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FEM Simulation of a highly accurate impact echo method of PC grout simulation using a time domain signal

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ABSTRACT: The impact echo method suffers from unstable generation of elastic waves, and it is difficult to distinguish the signal to be measured because the reflected wave overlaps the vibrations of the strike surface. Our research is aimed to improve the accuracy of this method. For this purpose, the impact points were arranged in a line. By two-dimensional finite element simulation we investigated whether its application to PC grout evaluation was possible. As a result of grout evaluation of tendon ducts with depth of 275 mm and diameter of 38 mm, we confirmed that parts missing grout could be detected.

1 INTRODUCTION

In existing pre-stressed concrete (PC) structures, tendon ducts, which are not completely filled by grout, the mixture of water and cement are conformed. The part not filled by grout threatens the safety of a structure by promoting steel corrosion within the structure. Therefore, accurate detection of ducts not filled with grout is important for the administration of concrete structures.

For this, we chose impact echo method (Sansalone & Streett. 1997). The principle of detecting sections missing grout is as follows. An impact generated wave, which is assumed to be a compression wave, propagates in a solid, such as concrete. An elastic wave reflected from the ungrouted part in the tendon duct, which is assumed to be air, is observed on the surface as a tension wave, because a phase change occurs. The grouted part, however, reflects a compression wave. Thus detection of an ungrouted part is possible.

However, one problem with the impact echo method is the existence of R-waves. When the surface of the wall is impacted, three types of wave occur: P-waves, S-waves and R-waves. If the measurement point is near the impact point, R-waves arrive at the measuring point before the reflected wave, and vibration caused by the R-wave remains even after it has passed. Because the reflected wave is only around one-tenth of the amplitude of the R-wave, it is difficult to specify the surface vibration of the reflected wave. Thus, we propose a highly accurate impact echo method, which uses the arithmetic mean of the time domain signal of many impact points. The locations of the impact points are determined when the influence of the surface wave is reduced, and the reflected wave from the tendon duct becomes large in arithmetic mean. We carried out experiments that arranged the impact points on the circumference of an ellipse and carried out two-dimensional finite element simulation to confirm the validity of this method.

This research is intended to improve the accuracy of the impact echo detection method. For this purpose, the location of impact points was arranged on a line. Using two-dimensional finite element simulation we investigated whether it could be applied to PC grout evaluation.

2 ANALYSIS

2.1 *Analysis model*

An analysis model using the finite element method (FEM) is shown in Figure 1. The tendon duct is steel of diameter 38 mm and thickness 0.5 mm. The depth from the surface to the centre of tendon duct is 275 mm. We simulated models for areas filled with grout and missing grout.

If the duct is grout filled, a reinforcing bar with a diameter of 32 mm was arranged in the centre of the

Table 1. Material properties.

	concrete	grout	tendon duct	PC bar	bullet
Young's modulus (GPa)	29.9	20	206	206	1.2
Poisson's ratio	0.167	0.18	0.3	0.3	0.36
density (kg/m^3)	2400	2500	7980	7980	1060

Table 2. Size of mesh for FEM simulations.

	concrete	grout	tendon duct	PC bar
maximum (mm)	1.5	1.0	0.55	1.0
minimum (mm)	0.26	0.92	0.50	0.28

duct. The material properties are shown in Table 1. Table 2 is a size of mesh for FEM simulations.

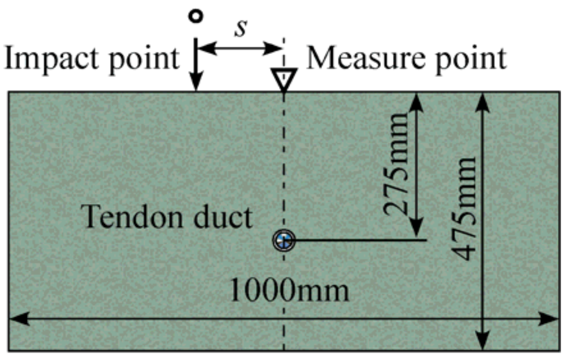

Figure 1. Analysis model for a concrete specimen.

