FINAL REPORT

DETERMINING WATER CONTENT OF FRESH CONCRETE BY MICROWAVE REFLECTION OR TRANSMISSION MEASUREMENT

By

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Virginia Transportation Research Council
(A Cooperative Organization Sponsored Jointly by the Virginia Department of Transportation and the University of Virginia)

In Cooperation with the U. S. Department of Transportation
Federal Highway Administration

Charlottesville, Virginia

August 1987
VTRC 88-R3

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ABSTRACT

In search of a rapid and accurate method for determining the water content of fresh concrete mixes, the microwave reflection and transmission properties of fresh concrete mixes were studied to determine the extent of correlation between each of these properties and water content. This report describes the procedures that were devised to measure these properties and the results that were obtained.

The results indicated that the microwave reflectivity and transmission of fresh concrete mixes are both sufficiently correlated to water content. Since these properties can be measured very rapidly without any pretreatment of the fresh concrete samples, microwave reflectivity or transmission measurement has the potential to be a rapid, nondestructive, and reasonably accurate quality-assurance method for measuring the water content of fresh concrete mixes, especially for a large capacity ready-mix plant. Although it is slightly more elaborate than reflectivity measurement, it is believed that transmission measurement may yield a more precise and accurate method.

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INTRODUCTION

The amount of water and cement present in a concrete mix greatly affects the physical characteristics of the concrete. Distress in hardened concrete is frequently the result of excessive water or inadequate cement content. Recent studies on the corrosion of reinforcing steel in concrete have revealed that in addition to providing a beneficial effect on the strength of hardened concrete, a low water-cement ratio also ensures a long service life for reinforced concrete structures exposed to deicing salts.

Consistent maintenance of proper water and cement content during the batching operations is very important. However, it hasn't been possible to ensure that only concrete meeting specified water and cement content is placed in a structure. This is because the latest methods for determining the water and/or cement content of fresh concrete are not sufficiently rapid, although their accuracy might be considered reasonable. According to a recent evaluation of these latest methods, a modified Kelly-Vail method appeared to be capable of yielding cement content with accuracy of ± 28 lb/yd^3 and water-cement ratio within 0.020 (1). However, it requires at least 15 minutes to use this method. Water content can also be determined simply by the microwave-oven drying method, whereby a sample of fresh concrete mix is heated in a microwave oven for about 30 minutes to remove the water. The reported accuracy of this method is within 0.0003 m^3 of water per sack of cement, or water-cement ratio of ± 0.005 at 95% confidence level (1).

In search of a truly rapid and yet reasonably accurate method for determining the water content of fresh concrete mixes, the microwave reflection and transmission properties of fresh concrete mixes were studied to determine the extent of correlation between each of these properties and water content. This report describes the procedures that were devised to measure these properties and the results that were obtained.

EXPERIMENTAL PROCEDURES

Measurement of Microwave Reflection

The setup used for measuring the reflection of microwave pulses from the surface of a layer of fresh concrete mix is illustrated in Figure 1. After a fresh batch of concrete was uniformly mixed in accordance with ASTM C192, it was poured into a wooden box that measured 20-in wide by 20-in long by 2-in deep. The mix was trowelled until its surface was reasonably flat. A microwave transducer, which serves both as a transmitter and a receiver of microwave pulses, was then centered 12 inches above the surface of the mix. An open-ended 12-in high box made of 1-in thick styrofoam was found to be a convenient means of supporting the transducer over the concrete mix, since the material is transparent to microwave pulses and would therefore not cause any complicating reflection. Then the amplitude of the microwave pulses reflected from the surface of this fresh concrete mix (AS) was measured and recorded with an oscillographic recorder. Figure 2a shows a typical recorded waveform that was composed of AS and other relevant reflections reaching back to the transducer.

