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RESCUE Testing of Full-Scale In-Situ Structures

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SYNOPSIS At SRI International a state-of-the-art technique for testing large-scale structures to dynamic motion resembling that from a large magnitude earthquake has been developed. The tecnhnique, referred to as repeatable earth shaking by controlled underground expansion (RESCUE), may allow actual full-scale structures to be tested in-situ. In this paper we present the results of a finite element simulation of a full-scale highway overpass loaded from ground motion produced by the RESCUE technique. Results indicated that the RESCUE technique could generate significantly enough ground motion to excite failure damage modes.

INTRODUCTION

For the past decade researchers at SRI International have been developing a technique for generating ground motion resembling that from an actual large magnitude earthquake to enable dynamic testing of full-scale complete structures (Bruce et al., 1970; Simons et al., 1985). The technique, referred to as repeatable earth shaking by controlled underground expansion (RESCUE), consists of placing an array of specially designed sources in the ground to load the soil with a series of pressure pulses. The pressure pulse characteristics can be tailored to maximize the response of the structure being tested. Because RESCUE loads the soil around the structure, it allows study of the soil-structure interaction effects on the structure's response.

RESCUE can be used in two ways. First, it can be used to set up a large-scale testing facility. Large-scale structures of interest would be constructed on a permanent soil test bed that is loaded using RESCUE sources. This application of RESCUE would produce a dynamic testing facility resembling a large-scale shaking table but with inclusion of soil. Second, RESCUE can be fielded around existing structures to test the dynamic response of actual full-scale structures in situ.

This paper outlines the RESCUE experimental technique and its application to testing highway overpass structures. Finite element calculations were performed to determine the feasibility of using the RESCUE technique to study the dynamic response of a two-bay reinforced concrete highway overpass to strong ground motion. The results of the calculations showed that the RESCUE technique could be used to excite large displacement response of the highway overpass, possibly leading to structural failure.

EXPERIMENTAL NEED

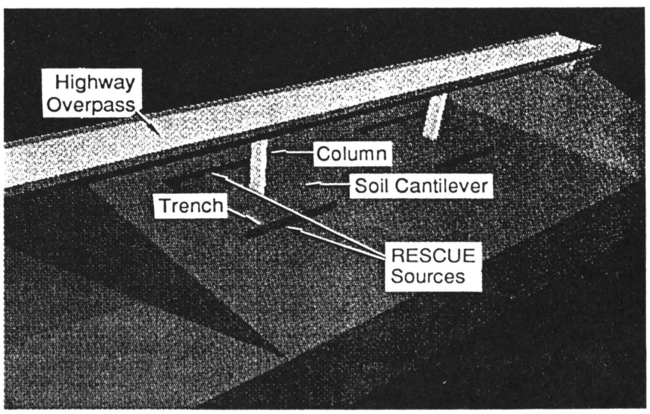
Currently, three research techniques are commonly used to evaluate the ability of a structure to withstand earthquake loading. First, quasi-static testing is performed on large-scale structural components, such as a single column of a highway overpass. This testing technique has proved very useful for evaluating relative component strengths for different design details, such as highway overpass columns with and without steel jackets. However, this technique does not reveal how strengthening a specific component of a structure influences the response of the complete structure. For example, adding steel jackets to columns may prevent the columns from failing, but it may simply transfer failure to another area, such as the foundation. Thus, to evaluate the overall response of a structure, it is necessary to perform tests on complete structures.

The second research technique consists of dynamically shaking small-scale structures using a shake-table. This technique is useful for evaluating the response of a complete structure. However, only relatively small-scale structures can be tested, and for systems in which soil-structure interaction is important, it is difficult to accurately include the soil.

