Shake Table Testing of Stiff Model Statue Structures Considering Mass Eccentricity

Christine E. Wittich & Tara C. Hutchinson
Department of Structural Engineering, University of California-San Diego

ABSTRACT
The response of eccentric rigid bodies to seismic loading is of paramount importance for the protection of culturally important statues and can be easily extended to building contents and mechanical equipment. The analysis of cultural heritage artifacts, statues in particular, has been a historically neglected area of structural and earthquake engineering with advances only being made in the past decade or so (Nigbor, 1989). Yet, their high cultural, national, and religious significance combined with observations of toppling from recent earthquakes gives impetus to their study (Thomas, 1960; Berto, 2012; Rosetto, 2012). Culturally important statues have been observed to be typically constructed out of a single piece of marble and to be resting unrestrained on a stone pedestal with a high coefficient of static friction. As a result, they are expected to respond to seismic loading in the predominant rigid body modes of rocking, sliding, and slide-rocking. To date, few experiments have been conducted to understand the dynamics of typical rigid bodies.

SPECIMEN DESIGN
Guided by the results of the field survey, the experimental specimen is designed such that a consistent set of weight plates can be arranged to shift the center of mass in three directions. This will vary the critical geometric parameters for rocking: center of mass and slenderness. As such, the specimen can represent 84% of statues surveyed. Furthermore, the specimen is fixed to a marble base which rests unattached to another piece of marble on the shake table. This maintains the in-situ frictional interface and rebound properties. Figure 3 contains an image of this experimental specimen and setup in the UCSD Powell Laboratory as well as an image of the specimen post-shaking with the catch system engaged.

FIELD SURVEY
A field survey was conducted in Italy which included obtaining three-dimensional reconstructions of 25 culturally important statues. These reconstructions are used to obtain the geometric parameters that theoretically govern rocking and sliding responses. Light detection and ranging (LiDAR) and structure-from-motion (SfM) were used in the field to obtain the point clouds which were then triangulated into the fully enclosed meshes. (Wittich et al., 2012; Wittich & Hutchinson 2013) An example is seen in the figure at right.

GROUND MOTION SELECTION
Each configuration of the specimen is subjected to a suite of 12-15 input motions (Figure 4). Two near-fault pulse-type ground motions were selected along with the corresponding transient and extracted pulse motions. A broadband motion was selected for use in an experimental incremental dynamic analysis. An increasing sinusoidal protocol was also developed in order to induce many cycles of rocking and sliding behavior.

INSTRUMENTATION
In order to record the observed three-dimensional rotation, sliding, slide-rocking, accelerations due to impact, and angular accelerations, a large network of sensors was used: (7) string potentiometers, (22) accelerometers, (8) high definition cameras for monitoring using grid and circle patterns on specimen.

PRELIMINARY RESULTS
The following is a sequence of rotational time history responses of the specimen in its tallest configuration with varying degrees of in-plane eccentricity. The effect of the pulse-like ground motion is clearly seen with comparison to the response of the transient motion. In addition, the eccentricity, as expected, one-sidedly accentuates the response and leads to overturning.

ACKNOWLEDGEMENTS
This work was supported by the National Science Foundation under IGERT Award RDGE 0966375, “Training, Research, and Education in Engineering for Cultural Heritage Diagnostics.” Additional support was provided by the World Cultural Heritage Society, Friends of CISA3, and the Italian Community Center of San Diego. The authors thank Dr. Richard Wood for his assistance during the field work conducted as part of this study, and Profesor Falko Kuester for his input to the scope of the work. Findings from this study are those of the authors and do not necessarily reflect the opinions of the sponsoring agencies.

REFERENCES