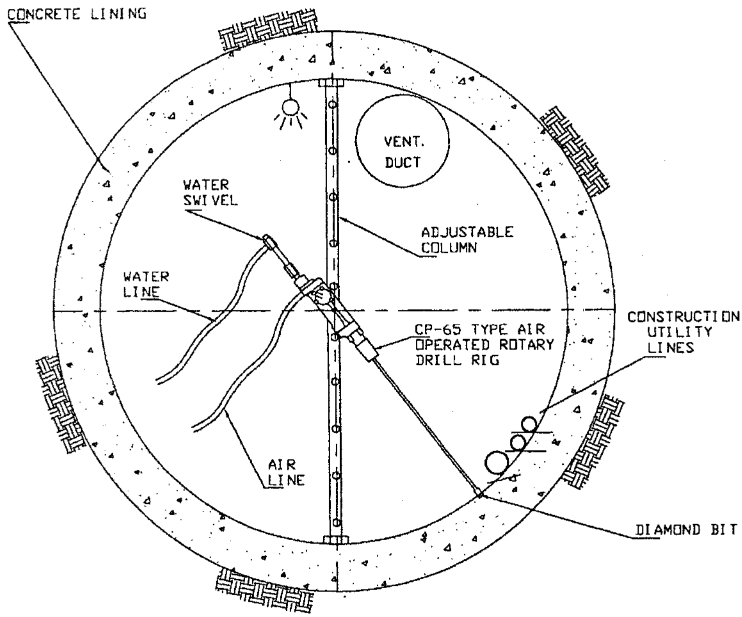

FIG. 4-6. Typical Column-Mounted Rotary Drill Rig

and reinsertion for every core run can become time consuming. This can add considerable cost and time to the overall grouting schedule. An example when this requirement would become a timely process would be when drilling a ring of 20 or more curtain grout holes to depths of 12 m (40 ft) in a 2.4 m by 2.4 m (8 ft by 8 ft) tunnel. In such a case a second drill may be needed to to complete a single ring.

For these reasons some contractors prefer to use diamond plug bits rather than coring bits to drill deeper holes. Plug bit drilling has a slower advance rate than coring because the full rock volume of the hole is ground up in the drilling process, as opposed to only the circumference being cut by a coring bit. A plug bit, however, does not produce a core to remove, so it is not necessary to pull the drill rods from the hole until the full depth of the hole is reached. Because of the fine granular nature of the drill cuttings produced by rotary diamond drilling, only water is used to remove drill cuttings from the hole. Air is not required.

This type of rotary drilling equipment is small enough to be transported and set up by two workers. The drill itself can easily fit into a wheelbarrow for transport or can be carried by workers from one grouting location to another along the tunnel alignment.

