ICUS/INCEDE NEWSLETTER

International Center for Urban Safety Engineering

International Center for Urban Safety Engineering

Institute of Industrial Science
The University of Tokyo

VOLUME 3 NUMBER 4
JANUARY -MARCH 2004

STRUCTURAL DAMAGE TO BUILDINGS DUE TO BAM EARTHQUAKE OF DECEMBER 26, 2003, IRAN

By

Kooroush NASROLLAHZADEH NESHELI*

On December 26, 2003 at 01:56:56 GMT (05:26:56 a.m., local time), a destructive earthquake hit Bam City (29.09 °N, 58.35 °E) in Kerman Province, SE Iran. The Bam Earthquake caused numerous casualties (more than 45000 dead) and extensive damage to different types of buildings. Considering the earthquake focal distance was around 7 km, the buildings in Bam experienced a near-source earthquake. The majority of buildings were made with adobe and mud. In fact, the worldwide fame of Bam is due to its historical adobe houses. The most ancient adobe citadel in the world (more than 2000 years old) is located in this city and was severely damaged in this earthquake. The other building structural types include: un-reinforced masonry (URM) building, confined masonry building, steel frame, and reinforced concrete frame. In this article, building damage in terms of their structural types is discussed.

Earthquake-damaged view of historical adobe citadel (Arg-e-Bam)

Introduction

Regardless of some special characteristics of the Bam Earthquake (e.g. near-source location of structures), the observed failures of buildings were very similar to past earthquakes in Iran. What has been repeatedly observed is that construction and design do not conform to seismic resistant codes. While Iranian code of practice for seismic resistant design of buildings (the so-called Standard No. 2800) was revised by the Building and Housing Research Center (BHRC) in 1987 and became mandatory after Roodbar-Manjil Earthquake (1990), we still face many newly-constructed buildings which are not following the code. In Bam Earthquake, the buildings which observed main requirements of Standard No. 2800 could survive, demonstrating the efficiency of the code. There is, therefore, a high demand to establish a system so as to make sure that the standards come into effect.

In this article, buildings in affected areas are classified by construction material and method, and damage to each structural type is discussed.

Adobe

Adobe buildings are found in most areas of Bam city. Thick walls, heavy roofs, low strength of constituent materials (i.e. mud) and lack of integrity between components are characteristics of these houses. As there is no structural system to resist lateral loads, adobe buildings suffer large damage in earthquakes. The roofs in some adobe buildings were constructed in the form of a vault or a dome. Such roofs could partially survive during the earthquake, due to their special shape, provided that the walls support them. However, lack of integrity between roof and wall is a common problem in this type of buildings, causing total collapse of house.

Although the Iranian code prohibites new construction of adobe buildings, there is still a question about what we can do with the existing adobe houses, which are extensively distributed in rural areas in the country. It is recommended to conduct research on developing effective and cheap retrofitting techniques for adobe buildings.

Failure of unreinforced masonry walls and collapse of roof beams

Unreinforced masonry

The walls in this type of buildings are made of bricks and the roofs are constructed by laying bricks and mud between steel beams (this type of low-rise arch roof is called as “Jack Arch” in Iran). Because there are no confining ties or other types of reinforcement in these buildings, they are likely to collapse during earthquakes. In the absence of vertical and horizontal concrete ties, there is no integrity for an unreinforced masonry building. Therefore, as lateral forces apply to the structure, the supporting walls separate from each other at the corners of the building and are subjected to the out-of-plane deformations. Consequently, the roofs fall due to weak connection between roof beams and supporting walls.

Confined masonry

This type of building demonstrated good seismic performance. As indicated in Standard No. 2800, in all structural walls of all masonry buildings, one or two stories, irrespective of whether they are constructed with bricks, cement blocks or stone, confining ties must be constructed. Vertical and horizontal confining ties provide integrity for the building and make a seismic-resistant structure. By constructing tie-columns in the main corners of the buildings, the connection of

Vertical and horizontal ties maintain the stability of building

Tilt of building due to soft story formed in the first floor

walls at the intersections can be maintained.

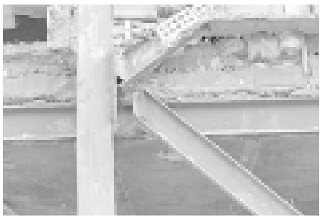
It should be noted that good seismic performance of confining ties could be expected only if the ties are well executed. In other words, the ties with poor quality of concrete are not able to develop a seismic resistant mechanism.

