An appreciation of the Schmidt rebound hammer*

by J. Kolek, B.Sc.(Eng.)

CORRIGENDA

In the caption to Figure 2 of the paper, entries 4, 5 and 6 of the key should read:

4 rider 5 scale 6 mass

In the caption to Figure 7 of the paper *for* Davance *read* Dawance

In page 35, column 2, line 8: *for* 25 *read* 35

Contribution by A. R. Cusens

(University of Khartoum)

Mr Kolek is to be congratulated on his comprehensive and interesting paper on this subject.

In view of the conclusion as to the influence of size and curing of specimens, the value to the general reader of Figure 7 would be enhanced if the type of specimen and curing details were given for each experimenter.

I do not quite understand how " in problems associated with the demoulding or the removal of shuttering the hammer can be of great value ". According to Figure 5, the rebound number changes only from 8 to 12·5 in the first two days, i.e. during the normal period in which demoulding is carried out (at least in precast work). The low sensitivity of the rebound hammer at low strengths is again illustrated in Figure 9. Mr Kolek further states that " the results of floated or trowelled surfaces will give higher scatter of individual results, hence the confidence limits for such a correlation will, in general, be low ". Normally, if the concrete is still in the mould, one must rely upon readings on a floated or trowelled surface. In these circumstances, I venture to suggest that personal judgement is likely to be as reliable as the rebound hammer.

It is difficult to see from Figure 10 how a rebound number of 25 was estimated† to give a safety factor of 2 with regard to the B.S. limit of attrition. My estimate of this number is 30–32, depending upon the position chosen for the curve. Incidentally, the use of the hammer in this connexion seems logically to hold more promise than its use in comparison with crushing strengths.

I feel that the inclusion of cubes E was a mistake. These are described as emanating from sub-standard wooden moulds. From this the reader is presumably intended to conclude that the crushing results are of dubious value. To add this doubt to other doubts regarding the rebound hammer is to introduce an unnecessary red herring.

In the absence of other evidence, it is hard to accept that the common curve for cubes A and B is due to anything other than mere coincidence, when it is considered that the curing procedure, age and condition at test of the two groups were quite different and that a further change of age and curing produced results such as those of cubes D. It would be interesting to have results for other placing and curing procedures, intermediate ages and conditions at test in order to settle this point. I suggest that the method of compaction is likely to affect the calibration curve as much as the other variables considered.

Finally, I cannot agree that the Schmidt hammer is ever likely to give a much more realistic result than the testing machine. The crushing of cubes for quality control has its weaknesses, one of which is that more care is probably given to the compaction and subsequent curing of cubes than to the structural unit. However this is no more unrealistic than the testing of small portions of the surface of the concrete of the unit. In the case of high-strength concrete where mechanical compaction is used a skin of mortar forms at the mould face. It is this skin which is tested by the Schmidt hammer and not the bulk of the concrete. For low-strength concrete, the calibration of the hammer is insufficiently sensitive to be of much use.

Contribution by T. N. W. Akroyd, M.Sc.(Tech.), A.M.I.C.E., A.M.I.Struct.E.

(Constructional Services Limited)

There appear to be two schools of thought on the use of the rebound hammer, those who think it might be of some utility if they could restrict its use to one type of concrete structure made with one type of aggregate and uniform cement with the concrete cured and tested under constant conditions; and the second school who produce graphs and curves relating the rebound number to everything from the modulus of rupture to the modulus of elasticity.

To some extent it appears to me that Mr Kolek belongs to the first school in that in his paper he cites the following as limitations of the Schmidt hammer.

(1) Fifteen readings should be taken in one locality and the mean taken as representative of the concrete.

(2) Whilst the test can be made with the hammer at any angle, at each angle the rebound will be different for the same concrete and will require separate correction

*Pages 27-36.

†See correction given above. Ed.

