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Shake Table Testing of Seismically Restrained Masonry Parapets

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Abstract –Past seismic events, have repeatedly served as reminders of the hazards posed by unreinforced masonry parapets. These parapets can be found in old residential buildings as well as heritage sites serving a great source of tourist attraction. Observed failure modes have revealed several cases where adopted retrofit techniques were inadequate to effectively secure parapets during earthquake-induced vibrations. This paper reviews shake table testing done for the dynamic behavior of masonry parapets. Parapet construction and retro-fit procedures are presented, followed by a discussion of the developed failure modes as well as the response of the retrofitted parapets.

Keywords: Parapets, Retrofitting, Seismic Analysis, Shake table

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INTRODUCTION

Freestanding nonstructural components such as unreinforced masonry (URM) parapets pose a significant falling hazard and, in past earthquakes, have caused numerous injuries and required costly repairs. Unreinforced masonry parapets typically fail out of plane because of rocking at the roofline. The result is damage to the roof or adjacent properties or falling to the ground below. Consequently, unsecured URM parapets represent a safety hazard to both building occupants and nearby pedestrians. To mitigate the hazard of URM parapets, some authorities have enforced ordinances requiring them to be secured or removed. Most ordinances and suggest general rules for assessing and securing nonstructural elements. As a result, a mixture of seismic improvement techniques is implemented on existing buildings, which leads to a wide range of seismic performance levels for the secured parapets. Concrete bond beams, steel braces connected to the roof structure, steel strips fixed with adhesive anchors or struts at the edge, steel corner connections, vertical steel bars inserted into the parapet, and replacement with lightweight replicas are some of the retrofit techniques identified during inspection of damaged URM buildings. Generally, better earthquake performance was observed in braced parapets than in other retrofit techniques.

LITERATURE REVIEW

a) Shake Table Tests on a Non-Seismically Detailed RC Frame Structure

Akanshu Sharma, G.R. Reddy and K.K. Vaze

A reinforced concrete (RC) framed structure detailed according to non-seismic detailing provisions as per Indian Standard was tested on shake table under dynamic loads. The structure had 3 main storeys and an additional storey to simulate the footing to plinth level. In plan the structure was symmetric with 2 bays in each direction. In order to optimize the information obtained from the tests, tests were planned in three different stages. In the first stage, tests were done with masonry infill panels in one direction to obtain information on the stiffness increase due to addition of infill panels. In second stage, the infills were removed and tests were conducted on the structure without and with tuned liquid dampers (TLD) on the roof of the structure to investigate the effect of TLD on seismic response of the structure. In the third stage, tests were conducted on bare frame structure under biaxial time histories with gradually increasing peak ground acceleration (PGA) till failure. The simulated earthquakes represented low, moderate and severe seismic ground motions. The effects of masonry infill panels on dynamic characteristics of the structure, effectiveness of TLD in reducing the seismic response of structure and the failure patterns of non-seismically detailed structures, are clearly brought out. Details of design and similitude are also discussed.

b) Seismic Retrofitting of Historic Masonry Buildings – Case Study

Santhakumar A R, Mathews M.S., Thirumurugan S, and Uma Rao.

Masonry heritage building built during early part of 19th century have characteristic colonial architecture using masonry walls and jack arch roofing supported on steel beams. They are highly vulnerable to failure during earthquakes. This paper describes a methodology to quantify their vulnerability and then based on this a scheme of structural retrofitting is suggested. The aim of this presentation, through 4 case studies of buildings located in Delhi, India, is to exemplify various aspects of analysis, design and execution methodology of the retrofitting scheme for such important heritage structures. The assessment of vulnerability is based on its location, codes of practice with respect to materials and loading. The main challenge in choosing the appropriate retrofitting scheme lies in retaining the architecture and aesthetics. Also the retrofitting has to be completed in the least possible time causing minimum disturbance to the occupants. This has been achieved through a combination of Ferro-cement bands and FRP sheets. The execution of retrofitting was considered to make use of available local materials and expertise. The building is analyzed in detail and the areas where stress concentration takes place is further strengthened.

c) Out-of-Plane Dynamic Response of Unreinforced Masonry Bearing Walls Attached to Flexible Diaphragms

Can C. SIMSIR, Mark A. Aschheim and Daniel P. Abrams

The paper summarizes research on the out-of-plane behavior of unreinforced masonry bearing walls in buildings subjected to earthquake motions. Results from a set of shake table tests revealed that, in general, the walls performed very well despite the intensity of the base motion and the slenderness of the wall. Experimental results are compared with those simulated using SDOF and MDOF computational models. The validated models are useful for establishing that permissible limits on wall slenderness as prescribed by current seismic guidelines (FEMA356) can be increased. A two-degree-of-freedom model is introduced as a simple tool for dynamic stability analysis of unreinforced masonry walls.

