NOTICE

Study of Wire Rope Systems for Seismic Protection of Equipment in Buildings

by

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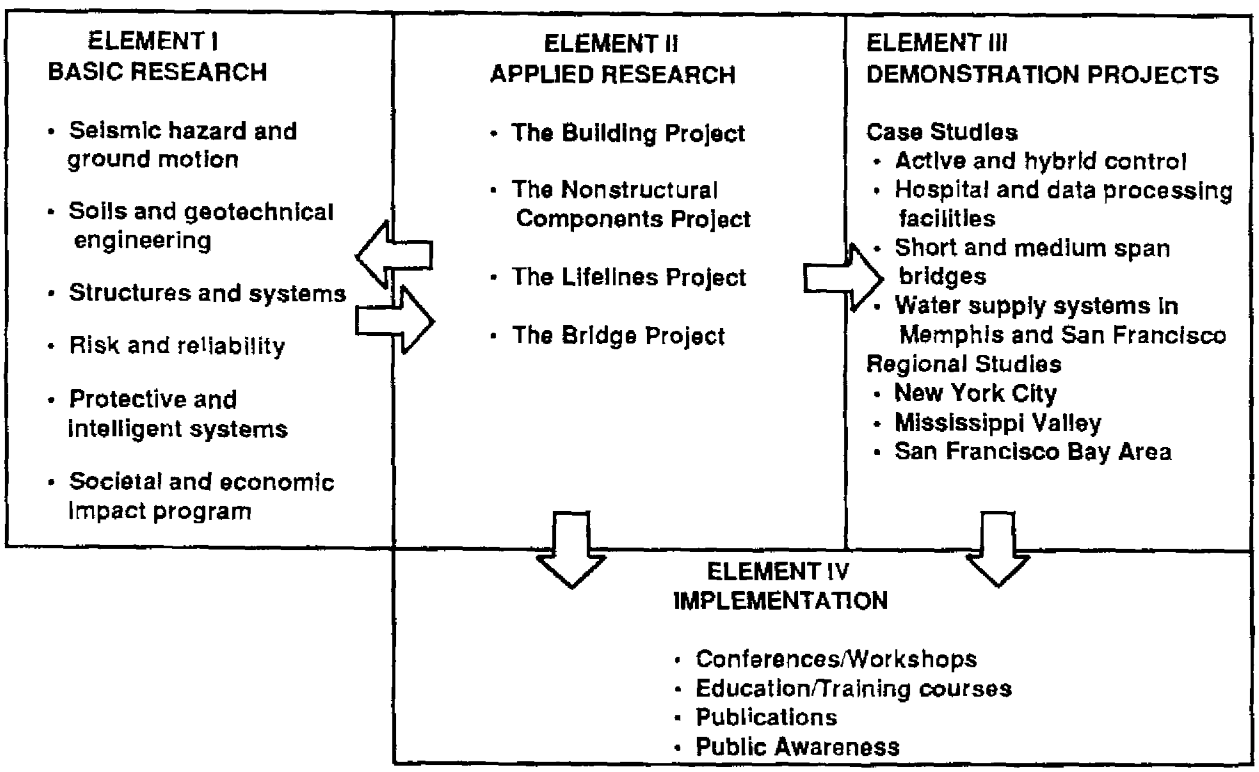
PREFACE

The National Center for Earthquake Engineering Research (NCEER) was established to expand and disseminate knowledge about earthquakes, improve earthquake-resistant design, and implement seismic hazard mitigation procedures to minimize loss of lives and property. The emphasis is on structures in the eastern and central United States and lifelines throughout the country that are found in zones of low, moderate, and high seismicity.

NCEER's research and implementation plan in years six through ten (1991-1996) comprises four interlocked elements, as shown in the figure below. Element I, Basic Research, is carried out to support projects in the Applied Research area. Element II, Applied Research, is the major focus of work for years six through ten. Element III, Demonstration Projects, have been planned to support Applied Research projects, and will be either case studies or regional studies. Element IV, Implementation, will result from activity in the four Applied Research projects, and from Demonstration Projects.



