Using the Rescue Technique to Investigate the Soil–Structure Interaction for a Nuclear Reactor

P. R. Gefken, J. W. Simons
SRI International, Menlo Park, CA USA

INTRODUCTION

SRI International is conducting an ongoing program, funded by NSF, to develop an experimental technique for shaking soil-structure systems to large-amplitude earthquake-like ground motions (Bruce et al., 1979; Simons et al., 1985). The technique, called repeatable earth shaking by controlled underground expansion (RESCUE), produces pulses of ground motion by controlled expansion of an array of rubber bladders buried in the ground. At small scale, the technique can be used to conduct carefully controlled scale-model experiments to study the dynamic response of soil-structure systems to ground motion and to help verify computer codes. At large scale, the technique has the potential for investigating dynamic response of in situ structures.

This paper briefly describes the RESCUE experimental technique and its application to testing of large- and small-scale in-situ nuclear reactor models. Finite element calculations were performed to determine the feasibility of using the RESCUE technique to study the dynamic response of General Electric's (GE's) design for a buried, base-isolated nuclear reactor, PRISM. The results showed that the RESCUE technique could be used to excite large displacements for the low frequency response modes of the PRISM reactor.

EXPERIMENTAL TECHNIQUE

The RESCUE technique produces ground motion by simultaneous expansion of a planar array of buried vertical sources. This expansion moves the soil, which excites the structure. Because the sources do minimal damage to the surrounding soil, sequential pulses of ground motion can be applied to the structure. The technique is shown schematically in Fig. 1a.

The source design shown in Fig. 1b comprises 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. 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 (Fig. 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 loading characteristics are controlled by the amount of propellant and timing of the venting of gases from the steel canisters into the rubber bladder and from within the rubber bladder to outside the source. The venting time of the gases into the rubber bladder controls the pulse rise time and the venting of gases from within the rubber bladder to outside the source controls the

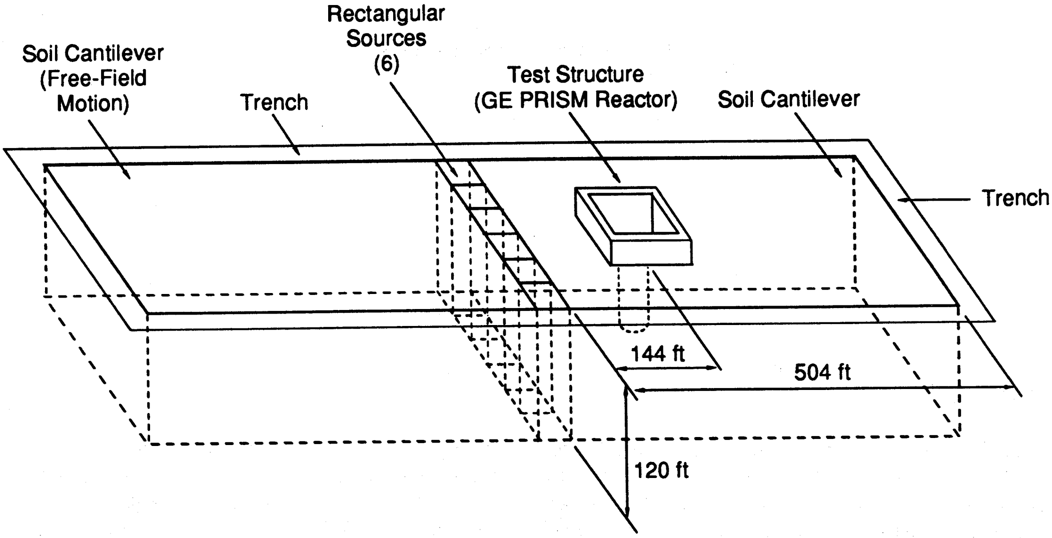

Figure 1a. RESCUE experimental technique schematic.

