Protecting Collections in the J. Paul Getty Museum from Earthquake Damage

In 1983 the Getty Museum in Los Angeles, California began efforts to reduce the damaging effects of earthquakes to its collections by:

Characterizing the overall geology and seismic history of the museum site and describing a worst-case seismic event that might occur within a reasonable time frame and at a reasonable risk level,

Determining the overall response of the museum building to such an event,

Determining how the contents of the building (collections, display furniture, and fixtures) would respond to the earthquake motions and forces, and

Developing seismic mitigation approaches to protect the collections.

The four basic methods which were developed to mitigate damage will be discussed in the latter part of this article. They are:

Lowering the object's or object assembly's center of gravity by adding weight to the lower parts of the display assembly,

Lowering the center of gravity by adjusting the proportions of the display assembly (adjusting the base to height ratio for more stability),

Restraining objects by firmly securing them to the floor, pedestals, shelves, wall, and/or supporting mounts. This approach requires that the object have sufficiently high inherent strength and rigidity (or have them enhanced by a supporting mount) to withstand the earthquake forces, and

Allowing sliding of the display furniture by the use of base isolation mechanisms.

Defining the seismic threat

The mitigation approaches discussed above, particularly base isolation, could only be undertaken when a thorough understanding of how earthquakes affect structures and contents was achieved. The assistance of experienced seismic engineers and seismologists was necessary to establish the characteristics of the worse case scenario earthquake predicted for the area and specific site where the collection is housed.

The duration, strength, frequency content, and potential for displacement of the simulated earthquake, as well as the response of the building (indeed the specific areas of the building) where the collections are housed, give direction to any efforts in developing mitigation approaches. For example, it is more important to know the peak acceleration, velocity, and predominant period of an earthquake (and the building and object response), than it is to know the expected Richter scale magnitude since the former can provide measurable design criteria. Insufficient design can be useless and even make things worse during an earthquake.

In 1984 the Getty Museum commissioned Lindvall, Richter, and Associates to prepare a geologic and seismologic study of the museum site and a geotechnical and structural response study of the Villa museum building,[1] later updated by the URS corporation.[2] The museum defined an event with an 80% probability of being exceeded in 50-years (reoccurrence estimated to be every 225 years) as an acceptable risk level.

The study identified two events that would have the most impact upon the museum: an 8.3 Richter scale earthquake on the San Andreas fault, some 67.5 km away from the museum (resulting in a horizontal ground acceleration of 0.2 g at the museum site) and a 6.5 Richter scale earthquake on the Malibu Coast/ Santa Monica fault system at a distance of 1.6 km (potentially producing a maximum 0.7g horizontal ground acceleration at the museum site).

Determining the behavior of objects

The conclusions of the Lindvall report provided dynamic data for use in analyzing the behavior of art objects housed at the museum, such as the 1990 research by Aghbabian, Masri, and Nigbor [3] that attempted to predict the seismic response of art works by modeling generic categories that represented groups of similar objects.

From these studies basic criteria for stability have evolved. For example, the response of a rigid object to earthquake induced forces and motion can be sliding or, if the friction between the object and the supporting plain is high enough, rocking and eventual overturning. Rocking and overturning are based both on the nature of the earthquake and the object's (or object assembly's) geometry and mass distribution. Figure 1 shows an overturning chart based on data from the Getty site design earthquake.

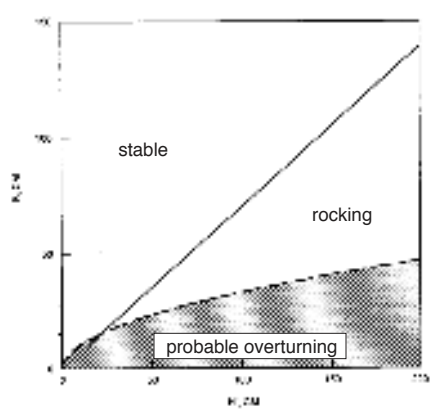

Figure 1. Rocking stability chart for the Getty Villa. Primary horizontal component peak acceleration is 687 cm/sec^2 (0.7g) and peak velocity is 33.9 cm/sec . Reprinted from M.S. Agbabian, et al, *Evaluation of Seismic Mitigation Measures for Art Objects*, p. 38.

Rocking and sliding will occur when the ratio of the maximum horizontal acceleration is greater then B/H aspect ratio: $a_{max} > B/H$. Overturning will occur when the relationship of the aspect ratio to velocity of the earthquake is as follows: $V_0 > 10\ B / \sqrt{H}$. Whether rocking, sliding, or overturning occurs also depends upon the location of the center of gravity as in figure 2.