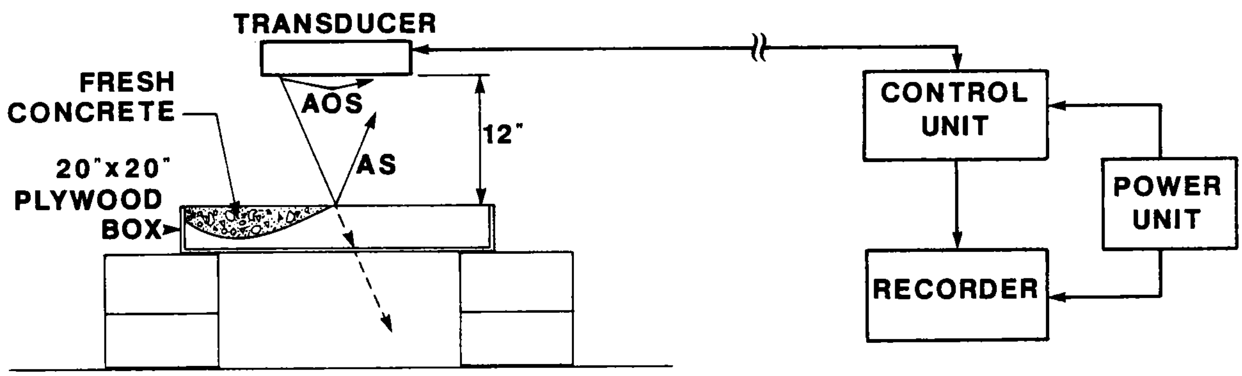
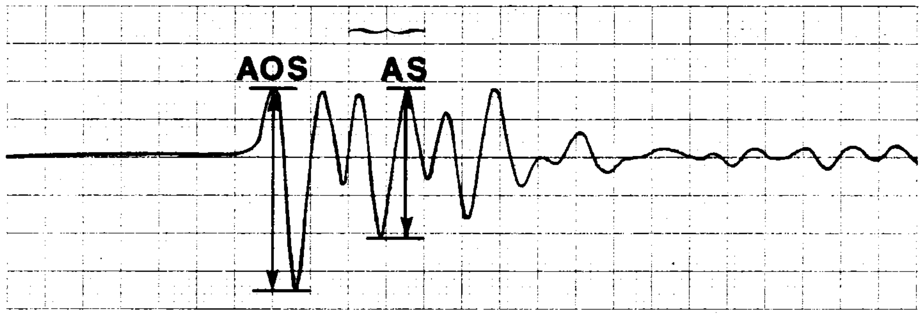
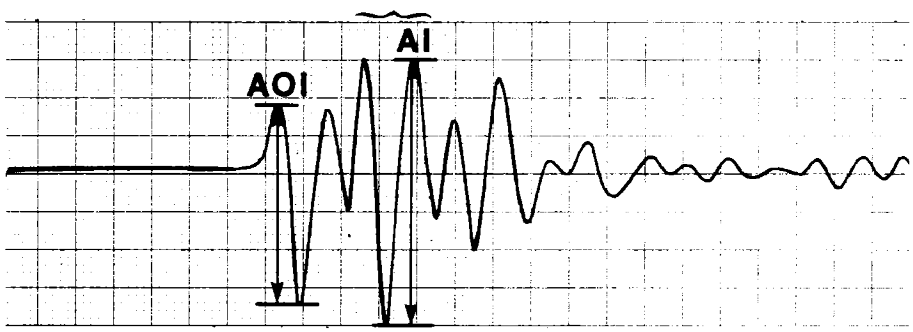


Figure 1. Measurement of the reflection of microwave pulses from the surface of a layer of fresh concrete mix.

To measure the amplitude of the initial microwave pulses striking the surface of the concrete mix (AI), a piece of aluminum plate that measured 20 in x 20 in was then placed on the surface of the concrete mix. This caused all the microwave pulses that would otherwise strike the surface of the mix to be reflected back to the transducer, since the metal is practically a perfect reflector. Afterward, AI was similarly recorded with the oscillographic recorder (an example of this waveform is shown in Figure 2b). Figure 3 illustrates the setup for measuring AI.



(a)



(b)

Figure 2. Waveforms of reflections from: (a) a fresh concrete mix (AS), and (b) an aluminum plate resting on top of the concrete mix (AI).

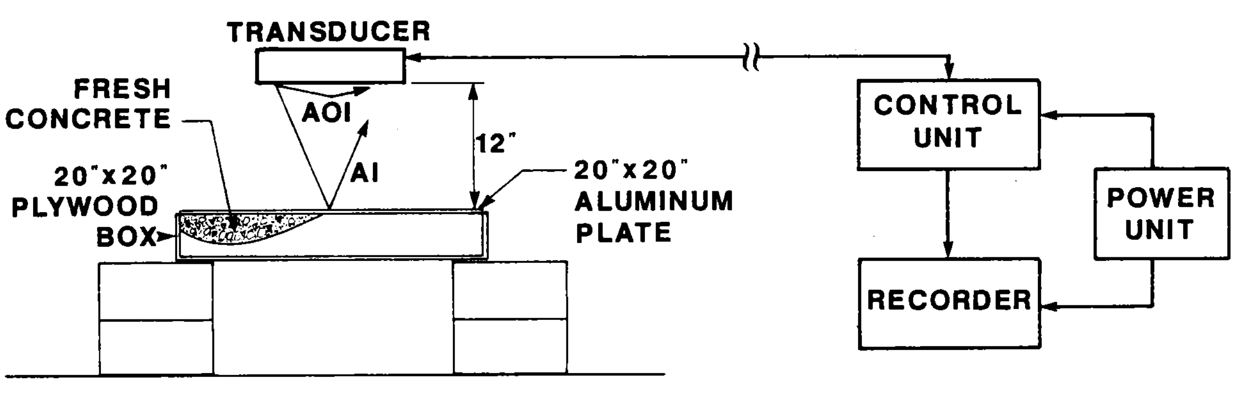


Figure 3. Measurement of the amplitude of initial microwave pulses striking the surface of the concrete mix.

The microwave reflection property of this fresh concrete mix was then expressed in terms of its reflectivity (ρ), which was defined as

$$\rho = (AS \times AOI)/(AI \times AOS) \qquad (1)$$

where AOS and AOI are the radar signals traveling through air from the transmitting to the receiving antenna during the measurements of AS and AI, respectively.

Measurement of Microwave Transmission

Figure 4 illustrates the setup devised for measuring microwave transmission through a layer of fresh concrete mix. Two identical transducers were used. These transducers generate microwave pulses with a width of 1.1 nanosecond, and a central frequency of 900 Mhz. Each transducer consists of both transmitting and receiving antennas, and therefore normally operates as a transmitter and receiver, as in the setup for measuring reflection. However, during the measurement of transmission, an electronic breakout box was used to enable one transducer to function only as a transmitter while the other functioned only as a receiver.

