콘크리트에서의 One-Sided 응력파 속도 측정 기법의 적용에 관한 연구

Application of Advanced One-sided Stress Wave Velocity Measurement in Concrete

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Abstract

In this study, the advanced one-sided stress wave velocity measurement method was applied to investigate the effects of composition, age and moisture content in concrete. Two concrete specimens that have different composition were used to figure out the change of the Longitudinal and Surface wave velocity due to different composition. The other concrete specimen was cast and the Longitudinal and Surface wave velocity was monitored during curing process. After 28-day old, the effect of moisture content in the concrete specimen to the stress wave velocity is presented in this paper during the time period 43-74 days after casting. For drying process, an aggregate drying oven was used. A conventional ultrasonic through transmission method was used to compare with the results determined by the one-sided method.

Keywords : Concrete, One-sided velocity measurement, Longitudinal wave, Surface wave, Composition, Moisture content, Age

1. Introduction

The stress wave velocities on materials depend on their own material properties, such as Young's modulus. Therefore, the stress waves propagate at different velocities through

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concretes which have different composition. Additionally, material properties in concrete can be back-calculated by the accurate stress wave velocity measurement. During curing process in concrete (less than 28 days after casting) chemical reaction inside concrete takes place. Thus, concrete properties shows apparent change during the time period of curing. In this study, the change of the Longitudinal(L-) and Surface(R-) wave velocities during curing process(for 28 days after casting) were monitored with the advanced one-sided stress wave velocity measurement method. It is also known that when concrete contains moisture, the stress wave velocity increases in concrete than when concrete is absolutely dried.[1] During drying process, There is a moisture gradient within concrete specimen: the surface area of the specimen has lower moisture content than the center area. Since the result with the advanced one-sided stress wave velocity measurement is affected only by the surface area of concrete, it is expected that there is discrepancy between velocities obtained by this one-sided method and those obtained by the conventional methods, such as through transmission pulse velocity method. The objective of thes study is establish the relationship in concrete between the stress wave velocities and composition, age, and moisture content.

2. Experimental Procedure

In this study all experiments were perform on the exact same condition as in "Development of Advanced One-sided Stress Wave Velocity Measurement in concrete". The spacing between the impact point and the receiver closer the impact point and two receivers is 50mm, respectively. On each specimen, the velocity measurements were performed 10 times. The average value of 10 measured velocities on the specimen was considered as the stress wave velocity of the concrete specimen. In order to verify the velocities measured with this one-sided method, through transmission pulse velocity method was used to corroborate the L-wave velocity of all specimens, as described in ASTM C597.[2] For each specimen, the stress wave velocities with the trough transmission pulse velocity method were measured on 5 test locations. The average value of 5 measured velocities on each test point was considered as the stress wave velocity for verification. The L-wave velocities measured by the one-sided method and the through transmission method are shown as $V_{L,o}$ and $V_{L,v}$, respectively. Consistency of the test was determined from the variability of the repeated tests as measured by the coefficient of variation of the sample.

3. Test Specimen

All concretes were comprised of Type I portland cement, well graded washed sand, and pea gravel with a maximum size of 9.5mm. Concrete specimen C2 also contained

Table 1 Test specimen description

Name	Dimensions (cm)			Composition	Test age	f_c'
	length	width	thickness	(c:w:fa:ca)	(days)	(Mpa)
C1	10.2	22.9	5.2	1 : 0.5 : 2.0 : 2.0	158	33.6
C2	10.2	22.9	5.2	1 : 0.18 : 1.12 : 1.44	98	92.6
C3	40.6	40.6	10.2	1 : 0.4 : 0.42 : 1.0	1-28 and 43-74	47.8

