

DEPARTMENT OF MATERIALS AND CONSTRUCTION

Sonoscope Applied to Maintenance of Concrete Structures

SIEGFRIED M. BREUNING, *Research Assistant*, and

A. J. BONE, *Associate Professor*

Joint Highway Research Project, Massachusetts Institute of Technology

THE sonoscope is an electronic device for the nondestructive testing of materials. The instrument measures the time delay of a shock wave sent through the material, from which the velocity of propagation of sound waves can be computed. This velocity represents a measure of the quality of the material.

Testing techniques for various types of structures are discussed. Tests on prestressed-concrete beams loaded to failure show a close correlation of sonoscope readings with the behavior of the beam. The influence of reinforcing steel is shown by tests on a reinforced bridge pier. The detection of cracks and deterioration in concrete are both demonstrated by tests of several bridge members. A graphical presentation of sonoscope results on a bridge pier is then discussed.

The results of these tests indicate that the sonoscope can be a valuable supplement to visual inspection.

● THE sonoscope, an electronic instrument for the nondestructive testing of concrete and other materials, was developed about 8 years ago. Since that time a number of units have been placed in operation in different countries.

The instrument operates by measuring the time delay of a sound wave passing through the material to be tested. An electrical impulse, generated in the control unit, is sent to a sending transducer head where it excites a block of crystals of rochelle salt. This block emits a wave of 20,000 cycles per second, which travels from the sending transducer through the material being tested to the receiving transducer. There the signal is reconverted into an electrical wave, which is then displayed on the face of the cathode-ray tube in the control unit. Provision is made for measuring the time delay between initiation and reception of the beginning of this wave. The path length between transducers divided by this time delay gives the average velocity of wave propagation in the

material being tested. The amplitude of the received wave may also be measured on the screen.

It has been established that there is a definite relationship between this average velocity and the quality of the concrete through which it passes.

Detailed information about the design of the instrument, its operation, and test results from its use have already been published extensively (*1*).

The Joint Highway Research Project at the Massachusetts Institute of Technology acquired a sonoscope in December of 1952. The objective has been to develop its usefulness to the project sponsors, the Massachusetts Department of Public Works, as a diagnostic tool for the maintenance of concrete structures. The first year's testing program has been spent largely in becoming familiar with the instrument, its operation, uses, and limitations; from this a number of ideas have been developed which form the substance of this paper. During the coming year it is expected that the

soniscope will be used to a greater extent for routine maintenance purposes.

A few aspects of some of the projects on which the soniscope has been used so far will be described. These bring out a number of ideas and findings that are felt to be new and perhaps useful to others working in this field.

LABORATORY TEST OF PRESTRESSED BEAMS

A series of prestressed-concrete beams which were tested to destruction by the Joint Highway Research Project as part of another study gave an excellent opportunity to observe their progressive failure with the soniscope.

The detection of cracks, which is one of the established uses of the soniscope, was the primary objective of these tests. To observe this, the path had to traverse that zone of the beam where the first cracks would appear. The path also had to be perpendicular to the cracks in order for them to affect the velocities. On the other hand, the path had to be short enough so that even a small crack would cause enough deviation to give a significant drop in velocity.

Figure 1 shows the dimensions of the beams and the arrangement of the transducers. At first, the transducers were applied to the beams by hand after each load increment had been added. This proved to be unsatisfactory. The inaccuracies of manual application are greater than some of the changes in beam characteristics that cause only minute changes in sound velocities. Uneven contact pressure proved to be the primary inaccuracy; slight changes in location and amount of contact lubricant were of secondary importance. The manual method also was dangerous for the operators in case of sudden failure of the beam. Later, transducers were strapped to the beams and remained in place throughout the tests. This procedure limits measurements to one path only, whereas it is sometimes desirable to study velocities along several paths for each load increment.

Figure 2 shows the results of a typical bending test under third-point loading. The bottom fiber of the beam had an initial compressive stress of 1,500 psi. due to prestressing. As load was applied this decreased, and at a total applied load of 3,800 lb., all initial compression was balanced by the tension caused by bending so that the bottom fiber was at zero stress. When further load was applied, tension developed in the concrete, eventually causing crack-

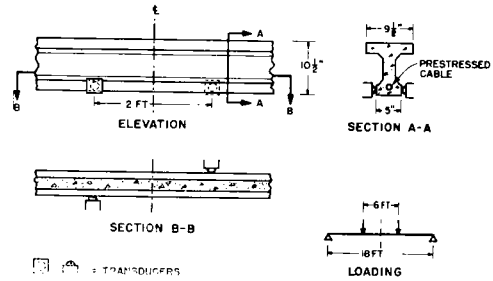


Figure 1. Location of transducers for test of prestressed-concrete beam.

ing. This stage was important, as it occurs just previous to failure. In practice it would be helpful to be able to detect when that is about to occur.