The procedure consisted of transferring a sufficient amount of a freshly mixed concrete into the wooden box, which was centered over the receiving transducer. The concrete was then consolidated as thoroughly and as quickly as possible with an electric vibrator before it was finished with a trowel so that its surface was reasonably flat and flush with the top of the box. Afterward, the transmitting transducer was centered over the mix and directly aligned with the receiving transducer. Figure 5 shows a typical recorded waveform of microwave pulses (AT) that were transmitted through a layer of concrete mix and had reached the receiver.

The transmission property of the fresh concrete mix was then expressed in terms of a quantity (T), which is defined as

$$T = AT / AI \qquad (2)$$

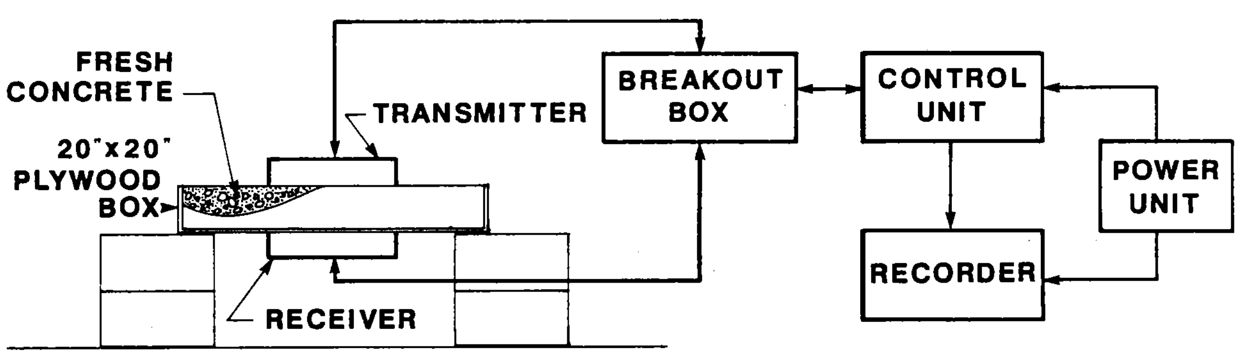


Figure 4. Measurement of transmission through a layer of freshly mixed concrete.

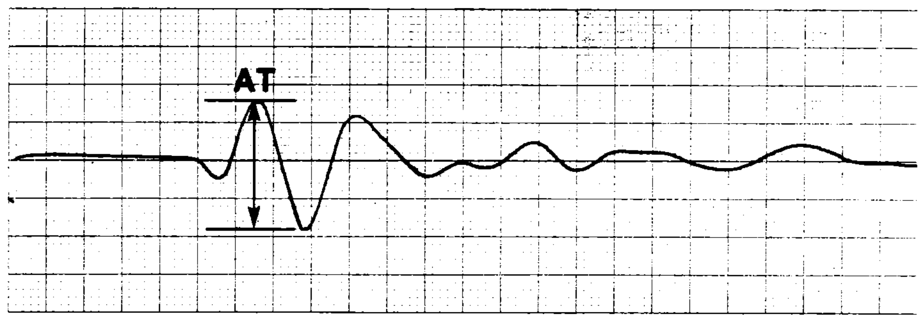


Figure 5. Waveform of transmission through a layer of fresh concrete mix.

RESULTS AND DISCUSSION

Microwave Reflectivity Measurements of Fresh Concrete Mixes

The second wavelet (AS) in Figure 2a is the reflection from the surface of a concrete mix. Its measured peak-to-peak amplitude can deviate from its true value due to instrument drift. Instrument drift, which varies from time to time, can also affect the measured peak-to-peak amplitude of the reflection from the aluminum plate (AI). Instrument drift was corrected for by including AOS and AOI, which are the first wavelets in Figures 2a and 2b, respectively, in equation 1. In the absence of any instrument drift, the amplitudes of these wavelets should be equal and constant since they are the radar signals travelling through the air from the transmitting to the receiving antenna.

Before the amplitudes of wavelets AOI and AOS could be used in equation 1, these wavelets had to be properly resolved from their respective neighboring wavelets, which according to Figures 2a and 2b happened to be wavelets AI and AS. This necessary resolution was achieved by placing the transducer at an appropriate distance from the aluminum plate (or the surface of a fresh concrete mix) so that AOI and AI (or AOS and AS) would arrive at the receiving antenna with sufficient separation in time to avoid overlapping. That distance happens to be dependent on the pulse width of the transducer, and can be easily determined by varying the distance between the transducer and the surface of a concrete mix and observing how the resolution of AOS and AS is affected. Figure 6 shows some recorded waveforms that corresponded to various transducer distances. These waveforms indicated that, at any distance less than 12 in, wavelets AOS and AS would arrive too close together at the receiving antenna and therefore would interfere with each other. At 12 in, there appeared to be sufficient separation between these wavelets to allow measurement of their amplitudes with minimum interference. Thus, the distance between the transducer and the concrete mix (or the aluminum plate) in the setups for the measurement of reflection was set at 12 in.

