My first experience in shotcrete was in 1966 on the Glendora Tunnel in California. At that time Shotcrete was considered by many to be one of the dark occult arts. The high priests could be observed tasting accelerators to determine their effectiveness, smelling a mix to see if it was adequate, and nodding sagely at our puny efforts to get more on the crown than we did on the invert.

Since that time, meetings such as this and the continuing exchange of information between all of you in the industry has dispelled the myths. We have a better understanding of the realities of this remarkable tool we call shotcrete.

Incidentally, a number of years ago I wondered if I was missing something and did try the taste and sniff tests. I determined two things. It takes almost a full pint of good scotch to get rid of the taste and three weeks to get my sinuses back to normal.

I would like to break my discussion of shotcrete equipment into three topics.

The shotcrete machines or guns

The material delivery systems

Accessory items

*Vice President, Contractors Warehouse Inc.
I am also going to depart somewhat from the specific subject of this meeting, that of "Shotcrete for Ground Support" in my remarks on equipment. This end use of shotcrete equipment is still relatively underutilized and accounts for only a small proportion of machinery sales worldwide. Most R & D work is aimed at improving equipment used in the primary end use fields of refractory placement and structural and architectural shotcrete. Innovations and improvements in these fields are responsible for the equipment you are using today and will be using next year. I will be discussing some recent adaptations to your particular end use.

I will be limiting my remarks to equipment utilizing the principle of pneumatic conveyance. My knowledge of concrete pumping is confined to the observation of only a few jobs and furthermore, I have an extremely strong conviction that only high velocity placement will achieve the densities and strengths required in engineered applications of shotcrete.

Although we manufacture pneumatic conveyance equipment to handle both wet and dry mixes we prefer that engineered applications be performed with the dry process because of the lower water/cement ratio and the later reaction between the water and cement.

A shotcrete machine is a mechanism to meter a granular material into an airstream. It is nothing more nor should it be anything less.

It does not add to or detract from the properties or quality of the mix fed into it.
It must perform this metering function smoothly and consistently, hour after hour, at a throughput rate to fit the job. It must supply to the nozzleman a smooth flow of material at the proper velocity.

If a machine can perform these functions it can indeed be classified as an adequate shotcrete machine. A number of manufacturing companies have machines on the market which perform these functions.

I have heard a number of stories about the birth of the equipment we use in the pneumatic application of cementitious materials. The most popular one concerns the efforts of Carl Akeley at the Smithsonian Institution soon after the turn of the century. He developed a single chamber pressure vessel to spray plaster onto wire forms in order to provide a smooth base for the skins of mounted animals. This was a batch type unit and had to be depressurized when empty to allow the next batch to be loaded.

The second and third innovations of our equipment are better documented. They were made by S. W. Traylor of the Allentown Cement Gun Company after he purchased the Akeley rights in 1915 and consisted of adding another chamber on top of the first so that material could be brought into the bottom chamber (or bell) through the connecting airlock. He also added a rotating spoked wheel in the bottom bell that pushed material over the outlet hole. Since both these innovations were introduced about the same time, let us lump them together and call the resulting machinery the second generation of equipment evolution.
The third generation was introduced in the Thirites in the form of the "Jetcreter" machine. A horizontally rotating barrel with a number of vertical cylindrical chambers operating between two sealing plates was the contribution of this unit. Material gravity fed into the chambers at one point in the rotation. As the rotation proceeded the chamber was sealed by the plates until aligned with the outlet port where air injected through the top plate forced the material down out of the chamber, through the outlet neck and into the hose. Because only the individual chamber was pressurized when it rotated to the proper position, the charging hopper was open to the atmosphere and did not require the manual valving-down of the material. This was in fact, the first automatic gun.

The fourth generation was introduced in approximately 1960 by Frank Reed with the patented feed system utilizing "U" shaped cavities in a rotating feed bowl. (See Figure 1). Only one sealing plate is used, it covering only approximately 20% of the upper surface of the feed bowl. This leaves 80% of the rotation open for charging of the cavities or pockets. As the charged pocket rotates under the sealing plate the inner leg of the pocket indexes with a compressed air port and the outer leg indexes with the outlet port. The material is forced up out of the pocket and into the outlet neck and to the hose. The dividers between the pockets are relatively thin and thus each pocket starts its discharge before the preceding one is finished. This results in an extremely smooth feed to the nozzle.
Figure 1
Operating Characteristics of the Reed Patent
The "Reed Guncrete" machine has had, for approximately two years, higher unit sales than any other gun throughout the world.

I might also point out at this time that there are two other types of machinery that have been developed, both using low pressure air for conveyance. They are quite similar in that they drop the material into a moving airstream. One type utilizes, as an airseal, a star feeder and the other the material load in an auger. It is my opinion that neither type of machine can ever be adapted to pressures high enough to achieve proper particle velocity for shotcrete application. I mention them here merely to recognize their existence.

