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EVALUATION OF SEISMIC SPATIAL INTERACTION EFFECTS THROUGH AN IMPACT TESTING PROGRAM (U)

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SEISMIC SPATIAL INTERACTION EFFECTS-EVALUATION THROUGH AN IMPACT TESTING PROGRAM

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ABSTRACT

The consequences of non-seismically qualified objects falling and striking essential, seismically qualified objects is an analytically difficult problem to assess. Analytical solutions to impact problems are conservative and only available for simple situations. In a nuclear facility, the numerous "sources" and "targets" requiring evaluation often have complex geometric configurations, which makes calculations and computer modeling difficult. Few industry or regulatory rules are available for this specialized assessment.

A drop test program was recently conducted to "calibrate" the judgment of seismic qualification engineers who perform interaction evaluations and to further develop seismic interaction criteria. Impact tests on varying combinations of sources and targets were performed by dropping the sources from various heights onto targets that were connected to instruments.

This paper summarizes the scope, test configurations, and some results of the drop test program. Force and acceleration time history data and general observations are presented on the ruggedness of various targets when subjected to impacts from different types of sources.

INTRODUCTION

The consequences of Seismic Category II objects ("sources") falling and interacting with Seismic Category I objects ("targets") during an earthquake has been an analytically difficult problem. These interactions are often referred to as II/I interactions. The wide variety of equipment source and target combinations that exist in any facility adds to this challenge. In addition, the analytical complexities introduced by various structural characteristics, geometric configurations, and impact loads make it difficult to predict the consequences of II/I interactions by analytical means.

The criteria that govern the Seismic Qualification Utility Group (1991) evaluation of target and source interactions are based on engineering judgment concerning failure mode, which must be both credible and significant. Although there are several EPRI and NUREG documents that address seismic interactions from the view of identifying potential hazards (Kennedy et al. [1991], Thatcher [1989a], Thatcher [1989b], and Stevenson and Smith [1990]), guidance related to predicting damage resulting from component interactions is limited. In the case of protective barrier design, conventional evaluation procedures such as *NUREG-800, Standard Review Plan,* Section 3.5.3 (NRC 1981), are applied in cases where fragments strike simple structural elements. However, conventional evaluation procedures are not readily applied to the irregularly shaped sources and targets, which are common in many industrial facilities.

SOURCE AND TARGET SELECTION

A test program was conducted to evaluate the potential effects of seismic impact from falling objects for various combinations of sources and targets in existing facilities. Sources and targets were chosen based on a seismic interaction review of one facility (ASME 1992). In that review, over 130 potential interaction hazards were identified during field walkdowns of 25 systems. Many of these hazards can be grouped into the equipment categories listed below.

Sources include:

- Pipe and conduit
- Cable tray
- HVAC duct
- Cement - fiberglass wallboard
- Ceiling panel
- Fluorescent and incandescent light fixtures

Targets include:

