EARTHQUAKE HAZARD CENTRE
NEWSLETTER

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Contents

Editorial: How reliable is the 'test of time'?

In many areas of life there is a firm belief in the validity of the 'test of time'. Time, as understood by its duration, tests artefacts made by human beings. If something has 'stood the test of time' it is considered durable and reliable; it has performed satisfactorily. Unfortunately, the test of time is a notoriously flawed concept in the context of the seismic safety of buildings. This has been demonstrated recently by last week's central Italy earthquake.

The modest Magnitude 6.3 quake was centred near the medieval city of L'Aquila. Admittedly, the focus was a shallow 10km beneath the ground surface and so the earthquake energy release concentrated in the epicentral region. In many areas of the city the damage was devastating. Approximately 300 people died and over 100,000 are homeless.

This earthquake was not a one off. In fact, it was a repeat of two previously damaging quakes. In both 1461 and 1703 the city had been been virtually destroyed before and rebuilt using similar seismically vulnerable construction. Last week, buildings that had been inhabited for hundreds of years, collapsed. Those built in medieval times are constructed in stone masonry. Facing stones forming wall surfaces are infilled with random-rubble. Under intense ground shaking this construction often partially or totally disintegrated. Rubble returned to rubble in a matter of seconds even though it had withstood the ravages of time, successfully bearing gravity and wind loads for such a long time. Videos taken of the damage region that can be viewed on the internet show huge mounds of rubble that originally filled the streets, but now line them.

Some newer construction also performed extremely poorly. It was not uncommon for multi-storey buildings to pancake. One eye witness spoke of a 1970's hotel "collapsing like a pack of cards." It is not surprising that stone masonry construction crumbles under earthquake shaking since it often has not been provided with tension elements, like metal ties, to bind its components together. But it is inexcusable for modern construction in a seismic zone to behave in such a brittle manner.

Modern buildings are designed for just a small proportion of the inertial forces and displacements that occur in a damaging quake. That is why buildings need to be designed to perform in a ductile way. Then, since they are ductile, in the situation of seismic overload, some of their structural elements will be damaged; members will crack, steel will yield in tension and perhaps compression, but collapse will be avoided.

If you, like me, practice in a seismic zone, there is a reasonable probability that buildings you have been involved with, perhaps even have designed, will experience seismic overload. Do all you can to provide these structures with ductility. Then they will pass the test of time – including earthquakes!

Virtual Site Visit No. 16: Safety of brick cladding and partition walls, Peru

Fig. 1 The partial-height front wall and the interior brick partitions are vulnerable to face-load collapse.

In this Site Visit, we observe three multi-storey buildings under construction in Peru (Figs. 1 – 3). We focus not upon structural elements, but upon the unreinforced masonry cladding and partition walls.

During an earthquake these walls experience several actions that will decrease their stability and seismic safety. First, the floor slab above a wall will move horizontally in all directions relative to the floor that is supporting the wall. Relative movement normal to a wall doesn't have much effect, but any in-plane movement will weaken the top of wall-to-slab connection above. Sliding might occur along this interface, or if the connection is strong, diagonal shear cracking will probably occur in the wall.

Secondly, the walls will experience high levels of horizontal acceleration and inertia force. At the upper levels of these buildings, accelerations well in excess of 1.0 g (acceleration due to gravity) are likely during a design-level earthquake.

Due to both of these effects, relative displacement and horizontal accelerations, it is likely that severe damage could occur to the unreinforced masonry walls. Unless they are reinforced and physically connected to floor structures above with some sort of steel reinforcing, they will probably collapse, falling into and out of the building. Such unreinforced walls represent a considerable hazard to those within and outside the building.

Partial-height walls are also vulnerable. Unless they have vertical reinforcing steel within them, they can't act as vertical cantilevers and are therefore at risk of toppling.

All these brick walls are usually finished with smooth plaster and then painted. They look good, but unless provided with sound seismic detailing they are a considerable seismic hazard.

Fig. 2 Free-standing walls are likely to topple under horizontal inertia face-loads.

Fig. 3 If these unreinforced brick cladding walls are not restrained by steel detailing, they are potentially dangerous.

Summary of "Dissemination of earthquake resistant technologies for non-engineered construction" by B.H Pandey, K. Okazaki and S. Ando from the 14th World Conference on Earthquake Engineering, October 12-17, 2008.