There are literally thousands of the earlier design guns still in operation in many industries. Some are still being made by a variety of small manufacturers. In my opinion, any gun utilizing third generation, or later, technology can meet my earlier definition of adequacy as a shotcrete machine.

The choice of a particular machine by a contractor should be based, as are his other decisions, upon the economic value of that machine to his job. Initial cost, operation cost which would include crew size, maintenance labor and wearing parts cost per yard of throughput, and finally the resale value of the used equipment all are determining factors in computing this economic value.
These factors are not peculiar to the ground support segment of our industry. They apply equally in a steel mill where high temperature linings are sprayed in furnaces, ladles, ovens, etc. or to a housing contractor erecting shotcrete housing. Swimming pool contractors, chimney contractors, bridge contractors, fireproofing contractors all depend on the economic value of the equipment they use.

I'd like to take time to explain something of the philosophy of our manufacturing company in order for you to better understand the way we have approached equipment design and innovations.

In simplistic terms, we are in business to make a profit. To make a profit, we must sell machinery. To sell machinery we must offer to the contractor equipment that he can utilize to make a profit for himself. Equipment with an economic value high enough for us to compete with other equipment manufacturers for his dollars, and high enough for the contractor to compete with alternative methods of doing the same job.

One of the prime factors in the economic value of a machine is initial cost. Our approach to keeping initial cost low is by use of a modular concept in which a standard base or core unit is augmented by a great number of variable combinations of a limited number of interchangeable parts. The available combinations allow the contractor to get a machine tailored to his particular job. The variables allow him to change that machine in a few minutes, at low cost, to meet a different job demand. This approach allows us to
use mass-production and assembly line techniques and build a greater number of standardized machines. We feel our continued growth is better served by earning a smaller profit on a larger number of machines than by taking a large profit on just a few machines.

The cost of operating labor on Reed equipment has been kept low by its design features. It is an automatic feed gun and requires no pot-man. The smooth feed allows the nozzleman to handle higher throughput rates. The compactness and low weight of the machine gives it great portability. The low profile allows it to be charged efficiently.

Maintenance labor has been kept low, again by design features. One man without tools can disassemble, clean and/or change replaceable wear parts, and reassemble the machine in as little as ten minutes.

Wear parts have been designed to be inexpensive and/or renewable.

The resale value of used Reed equipment runs approximately 60% of its new price and because of demand, is rarely found on the market.

The acceptance of Reed equipment in all phases of the shotcreting industry has given us proof that both our philosophy and design are sound.

This acceptance is not something that we take for granted. Improvements in shotcrete machinery, like any other type of construction equipment, are needed to continually improve efficiency and lower overall costs. The same philosophy I was discussing carries over
into this area. Reed Manufacturing Company intends to remain the prime supplier in the shotcrete industry as long as there is an industry. Therefore, we have recently added the sixth person to what we call our field staff. These people work with contractors and with our dealer personnel world wide, identifying problem areas and suggesting changes and areas of research to our Research and Development Department. In each instance of a delivery of Reed equipment to a new user, one of our field staff, or one of our dealer's personnel works with the new user's crew and trains them in the operation and maintenance of the equipment. This enables us to have a constant line of communication back to the factory. Our Research and Development Department has a number of parameters they must observe when implementing the improvements in equipment developed as a result of their investigations of field problems. Any new equipment parts must be interchangeable with current model parts and must be able to retrofit any past machines in the same series. This allows any user to upgrade his equipment to current standards.

If a change or innovation is a major one and cannot be retrofitted into a current model machine it must be held for the next model. Series Three machines have been in production for almost four years and current production models include many retrofit improvements. Series Four machines will be introduced with major improvements when final design and extensive prototype testing is completed. Our current target for the marketing of standard sized Series Four equipment is in the Fall of 1977. A new mini-sized unit designed
primarily for refractory and coal mining applications was placed on the market two months ago. This gun has the Series Four configuration and has been reduced to 360 pounds total weight. The Series Five equipment idea file is already under development and fabrication, and testing of these ideas have already started.

I stated earlier that an adequate shotcrete machine does not add to or detract from the properties or quality of the mix fed into it. What does affect these properties is the material delivery system. More times than I care to remember over the years, I have visited or worked with shotcrete operations where material is batched and mixed at a central plant using sand with a 12% plus moisture content, dumped into a transit mix truck that has just been washed and still has 10 gallons of water in the drum, driven the forty-five minutes to the jobsite, stood in line at the job slowly revolving in the hot sun for another forty-five minutes. A laborer is assigned the task of rubbing the golf ball sized lumps back and forth over the screen until they are small enough to go into the machine while another is using a coffee can to sprinkle accelerator taken from a sack that was opened three days ago before it rained. At this point the contractor says, with a straight face, "I'm going to have to change machines. The rebound is too high and the strengths are too low."