- 3/4-inch conduit
- 2-inch conduit

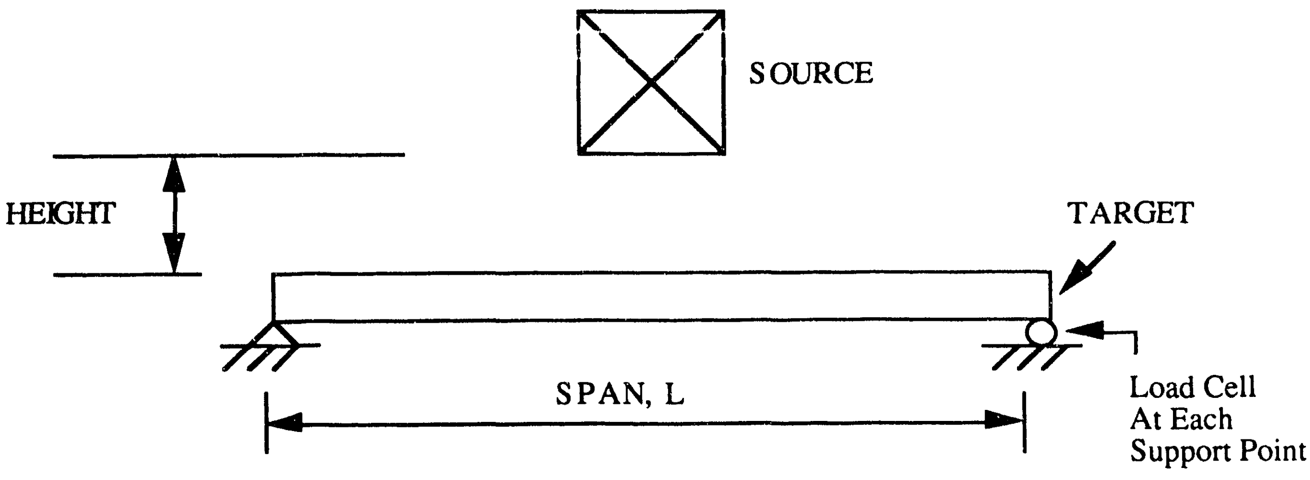

Figure 1. Simple Support Beam Configuration

- HVAC duct
- Protective barrier
- Aircraft safety cable
- Electrical cabinets (approximately 5 in. × 10 in. × 19 in. and 4 in. × 7 in. × 14 in.)
- Electrical cabinet (approximately 24 in. × 25 in. × 70 in.) with relays mounted inside
- Emergency light battery pack enclosure

The test program consisted of various combinations of these sources and targets. The sources were dropped from various heights onto targes connected to instrument equipment.

TEST INSTRUMENTATION AND RECORDS

Targets such as the conduits, HVAC duct, and the protective barrier were arranged in a simple support beam configuration with load cells mounted at each support point (Figure 1). The aircraft safety cable target was draped below the source to capture it during the fall (Figure 2). The cable was connected to load cells at each end. Force/time history plots were generated for all of these test cases.

The large electrical cabinet target contained an accelerometer mounted near the relay locations. This configuration produced an acceleration time history plot for each of the tests. In addition, the relays were electrically energized and monitored for chatter during the tests.

Photographs were taken of the test articles before and after testing to help characterize the results. In addition, all drop tests were filmed using a high-speed camera. The movie film was later converted to slow-motion video for evaluation purposes.

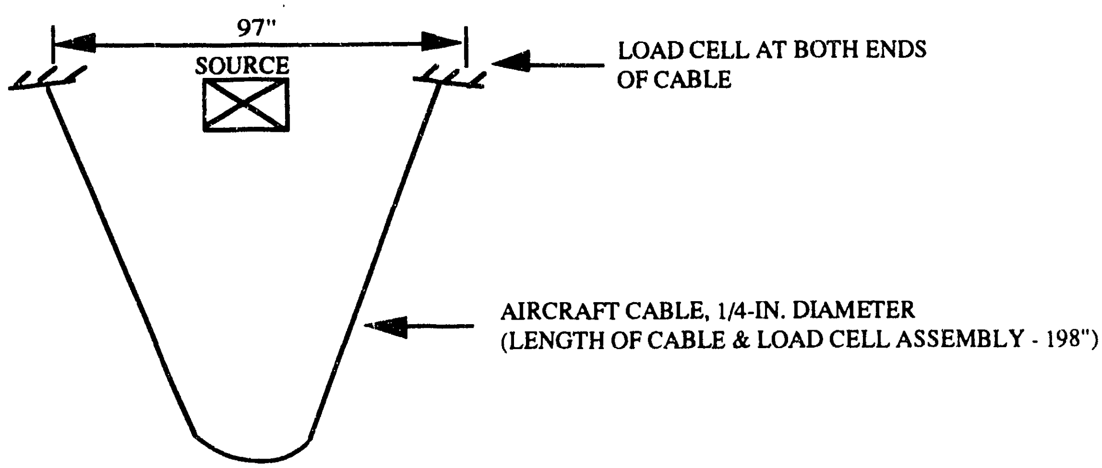

Figure 2. Aircraft Safety Cable

TEST RESULTS AND OBSERVATIONS

A total of 122 tests were performed and the information is being evaluated for a final report. An exhaustive discussion of the test results is beyond the scope of this paper. However, several observations of particular interest warrant discussion.

Overall Ruggedness of Targets

In general, objects tested were more rugged than one would intuitively have imagined before the test. For example, the electrical cabinets repeatedly absorbed impacts from a variety of small- to medium-sized sources (i.e., incandescent and fluorescent light fixtures, ceiling tiles, transite wallboard, and 3/4-inch conduit) with little or no resulting damage to the cabinet housing. This finding suggests that smaller sources may be allowed to impact the cabinets if sensitive relays are not housed inside and cabinet anchorage can withstand the additional impact load.

The empty 3/4-inch conduit deformed plastically at mid-span even when struck by sources such as the fluorescent light fixture. However, local collapse of the conduit wall was never observed. Functionally, this condition suggests proper continuity of the cables would probably have been maintained if the target conduits had been tested with cables in them.