In order to have a three-dimensional resisting system, tie-columns should be properly connected at all intersection points to tie-beams. If there is no suitable detailing for reinforcing bars in the concrete joints, the building can not stand against earthquakes. Moreover, the distance between axes of two successive tie-columns should be limited to 5 meters according to Standard No. 2800. The confined masonry buildings, which did not observe the above-mentioned points, failed during the Bam Earthquake.

Steel frame

Among steel-framed buildings in Bam City, those which had a seismic resistant system by using, for instance, steel bracings in two orthogonal directions could stand during the earthquake.

One common problem that was observed in several buildings in the city was the formation of soft stories. Other problems were related to inadequate design and poor detailing. For instance, the connection plate of x-bracings to the beam-column joint did not have enough dimensions and/or the welding at the interface of the connection plate and column was not adequate. Consequently, the bracings were cut from the beam-column joint during the earthquake. This, in turn, led to a lateral stiffness decrease of the corresponding story and caused the change of the location of the rigidity center, generating additional undesirable torsion to the building. Another major problem in steel connections was poor quality of welding. This came from lack of trained workmanship to perform appropriate welding during the construction process.



Separation of x-bracing elements from the column due to poor quality of welding

Concrete frame

Reinforced concrete (RC) frames were fewer in number in comparison with the other types of buildings in Bam City. These RC buildings performed relatively well in this earthquake. Some of observed damages were related to bond slip and lack of column confinement in the plastic hinge.

Conclusions

What has been observed in earthquake-damaged areas in Bam City was mostly related to “seismic vulnerability” rather than “seismic hazard”. In other words, the buildings suffered much damage mainly because the structures did not follow the seismic-resistant codes of practice. In this regard, just to have a good code does not work. What is strongly needed is to establish a system so as to control different stages of construction process including: design, on-site performance, quality of materials, and so forth. On the other hand, the problems that are associated with the existing structures are mainly related to lack of an effective system for promoting retrofitting procedures. Such a system should provide financial incentives for owners along with economical retrofit techniques so as to encourage people to strengthen their buildings.

** Scientific Board Member, Building and Housing Research Center (BHRC), Iran*

PROPOSAL OF A NEW ECONOMIC RETROFITTING METHOD FOR MASONRY STRUCTURES

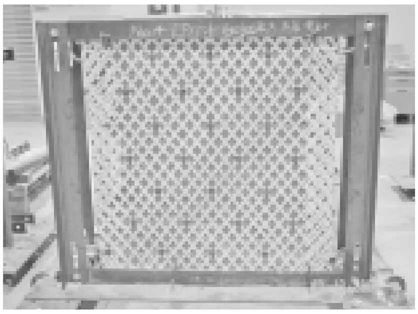
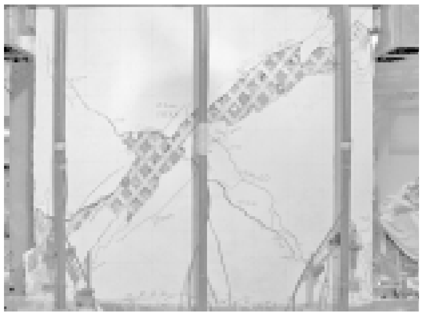
By

*Paola MAYORCA**

Introduction

Masonry is a construction material widely used around the world due to its low cost and construction easiness. More than 30% of the world's population lives in a house of unbaked earth, which is one type of unreinforced masonry. During the last century, human casualties during earthquakes were mainly caused by structural damage, being the failure of unreinforced masonry structures responsible for more than 60% of them. The vulnerability of masonry structures under seismic loads has been recognized long ago and efforts to provide guidelines for the construction of sound earthquake resistant houses have been remarkable. In spite of this, every year casualties due to collapsing masonry houses during earthquakes are reported.

Several types of retrofitting have been developed for unreinforced masonry structures. For strengthening this type of houses in developing countries, a suitable retrofitting technique should guarantee not only its efficiency in terms of improvement of the seismic resistant characteristics of the structure (strength, ductility and energy dissipation). It should also be considered that: 1) the used material is economical and locally available and 2) the required labor skill is minimum. In this context, a new retrofitting method for unreinforced masonry structures is proposed.