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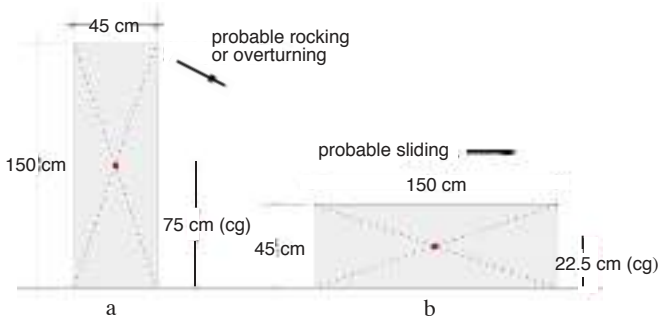


Figure 2. An overturning or sliding response is directly related to the aspect ratio. In a the object will most probably rock and/or overturn, while in b, with a lower center of gravity and a more favorable aspect ratio, the response will be sliding (assuming a sufficiently low coefficient of friction between the object and the support plane).

Altering the aspect ratio and/or adding weight to the lower sections of the assembly are two ways the center or gravity can be lowered for greater stability. Before this is attempted however, calculating the actual location of the center of gravity of any object or assembly is essential.

Determining the center of gravity

The term center of gravity (cg) describes a theoretical point within the mass of an object or object assembly where all earthquake forces are focused. The lower the center of gravity is the more stable and resistant to rocking and overturning the object or assembly is. One of the simplest methods of determining the cg is to measure the maximum depth, width, and height of the object and then translate those dimensions into a geometric volume that closely resembles the object's shape, assuming an even weight distribution throughout the entire volume of the object. The center of gravity will be roughly the same as the calculated center of the geometric volume, see figure 3.

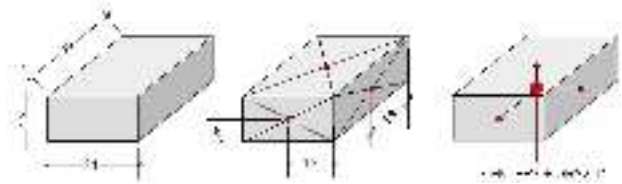


Figure 3. A simplified method of determining center of gravity locates the center of a geometric volume. This assumes however that the simplified geometric model accurately reflects the mass of the object and that the density of material is consistent throughout.

Determining the Equivalent Block

When an object is composed of segments with differing dimensions or densities, each segment can be translated into a geometric shape and the equivalent block determined (figure 4). This method can be advantageous when an object is complex in shape; is made of a variety of segments; has an eccentric distribution of mass; or is part of an assembly (such as a sculpture and pedestal combination). If the separate components cannot be weighed, calculations can be made based on standard material property references.

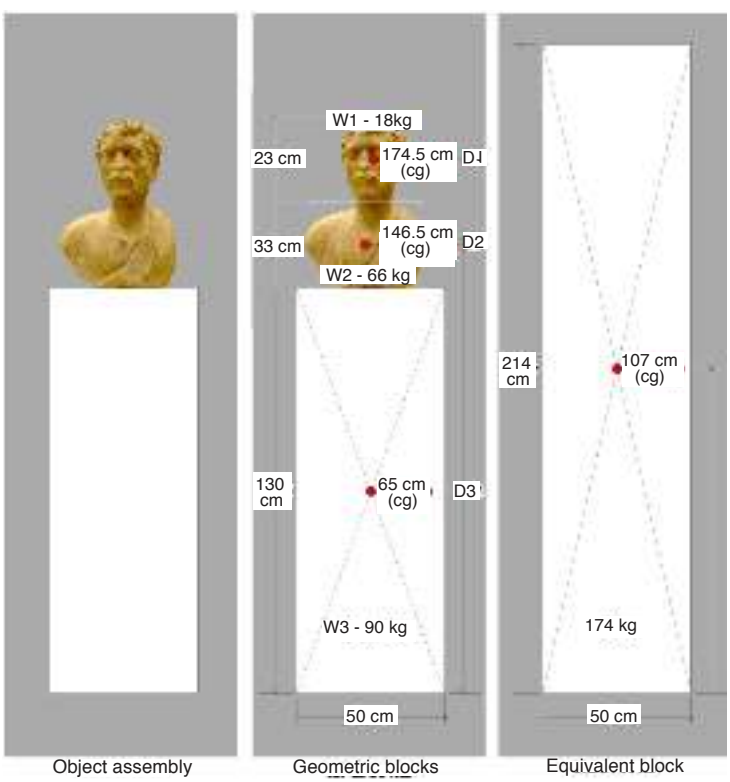


Figure 4. Determining the equivalent block of an object assembly, in this case a sculpture and a pedestal combination.

