# Steep Slope Stabilization with Fiber-Reinforced Shotcrete

*by Michael Ballou*

For the past 150 years or so, roads have been built through the mountain passes in the western U.S. and Canada. Sometimes these roads led to mines; sometimes they started as logging roads. Some were built for access roads for the railroad. Many were built so that people could drive wagons, stagecoaches, and later, automobiles to their destinations. As time went on, some of these roads were abandoned, while others were turned into highways and scenic byways. These roads can be seen on maps, criss-crossing through mountain passes, valleys, and wherever passage was possible. Many of these roads were constructed along mountain slopes, carved out using the largest equipment available at the time, sometimes by hand work, and sometimes by blasting through rocky areas. Road conditions in some of these areas can change dramatically throughout the year. In the mountains, vast amounts of snow can accumulate during the course of just a few days. Sometimes there are heavy rain storms. There can be snow avalanches and mudslides from the rain and snow. In times of drought, vegetation might dry out and die, leaving slopes exposed to erosion, increasing the probability of avalanches and mudslides. Because of varying climactic conditions, freezing-and-thawing cycles, radical changes in the amount and nature of moisture, steepness of slopes, and other factors, slopes need to be stabilized so that rocks, trees, debris, and other factors not listed do not unearth themselves and become hazards to all things below them. One of many ways to secure and stabilize highway slopes is by the use of fiber-reinforced shotcrete (FRS), usually along with either rock bolts or some other mechanical device drilled into the rock or slope. This paper provides an overview of why fiber-reinforced shotcrete is an excellent choice in lieu of plain shotcrete reinforced with either welded wire mesh or rebar mats for such slope stabilization work.

There are several factors that designers must consider when deciding on a suitable method for slope stabilization for steep mountain slopes along roadways.

**Aesthetics** are a primary consideration. An effort must be made to try to achieve a slope stabilization solution that fits harmoniously into the mountain surroundings and does not distract from the natural beauty of the area. No one wants to drive through beautiful mountains and see some ghoulish-looking gray mass that evokes thoughts of gargoyles or something from a cheap horror movie hanging from the mountain sides. Some of us have seen shotcrete slope stabilization projects that look like that, and we shudder with disgust. Such projects do not honor the environment and reflect poorly on the shotcrete industry. A shotcrete slope stabilization project should provide an aesthetically pleasing solution to stabilizing a slope. This can be accomplished with a creative design that blends the shotcrete into the natural landscape.

In-place **cost** is always an issue. Fiber-reinforced shotcrete is an excellent choice for minimizing costs. Major factors affecting project costs include the following:

- *Crane and equipment costs*: Large, bulky cranes do not mix well with mountain passes and tight clearances on roadways. However, at times there is no other way to place mesh or rebar mats. It is costly to keep moving and setting-up the large cranes required to move reinforcing steel (refer to Fig. 1). Along with the crane, there needs to be a man-lift to position iron workers adjacent to the slope in order to tie the rebar to the slope. If there is not a man-lift available, or if one does not fit because the crane takes up all of the working space, workers will need to traverse and climb along the slope and tie off the rebar to the rock bolts. This can often be dangerous and is always less efficient and bothersome. The rate at which rebar is placed and secured slows dramatically when working on rough terrain.

*Fig. 1*

If FRS is used, the FRS can be applied with workers in a man-basket, safely spraying shotcrete onto the contours of the mountainside. This is usually done with an initial layer of plain gray FRS, which can be reinforced with either steel fibers or macro-synthetic fibers applied directly to the slope surface over the rock bolts (refer to Fig. 2). Afterward, a final layer of (sometimes pigmented) FRS is applied. This final layer is almost always macro-synthetic reinforced shotcrete so as to reduce the chances of corrosion creating staining that can occur with steel fibers. Mixtures made with macro-synthetic fibers are easier to mold into shapes on slopes than shotcrete made with a heavy dose of steel fibers. The final layer of shotcrete covers the rock bolts completely (refer to Fig. 3).

- *Schedule*: A window of working opportunity can open and then close quickly on the steep, high mountain passes in the western mountains. Snow and cold can occur even in the summer months, although generally there will be about 6 months in which to perform work on slopes after the spring thaw. Because of the limited number of work days available, delays must be minimized.