silica fume which was dosed 18% by mass of cement and a superplasticizer admixture which was dosed 4% by mass of cement. After the components were mixed, the fresh concrete was placed into constructed wooden molds. After consolidation, the surface of the fresh concrete was finished, covered with waterproof sheeting, and left to cure for 24 hours in the laboratory. The mold were then stripped and the hardened concrete specimens were placed in a controlled humidity and temperature curing room for a period of 28 days. After this curing period, the concrete specimens C1 and C2 were stored in laboratory air without additional special curing treatment. Concrete specimens C1 and C2 were considered to be mature, air-dried concretes since these specimens were subjected to one-sided velocity measurements and verifying ultrasonic measurements at least 90 days after manufacture and at least 66 days after termination of the moist curing process. Concrete specimen C3 was used in two capacities: it was considered to be a young, hardening concrete throughout the 28-day the moist curing process and was considered to be a mature concrete with varying moisture content condition during the time period of 43~74 days after casting. 36 days after casting, specimen C3 was saturated by submersion in a water bath for seven days. The specimen was then removed from the water bath and allowed to dry naturally in laboratory air. Three gentle heating treatments were also applied in order to accelerate the drying process without causing excessive shrinkage cracking: specimen C3 was placed in an aggregate drying oven for a period of 3 hours at 93℃, 5 hours at 93℃, and 24 hours at 38℃ 12 days, 13 days, and 18 days respectively after removal from the water bath. One-sided velocity measurements and verifying ultrasonic measurements were performed throughout the drying process. The moisture content was monitored by measuring the mass of the specimen.

The age of each concrete specimen at the time of the one-sided and traditional ultrasonic tests is listed in Table 1. Companion 101.6mm x 203.2mm cylinders were cast for each mix on order to measure the 28 day compressive strength of the concrete f_c' as described in ASTM C39.[3] The compressive strength tests are listed in Table 1.

4. Test Results

4.1 Mature, Air-dried concretes

The test results for the one-sided and verifying measurements performed on mature

Table 2 Measured one-sided and associated verifying L-and R-wave velocity data

Specimen	$V_{L,o}$(km/s) Coefficient of variation(%)	$V_{L,v}$	V_R(km/s) Coefficient of variation(%)
C1	3.99, 3.2%	4.12	2.24, 2.5%
C2	4.44, 0.7%	4.55	2.70, 0.7%

air-dried concretes are presented in Tables 2. The consistency of $V_{L,o}$ measurements remains significantly poorer than that of the $V_{L,V}$ for specimen C1, but is better than that of the $V_{L,V}$ for specimen C2. The consistency of V_R values is better that of associated $V_{L,o}$ measurements for all concrete specimens

4.2 Hardening Concrete

The one-sided and verifying tests were performed in concrete specimen C3 starting 1 day after casting and continuing regularly for a period of 28 days. The results of the L-wave measurements are shown in Fig. 1. Clearly, it is possible to perform $V_{L,o}$ measurements on concretes as young as 1 day old. However, it is clear that the consistency of the $V_{L,o}$ results (open circles), as characterized by the range of repeated test results, is much poorer than that of through transmission $V_{L,v}$ results (solid diamonds). The plot of the average values for $V_{L,v}$ (dashed line) shows the expected initial sharp increase in velocity with age during the first few days followed by an asymptotic leveling at approximately 20 days after casting. The average of $V_{L,o}$ (solid line) shows a global velocity increase with increasing age similar the $V_{L,v}$ measurements, but also shows local, significant fluctuation. V_R measurements can also be obtained on concrete as young as 1 day old, as seen in Fig.2. The consistency of V_R values are significantly better than that for $V_{L,o}$ especially on or before the concrete age of 15 days. The average value of each measurement (solid line) shows the same

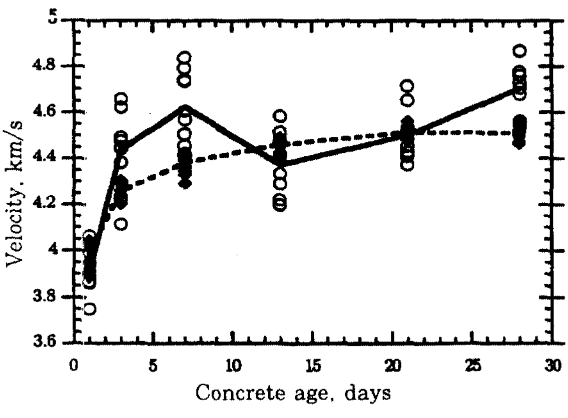

Fig. 1 The change of L-wave velocity measured by the one-sided method and through transmission method with aging

