STRUCTURAL RESPONSE OF SULPHUR-BAMBOO REINFORCED EARTH MAT TO SEISMIC LOADING

by

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SYNOPSIS

This paper presents the preliminary test results of the structural response of a compacted embankment reinforced with bamboo earth mat under various seismic loadings. Observations include the cracking and failure patterns and the time required for failure. In addition, fracture toughness and tensile strength tests of the compacted soil were performed in order to correlate these values to the cracking pattern of the embankment during the seismic loading tests. Good results were found in that the embankment reinforced with the bamboo earth mat gives better performance in comparison with nonreinforcement in all cases studied.

INTRODUCTION

Bamboo as a low-cost construction material has been used in many parts of the world, however, it has not been widely used in today's modern construction field because of its low modulus, low skin friction, and high sensitivity to moisture (Chu,1914; Wang,1944; Narayana and Abdul Rahman,1962; Cox and Geymayer,1969). Many researchers have attempted to use numerous techniques to improve this material by using bitumin, paint, cement, etc., however, studies made at Lehigh using a polymer and/or sulphur-sand coating give favorable results in comparison with these previous techniques (Fang, Mehta and Jolly,1976). Impregnation techniques and increased bond strength for this material are being developed. Considerable work has been done at our laboratory to measure the basic engineering properties of bamboo. Tests indicate that the strength to weight ratios are excellent in tension, compression and flexure for bamboo culms and consequently, show good properties to be utilized as a basic construction material. Numerous applications for the use of bamboo in modern construction fields are also being explored. Some of these applications of sulphur-bamboo are as mat foundations to control sinkholes in limestone regions (Fang and Mehta,1976), slope stabilization, bamboo-pile foundations, retaining walls, concrete or adobe reinforcement in low-cost housing, and reducing heave in expansive clay areas.

The concept of 'reinforced earth' (Vidal,1969; Lee et al,1973) which originated in France involves utilizing a series of thin metal reinforcing strips placed horizontally in layers throughout a mass of granular material. The strips 'reinforce' the material which is then held in place solely by internal friction between the strips and the material. This concept has been confirmed both theoretically and experimentally by Lee et al (1973), Romstad et al (1976) and Shen et al (1976). In recent years, this technique has been used frequently in the U.S.A. to make reinforced earth retaining walls (Lee et al,1973; Shen et al,1976) and construct foundation slabs in dolometric regions having sinkhole problems because of the obvious cost saving over conventional reinforced concrete used for such purposes (Steiner,1975). However, the steel strip used for the reinforced earth is very expensive, especially

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for developing countries where the steel is not only costly but hard to get. Further savings can be obtained by replacing the steel strips with bamboo mats possessing high tensile, flexural and straining capabilities.

The objective of these preliminary experiments was to investigate this concept of bamboo mat 'reinforced earth' for resisting seismic forces under laboratory conditions. The experiments were carried out on a standard shaking table with both compacted sand and clay embankments. Cracking patterns and the time required to reach failure at a given frequency for with- and without-reinforced bamboo mats were observed. Engineering properties of soil including tensile strength and fracture toughness as used in the study are discussed. It is concluded that the utilization of the bamboo mat will be effective for slope control against seismic loading.

EXPERIMENTAL STUDY

A. Test Equipment and Materials

Shaking Table: A standard shaking table with maximum load capacity of 100 pounds (444.8N) was used. The frequency of the table can be adjusted manually while machine is in operation from 10 to 60 cycles per second and adjustable to accelerate and decelerate automatically and uniformly at any selected range within the limits of 10 to 60 cps. Automatic operation is continuous unless interrupted. Displacement is also adjustable while machine is stopped from 0" to 0.150" (0 to 0.38 cm). The table area is 15" x 18" (38.1 cm x 45.72 cm) as shown in Fig. 1.

Soil and Sand: Silty clay with liquid limit = 32, and plasticity index = 11 *(Unified Soil Classification is CL) was used for this study.* The maximum dry density and optimum moisture content determined by standard AASHTO compaction were 106 pcf (16.65 KN/m^3) and OMC = 16%. For the sand, clean uniform river sand was used with a uniformity coefficient = 3.8.

Bamboo: For the short-term laboratory study, there was no significant difference between sulphur treated or nontreated, however, for the long-term in situ condition, the sulphur-treated bamboo strips will give higher bond strength and modulus of elasticity with low swelling potential. The detailed procedure and the performance results of the sulphur-treated bamboo pole is presented in a separate paper (Fang et al,1976). A brief description of this technique is presented as follows: Sand blasting used to remove the smooth skin of air dried bamboo which is then wrapped with thin wire (Ex: chicken wire, plastic, or hemp) along the length of the bamboo. The reason of this is to reduce the swelling during the curing period (or during construction period). Bamboo pole is then soaked in liquid sulphur at a temperature of 120°F for 45 minutes. Just before the air dries the bamboo, a coat of sand is applied on the bamboo surface in order to increase the bond stress.

