

# Soil and Rock Slope Stabilization Using Fiber-Reinforced Shotcrete in North America

by Mike Ballou and Matt Niermann

**S**oil and rock slope stabilization issues, ground control problems, and erosion vary greatly throughout North America. This is mainly because of the vastness of the continent; different climates, rainfall, and humidity; as well as, in some areas, freeze-thaw and snow conditions. Identifying a simple solution for slope stabilization that will work everywhere in North America is impossible. However, there are places where a simple solution is possible using fiber-reinforced shotcrete (FRS). The purpose of this paper is to describe some applications where FRS has produced satisfactory results, with reasonable costs and often with a significant reduction in total construction time. The use of shotcrete for slope and rock stabilization has increased substantially in the past few years. This paper explains why some design firms and contractors are switching from wire mesh and rebar to fibers.

## Reasons to Switch from Mesh and Rebar to Fibers

*Reduction of material*—FRS allows the shotcrete to follow the contours of the slope. It is difficult to position mesh and rebar at a uniform height over uneven ground surfaces. Extra shotcrete is required to build out from the ground surface and provide cover for the mesh or rebar.



Figure 1: Mesh reinforced shotcrete—frost heave damage—Montana, 1999.

*Reduction of labor*—It takes less time and skill to reinforce shotcrete with fibers than with mesh or rebar. Fiber reinforcement is an advantage when skilled labor is very expensive or unavailable. The reductions in labor and material create the potential for an accelerated schedule and additional savings in other areas.

## Slope Stabilization Design Considerations

Choosing between steel fibers or mesh for a particular project is made easier if we review the design considerations for slope stabilization. The following is a list of factors that the designer should keep in mind for slope-stabilization projects:

*Slope height and angle*—Steep slopes are often difficult or impossible to place mesh and rebar on without special equipment such as man lifts, which are situated on the stable roadway below the project.

*Ground surface condition*—Pins must be driven into the ground to hold the mesh or rebar in place. This can be difficult depending on the type of soil or rock. If the ground surface is highly fractured or uneven, it may be difficult to achieve the required cover on both sides of the mesh and rebar.

*Ground water*—Drainage must be provided to prevent the buildup of water pressure on the back of the shotcrete facing. Weep holes, geocomposite drainage board, and horizontal drains are all common ways of removing water.

*Rock bolt or soil nail spacing*—If rock bolts or soil nails are required for stability reasons, the shotcrete facing must be designed to span between the anchors.

*Earth pressures and arching ability*—Soil nail facings will develop positive bending moments in the sand and midspan between nails, and negative bending moments at nail-head locations. The magnitude of these moments depends on the soil strength. Conventional mild steel reinforcement may be placed in specific areas to resist large moments that exceed the capacity of steel fiber-reinforced shotcrete alone. The conventional reinforcement (rebar or heavy mesh) will also add some ductility in shear friction to prevent a punching failure (Smith, Pearlman, and Wolosick 1993).

*Freeze-thaw problems*—Special consideration needs to be given to frost-susceptible soils located

in freezing climates with access to ground water. If ice lenses are allowed to form beneath a shotcrete facing, it is difficult to keep the shotcrete from cracking or heaving (see Figure 1 and 2).

## Fiber-Reinforced Shotcrete Design Considerations

There are many types of slopes that can be supported with shotcrete, and the variables involved in the design of each slope will vary. As a result, the loading conditions will be different for every job. The loading conditions must be known to determine what type of fiber will work best for each application and the optimum fiber dosage.

Fibers are generally classified as providing either secondary or structural reinforcement. Secondary reinforcement indicates that the primary purpose of the fiber is to reduce plastic and restrained drying-shrinkage cracking. Structural reinforcement indicates that the fiber is intended to replace wire mesh reinforcement. Slope- and rock-stabilization applications typically require the strength provided by structural fibers.

There are many types of steel and synthetic structural fibers. The physical properties of these fibers are well documented. Extensive tests have also been performed on fiber-reinforced shotcrete specimens. Standard ASTM tests may be performed to measure the flexural strength and toughness of fiber-reinforced shotcretes. These tests may be used to verify the quality of fiber-reinforced shotcrete placed in the field.

It is not the intent of this paper to discuss fiber types, performance, or toughness in great detail, but it is important to note that choosing a fiber and proper mix design can be the most critical decision that a designer makes when considering FRS for slope stabilization. Clearly, each project is unique and must be treated as such.