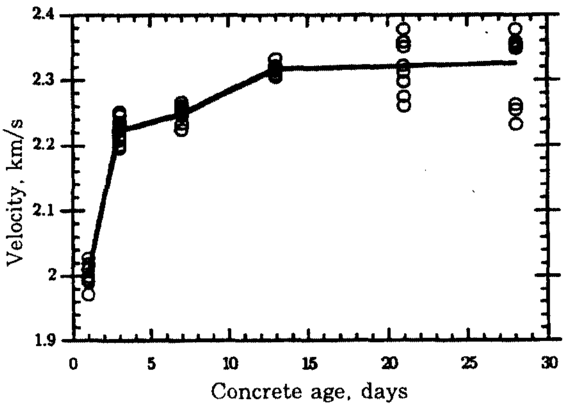

Fig. 2 The change of R-wave velocity measured by the one-sided method with aging

behavior as that seen with the $V_{L,v}$ measurements; a significant increase in velocity during the first few days after casting followed by an asymptotic leveling at approximately 20 days.

4.3 Mature Concrete with Varying Moisture Conditions

The one-sided and verifying tests were performed on concrete specimen C3 starting from a saturated state and continuing regularly for a period of 25 days as the specimen dried, in laboratory air and also with three oven drying sessions, until a moisture content equilibrium state was reached. A reduction in specimen mass is assumed to be solely a result of loss of free moisture in the material. Since the loss of free moisture occurs at the expected surface of the specimen, the drying procedure is assumed to generate a moisture gradient in the material. The effects of the three oven heating treatments are evident as significant drops in mass. The moisture content of the specimen was assumed to reach an equilibrium state after the third oven heating since the rate of mass loss was significantly reduced.

The effects of material surface drying on the one-sided and verifying tests can be seen in Fig. 3 and 4. As the concrete dries, the measured values of $V_{L,o}$ and $V_{L,v}$ reduce, as shown Fig. 3. A slight increase in both $V_{L,o}$ and $V_{L,v}$ values may be observed as the concrete approaches moisture content equilibrium. When the concrete is saturated at the beginning of the drying procedure, the $V_{L,o}$ values (open circles) and the verifying $V_{L,v}$ values(solid diamonds) are in close agreement. As the concrete mass is reduced and the moisture gradient is developed as the surface material dries, the two measurements diverge from each other, the one-sided measurement being significantly lower in value. As drying continues and the moisture content of the specimen nears the equilibrium state, the difference in the two measurements reduces. The consistency of $V_{L,v}$ measurements, as characterized by the range of repeated measurements, remains consistent. The consistency of the one-sided measurements, however, becomes poor as the moisture gradient increase, with the poorest consistency coinciding with the largest discrepancy between one-sided and verifying measurements. The V_R measurements throughout the drying process show the same trend as seen with $V_{L,v}$ measurements as seen in Fig. 4:V_R reduces significantly as the drying procedure commences from the saturation condition with an increase in V_R as the equilibrium state is approached. It is interesting to note that the consistency of the V_R measurements is good at the saturation and equilibrium state conditions but is poorer when a moisture gradient exists. It is clear that $V_{L,o}$ measurements, near the surface of the specimen, are most sensitive to changing surface moisture condition while $V_{L,v}$ measurements, through the thickness of the specimen, are least sensitive. All three measurements show reduction, leveling and increase in velocity as concrete approaches moisture content equilibrium.

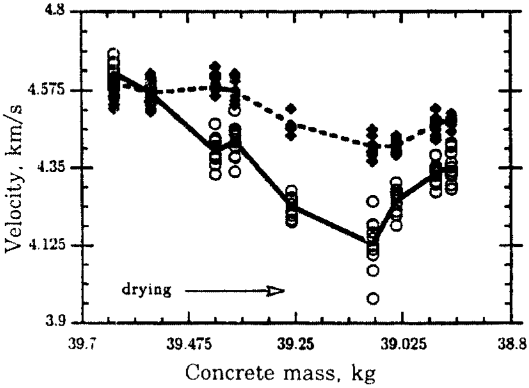

Fig. 3 The change of L-wave velocity measured by he one-sided method and through transmission method throughout drying process