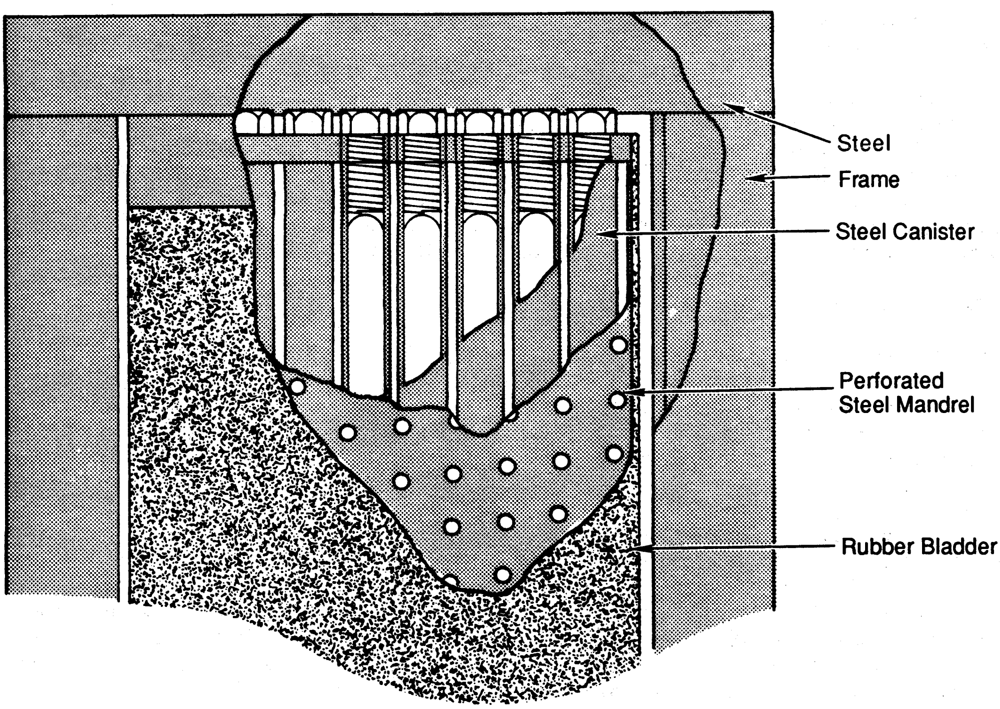

Figure 1b. Source design (viewed from the test structure).

pulse duration. Ground motion can be increased by digging trenches around the test site, as shown in Fig. 1a, to produce a soil cantilever. The dimensions of the soil cantilever and the loading characteristics can be optimized to maximize the response of the test structure. The design shown in Fig. 1a allows testing on both sides of the sources. If one side is kept vacant, the sources simultaneously load a soil cantilever with and without an in-situ structure, allowing comparison of the soil response with the structure to that of the free-field motion.

APPLICABILITY OF THE RESCUE TECHNIQUE TO TESTING OF NUCLEAR REACTORS

To illustrate the applicability of the RESCUE technique to testing of small- and large-scale in situ nuclear reactor models, we performed finite element computations on a full-scale GE PRISM reactor using the DYNA3D finite element code. The primary objective was to determine the feasibility of using the RESCUE technique to perform dynamic testing of the PRISM reactor. The loading characteristics and dimensions of the soil cantilever were designed to maximize the response of the PRISM reactor.

The reactor was modeled as a rigid body supported by base isolators within a rigid silo. The horizontal and vertical stiffness of the base isolators were chosen to produce the correct natural frequencies in the horizontal and vertical directions (0.75 and 28 Hz) for the actual PRISM reactor. The damping of the base isolators was not included. Soil properties were those of the soil at our testing site at Camp Parks near Livermore, California, and are summarized in Table 1.

Table 1

CAMP PARKS SOIL PROPERTIES

Weight: 120 lb/ft^3
Shear Modulus: 2.00×10^3 psi
Bulk Modulus: 1.25×10^4 psi
Compression Wave Speed: 960 ft/sec
Shear Wave Speed: 640 ft/sec

The applied loading characteristics chosen consisted of a pressure pulse with a peak pressure of 100 psi near the surface decaying linearly to zero at the cantilever base. The pulse duration was 1 second. The dimensions chosen for the soil cantilever were length of 504 feet and depth of 120 feet. The PRISM reactor was located 144 feet away from the loaded surface (Fig. 1a). These soil cantilever dimensions and the applied loading produced the displacement response spectrum for the soil motion shown in Fig. 2a at the location of the PRISM reactor. At the horizontal natural frequency of 0.75 Hz (natural frequency of PRISM reactor), a maximum displacement of 20 inches is achieved. This displacement is approximately equal to the maximum distance the PRISM reactor can translate within the silo before hitting the silo walls, as shown in Fig. 2b. A vertical displacement of 0.03 inch was produced at a frequency of 28 Hz. Rotations of the PRISM reactor within the silo were small.

