. Due to the temporary nature of the mitigation and the urgency of having the system in place, corrosion protection was not required, and greatly expedited the delivery of the posts. It was reported that 57 posts were installed and over 700 linear feet of mesh was hung by August 5, 2016.

Yeh personnel visited the site on August 10, 2016 and the fence was nearly completed, Figure 7. Final completion of the fence was delayed until later in the fall to facilitate the completion of the temporally suspended Phase 2 of the anchored mesh system.

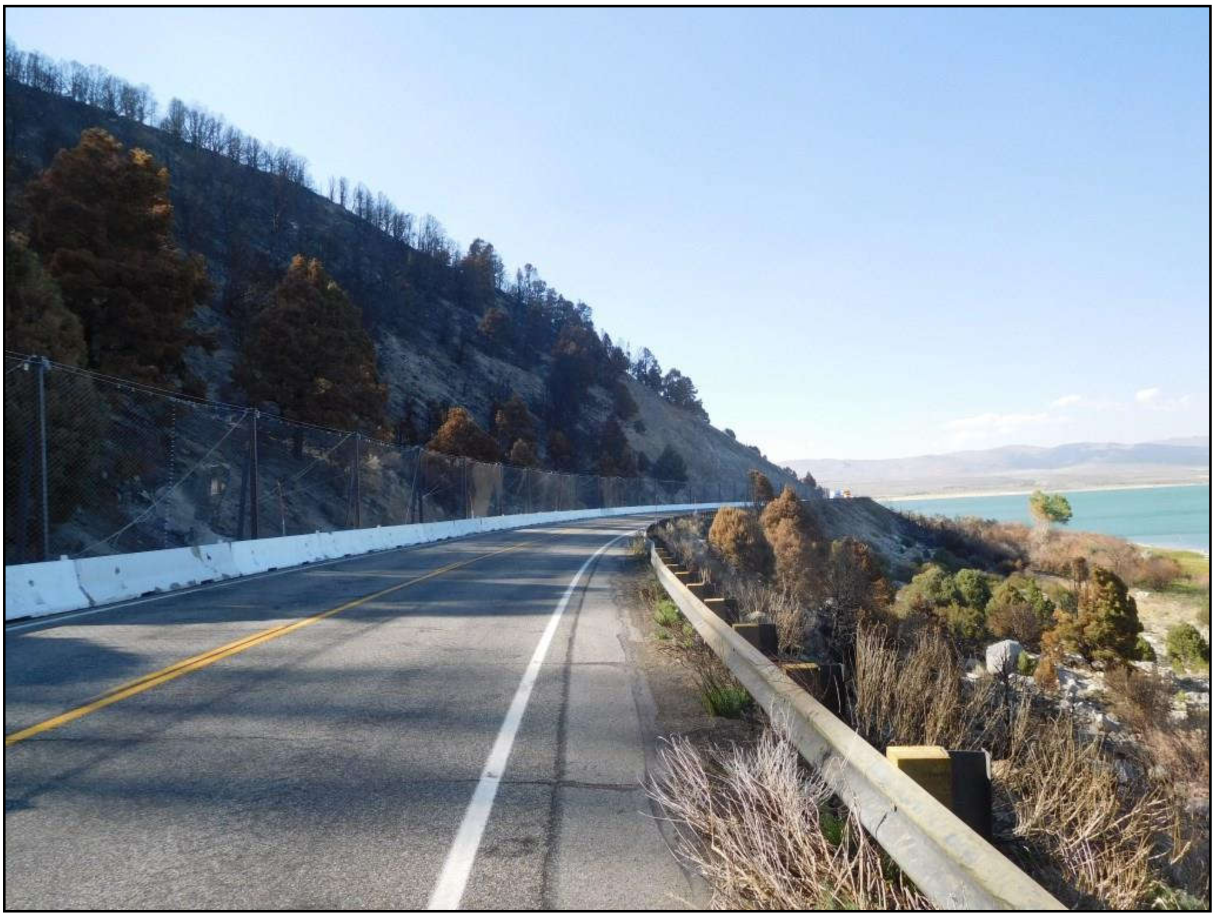

Figure 7. Completed rockfall fence looking north along US 395

PERFORMANCE

After the fences were installed, Phase 2 of the programmed anchored mesh project began and was completed by the end of November 2016. No significant rockfall events were reported until March 12, 2017 when the 3m GBE 500AR fence experienced an impact in the early morning hours. The event resulted in the rock being retained by the fence, but the impact elongated the

TECCO high tensile steel mesh enough that the force of the impact struck the adjacent concrete K-rail, resulting in a portion of the concrete spalling off into the traveled way, Figure 8.

Figure 8. Rockfall event occurring on March 12, 2017 retained behind 3m Geobrugg GBE500AR flexible rockfall fence. (Photo credit: Joe Blommer, Caltrans)

The source area of the rockfall was approximately 100 ft vertical height on a slope above the 10ft (3m) fence. Based on the damage to the K-rail and the deformed Tecco mesh, it appears that the rock rolled across the catchment with a significant rotational and translational velocity, struck the K-rail and was retained by the fence mesh. Rocks observed in the catchment behind the impacted fence were 3ft x 3ft x 2ft, 2ft x 2ft x 1.5ft, and 1.5ft x 1.5ft x 1ft. K-rail debris was 6 inches and smaller and were reported by the California Highway Patrol to be scattered across the traveled way. The impact did not engage the friction brakes, indicating that the impact was below the upper energy capacity of the fence. While the Tecco mesh permanently deformed, it did not require any repair to maintain its effectiveness.

SUMMARY AND CONCLUSIONS

By utilizing simple and effective field methods, in conjunction with published reference documents, a rapid rockfall assessment can be performed, allowing mitigation to be designed and implemented under an expedited timeframe. Once a mitigation solution was chosen, working with the manufacturer permitted design modifications to be made which accommodated the project constraints. The rapid mobilization of the contractor and the expedient delivery of fence components allowed the installation to be completed in short order. While likely not feasible for all installations, a practical, innovative post support system functioned effectively for this project, allowing the system to be installed rapidly in response to the elevated rockfall risk.

The system has performed as anticipated, retaining rockfall events up to the design event effectively. Due to the optimization of the catchment area and the need to prevent errant vehicles from impacting the fence, the K-rail remained in place and within the elongation zone of the mesh after the installation of the fence. While preventing traffic from striking the fence, the K-rail has the potential to be impacted by rockfall events and spall off into the traveled way. This occurrence was anticipated at the design phase, and measures to mitigate this undesirable result were recommended, including hay bales and timber lagging between the fence mesh and the K-rail.

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