1. INTRODUCTION

Any good technology can be of help to society only if it is accepted by and distributed to its people. This also applies to earthquake technology for safe housing, particularly since the decision of individual homeowners regarding building typology and construction affects the risk of building damage in earthquakes. In communities where building production is based on an sowner-built system where construction of house is controlled by homeowners, earthquake technologies need to be trickled down to the community and individual level for effective application. The continuous loss of lives in developing countries in recent earthquakes implies that the current state of earthquake technologies has not reached the communities that need them the most. However, technology cannot simply be imposed, but rather any efforts for earthquake risk reduction requires understanding of community safety culture. This approach needs an effective dialogue between "experts" and "common people" in which modern research outcomes and knowledge of earthquake technology is translated and transferred into non-technical language.

2. NON-ENGINEERED CONSTRUCTION

It has been repeatedly observed that people are killed in earthquakes mostly due to the failures of non-engineered buildings. These non-engineered buildings are normally in the form of houses, mostly built informally by homeowners themselves with input from local masons and do not have the required engineering input during the construction phase.

In community surveys carried out in Indonesia and Pakistan with 800 households for this study, it was found that local masons build 61% and 90% respectively of houses with no input from professionals and/or contractors. Homeowners and local masons take care of all stages of the building delivery process, that is, planning, design and construction. The building code enforcement is not effective in these constructions as there is very limited access to professional experts, and governments also do not have capacity to monitor and enforce the code provisions.

3. CASE STUDIES ON ROLE OF TECHNOLOGY DISSEMINATION IN SAFE HOUSING

The objectives of the implementation studies of earthquake technology dissemination were: creating awareness of earthquake risk and providing means for risk reduction by making houses resistant to future earthquakes; enhancing knowledge, understanding and motivation of people to adopt earthquake technologies; and developing skills of local masons and craftsmen to implement safe techniques in construction.

Community earthquake education incorporates the aspects of:

1. Public involvement in model earthquake projects;
2. Mass awareness through demonstration of existing risk and use of earthquake-safe techniques;
3. Communications and social marketing of technology; and
4. Education and training for earthquake resistant construction techniques.

Case studies of Afghanistan, India, Iran and Nepal as examples of technology dissemination are described as follows.

The program included developments of guidelines in Persian for local masons and craftsman; the training of technicians and masons on the use of the guidelines; the exhibition of earthquake safe construction methods through a real scale model wall and reinforced bar layout for beam-columns in Kabul University; and simple improvised shake table demonstrations for typical Afgan houses. In the entire process, the Ministry of Urban Development and Housing (MUDH), Ministry of Rural Rehabilitation and Development (MRRD) were engaged for national capacity building. The training guidelines developed were later adopted as recommended construction practice by MUDH.

The earthquake of January 26, 2001 hit the state of Gujarat, India causing extensive loss of life and property. It has been observed from past experiences that the lessons of earthquakes are often forgotten, particularly in rural construction, where buildings are often rooted in traditional culture, and therefore making these buildings more vulnerable.

The technology dissemination activities included field demonstration testing by making two half-size models of typical rural construction – one normal and the other with improved construction technologies (retrofitted) – and testing them with shocks; and conducting training programs. A study of the impact of demonstration and training in the community shows a significant increase in the level of confidence among masons and carpenters in using earthquake technology. This has led to the institutionalization of earthquake safety training for masons and carpenters constructing housing in India. Furthermore, in Gujarat, masons trained in earthquake-safe construction have formed an association to expand and market earthquake-safe construction in the communities.

70% of the houses in Bam were reported as destroyed in the earthquake that occurred on 26 December 2003. Improvised shake table demonstrations, on-the-job training of masons during the construction of the model houses, and training workshops on safer housing were the major activities of technology dissemination targeting technicians. The most significant impact of the activities in Bam was the realization of the effectiveness of simple affordable technology based on local materials for safe housing by the Housing Foundation, the government entity looking after housing reconstruction of Bam City.

