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Analysis on the Dynamic Properties of Hardfill Materials

Yunfeng Peng[1, a] and Yulin Yuan[1, b]

[1] College of Hydraulic & Environmental Engineering, China Three Gorges University, Yichang, China

[a]whpyf@qq.com, [b]947588681@qq.com

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Abstract. Hardfill is a roller compacted cement sand and gravel material which similar to the lean RCC (Roller Compacted Concrete). In recent years, hardfill materials have application in mass structure specifically in hydraulic structures, because of its advantages such as low cost and environmentally friendly. In order to study dynamic properties of hardfill material during earthquake, cyclic loading tests have been carried out. According to the results of tests, the elasticity of stress-strain relationship was confirmed by cyclic loading tests under conditions that the maximum compressive stress didn't exceed the linear range of hardfill material. And than, the elasto-plasticity is observed when cyclic loads exceeds the linear range of hardfill material. Moreover, the reactive products for each specimen were examined, and it was observed that some typical needle structured ettringite was generated due to the blending of cement; the micro-structures of hardfill were studied by means of SEM and EDS.

Introduction

With increasing research on the development and usage of economically and environment friendly materials, many studies on new type structure material. Hardfill, a new type of structure material, which can be considered as a less strict sense lean RCC (Roller Compacted Concrete), is a roller compacted cement sand and gravel material [1]. The hardfill material was first proposed in 1992, which is called CSG (cemented sand and gravel) in Japan [2-4]. It has several advantages, including low cost, simple and quick construction and environmentally friendly. In recent years, hardfill materials has application in mass structure such as airfield runway, ports, docks, roadbed engineering of speedway, and more specifically in hydraulic structures [5-6]. China is known as a prominent earthquake country in the world. Therefore, important civil engineering structures must have sufficient aseismic performance against severe earthquakes. Especially, because the hydraulic structure is very important structure, it must be designed to ensure the safety against seismic loads.

In this paper, introduction of a hardfill material structure, result of stress analyses and dynamic properties of hardfill material confirmed by cyclic loading tests are described. From the test results, it is confirmed that a stress-strain curve clearly showed non-linearity compared with concrete. The elasticity of stress-strain relationship was confirmed by cyclic loading tests under conditions that the maximum compressive stress did not exceed the linear range of hardfill. The purpose of this study is to examine the dynamic properties of hardfill and provide data that may be useful for evaluating the earthquake-resistance capability of hardfill structure.

Introduction of Hardfill Material

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In the face of urgent demands for lower cost and the protection natural environment, future hydraulic structures must be constructed at lower cost and environmentally friendly than in the past. Hardfill is a material prepared by adding cement and water to raw material such as riverbed gravel or excavation rock that can be easily obtained near dam sites, and mixing it by simple devices. Because a quarry, aggregate plants and turbid water treatment facility can be diminished largely by using hardfill, lower cost of dam construction works, protection and conservation of the environment can be achieved. Fig.1 shows a typical production process of hardfill dam [4].