B. Test Procedure and Results

Compaction: The soil was compacted with a Proctor hammer in a wooden box the same size as the shaking table (see Fig. 1). The molded dry densities vary from 100 pcf to 120 pcf and the molding water content varies from 10% to 18%. *The slope of the compacted embankment varied from 1:1, 1:1.5, 1:2, 1:2.5,* 1:3 and 1:3.5. The height of the embankment varied from 4" to 6" (10.16 cm to 15.24 cm). Regarding the size of the bamboo strip, the length and spacing can be estimated theoretically by use of limit analysis techniques as suggested by Fang et al (1973) and shown in Fig. 2. For the sand, three densities (dense, medium and loose) were used and each case was saturated during the testing.

Seismic Loading: Six tests were performed with varied frequencies from 10 to 60 cps. Two displacements were used: 0.05" (0.123 cm) and 0.10" (0.245 cm). During the tests, the cracking patterns and cracking growth were observed with time for a given frequency. Typical results are shown in Figs. 2 and 3.

Fracture Toughness and Tensile Strength Tests: In addition to the seismic loading tests, fracture toughness, K and tensile strength tests were also performed on the compacted clay. The purpose of these test results intends to correlate the cracking pattern of the embankment during the seismic loading tests. The tensile strength test was performed by unconfined penetration test (known as the double-punch test) as developed by Fang and Chen (1971). The toughness test was performed by use of a standard 3" x 3" x 0.25" (7.62 cm x 7.62 cm x 0.635 cm) specimen. These tests were performed at various dry densities and moisture contents, the same as the seismic loading tests. In all cases, the higher tensile strength and toughness value existed on the dry side of the optimum moisture conditions. For this study, the higher values existed at moisture content equal to 14% which is 2% above the optimum moisture condition (the optimum moisture content of compacted soil for this study is 16%).

SUMMARY AND CONCLUSIONS

1. For all cases, the clay embankment without the bamboo mat fails quickly, as soon as the cohesion and friction forces are overcome, whereas, the clay reinforced with a bamboo mat lasts longer under the same seismic loading (see Figs. 2 and 3).

2. For in situ long-term conditions, the bamboo mat treated with sulphur will give higher stresses and have a low swelling potential. The length and spacing of the bamboo mat can be estimated during the planning stage as suggested by Fang et al (1973).

3. Higher tensile strength and fracture toughness, K exist on the dry side of the optimum moisture conditions. During the seismic loading testing, it was also indicated that the cracking pattern and growth rate is less at the dry side of optimum condition.

4. For in situ compaction for embankments, the maximum compaction effort should be used, especially around the bamboo mat. The air void around the bamboo mat should be at a minimum in order to reduce swelling and decay of the bamboo.

5. Using the bamboo mat to replace the steel strips will generate great savings and will serve the same purpose for the 'reinforced earth' idea.

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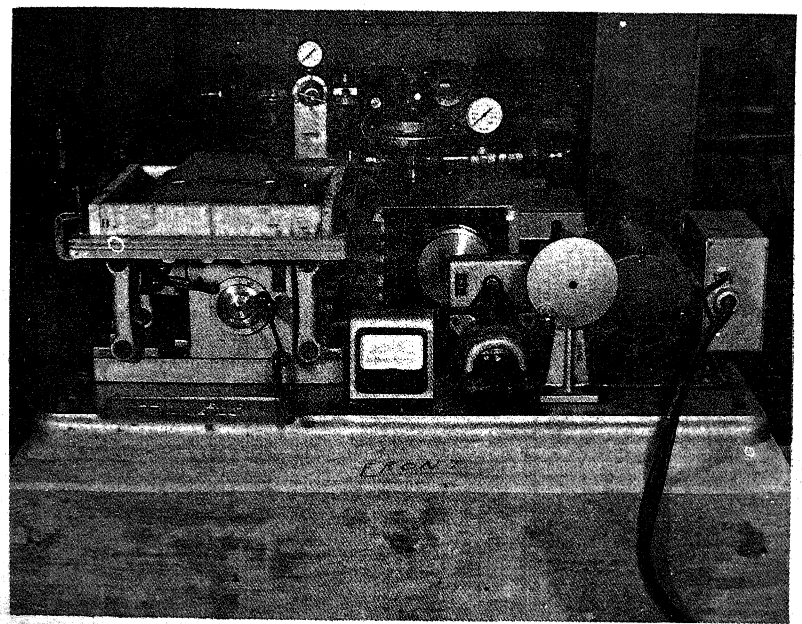