$$\frac{(D1 \times W1) + (D2 \times W2) + (D3 + W3)}{W1 + W2 + W3}$$

D= Distance from the ground to each section's *Cg*
W= Each section's weight
Hcg = Height of the equivalent block

If: D1 = 174.5cm and W1 = 18 kg,
D2 = 146.5cm and W2 = 66 kg,
D3 = 65cm and W3 = 90 kg.

then:

$$\frac{(174.5 \times 18) + (146.5 \times 66) + (65 \times 90)}{18 + 66 + 90} \text{ or: } \frac{18660}{174} = 107.2$$

Thus the equivalent block has a center of gravity at 107 cm and 2*Hcg* formula gives us an equivalent block height of 214 cm.

Using the effective aspect ratio formula, $.5B/H_{cg}$, (25/107), we find that the unit has an effective aspect ratio of 0.23.

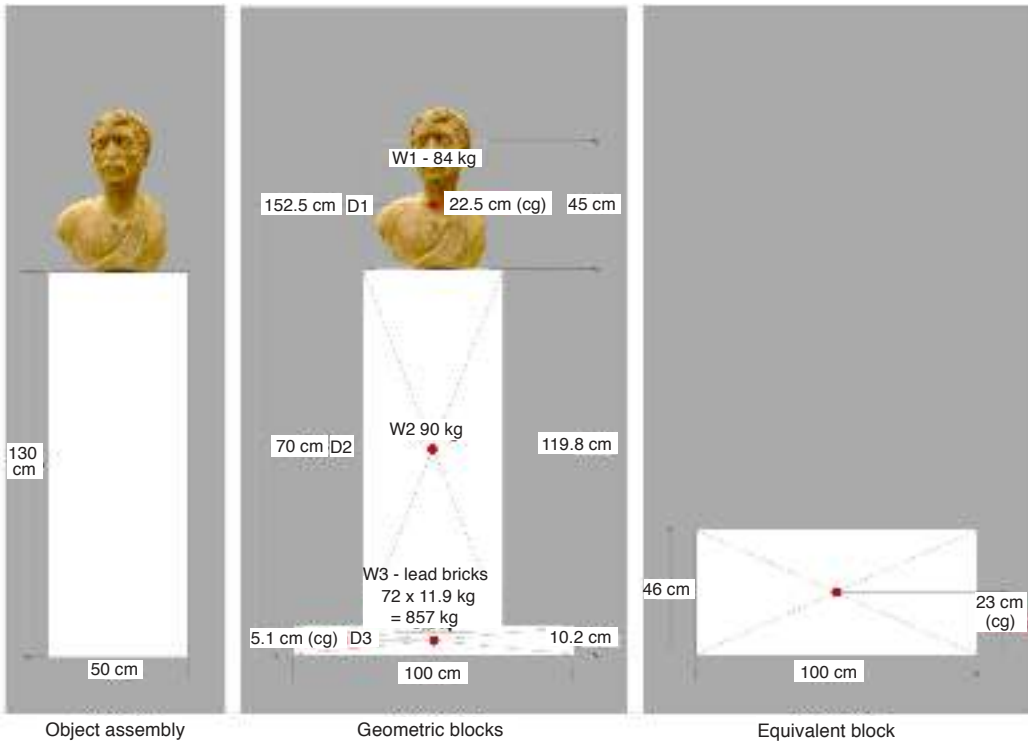


Figure 5. Looking at the system's new equivalent block, the cg has been lowered to 23 cm by adding 857 kg and increasing the base by 50 cm.

NOTE: The center of gravity must be calculated for the added weight mass, in this case lead. Stacking the weight too high will cause the mass to become unstable.

Lowering the center of gravity by adjusting the proportions of the exhibition furniture

If a resultant center of gravity is found to be too high, the cg can be lowered using a number of approaches. For example, the object can be fastened to the floor. Although this provides the most stability of any option, the object must be sufficiently sound to withstand the earthquake forces transmitted to it. The base or pedestal can be made wider or weighted for greater stability. An appropriately sized base plate or an enlarged base at the bottom of the pedestal are also options as shown in figure 5.

Calculating the effective aspect ratio of the assembly in figure 5 reveals a more favorable effective aspect ratio.

It should be noted that if the height of the plinth/added weight component in figure 5 increases beyond the height of the added weight mass (perhaps due to aesthetic design concerns), the plinth and weight mass should be treated as two separate components in the calculations for equivalent block.