The reinforcing cable of this beam was located in the bottom flange and was unbonded. It was encased in cardboard tubing so that little chance exists that the steel might have influenced sound velocities. At 8,600 lb. of applied load there was danger of sudden failure of the beam and the transducers were removed.

The graph shows that velocity decreases slowly as the compression in the bottom flange is reduced. As the bottom flange changes to a state of tension velocity decreases more rapidly. This is readily explained by the behavior of concrete in tension. The bond between aggregate particles varies considerably, so that

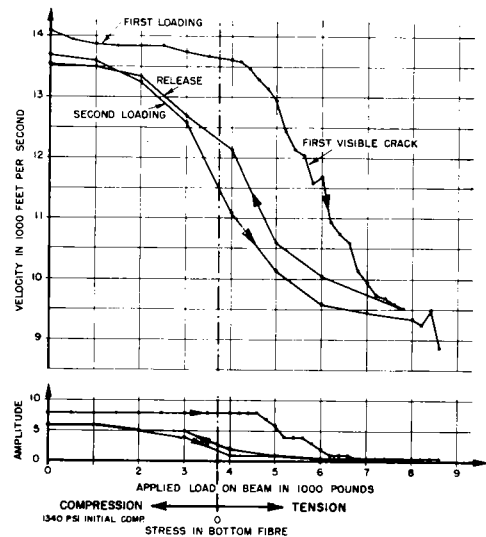


Figure 2. Prestressed beam in loading test.

at tensions much lower than failure minute cracks occur where the most-weakly bonded particles break apart. These are perpendicular to the stress and to the wave path in this case. The sound wave must detour all these minute cracks and thus traverses an increased path length, resulting in a decreased average velocity. Internal cracking continues at an increasing rate as tension in the bottom part of the beam is increased. Eventually a further load increment weakens the cross-section to such an extent that sudden failure occurs in the form of a continuous visible crack. This stage is shown on the graph by a rapid drop in velocity, which means a complete detour of the sound wave around the crack. After some additional cracking has occurred, the sound wave is deviated so much that its path length increases less and less with further cracking, which results in the curve of average velocities leveling off.

Release of applied load removes tension due to bending, the initial prestressing compresses the concrete again, and the cracks close. How successful the recovery of the concrete really is can be appreciated by the recovery of the soniscope velocities. As compression first occurs again in the zone previously subjected to tension, a fairly sudden increase in velocity takes place, probably caused by the decrease in path length when the sound again travels across the closed cracks. That the velocity never recovers its original value may be attributed to a certain amount of minute cracking which cannot be closed again. Upon reapplication of the load the velocity curve retraces the unloading curve as the cracks are reopened.

Amplitudes of the standing wave pattern are plotted on the lower part of the graph. These change coincidentally with changes in the average velocity.

The tests show that the velocities decrease rapidly as tension is applied to the concrete. This decrease is observed considerably before visible cracks appear. Since this occurs before failure, it might be a valuable tool for testing prestressed concrete.

The tests also indicate that velocities rise as compression is applied. This has also been observed in other tests. However, the variations are very small and it is doubtful that any use can be made of this information.

Another significant result of this investiga-

tion is the nearly complete recovery of soniscope velocities when the load is released. This indicates that the cracks are closed very tightly, which is one of the advantages of prestressing.

INFLUENCE OF REINFORCING STEEL

Soniscope velocities in reinforcing steel are in the vicinity of 17,000 ft. per sec., which is slightly higher than in good concrete, where velocities range from 13,000 to 15,000 ft. per sec. It is, therefore, possible that in testing along a path parallel to reinforcing steel the wave travels through the steel rather than through the concrete. Several test results have shown definitely the influence of the steel. Other tests, however, have not been affected by reinforcing. It is often difficult to determine how much the steel is influencing a particular test.

One example of a definite influence of steel was observed on a bridge pier in Williamstown, Massachusetts, where the depth of a horizontal crack caused by bending of the pier was to be determined. In this case the reinforcing steel carried the wave across the crack so that the distance between vertical reinforcing bars was determined rather than the depth of the crack.

