A Technique for Measuring the Rate of Erosion of Cave Passages

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In recent years spelæology has progressed from being a qualitative art to being more and more a quantitative science. Many measurements have been made on the physical aspects of caves including such quantities as the flow of cave streams under normal and flood conditions, and the concentration of dissolved calcium carbonate present. From these measurements estimates have been made of the rate at which limestone is being removed from an area of cave. It is, however, difficult to relate this measurement with the rate at which the actual cave passage is being formed, and it is this rate which, perhaps more than any other, is of greatest interest to spelæologists. The technique to be described is one which has been developed to measure this quantity, that is, to measure the rate at which the rock surface is being eroded by water action both by corrosion and corrasion. This paper is an interim report describing the technique; it is hoped to present the results at a later date when data have been gathered over a long enough period of time.

The basis of the technique is the principle of Kinematic Location. In order to fully define the position of an object in space it is necessary to place six kinematic restraints on it, three preventing translational motion, the other three preventing rotational motion. If fewer than six constraints are applied, then the object is left free to move; if more than six are applied then its position is indeterminate. In this experiment it is necessary to be able to position an instrument with absolute precision on a datum on the rock face, and the arrangement known as Kelvin's Clamp is used. This basically is a method of applying the necessary six constraints, and only six constraints, to an object. Its advantage is that the accuracy of location is substantially independent of the precision with which the basic parts are made.

The clamp consists of two parts, the base and the tripod. The base is normally the fixed part and comprises three carefully shaped indentations. One of these is a small conical depression, one is a small V groove, and the third is a flat surface. On these three indentations a rigid tripod is placed. The legs of the tripod end in hemispheres. When the first leg is located in the conical indentation it is found that the three translational constraints have been applied to the tripod; it can no longer move sideways. backwards or forwards, and gravity prevents it moving vertically. The second leg now locates in the V groove. This prevents two of the possible angular rotations from occurring. When the third leg comes to rest on the flat surface the tripod is then fully constrained. By the principle cited above it follows that if the tripod is removed and replaced it will again locate in precisely the same position.

In practical terms the principle of Kelvin's Clamp is realized as follows. At the site where a measurement is to be taken three steel pegs are set in the rock surface, at the apices of a 7-in. equilateral triangle. One of these pegs has a conical indentation in it, another has a V groove in it and the third has a flat surface. These pegs remain in position permanently and provide a datum from which all measurements are made.

The instrument for measuring the rate of erosion consists, in essence, of a tripod with a depth-measuring meter on it. The legs of the tripod terminate in hardened steel hemispheres ($\frac{1}{4}$ in. diameter). On this tripod is mounted a "clock-gauge" precision meter which indicates on a scale the linear movement of its probe. The particular clock-gauge employed indicates the movement in increments of $\frac{1}{10000}$ in. The probe has a hardened steel hemispherical tip $\frac{1}{8}$ in. diameter, and this bears on the rock surface. The clock-gauge is completely enclosed in a watertight compartment, the probe being sealed with a thin rubber membrane. A mirror and window permit the scale to be read without parallax (*Fig.* 20).

To take a reading the pegs in the stream bed are carefully cleaned, and the legs of the tripod are placed on them. The probe of the clock-gauge is gently lowered until it makes contact with the rock surface, and a reading is taken. By virtue of the fact that the tripod is equilateral it can be placed on the pegs another two ways round, thus yielding three readings per set of pegs.

Some time later the instrument is replaced on the pegs, and a further three readings are taken. These readings will be referred to the datum in precisely the same manner as the first set, and hence subtraction of the one set of readings from the other will directly yield the depth of rock that has been eroded during the time interval.

