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9

SECONDARY SYSTEMS, EQUIPMENT AND NONSTRUCTURAL ELEMENTS

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EVALUATION OF SEISMIC MITIGATION MEASURES FOR ART OBJECTS

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ABSTRACT

This research develops quantitative techniques and procedures for the evaluation of current and future earthquake damage mitigation measures for art objects. This neglected topic of earthquake engineering research was highlighted during the recent Loma Prieta Earthquake, during which significant damage was done to the collections of several art museums. Analytical and experimental techniques are combined to allow determination of fragility levels for specific art objects and to determine the effectiveness of applicable seismic protection methods.

INTRODUCTION

The earthquake resistance of irreplaceable art objects in seismically active regions is important because of the possibility of damage to historical and cultural art objects in museums and other public institutions. Development of methods to increase the earthquake resistance of art objects, while at the same time allowing them to remain on public display, is a complex problem. Several unique constraints make the problem of art protection more difficult than other building contents protection problems. Rigidly fastening the objects to their supports is often impossible. Material properties are nonuniform or unknown in most cases. Finally, any earthquake protection measures must aesthetically blend with the art object.

The earthquake resistance of an art object depends upon both the object's characteristics and the methods used for its support. To increase earthquake resistance, both the object itself and the support system can be modified. Examples of modification of the object include adding mass to lower the center of gravity, and introducing internal damping devices. Examples of support system modification include suspension devices, viscoelastic mounts, and base isolators.

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Several excellent references, including those by McGavin [7], FEMS [2], Holmes, McGavin, Holmes[7], and BSSP [1], describe methods for protecting important building contents from earthquake damage. All of these guides are qualitative in nature. None address the specific requirements for art object protection. There is a definite need for quantitative criteria for the application of earthquake damage mitigation measures for art objects.

The purpose of this research was to quantitatively evaluate some of the earthquake mitigation methods currently being used or contemplated by the staff of the J. Paul Getty Museum for the support and protection of art objects. This evaluation was accomplished in two phases. Phase I consisted of a general study of the earthquake response characteristics of these art objects and it included a classification of art objects, structural and material properties, and dynamic response behavior into types of earthquake resistance parameters that can readily be analyzed or verified experimentally.

In Phase 2, specific generic art object/support systems were identified for detailed evaluation in accordance with the plan defined in Phase I. Nine generic systems were evaluated; six for the art object/support systems alone and three for different classes of base isolators. With appropriate parameters, these generic systems can be used to study most of the art objects in the data base. Analytical and experimental analyses were performed to determine the response behavior of the generic systems under specific simulated earthquake excitations.

ART OBJECT/SUPPORT MODELING

Every art object is unique in both configuration and materials. To develop a systematic method for determination of fragility level and design criteria for possible mitigation measures, a structural classification system for art objects was created. This classification system is based upon a database of actual art objects properties.

Database Development

In order to develop an art object database for use in this study, selected art objects from the collection of the J. Paul Getty Museum were categorized by their art object type, support type, probable earthquake response mode, and seismic mitigation method (if used). Each categorization contained a limited number of categories. Table 1 lists the possible Earthquake Response Categories.

After categorization, applicable parameters were then measured or estimated for each selected art object/support system. These parameters were described the system's structural configuration, boundary conditions, and material properties. Structural parameters included mass, dimensions, location of center of gravity, and mass distribution. Boundary conditions included type of mount, dimensions, and type of isolation (if used).

A companion material property database was also developed using available published information.

Generalization of Art Object/Support Systems

Based mainly upon the probable earthquake response modes, representative generic art object/support system models were established using the data base. This allowed appropriate methods of analysis, as well as analytical and physical models, to be chosen for different groups of systems. Individual art object/support systems can be related to the generic systems using appropriate parameters.

An art object/support system can be considered rigid in terms of earthquake response if it has no significant structural resonances below about 20 Hz. Therefore, earthquake response was be divided into two main groups, Rigid and Flexible. It will generally be very clear whether an art object belongs in the Rigid or Flexible response group; a marble statue is in the Rigid group, while a suspended painting or a slender metal sculpture belong in the Flexible group. A majority of the art object/support systems in the data base fit into the Rigid Response group.

Several generic models within each response group were developed and studied. In addition, three generic base isolated system models were studied. These models are listed in Table 2.

Earthquake response of these generic system models was then studied both analytically and physically, and parametric failure levels were determined. Results derived using these generic systems can be applied as design criteria to individual art object/support systems using the appropriate parameters and approximations.

ANALYTICAL STUDIES

Simplified mathematical or computer simulations of the six generic art object/support system models were developed and implemented. Most of these simulations are based upon published research or basic earthquake engineering concepts. System response to earthquake excitation was then studied numerically using a Representative Earthquake Accelerogram shown in Figure 1. This is a synthetic accelerogram developed by Lindvall, Richter & Associates[4].

Generic models were studied for a range of parameters compatible with the art object/support systems in the data base. Results were presented in the form of design charts or formulas which can be applied to particular systems using appropriate parameters. In many cases, results were experimentally verified.

Rigid body rocking (overturning) criteria were developed using the simplified criteria detailed by Ishiyama[3]. Ishiyama's simple formulas for the thresholds of rocking and overturning are based upon basic principles of statics and rigid body dynamics. In addition to the physical dimensions, only the peak acceleration and velocity are required to determine approximate thresholds for rocking and overturning, respectively. In this study, these formulas were extended to nonuniform bodies. Figure 2 shows the rigid body rocking stability regions calculated for the Representative Earthquake Accelerogram.

Sliding response of rigid bodies has been studied in detail using a variety of analytical approximation techniques. A recent study by Moser[6] summarizes previous work and presents several new analytical techniques. For this study, the response of a sliding rigid body to triaxial base motion was determined numerically using a specially developed computer program. Both the relative displacement and absolute velocity and acceleration were calculated for given friction coefficients and excitations. Figure 3 plots, for the Representative Earthquake input, calculated peak displacement versus friction coefficient.

Standard linear formulas for estimating stresses were applied to both rigid and flexible generic system models. Linear response spectrum techniques were added to the flexible response model. Because of the extreme variability and uncertainty in the material properties of art objects, these formulas should be used with caution.

A nonlinear analytical model was developed for the simplified generic swinging response system (i.i. hanging paintings). This model was solved numerically for the Representative Earthquake Accelerogram.

The three generic base isolation models were analytically modelled using simple linear or nonlinear parametric equations. These equations were solved numerically to provide appropriate response parameters. Figure 4 shows a sample nonlinear response spectrum for the generic horizontal base isolator, calculated using the Representative Earthquake Accelerogram as input.

EXPERIMENTAL STUDIES

Analytical modelling of even simple structural systems requires the use of approximations to fit the real system to the model. As the structural systems get more complex, these approximations can lead to large errors in the predicted behavior when compared with actual behavior of the system. It is therefore necessary to experimentally verify even simple analytical models and the accompanying parameter approximations prior to their application to a new class of structures.

Experimental studies were performed on a subset of the generic models described in Table 2. The studies concentrated on rigid sliding and rocking models, as a majority of the art object/support systems fall into these response categories and the corresponding analytical models were newly developed or extended from previous research and required verification.

Experimental parameter approximation studies were performed for the swinging models corresponding to Response Categories DYN1 and DYN2. Experimental studies were also performed for the three types of generic