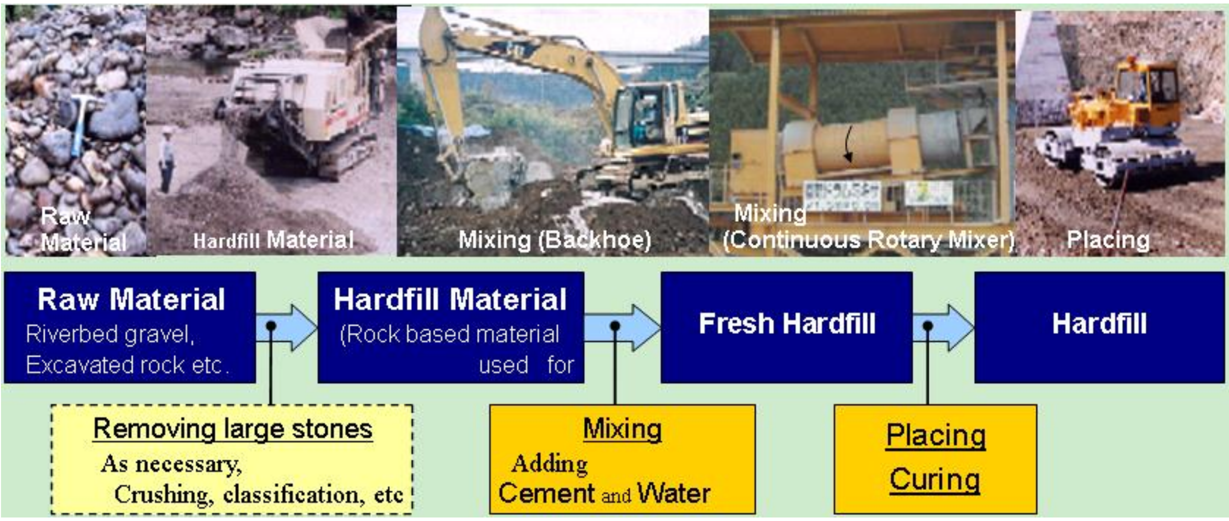
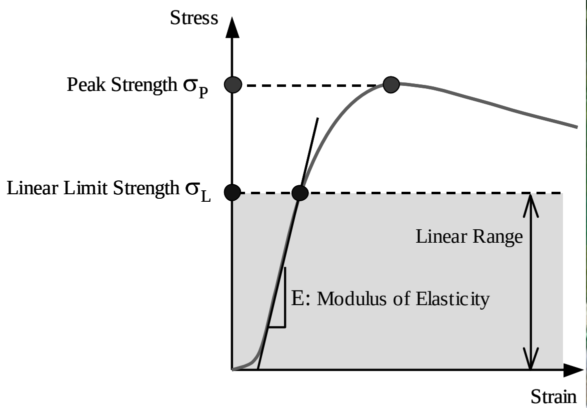


Fig. 1 Hardfill production process

Mechanical properties of hardfill material are effected by the grain size distribution curve of unit cement content, raw material, unit water content and so on. Basic properties of hardfill material, such as modulus of elasticity, compressive strength, tensile strength, stress-strain curve and so on, are obtained by laboratory tests. Fig.2 shows a typical stress-strain curve of hardfill material obtained by a uniaxial compression test [5]. As the shape of stress-strain curve is non-linear, it is considered that hardfill material is an elasto-plasticity material.

As shown in Fig.3, a typical hardfill dam is a new type of dam, which uses a new type of material called "hardfill". The dam has the advantages of both CFRD (Concrete Face Rockfill Dam) and RCCD (Roller Compacted Concrete Dam), and many other advantages of its own, such as greater safety, shorter construction period, lower construction costs and better performance on environmental protection.



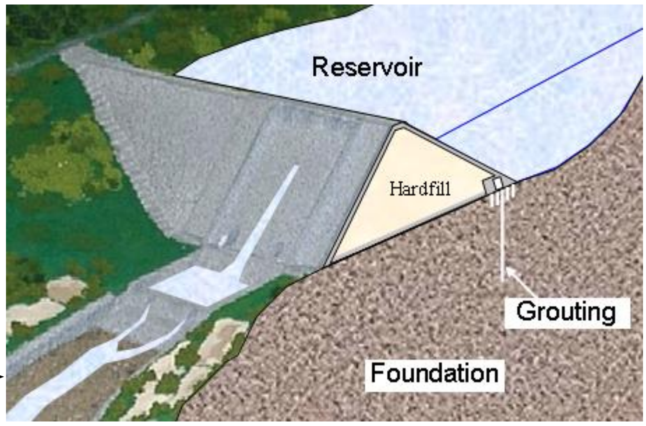


Fig. 2 Typical stress-strain curve of hardfill **Fig.3** Sketch of a hardfill dam

Dynamic Test of Hardfill Material

Test Conditions. In order to investigate dynamic properties of hardfill material under earthquake conditions, cyclic loading tests of hardfill material were carrying out by the uniaxial compression test in a laboratory [7]. Fig.4 shows the uniaxial compression instrument used for tests. The sizes of hardfill material test specimen were 300mm in height and 150mm in diameter (shown in Fig.5). Hardfill test specimen was made by mixing the raw material with cement (80kg/m^3) and water (105-135kg/m^3), and compacted by hand vibrator. Table 1 summarizes the test cases of cyclic loading tests; Fig.6 and Fig.7 show the patterns of cyclic loadings.