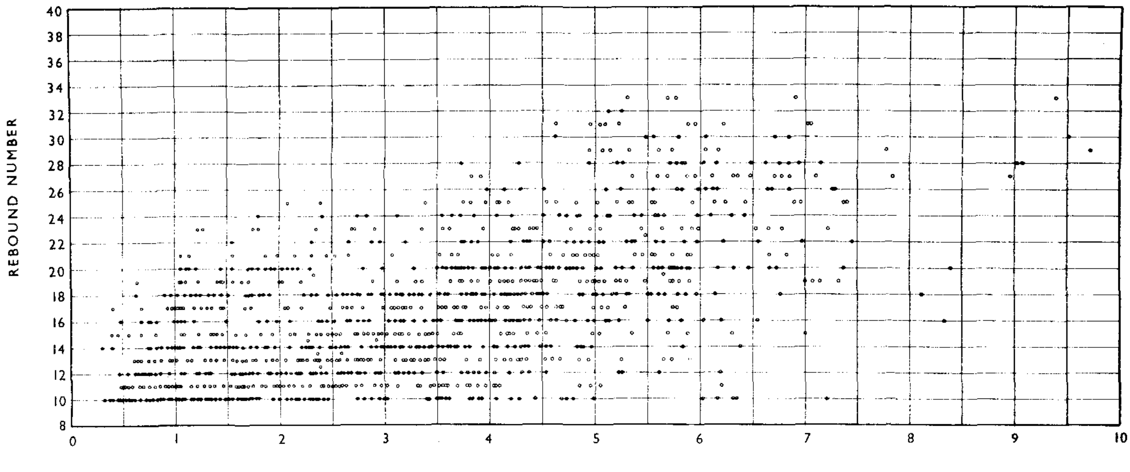

Figure 1

charts. For the sake of expediency and greater accuracy the user should adopt one angle of test and where small test pieces are used this should be vertically downwards.

(3) Smooth, uniform, preferably moulded surfaces are to be preferred for test.

(4) The presence of an air bubble underneath the surface will give an unrepresentatively low result whilst the presence of a large particle of aggregate below the surface will give a high result. Floated or trowelled surfaces will give consistently high results and a high scatter of results.

(5) A repeated test at or near the same spot will give a lower reading; this must be contrasted with the requirement for 15 readings in one locality.

(6) Age, size of specimen and curing conditions all affect the results so that correlation between strength and rebound number varies, depending on these factors.

However, Mr Kolek does illustrate his paper with a number of graphs which indicate a relation between rebound number and other properties of the concrete.

Figure 7, which illustrates the relations of rebound number to crushing strength obtained by different workers, shows that for a rebound number of 30 the crushing strength varies from about 2,500 lb/in² according to Chefdeville to over 4,500 lb/in² according to Kolek. The results of tests shown in Figure 8 do not seem to be related in any way to any of the calibration curves in Figure 7. This appears to support my contention that there is no basis for assuming that there is or should be any relation between the rebound of the hammer and the strength of concrete; in addition, Mr Kolek's finding that there is a variation in hardness with the depth from the surface of concrete points to the absence of any fundamental relation.

According to the physics of rebound it would seem that, if the concrete sample were large and perfectly elastic, all the energy imparted to it by the hammer would be returned and cause the rebound of the hammer. But, of course, owing to the intrinsic properties of the concrete, there is some damping. This damping effect will probably vary according to the type of aggregate used, the mix properties, the percentage voids in the concrete and also the water content.

Where the sample is not large in comparison with the hammer, different results will be obtained. Similarly, I have noticed that on some concretes indentations of different size are produced and different rebound numbers are obtained for the same strength. In fact the same concrete, say a cube specimen, can give different results on different faces so that not much reliance can be placed on the values obtained.

During the period August 1956 to February 1957, a series of tests was carried out on 6 in. concrete cubes and the Schmidt rebound hammer was used. All the cubes were tested vertically downwards, resting on a concrete floor. The cubes were either 7 or 28 days old and were tested in a saturated condition after having been removed from a curing tank at 60°F ± 1°. The surface of each cube was dried before testing and immediately afterwards it was crushed in a 200 ton Avery machine. In the majority of cases typical Thames Valley aggregates were used and the cement was standard laboratory cement from one source. Except for cubes of high workability which were hand-compacted, all other cubes were vibrated on an Allam vibrating table.

Thus many, if not all, of the factors mentioned above were constant.

Some of the results of this series of tests are shown in Figure 1. Many of the results have had to be omitted, it being impossible to plot them all and at the same time maintain clarity in the diagram. Thus, for example, for a rebound number ± of 10, seventy-four results were obtained from cubes which had strengths varying from 300 to 1,800 lb/in² in increments of approximately 30 lb/in². The highest result ever obtained with a rebound number of 10 was 7,200 lb/in². Of the 104 results obtained with this rebound number, only 13 were above 4,000 lb/in², so that with the lowest reading on the scale there appears to be over a 90% chance that the resulting strength will be between 250 and 4,000 lb/in² !

However, the results do agree with Mr Kolek's calibration curve in that readings as high as 40 or above are seldom obtained with concrete cubes up to 28 days old.

However, on the basis of our results, I believe the Schmidt rebound hammer may be of some value in certain restricted circumstances. Unfortunately, the conditions for its use have never been sufficiently restricted for the results to be of any value in practical site or laboratory work.

