Discussion on a paper published in the

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Variation of concrete strength in existing buildings*

R. G. Drysdale

Contribution by J. H. Bungey, MSc, DIC, CEng, MICE

University of Liverpool, Department of Civil Engineering

The paper by Dr Drysdale provides some interesting and very useful results correctly supporting the use of ultrasonic testing techniques. Whilst I agree with the conclusions, I should like to make a few comments regarding the possible effects of reinforcement upon test results.

It appears that direct pulse-velocity measurements were taken at standard positions on all the columns tested. The position of binders relative to these positions, and also the size and location of main reinforcement, may thus produce a varying influence upon the results obtained. The extent of this influence will depend upon the relative sizes of bars and members. Provided that binders are confined to the periphery of the section, their effect is likely to be small but, if 'internal links' exist, they may cause a significant increase in pulse velocity for readings taken nearby. The effect of main reinforcement is again likely to be small unless bars lie directly on the path of the pulse but, if this does occur, a velocity enhanced by over 5% may result for likely reinforcement quantities. This, combined with an internal link lying close to the path, could cause very much greater increases. It would seem reasonable to assume that the net result of these effects is marginally to increase the mean of a group of readings, but also to cause an increase in standard deviation, which may be more significant. Hence the use of this method to measure over-all quality control of concrete may tend to underestimate the degree of control obtained unless some allowance for the presence of reinforcement is made either during testing or in the interpretation of results.

Any small change in concrete strength variation between columns of different size may well have been masked by the effects described above. The apparent 2% strength increase at the bottom of columns indicated in Figure 2 seems more likely to have been caused by the increased reinforcement in those regions in the form of starter bars for the columns, rather than the detection of higher concrete strengths.

Similarly, Dr Drysdale's proposal that a change in pulse velocity with floor level is due to more difficult working conditions must be questionable. Tests in progress in the Department of Civil Engineering of the University of Liverpool indicate changes in pulse velocity of up to 3% due to the stress history of an uncracked concrete specimen. This effect is likely to have greatest influence in upper floors, where the live/dead load ratio is highest and would result in a decrease in pulse velocity. The trend indicated in Figure 3 seems to be based principally on the results for building 8, which is used elsewhere as an example of poor quality control. These factors must raise the question of whether or not this testing technique can be expected to detect reliably such small trends in concrete quality as claimed by Dr Drysdale in Figure 3, especially when reinforcement effects are not considered.

*Pages 201 to 207 of *MCR* 85

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Reply by the author

Mr Bungey has raised several important questions which were not dealt with in the paper but were considered in the investigation. Before field testing began, a series of 17 laboratory-prepared prisms with various quantities of reinforcing steel was used to ascertain the effect of longitudinal reinforcement and column ties upon ultrasonic-pulse-velocity measurements. It was found that ties and longitudinal bars which lay directly in the path of the pulse did increase the pulse velocity. When bars were more than 50 mm from the shortest pulse path, there did not seem to be any effect.

Another aspect included in the field investigation was the determination of the location of reinforcement in columns*. A cover-meter instrument based on the magnetic principle was used to locate the position of longitudinal bars and column ties in approximately one-fifth of the columns tested for ultrasonic pulse velocity. The positions of longitudinal bars and ties were marked on several columns in building 3 and pulse-velocity readings were recorded at the cross-points of a 50 mm square grid drawn over the mid-height region of these columns. The pulse velocities tended to be either unaffected or slightly lower when longitudinal bars or ties lay directly in the pulse path. A possible explanation is that compaction of concrete around reinforcement may not be as effective in real columns. Regardless of the possible explanation, these conflicting results led to the decision to avoid having reinforcement directly in the path of the pulse. In almost all cases, this was accomplished simply by taking measurements through the centre of columns. However, in some cases, bar arrangement and column-tie configurations necessitated moving the point of measurement to one side of centre. Therefore it was concluded that only reinforcement which was badly out of place in columns which were not included in the bar location survey would have some effect upon the pulse velocity. It was anticipated that the precautions taken were effective in removing this aspect as a significant source of experimental error.

In Figure 2 the abscissa is incorrectly labelled and should read "PULSE VELOCITY RATIO". Then the 2% pulse velocity increase corresponds to the approximately 8% increase in strength at the bottom of columns as shown in Figure 1. This variation in concrete strength has been found for columns fabricated in the laboratory without reinforcement.

My interpretation of the trend toward lower strengths at higher floor levels certainly cannot be considered proved by the results presented. However, since an attempt was made to eliminate the influence of reinforcement upon pulse velocity, it is suggested that the identified trend should be expected because of the observed difficulty in providing proper curing at great heights. It is my understanding that stress history has little effect for low stresses. The only building which is likely to have been loaded to more than 25% of the concrete strength is the parking structure (building 6). At the time of testing, building 8, for instance, had remained empty for the 5 years since construction.

*DRYSDALE, R. G. Placement errors for reinforcing in concrete columns. (Accepted for publication in the *Journal of the American Concrete Institute*.)

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