## Mix Designs

Shotcrete may be placed using either wet- or dry-mix methods. Wet-mix shotcrete is used whenever possible to reduce excessive rebound. However, there are places, especially in remote areas, where dry-mix shotcrete is more cost-effective, especially on small projects. Most dry mixes work well with fibers, provided a proper mix design and proper equipment for placement are used.

Mix designs should be selected for each application, with a few rules of thumb in mind. It is best to use a mix design that meets the need of the application without being too expensive. However, it is now considered common practice for most FRS projects that the mix design should include silica fume if the shotcrete is going to be applied on a hard surface. Silica fume improves the adhesive properties of wet- and dry-mix shotcrete, enabling the silica fume to stick to

Mesh reinforcement



Dramix® steel wire fibers

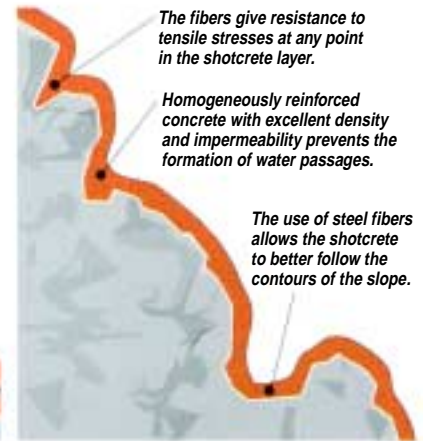


Figure 2: Cross section of shotcrete lining (Bekaert Corp., 2002).

Table 1: Fiber types—examples of different types of steel fibers used in sprayed concretes (Banthia, 1999).

F <sub>1</sub>		
F <sub>2</sub>		
F <sub>3</sub>		
F <sub>4</sub>		
F <sub>5</sub>		

inclined and vertical surfaces better. Avoid using excess water or accelerator, as these additions make a weaker concrete/shotcrete (Morgan et al. 1987, 1988b; Morgan and Neill 1991).

## Dry Process Mixes

Most mixes contain ordinary portland cement, sand, and aggregates that have been put through a screen to ensure that there are no big rocks to clog up pumps, ruin equipment, or delay projects. Research and experience points to increased popularity of the use of fly ash and silica fume, as discussed previously. Table 2 shows a typical design for steel fiber-reinforced shotcrete (Wood 1992), which is used quite a lot in North America (S.A. Austin).

## Wet Process

The wet mix must be designed to suit each particular job site. If the steel fibers are added at a batch plant and trucked to the job site, they must be added according to the steel-fiber manufacturer's direction. Most of the directions will be similar to Table 2.

The wet-process shotcrete is affected by the aggregate size, pumping distance, efficiency of

Table 2: Steel fibers used in shotcrete should never be longer than 30 mm long, unless special large nozzles are used to spray the SFRS.

Material/Property	Comments
Cement content	18 to 21% by mass of dry component.
Silica fume	8 to 13% by mass of cement.
Aggregate gradation	ACI 506R-90, Table 2.1, Gradation No. 1, or (more commonly) No. 2.
Steel fiber type	High strength, deformed, drawn, or slit sheet steel fibre.
Aspect ratio	Length: Equivalent diameter ratio of 50-70.
Steel fiber addition rate	50-80 kg/m <sup>3</sup> (85-135 lb/yd <sup>3</sup> ) depending on required toughness.
Admixtures	<ol style="list-style-type: none"> <li>1. Water reducers used in wet-mix shotcretes at about 0.5 l/100 kg cement (8 fl.oz/100 lb cement).</li> <li>2. Superplasticizers required in wet-mix silica fume shotcrete at 1 to 1.5 l/100 kg cement (16 to 24 fl.oz/100 lb cement).</li> <li>3. Air entraining admixtures used in wet-mix shotcrete where freeze-thaw durability important (10 to 12% air content at pump, 4 to 6% air content as-shot).</li> </ol>
Accelerator	Dosage depends on accelerator type and required setting time (2 to 5% by mass of cement typical).
Water-cement ratio	0.3 to 0.4 for dry-mix shotcrete. 0.4 to 0.5 for wet-mix shotcrete.
Slump	40 to 100 mm (1½ to 4 in.) for wet-mix shotcrete.

Table 3: Summary of mix design concepts (Morgan, 1990).

