CHAPTER 6
SURFACE TREATMENT

6-1. General. Surface treatment of rock can be accomplished by a variety of methods. Chain link fabric, welded wire fabric, mine ties, steel strapping, and shotcrete are the most common methods used. The value of each method has been demonstrated in laboratory tests and in numerous tunnels, natural or excavated slopes, and chambers. Therefore, the choice of which method or combination of methods to use must be based on experience, other projects, and economics. Examples of surface treatment are shown in figures 6-1 through 6-3.

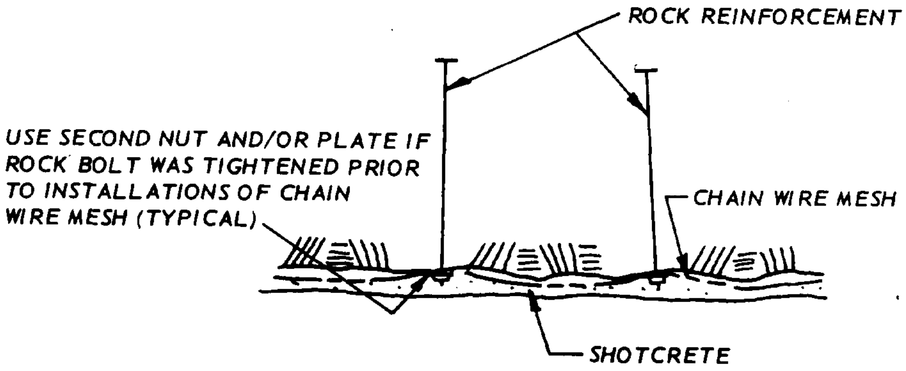


Figure 6-1. General surface treatment-wire mesh and shotcrete.

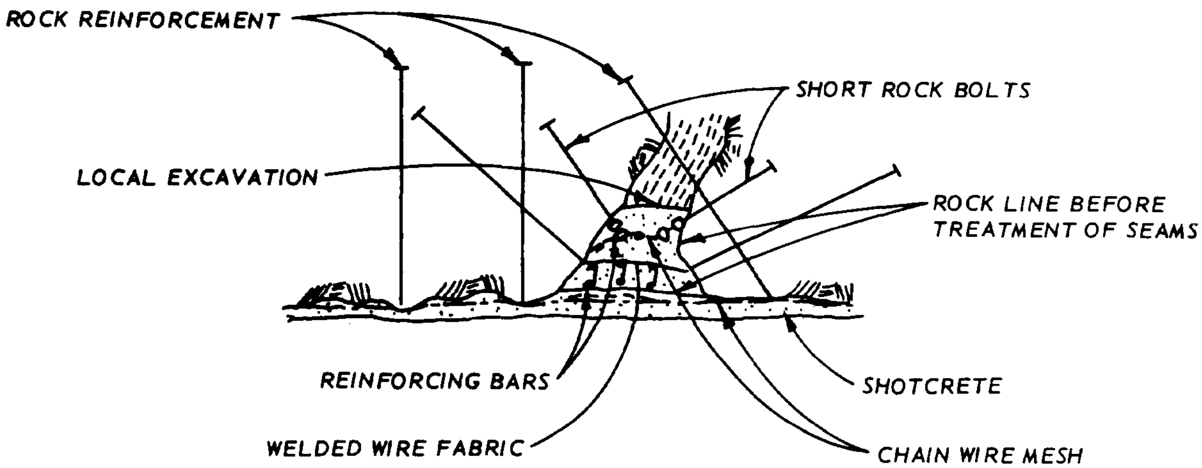


Figure 6-2. Typical local structural treatment of wide seams and fractured zones.

