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SEISMIC DAMAGE MITIGATION CONCEPTS FOR ART OBJECTS IN MUSEUMS

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SUMMARY

The earthquake resistance of art objects and artifacts in museums is of paramount importance in seismically active regions, as these objects have great historical and cultural value. There are various methods to increase the resistance of art objects and their support systems. This paper reports on research in progress to evaluate seismic damage mitigation concepts for art objects and artifacts. Analytical and experimental techniques are combined to evaluate current and proposed mitigation concepts for different categories of museum contents.

INTRODUCTION

The J. Paul Getty Museum in Malibu, California has been actively developing seismic damage mitigation methods for art objects over the last ten years. The purpose of the ongoing research described in this paper is to analytically and experimentally evaluate current and proposed seismic mitigation methods developed by the Museum. Results will be used to develop procedures and guidelines for increasing the earthquake resistance of art objects in the J. Paul Getty Museum. This information will also be made available to other museums.

Prior to applying seismic damage mitigation measures to the contents of a particular museum, a seismic risk analysis of the museum building(s) should be performed and ground motion criteria developed. For the J. Paul Getty Museum, this was done in a previous study. An accelerogram was developed for the maximum probable earthquake with an 80% probability of occurrence over the next 50 years. Figure 1 shows the three components of this accelerogram. Evaluation of the seismic mitigation measures for the Museum's contents will be based upon this accelerogram. It should be noted that the damaging capacity of an earthquake depends on the characteristics of the accelerogram, and seismic criteria for each museum site should be developed separately.

The earthquake resistance of an art object depends on both the object's structural characteristics and the method used for its support. While both the object and the support system can be modified, the modifications cannot interfere with the appearance of the art object to the viewer, and usually modifications to the support are the preferred method.

Every art object or artifact will have different structural characteristics and support methods. Sketches of several examples are shown in Figure 2. As a first phase for this study, art objects are categorized and described by a minimum number of structural parameters. To facilitate this categorization, a subset of the Museum's collection was studied and a data base was created containing parameters for both the object and support properties. This data base is used to develop generic analytical and physical parametric models for the art object/support systems. These generic models establish the basis for more individual and in-depth analysis of each object.

The response of these models to the Museum's design earthquake is determined both analytically and experimentally. The effects of appropriate seismic mitigation methods on the responses are then be evaluated.

CATEGORIZATION OF ART OBJECTS

In order to develop an art object data base 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). The categories for these four descriptors are listed in Figure 3. Applicable structural parameters were then measured or estimated for each selected art object/support system. These parameters were chosen to describe the system configuration, boundary conditions, and material properties.

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

ANALYTICAL STUDIES OF ART OBJECT/SUPPORT SYSTEMS

Simplified mathematical models are developed for many of the generic art object/support systems. Figure 4 shows the basic models that are being used.

Many of the systems can be considered rigid in the seismic frequency range. The earthquake response of these rigid systems will be controlled by either rocking or sliding. Three-dimensional numerical models for sliding (Coulomb friction) and rocking response are therefore used to study the response of these systems to the design earthquake.

Single or multi-degree-of-freedom dynamic models are used to model those systems which are not entirely rigid. Examples include suspended paintings, slender sculptures, and long-case clocks.

Some isolation systems currently in industrial use, such as viscoelastic or friction-type base isolators, are designed to respond in a highly nonlinear way. These are modeled using currently accepted nonlinear or equivalent linear techniques.

Combinations of these models are needed to study the earthquake response of the more complex generic systems . When simplified mathematical models do not adequately describe the response of a generic system, finite element methods are applied. In all cases, response calculations are based upon the Museum's design earthquake time history and include the effects of combined vertical and horizontal excitation.

Using these generic art object/support system analytical models, parametric studies will be performed to determine the ranges of model parameters for which the systems survive the design earthquake. Optimum configurations will be determined for each generic system. Where isolation devices are used, the effect of these devices on the performance of the system will be evaluated. Results will be displayed using design charts showing proximity spectra for sliding objects, angular rotation for pendular objects, or influence of isolator parameters on earthquake response.

Response of Sliding Rigid Systems. Many art object/support systems respond to earthquake excitation by sliding, either internally (i.e. object sliding on its pedestal) or externally (i.e. object/pedestal system sliding on floor). In fact, one seismic damage mitigation method is to allow a system to slide more freely by decreasing the base friction using a teflon bearing surface. During an earthquake, a sliding system can fail by impact with another object or a wall, or by exceeding stability limits.

A computer program was written to numerically solve the three-dimensional nonlinear equations of motion for a sliding system. This numerical solution includes the effect of vertical excitation and the stick-slip nature of the response. Using the design earthquake as the input excitation, maximum slip displacement versus friction coefficient was calculated. These data are plotted in Figure 5. Data of this type will be useful in the safe placement of such sliding art object/support systems within the Museum. Knowing the approximate friction coefficient of the sliding surface, the museum staff will be able to determine how far an object or system must be placed from adjacent objects or boundaries to prevent impact damage during an earthquake.