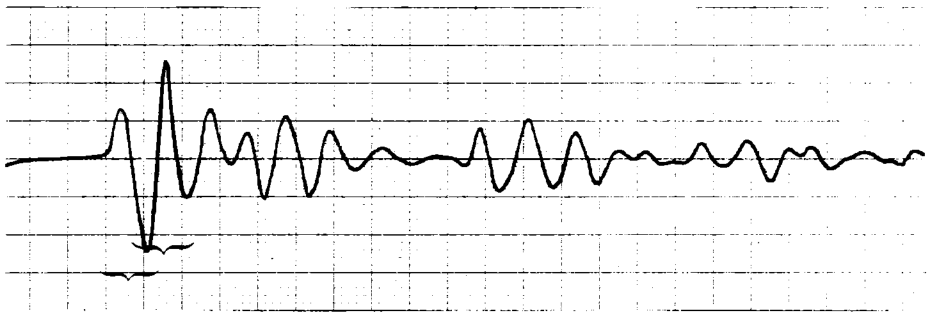
The first series of reflection measurements was conducted on a series of four concrete mixes made from a Type II cement, a coarse granite aggregate and a siliceous sand, at W/C's of 0.45, 0.50, 0.55, and 0.60. The amount of cement and aggregate used was kept uniform: a fine aggregate-coarse aggregate ratio of 0.690 ± 0.010 and a cement-aggregates ratio of 0.210 ± 0.006, was maintained for each of the four mixes. For each mix, four different batches were made. Excluding the transfer of a concrete mix from the mixer to the wooden sample box, the actual time required to make the measurement was usually less than 30 seconds. The precision associated with each individual measurement is estimated to be approximately ± 0.009.

When the average reflectivity of each mix was plotted against its W/C, as shown in Figure 7, it is evident that there was a reasonably good linear correlation between these parameters. For the next series of mixes, which was identical to the first series except that an air-entraining agent and a water reducer were added in a dosage suggested by their respective manufacturer, similar correlation between these parameters was also observed (see Figure 8). This relationship appeared to be significantly different from the former one, indicating the existence of influence by the admixtures on the reflectivity of the mix.

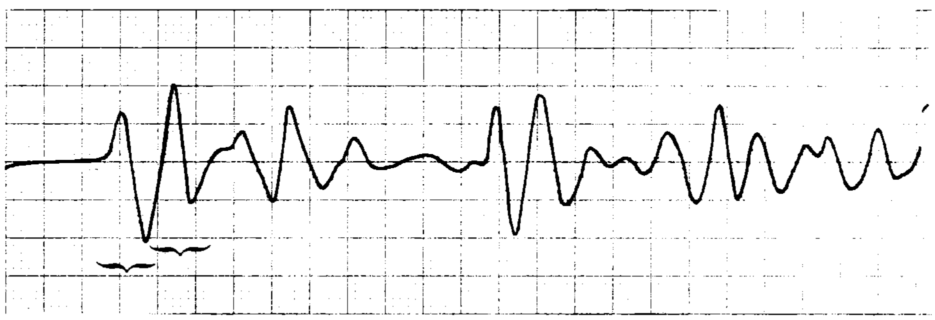
When a Type III cement was used in a third series of concrete mixes, still another correlation between reflectivity and W/C was obtained (see Figure 9). When the coarse granite aggregate was replaced by a coarse dolomite aggregate, another correlation was obtained (see Figure 10).

These results indicate that the type of cement and aggregates used may also influence the reflectivity-vs-W/C relationship. Although only one air-entraining agent and one water reducer were used, it is possible that the types of these admixtures may also influence the relationship. Consequently, before this relationship can be applied in a quality-control procedure, at a ready-mix plant or a construction site, a calibration curve appropriate for the materials to be used would have to be established.

When this relationship between W/C and reflectivity is used as a calibration line in quality-control procedures for determining the W/C of fresh concrete mixes, the attainable precision may well be no worse than ± 0.011, based on the precision in the measurement of reflectivity and the slopes (or sensitivities) of the different linear relationships that were observed (see Table 1).



6 In.



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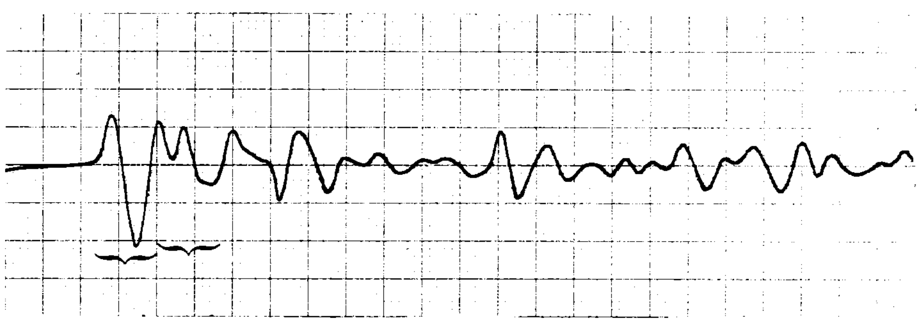
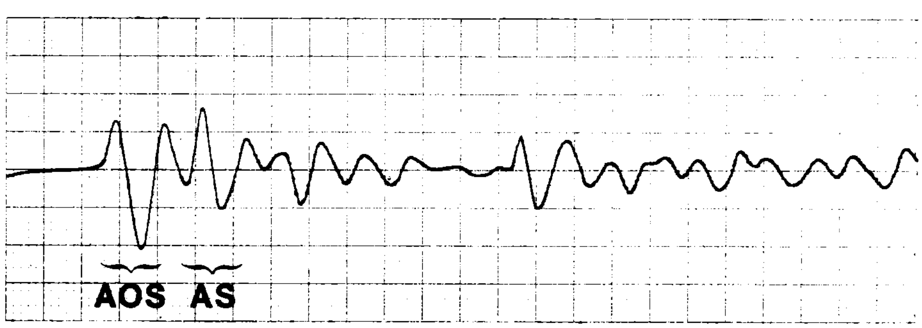


10 In.



12 In.

Figure 6. Reflection waveforms with transducer at various distances from a concrete mix.