We are dealing with the chemical reaction between water and cement in our mixes. It is important for best results to have that reaction take place as the mix is placed and not ten or fifteen
minutes before. Pre-hydration of the cement will dramatically reduce the in-place strengths of the mix in relation to the length of time before it is used.

There are two methods used in keeping the water and cement apart until the proper time.

One method is by using a jobsite proportioner/blender in which the cement comes in contact with the damp aggregates only seconds before the material is fed into the gun. Maximum reaction is achieved. This is highly evident in the results just given us from tests at the Ball-Healy-Granite Job.

Another is by drying the aggregates prior to blending them at the central plant. This allows for the transport and waiting time needed without a great loss of reaction.

Mining operations are using a high volume of bone-dry, premixed bagged material. Material in this state can be taken underground on the non-production shifts and stored near the final use point for relatively long periods of time. Bagged materials are currently available in small aggregate, large aggregate, and fiber-reinforced shotcrete mixes.

In North Florida, contractors have available to them sealed bulk tank truck loads (17½ c.y.) of small aggregate material, bone-dry and preblended. These hopper trucks have a clamp arrangement under each of their two valves which mates to a Reed Gun base and allows the truck to act as a super hopper for the gun. These sealed units can be stored for an indefinite time before use.
Although it is possible to place bone-dry mixes through a standard nozzle, the dusting and rebound will be slightly higher than that experienced when using damp aggregates. This can be improved by using an old refractory technique of placing a secondary water injection ring back in the hose from the nozzle. The farther back from the main nozzle, the more effect the secondary water ring has. There is, however, a maximum limit of approximately twenty-three feet, whereafter you will induce hose plugs. We don't know why yet, but suspect that saturation of the fines is starting during the one fifth second it takes the material to travel this distance.

For the best results using bone-dry materials, we can again borrow from refractory techniques and pre-temper or predampen the mix just prior to gunning. This process has a great effect on reducing both dusting and rebound loss while still minimizing the effects of pre-hydration. Metering a quantity of water (usually three to five percent) into the mix at this point, we also relieve the nozzleman of controlling a great portion of the hydration water needed and let him concentrate on fine tuning the additional quantity and his other concerns.

We have been producing since February of this year, an automatic predampening device called the "Reed-Mate" which is being used in both refractory and shotcrete application. The high cost of the special refractory mixes and the resultant savings in the elimination of rebound losses in that phase of the industry led to the design of this machine. The gaining popularity in the use of bone-dry shotcrete mixes has created additional demand for this product.
I have a word of caution about using bone-dry mixes without predampening. Make sure the hose you use has a conductive tube or an embedded grounding wire. Static buildup is severe when moving a bone-dry mix through a hose at high velocity, and must be eliminated.

I passed over rather lightly the use of fiber-reinforced mixes in mining applications. Coal mines are presently using this high tensile strength material to support the wide span flat roofs found in their operations. They are also using this material as a sealant against air slaking, as a fireproofing material against exposed seams, and to build blast proof bratrices or air curtains. Since the inception of these lining programs, serendipitous benefits have shown up in the way of increased lighting levels, decreased cleanup and rock dusting costs and a discernible reduction in the power consumption on ventilation fans.

Since the last conference we had the opportunity to participate in another interesting development. In many small bore tunnels there is no room for a shotcrete machine at the heading without disruption of the mining cycle. An alternative method was designed for use at the Tonner Tunnel in Los Angeles County. The shotcrete equipment was permanently set up outside the portals and as driving continued, steel pipe was used down the tunnel to carry the material stream. No problems were encountered. The production rate dropped from 10 c.y. per hour at the portal to 4½ c.y. per hour at the deepest midpoint of 950 feet. No special air injection systems were used in the pipeline on this job but we have used them on other applications to move material over 2,000 feet.
I was speaking earlier about adaptations of technology from the other areas of shotcrete application to that of ground support. One such recent adaptation is the spinning nozzle system used for relining furnaces and ladles in steel mills being modified, automated and improved for use as a deep shaft lining device. A paper on that system is yet to come in this session.

Another item, currently in use in refractory applications, for which I see a possible adaption to your field, is the low voltage electrical control devices which enable the nozzleman to control the gun functions. This eliminates one of the problem areas of communication between the nozzleman and personnel near the gun.

In closing, gentlemen, I would like to share an optimistic view with you. We have seen a growing trend in the use of shotcrete for ground support. We feel this trend will continue and accelerate. Perhaps by the time of our next conference we will see the rest of the industry borrowing from your technology.