Research tasks in the **Nonstructural Components Project** focus on analytical and experimental investigations of seismic behavior of secondary systems, investigating hazard mitigation through optimization and protection, and developing rational criteria and procedures for seismic design and performance evaluation. Specifically, tasks are being performed to: (1) provide a risk analysis of a selected group of nonstructural elements; (2) improve simplified analysis so that research results can be readily used by practicing engineers; (3) protect sensitive equipment and critical subsystems using passive, active or hybrid systems; and (4) develop design and performance evaluation guidelines.

The end product of the **Nonstructural Components Project** will be a set of simple guidelines for design, performance evaluation, support design, and protection and mitigation measures in the form of handbooks or computer codes, and software and hardware associated with innovative protection technology.

The **protective and intelligent systems program** constitutes one of the important areas of research in the **Nonstructural Components Project**. Current tasks include the following:

1. Evaluate the performance of full-scale active bracing and active mass dampers already in place in terms of performance, power requirements, maintenance, reliability and cost.
2. Compare passive and active control strategies in terms of structural type, degree of effectiveness, cost and long-term reliability.
3. Perform fundamental studies of hybrid control.
4. Develop and test hybrid control systems.

One of the passive protective systems considered in this program is the wire rope system, which has found wide applications in shock and vibration isolation of equipment. In this report, applications of this type of energy dissipation system to seismic isolation of a selected class of equipment are investigated. Both analytical and experimental work has been carried out, and the results show that stiff wire rope systems may provide some degree of protection of equipment in buildings while allowing very small displacements.

ABSTRACT

Wire rope isolators have found numerous applications in the shock and vibration isolation of military hardware and industrial machinery. In this study, the usefulness of these devices for the seismic protection of equipment in buildings is investigated. Installation methods of entirely supporting equipment on wire rope isolators and of combining them with locked casters are experimentally and analytically studied. It is found that the use of wire rope isolators in stiff configurations may substantially improve the seismic response of equipment in comparison to other installation methods.

Mathematical models for describing the hysteretic behavior of wire rope isolators are developed and experimentally calibrated and verified. Analytical predictions of seismic response are shown to be in good accord with experimental results.

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SECTION 1

INTRODUCTION

Seismic base isolation is a design technique that is becoming widely accepted and is being studied with continually increasing interest. The principle of seismic isolation is to introduce an interface at the base of a structure that can attenuate the magnitude of the horizontal movement of the ground transmitted to the structure during an earthquake. This results in a significant reduction in floor accelerations, story shears and interstory drifts, thus providing protection to the structure itself as well as to all items and equipment mounted on the structure (Kelly 1982, 1985, 1988; Zayas 1987; Chalhoub 1988, 1990; Tsai 1989; Buckle 1990; Mokha 1990, 1991; Constantinou 1990b, 1991; Manolis 1990; Juhn 1992).

The reduction of the seismic forces imparted to the structural system is achieved by introducing flexibility and energy absorption capability in the isolation system. The introduction of flexibility increases the fundamental period of the isolated structure to values well above the predominant period of the earthquake excitation so that the isolation effect is primarily produced by deflection of the earthquake energy (Kelly 1991). This desirable effect is, however, produced at the expense of large isolation system displacements which are in the range of 8 to 20 in. (200 to 500 mm) for strong earthquake excitation. While the displacements appear to be large, they are in reality small in comparison to the building dimensions and can be accommodated by the isolation system without, usually, instability problems.

The same principle may be used to isolate and directly protect sensitive equipment housed mainly in conventionally constructed buildings where the high floor accelerations during an earthquake can be catastrophical for them.