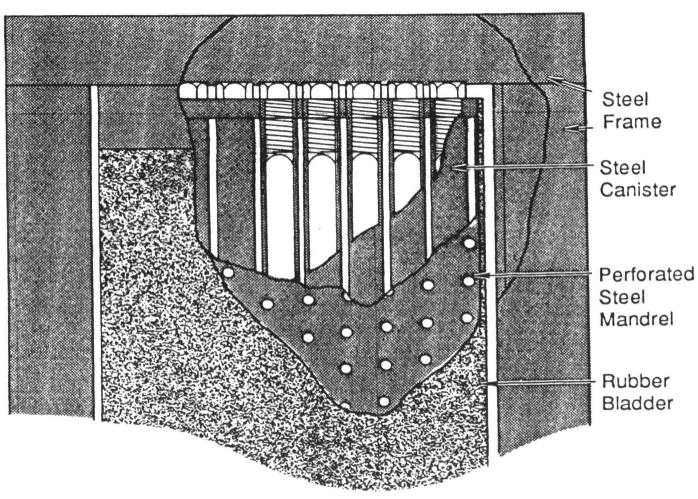
The third research technique is to study structural damage resulting from an actual earthquake. This technique has been effective for understanding the response of complete structures including the surrounding soil and then designing earthquake-safe structures. However, the time between earthquakes is typically long and unpredictable. This suggests that controlled testing of large-scale complete structures with their soil foundations is needed. RESCUE is a technique that would complement this technique as well as large-scale component testing and small-scale shake table testing.

EXPERIMENTAL TECHNIQUE

The RESCUE technique produces ground motion by simultaneously expanding a planar array of buried vertical sources. This expansion dynamically moves the soil, which excites structural response of the structure. Because the sources do minimal damage to the surrounding soil, sequential pulses of ground motion can be applied. In applying the RESCUE technique to test a highway overpass, the RESCUE sources would be placed in trenches surrounding the highway overpass columns. The technique is shown schematically in Figure 1a. The trenches that encompass the RESCUE sources form a soil cantilever. The dimensions of the soil cantilever as well as the pressure pulse on the soil generated by RESCUE can be tailored to maximize the dynamic response of the structure being tested.



(a) RESCUE experimental technique schematic.



(b) Source design (viewed from the test structure).

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Figure 1.

The source design shown in Figure 1b consists of a rubber bladder around a rectangular mandrel. Propellant (rifle powder) is burned in steel canisters inside the source, producing high pressure gas that is vented into the source in a controlled manner, causing expansion of the rubber bladder against the soil. When the bladder expands, it moves the soil. The source is surrounded by a steel frame that prevents failing of the soil at the free surface. The sources can be lined up (Figure 1a) to increase the width of the test area. Each source can contain up to eight canisters to produce a maximum of eight pulses.

The characteristics of the generated pressure pulse can be controlled. The peak pressure depends on the amount of propellant burned in the canister. The rise time of the pulse depends on how quickly the gas from the canisters is vented into the rubber bladder, and the pulse duration depends on the timing of the release of pressure from the rubber bladder to outside the source.

FEASIBILITY OF USING THE RESCUE TECHNIQUE TO TEST A HIGHWAY OVERPASS

To illustrate the concept of using the RESCUE technique to test a full-scale in-situ highway overpass, we performed finite element calculations using the finite element code DYNA3D. The primary objective was to determine the feasibility of using the RESCUE technique to perform dynamic testing of a full-scale highway overpass. The loading characteristics and dimensions of the soil cantilever were designed to produce a large displacement response of the highway overpass.

The highway overpass was modeled as a three-span structure with two columns and two abutments and with spans of 120 ft between the columns and between the columns and the abutments. The column dimensions were a cross section 10 ft by 6 ft and a height of 35 ft. As a foundation, the column was embedded 20 ft into the soil.

The cross section of the bridge deck was a box beam construction with an overall height of 7 ft and with a roadway 32 ft wide. We modeled an expansion joint in the span between the two columns adjacent to the right column (shown in Figure 1a).

The trenches around the bridge column were 40 ft deep and 50 ft on a side, producing a 50-ft-square soil cantilever with the bridge column at the center. The applied loading was a series of 6 haversine pressure pulses at a frequency of 2.5 Hz, with a peak pressure of 200 psi and a pulse duration of 0.2 s. To account, in an approximate way, for the effects of the hydrostatic pressure of the soil with depth, the pressure profile along the vertical dimension of the cantilever was assumed to be linear with a peak pressure of 200 psi at the ground surface and zero pressure at the base of the soil cantilever

Pressure was applied to two adjacent faces of each cantilever resulting in ground motion at 45 degrees to the direction of the roadway. The loading on the two columns was not in phase; we assumed a delay of 0.020 s between the loading of the left and right column. We assumed gravity loading was present.

The soil was modeled as an elastic material with a Young's modulus of 1×10^6 psi and a Poisson's ratio of 0.15. The concrete was modeled using the concrete model available in DYNA3D with an assumed unconfined compressive strength of 3500 psi. We assumed a reinforcement ratio of 2% steel in the columns and in the column/span joints. At the expansion joint we assumed a tensile strength for the concrete of 400 psi.