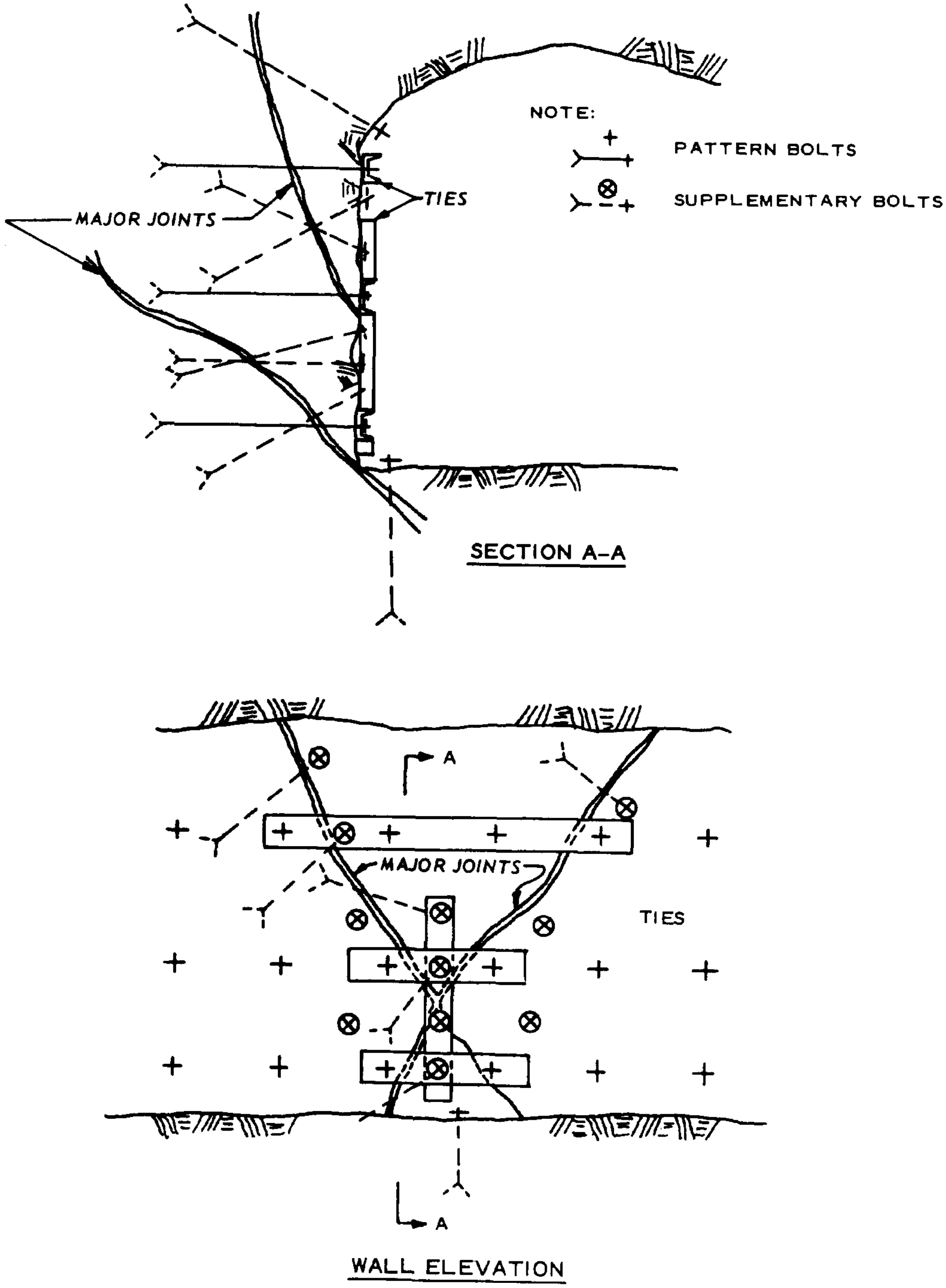


Figure 6-3. Typical use of ties and supplementary bolts.