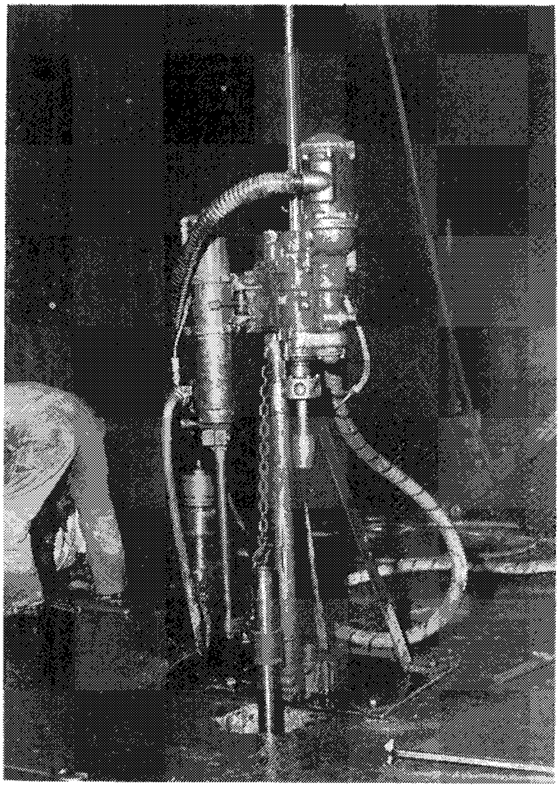

FIG. 4-7. CP-65 Column-Mounted Rotary Drill Rig

4.1.3 Down-Hole Drill (Down-Hole Hammer) Drilling

In the down-hole drill, also called the down-hole hammer, drilling method, the drill rods, hammer, and bit, located at the bottom of the hole, are rotated by a drill motor located on the main body of the drill. In this arrangement, unlike percussion drilling, the hammering action takes place at the bottom of the hole where the chipping work is done, thus the name down-hole drill. The hammer, which produces the up-and-down piston action, is powered by high-pressure air. The theory is that because the hammering force is delivered at the bottom of the hole, where the work is done, there is no energy lost through the drill rods, thus maximum hammering force is applied to the rock. In standard percussion drilling, much of the hammer energy needed to chip the rock is lost as it is transmitted through the drill rods. The energy loss increases as the depth of the hole increases.

Down-hole drills are gaining wider use in grouting applications performed from the surface, such as grout curtain drilling for dams, where holes are relatively deep (Continental Drilling, 1993). Presently, however, their use is not widespread underground. This may be due in part to the fact that most grout holes drilled underground are relatively short and down-hole drilling becomes more economical as drilling depth increases. Also, down-hole drills are not presently in common use for other underground drilling applications; therefore, the technology is not well known to the underground industry.

4.2 MIXERS

Two types of mixers predominate in underground grouting applications, paddle mixers and colloidal mixers. The paddle mixer is the older of the two and is still used more frequently underground on smaller projects than the colloidal mixer. This is especially true for the contact grouting of tunnel and shaft linings and for filling the large voids frequently found in naturally occurring underground caverns and cave systems. In these applications the complete wetting and dispersion of the cement particles in the grout mix, a shortcoming of the paddle mixer, is not as critical as when performing consolidation and curtain grouting. Also, in contact, cavern, and cave applications, short interruptions of grout injection due to a slower mixing rate of paddle mixers are more tolerable.

A paddle mixer consists of either vertically or horizontally mounted paddles that rotate slowly within a cylindrical tank. During the mixing process, the grout materials are stirred and thrown against baffles attached to the side of the tank. The baffles prevent the formation of a vortex within the swirling mixture, which can cause centrifugal separation. The heavy materials are thus better broken apart and more evenly distributed throughout the mixture. Once completely mixed, the grout is discharged from the mixer into an agitator tank when a single-mixer arrangement is used or directly into the grout pump when using a twin-mixer arrangement (Figs. 4-8 and 4-9). In either arrangement, grout should be discharged by direct suction, not gravity, into the grout pump.

Gravity discharge into the pump should be avoided because it can potentially allow air to enter the pump. The presence of air in the grouting system can cause erroneous pressure readings. Gravity discharge still, however, remains a popular method. Therefore, the use of a direct suction system should be made a requirement in the specifications.

Paddle mixers range in capacities from approximately 283 L (10 ft^3) to 1,417 L (50 ft^3) and larger. The size and arrangement of mixer(s) chosen depends on the amount of grouting expected, the type of grouting to be performed, and the size of the working space available for the equipment.

The high-speed "colloidal" mixer was introduced in the United States in 1955 by the Colcrete Company of Strood, England (Weaver 1991). It works by recirculating the grout through a centrifugal pump. The pump, which