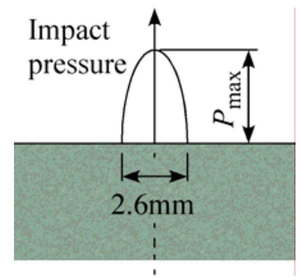

Figure 2. Pressure distributions as hertz distribution for a diameter of 2.6 mm.

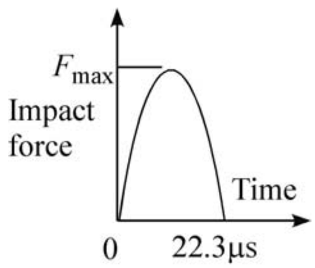

Figure 3. Load amplitude acts sinusoidally on the contact region in the time domain.

2.2 *Load conditions*

The load conditions were excited with an airsoft gun. The airsoft gun shoots 6 mm plastic pellets from the muzzle with velocity of about 100 m/s. The mass of a pellet is 0.12 g. The material properties of the pellet are shown in Table 1.

From additional experiments, we learnt that the average contact diameter of a pellet was 2.6 mm. The impact force given to the concrete surface as a hertz distribution is shown in Figure 2. Assuming that the impact velocity of a pellet was 100 m/s and the reflection velocity was 50 m/s, the contact time (Gugan, D. 2000), calculated from the material properties in Table 1 was 22.3 μs. It was assumed that the load, which varied sinusoidally during this contact time acted on the contact region as shown in Figure 3. The maximum pressure Pmax is 360 MPa (Timoshenko, S.P. & Godier, J.N. 1982).

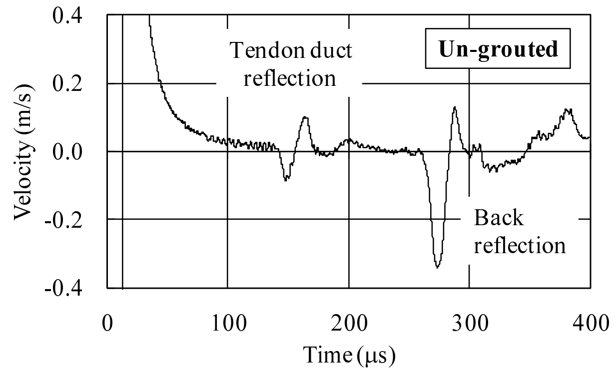

Figure 4a. Velocity in the direction normal to the measurement surface (s = 0 mm) for missing grout.

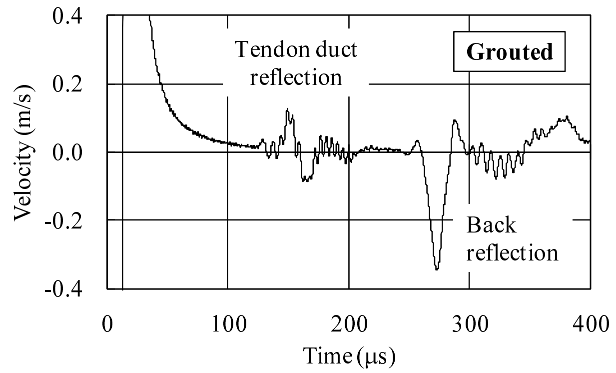

Figure 4b. Velocity in the direction normal to the measurement surface (s = 0 mm) for a grouted duct.

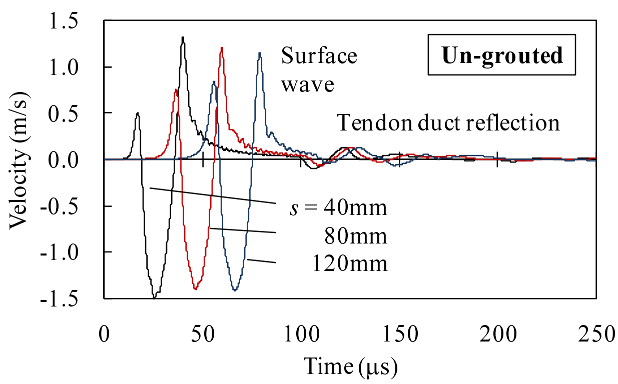

Figure 5. Velocity in the direction normal to the measurement surface (s = 40 mm, 80 cm, 120 cm) for a missing grout.