Earthquake technology dissemination in Kathmandu, Nepal

In Kathmandu, Nepal, a big earthquake is considered long overdue in the Himalayan zone. The leading role of an NGO, National Society for Earthquake Technology (NSET), is in technological and policy awareness. Tools and channels of disseminations include, but are not limited to, radio and TV shows, public lectures, shake table demonstrations and exhibitions, drills and simulations, vulnerability tours, earthquake safety clinics, homeowners' orientations, paper-based publications, rallies and street shows, student art competitions on earthquake safety, and engagement of engineering students in development of a vulnerability database of buildings in cities. Besides achievements in social awareness and education for seismic safety, the impact of these activities is also visible in formal sectors where building codes are now enacted at city government level, and central government, where building safety is a major policy. Furthermore, international agencies are also active in earthquake risk management programs.

4. TOWARDS MOTIVATION AND ACTION FOR SAFE HOUSING

A risk perception survey on the seismic safety of buildings targeting residents was carried out by GRIPS in Nepal, Indonesia, Pakistan and Turkey. The survey is conducted in two kinds of communities in each country with approximately 400 randomly selected households in each community. The surveyors visited the selected houses to conduct an interview and questionnaire with each householder. Results of the survey have been analyzed from the perspective of the contributing factors to motivate individual homeowners towards seismic safety of houses they own or build.

Whereas more than 80% of respondents in Turkey are confident that their houses are safe from earthquakes, most of the residents (more than 60%) in Nepal, Pakistan and Indonesia feel that their houses are unsafe from earthquakes. 62% of the residents in Nepal, who feel unsafe, responded "No" to the question when they were asked whether they do have plan for safer housing in future. This is despite an overwhelming 86% of respondents who think their house would collapse in the event of an earthquake. In Indonesia and Turkey, only 33% of respondents who feel their house is unsafe, have no plan for safer housing.

In all countries, poor construction materials are a major factor in weak houses. Most of the residents, more than 95% in all countries, consider neighboring houses pose a threat. A significant portion of residents in Turkey (38%) said that they could invest a maximum of one month's salary into protecting their houses from earthquakes, whereas in Indonesia and Pakistan, 45% and 80% respectively responded that they can spend 5 years worth of their salary to protect their houses from earthquakes. Contrary to the expected concept that loss of life would be considered more terrible than loss of housing property, only 31% and 29% respondents in Indonesia and Pakistan respectively said they can invest 5 years worth of their salary for protecting family members in the event of an earthquake.

From the analysis of data from the questionnaire survey, and the lessons from the pilot case studies of community-based initiatives of earthquake safe housing in developing countries of the Asia-Pacific region, the following factors are found as most likely to contributing in determining the motivation of individual for seismic safety of their houses.

4.1. Economic consideration

The issue of livelihood always comes first to those in situations of poverty. Due to the distant risk of earthquake disasters, earthquake safe construction becomes a lesser priority for people than their immediate needs. In the case of seismic retrofitting, it is difficult to convince homeowners to have a fully-fledged retrofit, as it is costly and complex in nature. In the case of post earthquake rehabilitation, retrofitting can go well with the repair. Accordingly, this is the best window of opportunity for intervention.

4.2. Knowledge of buildings

Unless homeowners have the knowledge to make their houses safe, communication of risk should be targeted at individuals as action results from the threat to the individual or their family rather than a threat at community level. A homeowner acts only when he or she is aware of the risks of their house, and has basic ideas of what should be done to eliminate such risks.

Earthquake education should be accompanied with accessibility to technology. Earthquake education is redundant if there are no services or technology available to people when retrofitting or building houses. If a community does not have regular access to engineering services, training of local craftsmen should be the part of program to empower and educate communities in seismic risk reduction.

4.3. Building construction delivery process

In the case of an owner built system, homeowners themselves decide on construction matters and there is usually no formal regulations. Technical input in configuration and construction is sought from local masons and contractors. Basic knowledge of housing safety to homeowners makes a big difference in making earthquake resistant housing.

4.4. Housing as cultural reflection in the neighborhood

The motivation for individual families to adopt better technology and safety also comes through the observation of the same in the neighborhood. Experiences are that if a well-respected member of neighborhood adopts safe technology, chances are high that it spreads to other households.

5. TOOLS FOR EARTHQUAKE EDUCATION

Videos of past earthquakes in the same region or in other areas of similar housing conditions are very effective to create images for people of what may happen in the event of an earthquake in their community. Photographic exhibitions of past earthquakes in the same communities are an effective means for convincing people of the risk. Awards to encourage and recognize the contribution of people can be a useful method of motivating and supporting earthquake safety in community. Certification of masons trained on earthquake resistant construction provides moral boost and also helps with marketing. Furthermore, innovative tools have been developed, such as a shake table test of a demonstration pair of scaled building models made of sub-standard materials like adobe and brick.