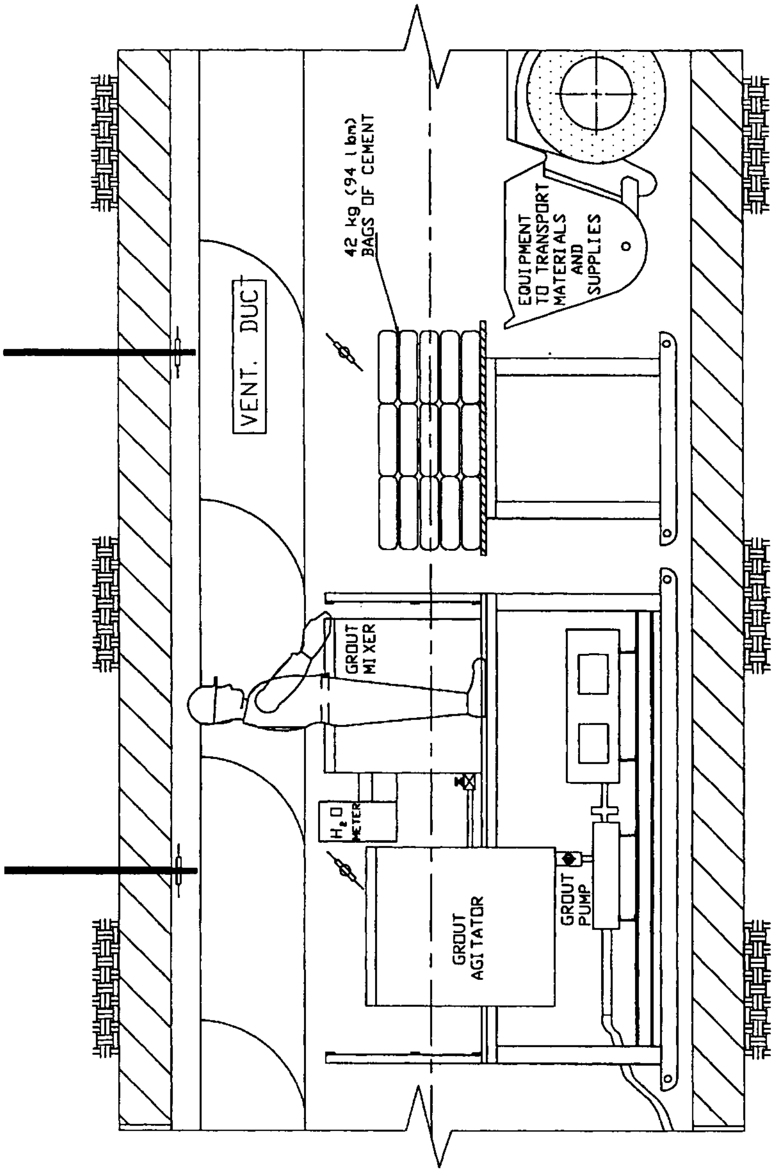

FIG. 4-8. Longitudinal Section of Typical 4 m (12 ft) Finish Diameter Tunnel Showing Single-Mixer and Agitator Arrangement

