Study on Structural Characteristics of CSG Dam

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Abstract. CSG is a roller compacted cement sand and gravel material which similar to the lean RCC (Roller Compacted Concrete). In recent years, CSG materials have application in mass structure specifically in hydraulic structures, becase of its advantages such as low cost and environmentally friendly. In this paper, the 3D finite element method (FEM) is used to analyze the deformations and stresses in dam body and the impervious face under different load cases. Different dam slopes and different foundations rigidity in the range of usual engineering condition are considered to study the effects of these factors on the behaviors of the dam and its safety. In order to study dynamic properties of CSG 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 CSG.

Keywords: CSG dam, finite element analysis, structural characteristic, dynamic test

1. Introduction

With increasing research on the development and usage of economically and environment friendly materials, many studies on new type structure material. CSG, 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 CSG 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, CSG materials has application in mass structure such as airfield runway, ports, docks, roadbed engineering of speedway, and more specifically in hydraulic structures[5-6].

2. Trapezoid-Shaped CSG Dam

2.1. Construction of CSG Dam.

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. CSG is a material made by adding little cement to rock-like material such as riverbed gravel or excavation muck that can be obtained easily near dam sites, mixing it briefly with simple and rolling with vibration rollers, which can be considered as a lean RCC. From the Fig.1, CSG shows the elasto-plasticity behavior, only the elastic range of CSG is considered in a design. The "Elastic range strength" is defined as the maximum strength in the elastic range of the stress-strain curve of CSG.

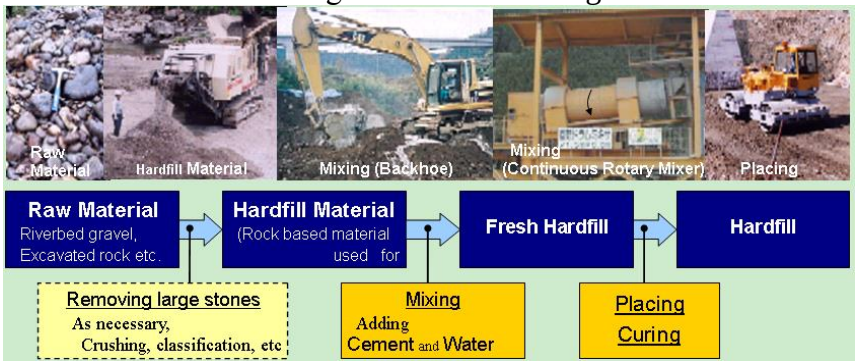


Fig. 1 CSG Production Process

Since continuous mixing plant (Fig.2) can manufacture a large amount of products at short time, continuous mixing plant is suitable for manufacture plant of CSG dam construction. The best feature of this plant is its energy saving effect. This plant is equipped with a static continuous mixer for mixing CSG. This mixer is set up in vertical direction, and then it is possible to mix materials with no electric power but only by gravity force. In addition, continuous mixing plant is more environment-friendly than the conventional batch mixing plant.

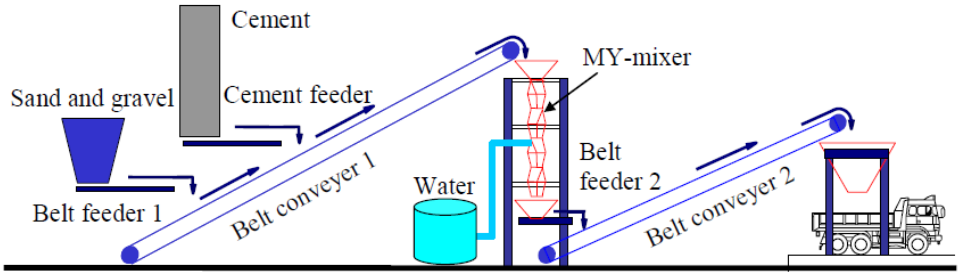


Fig. 2 Outline of Continuous Mixing Plant for CSG

2.2. Shape of CSG Dam.

Mechanical properties of CSG are effected by the grain size distribution curve of unit cement content, raw material, unit water content and so on. Basic properties of CSG, such as modulus of elasticity, compressive strength, tensile strength, stress-strain curve and so on, are obtained by laboratory tests. Fig.3 shows a typical stress-strain curve of CSG obtained by a uniaxial compression test [5]. As the shape of stress-strain curve is non-linear, it is considered that CSG is an elasto-plasticity material.

Fig.4 shows the typical profile which reflects basic characters of CSG dam, which is symmetrical trapezoid-shaped or approximately symmetrical. The shape of the dam body is intervenient between conventional gravity dam and CFRD (concrete faced rockfill dam), and the dam slople can be determined according to some facts of the specific project, such as foundation conditions, height of dam, performance of the filling material, and so on.