To investigate this problem three series of velocity readings were run. Each consisted of a number of readings taken over parallel 2-foot paths spaced at 2 inches along the surface of the pier.

Figure 3 shows the first series, which was taken vertically from 1 foot above to 1 foot below the crack. The second series was taken directly opposite the first series on the back of the pier where there was no crack. The third series was run horizontally parallel to the crack. The latter two series gave questionable results, but the data obtained from the first series are very significant, as shown on the graph at the lower left of Figure 3. The amplitudes and velocities for each parallel reading are shown, as well as two theoretical curves which were computed for the two limiting cases of wave propagation through concrete and steel.

The upper of these curves gives the maximum apparent velocities if the wave is assumed to travel through the steel for an optimum distance. Obviously, the velocities are highest when the transducer locations are closest to the steel. The lower curve assumes

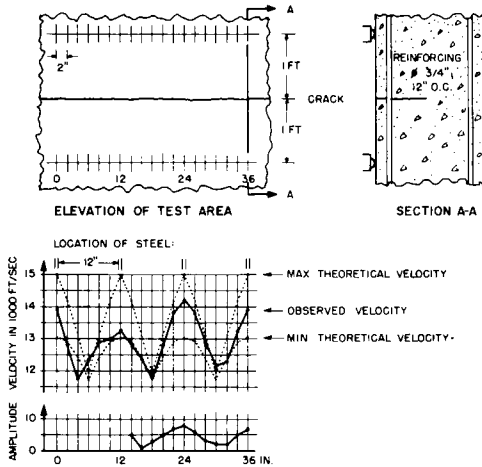


Figure 3. Influence of reinforcing steel.

that the wave does not travel in the steel, except just across the crack. This gives the minimum apparent velocities. Both theoretical curves have their maximum at the location of the steel and the velocities drop increasingly as the transducers move away from the steel. The curve of the actual velocities follows this same pattern.

The velocity curve agrees very well with the theoretical computations. The spacing of the steel bars indicated by the curve checks with that specified on the construction drawings. The location of the actual velocity curve between the two theoretical curves supports the theory that the actual distribution of wave travel is somewhere in between the theoretical extremes. It is definitely not the fastest possible path, which seems to indicate that the sound can transfer from concrete to steel and back only at points of good contact. This would explain the cases where no influence of steel was evident, even though the steel was entirely parallel to the wave path.

INVESTIGATION OF CRACKS AND DETERIORATION

Cracks and deteriorated concrete are two of the major problems to be met in the maintenance of concrete structures. Consequently this investigation has been directed primarily toward developing the soniscope as means of detecting their presence and defining their extent.

In testing a concrete structure by the normal

method of passing sound waves transversely through it, fairly accurate group velocities of wave propagation and a relatively dependable value of wave amplitude are usually obtained. These are often not sufficient, however. For example, these readings cannot indicate whether the wave has passed through two or more layers of concrete of differing velocities, such as will occur with surface deterioration. A low apparent velocity can also represent a change in actual path length, such as a detour around a crack, rather than a change in velocity caused by the material as a whole. Furthermore, a transverse crack, parallel to the direction of travel of the sound waves, will have no effect whatever on them, and the crack would therefore go undetected.

It was thus necessary to devise some means of securing additional test information that would help to solve these problems. This was done by taking readings on diagonal paths, as well as on the transverse paths normally used. This can usually be done without difficulty. The main disadvantage of this method is that two or three times as many readings must be taken. The results of the combined measurements, however, make possible a direct and more-positive interpretation of the data. Definite patterns are obtained for certain weaknesses in the material.

SURFACE DETERIORATION

Surface deterioration in concrete is a common occurrence and is detected easily by visual inspection. The condition of the center of the member is not evident, but it can be evaluated in accordance with the theory which follows.

Figure 4 shows both a transverse and a diagonal path through a concrete member. If the surface layers of this member are deteriorated, the velocity through them will be reduced.