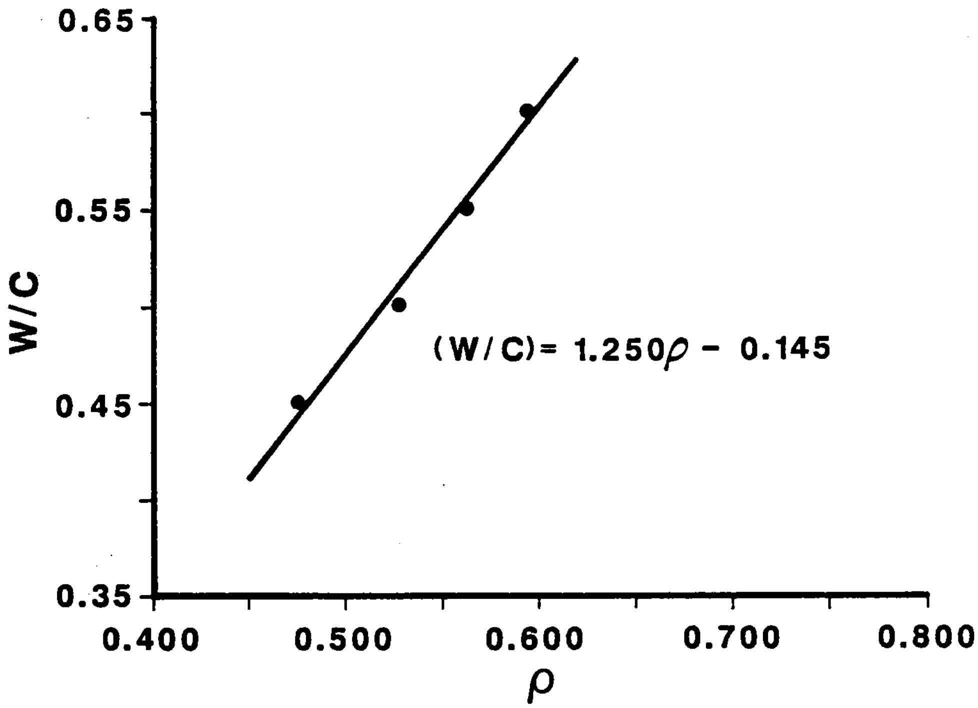


Figure 7. Relationship between reflectivity and water-cement ratio for concrete mixes (containing Type II cement, and coarse granite aggregate).

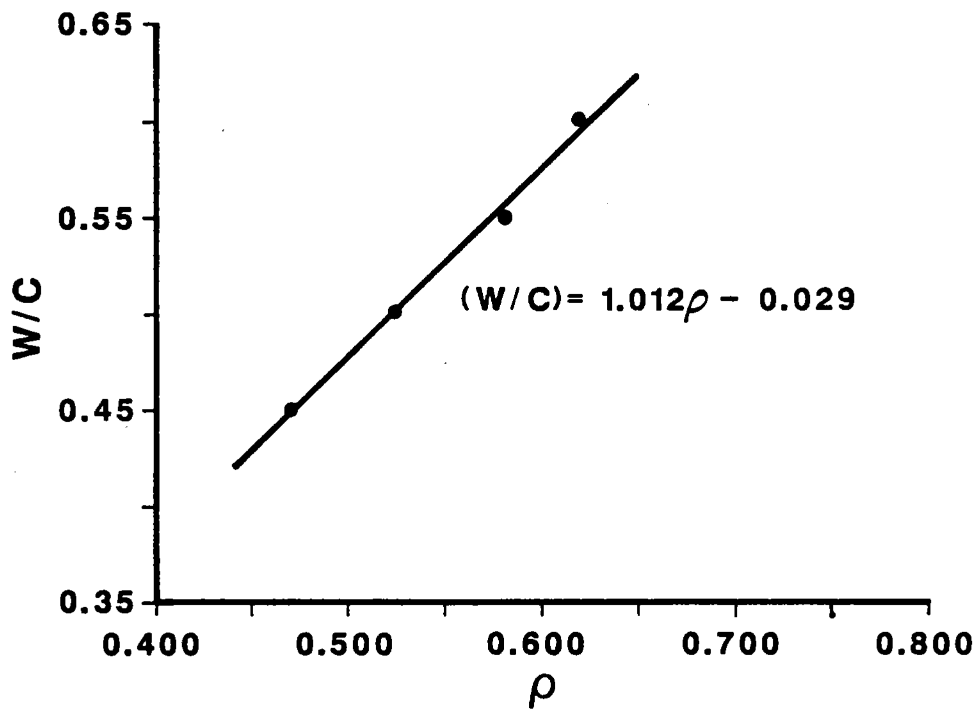


Figure 8. Relationship between reflectivity and water-cement ratio for concrete mixes (containing Type II cement, coarse granite aggregate, AEA, and WR).