Seismic mount making

The previous discussion assumes that the object is sufficiently robust and rigid to withstand any transmitted earthquake force. Since this is rarely the case, additional strength can be provided by introducing supportive mounts that cradle and restrain the object on display.

Effective mount making requires familiarity with diverse materials, including a wide range of metals, woods, plastics, synthetic composites, and fabrics. Mounts should always be made of stable materials that are non-abrasive, non-corrosive, stable, non-staining, and free of corrosive vapors. When designing a mount the contact point between a mount and an object should be sufficiently large; fit as intimately as possible; and always be non-abrasive. Small contact points result in higher point-load forces, thus a larger contact area is used to distribute the forces and provide a more secure mount-to-object connection.

Mounts should be designed in such a manner that the object and mount can be quickly separated if desired. Adhering a mount to an object should be avoided if possible.

A safety factor of three is generally considered good practice when choosing the strength of the material from which a mount is made. Dynamic forces due to earthquake motions can increase the total load on a mount by several magnitudes. This might translate into using a hook with an ultimate strength of 68 kg to hang an object weighing 22.68 kg.

Stationary/supportive mounts

While stationary/supportive mounts restrain objects and minimize dynamic loads that might be caused by the impact forces of rocking or falling, it is very important that the mounted object is sufficiently robust in nature to withstand a considerable proportion of the seismic load transferred through the building structure. Protection is dependent upon the object being firmly held to the mount at suitable points and over a suitably large area, and the mount must be securely fastened to the exhibition furniture, the wall, or the floor. The assembly must be rigid and respond as a single unit. Although a number of smaller objects on display at the

Getty Museum are restrained using very simple anchoring methods (such as wax or synthetic monofilament), more substantial mounts are the more common approach. These include the following:

Interfaces

Objects which do not sit in a stable and level position, have uneven contact with the supporting plane (floor, pedestal top, or case deck), or have the majority of their weight concentrated on small points (point loaded), require a custom interface to distribute the load evenly over the bottom surface or over the surface on which the object rests (figure 6). Such interfaces are made of high compression strength materials, such as filled epoxies. Prior to casting an interface, the underside of the object's base should be inspected for under-cuts or cavities to avoid any physical "locking" of the interface to the object itself.

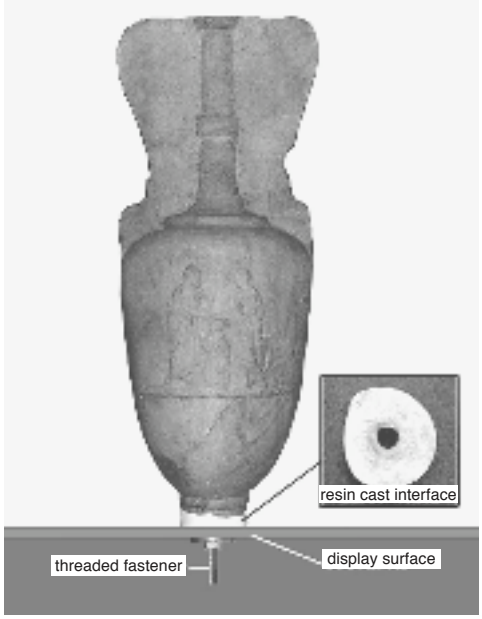


Figure 6. An example of an interface supporting the broken bottom edge of an object.

To cast an interface a modest amount of thixotropic epoxy is placed on a non-stick surface and covered with a sufficiently thick barrier of thin plastic film (such as the type used in the food service industry). The object is then lowered onto the plastic film and allowed to settle until the desired orientation is achieved and the excess epoxy is displaced.

At this point the object should be secured so that it does not shift while the epoxy is curing. Care should be taken to assure that none of the epoxy has come into direct contact with the object. Once the epoxy is fully cured the object is lifted away, the plastic wrap removed and the interface trimmed to the desired shape. In most cases the interface will be secured to the display deck rather than to the object.

Clips

Clips are relatively small point-of-contact mounts that restrain an object's movement but normally do not provide any support (figure 7).

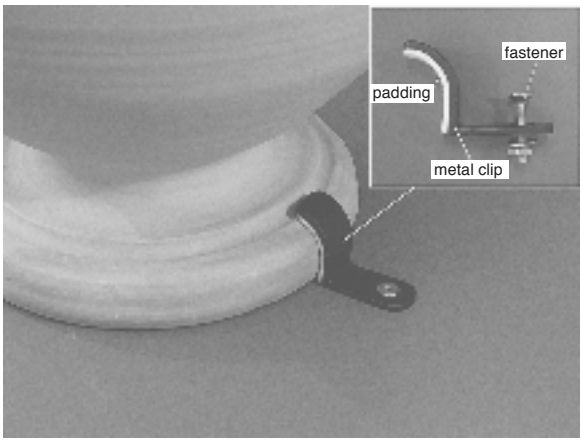


Figure 7. A typical clip assembly.