Contribution by R. C. R. Dalton

(The London Ferro-Concrete Co. Ltd)

Mr Kolek's article on the Schmidt rebound hammer will undoubtedly be of great value and interest to concrete engineers, in particular to those employed in the manufacture of precast concrete units. My company purchased a hammer (Type N2) in November 1957 and I have since gained some experience in the calibration and also the use of this instrument in the works of a precast concrete manufacturer.

The calibration curve was determined in a similar manner to that recommended by Mr Kolek except that only 15 readings were taken from each cube and of these five of the lowest and highest readings were rejected. The mean of the remaining 10 readings was used for calibration purposes.

The graph shown as Figure II is plotted from results obtained from 150 cubes 7 days old and cured in the works open curing area. These were tested with the hammer vertically downwards. The aggregate/cement ratio of 4·5 and grading of aggregates are constant within normal limits obtainable by the average precast concrete manufacturer. Rapid-hardening cement, washed sand, and ½ in. single-size gravel aggregates were the constituents. The majority of the cubes were taken from normal production, the minority consisting of those that gave the lower results. These were cast in order to increase the over-all range of the calibration curve. Mr Kolek's calibration curve for his combined results for cubes A and B is shown as a broken line on Figure II. There is a difference of approximately 1,000 lb/in² for any given rebound number. This difference further emphasizes Mr Kolek's suggestion that users prepare their own charts if they wish to obtain accuracy.

A rebound number of 30 on my graph gives a prediction of cube crushing strength of 5,000 lb/in² to within approximately ± 20%. The possible error for any result would appear therefore to compare very favourably with any prediction made from Mr Kolek's curve, on which accuracy decreases at the lower rebound readings and increases at the higher readings; with my curve there is an excessive scatter of results in the middle range of the curve. Mr Kolek may have some views on this but I suspect the reason is a lack of control during the production of the concrete. During the test programme for my calibration curve several intermediate curves were drawn, and there has been little noticeable change in the mean position, with the exception of the lower end of the curve, for which the rebound number for any given compressive strength has slightly increased.

Although the makers recommend that the use of the hammer be limited to an age range of between 7 and 90 days, I have found this considerably reduces its usefulness as a non-destructive test for the strength of concrete in my own particular work. I have therefore been carrying out tests to produce a 3-day calibration curve using concrete made to a similar specification. The results after 50 tests are encouraging and the mean interim calibration curve tends to follow the progression of our 7-day curve. There is, however, a high scatter of results in the lower strength range, as would be expected, and the results for the upper portion of the curve are limited to approximately 5,000 lb/in². I have felt justified in ignoring the maker's recommendations because in precasting works the compressive strength of normal reinforced concrete units at 3 days is high, and rebound readings in the region of 23—25 are quite normal.

The hammer is generally used in a horizontal position and tests were carried out on units and cubes to determine the conversion figure for the rebound number.

In the past—and this statement is based on my own experience—precast concrete manufacturers have found no difficulty in reaching the compressive strength required from any particular mix, because a low water/cement ratio is used to ensure early demoulding. Designers in reinforced concrete are now using the latest Code of Practice 114 to full advantage, and frequently require high-strength concrete. The Code of Practice also allows ample scope to the concrete engineer to reduce costs of material by using a reduced cement content. In order to achieve the latter he must design a suitable mix, and, if strict economy is needed, he must achieve a high degree of quality control. Even in a small precasting works there will be several mixes required for a variety of units for a number of different contracts, and all these may have to be produced by the same mixer station. There is an obvious need for frequent non-destructive tests on the finished units. Faced with the above problems, my company is making full use of the rebound hammer as a means of additional control of the quality of concrete and as a complementary test for the compressive strength of the concrete in cast units.

So far I have not found it possible to use the rebound hammer to determine the strength of concrete for the purpose of timing the demoulding of units, because at present the hammer is only used for 7-day tests. The majority of precast reinforced concrete units can be