The figure shows in simplified form the velocities in each layer and the average velocity; the latter is obtained from soniscope data. The velocities along the transverse path are plotted at the left. For the diagonal path which is plotted at the right, the higher velocity in the core of the member results in the fastest wave travelling along an S-shaped path. The distance travelled in the deteriorated surface layer with low velocity is shortened relative to the distance travelled in the center. Therefore,

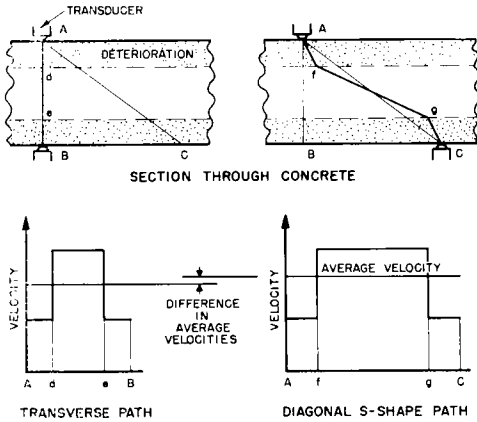


Figure 4. Comparative velocities of transverse and diagonal test paths for the detection of surface deterioration.

the average velocity obtained is higher than in the transverse path.

Typical data resulting from a study of surface deterioration are shown in Figure 5. A part of a concrete T-beam is shown. On the two horizontal Rows A and B, transverse and diagonal readings were taken, the latter at 2-foot

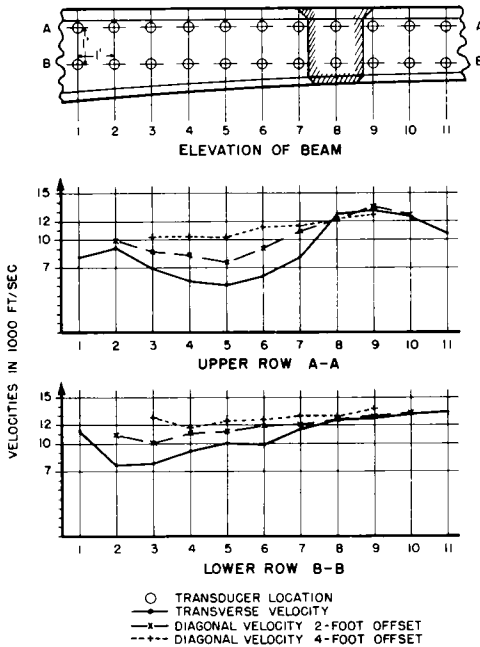


Figure 5. Typical data from a bridge beam showing surface deterioration.

and 4-foot horizontal offsets. The results for each row are plotted and illustrate the theory just outlined. The transverse velocities alone would suggest deterioration of the beam near the left end. Correlation of transverse and diagonal readings, however, indicates that deterioration has not progressed throughout the material, since the drop in average velocity on the diagonal is less than on the transverse path. This is especially evident for the diagonals with 4-foot offsets.

These T-beams contain reinforcing steel which might carry the wave and take the place of the assumed core of higher velocity. At the present state of this investigation this possibility cannot be definitely ruled out, although all the evidence seems to indicate that the reinforcing steel does not influence the velocities.

TRANSVERSE CRACKS AND DETERIORATION

If a crack is present in a transverse direction it will have little influence on the transverse velocity readings. Diagonal signals, however, must travel through or around the transverse obstruction. This is reflected by a decrease in average velocity.

A typical example is shown in Figure 6, a horizontal section through part of the concrete cap of a bridge pier. The test paths are indi-

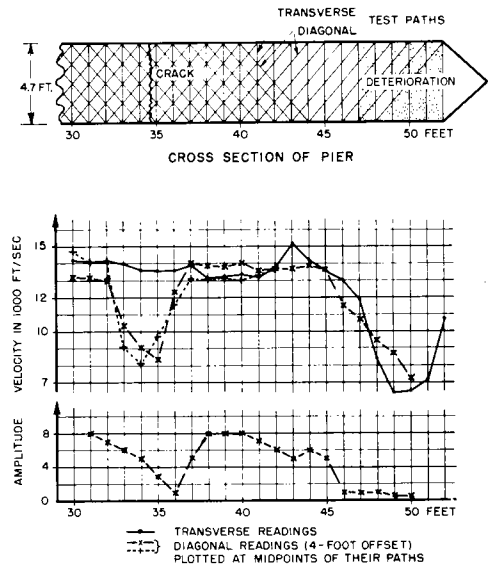


Figure 6. Typical data from a bridge pier showing a transverse crack and transverse deterioration.

cated, and the observed velocities are plotted below their midpoints. A transverse crack near the 35-foot mark appears to have no influence on the transverse readings but has marked effect on the diagonal ones.