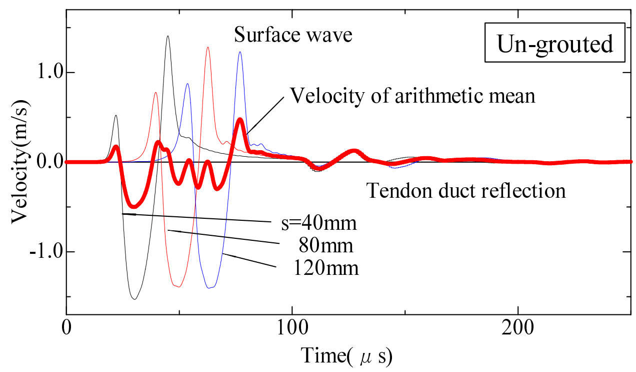

Figure 6. Velocity in the direction normal to the measurement surface (s = 40 mm, 80 cm, 120 cm) for missing grout.

3 RESULTS

Figure 4 shows the velocity in the direction normal to the measurement surface, which was excited directly above the tendon duct (s = 0 mm). Figure 4a shows the case of the missing grout and Figure 4b shows a duct filed with grouting. In Figure 4, the positive direction of velocity is the outward direction of the measurement surface. As shown in figure 4a, because the tendon duct is hollow when grout is missing, the velocity variation caused by the tendon duct reflected elastic wave is similar to the reflected wave from a bottom face. Therefore, the tendon duct reflected wave becomes a tension wave as the velocity changes from negative to positive. On the other hand, when the duct is filled with grouting, the tendon duct reflected wave becomes a compression wave, as velocity changed from positive to negative.

Generally, in the impact echo method, there is a distance between the excitation point and measuring point. So the surface vibration simulation result, with the excitation point shifted from directly overhead (s = 40, 80, 120 mm) is shown in Figure 5. The arrival time of the elastic wave will be almost equal in practice, but the magnitude of attenuation of the vibration is not useful because this simulation has not considered scattering and attenuation—it is a two-dimensional analysis.

In Figure 5, the delay of the arrival time of the surface wave is proportional to the distance—the difference in the arrival time is large. However, the propagation distance from the impact point to the tendon duct is almost equal, so the difference in the arrival times is small, as shown in Figure 6.

4 DISCUSSION

As a result of simulation, when the airsoft gun was used for excitation, the reflected wave from the tendon duct was identified in the measurement surface. It is necessary to ensure that the reflected wave has adequate amplitude for measurement.

In Figure 4, the amplitude of the tendon duct reflected wave is of the order of 0.1 m/s. This means that the same amplitude of surface vibration can be produced by impact pressure distributed along the tendon duct, as shown in Figure 2. In reality, if the load area in a circle with a diameter of 2.6 mm is considered, we expect a magnitude ranging from 1/100 to 1/1000 of this amplitude. When using a laser Doppler vibrometer or an acceleration pickup for the measurement, velocity amplitudes of the order of 0.1 mm/s can be measured.

However, it is expected that the attenuation of the elastic wave by tendon duct reflection is significant. Therefore, it is considered that judgment using a traditional method, based on multiple reflections of the elastic wave, is difficult.

Thus, we paid attention to the shape of the first reflected wave from the tendon duct, which is expected to be useful for tendon duct grout evaluation. In other words, the judgment criterion is whether the first reflected wave from the tendon duct is a compression or tension wave. Furthermore, shifting the results of surface vibration such that the tendon duct reflected waves arrive at the same time improves the waveform accuracy because the surface wave is weakened by a difference in the time of arrival and the reflected wave is strengthened.

5 CONCLUSIONS

We carried out FEM simulation which uses a soft air gun for excitation.

The reflected wave from a tendon duct 275 mm deep at the centre with a diameter of 38 mm, was identified by vibrating it with enough intensity to measure its surface vibration.

If the measurement point is fixed directly over the tendon duct, and the impact point moves at a right angle, the arrival times of the reflected wave is almost equal to that of the arrival time of the surface wave. Using this result, we can reduce the influence of the surface wave by synchronizing the time of arrival of reflected wave from the tendon duct.

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