Retrofitted wall before mortar overlay setting and after test

Proposed retrofitting method

Considering the previously mentioned conditions, a novel retrofitting method consisting of polypropylene bands (PP-bands) arranged in a mesh fashion and embedded in a cement mortar overlay is proposed. These bands are worldwide used for packing. They are cheap, resistant, and easy to handle.

At first, meshes are prepared with the PP-bands. The pitch and inclination vary according to the required earthquake resistance. Then, the masonry wall surfaces are cleaned and holes are drilled through the wall at a spacing of approximately 4 times the mesh pitch. After this, the PP-band meshes are set on both wall sides and fixed at the borders. Galvanized steel wires are passed through the wall holes and used to fix the meshes. The photo below shows the wall at this stage. Finally, a mortar overlay is placed on the wall surface.

To assess the retrofitting by PP-band meshes, masonry walls with and without reinforcement were constructed and tested in-plane.

Retrofitted wall performance

The PP-band meshes have a relatively low stiffness compared to the masonry walls. Because of this, they did not contribute to increase the wall peak strength. The mesh contribution was only observed after the wall cracked.

Immediately after the peak, corresponding to the diagonal cracking, the unreinforced wall strength dropped to 10 to 40% of the peak. On the other hand, the reinforced walls exhibited a 60% residual strength after the peak, which was sustained for at least 2% lateral drift. In the reversed direction, the reinforced walls also exhibited larger post-cracking strengths. The effect of the connectors and the mortar overlay in the wall performance was also observed in the tests.

These results showed the potential of using PP-band meshes as an effective and cheap masonry retrofitting method. Scaled model houses for testing on a shaking table are currently been prepared to further verify this technique.

** Post-doctoral fellow,*
Meguro Laboratory,
Institute of Industrial Science,
The University of Tokyo

A STUDY ON APPROACHES TOWARD BUILDING DISASTER RESISTANT COMMUNITIES IN CALIFORNIA

By

Miho YOSHIMURA

Recent damaging earthquakes have clearly revealed that retrofitting low earthquake-resistant structures is the key issue for earthquake disaster reduction. In spite of this, retrofitting activities are not being carried out efficiently especially for non-public structures in Japan. Some local governments in California, USA are promoting retrofitting more successfully than Japanese governments by providing various kinds of economic incentives for it. I investigated the current strategies, history, and clues for successful promotion, mainly in the City of Berkeley and the San Francisco Bay Area, through interviews and reference collection from Nov. 5 to Dec. 4, 2004. This research was done with the scholarship program for young researchers provided by the US-Japan Cooperative Research Program on Urban Earthquake Disaster Mitigation by the US National Science Foundation and the Japanese Ministry of Education, Culture, Sports, Science and Technologies.

The City of Berkeley (104,603 inhabitants) in San Francisco Bay Area has achieved several goals to improve building safety since the 1989 Loma Prieta earthquake. According to the Association of Bay Area Governments, ABAG, the ratio of retrofitted houses to all single-family residential houses is 38%. The city was honored in 1999 by the Federal Emergency Management Agency (FEMA) with the “Model Community of the Year Award” for the Project Impact: Building Disaster Resistant Communities. Project Impact is a nationwide campaign for helping community members prepare for natural disasters.

More than 90% of the housing stock in the city is wood-frame buildings. Many of the single-family wood-frame houses constructed before 1945 are not bolted to their foundation or lack wall bracing. Multifamily wood-frame residential buildings, particularly with all or part of the first floor used for parking (structures called “soft-first story buildings”) have a risk of collapse in case of intense shaking. These buildings need retrofitting.

The city has provided economic incentives for retrofitting these buildings since 1991. Its popular programs include the real estate transfer tax rebate, permit fee waiver and grant funds or loans to low-income house owners to retrofit their homes. Transfer tax is a local tax imposed by the city on the real estate exchange. Property transfer tax can be rebated up to 1/3 of the 1.5% tax for seismic retrofit work on residential structures or the structures which contain two or more dwelling units. Moreover, permit and inspection fees for retrofit work are waived by the city in case of residential buildings. The total reduction in the revenue for the city due to both programs amounts to 1 million dollar annually. These strategies are very innovative compared to those in Japan where retrofitting incentive programs mainly provide financial assistance and low interest loan for seismic evaluation or retrofitting work.

