PROPOSAL OF NEW FOUNDATION CONSTRUCTION WORKS WITH HIGH DAMPING AND MITIGATION PERFORMANCE; PART 1 FORCED VIBRATION TESTS OF TWO TYPES OF FOUNDATION BLOCKS AND SIMULATION ANALYSES

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ABSTRACT :

This study focuses on the progress of the damping and mitigation performance of foundations that will be built at soft ground sites, and proposes an improved foundation technique which implements backfilling of a damping composite material into trenches dug along a foundation area. The damping material is a mixture of asphalt with crushed stones and scrap tire chips. Forced vibration tests were conducted to confirm the effectiveness of the proposed foundation technique on two types of foundation blocks, those being, CF and IF; the former was constructed by a conventional construction method and the latter applied to the improved foundation technique mentioned above. We have carried out the 3-dimensional simulation analyses adopting a hybrid approach in which two foundations and the soil region adjacent the foundations are rendered using the 3-dimensional finite element model. Comparing with the response of the both foundations, it has been confirmed that the damping material adopted in the IF provides good attenuation and mitigation performance.

KEYWORDS: Damping mixtures, scrap tire chips, asphalt, forced vibration test, foundation blocks

1. INTRODUCTION

According to investigative reports of The Hyougoken-Nambu Earthquake in 1995 and The Mid Niigata prefecture Earthquake in 2004, it has been recognized that structures that adopt seismic isolation devices possess remarkable ability concerning the prevention of not only the loss of human life but also damage to structures and facilities. However, base-isolated structures can only prevent destruction due to earthquakes when they are constructed on sites having good soil condition. Therefore, foundation improvement work is indispensable for base-isolated structures that will be built on sites having soft ground conditions.

This study focuses on the progress of the damping and mitigation performance of foundations that will be built at soft ground sites, and proposes an improved foundation technique which implements backfilling of a damping composite material into trenches dug along a foundation area. The damping material is a mixture of asphalt with crushed stones and scrap tire chips, and from this point forward will be called “the damping mixture”. To comprehend the attenuation ability of the improved foundation technique and to verify the effectiveness of this work, we carried out forced vibration tests on two types of experimental foundation blocks; one was constructed by a conventional construction technique and the other employs the previous stated improved foundation technique. Here, the conventional construction technique is a procedure that involves backfilling of dug soil into trenches excavated along a foundation. Hereafter, the improved foundation and conventional construction techniques are called IF and CF, respectively. We performed the 3-dimensional simulation analyses adopting a hybrid approach in which two foundation blocks and the adjacent soil regions are modeled by 3-dimensional finite elements. The thin layer element method is applied to the free field ground region that surrounds the above finite element domain.

2. EXPERIMENT SITE AND FOUNDATION BLOCKS

Figure 1 shows the layout of our experiment site. The site is located at a vacant lot north of the experimental building at the Funabashi Campus of Nihon University in Chiba prefecture near Tokyo, Japan. The soil profile of the site is illustrated in Figure 2. The ground surface layer 2.8m and shallower is loamy in the Kanto district, and partially includes backfilling soil 0.1m deep. Cohesive soil distributes in the range of G.L.-2.8m to G.L.-3.5m. Tuffaceous fine sand can be seen in the range of G.L.-3.5m to G.L.-5.3m. Silty fine sand and fine sand alternate G.L.-5.3m and deeper.

The conventional foundation block (CF) had been constructed in August, 2003 (Ishimaru et al., 2004), and the improved foundation block (IF) was built one year following (Ikeda et al., 2005). The IF was constructed 6m to the east of the CF, both foundations had been supported by four soil cement columns and the existing soil layers. The tips of the improved soil cement columns are located at G.L.-2.8m, where loam and cohesive soil alternate, and its value for the standard penetration test is five and under.