6-2. Use of Wire Mesh and Fabric.

a. The most common type of surface treatment is wire mesh or fabric attached directly to the reinforcement elements. Such surface treatment can and should be used as a routine part of construction. The benefits include stabilization of deeper rock by holding loosened rock in place and control of unstable areas by containing loose rock rather than allowing it to fall. The safety benefits are obvious. The fabric should be galvanized if it is permanently exposed but may be ungalvanized if it is to be eventually covered by shotcrete or concrete.

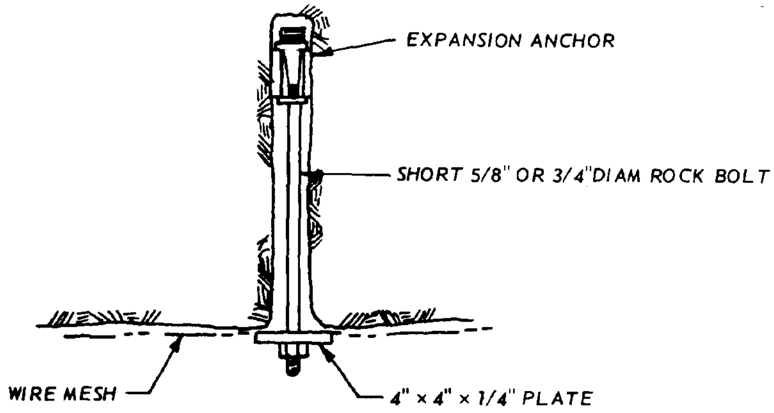
b. If maximum benefit is to be gained from wire mesh and fabric, intermediate attachment to the rock between primary reinforcement elements is necessary. Methods for such attachment are shown in figure 6-4.

6-3. Mine Ties and Strapping. These serve as a type of lagging between primary reinforcement elements. The surface restraint is more rigid than in the case of wire mesh. Strapping is very effective when it is continuous around exterior corners of cavity intersections, etc. A combination of strapping with wire mesh is most effective in preventing progressive loosening. An example of the use of mine ties is given in figure 6-3.

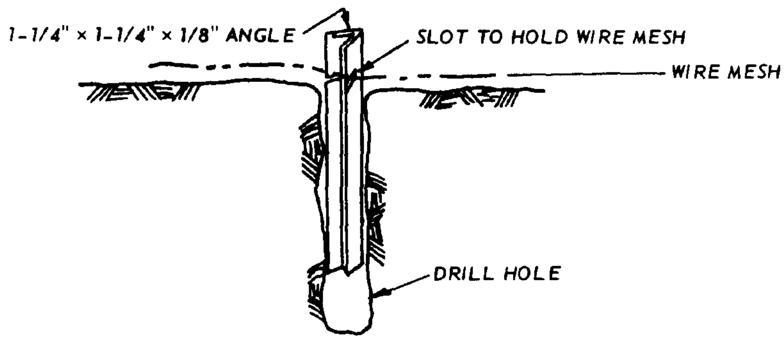
6-4. Shotcrete.

a. As with chain link fabric, a rational design method is not available for shotcrete. Its effectiveness, however, has been demonstrated on numerous projects around the world in recent years. In combination with rock bolt systems, the use of shotcrete as surface treatment is very effective in preventing surface ravelling. As with rock bolts, shotcrete is generally most effective (except in swelling ground) if it is applied shortly after excavation. When permanently exposed, the shotcrete should always be placed in combination with welded wire fabric or chain link fabric. Drain holes drilled through the shotcrete into the rock should be constructed to relieve hydrostatic pressure.