At the end of the pier there is a transverse area of deterioration which is also reflected clearly in the comparison of transverse and diagonal readings. As the transducers were moved into this area the transverse velocities dropped fairly rapidly. Diagonal readings extend 2 feet to either side of the location where they are recorded. They are affected, therefore, by the deteriorated area somewhat more gradually than are the transverse readings. The fact that some of the diagonal velocities are almost as low as the adjacent transverse ones apparently indicates that deterioration is present throughout the depth of the pier.

Visual inspection confirms these test results. A deteriorated area can plainly be observed where the pier protrudes from under the bridge. At this place moisture and rainwater collect between the superstructure and the cap causing the defect.

EVALUATION OF A BRIDGE PIER

The data discussed previously refers to only a small part of the total investigation carried out on a concrete highway bridge over a tidal river in Amesbury, Massachusetts. The piers of this bridge are faced with granite blocks except on the caps. Figure 7 shows the results on a typical pier. Velocities at all points where readings were recorded are shown graphically by dots. The magnitude of each reading is shown by the size of the dot, large dots representing low velocities. The dark areas indicate at a glance where the pier is defective. Cross marks represent test spots where no wave could be received. Transverse readings are shown in the top diagram, while the lower diagrams give horizontal diagonal velocities in two directions.

The interpretation of the velocity data is somewhat hypothetical. Some of the data shown do not fit any of the patterns discussed in this paper. However, other valuable information can be drawn from the data to give a fairly detailed picture of the condition of the pier.

The points where no reception was possible can be evaluated only by extrapolating trends indicated by adjacent velocities. If high ve-

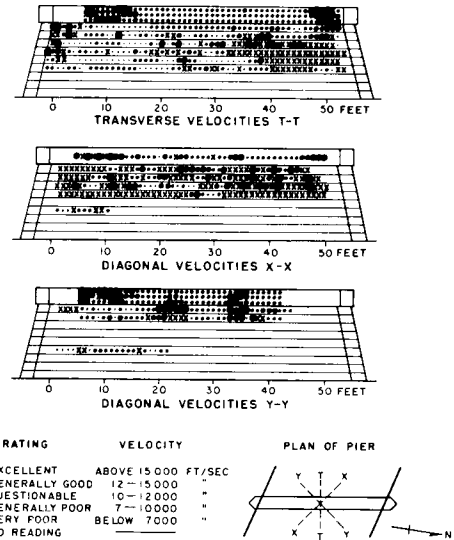


Figure 7. Graphical summary of soniscope velocities at a bridge pier.

locities prevail in the surrounding area, it is likely that a relatively thin weak area exists. This might be explained, in this case, by loss of bond between the concrete core and the granite facing. If low velocities prevail, deterioration is likely to be present.

The cap seems to be of fairly uniform quality, except at the ends (where extensive deterioration exists). Two vertical transverse cracks near the 23- and 34-foot marks are detected by the diagonal readings. It seems that in lower layers deterioration starts in the vicinity of these cracks. At the right end of the pier very few velocities could be observed, which is probably due to advanced deterioration or complete loss of bond between the facing and the core. This area extends towards the left at an elevation about halfway between the high- and low-tide levels.

The soniscope velocities indicate a general pattern of deterioration which agrees well with those found on similar bridge piers. Since the granite facing on the lower parts of the pier was in good condition, the defects indicated by the soniscope could not be anticipated by visual inspection.

CONCLUSIONS

The research discussed in this paper has been directed towards developing techniques

for routine testing with the soniscope. Problems encountered in practical testing have furnished the basis for the detailed investigations. From these, theories have been proposed to explain certain of the results. Many defects can be correlated with definite patterns of velocity and amplitude readings. Before these theories can be regarded as conclusive, confirmation by further field tests and controlled laboratory investigations is required.

The work discussed in this paper indicates the following conclusions:

1. Soniscope velocities increase slightly as compression increases.
2. Soniscope velocities decrease rapidly as tension increases, even before visible cracking occurs.
3. In some cases, reinforcing steel has a definite influence on the velocities. In other cases, it apparently has no influence. It is difficult to determine to what extent the steel influences the velocities in a particular test.
4. A combination of transverse and diagonal test paths gives detailed information about many of the defects in concrete. In most cases, the additional time needed to collect this data is justified.
5. Definite patterns of velocities along transverse and diagonal paths have been found for several defects. Among these are surface deterioration, transverse cracks, and transverse deterioration.
6. It is probable that patterns of velocities for other types of defects will be established as more experience is gained. This will greatly simplify the selection of test locations and permit more detailed interpretation of the test results.

The results obtained with the soniscope to date indicate that it has a definite potential value as a routine testing instrument.

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