Figure 1 LABORATORY STUDY OF BAMBOO MAT USED TO RESIST SLOPE FAILURE UNDER SEISMIC LOADING

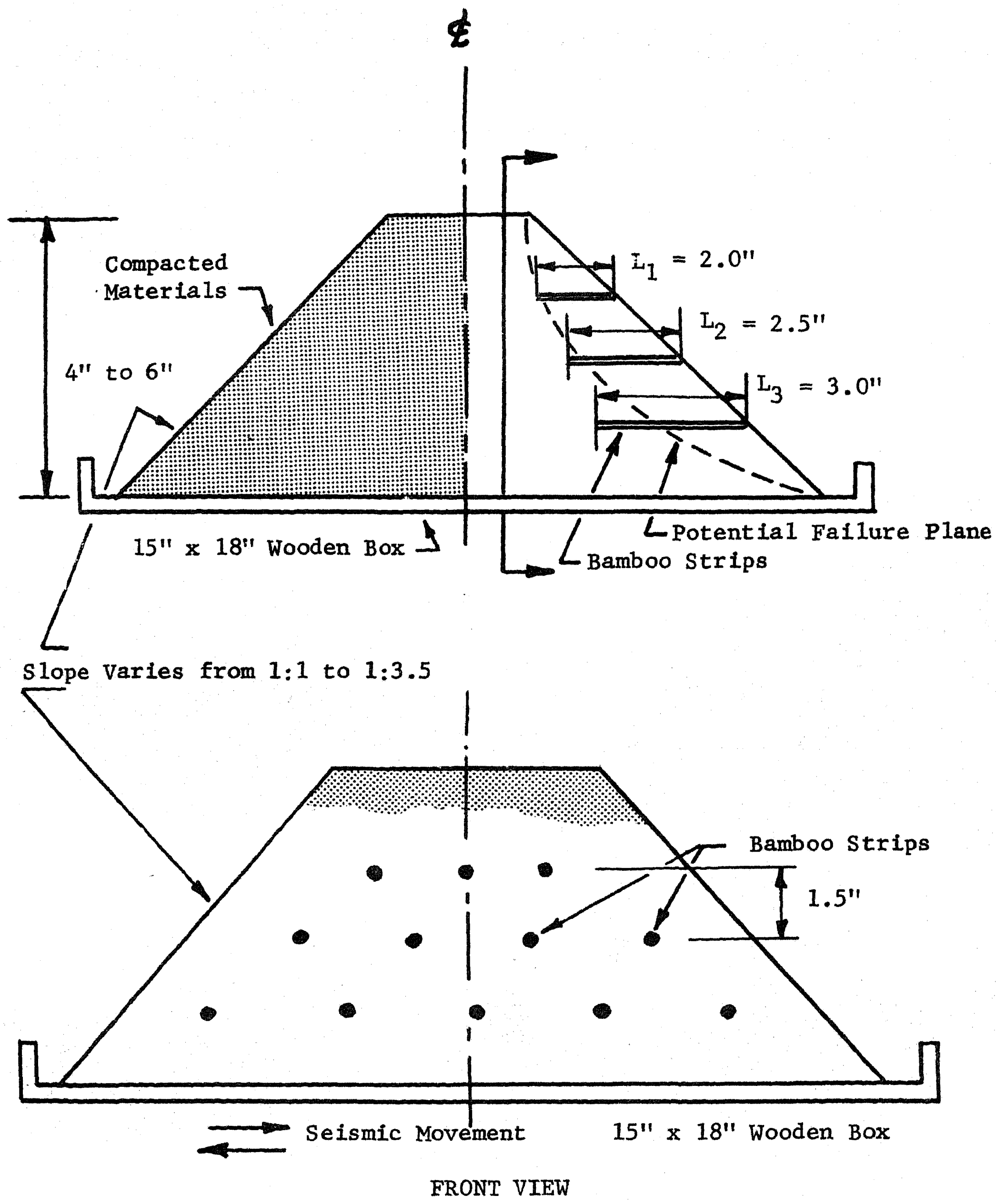

Figure 2 TYPICAL SET-UP OF BAMBOO EARTH MAT FOR RESISTING SEISMIC LOADING UNDER LABORATORY CONDITIONS

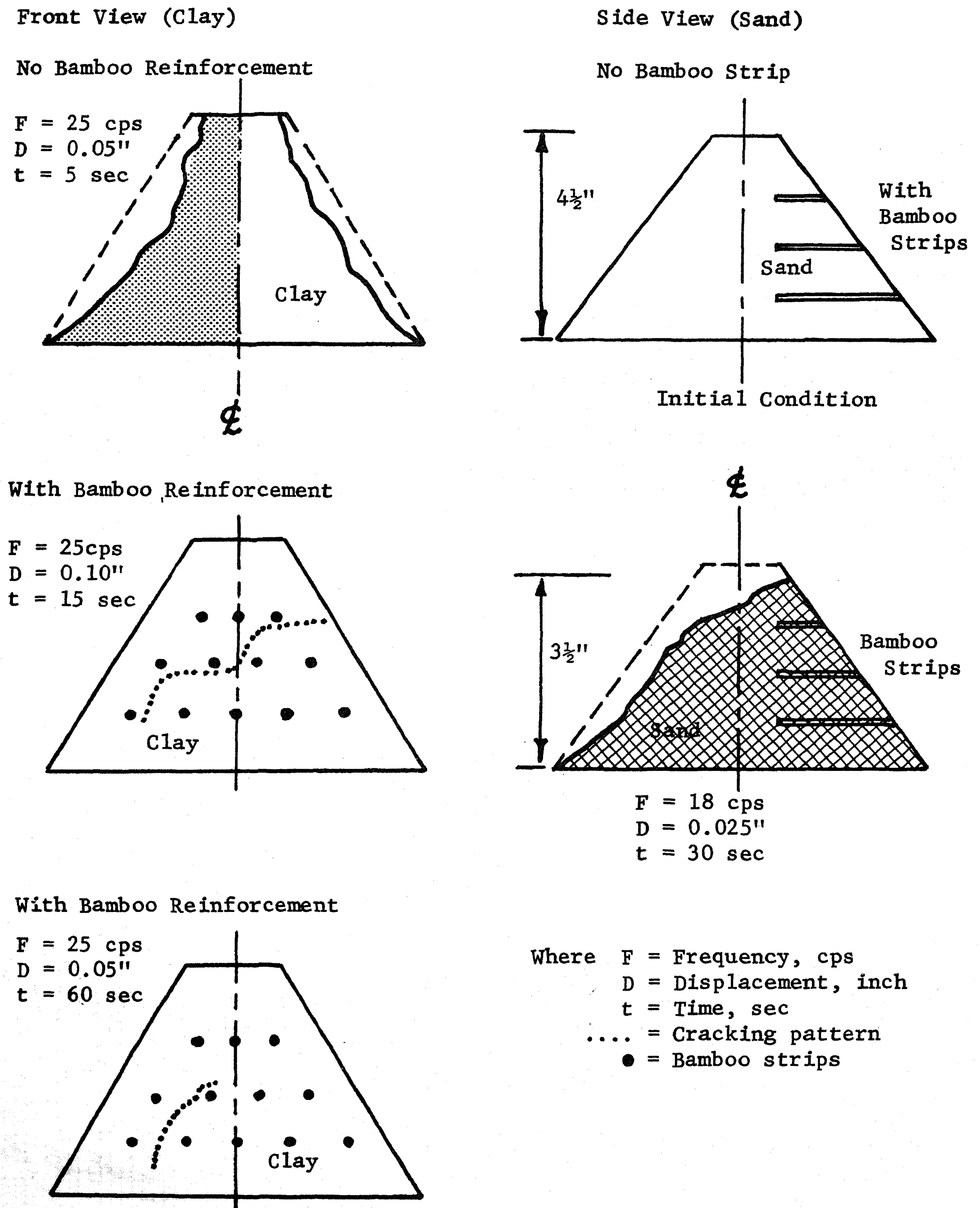

Figure 3 TYPICAL CRACKING AND FAILURE PATTERN OF COMPACTED EMBANKMENT WITH OR WITHOUT BAMBOO REINFORCED UNDER SEISMIC LOADING

DISCUSSION

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The paper brings out the versatility of the reinforced earth in various applications. A special advantage of the reinforced earth material during earthquake is its ability to undergo large deformation and maintain good structural resistance in a new displaced position unlike other forms of construction. This is observed very clearly in grouted bolt supports in tunnels having large rock movements in retaining walls resisting slide movements.

The author also mentions about Bamboo reinforced adobe in low cost housing. The arrangement of the reinforcement in walls for this purpose suggested by author would be of interest.

Author's Closure

Not received.