EXPERIMENTAL STUDIES OF ART OBJECT/SUPPORT SYSTEMS

Response characteristics of the generic art object/support systems are experimentally determined using representative physical models with variable structural parameters. A variety of dynamic test techniques are used, including random, impulse, and sine dwell. Experimental results are compared with the equivalent analytical model results, allowing the analytical models to be verified.

Specialized test fixtures have been designed and constructed in order to simulate the dynamic environment of the art object/support systems. Thus far, these fixtures incorporate a unidirectional simulation of the museum strong motion environment.

One or more physical models of each generic art object/support system will be constructed and tested. Where possible, these models will have adjustable configurations and properties so that a range of system parameters can be tested. Also, models (or actual examples) of the currently used seismic mitigation devices will be experimentally tested.

Base Isolation Device Tests. As part of the support systems evaluation, the performance of a seismic base isolation device suitable for use with art objects has been evaluated experimentally using a suspended test fixture and an electromechanical shaker. This was a ball-bearing type friction reduction device and was designed within the J. Paul Getty Museum.

The device was subjected to sine dwell excitation at various frequencies from 0.5 to 10 Hz, with a maximum input acceleration of about 0.6 g in a single direction. The response was measured using accelerometers both on the base and on the isolator. In Figure 6 the relative response (isolator/ground) is plotted versus frequency for three different isolator loads. From these data it can be observed that the isolator, which has a spring-damper centering mechanism, works quite well above about 2 Hz but has a resonance of the mass-spring system slightly below 1 Hz. Near resonance the isolator actually amplifies the ground motion slightly. The behavior of similar isolators under realistic earthquake inputs is under investigation.

SUMMARY AND CONCLUSIONS

Methods to increase the earthquake resistance of art object/support systems in the J. Paul Getty Museum are currently being evaluated. To date, an art object data base containing categorizations and structural properties of a subset of the Museum's collection has been created. An analytical model for sliding response has been developed and used to predict maximum slip versus friction coefficient. Using a specially-developed test fixture, a preliminary evaluation of a base isolation device has been carried out experimentally.

Generic art object/support system models, both analytical and physical, are being developed using the data base. These models form the basis for the evaluation of the seismic safety of the generic systems and the effectiveness and applicability of various mitigation concepts.

Procedures and guidelines for the application of seismic mitigation concepts for art objects and artifacts in museums will be developed from the results of this study.

ACKNOWLEDGMENTS

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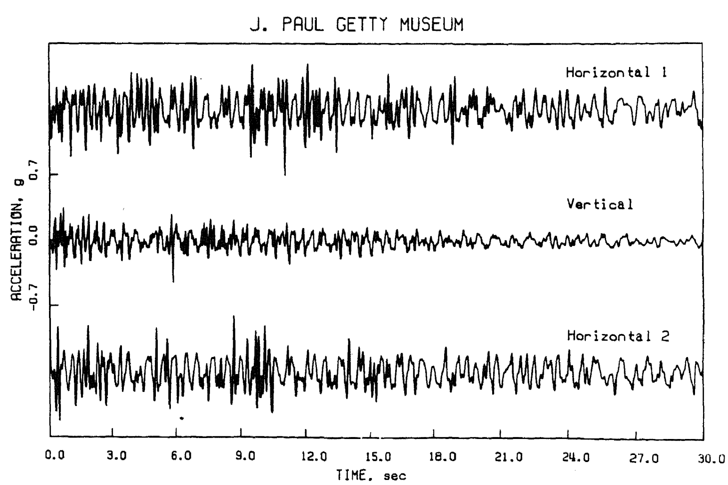

Figure 1: Maximum Probable Earthquake Accelerogram

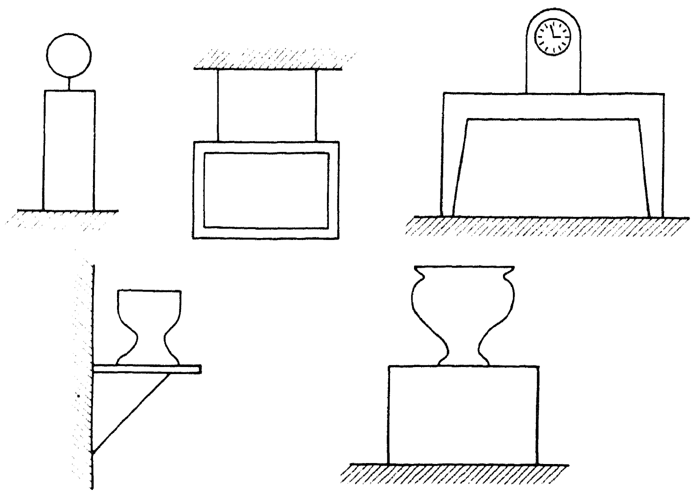

Figure 2: Art Object/Support System Examples

A. Art Object Categories
- VASE - small, flat-bottomed
- BUST - small, non "
- STAT - statues
- PNTG - paintings
- CLOC - clocks
- TBL4 - 4-legged objects
- TBL1 - 1,2,or3-legged objects
- PLAT - plates
- PANL - hanging panels
- LAMP - chandeliers
- CASE - display cases
- MISC