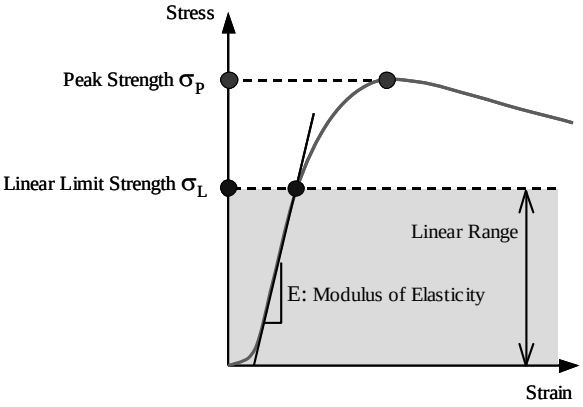


Fig. 3 Typical Stress-strain Curve of CSG

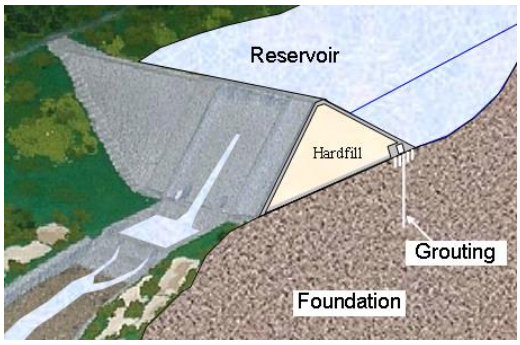


Fig. 4 Sketch of a CSG Dam

3. Stress Characteristics of CSG dam

3.1. FEM Analysis Model.

Three-dimensional FEM analysis status was conducted for static analysis. The height of the CSG dam is 70m and the crest width is 8m with the slope 0.7H: 1V.

3.2. Results of FEM analyses

Stress of the Dam. Fig. 5 shows the maximum and minimum principal stress distribution on dam body. In the σ_1 case, the dominant stress was -0.02MPa, revealing that would not develop tensile stress at all. In the σ_3 case, the dominant stress was -1.8MPa, revealing that much smaller stress is generated in contrast to gravity dam. Because it would not develop tensile stress on dam body, the unconfined compressive strength is the only requirement for CSG. According to Londe's finding[2], it is possible

to achieve a 5MPa(90d) unconfined compressive strength with a cement content of around 50kg/m^3, can meet the requirement for a dam 100m high. It is not only possible to use the low strength CSG as a construction material for the trapezoid-shaped dam, but also gets a high level of safety.

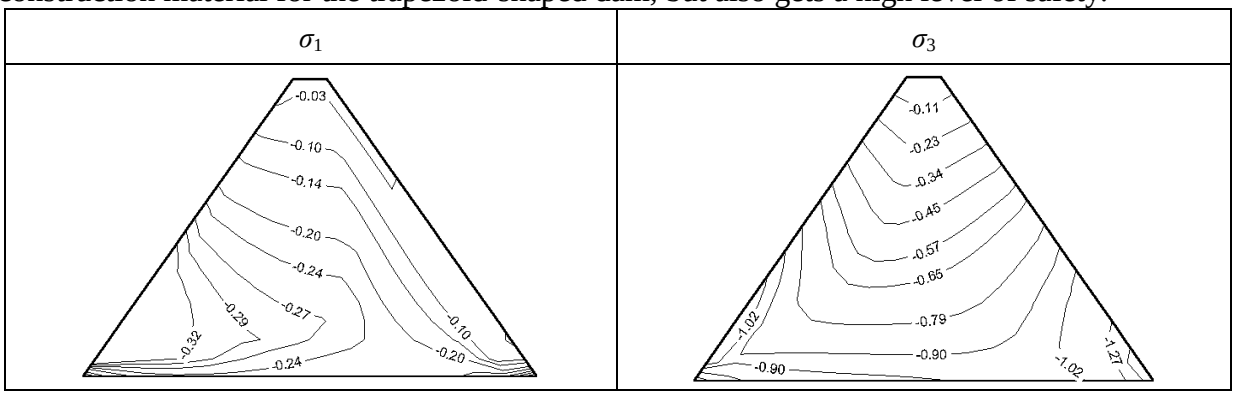
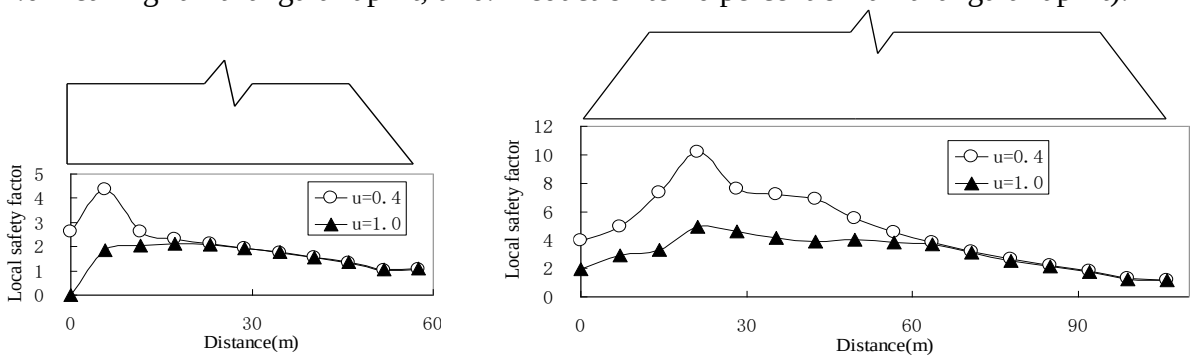