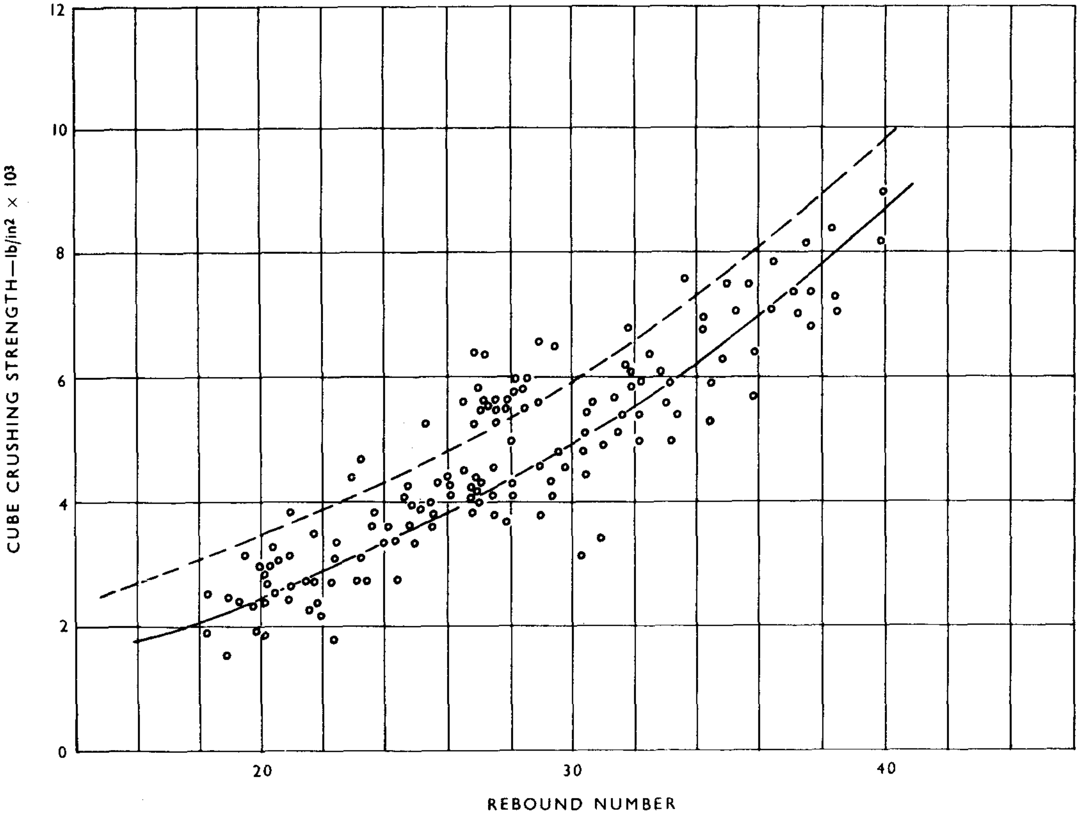

Figure II: Calibration curve for rebound hammer. Six-inch cubes made from a 1:1½:3 mix were crushed at 7 days.

demoulded between 24 and 72 hours, when rapid-hardening cement is used. Such aids as accelerators or steam curing are not necessary. If a calibration curve for 3–day readings can be produced, the rebound hammer will have numerous applications in the timing of demoulding during periods of low temperature.

The assessment of the strength of concrete as a function of time has been of considerable financial significance in the production of post-tensioned units. If readings are taken at intervals, post-tensioning can be carried out at the earliest possible moment and as soon as the compressive strength required by the designer at transfer of stress is reached. For this I am using the hammer on units under 7 days old, and using therefore a combination of quality control and non-destructive tests to determine when to carry out post-tensioning.

For all my company's contracts, designs for the concrete mixes are made at the works. On each set of preliminary test cubes rebound readings are taken at 7, 14 and 28 days. These readings are then used to determine an approximate correlation curve from the results of the crushed cubes. It is possible on any particular contract to determine at a future date the approximate compressive strength of the concrete in any portion of the structure and to check, if necessary, the degree of control being exercised in the production of the concrete.

A precast concrete structure which my company constructed a number of years ago was recently damaged by fire. Upon investigation, in some places it was impossible to determine visually whether or not certain units were structurally sound. As other tests were impracticable it was decided that the rebound hammer should be used. Various precast units in the structure which were unaffected by fire damage were used as a basis for a check on the rebound readings. I was not responsible for the tests carried out, but have been informed that the large difference in the rebound readings recorded for sound and unsound members made the extent of damage to the structure very evident.

This contribution endorses Mr Kolek's conclusions and a number of applications suggested by him are now being used by my company in the course of normal production of structural precast concrete units. As a result of intelligent usage, the rebound hammer is now an essential instrument in the control of concrete production.

Reply by the author

The author wishes to thank Dr Cusens for his interesting contribution, which discusses the substance of the paper, since he carried out practical work on other types of non-destructive methods of testing concrete. It is to be regretted, however, that Dr Cusens has presumably not had any practical experience with the rebound hammer and thus was unable to make comparisons.