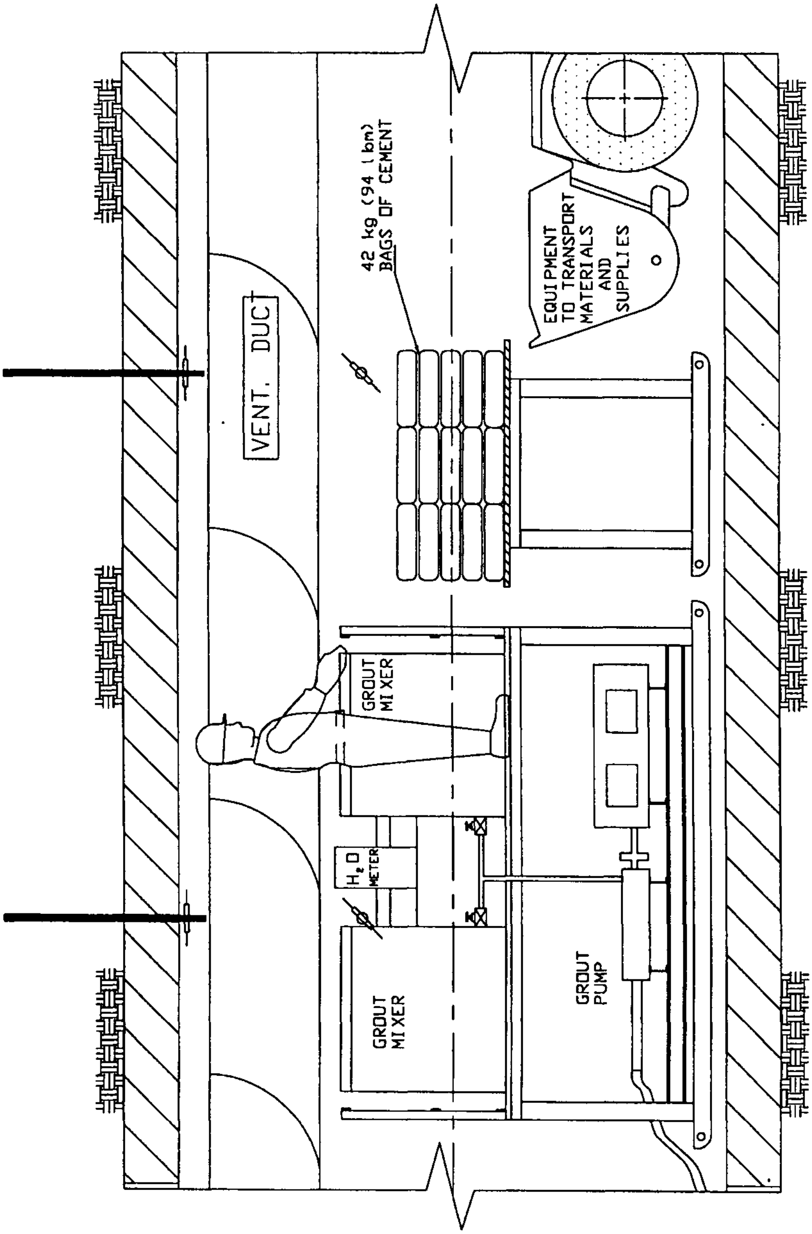

FIG. 4-9. Longitudinal Section of Typical 4 m (12 ft) Finish Diameter Tunnel Showing Two-Mixer Arrangement

operates at high speeds, of 1,500–2,000 revolutions per minute, imparts a shearing force to the grout as it passes through the narrow steel pump casing. The pump discharges the grout tangentially into a vertical cylindrical tank causing a vortex to form (Figs. 4-10 and 4-11). The centrifugal force created throws the heavier, unmixed grout fraction of grout against the tank walls, where it then runs down the wall and reenters the pump for further mixing.

The speed of mixing and the high output capacity are important attributes of colloidal mixers. The time required to produce a thoroughly mixed batch of grout is reported to be only 15 sec (Water Resources Commission of New South Wales 1981). Colloidal mixers range in capacities from approximately 283 L (10 ft^3) to 14,170 L (500 ft^3) and larger. As with the paddle mixers, the size and arrangement chosen depends on the amount of grouting expected, the type of grouting to be performed, and the size of the working space available for the equipment. Fig. 4-12 shows a complete rail-mounted grout plant consisting of colloidal mixer, agitator, and grout pump. The mixing action of the colloidal mixer produces grout with superior properties compared to grout mixed in paddle mixers. The current trend is to specify colloidal mixers rather than paddle mixers in contract documents for all grouting, but particularly for consolidation and curtain grouting.

Most grout mixing is performed relatively close to the injection location; other equipment arrangements are, however, sometimes employed. For example, a large colloidal mixing plant might be set up at the top of a shaft or just outside the tunnel portal. From these aboveground plants the thoroughly