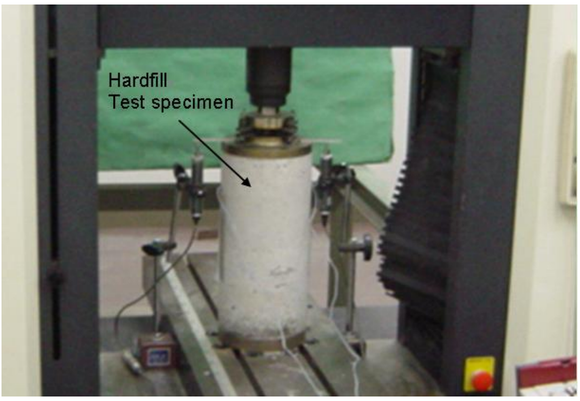


Fig.4 Uniaxial compression test of hardfill material

Fig.5 Test specimen of hardfill material

Table 1 Test cases

Case	Estimated compressive strength of hardfill		Pattern of cyclic loading
	Peak Strength □ σ_p (MPa)	Linear limit Strength σ_L (MPa)	
1	7.5	4.9	Peak load: 0.50σ_L Number of cycles: 5
2	7.5	4.9	Peak load: 0.75σ_L Number of cycles: 5
3	11.8	8.0	Peak load: 0.66σ_L Number of cycles: 20
4	10.2	6.1	Peak load: 0.45σ_L, 0.85σ_L, 1.25σ_L, 1.50σ_L Number of cycles: 1 in each maximum load
5	7.3	4.3	Peak load: 0.50σ_L, 1.15σ_L, 1.35σ_L Number of cycles: 3 in each maximum load
6	7.9	4.8	Peak load: 1.15σ_L Number of cycles: 50

Results of cyclic loading tests. Fig.8 and Fig.9 shows the results of cyclic loading tests. From the results, the linearity of stress-strain relationship was observed when the maximum compressive load did not exceed the linear limit strength (σ_L). The linearity of stress-strain relationship was also confirmed by the result of case 3, shown in Fig.8, even if the number of loading cycles increased. In case 4, peak loads were increased by cycles and exceeded the linear limit strength (σ_L). From the result of this case, it is observed that the elasto-plasticity was clearly appeared in the stress-strain curve and the residual strain increases cumulatively when a cyclic load exceeded the linear range of hardfill material [8].

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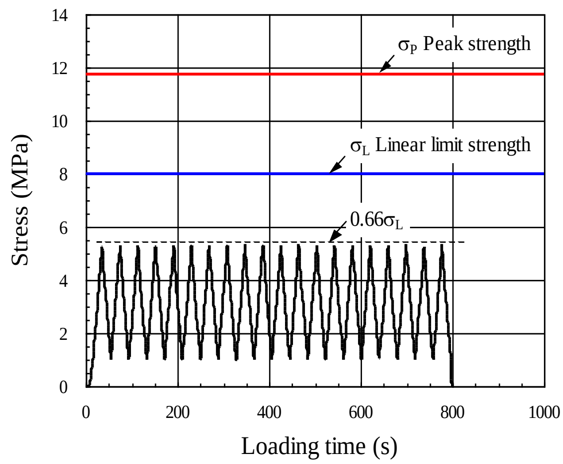

Fig.6 Loading pattern (case 3)