Material	Dry-mix shotcrete		Wet-mix shotcrete	
	kg/m <sup>3</sup>	lb/yd <sup>3</sup>	kg/m <sup>3</sup>	lb/yd <sup>3</sup>
Cement	400	674	420	708
Silica fume	50	84	40	67
10 mm coarse aggregate	500	843	480	809
Concrete sand	1170	1972	1120	1888
Steel fibres	60	101	60	101
Water reducer	—	—	2 L	52 fl.oz.
Superplasticizer	—	—	6 L	156 fl.oz.
Air entraining agent	—	—	if required	if required
Water	*170	*287	180	303
Total wet mass	2350	3961	2300	3876
Total water from premoisturizer and added at nozzle (based on saturated surface dry aggregate concept).				



Figure 3: Wet-mix steel fiber-reinforced shotcrete applied for soil nailing—Connecticut (Photo courtesy of Schnabel).

the pump, diameter of the hose, and required output rate. Small aggregates are used not for strength, but for pumpability. The addition of steel fibers will reduce the slump considerably, so water reducers are commonly used when the shotcrete is to be pumped long distances so that it can be pumped through the hose without clogging it up and damaging the pump.

## Job Site Basics

Fiber-reinforced shotcrete is new technology to many shotcrete crews constructing soil and rock-slope stabilization. It is easily adopted, however.

The key to any successful shotcrete operation is a correct mix design. In general, a quality shotcrete will pump and shoot well, regardless of fiber content. The typical fiber dosage does not usually require any major modifications to the mix design.

## Wet Mix

Fibers may be added to the shotcrete either at the batch plant or at the job site. If large quantities of shotcrete and fiber are being used, a conveyor belt may be set up at the job site to add fibers. If only small quantities are needed, it is easier to place bags in the truck by hand from an elevated, safe platform. It only takes about seven minutes to add fibers to the mixer truck using this method for a full load.

The addition of fibers will cause a marked decrease in slump. This, however, does not relate to a decrease in pumpability. Water should not be added to the shotcrete in order to increase the slump. A vibrator may be mounted on the hopper grate to move the shotcrete through and help feed the pump cylinders.

Good nozzleman techniques should be followed during shooting. Most fiber-reinforced shotcrete adheres very well to soil or rock. Thick applications of shotcrete are easier to apply if the ground surface is battered away from vertical.

## Dry Mix

The dry-mix technique differs from the wet process in that the mix is delivered to the job site, usually in bulk bags, which are raised over the hopper of the shotcrete gun. There are several brands of guns available that spray FRS shotcrete, steel fibers, and synthetic fibers. Use the manufacturer's suggestions when using whichever fiber chosen, or consult the fiber manufacturer for advice. Thousands of yards of FRS dry mix is successfully applied each year in North America, but the correct equipment is essential. The two most common problems with the dry-mix process are:

1) The wear pads on the shotcrete gun can wear out quickly due to the abrasive properties of the steel fibers. To solve this problem, it is best to

use wear pads made of denser material such as a neoprene material. The dense pads are a lot tougher, and won't wear out nearly as fast as the softer ones, and are not expensive. They also work almost as well as the softer pads to abate dust at the gun.

2) If the fiber of choice is a synthetic fiber, it is best to make sure proper equipment is selected. This means that the material that exits on the bottom of the gun needs to be larger than normal openings. This opening in the gun is where the shotcrete mix drops down into the hose on the way to the nozzle. If the openings are not big enough, the fibers will get hung up and bridge on each other, and they will block the exit. This, of course, creates a severe problem, as none of the material will get to the nozzle. Not all equipment will handle the new structural synthetic fibers without modification to the exits.

Fiber-reinforced shotcrete can be given a variety of surface treatments, including natural gun, screed, float, or trowel. If steel fibers are used and aesthetics are an issue, a flash coat of plain shotcrete may be applied to eliminate rust staining. Rust staining is typically very minimal because the fibers are usually covered with cement paste from the mix. The photo of a project using steel fiber-reinforced shotcrete applied to a rocky slope in Provo Canyon, Utah, shows no sign of rust stains. The shotcrete was applied in 1998. Even with a few years of exposure to rain, ice, and snow, the shotcrete is holding up well. This photo shows a layer of steel fiber-reinforced shotcrete that now (2002) has a beautiful shotcrete made to have a natural-looking rock surface.

Conclusion: Fiber-reinforced shotcrete for slope stabilization and soil-nailed walls really work. The process is simple, effective, and does the job easily and quickly. Several shotcrete contractors in North America have switched from standard mesh-reinforced shotcrete to fibers, and they are not likely to switch back.

## References

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Figure 4: Wet-mix shotcrete soil nails—South Carolina (Photo courtesy of Schnabel).



Figure 5: Steel fiber-reinforced shotcrete—Provo Canyon, Utah 1998 (Photo taken 2002).



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