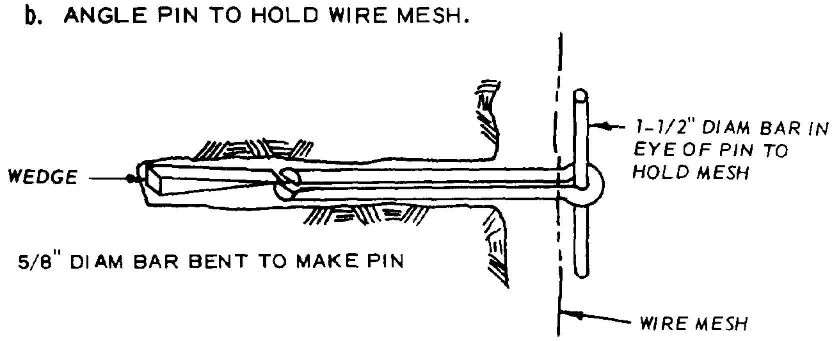
b. The use of shotcrete has provided savings on several projects and its successful use depends on the experience and judgment of the engineers and construction personnel at the project. As a method of surface treatment when used in combination with rock bolts, it is far superior to other methods of surface treatment but is also much more expensive. Because of these numerous variables, strict guidelines as to when to use shotcrete on a project cannot be presented in this manual. It can only be recommended that on each project its use should



a. SHORT EXPANSION ANCHOR.



b. ANGLE PIN TO HOLD WIRE MESH.



c. WEDGE MESH PIN.

Figure 6-4. Methods for intermediate attachment of wire mesh.

be considered when the method of surface treatment is chosen.

c. As in the case of wire fabric, shotcrete serves as a monitoring tool. The shotcrete is a brittle coating that will crack if there is major movement in the rock structure.

d. The following discussion pertaining to the material properties and placement of shotcrete is partially excerpted from EM 1110-2-2901.[3]

6-5. Material Properties and Placement of Shotcrete.

a. General.

(1) Shotcrete is defined by the American Concrete Institute as mortar or concrete conveyed through a hose and pneumatically projected at high velocity onto a surface. The force of the jet impinging on the surface compacts the material. A relatively dry mixture is generally used, and the material is capable of supporting itself without sagging or sloughing, even for vertical and overhead applications (ACI[20]).

(2) Shotcrete has been in use for more than 50 years for various types of construction. However, it has only recently been applied to tunnels and other underground support, following the development of high volume equipment and accelerating admixtures which cause the concrete to set up very rapidly. The state-of-the-art is best described in the proceedings of an Engineering Foundation Conference (ACI[21]).

(3) Shotcrete, applied immediately after excavation, seals and ties down the rock and provides a thin, strong, flexible membrane. It frequently speeds up the tunneling operation and may result in cost savings as compared with other tunnel support methods. It is best suited for tunnels excavated by drilling and blasting. Where appropriate, it should be listed as one of the bidding alternates.

(4) In Corps of Engineers tunnel construction, shotcrete will generally be used for initial support, prior to placing the permanent concrete lining. Occasionally, it may be used for final support, as in tunnels infrequently used and designed for low-velocity flows. Shotcrete is also used in a nonstructural capacity to seal rock surfaces and to keep them from air slaking, while at the same time preventing fallouts.

b. Material Properties.

(1) Shotcrete for rock support consists of portland cement, water,

sand, coarse aggregate graded up to about 1/2 inch, and a strong accelerator if the shotcrete is to be applied for tunnel support. The accelerator causes the shotcrete to start hardening immediately after application so that it will give early support to the rock. A minimum compressive strength of 700 psi at the age of 7 hours is readily achievable, and should generally be required. The accelerator also provides two other advantages.

(a) It permits the shotcrete section to be built up quickly in fairly thick layers (even in overhead applications) without falling out or excessive rebound.

(b) It enables the shotcrete to bond to wet surfaces. By increasing the amount of accelerator, shotcrete can be successfully applied even in local areas of light seepage. Any running water should be controlled by drains before shotcreting.

(2) Unfortunately, all present day accelerators which give good early strengths reduce the values at later ages, the amount of the reduction depending on the "compatibility" of the accelerator and cement used. This effectively places a ceiling of about 4000 psi on the 28-day strength which may be specified.