A three-point restraint is recommended when using clips to secure objects with round or oval bases. In these cases the clips are spaced as close to 120 degrees apart from each other as possible (figure 8).

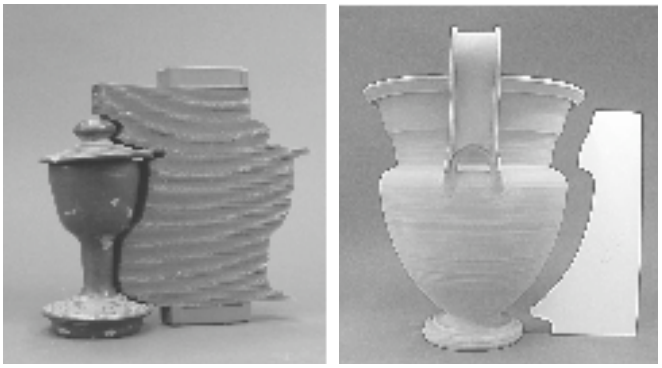
Figure 8. Object secured with clips and interface.

For square or rectangular bases clips on all four sides or at each corner are required. The edges of each clip should be slightly rounded and an appropriate felt or padding should be applied to the interior faces to protect the object's surface.

For objects that are mounted to the wall the clips may also support the object vertically (along the lower edge). In the instance of freestanding objects clips are normally applied to the object's base or lower edge. Caution must be exercised however since considerable stress will be concentrated at the point where the object is anchored during an earthquake. The taller the object is, and the higher the location of the center of gravity, the greater the forces will be at the anchor (clip) points. Stress failure at the area of load concentration (point loads caused by the clips) or at the area of material weakness is highly likely. Objects must sit flat, and if they do not, casting an appropriate interface is necessary.

Contour mounts

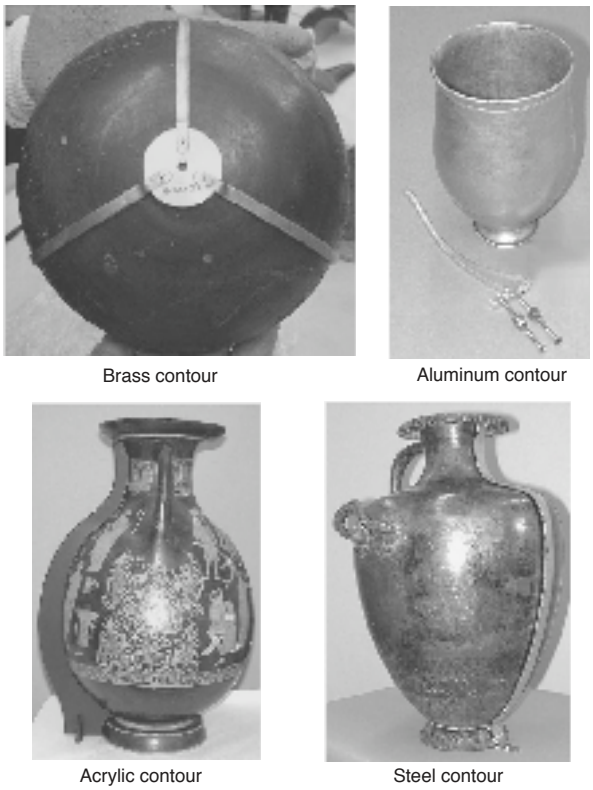
A contour mount is a supportive restraint that closely follows the exterior form of the object, providing complete contact along the object's profile. A measurement of the object's profile is attained using a profilometer, plastic contour gauge, or by cutting out and piecing together sections of stiff paper or cardboard as shown in Figure 9.



Use of contour gauge — Resultant profile

Figure 9. Using a plastic profile gauge and a profile cut in cardboard.

In most cases four basic materials are used to fabricate contour mounts; steel (including stainless steel), brass, aluminum, and acrylic (figure 10).



Brass contour — Aluminum contour

Acrylic contour — Steel contour

Figure 10. Four different styles of contour mount using different materials.

The material must have the strength and stiffness to support the object as well as withstand the earthquake load. Steel and brass are typically bent and/or welded to attain any given shape, whereas aluminum and acrylic parts are cut and/or adhered together to follow a pre-determined profile. Holes should be drilled through the mount at previously determined locations near the top and bottom where monofilament is inserted to secure the object to the mount as shown in figure 11. The interior surfaces should be felted and exterior surfaces finished. The mount is then secured to the display deck.