  The contractor can and must minimize the number and duration of lane closures. To close lanes on mountain roads, you need a flag person at each end of the closed portion, and, if both directions of traffic are stopped, a pilot car is needed. That's two or three people on the payroll who are not needed to be there all of the time. Provided the contractor can use a man-lift and situate equipment adjacent to the side of the slope, trucks, pumps, and equipment will only block one lane, and for a much shorter duration when using FRS, than it would take to tie rebar mats or welded wire mesh to a mountain side. Look again at Fig. 1. Those workers are way up there on that slope! Minimizing or even deleting the step of placing the rebar or mesh can shave significant time off a schedule and dramatically reduce project costs.
- *Design*: We can debate at length as to whether FRS measures up to the performance of mesh and rebar mats. Toughness tests have been performed for many years, and it has been demonstrated that the FRS stands quite well up to a point. In some large deformations, if cracks are too wide, the fibers will not carry the load. Cracks are unsightly on slopes, so an effort is made to design a thick enough layer with sufficient shotcrete to carry the loads. However, excessively thick layers of shotcrete are costly and wasteful.

There have been times when shotcrete was designed for a slope stabilization project and the contractor placed far more shotcrete than anticipated simply to cover the rebar or mesh properly. More than once I have seen contractors use as much as 50% more material than originally estimated. It doesn't take a genius to figure out that if you apply 30 to 40% more material than you need to, the costs will be excessive. One's first reaction to this might well be that is the fault of the contractor. However, it is often a result of the design. There may be equipment available that will bend and form rebar to fit the contours of a high mountain slope, but if this equipment exists, most of us have never seen nor heard of it. If the rebar is fixed to the rock surface, and if the surface is rough (which it usually is), then there are going to be voids to fill behind the bar that may be awkward to shoot properly (refer to Fig. 4). Therefore, the objective is to minimize the amount of mesh and rebar by optimizing the type and amount of fiber in the shotcrete mixture.

*Fig. 2*

*Fig. 3*

## Conclusions

FRS continues to gain popularity as an alternative to plain shotcrete reinforced with mesh and rebar for slope stabilization on rocky slopes in the western U.S. and Canada. When evaluating the merits of fiber reinforcement, wire mesh, and reinforcing steel, the designer needs to keep in mind these advantages from optimizing the use of FRS:

- Accelerated overall work schedule by not having to tie mesh or rebar on the slope;
- Safer job because workers can work off man-lifts for the entire project;
- Lower costs due to less shotcrete waste and equipment usage;
- Fewer lane closures due to not having to bring large cranes to the project, which block lanes and increase the need for extra labor; and
- Aesthetically pleasing rock formations created by using FRS that blend into the slope because they follow the contours of the slope.

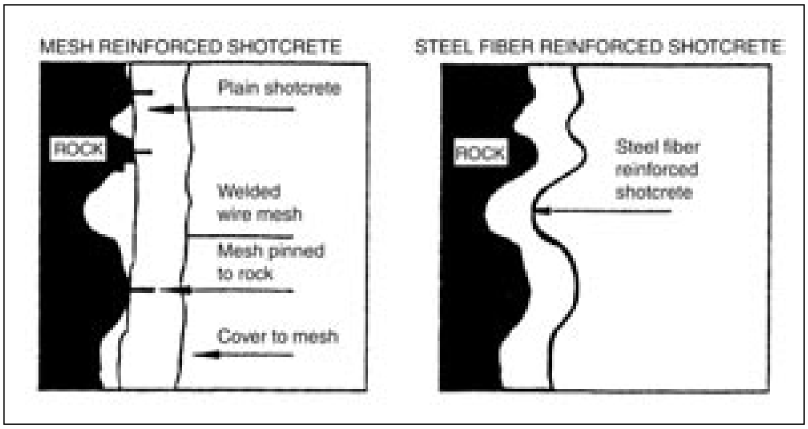


*Fig. 4*

We in the shotcrete industry love and believe in our process for installing concrete. We celebrate whenever we see owners, designers, and other contractors discover the many ways the shotcrete process gets the job done faster, better, and at lower cost. Conversely, we are disappointed when we see a shotcrete project that could have been better aesthetically. It is the duty of us all in the shotcrete industry to help design and build shotcrete projects that not only do the job structurally, but are pleasing to the eye and are a tribute to our industry.

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