The 14th World Conference on Earthquake Engineering
October 12-17, 2008, Beijing, China

BUILDING CAPACITY IN DELHI, INDIA TO REDUCE EARTHQUAKE RISK FROM EXISTING BUILDINGS

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ABSTRACT :

India's capital city of Delhi faces substantial earthquake risk both from distant large-magnitude earthquakes in the Himalayas and smaller local events. The project aims to build the capacity of the Delhi Public Works Department to assess and seismically retrofit vulnerable existing buildings that have important post-earthquake functions. Improved seismic performance of these buildings both protects the government employees working there and enables them to respond more effectively to an earthquake disaster. The project utilizes a practical learning approach whereby public works engineers are mentored by a peer review panel from India and the United States as they seismically retrofit five groups of important buildings. Project buildings include the main offices of the Government of Delhi, the police headquarters, a hospital, a school that serves as a relief center, and the disaster management authority. Participants have learned to apply performance-based earthquake engineering concepts, assess and design retrofit schemes for existing buildings, address issues of disruption and user requirements, rectify falling hazards, and apply additional risk reduction tools such as constructing new earthquake-resistant buildings or changing the use of a building. This paper discusses the lessons learned during this project and recommendations for measures to improve the results of subsequent, similar projects.

KEYWORDS: assessment, retrofit, urban, technology transfer, concrete

1. INTRODUCTION

India's fast-growing capital city is home to over 14 million people. One of the oldest inhabited cities in the world, Delhi is situated on the banks of the Yamuna River, a major tributary of the Ganges. The Indo-Gangetic Plains stretch northward toward the Himalayan foothills, 200 kilometers away. Like other cities located on these plains, Delhi is threatened by earthquakes generated by the tectonic collision of India and Asia (Bilham and Hough, 2006). The Delhi metropolitan area contains an amalgam of buildings: old and new, illegally built and well-designed, humble brick houses and gleaming new high-rises. Many of these buildings are vulnerable to earthquake damage. Delhi's significant earthquake risk is growing, but there is hope of reversing this trend.

1.1 Sources of Earthquake Hazard in Delhi

The earthquake hazard in Delhi comes primarily from great earthquakes along the Himalayas approximately 200 kilometers to the north as well as from local sources (Iyengar, 2000; Bilham, 2001; Parvez, 2004). The major thrust faults that underlie the Himalayas have several major sections, called *seismic gaps*, which have not experienced earthquakes for several hundred years. During that time, the continental collision of India and Tibet has continued, causing strain to build. Seismologists anticipate that the next major earthquake to strike the Himalaya will occur in one of these gaps (Khattri, 1987; Bilham and Ambraseys, 2005). The gap located closest to Delhi is the central seismic gap, which is a section of the main plate boundary stretching approximately 600 kilometers between the rupture zones of the 1905 Kangra and 1934 Bihar-Nepal earthquakes. The central seismic gap has not ruptured in a great earthquake in more than 500 years (Ambraseys and Jackson, 2003). The soft, deep alluvial sediments on the east side of the Yamuna River are expected to amplify the seismic waves from a Himalayan earthquake and cause damage in East Delhi both due to liquefaction and amplified motion in multi-story buildings with periods similar to that of the soil column (Iyengar, 2000). The situation is more complex on the west bank of the Yamuna. The rock outcrops of an extension of the Aravalli Hills will not tend to amplify shaking, but they cover a relatively small area. A much larger area of alluvium underlies much of central Delhi, including softer alluvium in the abandoned flood plains of the Yamuna to the west of the outcrops that may amplify shaking significantly (Iyengar, 2000; Parvez, 2004). Many of the buildings in Old Delhi are founded on stiffer soil but are highly vulnerable multistory masonry buildings, so even moderate shaking may cause significant damage. Local sources also contribute to the hazard, but potential magnitudes and recurrence intervals of such events are not well quantified (Iyengar, 2000).