Fig. 5 Principal stress distribution on dam body (Unit: MPa)

Stability analysis of dam foundation. From the viewpoint of structural stability, the symmetrical trapezoid-shaped CSG dam should have greater safety than triangle shape gravity dam. Fig. 6 shows the Distribution on local safety factor against sliding at basement of dam of two shapes respectively (u=1.0 meaning full triangular uplift, u=0.4 reduction to 40 percent of full triangular uplift).



(a) Triangle shape (b) Trapezoid shape

Fig. 6 Distribution on local safety factor against sliding at basement of dam

4. Dynamic Test of CSG

4.1. Test Conditions.

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 order to investigate dynamic properties of CSG under earthquake conditions, cyclic loading tests of CSG were carrying out by the uniaxial compression test in a laboratory [6]-[9].

4.2. Results of Cyclic Loading Tests.

Fig.7 and Fig.8 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 CSG.

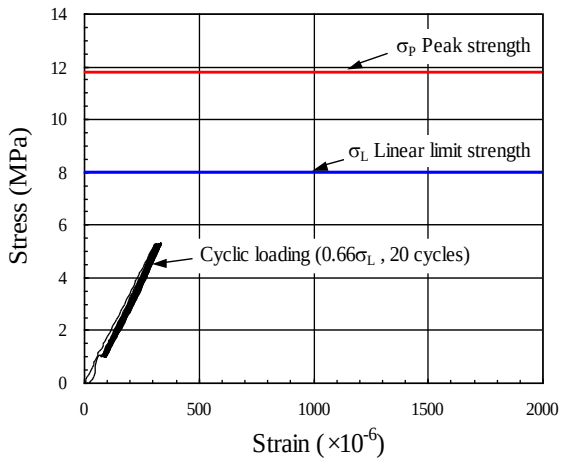


Fig. 7 Stress-strain curve

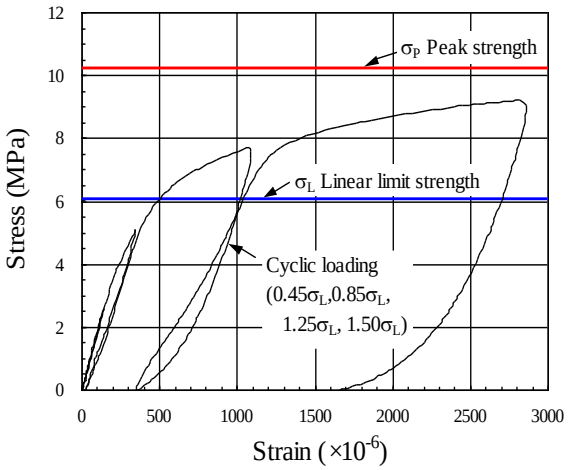


Fig. 8 Stress-strain curve

5. Conclusions

In this paper, the 3D finite element method (FEM) is used to analyze the deformations and stresses in dam body under different cases, and the characteristics of the dynamic material properties of CSG that were clarified by laboratory tests were described. There are some conclusions in the following.

A trapezoid-shaped CSG dam has much bigger weight and longer length for shear resistance than a conventional gravity dam. The safety against sliding of CSG dam is about twice as many as the conventional gravity dam. It is said that the high shear strength of dam foundation is not required in order to satisfy the safety against sliding. As a result, a trapezoid-shaped CSG dam can be constructed even on the poor foundation. Dynamic properties of CSG 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 CSG. In addition, it was also confirmed that the elasto-plasticity was clearly appeared when a cyclic load exceeded the liner limit strength of CSG.

The study and analysis show that CSG dam has greater safety than CFRD or gravity dam, so it's a dam with high safety.

Acknowledgements

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