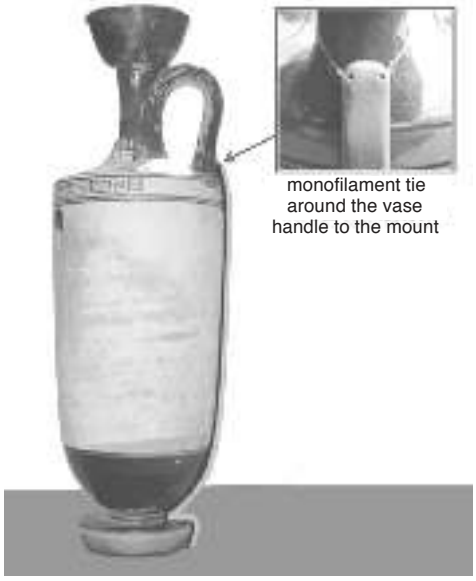


Figure 11. Monofilament tie-off to the object from the end of a contour mount.

Anchors

If an object has existing holes from previous mounting or restoration efforts, or if it is possible to safely drill appropriate holes to accommodate a mounting pin, it is advisable to anchor a mounting pin into the object using threaded anchor inserts into which the pin is threaded rather than adhered. Great care must be taken to thoroughly evaluate the fabric of the object surrounding the intended anchor points, ensuring that the material is sufficiently robust to withstand any seismic forces. Most off-the-shelf anchors have threaded interiors with knurled (roughened) exteriors. The internal threads allow fasteners to be easily removed, while the knurled exterior provides a rough texture to resist failure by pull-out.

Typically however, these anchors are designed to be press-fitted into the receiving holes. It is recommended instead that the anchors be adhered in place using a two-part epoxy. Ideally, anchors should be approximately 0.79mm smaller in diameter than the hole to assure a sufficient adhesive bond line all around the circumference of the anchor (figure 12).

Seismic base isolation (decoupling)

The discussion to this point has been limited to anchoring objects using a variety of support mounts that essentially made the object part of the structure. While this approach has a number of advantages, it also means that the seismic forces transmitted through the building will be fully experienced by the object. It also requires that either the mount be fully visible in the display or that an internal structure (often invasive to the fabric of the object) be introduced. Since this is not always possible and since objects can be too fragile to withstand the seismic load, an alternative approach is base isolation.

Isolation of structures has developed rapidly in the last several decades, but the isolation of building contents, like collections, has lagged behind.

Base isolation remains a new solution to the reduction of seismic forces. In general the isolation mechanisms and materials on which a building or an object rests are designed to absorb the motions and energies of the earthquake. Isolation mechanisms that have some form of restoring force are widely recognized as the most effective.

Decoupling, as an approach to seismic isolation, allows the floor under the object to move during an earthquake without transferring the full force of the earthquake to the object. In a sense the friction between the bottom of the object and the floor is eliminated or dramatically reduced through the introduction of low friction interfaces or mechanisms that provide limited lateral movement between the object and the floor.

There are a number of ways in which an object might be decoupled from the floor. As already described, early efforts to stabilize objects at the Getty Museum included altering the b/h ratios of pedestal/object assemblies by the addition of large steel plates to the bottom of the pedestals. These plates reduced the risk of overturning during an earthquake but did not, necessarily, stop rocking and the resultant dynamic pounding (rocking induced impact) at the lower edges of the pedestal. Teflon pads were added to the underside of the plates to reduce friction. Theoretically these pads allowed the pedestal to slide further reducing the overturning threat and minimizing the degree of rocking. In practice however this decoupling was imperfect since rocking, even overturning, was made even more likely by encounters of the sliding pedestal with imperfections in the floor that dramatically and suddenly, increased friction.

Using a site and building study done by Lindval Richter and Associates in 1984 which identified a maximum probable event (MPE) and then provided a "design earthquake spectra," it was found that any isolation mechanism being considered by the museum would have to have a period of greater than 0.9 seconds to get any reduction of acceleration input estimated to be 0.7g at its greatest.

The longer the period of the isolator the greater the isolation as long as sufficient room for displacement is provided. However at some point displacement demands would be impractical to accommodate either for reasons of display aesthetics, limited square footage in the galleries, or safety of the visitors.