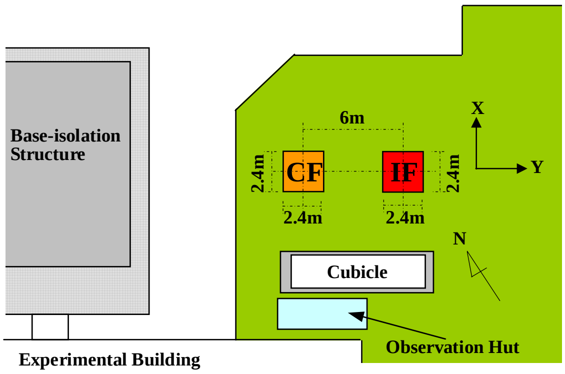

Figure 1 Schematic view of the experiment site

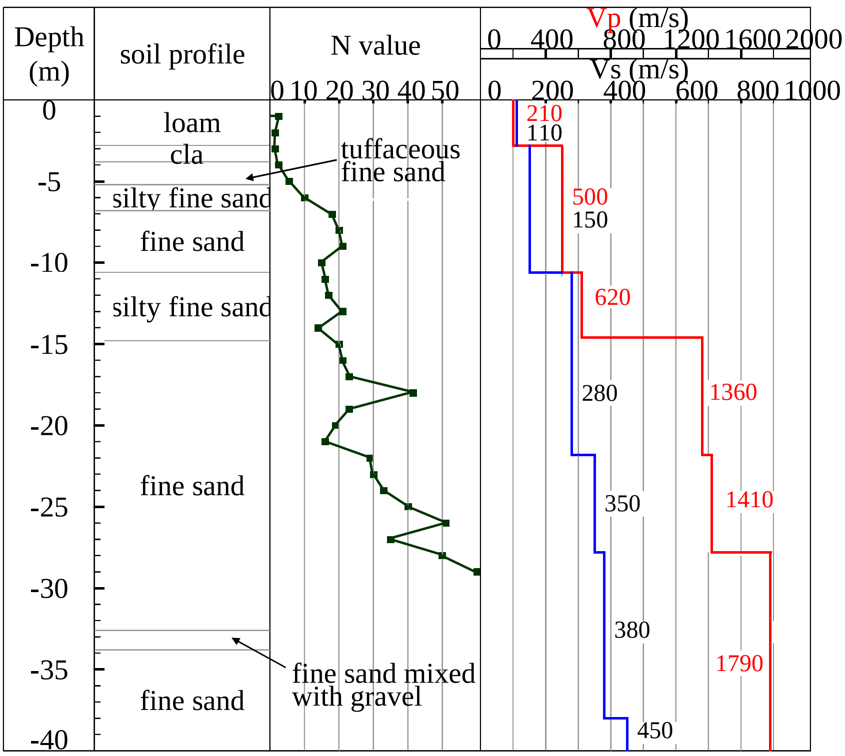

Figure 2 Soil profile of the experiment site

3. MATERIAL TEST RESULTS

3.1. Soil Cement Columns

The test block and the soil cement columns are shown in Figure 3. The dimensions of both blocks are 2.4m x 2.4m x 1.0m. The diameter of a soil cement column is 600mm and its length is 2.5m. Two core rods, 90mm in diameter and 2.5m in length, were obtained from a soil cement column which had a material age of 28 days. Figure 4 shows the density and the unconfined compressive strength distributions of the specimens against depth. The densities distributed uniformly against variations in depth and were in the range of 1.44 to 1.52g/cm^3. In comparison with both results of the CF and IF, the unconfined compressive strengths of all the specimens of the latter were slightly smaller than that of the former, and the deformation moduli (E_{50}) and densities of the two test results were almost identical. Properties obtained by the unconfined compressive strength tests are shown in Table 1.