However, earthquake motions, when transmitted through conventionally constructed buildings, which in strong excitation respond inelastically, reach the upper floors amplified and with their frequency content spread over a wide range of frequencies (Singh 1988; Lin 1985; Chen 1988). Isolation in this case becomes difficult. To achieve effective isolation, it is necessary to increase the period of the isolated equipment to large values which typically are larger than those required for effective isolation of buildings. This results in displacements which are unacceptably large for single equipment. Furthermore, the construction of very flexible isolation systems for single equipment is impractical because such systems are usually not capable of carring the weight of the supported equipment.

To counteract these problems, the Japanese construction industry developed elaborate isolation systems for computer floors which support a large number of equipment

(Fujita 1991). These systems utilize either low friction sliding bearings, or multi-stage rubber bearings, or pneumatic isolators.

The seismic protection of single equipment may be also achieved not by lengthening their period and thus deflecting the earthquake energy but by absorbing earthquake energy through a stiff and highly energy-dissipative system. Such a system may provide a degree of protection while allowing relatively small displacements. Makris 1992a and 1992b reported experimental results on a system consisting of helical steel springs immersed in highly viscous fluid for seismic protection of equipment. The system was used to support a slender equipment cabinet which was subjected to strong floor seismic motions. The system, which resulted in a frequency of 3.5 Hz in the isolated equipment, was capable of reducing accelerations by a factor of 2 in comparison to the non - isolated equipment, while allowing displacements at the isolation level which did not exceed 0.4 in.(10 mm). This spring - viscous damper system evolved from a widely used vibration isolation system.

Herein another system which is widely used in shock and vibration isolation of equipment is investigated for use as a seismic isolation system. Wire rope isolators are mounting assemblies made of stranded wire rope which is wound in the form of a helix and held between metal retainers (Fig. 1-1a). In a further development, arch wire rope isolators are formed by two groups of oppositely inclined, arch-like, open - bottom wire rope elements which are clamped between retainer bars (Fig. 1-1b).

Both helical and arch wire rope isolators consist of twisted stainless steel cable. They have flexibility in all three directions, large displacement capacity and inherent damping which results from rubbing and sliding friction between the intertwined cables. Their ability to absorb energy is simultaneous in all three directions. These isolators have found numerous applications in the shock and vibration isolation of industrial and defense equipment, electronic systems, critical machinery and other sensitive equipment.

In applications of shock and vibration isolation, wire rope isolators support the weight of the isolated system. Typically, the isolated system has fundamental frequency of the order of 10 Hz. Their energy dissipation capacity is, in terms of equivalent viscous damping ratio, about 0.1 to 0.2 of critical under small amplitude motion. The aforementioned frequency of about 10 Hz is that of a vertical or a horizontal mode of vibration since, typically, equipment are either squatty or are prevented from undergoing rocking motion. This is accomplished by attaching the equipment to a wall by wire rope isolators.

This study investigates the use of wire rope isolators as a means of providing seismic protection to single slender equipment which are only attached to vibrating floors.

First, helical and arch type wire rope isolators were used to support a slender equipment cabinet in four different configurations. The isolators provided a fundamental frequency (in the rocking mode) in the range of 1 to about 6 Hz in the four systems. Second, helical wire rope isolators were used to provide only restoring force in a computer equipment supported by locked casters. The fundamental frequency in this case was about 3.4 Hz. The isolated equipment were subjected on a shake table to floor excitation which was determined by filtering recorded earthquake motions through an actual 7-story building. Experimental results were also obtained for the equipment being either fixed to the floor or connected to the floor by other commonly used means. It was found that for certain configurations of wire rope isolators, it was possible to achieve substantial reduction of the acceleration transmission to the isolated equipment in comparison to other conventional means of support of the equipment. The results of this study are reported herein. Furthermore, analytical models describing the dynamic behavior of wire rope isolators are developed, calibrated and presented. The models are capable of describing,with good accuracy, the observed dynamic response of the tested equipment.