Based on the data developed from the design earthquake specific to the Getty Villa Museum differing degrees of protection can be achieved for the Getty collections by modifying certain aspects of the base isolator design. To achieve 60% isolation the mechanism must be designed with a 2 second period and to accommodate a minimum of 30.5 cm of displacement. This results in the lower portions of the object being subjected to a peak horizontal acceleration of approximately 0.3g. If the isolator is modified to accommodate 45.7 cm of displacement and designed for a period of 3 seconds, the lower part of the object will experience a peak acceleration of 0.2 g which is a 70% isolation. In both cases a 5% damping, introduced by the isolator mechanism itself, is assumed.

Figure 12. Threaded anchor adhered into marble head. The support pin is then threaded into the anchor.

A design originating in the museum's antiquities conservation department was tested at a commercial shake table in 1990 (sine dwell, random dwell, and simulated earthquake) and indicated that the mechanism had a natural period of 3 seconds, which when combined with an 18 inch (45.7 cm) displacement capacity provided an almost 70% reduction of the seismic forces at the top surface of the isolator. The shake table tests indicated that the isolator had a period of 2.4 Hz (approximately 4 seconds). This provided an acceptable compromise between displacement demands and size of the transmitted earthquake force.

The isolator design was fully adapted for the museum exhibits and although numerous alterations and improvements have been made, it is essentially what is used today at the Getty Villa Museum (figure 13).

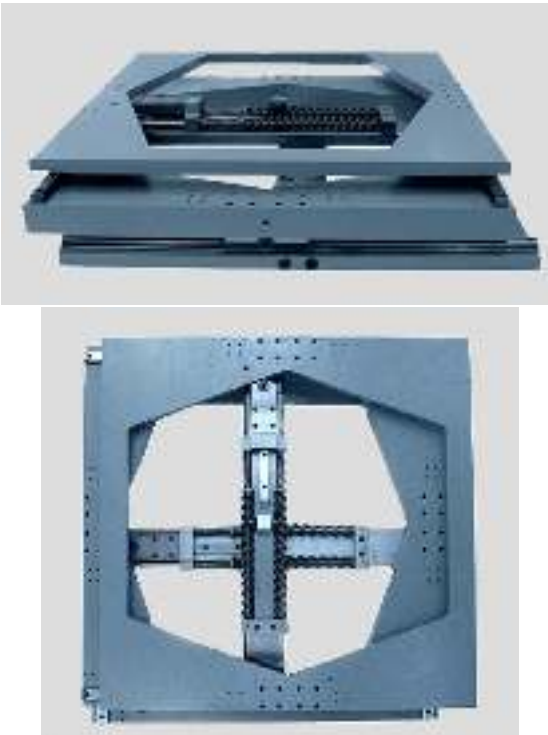


Figure 13. The isolator unit used at the Getty Villa.

The isolator is a three level de-coupling mechanism that offers relative displacement between the top, middle and bottom platforms. The top and middle platforms are supported by orthogonal sets of captured linear bearings that travel along rails. The orthogonal arrangement of these rail-bearing supports prevents torsional movements. Forces arriving at the isolator from a diagonal orientation are accommodated by a lateral "scissoring" action of the upper and middle platforms with respect to one another. The bottom frame is attached rigidly to the floor while the upper frame provides an attachment level for the pedestal, case, or object. Vertical restraint is achieved through the mechanical capture of the linear guide blocks to the rails they travel on. As a result there is no opportunity for uplift of the assembly during an earthquake. It should be noted that since 1984, subsequent earthquakes, especially the 6.6 Richter scale magnitude Northridge earthquake which occurred on January 17th 1994 (resulting in a 0.25- 0.50g lateral acceleration and a vertical record of 0.19 g in the Los Angeles area), some assumptions have changed in seismic engineering. The more recent events have led to a re-evaluation, carried out in 2005, of the design parameters for the Getty Museum (Villa) site. As a result of this new study vertical capture is given greater attention than in the past[3.]

Lateral displacement of the top and middle platforms is individually limited by a centrally mounted roller for each platform that travels along an angled ramp, compressing a series of springs which provide both a predetermined resistance to the lateral displacement and a centering force to the platforms. Spring rates are pre-determined to provide a natural period between 1 and 3 seconds, the variation is determined by the available displacement. A springs-in-series design provides two specific ranges of resistance to the lateral motion. A softer set of springs provides a longer period with less resistance. As maximum displacement is approached the stiffer set of springs offers greater resistance in order to accommodate larger earthquake forces and to avoid a sudden stop as the maximum displacement is reached.