Despite Delhi's long history, the historical record of earthquakes is not as complete as one might expect. Very little information is available about events before 1800. In 1720, an earthquake with estimated magnitude of 7.5 thought to have originated in the Garwhal Himalaya (Ambraseys & Douglas, 2004) caused damage to buildings and killed many people in Old Delhi (Khafi Khan 1874, as reported in Martin, 2006). The 1803 Barahat earthquake, which originated in the Garwhal Himalaya (Ambraseys and Douglas, 2004) and killed more than 300 people in Uttarkashi (i.e., Barahat) in Uttarakhand (Ambraseys and Jackson 2003), allegedly caused the collapse of the upper sections of the Qutub Minar (Martin, 2006). Delhi and the surrounding region have experienced several local small-magnitude events in the past fifty years, including the M6 Gurgaon earthquake that killed two people and injured approximately 100 in the Delhi-Gurgaon region (Nath et al, 1968). Damage occurred at Bijwasan, Delhi Cantonment, Ghatorni, Gurgaon, Jharsa, Khandsa, Muhammedpur, Palam and Shikohpur (Martin, 2006). Minor damage occurred in other parts of Delhi and many prominent buildings, such as Rashtrapati Bhavan and the Ashoka Hotel developed cracks (Martin, 2006). Delhi also experienced low levels of shaking during the Uttarkashi (1991), Chamoli (1999), Bhuj (2001), and Kashmir (2005) earthquakes.

1.2 Building Vulnerability, Earthquake Risk, and Risk Reduction Measures

Delhi has many highly vulnerable buildings constructed of either inadequately reinforced concrete or unreinforced brick masonry. Many of the buildings in the congested neighborhoods of Old Delhi and East Delhi are highly vulnerable multi-story brick buildings with irregular configurations. It will not take a large earthquake to damage these buildings. The city also has many reinforced concrete buildings built without adequate earthquake resistant detailing. In addition, many buildings were built illegally, with no regulatory oversight or quality control. Delhi is taking steps to rectify the problems posed by illegal buildings, but complicated social and political issues are involved, making progress slow. Meanwhile, rapid growth continues to present a challenge, as new building construction must keep pace with the city's burgeoning population. In the rush to construct new buildings, earthquake resistance may be overlooked.

The city's earthquake vulnerabilities are large and increasing, but the government has begun to take steps to address the risks. The Delhi Disaster Management Authority (DDMA) is working with GeoHazards International, USAID, and other partners to build the capacity of the Delhi Public Works Department (PWD) to assess and retrofit important buildings. The project's goal is to seismically retrofit important buildings so that they survive expected earthquake shaking with minimal damage and can be quickly cleaned, repaired, and put back into operation. Given the current vulnerability of many of Delhi's buildings, the government will need to mount a large relief and recovery operation if a major earthquake strikes the city. Such a task will be much more difficult if the offices of the government officials in charge of relief and recovery cannot be used due to earthquake damage. For this reason, GHI has introduced the concept of performance-based earthquake engineering, which allows engineers to design buildings to obtain better performance than the life safety standard provided by most model building codes, including the Indian Standard (IS) code.

2. PROJECT DESCRIPTION

The Delhi Earthquake Safety Initiative for Lifeline Buildings aims to improve seismic safety in India by building capacity to undertake seismic assessment and retrofit projects. To accomplish this goal, GeoHazards International (GHI) is taking an experience-based, hands-on approach, pairing highly regarded and experienced US practitioners, from the private, public, academic, and non-governmental sectors, with Indian counterparts to transfer knowledge and arrive at locally appropriate solutions. The vehicle for this approach is the seismic retrofit of selected important buildings in Delhi. A peer review panel comprising Indian and American experts provides technical expertise and mentoring to local engineers and officials responsible for carrying out the retrofit work. The project's purpose is to provide a model program for seismic evaluation and retrofit that can be replicated in India and other countries.

2.1 Participants

GHI's primary partner is the Government of Delhi, particularly the Delhi Disaster Management Authority (DDMA) and Delhi Public Works Department (PWD). At the national level, the Ministry of Home Affairs (MHA) and the National Disaster Management Authority (NDMA) provide support. The United States Agency for International Development (USAID) is funding GHI's participation in the project. The Delhi Government is providing funds for assessment and analysis, engineering design, and construction. During the project's second half, several private-sector partners provided funding or in-kind support for additional project activities. Major private partners included Swiss Reinsurance Company, who funded a hospital earthquake safety workshop, and Bechtel Corporation, who funded a school earthquake safety project in nearby Gurgaon. The peer review panel GHI assembled includes practicing engineers and researchers from Banner Health, Delhi Transportation and Tourism Development Corporation (DTTDC), Indian Institute of Technology (IIT) Roorkee, Melvyn Green & Associates, MHA, Rutherford & Chekene, Tandon Consultants Pvt. Ltd., Tobin & Associates, and University of California, Davis. The project includes participants from a number of other organizations, including Ahuja Consultants Pvt. Ltd., Central Public Works Department (CPWD), Engineering and Development Consultants, IIT Chennai, IIT Kanpur, National Institute of Disaster Management (NIDM), SDEC Consultants Ltd., SEEDS India, and project building users.