Twin building models, although they may look alike, are different in that one is constructed in a conventional method without using any earthquake resistant elements in construction, and the other is constructed with the same building materials but with simple quake-resistant technology. Comparing the damage, one can easily be convinced by the simple techniques of safer construction.

Counseling services like “earthquake clinics” are another effective tool for technological awareness. The term “earthquake clinics” is derived from medical concepts, applied to earthquake safety; the solution is in the form of cure and prevention. A group of experts give consultations to perspective homeowners who want to build houses. The earthquake clinics are more effective if they are combined with municipal building permit processes so that all aspiring homeowners can go the consultation service provided to them before construction commences. Another form of earthquake clinic was devised in Nepal. The “mobile earthquake clinic” where an expert team visits house construction sites and provides on-site consultation to the masons and contractors upon request. Print material like flyers, guidebooks and other resource material are distributed to the masons, homeowners and contractors for later reference. This method is very effective to intervene in construction at the right time.

6. APPROACH FOR EFFECTIVE DISSIMINATION OF EARTHQUAKE TECHNOLOGY IN COMMUNITIES

Integration of technology demonstration, capacity building of communities to use the technology, and educational and motivational activities for individuals in communities is essential for effective dissemination of earthquake safety measures in communities. Examples of technological intervention for the safety of houses against earthquakes are physically visible elements that provide a community with a sense of confidence in the use of those techniques.

Community facilities like schools, heath posts etc. are the best places to demonstrate earthquake-safe technology in communities. The technological improvements over traditional construction for earthquake resistance should be simple and understandable in order for them to be to adopted and implemented.

Communities need to be equipped with the necessary knowledge and skills to adopt safer construction practices. As masons are the technical service providers for the majority of housing construction in developing countries, they are the key stakeholders in transferring the technology at the grass roots level. Therefore, for capacity building of the community in safer technology, training of these groups is a must. The aspects of simplicity and ownership of technology by these groups is important for sustainable capacity building of communities on use of technology. Using demonstration models like seismic retrofitting of school buildings is effective to provide on-the-job training to masons and technicians. Awareness of the homeowners' motivation is also critical for safer construction of individual houses in the communities. The people in these communities have been found to be very receptive and interested in such technological issues.

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Summary of "Pakistan Earthquake Reconstruction and Recovery Program" by Ashan M. Sheikh and Saif M. Hussain from *STRUCTURE magazine*, November 2008.

On October 8, 2005 at 8:50 a.m. local time, a magnitude Mw=7.6 earthquake struck the Himalayan region of northern Pakistan and Kashmir. The earthquake caused widespread death and destruction in the region. The Pakistan government has launched a reconstruction and recovery program through the Earthquake Reconstruction & Rehabilitation Authority (ERRA), who has undertaken the enormous task of reconstruction and rehabilitation in the earthquake affected areas with the aim to "Build Back Better" in terms of physical infrastructure, size and scope of activities and quality of services to the people. This reconstruction program is funded by multiple private and public donor organizations, including a number of international donors. One such program which aims to build and strengthen goodwill between the Pakistani and American peoples is funded by the United States Agency for International Development (USAID). Camp Dresser McKee (CDM) is delivering the Pakistan Earthquake Reconstruction and Recovery Program (PERRP) to reconstruct schools and health facilities.

Coffman Engineers Inc., Los Angeles office (CEILA) was selected as a specialized structural engineering consultant to focus on earthquake resistant design and construction for the buildings that are proposed to be built under the program. PERRP is a very interesting and challenging project from a structural engineering perspective. This project started with a plan of construction for over 200 earthquake resistant public buildings, which included small clinics, primary schools, high schools and some relatively larger healthcare facilities. During the first year (Oct 2006 - Oct 2007), CDM developed a schedule to complete the design of 40 such buildings and to start the construction as soon as bids were awarded. The consultant team began this project with the assumption that all design work would be performed by local A/E firms. Due to various factors, including very high workload for local design firms resulting from an extremely busy post-earthquake construction market, limited number of properly qualified personnel and an inconsistent level of knowledge and proficiency in earthquake resistant design, it soon became clear that a small design office staffed by American design professionals located in CDM's Islamabad office was needed in order to oversee the work of local A/E firms.