Source Orientation at Time of Impact

Although it is obvious to most engineers that a glancing blow at an obtuse angle will produce a smaller impact load than a direct hit in normal alignment with the surface, the degree to which a slightly obtuse angle of impact reduces impact loads was surprisingly large.

The effects of impact angle were observed in tests of 2 ft × 3 ft pieces of 1/4-inch thick transite wallboard dropped on a protective barrier target made from 5 × 5 × 3/8 pieces of tube steel. Figure 3 shows the resulting force time history plot at the barrier support points from a 5-ft drop with an impact angle of ~90°. The peak impact load was 4000 pounds. When the drop height was raised to 10 ft but at a slightly obtuse impact angle, the resulting peak force (Figure 4) decreased to 3200 lbs even though the drop height had doubled! Similar results were noted throughout the test program when sources were either skewed or off center at the time of impact.

In general, it was noted that even under the controlled conditions of these tests, it was difficult to obtain a truly solid (direct) impact. This condition demonstrates the importance of only considering credible (feasible) angles of impact when reviewing potential concerns in the field. In many cases, only obtuse angle interactions are possible because of obstructions from other objects. This change should result in lower impact loads.

Relay Performance Characteristics

Two relays and an accelerometer were mounted inside of a floor-mounted electrical cabinet. Ceiling tiles, transite wallboard, and incandescent and fluorescent light fixtures were dropped onto the cabinet from heights of 8 feet or less. Vertical acceleration values were recorded and the relays were monitored for chatter. Relay chatter is of interest because it could disrupt certain electrical circuits through inadvertent actuation.

One relay was a Westinghouse-type SG relay. The other relay was a Potter & Brumfield model KRPA11AG. The seismic capacity of both relays is well documented through previous shake table tests. Based on these tests, the KRPA11AG relay is generally regarded to be "seismically rugged" and the Westinghouse-type SG relay is not regarded as "seismically rugged". However, the performance of these relays, when subjected to various impulsive loads, was unknown.

The drop tests were repeated for different relay contact conditions (i.e., normally open and normally closed). Acceleration values of over 10g were recorded during some of the tests. The KRPA11AG relay performed well regardless of the impact source. In contrast, the Westinghouse-type SG relay displayed significant chatter from the relatively minor impact of a ceiling tile dropped from a height of 2 ft.

The results from these drop tests involving the relays has generated considerable interest in performing more tests on the other "seismically rugged" relays. If additional tests to other relays yield similar results, the traditional practice of implementing hardware upgrades to preclude all potential impacts may be relaxed to allow certain cabinet interactions with small objects such as ceiling tile, light fixtures, or sprinkler heads.

DATA ANALYSIS OBJECTIVES

The test data are currently being studied and will be used to augment current seismic interaction evaluation criteria. A primary objective is to develop equipment interaction evaluation guidelines that can be used by seismic capability engineers during field walkdowns. These guidelines will serve to "calibrate" the judgment exercised by these engineers.

Another objective is to develop relationships between the peak load from any given drop test and the observed response. These observations will be used to formulate dynamic models that characterize the source and target interaction response. These models will be a helpful design and evaluation tool in that, without the aid of test data, it is difficult to accurately determine the response for the many complex shapes typically found in facilities.

CONCLUSIONS

A comprehensive drop test program has been implemented that evaluates the consequences of potential dynamic interactions between typical equipment targets and impact sources that may occur during a seismic event. As a result of this program, preliminary observations have been formulated about the overall ruggedness of the targets, the parameters which influence peak impact loads, and the chatter sensitivity of selected relays. Test data analysis is currently underway and will be used to upgrade Savannah River Site seismic interaction evaluation criteria. The end result of these efforts should be significant project cost savings through the reduced evaluation time needed to perform seismic interaction reviews and through a reduced number of support upgrades needed to prevent or lessen the effect of seismically induced impacts.