2.2 Project Buildings

The buildings being retrofitted as part of this project are the Delhi Secretariat, the Delhi Police Headquarters, Ludlow Castle School, a ward block and associated structures at Guru Tegh Bahadur (GTB) Hospital, and several buildings at the Divisional Commissioner's office complex at 5 Sham Nath Marg. Project buildings house a number of important Government of Delhi activities that will be even more critical following an earthquake. The Delhi Disaster Management Authority selected the five building complexes based on their post-earthquake needs. The buildings provide a variety of construction types and sizes that have exposed Delhi PWD engineers to differing earthquake vulnerabilities and potential retrofit solutions.

2.1.1 Delhi Secretariat Building (Dilli Sachivalaya)

The Delhi Secretariat houses the offices of important Government of Delhi officials, including the Chief Minister. The Secretariat, shown in Figure 1, is a rehabilitated building originally designed for use as athlete housing in the 1982 Asian Games, but not completed in time. The partially completed building was in disuse and open to the elements for approximately 20 years before the extensive corrosion and environmental damage was repaired and the building was rehabilitated for use as the Secretariat. The building will be retrofitted to the Life Safety plus Damage Control performance level for the Design Basis Earthquake (DBE), and the Collapse Prevention performance level for the Maximum Considered Earthquake (MCE). The building is a reinforced concrete frame with few infill walls. The frame does not have ductile details and was designed for very low levels of earthquake shaking (3% g). The building has numerous irregularities in both plan and elevation, and three 10-story wings with insufficient seismic separation from the 12-story central core.

Figure 1. Delhi Secretariat Building (left) and Delhi Police Headquarters (right). Photos courtesy Delhi PWD.

2.1.2 Delhi Police Headquarters Building (MSO Building)

The Delhi Police Headquarters building houses the Police Commissioner's office and the police control room (dispatch center), as well several important offices of the Delhi PWD, including the offices of the Engineer-in-Chief and the Chief Engineers for Delhi's four administrative zones. These engineers will play crucial roles following an earthquake, such as inspecting buildings for damage; repairing buildings, bridges, and streets; and restoring utility services. The Police Department will need to maintain law and order and respond to emergency situations. The 14-story building, shown in Figure 1, was constructed in three phases separated by expansion joints 6" (150 mm) wide. Phase 1 has a core with two stiff but weak H-shaped shear walls, making it very stiff in comparison to Phases 2 and 3, which have flexible moment-resisting frames and no shear walls. The frames do not have ductile details as defined by current standards. The performance goal for the retrofit is life safety plus damage control in the DBE, with a collapse prevention check for the MCE. The proposed retrofit solution adds new shear walls and improves the performance of the existing Phase 1 walls.

2.1.3 Ludlow Castle School (renamed Pratibha Rajakiya Vikas Vidyalaya)

Ludlow Castle School (now known as Pratibha Rajakiya Vikas Vidyalaya) is a government school with approximately 1700 students, shown in Figure 2. Due to its close proximity to the Divisional Commissioner's office complex, the school will serve as an emergency shelter and relief distribution point in the event of an earthquake or other disaster. The school has two main buildings: the classroom block and the multi-purpose room, a free-standing auditorium. The classroom block is a three-story unreinforced brick masonry building with reinforced concrete floors. The classroom block retrofit uses a prescriptive system of micro-concrete seismic belts developed in India and specified in the Indian building code IS 13935 (BIS, 1993). The retrofit scheme for the Multipurpose Room has not yet been finalized because the building was originally supposed to be replaced. Retrofit construction in the classroom block was nearing completion as this paper went to press.

Figure 2. Ludlow Castle School classroom block undergoing retrofit (left) and multipurpose room (right)

2.1.4 Guru Tegh Bahadur Hospital

GTB Hospital is a 1000-bed hospital that provides healthcare to thousands of Trans-Yamuna and East Delhi residents daily. Given the vulnerability of many buildings in East Delhi, the hospital's services will be badly needed following a strong earthquake. The project is primarily considering the 750-bed ward block. The 8-story ward block building, shown in Figure 3 below, has a reinforced concrete frame system with some brick infill walls. The building comprises four L-shaped blocks framing a central courtyard. The building will be retrofitted to the Immediate Occupancy (IO) performance level for the DBE and the Life Safety performance level for the MCE. The frame does not have ductile details, but members are large, and project analyses showed that anchoring the brick infill walls is the only measure needed to achieve IO performance.