Deficient Structural System

The structural system proposed by the local firms for these two buildings was the same system typically used in building construction in Pakistan, i.e. masonry infilled concrete frames (MICF). A number of the common deficiencies found in such typical systems were evident in early versions of the structural drawings for these projects, such as frame members not properly detailed for ductile behavior, masonry infill walls not reinforced for out-of-plane loading, infill walls not isolated from the adjoining concrete frames, roof/floor diaphragms not properly connected to the lateral system, inadequate layout of footings etc. Furthermore, the design was based on inappropriate seismic design criteria. The design oversight office called for a comprehensive structural redesign of these projects based on a proper and rational structural design approach as outlined below, in accordance with the CEILA formulated basic seismic design criteria and approach mentioned above. It is important to note that this type of flawed structural system (MICF) is quite common, not just in this part of the world but also in quite a few other countries around the globe (Figure 4).

Adequate Structural Design

As mentioned above, following consultation between CEILA, CDM and USAID it was decided that the prudent approach for the PERRP project would be to utilize code conforming structural systems properly designed and detailed for a satisfactory level of earthquake resistance, aimed at a "Life-Safety" performance objective in a major earthquake of the type experienced in Kashmir in October

Fig. 4 Poor structural performance of MICF Buldings during an earthquake.

2005. The Uniform Building Code (1997 UBC) was selected as the base document for the project. The UBC is very well known across the world, including in Pakistan where many provisions of this code are routinely, albeit sometimes inappropriately, used by local engineers to design buildings. The concrete design provisions of the UBC, which are essentially the same as the ACI code, are the most commonly used concrete structural design provisions in Pakistan. Given the numerous problems with typical MICF construction in Pakistan, and after a study of various alternatives, it was decided that reinforced concrete shear walls would be used as the primary lateral-force-resisting system for the PERRP buildings. This made eminent sense since, these buildings already had numerous partition or exterior walls called for in the architectural design. A few of these walls could easily be used as shear walls, and other nonstructural walls would be properly designed and detailed to perform satisfactorily in large earthquakes. Reinforced concrete slab-beam-column construction was used to resist gravity loading and reinforced masonry block walls were used as nonstructural partitions. The decision to use reinforced concrete and masonry blocks for wall construction is based on a number of parameters, like abundance of ingredient materials in the region, low cost of construction, easy availability of trained workforce, low maintenance costs and the inherent durability of concrete.

Like most building projects in high seismic areas of the United States, structural engineers sometimes face challenges as they work with architects to ensure adequate lengths of shear walls along the perimeter/exterior of the building. Openings for windows, doors, breezeways etc. have to be contended with to obtain contiguous shear walls piers that run from roof to foundation. The demand for large windows is greater in this region of the world, because classrooms rely primarily on daylight for adequate visibility. The design group, working closely with the local architectural consultants, has managed to obtain adequate lengths of walls along the perimeter of the PERRP buildings. One such example of shear wall layout is shown in Figure 5.

Concrete beam-column members are used to support the concrete floor and roof slabs for tributary gravity loading only. These "frames" are not part of the lateral-force-resisting system. The columns are detailed to maintain support of gravity loading when subjected to the expected inelastic deformation caused by the earthquake forces. When the building frame is subjected to inelastic level deformation, a hinge is typically formed at the top of the column. Providing extra ties in the column keeps the column intact and prevents total or partial building collapse which is the minimum life-safety and serviceability requirement of the building code. The Code requirements for column rebar confinement result in a fairly large number of ties in the columns.

However, diaphragm action and the need for proper diaphragm design of these elements is commonly not well understood by the local consultants. The concept of story shear, drag, collector and chord forces in the diaphragms had to be explained and illustrated. This eventually led to the proper design of these seismic force resisting elements, and to their inclusion in the design drawings.

Concrete Masonry Unit (CMU) block walls have been used for partitions and exterior walls for these projects. These blocks are locally manufactured (per ASTM C90) and are readily available in the market. The block walls are isolated at the top to allow for the in-plane movement of the diaphragm, but anchored and properly reinforced for out-of-plane loading as shown in Figure 6, so the walls do not collapse and injure or kill occupants or pedestrians during an earthquake.

Fig. 5. Girls High School, Chowki, located in AJK Pakistan.