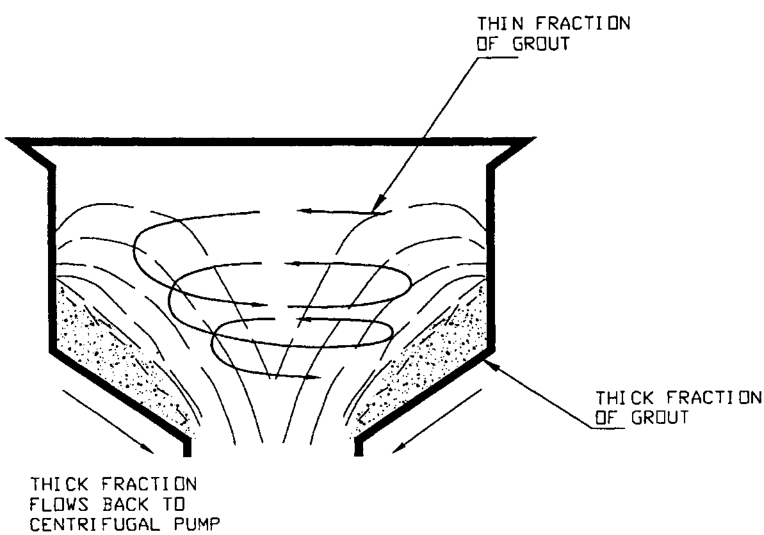

FIG. 4-10. Vertical Cylindrical Tank of Colloidal Mixer Showing Formation of Vortex

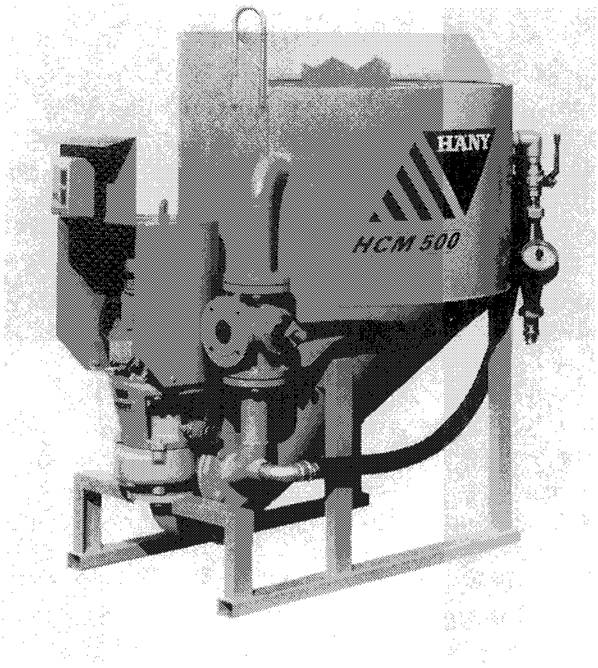

FIG. 4-11. Colloidal Mixer

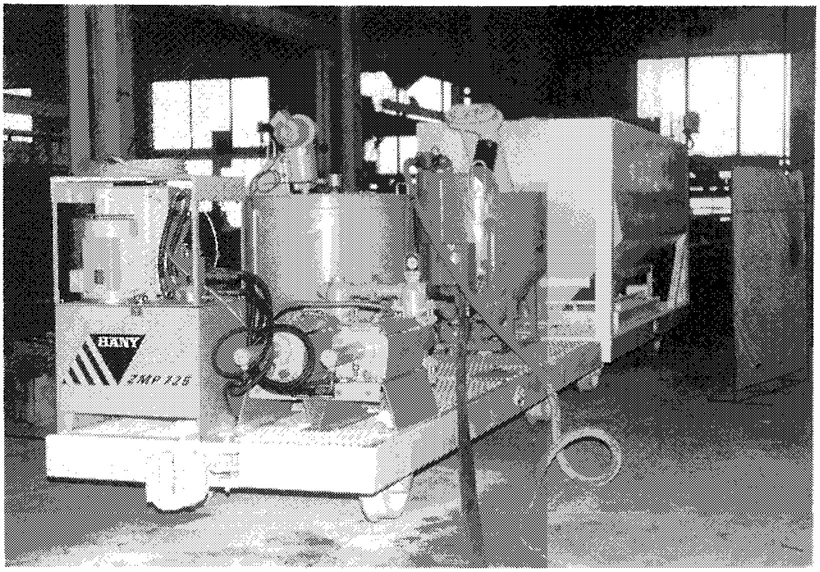

FIG. 4-12. Rial-Mounted Colloidal Mixer with Agitator and Grout Pump

mixed grout is pumped underground through a system of pipes. The grout is discharged into an agitator tank that in turn feeds the grout pump near the point of injection (Fig. 4-13).