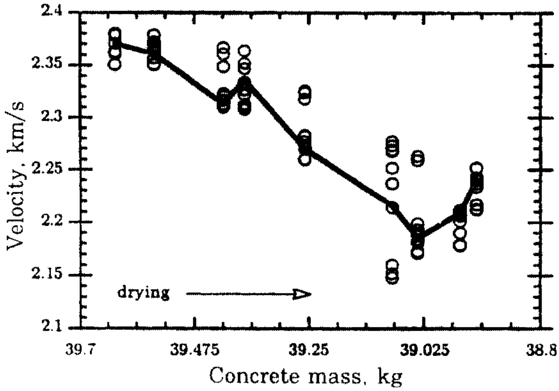

Fig. 4 The change of L-wave velocity measured by the one-sided method and through transmission method throughout drying process

5. Conclusion

According to the above results, this particular behavior suggests the $V_{L,o}$ values are accurate, but the discrepancy between $V_{L,o}$ and $V_{L,v}$ measurements is a result of material inhomogeneity with respect to propagating wave path. This supposition is supported by the data presented in Fig. 3 where it is shown that $V_{L,o}$ values are in excellent agreement with $V_{L,v}$ values when the specimen is in the saturated state and, as a result, the material properties of the two wave paths are similar. When the concrete is subjected to drying, it can be assumed that the material properties of the two wave path become distinct with respect to moisture content. It has been reported in the literature that L-wave velocity is significantly affected by the moisture content of a concrete; higher moisture contents result in increased velocity[1]. As the specimen reaches moisture content equilibrium at the end of the drying procedure, the discrepancy between the values of $V_{L,o}$ and $V_{L,v}$ reduces to a fairly constant value. This remaining discrepancy suggests that residual moisture is trapped within the specimen which will not be released with subsequent air drying. Thus, it appears that one-sided L-wave velocity measurements are much more sensitive near surface properties than through transmission measurements and somewhat more sensitive than one-sided V_R measurements. This sensitivity to surface conditions suggests $V_{L,o}$ measurements as a tool for monitoring of near-surface concrete distress such as freeze-thaw damage, alkali-silica reactivity, and salt scaling damage.

$V_{L,o}$ and V_R values can be obtained from concrete as soon as 1-day after casting and throughout the hardening process, as shown in Fig. 1 and 2. Since the consistency of the obtained $V_{L,o}$ results is poor relative to that of repeated $V_{L,v}$ tests, it is difficult to make conclusive deductions concerning the average behavior trends of $V_{L,o}$ with respect to concrete hardening. However, one can infer that the behaviors of $V_{L,o}$ and $V_{L,v}$ measurements are generally similar and not clearly distinct. The consistency of repeated $V_{L,o}$ measurements for mature concretes is good for high strength concrete (C2) and for concretes with similar material properties with respect to wave path (C3, saturated condition), but is worse for normal strength concrete (C1) or inconsistent materials properties with respect to wave path (C3, drying state). However, the distinction between $V_{L,o}$ and $V_{L,v}$ data as the specimen surface dries from the saturated state is greater than the range of values from repeated tests, as seen in Fig. 3. Thus, it can be assumed that the observed distinction between $V_{L,o}$ and $V_{L,v}$ values, as a function of the moisture content of the surface, is not spurious and that obtained $V_{L,o}$ values are accurate.

The consistency of repeated V_R measurements is notably better than that of $V_{L,o}$ for all concrete specimens. In fact, the consistency of V_R measurements is better than that for the standardized $V_{L,v}$ measurements in all concretes. Thus, confidence may be placed in observed V_R behavior in concrete even though the absolute values of obtained V_R results may be slightly low. Namely, the observed increase in V_R with aging, similar near the surface reduces can be considered as accurate measurements of behavior. Very consistent V_R values can be obtained from concrete as soon as 1-day after casting and throughout the early hardening process. Thus, measurement of V_R may be suitable for monitoring the strength gain of hardening concrete. It is interesting to note that the consistency of repeated V_R measurements appears to worsen as the material properties change with respect to depth from the surface, as seen in Fig. 4. The consistency of V_R measurements appears to be better in specimens with homogeneous material properties; this same behavior was noted for $V_{L,o}$ measurements as well.

6. Reference

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