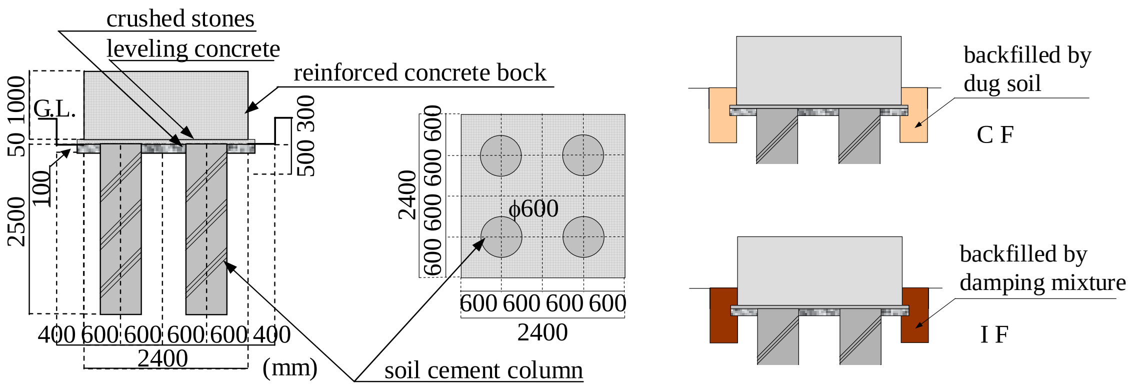

Figure 3 Two types of foundation blocks, CF and IF

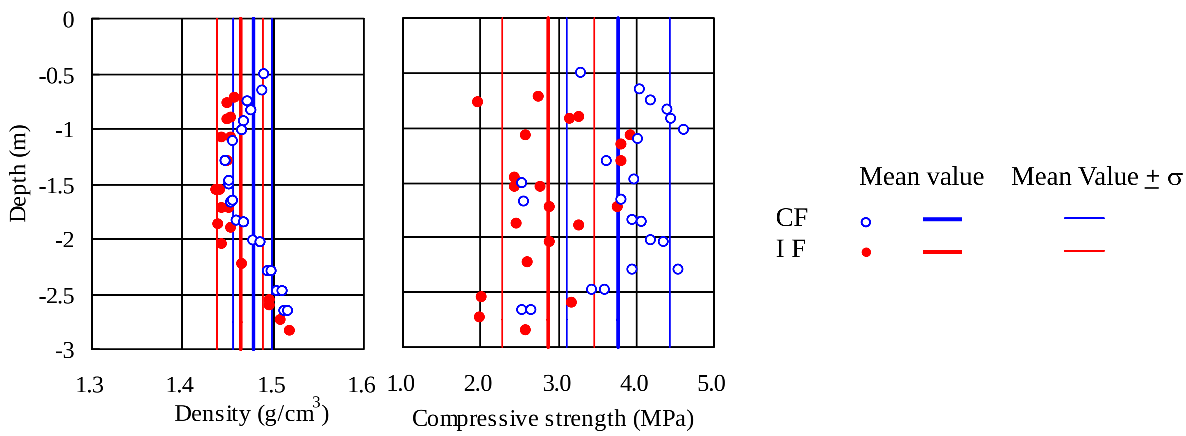

Figure 4 Density and unconfined compressive strength distributions against depth

Table 1 Results of unconfined compressive strength tests of soil cement columns

Test results	Deformation modulus E_{50} (MPa)	Density ρ (gr/cm^3)	Unconfined compressive strength q_u (MPa)
CF (conducted in 2003)			
Mean value	1462	1.48	3.77
Standard deviation	200	0.02	0.67
IF (conducted in 2004)			
Mean value	1456	1.46	2.86
Standard deviation	130	0.02	0.59

3.2. Damping Mixture

In order to obtain basic material features of the damping mixture paved into the trenches dug along IF, cyclic triaxial tests have been conducted. Diameters and lengths of the specimens are about 100mm and 190mm, respectively. Figure 5 shows examples of hysteresis loops of deviator stresses and axial strains of the damping mixture for variations of mixed rates of scrap tire chips to crushed stones. The former particle sizes are less than 10mm and the latter are in the range of 2.5mm to 5.0mm. The mixed rates of the chips to crushed stones are defined by the ratio of the mass of tire chips to the total mass (the tire chips and crushed stones). Compared with zero mixed rates of the tire chips, the initial secant moduli of the damping mixture with 12.5% mixed rates undiminished and its equivalent damping constants increased.

Finally, we selected the damping mixture of 12.5% to backfill the trenches dug along the IF. The mixing of the damping mixtures is illustrated in Table 2. Figure 6 represents the result of the experiments for various load levels with 50kPa confining pressure and 0.1Hz frequency. At a small strain level (0.01% and below), it is found that the equivalent Young's moduli and the equivalent damping constants of the damping mixture are about 120MPa and 20%, respectively.