A standard concrete batch plant can also be used to proportion and mix the grout at an aboveground location. The thoroughly mixed grout can then be discharged from the plant directly into a specially designed piece of equipment called a "Moran car." A Moran car is a horizontal concrete or grout agitator tank that rides on a railroad track. It is used to transport concrete and grout underground (Fig. 4-14). Moran cars are sized to carry between 4.5 and 9 m^3 (6 and 12 yd^3) of grout. From the Moran car the grout is transferred into a standard grout agitator and pump arrangement located close to where the grout is to be injected. Rubber-tired versions of the Moran car are also used to transport grout underground. Sometimes, depending on the location of the batch plant, it is necessary to transfer the grout from the batch plant into a concrete transit mix truck and than into a Moran car.

Grout from concrete batch plants can also be delivered down drop-pipes, which are small diameter shafts or drill holes installed to deliver grout and concrete to underground locations. It is also common for grout to be discharged from a transit mix truck into pumps at the top of the shaft or tunnel portal and pumped via pipelines to the point of injection.

4.3 AGITATORS

An agitator is a storage tank where the thoroughly mixed grout from the mixer is stirred by a slowly revolving paddle to keep the particles of unstable grout in suspension while awaiting injection. Since the stirring action alone cannot keep the denser particles of grout from settling out of the mixture, baffles are attached to the sides of the tank to help produce turbulence, thereby reducing settlement during agitation. Some agitator manufacturers create this turbulence by mounting the paddle at a diagonal to the vertical axis of the tank (Fig. 4-15).

Agitators range in capacities from approximately 283 L (10 ft^3) to 14,170 L (500 ft^3) and larger. It is important to size the agitator capacity to about 25% greater than the mixer capacity. This allows the entire contents of the mixer to be discharged into the agitator before the agitator runs dry, thus avoiding interruptions of the grout injection and the possible ingestion of air into the pump. The discharge port from the mixer to the agitator, as well as the discharge opening of the grout return line, which returns unused grout back into the agitator, should be equipped with a mesh screen. The screen filters out lumps of unmixed grout, pieces of cement bags, scale from grout lines, and other foreign material. If not removed, these contaminants can clog the grout hole, thereby causing premature refusal and interruptions to the grouting operation.