The response of the overpass is shown in Figures 2 and 3. Figure 2 shows displacement histories in the transverse and longitudinal direction at the base of the column, at the top of the column, and at the middle of the center span. The peak ground motion at the base of the column was about 8 inches peak to peak in both the transverse and longitudinal direction. The displacements at the top of the column and at midspan were considerably less during the initial portion of the shaking. At about 1 s, the concrete at the expansion joint fractured and the right end of the center span fell to the ground as shown in Figure 3.

CONCLUSIONS

The RESCUE technique can tailor the loading characteristics and the test site (soil cantilever dimensions) to maximize the excitation of a structure at a desired frequency response. The finite element calculations show that the RESCUE technique can be used to excite the low frequency and large displacement response modes of a highway overpass and to investigate the dynamic response of the structure including soil-structure interaction. The RESCUE technique could be used to study the dynamic response for a wide variety of highway overpass designs having different frequency response characteristics.

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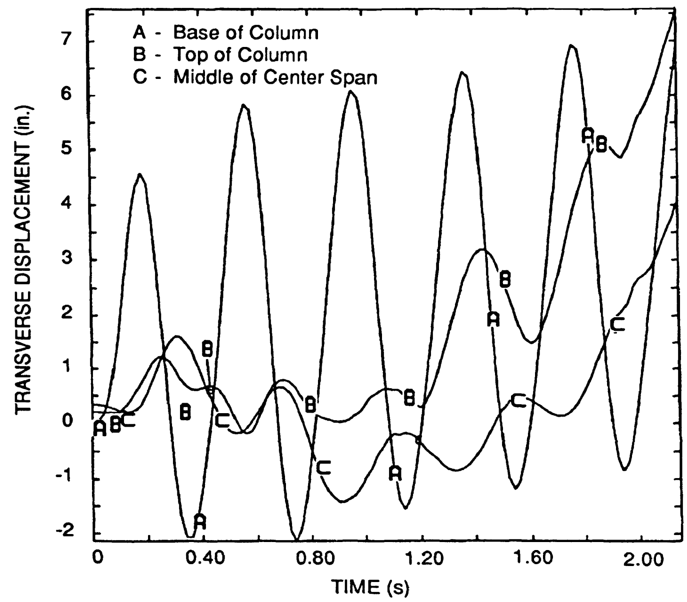
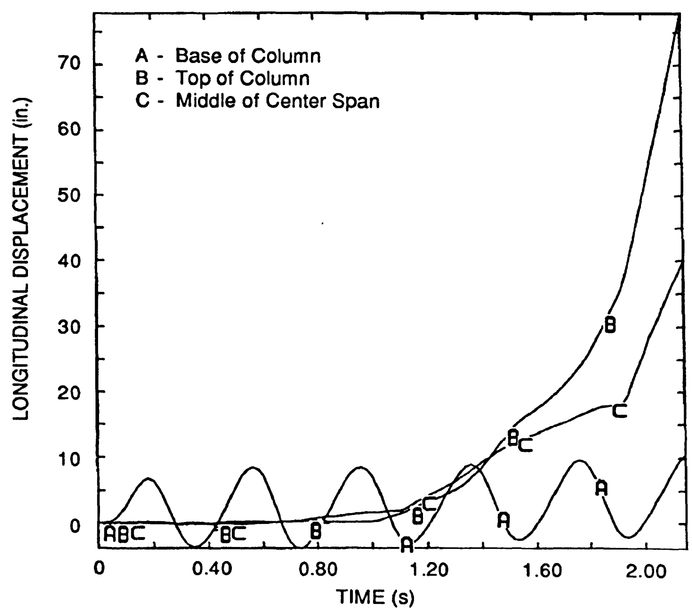


(a) Transverse Direction



(b) Longitudinal Direction

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Figure 2. Displacement histories of highway overpass.

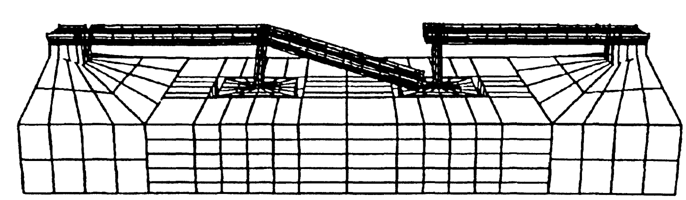

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Figure 3. Highway overpass at 2.0 s.