From the Construction Management point of view I believe there are two primary considerations for judging Methods of Payment.

1. The method of payment should encourage good construction techniques and practices.

2. The method of payment should be capable of only one interpretation, both as regards measurement and payment.

These are good considerations from both the Contractors and Owners point of view for all work. They are particularly valuable in dealing with new construction work and techniques in their developing stages.

Shotcrete is such a work item and although it has been used for some time abroad, it is relatively new as a means of permanent tunnel support here. While it was used as a means of temporary support, just one more tool in the Contractor's armory, there was less need to be concerned about methods of payment, either because it was not a separate item of pay, being included in the cost of excavation or it was a very small item.

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I am going to consider the problems of measuring shotcrete. Shotcrete is placed against rock by its nature this is an uneven surface. Even when shotcrete is used in machine bored tunnels, they rarely do not have some rock fallout. This means that the receiving surface is generally irregular and for most practical purposes is unmeasureable. The finished surface is also uneven due to the method of application and is also difficult to measure, although it's less irregular than the rock face.

Therefore shotcrete is very difficult to measure in place, although it is the most obvious solution, as it is the way concrete is measured. There have been several attempts to measure it in place, most commonly using pins but also by coring or probing. It is almost impossible to measure when the shotcrete is not required to be placed in a uniform layer, but around steel sets, hydraulic pressure relief systems and other inclusions.

When we evaluate this method of measurement against the criteria first mentioned, the method has some advantage from the point of view of workmanship in that it does not pay for rebound. It would pay, however, for voids formed by bridging of the shotcrete. The real problem with this method is, when it is judged by the second
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criteria. With the irregular surfaces there is no way that either the owner, the contractor or the engineer, can know what he is buying. The necessary location of pins, probes or cores is bound to be arbitrary whether they are a fixed pattern or are located in the field. There is no way prior to placing that anyone can tell what he will pay or will be paid for. Therefore this is a major disadvantage of this method. There is a further disadvantage in that it is very difficult to estimate the quantities to be put in the contract. The quantities can really only be guessed for which can make problems for the owner, if the guess is bad. Also it encourages gambling by the contractors using upset bids on possibly low quantities. The cost of placing the pins is also appreciable.

There is one other problem which really concerns the first criteria on workmanship. The quantity obviously depends on the overbreak. The overbreak is at least partly determined by the contractors method of excavation. This is particularly true with conventional mining. The contractor has a choice of a slower excavation with a smaller overbreak or a faster, but higher overbreak methods. In general methods giving less overbreak are safer and show the better workmanship. Therefore if this method of payment pays more
for greater overbreak, then it encourages poor workmanship.

Now I would like to discuss probably the most common method of measurement of payment. This is measurement of the volume of shotcrete through the nozzle. This is probably the most popular method for the contractors. This used to be really a calculated volume from the weight batched aggregates with cement and additive often paid for separately or also by calculated volume. Now there is a lot more volume batching being used and also a meter at the nozzle to measure the volume actually projected.

Judging this against the criteria it is fairly obvious that there is one major drawback. The owner pays for the rebound. There are several reasons for rebound not all of them are within the control of the contractor. The angularity of the surface will affect the amount of rebound. This is only very limitedly within the control of the contractor and his blasting procedures. The use of reinforcement or mesh increases the rebound. However, the principal control of rebound is in the hands of the nozzleman. A good nozzleman can keep rebound down below 25% if he keeps flow rate through the nozzle. If the rate of flow is raised and the air or water pressure is
increased the rebound increases. The better the nozzleman the less rebound at a higher flow or placement rate. In general the contractor has a choice to increase his placement rate or increase the waste. A careful placement can produce a better end product. Payment on this basis encourages the use of faster production rates, but it also encourages the use of less experienced nozzlemen and poor control. This can be limited by excluding payment for rebound over a certain percentage, this has often been 30%, but rebound is difficult to measure with any accuracy.

From the point of view of the second criteria this method is good. It is clear or can relatively easily be made clear on how the measurement of this quantity is to be made, so that everyone can know ahead of time exactly what will be paid, unless a maximum rebound clause is added. Without a limiting rebound clause it is even more difficult to arrive at a quantity for bid purposes which makes considerable problems for the owner, and his budget.

The last major method of measurement in the payment by linear foot of tunnel or by lump sum. This method does not measure the shotcrete quantity in any way, but includes cost of a specified amount of shotcrete in with
the excavation and sometimes with concrete as well. Looking at it from the point of view of workmanship. It encourages the contractor to reduce the rebound as it only pays for what is in place. However, it does encourage the trapping or "rolling" of rebound into the placed shotcrete - thus requiring a tighter inspection control. It also pays for voids, if they are undetected.

Using the second criteria it gives the clearest method of payment with minimal chance of over or under-runs. However, it takes no account of the actual amount of shotcrete placed, merely requiring a theoretical minimum and therefore where additional overbreak of the rock surface occurs it does give impetus to the placing of claims for these conditions. A potential drawback is the nonpayment for the work until all the work in the lump sum is completed. This can be avoided by breaking down the lump sum for payment purposes.

In summary of the three methods of payment used judged against the original criteria all three have some defects, but the last one, which admittedly places more risk on the contractor probably suits the normal owner with a relatively fixed budget better and best encourages good workmanship and the clearest understanding of what will be paid.
From the contractors point of view low, or zero risk type jobs do not work in the experienced contractors favor as with low risks a contractor with limited experience can compete on equal terms. From the Construction Management view point an experienced contractor is highly desirable, so a higher contractor risk method of paying for shotcrete may help to lead to a more desirable contractor.

Lastly I want to look at the encouragement of new methods. As long as the method of payment is concerned with the end result it will not discourage new methods. Measurement during placing such as thru the nozzle should effect the method placing and restrict some possible placing method. In general, however, new techniques and materials depend more on the specification method of payment and more on their economics than how they are measured.