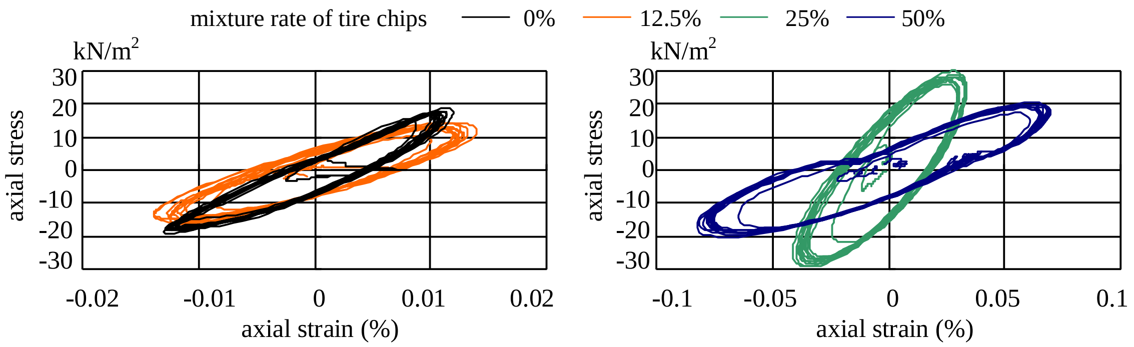

Figure 5 Hysteresis of axial stresses and strains at various mixture rates of scrap tire chips

Table 2 Blending of mixture of asphalt with crushed stones and scrap tire chips (mixed rate: 12.5%)

	Mass ratio (%)	Density (gr/cm^3)	Mass (gr)
Crushed stones	58.6	2.7	1983.6
Tire chips	8.4	1.2	284.4
Slow curing	12.0	2.7	406.0
Fine sand	11.0	2.7	372.0
Filler	10.0	2.7	338.0
Total of aggregate	100.0		3383.0
Asphalt	7.5	1.0	274.3
Total (aggregate + asphalt)			3657.3

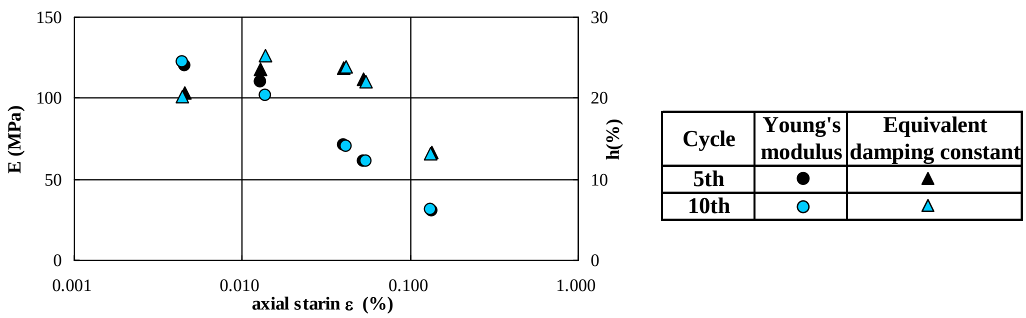

Figure 6 Strain dependence on equivalent Young's moduli and damping constants of specimens

4. FORCED VIBRATION TESTS

4.1. Test Schedule

To confirm the progress of attenuation performance of the IF, we carried out forced vibration tests under various conditions on the trenches dug along the IF. Figure 7 shows the timetable for the forced vibration tests. The trenches excavated along the CF, whose width and depth are about 0.4 m and 0.8 m, respectively, were backfilled with the dug soil up to ground level. Conditions of the trenches excavated along the IF from Stage 2 to Stage 6 are as follows. First, we backfilled the trenches along the IF with the dug soil up to the ground surface level (Stage 2). Then, we excavated the trenches 0.3m deep (Stage 3). Next, we made the trenches 0.8m deep (Stage 4). At Stage 5 we filled in the trenches with the proposed damping mixture and carried out a forced vibration test to confirm the mitigation ability of the damping mixture for the oscillation of the IF. The vibration generator was mounted on the CF until Stage 5. We remounted the shaking machine from the CF to the IF and conducted an experiment focusing on the attenuation performance of the damping mixture (Stage 6).

4.2. Test Results

While the CF was oscillated by the shaking machine, forced vibration tests (from Stage 2 to Stage 5) relating to various conditions of the trenches dug along the IF, were carried out. Figure 8 shows amplitude functions of the response displacement curves per unit exciting force in the direction of the exciting force on the upper surface of the IF at Stage 2, 3 and 5. At the peak frequencies, the magnitude of amplitudes of IF at Stage 5 is 15%-30% smaller than at Stage 2. It was expected that the damping mixture would play an important role in the progress of mitigation ability of the structures.