d) Pseudo-Dynamic Testing of Unreinforced Masonry Building with Flexible Diaphragm

Jocelyn Paquette and Michel Bruneau

A full-scale one-story unreinforced brick masonry specimen having a wood diaphragm was subjected to earthquake excitations using pseudo-dynamic testing. The specimen was designed to better understand the flexible-floor/rigid-wall interaction, the impact of wall continuity at the building corners and the effect of a relatively weak diaphragm on the expected seismic behavior. The unreinforced masonry walls of this building were also repaired with fiberglass materials and re-tested. The overall building was found to be relatively resilient to earthquake excitation, even though cracking was extensive. The repair procedure was demonstrated to enhance this behavior. It was found that even though the diaphragm did not experience significant inelastic deformation, some (but not all) of the existing seismic evaluation methodologies accurately capture the rocking/sliding behavior that developed in the shear walls under large displacement. The responses of the wood diaphragm and its interaction with the shear walls have also been studied. The evaluation of experimental results and the comparison with the existing procedures have revealed that the diaphragm deflections observed experimentally closely matched those predicted using the FEMA 356 and ABK models.

e) Seismic Retrofitting of Mani Mandir Complex at Morbi, Gujarat, India

Alpa Sheth, R D Chaudhari, Ejaz Khan, Divay Gupta and Malvika Saini

The Mani Mandir complex (100m × 100m in plan) is an important historic monument of the town of Morbi in the western state of Gujarat, which suffered significant damage during the M7.7 Bhuj earthquake of 2001 in India. As part of the earthquake reconstruction program, the Government of Gujarat decided to seismically retrofit this complex. The project was divided into two phases of design and execution; this paper discusses the evaluation and design procedures recommended for execution. A detailed condition survey was carried out and measured drawings were prepared. A comprehensive retrofit program was formulated. Conservation principles, minimum intervention and consonance with the heritage character of the building were important considerations in selecting the retrofit program. The complex was modeled using finite elements and behavior was studied of the existing structure as well as retrofit structure. The retrofit measures recommended included discriminate use of internal reinforced concrete skin walls, providing a rigid diaphragm behavior mechanism in existing slabs, introducing stainless steel reinforcement bands in the existing masonry walls, cross-pinning and end-pinning in walls and pillars, and strengthening of arches and elevation features.

f) Methodology for Mitigation of Earthquake Hazards in Unreinforced Brick Masonry Buildings

Kariotis, J.C., Ewing, R.D., Johnson, A.W., and Adham, S.A.; ABK, A Joint Venture, El Segundo, California, USA.

Seismic hazards in existing unreinforced masonry buildings were investigated in order to provide a methodology to strengthen these buildings to appropriate resistance levels. The testing program was comprised of static and dynamic testing of walls and diaphragms, both in-plane and out-of-plane, and of anchorages between walls and diaphragms. In these guidelines for the analysis of existing buildings, there were several significant departures from the code provisions for new construction. Results can be used as retrofit guidelines in accordance with the three seismic hazard levels of the 1978 ATC provisions based on effective peak accelerations of 0.1, 0.2, and 0.4 g.

Relevance to present national and global scenario of construction industry

The results of these tests can be easily interpolated to various structural members like load bearing walls, water tanks, bridges and masonry columns as well as non-structural members like parapets, dividing walls, ceilings and windows.

Currently in India retrofitting based on shake table analysis is being done on many heritage sites. These include the Taj Mahal, the Qutub Minar, the India Gate, and the Golconda Fort.

Internationally, shake table analysis are extensively done for high rise buildings and earthquake proofing especially in Japan, South Korea and Mexico.

CONCLUSIONS

A brief review of several literatures presented shows application of shake table testing for various masonry blocks. It was found that several historic sites are in extreme need of repairs for their unreinforced masonry walls. These are liable to collapse causing damage to life and property. Shake table testing can be done to analyze the masonry walls, and then decide the methods for retrofitting of these structures. Shake table testing is a direct way to simulate earthquake ground motion effects. Although shake table tests are limited due to its time requirements, cost and shake table availability, they provide a satisfactory result for seismic analysis and can be used for various boundary conditions as well as up to 6 degree of freedom and various sizes of payload.

These tests are useful in high rise, low rise, ancient as well as modern structures. And the shake table testing of heritage sites is a necessity for safety, tourism, and advancement in structural and civil engineering.

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