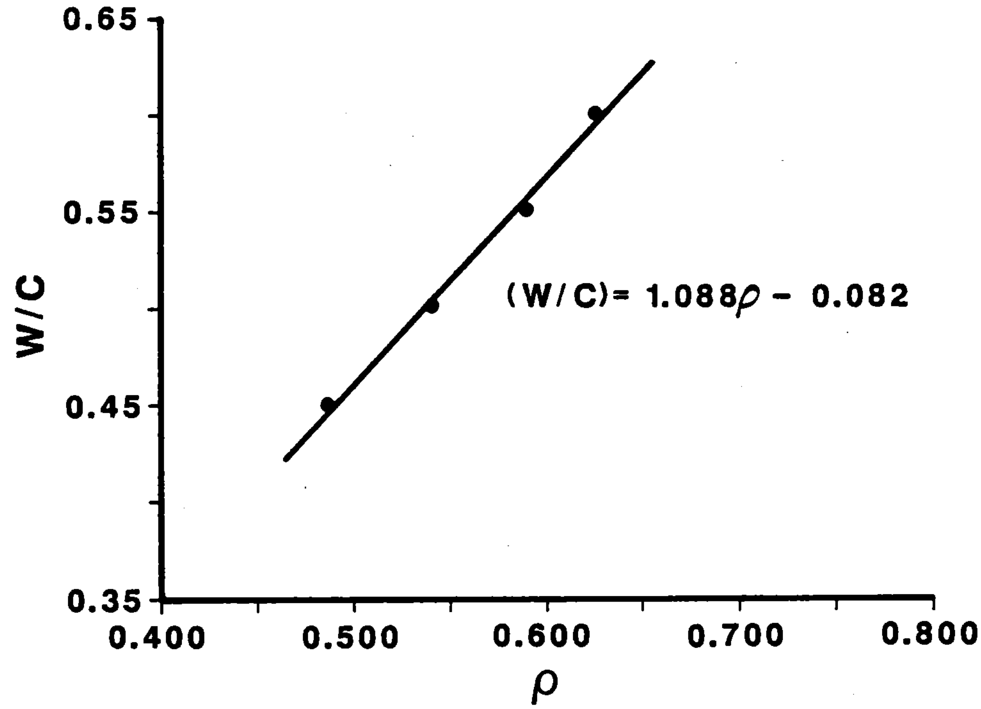


Figure 9. Relationship between reflectivity and water-cement ratio for concrete mixes (containing Type III cement, coarse granite aggregate, AEA, and WR).

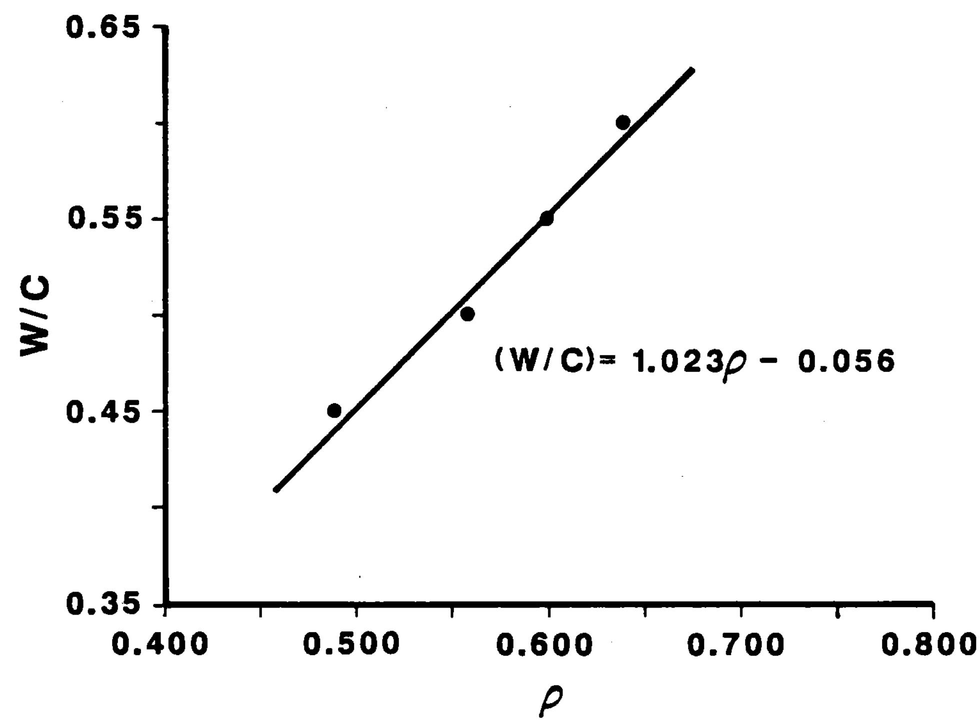


Figure 10. Relationship between reflectivity and water-cement ratio for concrete mixes (containing Type III cement, coarse dolomite aggregate, AEA, and WR).

Table 1

Precision Associated with the Procedure for the Measurement of Reflectivity and the Calculated Water-Cement Ratio

Concrete Mix Materials	d(W/C)/d(ρ)		Precision in the Measurement of Reflectivity		W/C
Type II cement; granite	1.250	x	±0.009	=	±0.011
Type II cement; granite; AEA; WR	1.012	x	±0.009	=	±0.009
Type III cement; granite; AEA; WR	1.088	x	±0.009	=	±0.010
Type III cement; dolomite; AEA; WR	1.023	x	±0.009	=	±0.009

However, based on an analysis of the regression equations given in Figures 7 - 10, the accuracy of the predicted (or calculated) W/C could be as low as ± 0.038, at 95% confidence level, which is allowed by the procedure used (see Table 2). Of course, this degree of accuracy doesn't compare favorably to that reported for the slower microwave-oven method and the modified Kelly-Vail method. It is believed that the procedure can be modified to improve the accuracy sufficiently so that when the relative ease and speed with which reflectivity measurement can be performed is also taken into consideration and compared with the latest methods, this approach for determining the water content of concrete mix may prove to be advantageous to use.

