Application of Impact-Echo Method to Heterogeneous Materials

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Heterogeneous materials such as rocks cannot be expected to have uniform quality and properties when used as structural materials. For example, in case of large rocks with a diameter greater than one meter that could be used to protect wall, measures should be taken to identify defects, such as internal cracks or fracture zones, whose adverse influence on material strength cannot easily be detected using traditional, destructive testing methods that rely on a few, small samples, such compression strength tests on cores taken from the rock. In these instances, the impact-echo method, which is simple enough for on-site tests and has good accuracy, could be used as a quick test method to evaluate material strength and detect internal defects in large rock specimens. In this study, measurements using the impact-echo method were performed on various types of rocks whose structural response was studied under large impact loads. The applicability of impact-echo method for estimation of rock strength was verified by comparing these measurements with those from other, more traditional, compression strength tests.

Key Words: heterogeneous material, impact-echo method, compression strength, rock

1 INTRODUCTION

Large boulders have been used for structural components for some time-from pyramids to roman viaducts to building bearing walls to devices used to protect buildings from accidental or purposeful vehicular impacts.

Heterogeneous materials such as rocks, however, cannot be expected to be uniform in quality when they are used as structural materials. Therefore, it is necessary to perform tests in advance to check if the required structural design strength and stiffness of the rock can be attained. In the case of large rocks with a diameter greater than one meter, measures should be taken not only to more accurately ascertain the bulk strength of the material, but to also locate defects, such as major internal cracks, fracture zones or voids, that could adversely influence bulk properties and are not easily detected using traditional, destructive, tests involving small cores taken from the larger specimens. In this case, nondestructive testing, which is simple enough for on-site tests and has good accuracy, could be used as a method for evaluating the strength while concurrently detecting internal defects of large rocks on site.

For the purposes of this study, small test specimens and large full-scale specimens were prepared from various types of rocks to protect buildings from accidental or purposeful vehicular impacts. This study focused on use of the impact-echo as a nondestructive method to heterogeneous materials. After determining a relationship between types or dimensions of test specimens and their strengths, applicability of the impact-echo method was evaluated for estimating the strengths of heterogeneous materials.

2 IMPACT-ECHO METHOD

In the impact-echo method [1], elastic waves generated by striking a concrete surface with an impactor are measured with a vibration sensor installed near the impact point. The generated elastic waves propagate through the concrete being tested and are reflected many times at the discontinuities such as surfaces of specimens; voids (boundary with air); or cracks. This reflective property can be used to estimate the dimension and thickness of the tested concrete member and the distance to a discontinuity such as a crack or void. Figure 1 illustrates the impact-echo method.

The thickness $T$ of the member or the distance $D$ to a void can be calculated because the frequency component at which the distance and the half wavelength coincide is amplified by multiple reflections, as shown in the following equation:

$$ T \text{ or } D = \frac{C_p}{2f} $$

where $C_p$ is P-wave velocity, and $f$ is peak frequency.

Figure 1 Impact-echo method
3 MEASUREMENT SYSTEM

The measurement system used in this study consists of impactors (steel balls) of various diameters, a sensor and a data recorder (dynamic strain meter), as shown in Figure 2. The sensor is an accelerometer with a measurement range of 1 to 25,000 Hz. The sampling time interval of the data recorder was set to one microsecond. Four types of steel balls (11, 51, 76 and 114 mm in diameter) were used as impactors for the measurements conducted in this study, as discussed below.

4 TEST SPECIMENS

Test specimens consisted of three types of rocks, two types of granite (American Black and Kitledge Gray) and limestone, which were taken from larger specimens prepared for examinations under purposeful vehicular impacts. Measurements of each type of rocks were first conducted in a laboratory to ascertain the difference of materials. Once the performance of laboratory tests was checked, field tests of specimens having about 1m or more size were performed to check the applicability to large scale.

In the laboratory, measurements were performed to small cylindrical test specimens that had undergone split tensile strength tests and splitted into two pieces as shown in Figure 3. Table 1 shows both the name and length of each specimen tested. All specimens had a diameter of 57 mm. In the table, G1 and G2 represent the two granites, American Black and Kitledge Gray, and L1 represents limestone. Ten specimens were tested for each rock type, for a total of 30 test specimens.

The field tests were performed on larger specimens of the rocks with each large rock having a volume of approximately 1 m³. Figure 4 shows the test specimens and Table 2 lists their names and dimensions. Initial measurements were taken of each large rock specimen as placed in the field for its large impact test (Test 1). Additional measurements of the same specimens were then taken after they were relocated and repositioned and, in some instances, cut into smaller pieces (Test 2). The difference between Test 1 and Test 2 is that all of the three types of rocks were tested in Test 1, while in Test 2 only American Black specimens were tested. Since specimens measured for both Test 1 and Test 2 were identical, additional measurements permitted evaluating effectiveness of the impact-echo method for large specimens whose results were influenced by specimen orientation and the size of impactors.
5 MEASUREMENT WITH IMPACT-ECHO METHOD