B. Support Categories
- FREE - free-standing
- FIXD - fixed-base
- RODS - rod-supported
- SUS1 - suspended, 1 DOF
- SUS2 - suspended, 2 DOF
- PEDE - on pedestal
- CAS1 - in floor case
- CAS2 - in wall case
- COMP - composite system
- BRAC - braced from side

C. Response Categories
- RIG1 - rocking or sliding
- RIG2 - stress failure at base
- RIG3 - internal stress failure
- DYN1 - 1 DOF pendulum
- DYN2 - 2 DOF pendulum
- DYN3 - dynamic stress failure, base
- DYN4 - dynamic stress failure, internal

D. Isolation Categories
- FRIC - friction reduction
- DAMP - elastomer pads
- SPRI - spring
- ISO1 - horiz. base isol.
- ISO2 - 3 DOF base isol.

Figure 3: Art Object Categories

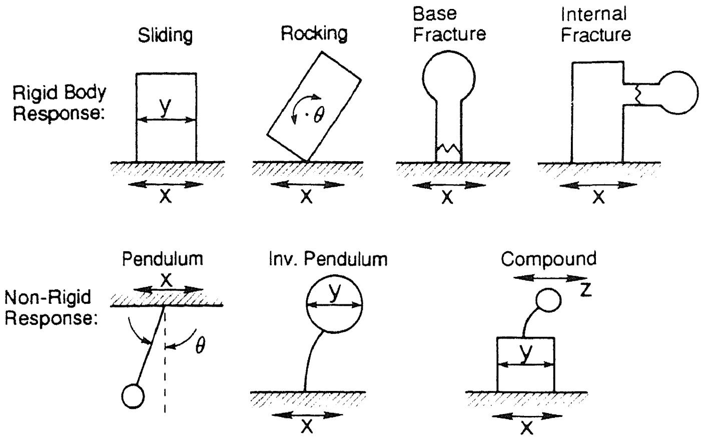

Figure 4: Basic Analytical Models

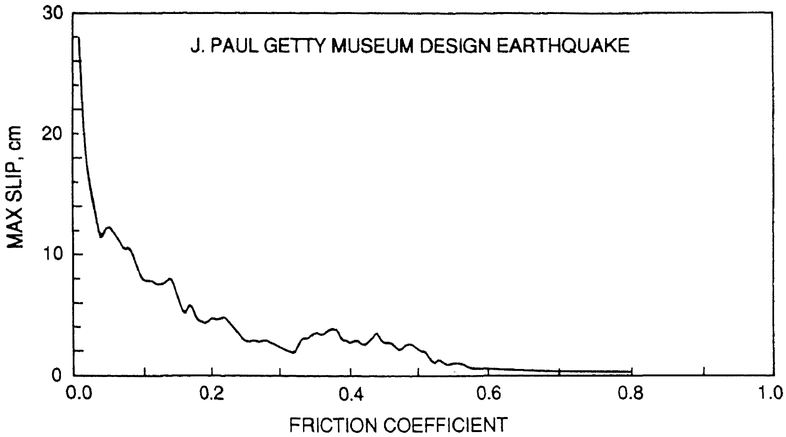

Figure 5: Maximum Slip vs. Friction Coefficient for Design Earthquake

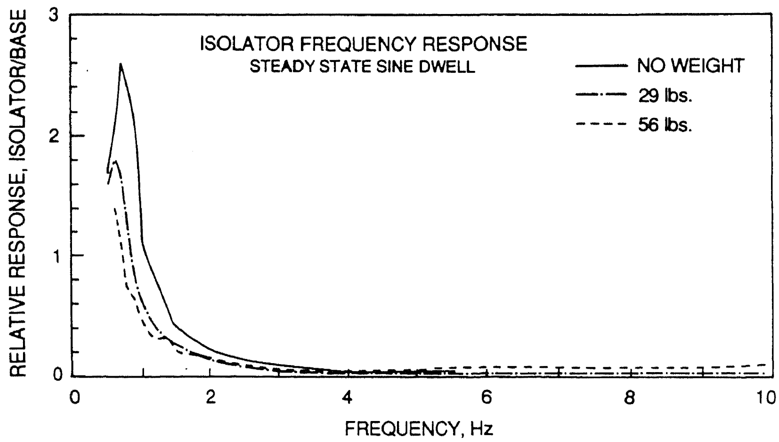

Figure 6: Measured Isolator Frequency Response