(3) As part of the mix design studies at the beginning of the job, tests should be made to arrive at the best combination of brand of accelerator and cement, and percent of accelerator to be used. Normally, molded specimens are made just to establish the approximate range of proportions. Then a few test panels or representative areas in the structure are gunned, and cubes or cores extracted for determining 7-hour and 28-day strengths. All values are reported in terms of core strengths which have been corrected to a length to diameter ratio of two. Cube strengths should be reduced by 15 percent. Strengths in these preconstruction tests should exceed the specified strength by at least 20 percent.

(4) Regulated set cement, which gives accelerated strength development without the need for an accelerator, has been used on an experimental basis with promising results.

c. Quality Control.

(1) It must be recognized that shotcreting is a specialized process, quite different from conventional concreting. There are many variables (conditions under which it is placed, equipment used, competence of the application crew, and others) which affect the quality of shotcrete in general construction (Reading[42]). Even more

attention must be given to quality control in underground support construction, because present accelerators contribute to variability and because quality requirements are higher than for most other shotcrete work (Reading[43]). Designers should familiarize themselves with the material, and inspection personnel should be properly instructed at the beginning of the job. The contractor should be required to demonstrate (usually as part of the mix design studies) that his personnel, equipment, materials, mix design, and procedures will produce shotcrete of the quality required. Even at best, the degree of quality control can hardly be expected to equal that for concrete.

(2) Tests should be made throughout the job to assure that the in-place product is satisfactory. A program of routine coring from the structure is normally recommended. As an alternative, test panels gunned periodically may be supplemented with occasional cores from the structure.

d. Equipment and Application.

(1) The dry-mix process (where the mixing water is added at the nozzle) is preferred for tunnel support shotcrete because it is better adapted to the use of accelerators. Particular care should be taken to see that the admixture is accurately proportioned and uniformly mixed with the other materials. The wet-mix process is more difficult to control because it requires that the accelerator be added before the mix enters the hoseline. Therefore, the mix might set up before it reaches the nozzle. However, the use of the wet-mix process without accelerators is satisfactory for other applications as is open excavation where high early strength is not required.

(2) In tunnel work, it is normal practice to apply a 2-inch layer of shotcrete as soon as practicable (usually within 2 to 3 hours) after the section is mined, and before mucking out is completed. It is often a safety hazard to have the nozzle operator working on the muck pile; a better method is to have the nozzle operator work from a platform on an adjustable hydraulic crane boom. Where the tunnel is large and it is judged that there is some risk of rock fallout from the crown before the application is completed, a "robot" may be used; here the nozzle operator sits in the protected cab of a crane 15 to 20 feet away, and controls the nozzle from that location. Good lighting, so that the nozzle operator can see the area being shotcreted, is essential. This is particularly important where the nozzle operator is a considerable distance from the work (where a robot is used).

(3) A second 2-inch layer is generally applied within 8 hours after mining, and a third layer (where required) within 24 hours.

(4) If the tunnel is excavated by drilling and blasting, the surface is likely to be irregular, with considerable overbreak. Care should be taken to get the full design thickness of shotcrete on the inside surfaces and particularly at the outer edges or corners of the overbreak. The shotcrete will normally round out the base of the cavity.

(5) The mix and application procedures should be carefully controlled so that the in-place shotcrete is dense and sound, and rebound is held to the lowest practicable quantity. The best results are obtained by keeping the nozzle normal to the surface of application.

(6) Shotcreting, particularly the dry-mix process, is accompanied by considerable dust, which is a health hazard and obstructs the visibility of the nozzleman. Good ventilation is needed to keep dust at a minimum. Other necessary safety precautions include face protection and a respirator for the nozzleman, and protection of the skin against cement and especially against caustic accelerators.

(7) Curing requirements (moisture retention and temperature) are about the same as for conventional concrete used in tunnels. However, no curing medium need be applied if the relative humidity in the tunnel is above 85 percent.