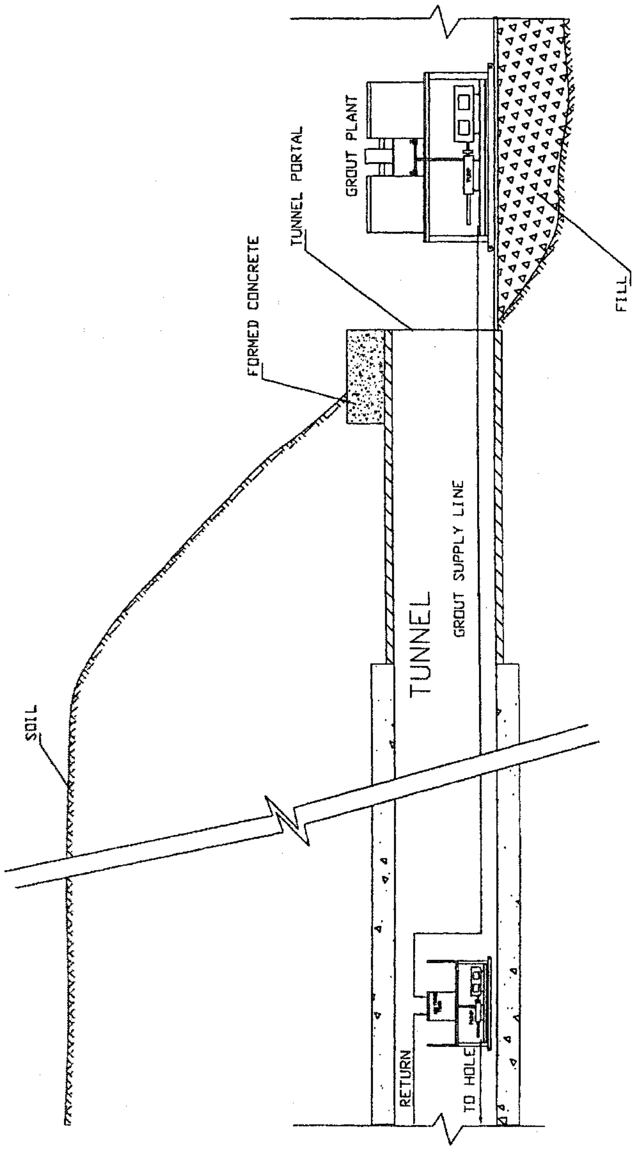

FIG. 4-13. Large Colloidal Mixing Plant Set Up outside Tunnel Portal

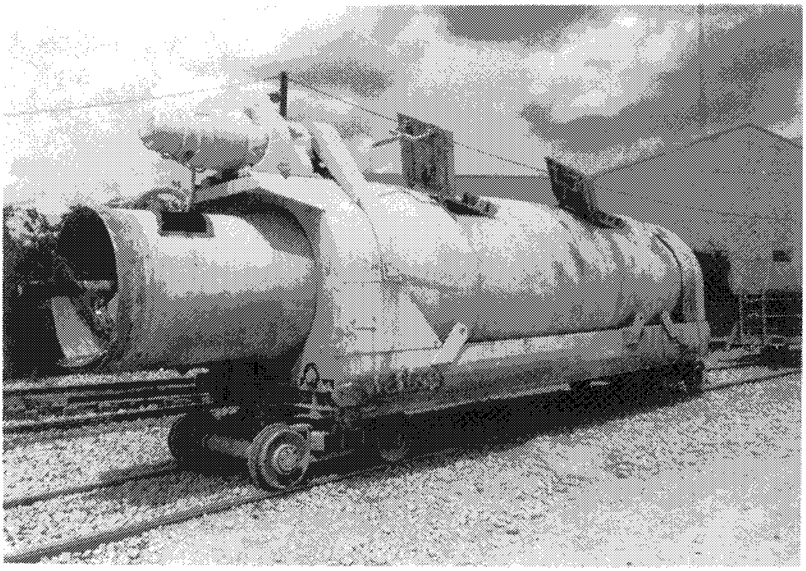

FIG. 4-14. Moran Car

4.4 WATER METERS

Water meters for measuring the amount of water added to the grout mix should always be required by the specifications. Other methods, such as calibrated buckets and predetermined water level markings on the sides of the mixing tank should not be allowed. Water meters calibrated in United States gallons, Imperial gallons, liters, cubic feet, and cubic meters are all available.

A common method of proportioning grout for underground applications in the United States is by volume, especially on small grouting projects. When using the volumetric method, the water meter should be calibrated in cubic feet. Water meters calibrated in U.S. gallons should be avoided because the quantity calculation can become confusing to the mixer operator. This is especially true when it is necessary to change the water:cement ratios midway through grouting a hole. When grout quantities are expected to be large, high-capacity batch plants are used. These high-capacity plants generally proportion the grout materials, including water, by weight rather than volume.

Water meters are available for water-line sizes from 16 mm (5/8 in.) to 38 mm (1.5 in.). The most common size of water line used underground is 25 mm (1 in.). Use of water lines smaller than 19 mm (3/4 in.) should not be allowed. The use of smaller-size lines cause an increase in the time required to charge the mixer with water. This in turn can cause an interruption of the grout injection.