SOME PRACTICAL DETAILS

One of the more difficult points which had to be solved was the method of fixing the steel pegs in the cave floor, and protecting them from corrosion. An epoxy resin was tried, initially, to cement the pegs in position, but the greatest difficulty was experienced in making the adhesive key to the wet rock surface. An alternative method tried was a small steel assembly which was inserted into the hole, and which, when it was tightened up, expanded radially outwards, biting into the rock. This method, however, suffers from being unduly expensive as the small assemblies have to be made individually. The third method tried was one using a "Rawltamp", in which a lead sleeve is inserted into the hole and splayed outwards; inside this is a threaded sleeve and into this a bolt is screwed. It has not yet been determined whether this

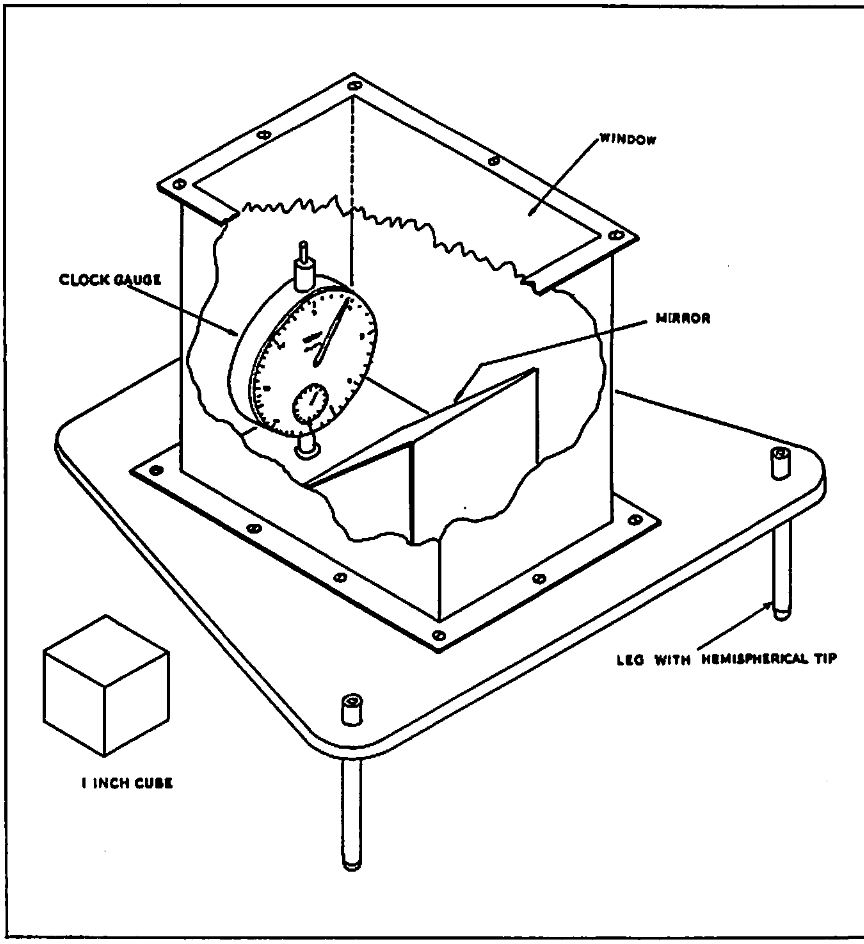

Fig. 20.

method is safe from electrolytic corrosion. Two grades of stainless steel were used for the actual pegs themselves, EN57 and EN58B, the latter proving substantially the better, and is, as far as has been determined, immune from water corrosion. In all cases the pegs are covered with a layer of waterproof grease between measurements. Star drills were used to make the holes, which were positioned with a steel template.

There is one point which must always be borne in mind when using this technique and that is that any distortion of the instrument resulting from knocks will make comparison of all future measurements with past ones void. Similarly, no two instruments can be constructed to take the same measurement. Because of this, stringent precautions to prevent knocks must be taken when carrying and using the instrument in the field.

THE ACCURACY OBTAINABLE

Several stations have been sited in Co. Clare, Ireland, and measurements are being taken. The immediate results have been very promising; under good conditions, such as clean shallow streams with firm rock, it has been possible to measure depth of limestone removed over periods as short as 2 days. The repeatability of readings is about plus or minus twenty millionths of an inch ($\pm 0{\cdot}00002$). Under worse conditions, such as streams with algæ growing in them, or badly pitted rock surfaces, a repeatability of plus or minus one hundred millionths of an inch ($\pm 0{\cdot}0001$ in.) is typical.

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