Figure 9 shows the displacement resonance curve of the IF at Stage 6, the CF at Stage 1 wherein the CF only existed and at Stage 2. Compared with the results at Stage 1, it can be seen that the resonance frequency at Stage 2 shifts to a higher frequency range and the maximum response value is reduced. It is reasoned that the rigidity of the surface soil became harder by aging and cross interaction effects. The amplitude at Stage 6 at the peak frequency, 9.6Hz, is reduced by about 35% compared with the test results of Stage 2. It is herein indicated that the damping mixture backfilled into the trenches dug along the foundation has good attenuation performance.

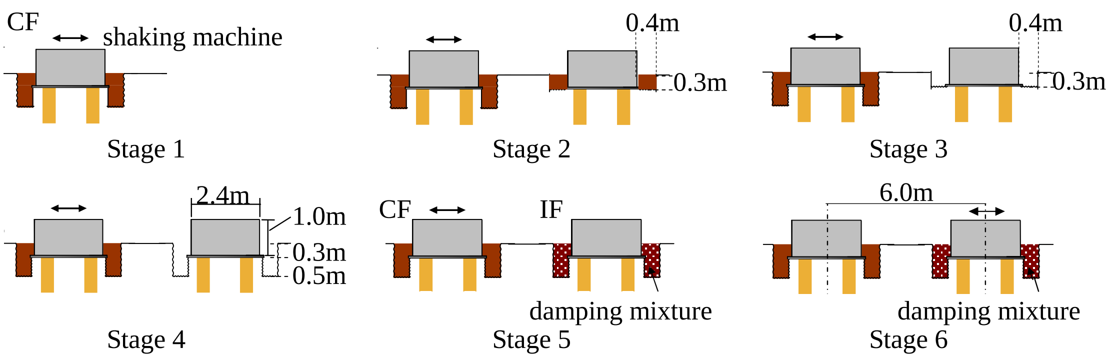

Figure 7 Schedule of forced vibration tests

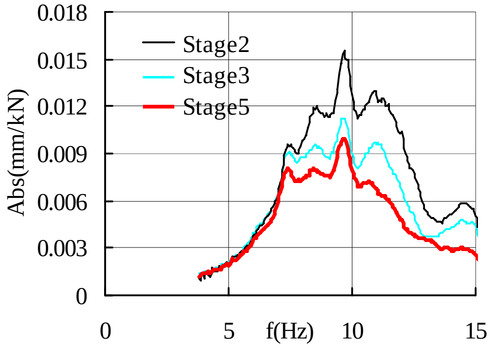

Figure 8 Resonance curves of IF in Stage 2, 3 and 5

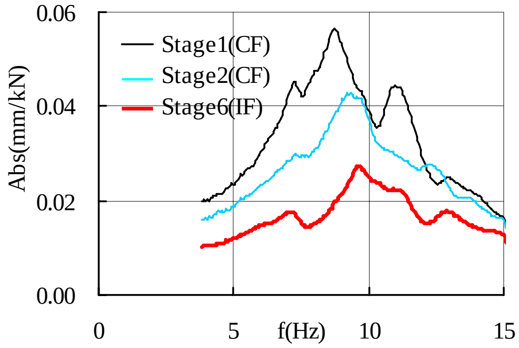

Figure 9 Resonance curves of CF in Stage 1 and 2 and IF in Stage6

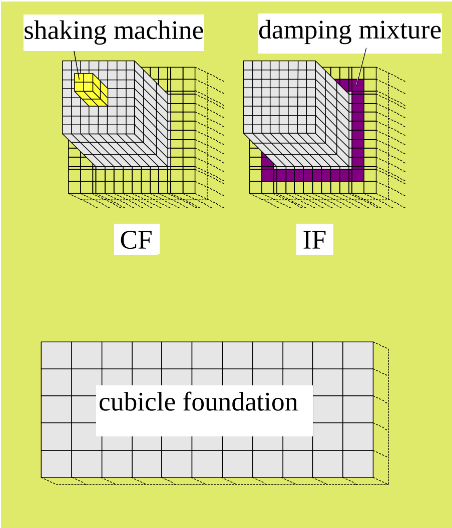

Figure 10 Models of hybrid approach

Table 3 Properties of numerical analysis

Depth (m)	V_s (m/s)	ρ (t/m^3)	Poisson's ratio	Damping ratio
1.0	90	1.4	0.311	0.03
2.7	90	1.4	0.311	0.03
5.4	150	1.6	0.451	0.03
10.6	280	1.7	0.372	0.02
14.7	280	1.7	0.478	0.02
21.7	350	1.7	0.465	0.02
27.8	380	1.8	0.461	0.02
38.0	450	2.0	0.466	0.02
45.2	420	2.0	0.461	0.02
Material				
Foundation blocks	-	2.4	0.20	0.00
Leveling concrete	-	2.4	0.20	0.00
Damping mixture	163	1.68	0.35	0.20