Table 2

Accuracy of Calculated Water-Cement Ratio, From Measured Reflectivity

Concrete Mix Materials	Std. Error of Estimate of W/C (Calculated)	95% Confidence[2] Interval
Type II cement; granite	0.0118	±0.034
Type II cement; granite; AEA; WR	0.0082	±0.024
Type III cement; granite; AEA; WR	0.0080	±0.023
Type III cement; dolomite; AEA; WR	0.0132	±0.038

Although the setup devised for measuring reflectivity in this investigation utilizes a relatively shallow wooden box for containing a sample of a concrete mix, for an actual quality-control application of this procedure, a setup more appropriate to the particular situation involved may be devised. For example, in a large capacity ready-mix plant, the procedure could conceivably be setup in such a manner that the reflectivity of a freshly mixed concrete could be measured automatically along a production line. Of course, it must be emphasized that a calibration curve that is representative of the materials being used must be established first.

Microwave Transmission Measurements of Fresh Concrete Mixes

The first series of transmission measurements was conducted on four concrete mixes made from the same Type II cement, coarse granite aggregate, and sand that were used earlier in the reflection measurements, and at the same four W/C's. The same air-entraining agent and water reducer were used too. Again, for each of the four design mixes, four different batches were prepared. As in the measurement of reflectivity, the actual measurement of transmission usually required less than 30 seconds. The precision associated with the measured transmissions was approximately ± 0.009.

The results for this series of measurements are plotted in Figure 11. It is evident that there is an inverse linear relationship between the known W/C and the measured transmission.

Figure 12 shows the results obtained in another series of measurements, which was made on concrete mixes that were made instead with the same coarse dolomite aggregate used earlier. Again, the existence of an inverse linear relationship between W/C and transmission is demonstrated. However, this relationship is slightly different from that observed for the mixes containing the granite aggregate. This apparent dependence of transmission-vs-W/C relationship on the mix material used is consistent with the observed dependence of the reflectivity-vs-W/C relationship on the mix materials. The relatively lower transmission for mixes with the dolomite aggregate by comparison with the transmission for mixes with the granite aggregate is also consistent with the comparatively lower reflectivity for the latter mixes.

It must be noted that in this mode of measurement, it is relatively important for the transmitting transducer to be properly aligned with the receiving transducer, and the alignment should remain constant. Any slight shift in this alignment between two consecutive measurements of the same concrete mix would result in large deviation in the measured transmission of a concrete mix.

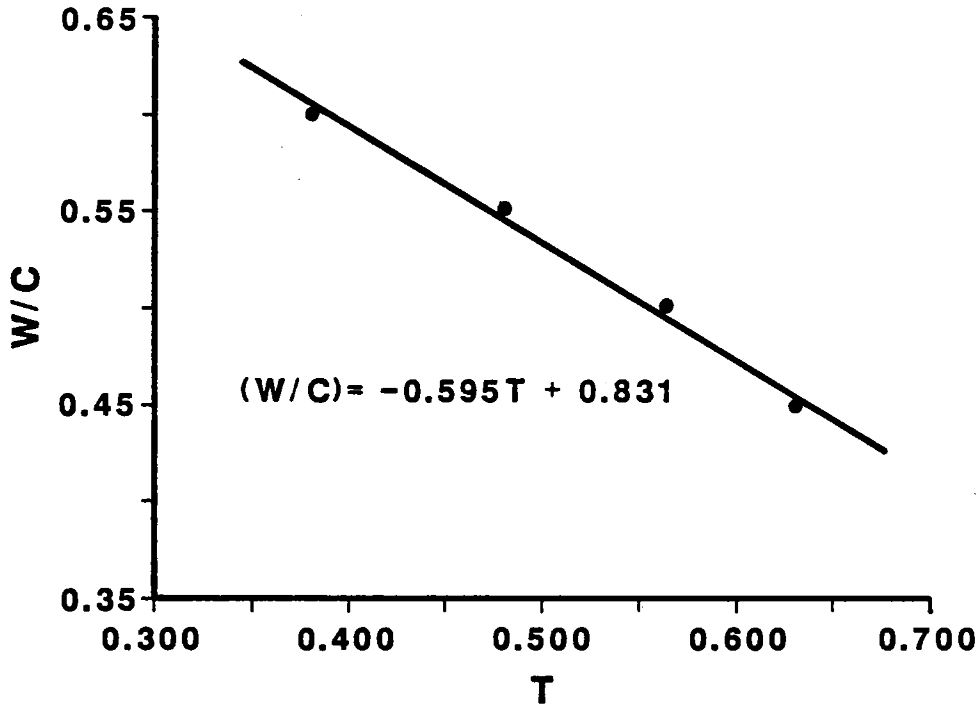


Figure 11. Relationship between transmission and water-cement ratio for concrete mixes (containing Type II cement, granite coarse aggregate, AEA, and WR).