In addition to the above-mentioned measures, the city library maintains a tool-lending library where community members can borrow the tools needed to retrofit their houses. The city also provides building retrofit education programs assisted by non-profit organizations. These activities aim at promoting house owners to retrofit by themselves.

With slight changes due to administrative differences, I believe that there is a large benefit of adopting similar strategies in the Japanese system that have proven so successful in promoting private building retrofit in California.

Soft-first story building

Welcome to Dr. Amano, visiting Professor

ICUS welcomes its new staff Dr. Reiko Amano, who has joined ICUS as a Visiting Professor from February 2004. Dr. Amano is a Deputy General Manager of the Kajima Corporation, Tokyo. Here, we present a self introduction of Dr. Amano for our readers.

I have been working for Kajima Corporation since 1980. My specialization is in design of different types of bridges. I have been engaged in developments of various types of bridges using latest PC (Pre-stressed Concrete) technology as a designer, a researcher and a construction manager. In 1986, one of our main works, Birdie Bridge, a stressed-ribbon type bridge using the composite material with concrete and FRP, received Tanaka Award from the Japan Society of Civil Engineers (JSCE). Another of our works, "The Seismic Design Method for PC Bridges with High Pier", which was adopted to Washimi Bridge, received JCI Technical Award in 1989.

During my stay in Indonesia from 1997 to 1998, I concluded my doctoral dissertation based on my research experiences of developments of unique structures, and proceeded to obtain doctoral degree from the University of Tokyo in 1999. In recent years, my major concerns are environmental protection systems and fire prevention systems. Last year, we developed a unique fire prevention system called "Water Screen System", which can be adopted to subways, underground highways, underground shopping arcades and so on.

ICUS Activity Records

- *Prof. Yasuoka delivered a lecture at AIT and carried out a field survey at Sri Samrong, Thailand together with Dr. Endo (Feb 24-28).*
- *Prof. Meguro carried out a damage investigation survey of Bam earthquake together with Dr. Yoshimura (Feb 16-26).*
- *Prof. Ooka attended the annual meeting of AGS in Sweden (Mar 29-28).*
- *Prof. Dutta visited AIT for collaborative research at RNUS (Feb 10-Mar 31) and carried out GPS survey and field investigation for a research project in Sri Lanka (Feb 14-22).*
- *Dr. Kato, Dr. Endo and Dr. Yoshimura visited AIT for collaborative research at RNUS (Mar 11-13), and visited India for research investigation related to RNUS (Mar 14-17).*
- *Dr. Endo carried out a field survey related to eucalyptus in Chile (Mar 21-29).*

3rd International Symposiumon Urban Safety Engineering on Octorber 18-19, 2004

ICUS is going to organize the 3rd International Symposium on "New Technologies for Urban Safety of Mega Cities in Asia" jointly with the Indian Institute of Technology Kanpur (IITK), India. The symposium will be held in Agra, India during October 18-19, 2004. The symposium will focus on the following areas;

- Safety assessment of existing infrastructure
- Seismic rehabilitation and retrofitting of structures
- Planning and development of urban infrastructure
- Environmental impact of urbanization
- Advanced technologies for assessment of urban safety

The various deadlines for paper submission and registration are as follows:

- Submission of abstract: June 30, 2004
- Notification of acceptance: July 15, 2004
- Submission of full paper: August 15, 2004
- Last date of registration: September 15, 2004

Dr. Sudhir Misra, an Associate Professor of IITK, is the Secretary of the Organizing Committee. He can be contacted for further details in the following address:

Dr. Sudhir Misra
Department of Civil Engineering,
IIT Kanpur
Kanpur 208016, India
E-mail: usafety@iitk.ac.in
http://icus.iis.u-tokyo.ac.jp/isus04/
Tel: (+91-512) 259-7346
Fax: (+91-512) 259-7395

News from Regional Network Office of ICUS/AIT in Thailand

The Regional Network Office for Urban Safety (RNUS) has initiated a series of seminars at AIT from the beginning of 2004 on various issues emphasizing new technologies for urban safety and security by inviting researchers and experts working in these areas. A total of four seminars have been organized during the last three months.

The first seminar was delivered by Dr. Takahiro Endo on February 24, 2004 on applications of Hyperspectral Remote Sensing. Dr. Endo, a Lecturer of ICUS, University of Tokyo, Japan, spoke to a packed classroom about the basics of hyperspectral remote sensing and its usage. One of the main focuses of his presentation was application of hyperspectral remote sensing in estimation of damaged concrete for urban safety.