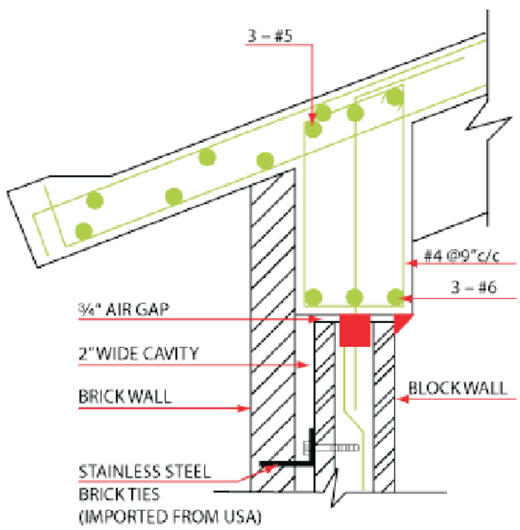

Fig. 6. CMU/ Brick veneer connection detail.

Construction Considerations
The structural performance of buildings in large earthquakes, where ductility is of greater importance than simply the elastic strength and stiffness of structures, depends heavily not only on proper structural design and detailing but, perhaps more importantly, on proper quality control during construction. This aspect of delivering earthquake-resistant building structures for this project was particularly emphasized by the CDM/CEILA team. A concerted effort was made to develop proper observation and inspection requirements duly noted in the specifications, training the inspectors and keeping close tabs on the construction of seismic system elements on-site. As part of this process, regional inspection offices in the vicinity of actual construction sites were set up. These inspection offices are staffed with experienced inspectors and resident engineers who are further trained on the UBC-97 Chapter 17 inspection program. A detailed construction inspection program which outlines the various types of inspections, different stages for these inspections and inspection frequency has been developed.

Summary and Conclusions
The PERRP Program, funded by USAID, aims to build hundreds of adequately earthquake-resistant schools and healthcare facilities in northern Pakistan following the devastating earthquake of October 2005. Though there are a number of well educated and knowledgeable structural engineers practicing in Pakistan, CDM/CEILA's experience has shown that the overall practice of earthquake resistant structural design and construction often does not meet the standards that one might expect in high seismic regions. It is also often mistakenly assumed that systematic, well planned and effectively implemented improvements in design will end up substantially increasing the cost of building construction in these regions. The PERRP experience has shown that this is not quite the case. With very modest increases in total construction costs resulting from the adoption of the measures explained above, a significant enhancement can be obtained in the expected seismic performance of newly built structures, thus saving lives and reducing damage in sure-to-come future temblors.

"Learning from Earthquakes" from *EERI Newsletter*, February 2009, Volume 43, Number 2

Papua Earthquakes of January 3, 2009
On January 3, 2009 (Indonesian time), an M7.6 earthquake in the pre-dawn hours and an M7.4 earthquake three hours later shook the remote east Indonesian province of West Papua. The region nearest the epicentre is sparsely populated and attracts tourists thanks to its diving sites, wildlife, and spectacular scenery. The capital city of Manokwari is the nearest major city (population 161,000) and is located about 145km and 85km from the first and second large shocks, respectively. Epicentral depths were 17km and 23km for the M7.6 and the M7.4 earthquakes respectively.

In Manokwari, about 250 houses were lightly to heavily damaged with one collapse. Two people were killed and 72 injured. Numbers may have been two or three times larger throughout the entire province.

M6.1 Cinchona, Costa Rica, Earthquake of January 8, 2009
The earthquake epicentre was located in an area that borders the northern limit of the Central valley (major city San Jose, 2 million inhabitants, approximately 30km NNW) just east of the Poas Volvano, at a depth of 5km, according to the USGD. The town of Cinchona (300 inhabitants), nearest to the epicentre, was completely destroyed.

Damage is widespread in the epicentral region. The area consists of a mountainous terrain with rainforests and waterfalls.

To date, the National Emergency Commission (www.cne.go.cr) reports 33 people dead, 7 missing, 2,326 displaced individuals, 91 seriously injured, 267 single-family dwellings damaged, 251 destroyed, and losses estimated at US$100 million in an area that covers 180km^2.

There is much to be learned from this earthquake in the areas of landslides, highway failure, environmental impact, power lifelines, power plant generation response, and vulnerability of single-family dwellings.

Earthquake Hazard Centre
Promoting Earthquake-Resistant Construction in Developing Countries

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