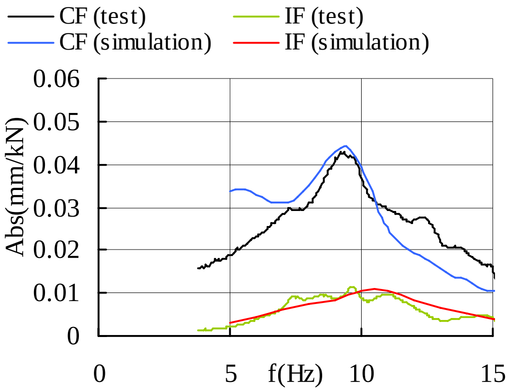

Figure 11 Comparison of response curves of both foundations by test and simulation in Stage 2

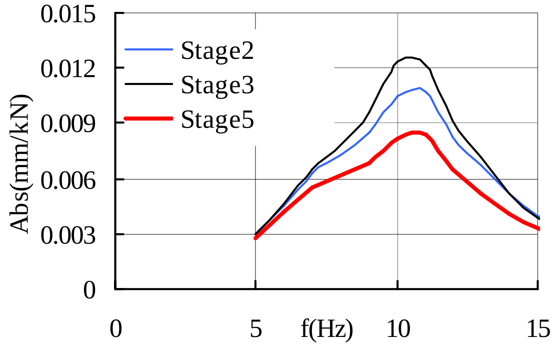

Figure 12 Comparison of response curves of IF by simulation in Stage 2, 3 and 5

5. SIMULATION ANALYSIS OF FORCED VIBRATION TESTS

After the experiments, we carried out the 3-dimensional simulation analyses for stages 2, 3, 5 and 6 using a hybrid approach (Ikeda et al. 2003). In the hybrid approach, both the foundations and soil regions surrounding the foundations, including trenches, are modeled by the 3-dimensional finite element. The thin layer approach is applied to the free field ground regions surrounding the above finite element domain. We also model a cubicle (a power transformation vessel) foundation. Figure 10 shows a bird's-eye view illustration of the hybrid model in Stage 5. Table 3 shows the properties of soil, both foundation blocks and the damping mixture.

Figure 11 illustrates the resonance curves of displacement per unit exciting force, in the direction of the exciting force, on the upper surface of the CF and the IF by the experiments and analysis at Stage 2. The first peak frequency and its amplitude of resonance curves of the CF by the analysis are in substantial agreement with the experiment results. The amplitude of the resonance curve of the IF by the analyses is reasonably close to the average of the test results, and both frequency dependencies are approximately identical. Figure 12 displays the analysis results of the resonance curves concerning the displacement of the IF at Stages 2, 3 and 5. The tendency expressed by the results of the experiment is that the amplitude of the response curves becomes smaller at the peak frequency when the depth of the trench excavated around the foundation block is shallow. The amplitude at the peak frequency at Stage 5 is reduced by about 25% compared with that at Stage 2. This indicates that the attenuation effect of the mixture of damping mixture is higher than that of backfilling soil, and the simulation analysis results agree with the test results.

6. CONCLUSIONS

We have proposed an improved foundation technique which is a procedure of backfilling a newly-adopted damping mixture of asphalt with crushed stones and scrap tire chips into trenches dug along foundations to enhance the attenuation and mitigation performance of the structures. According to the results of cyclic triaxial tests, it was found that the equivalent Young's moduli and the equivalent damping constants of the damping mixture, at the strain level of 0.01 percent and under, became approximately 120MPa and 20 percent, respectively.

After verification of the high damping ability of the proposed mixture by way of cyclic triaxial tests, forced vibration tests on the CF and the IF were conducted. From the results of the experiment and the simulation analyses, it was confirmed that the damping mixture backfilled into the trenches dug along the IF provided favorable attenuation and mitigation performance. The amplitude of the displacement function on the IF at the peak frequency, 9.6Hz, was reduced by approximately 35% compared with that of the CF. After the forced vibration tests, we have continued seismic observation at the experiment site (two types of foundation blocks and their adjacent soil). The results of the analyses of the observation records are mentioned in the accompanying (Part 2).

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