Then on 27 February 2004, RNUS facilitated the organization of the 2nd Seminar on "Remote Sensing from Local to Global Scale." The presentations were given by Prof. Yoshifumi Yasuoka who talked on "New Technical Trend in Remote Sensing – Its Application to Civil Engineering" and by Dr. Dennis Dye who discussed "Photosynthetically Active Radiation and the Terrestrial Carbon Cycle". In the seminar, the two scientists presented recent scientific developments in the field of remote sensing and its applications in civil and environmental engineering. Prof. Yasouka is the Deputy Director General of the Institute of Industrial Science under the

Prof. Y. Yasuoka and Dr. D. Dye during their talks at the Seminar on March 12, 2004 at AIT

University of Tokyo. Dr. Dye is the Group Leader of the Ecosystem Change Research Program, Frontier Research System for Global Change, Japan.

On March 2, 2004, RNUS organized a seminar on "Numerical Models in Fluid and Their Applications" by Dr. Keisuke Nakayama, a Senior Researcher of the National Institute for Land and Infrastructure Management, Japan. In his presentation, Dr. Nakayama discussed the various types of numerical models which can be applicable for modeling of ecological system in bay areas of coastal cities. A case study of Tokyo bay was presented in his lecture. He applied various numerical methods and conducted laboratory tests to understand the flow field and stratification phenomenon in Tokyo bay, and predict the ecological system.

Dr. Yoshitaka Kato, an Assistant Professor and Ms. Miho Yoshimura, a Research Associate of ICUS, the University of Tokyo, delivered talks at the 4th seminar of the series organized by RNUS at SCE, AIT on March 12, 2004. Dr. Kato talked on recent problems and maintenance of concrete structures in Japan. He elaborated some of the major problems encountered by the Japanese civil engineers in evaluating the concrete structures using Non Destructive Inspection (NDI). He introduced a new NDI technique, which can be effectively used to deal with the current problems. Ms. Yoshimura introduced a new Retrofitting Promotion System (RPS) for low earthquake-resistant structures in earthquake prone countries that could serve as driving forces for the promotion of retrofitting of weaker structures. She mentioned that the effectiveness of the RPS was verified on the basis of the recovery activity data after the 1999 Kocaeli earthquake, Istanbul, Turkey and through this process, several advantages for both governmental and citizen sides were identified.

Editor's Note

Since 2002, ICUS has been holding international symposium on urban safety every year. The 2nd symposium was held in Japan in October 2003 and the upcoming 3rd symposium would be held in India in October 2004. I visited India with my colleagues Dr. Endo and Ms. Yoshimura for a preparatory meeting of this symposium in March. We arrived at Delhi around midnight and went to Agra, the city famous for the Taj Mahal, by car the following morning. The distance of just about 200km took around 5 hours to travel. During this journey, among many other things, I could feel the variety of differences between Japan and India. For instance, maintenance situations of infrastructure, traffic rules, and so on. I believe that the differences in these practices depend on the differences between the cultures and sense of value of each country and similarly infrastructure maintenance in a country is also closely related to its culture. So, we should never enforce our rules in a partner country as they are when we support infrastructure development in a developing country. It is extremely important to understand the culture and the sense of value of that country.

ICUS set up the regional network office at AIT (Asian Institute of Technology) in 2002. Since then, Dr. Dutta has been successfully working on collaborative projects in cooperation with researchers in Thailand. Dr. Dutta recieved a M.Eng. from AIT and a Ph. D. from the University of Tokyo. So, despite being an Indian, he is well versed with the cultures of Thailand and Japan. However, upon reaching here, I find that I do not know the culture of Thailand at all. I believe the level of my understanding of the Thai culture would ultimately affect the level of success of my research in Thailand. So, my first step in Thailand would be towards learning the Thai culture and to try and work and think like a Thai.

(by Kato)

International Center for Urban Safety Engineering, ICUS
Institute of Industrial Science, The University of Tokyo
4-6-1 Komaba, Meguro-ku, Tokyo 153-8505, Japan
Tel: (+81-3)5452-6472, Fax: (+81-3)5452-6476
E-mail:icus@iis.u-tokyo.ac.jp
http://icus.iis.u-tokyo.ac.jp/

PRINTED MATTER

International Center for Urban Safety Engineering