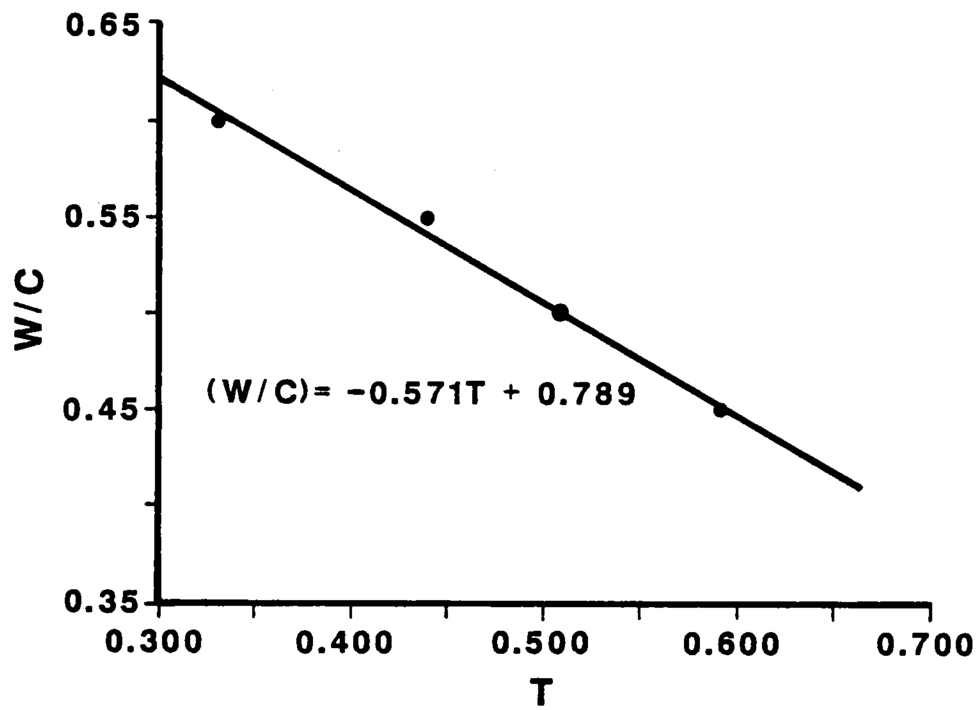


Figure 12. Relationship between transmission and water-cement ratio for concrete mixes (containing Type II cement, dolomite coarse aggregates, AEA, and WR).

When the curves in Figures 11 and 12 are used to determine the W/C of concrete mixes made from the respective set of materials for which the curves were derived, the predicted W/C would have precision of ± 0.005 (see Table 3). The accuracy resulting from the procedure (and setup) used in this study should be approximately ± 0.024 of the W/C, at 95% confidence level (see Table 4). Even though this accuracy is not yet comparable to that of the microwave-oven drying method, it was at least equal to that of the modified Kelly-Vail method. Furthermore, this procedure can be readily modified to yield a significantly better accuracy.

In comparison with the precision and accuracy associated with reflection measurements (Tables 1 and 2), that associated with the transmission measurements appeared to be better. Therefore, it would appear that a new test procedure for determining water content of fresh concrete mixes that is based on transmission measurements is likely to yield more precise and accurate results than one based on reflection measurements.

Table 3

Precision Associated with the Procedure for the Measurement of Transmission and the Calculated Water-Cement Ratio

Concrete Mix Materials	d(W/C)/d(T)		Precision in the Measurement of Transmission		Precision in the Measurement of W/C
Type II cement; granite; AEA; WR	0.595	x	± 0.009	=	± 0.005
Type II cement; dolomite; AEA; WR	0.571	x	± 0.009	=	± 0.005

Table 4

Accuracy of Calculated Water-Cement Ratio, From Measured Transmission

Concrete Mix Materials	Std. Error of Estimate of W/C (Calculated)	95% Confidence Interval
Type II cement; granite; AEA; WR	0.0078	± 0.023
Type II cement; dolomite; AEA; WR	0.0083	± 0.024

CONCLUSIONS

1. The microwave reflectivity and transmission of fresh concrete mixes are both linearly related to W/C. However, it is apparent that these relationships may be affected to some extent by the type of cement, aggregate, and admixtures used. Therefore, if either reflectivity or transmission measurement is to be used as an indirect way of determining the water content of fresh concrete mixes in a quality-assurance procedure, a calibration curve suitable for the materials to be used should be established first.

2. In all the mixes used in this investigation, the quantity of cement and aggregate used was kept constant. In a mixing plant, it is likely not to be that simple, since these quantities will almost certainly vary. However, because the relative dielectric constant of water is an order of magnitude larger than that of the other ingredients of a typical concrete mix, it is likely that within the normal ranges of concentrations within which these other materials are normally used, water content may be the dominating factor in these relationships, and reasonable fluctuation in any of these concentrations may have only an insignificant effect. Nevertheless, further study is needed to confirm this point.

3. Reflectivity measurement is reasonably straightforward and rapid. Although the procedure used in this study didn't yield acceptable accuracy, in comparison with those reported for the latest methods, the procedure can be improved.

4. Transmission measurement is also reasonably simple and rapid. The procedure used yielded accuracy that appeared to be at least equal to that of the modified Kelly-Vail method. More important though, improvement can be made readily to this approach for determining the water content of fresh concrete.

5. Both reflectivity and transmission measurements showed a potential for fulfilling the need for a rapid and reasonably accurate method for determining the water content of fresh concrete mixes. Both procedures are amenable to automation for use in large-scale mixing plants.

6. A procedure based on transmission measurement is likely to yield a more precise and accurate method than based on reflectivity measurement.

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