Dr Cusens's suggestion that personal judgement can be as reliable as the rebound hammer in the estimation of the early strength of concrete, which is important in choosing the right time for demoulding, is in complete contradiction with my experience and was based on misinterpretation of some of my results. It is frequently forgotten, or not fully realized, that winter temperatures can considerably upset the usual pattern of periods between casting and demoulding. It is cases of this kind which present the engineer with the dilemma of losing time and disorganizing routine or damaging the casting. Whereas Figure 5 of the paper shows only a typical development of hardness and therefore strength, it should be realized that the shape of the curve will vary considerably with the curing conditions and therefore typical results should not be used for un-typical cases. It is those cases, relatively few as they may be, that call for control by a test and not merely by personal judgement. Although in the type of precast work for which the rebound hammer can profitably be used, the sides of the mould are removed, more often than not, within 2 days, the casting is left on the base of the mould until it is certain that the strength of concrete has passed the required minimum. It is chiefly such cases, numerous in precast work, which the author had in mind when suggesting the use of the hammer in problems associated with demoulding.

With regard to the reference in the paper to Figure 10, the author apologizes for giving the wrong rebound number, which should be 35, in the example of a factor of safety of 2 with respect to the limit of attrition.

It is difficult to follow Dr Cusens's conclusion that there is more promise for the hammer in predicting the attrition resistance than in predicting strength. It is generally known that other things being constant, attrition resistance is proportional to the strength.

The author does not agree with Dr Cusens that some results should have been excluded from the paper because they throw an unfavourable light on the reliability of the hammer. As Figure 8 clearly points out, the rebound hammer is only as reliable as the calibration curve derived for a limited range of variables. Dr Cusens is, therefore, allowing a glimpse at the obvious by suggesting that the common curve for cubes A and B is a pure coincidence. The author thought it desirable to specify known details in order that the results could be utilized in some wider context.

The author agrees with Dr Cusens that, for a thorough study of this non-destructive method of testing concrete, it would be desirable to have results for a number of ranges of variables but it is his conviction that the hammer can only be satisfactorily used as a practical aid in conjunction with a self-derived calibration curve.

The author, has, in fact, some limited evidence that the method of compaction does affect the calibration curve. Cubes cut from a hydraulically pressed kerb showed higher strengths than predicted on the basis of cubes cut from vibrated kerbs. It would, indeed, be surprising if this was not the case when one takes into consideration that the mixes used are of necessity extremely dissimilar.

The author has also evidence that the degree of compaction by vibration has very little, if any, effect on the rebound number. This is a further serious limitation of the hammer.

Dr Cusens argues that the testing of a small portion of the surface of a unit is unrealistic. Nevertheless such tests are widely used in practical metal testing. The skin of mortar that forms at the mould face is, for roughly constant time and acceleration of vibration, a function of the original components of the mix and thus can be regarded as representative of the bulk of the concrete for a given calibration.

The author wants to emphasize the fact that, despite the many and, in some cases, serious limitations pointed out here and elsewhere, the hammer can become a useful instrument in the hands of an intelligent user. Engineers are often awe-inspired when the " practical " man hits the concrete with a steel hammer and so predicts the strengths but may hesitate to recognize the same principle embodied in an instrument.

Mr Akroyd's results represent a valuable contribution to the proper appreciation of the limitations of the rebound hammer.

The calibration curves in Figure 7 were derived for the horizontal position of test and my calibration curve for cubes A and B shown in Figure 9 had therefore to be reduced by formula (14) in order to make a direct comparison possible. Taking into account all the variables in the derivation of the calibration curves in Figure 7 and remembering that the use of self-derived calibration curves has been recommended for non-destructive testing, it is not at all surprising that there should be a discrepancy.

The author agrees with Mr Akroyd that there is no fundamental relation between the rebound of the hammer and the strength of concrete, but nor is there one between any of the hardness tests for metals and their strength. Even if the empirical relation between the two is purely coincidental, surely this is no basis for condemning a test method of this nature.

It is true, as Mr Akroyd suggests, that different readings are obtained on the sides and the bottom of a cube as cast. Accordingly, only the results obtained on the sides were used in the paper.

Finally, the author contends that Mr Akroyd may be justified in reaching his final conclusion on the basis of his own test results but would not agree that his conclusion can be taken to refer to the work of other experimenters carried out so far.

The author is grateful to Mr Dalton for making his valuable contribution and for backing his discussion by extensive test results of his own. His results and conclusions are on the whole a confirmation of the author's results.

The greater scatter of results in the middle range of Mr Dalton's curve can only be attributed to less rigorous enforcement of control.

The author wishes to encourage Mr Dalton in attempting a calibration curve for concrete at the age of 3 days. Such a calibration curve, provided it is of reasonable precision, would undoubtedly enhance the usefulness of the hammer as a means of quality control.