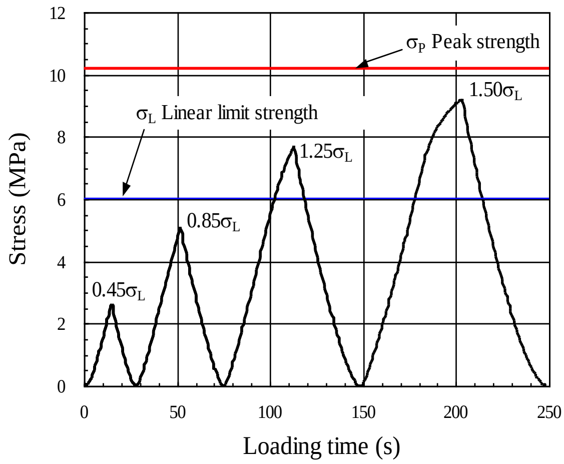

Fig.7 Loading pattern (case 4)

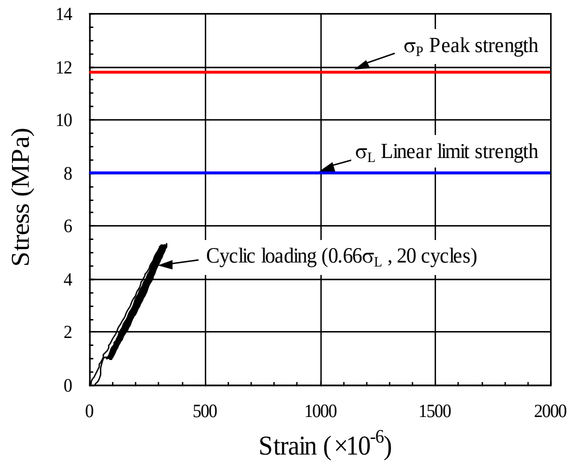

Fig.8 Stress-strain curve (case 3)

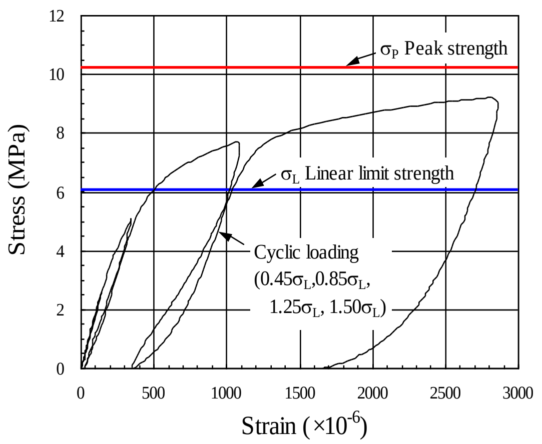

Fig.9 Stress-strain curve (case 4)

Micro-structure of Hardfill Material

In this study, an SEM (Scanning electron microscopy) was used to examine type and distribution of production due to hydration on the surface of a specimen. In addition, its constituents were analyzed by energy dispersive spectroscopy. EDS (Energy dispersive spectroscopy) is an analytical technique used for the elemental analysis or chemical characterization of a sample. From the results, some productions due to the hydration of cement mixed in the hardfill material are observed. SEM results showed that the greater the volume of cement, the greater the generation of needle-shaped ettringite.

Conclusions

In this paper, the characteristics of the dynamic material properties of hardfill material that were clarified by laboratory tests were described, and the micro-structures of hardfill material were studied by means of SEM and EDS. The results of analyses and material tests are summarized in the following.

(1) Dynamic properties of hardfill material were confirmed by cyclic loading tests. The linearity of stress-strain curve was confirmed when the maximum compressive load did not exceed the linear limit strength of hardfill.

(2) SEM results showed that the greater the volume of cement, the greater the generation of needle-shaped ettringite.

(3) In a basic design of hardfill dam, the strength and the modulus of elasticity in linear range should be used as material properties of hardfill material. Therefore, even if the large load that exceed the linear limit strength acted on a dam body in case of an unexpected serious earthquake etc., brittle failure would be hard to occur in the hardfill dam because hardfill material has a wide range of plasticity.

Acknowledgement

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