The diameter of an impactor was chosen according to the size of the test specimen. Figure 5 shows the relationship between measurement dimension (for example, the thickness of a slab) of a test specimen and diameter of an impactor examined from a previous study [2]. A filled circle represents a case where the maximum peak appeared at the frequency corresponding to the dimension of the test specimen. And a filled square and a filled triangle represent cases where the second and third maximum peak appeared at the frequency corresponding to the dimension of the test specimen, respectively. Figure 5 indicates that, when estimating the dimensions of concrete members by using the impact-echo method, it is necessary to select an impactor of an appropriate size (diameter equal to about 6 to 17 times the dimension to be

![Figure 5: Relationship between measured length and impactor size](image)

![Figure 6: Fourier spectra for small test specimens](image)
measured). According to this rule of thumb, a steel ball of 11 mm in diameter was used as an impactor for small test specimens and four diameters of steel balls (11, 51, 76 and 114 mm) were used as impactors for large test specimens.

5.1 Laboratory results

Figure 6 shows representative Fourier spectra obtained from the small test specimens. In this figure, a total of ten G1 test specimens (American Black granite) were measured three times each. The result shows a maximum peak frequency at around 25 kHz in most cases and an average propagation velocity of 6,109 m/sec. Results obtained from the G2 test specimens (Kitledge Gray granite) shows peaks around 9 kHz and 16 kHz and average propagation velocities of 4,043 m/sec in the 16 kHz range, where a higher percentage of peaks appeared. The average propagation velocity for the L1 specimens (limestone) is 5,065 m/sec.

5.2 Field measurement results

Measurements of large test specimens were conducted twice. In first measurement (Test 1), steel balls of 11 mm and 51 mm in diameter were used as impactors. In the second measurement (Test 2), steel balls of 76 mm and 114 mm in diameter were used as impactors. Each measurement point was measured three times, respectively. Figure 7 shows the measurement results for one specimen examined during both Test 1 and Test 2 (X11 in Test 1 and B12 in Test 2). The dimensions of the specimen measured by a tape measure are 75 cm and 100 cm. The dimensions measured from B12 are slightly different from those from X 11 although they are the same test specimen. The reason for the difference would be its irregular shape of the test specimen and different measured points.

In the measurements (X11-1, X11-2) of Test 1, maximum peaks did not appear at frequencies corresponding to the 75 cm and 100 cm side dimensions that were parallel to the impact direction. It can be seen from these results that it is difficult to determine frequencies corresponding to dimensions unless prior information on those dimensions is available. These results also indicated that a 51 mm in diameter impactor was too small for to accurately measure the large dimensions like 75 cm or 100 cm.

In the measurements (B12-4, B12-5) of Test 2 conducted with an impactor of 76 mm in diameter, the maximum peaks, which are indicated by inverted triangles in Figure 7, appeared at the frequencies corresponding to the measured dimensions of 74 cm and 97 cm. In the measurements (B12-1, B12-2) conducted with an impactor of 114 mm in diameter, the maximum peak clearly appeared at the frequency corresponding to the measured dimension of 97 cm, but did not appear clearly at the frequency corresponding to the measured dimension of 74 cm. This indicates that an impactor of 114 mm in diameter is slightly too large for the measurement of 74 cm.

It may sound contradictory to say that when conducting measurement with the impact-echo method, the appropriate size of an impactor should be determined prior to the measurement although the dimensions of the test specimen are not known. In many cases, however, approximate dimensions of the specimen are known in advance (for example, in the detection of voids in tunnel structures). If information for exact dimensions of the specimen is not available, it is desirable that the size of an impactor is determined after estimating approximate dimensions of the specimen, or that the measurement is conducted with two or more impactors and then the most appropriate dimensions of the specimen would be estimated.

5.3 Comparison of impact-echo tests and compressive strength tests

Figure 8 shows (from left to right) (a) propagation velocities of small test specimens, (b) propagation velocities of large test specimens measured by impact-echo tests, and (c) unconfined compressive strengths determined by compression tests. The results shown in (b) and (c) indicate that propagation velocities of large test specimens and unconfined compressive strengths are somehow related. In other words, the order of the propagation velocities in different types of rocks (G1, G2, L1) is fairly similar to that of the unconfined compression strengths.
The order of the propagation velocities of the small specimens, however, is different (G1, L1, G2) from that of the unconfined compression strengths. The cause of this difference could not be identified in the tests conducted in this study. It has been found, however, that the strength of full-scale rocks can be estimated from the propagation velocity in not small but large test specimens. And the possibility that the large and small size specimens would involve cracks or defects can be considered also. As a next step, the authors intend to examine the microstructure of rocks in detail and conduct studies on topics such as the effect of size on failure due to internal defects.

6 CONCLUSIONSD

The impact-echo test results performed to the heterogeneous material can be summarized as follows:

(1) It is possible to measure the dimensions of large test specimens by using an impactor of appropriate size.

(2) It was confirmed that the measurement results for full-scale specimens were correlated with compression strength test results.

(3) The results for the small specimens were not correlated with compression strength test results. It seems that different settings are necessary for different types of rocks.

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References