ACKNOWLEDGMENTS

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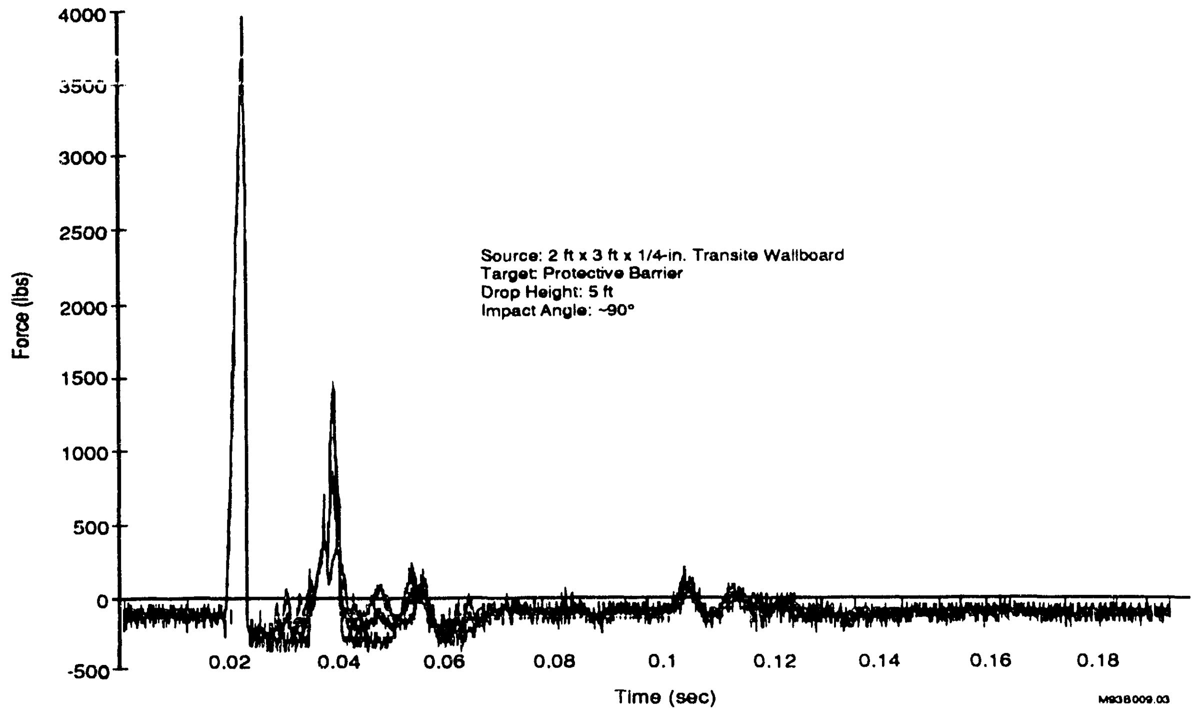

Figure 3. Test 50

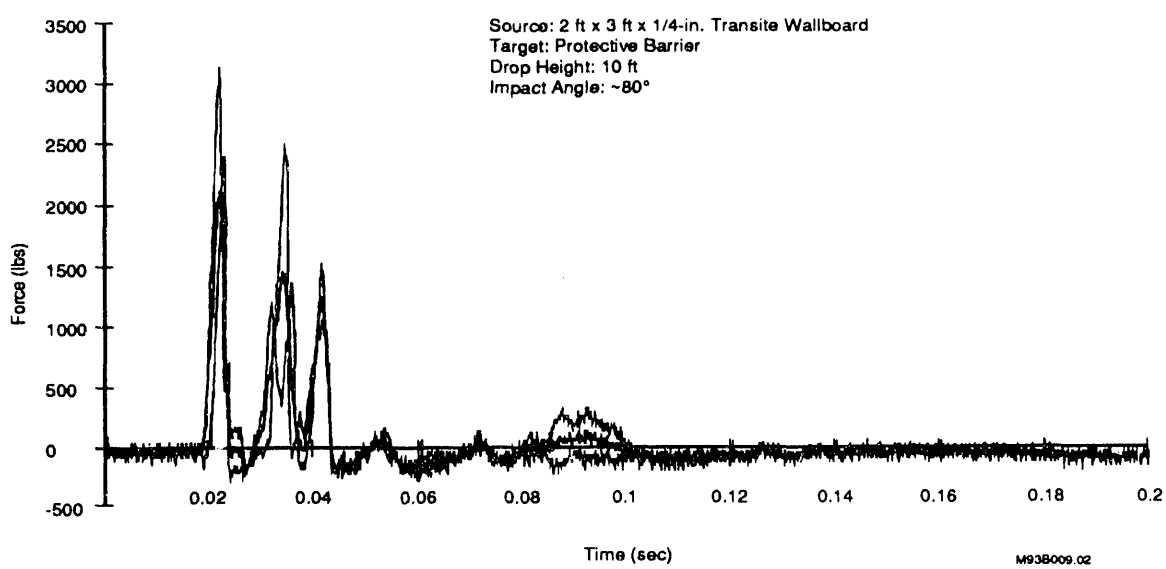

Figure 4. Test 51

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