Figs. 3a and 3b show the respective horizontal and vertical velocity response spectra (solid lines) for the soil motion near the silo containing the PRISM reactor. These spectra are compared with design spectra (dashed lines) calculated using the NRC site-dependent guideline spectra for a magnitude 6.5

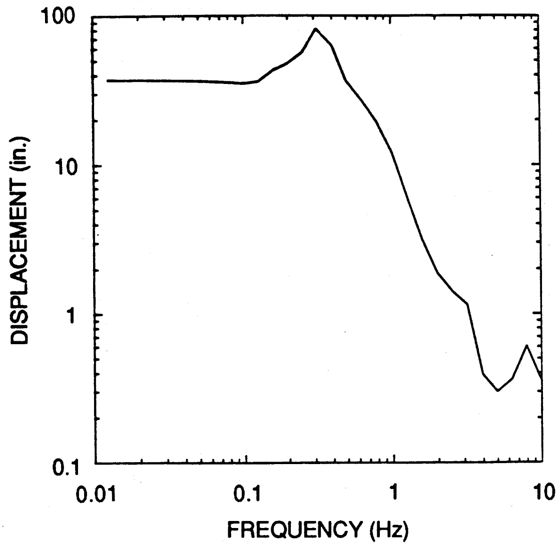

Figure 2a. Displacement response spectrum for horizontal motion.

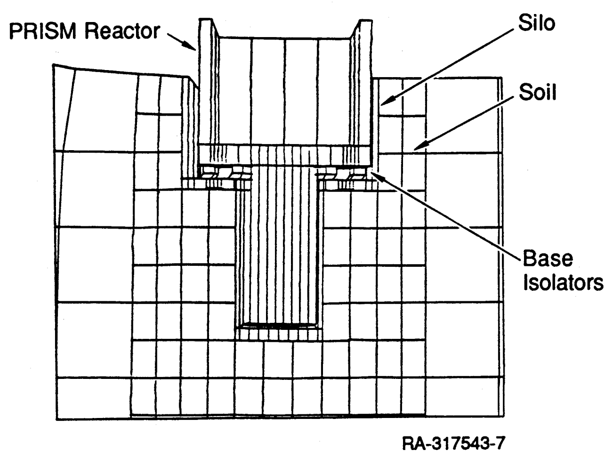

Figure 2b. Maximum relative position of reactor in silo.

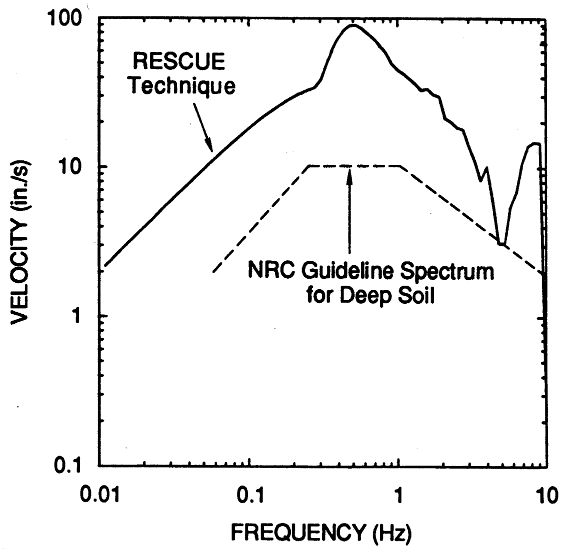

Figure 3a. Velocity response spectra for horizontal motion.

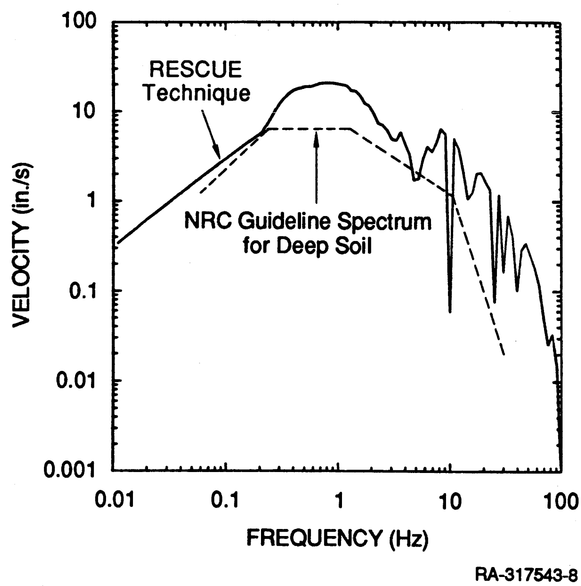

Figure 3b. Velocity response spectra for vertical motion.

earthquake at an epicentral distance of 30 miles in deep soil (Reddy, 1983). For the horizontal and vertical soil motion, the RESCUE technique exceeds this design spectra over a wide range of frequencies.

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 computations illustrate that the RESCUE technique can be used to excite the low frequency and large displacement response modes of GE's PRISM nuclear reactor to determine the response of the structure including the silo and soil. Furthermore, the horizontal and vertical soil motion near the silo exceed the NRC guideline velocity response spectrum for a 6.5 magnitude earthquake with an epicenter 30 miles away. The RESCUE technique could be used to study the dynamic response for a wide variety of nuclear reactor designs with different frequency response.

REFERENCES

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