During the 1990 testing the isolator was attached to a full-scale model of the object being considered for exhibition. The weight distribution of the model accurately mimicked that of the original sculpture as did the approach to assembly of the object's fragments and attachment to the base and isolator. The 100% design earthquake (maximum probable event, MPE) motion was filtered to remove periods greater than 4 seconds to insure that the maximum displacement of the table would not be exceeded. Although some whipping at the top of the sculpture-model was experienced, the top of the sculpture displaced with a max excursion of 2.5 inches (6.3 cm). The predicted 0.7 g peak was reduced to 0.1 g at the top of isolator (a 70% reduction), 0.15g at the top of pedestal (60% reduction), and 0.3g-0.4g (a 35% - 45% reduction) at the top of the sculpture.

Since the isolator was designed for a full 45.7 cm displacement, ample reserve was provided by the design. Realistically however this amount of displacement is not always possible due to the limitations of gallery space, aesthetic proportions of pedestal to object size, and safety of the visitor should the isolator and ground experience displacement while the visitor is standing in close proximity.

It should be noted that while isolators absorb a given percentage of the seismic forces, they can never eliminate the need for seismic mounts and structurally robust exhibition furniture.

Casework

The structural design of exhibition casework is a critical component in any effort to mitigate seismic damage to exhibitions. Display cases and pedestals must be sufficiently stiff and structurally strong, designed to withstand dynamic

forces beyond the predicted event while remaining intact and securely anchored to the building. As a general rule of thumb designing for a force of 3g (which includes a safety factor of 3 or more) meets a wide variety of needs.
The design of a case or pedestal structure should provide direct support under the display surface and artwork (figure 14). This support structure should be rigidly connected to the structural elements of the case or pedestal. The casework structure should include attachment points to either the building or an isolation system.

Figure 14.
An aluminum structure supporting a large sculpture.
The frame is then covered with a facing for display.

Anchoring casework
Anchoring the casework to the floor or wall is always the best choice, since this fixes the artwork and display furniture firmly in place resulting in a synchronous movement of the object with the casework and the casework with the building. It is important however that these anchoring points and the hardware used is sufficiently strong to resist the forces imposed on them during an earthquake.

Conclusions

Many of the suggested solutions outlined in this paper for the protection of collections from seismic threats have concentrated on exhibition conditions. It should be kept in mind that the majority of many collections are not on display, but rather placed in storage areas where the threat of seismic damage can be just as great, if not greater (due to density) than in the galleries.

The concepts of mitigation presented here work equally well for storage facilities, where mitigation efforts can be applied with less concern for aesthetic presentation. Tying objects to shelves that have been firmly secured to a wall; placing large restraining lips or ledges along the length and outer edges of shelves; and placing soft buffering foam pads between objects in close proximity or carving individual cavities in large blocks of ethafoam for storage are all effective ways of protecting stored collections. None are excessively expensive, nor do they necessarily need extensive engineering studies to carry out.

The efforts to protect collections from earthquake damage continually evolve, as do seismology and our understanding of the nature of earthquakes. It will only be through close collaboration that we will advance the efforts of preservation and reduce the number of collections that may suffer from inevitable earthquakes yet to come.

REFERENCES

1. Lindvall Richter and Associates. *Geologic and Seismic Safety Evaluation of the Main Museum Building for the J. Paul Getty Museum, Malibu, California*. (1984). Internal report on file at J. Paul Getty Museum, Department of Antiquities Conservation.

2. URS Corporation. *Ground Motion Response Spectra and Time Histories, Getty Museum, Malibu*, (2005). Internal report

3. Agbabian, M.S., Masri, S.F. and Nigbor, R.L. *Evaluation of Seismic Mitigation Measures for Art Objects,* GCI Scientific Report. J. Paul Getty Trust Publications, 1990, Los Angeles.

Tool/Supply Sources

McMaster-Carr Supply Co. (almost everything)
mcmaster.com

MSC Industrial Supply Co. (almost everything, good epoxy source)
mscdirect.com

Tool Crib of the North (tools)
toolcribofthenorth.com

Micro-Mark (small hand tools)
micromark.com

Rio Grande (jewelers supplies)
riogrande.com

Benchmark (mountmaking supplies)
benchmarkcatalog.com

University Products (conservation supplies)
archivalsuppliers.com

Conservation Support Systems
silcom.com

Conservation Materials, Ltd.
(800) 733-5283

ITW Philadelphia Resins (Phillyseal R, epoxy putty)
philadelphiaresins.com

Helpful References

Pocket Ref, Thomas J. Glover, Abbeon Cal, Inc.

Machinists' Ready Reference, Clarence Weingartner, Prankken Publications.

Machinery's Handbook, Erik Oberg, Franklin Jones, and Holbrook Horton, Industrial Press Inc.

The J. Paul Getty Museum at the Villa will hold a
Mount Making Forum, on March 28th, 2008.
For more information contact MDLowry@getty.edu.