Figure 3. A portion of the GTB Hospital campus, where the ward block is the cream-colored building at right (photo courtesy Delhi PWD).

2.1.5 Divisional Commissioner's Office Complex

In addition to the Divisional Commissioners office, the complex includes the Delhi Disaster Management Authority, the Labour Department, and a police control room. The complex has four separate but closely spaced buildings shown in Figure 4. Blocks A and B are unreinforced masonry buildings that may be retrofitted or replaced; a final decision is pending. Block A is nearly a hundred years old, and may be a heritage structure. Block C is a 4-story reinforced concrete frame with a first story load-bearing unreinforced stone and brick masonry wall, a system known as the Bombay pattern. Block D, a reinforced concrete frame with masonry infill walls, has four stories plus a basement. Blocks C and D are being retrofitted with external shear walls schemes to the Life Safety plus Damage Control level for the DBE, with a Collapse Prevention check at the MCE. Construction of Block D's retrofit measures was well underway as this paper went to press.

2.3 Approach

The engineering peer review panel has served as the primary means of experience and knowledge transfer. Six peer review panel meetings have been held to date, with final meeting planned for late August 2008. All of the meetings except one have been held in Delhi. The second meeting was held in Palo Alto, California and included a number of technical tours of retrofitted buildings in the San Francisco Bay area as well as presentations by local earthquake engineering experts. A

Figure 4. Blocks A, B, C and D (left to right) at the Divisional Commissioner's Office Complex.

3. CHALLENGES

As primarily a capacity-building effort, the project faced several challenges that made transferring the requisite technical knowledge more difficult.

3.1 Keeping the Core Group of Personnel Intact

The first challenge was the high turnover rate within partner government agencies, including the Delhi PWD and the DDMA. Throughout the Indian Government, officials and employees are constantly being transferred to new positions within their agencies (in the case of engineers) and in other agencies (in the case of government officials). The transfers are a part of life in the Indian Administrative Service (IAS) and other civil services. For this reason, IAS officers are trained to be generalists, as it is anticipated that they will hold many different government positions during their career. However, premature transfers, short tenures and rapid turnover are common and have been identified as problematic in other agencies (Chand, 2006). It is difficult to go against the system and restrict transfers, even though capacity-building projects greatly benefit from the stability produced when key participants remain in their posts for the duration of the project. It is also difficult to execute capacity-building projects more quickly to reduce the chance of transfers, because this might compromise the time-consuming but necessary knowledge diffusion process.

Capacity-building projects typically focus on training and mentoring a core group of people so that they can do things they could not do before, and can train others to do likewise. This process becomes significantly more difficult if the members of the core group change, so one attractive strategy is to keep the core group intact by preventing or reducing transfers. GHI and its partners in this project tried this strategy, with mixed results. GHI and partners succeeded in preventing the transfer of the top public works engineer in charge of the retrofits, but saw all the other engineering team leaders transferred. Preventing transfers required tremendous effort, took up valuable time, and caused delays. However, the cost of letting transfers occur was also high. The training given to the engineers who were subsequently transferred no longer benefited the project, and was less likely to be used in their new positions in areas of lower seismic hazard. Their replacements had to be trained and familiarize themselves with the project buildings, which took time. Also, the period immediately prior to the transfer was sometimes rendered less productive due to the transferee's "lame duck" status. For example, one engineer rejected all bids and refused to select a contractor for the seismic retrofit of a project building after he learned he would be transferred, because he feared his decision might be questioned. The bidding process had to be repeated from the beginning, which caused a delay of approximately five months for that building.

GHI faced several difficulties in implementing the strategy of trying to prevent transfers. One hurdle was that in the case of public works departments, transfers are often linked to promotions, so restricting transfers could delay career advancement. GHI was concerned about this unintended consequence for participants. Project participants also had to deal with the fact that unfortunately, transfers can be initiated for political reasons. The project was affected by a rivalry between two agencies that resulted in the project's engineers being deliberately targeted for transfers, with the goal being to reduce the project's effectiveness. This type of transfer required project supporters to expend more time trying to block it. Due to this targeting, GHI surmises that the project faced more transfers and attempted transfers than average, but no data are available to support this contention.

3.2 Dealing with Competing Pressures
Project participants from the Delhi PWD are respected engineers, and their time was and is in demand. For much of the project, these engineers were also responsible for other projects that took up a great deal of their time. GHI advocated for a dedicated group of engineers that would focus only on seismic retrofit. Delhi PWD eventually formed the Retrofit and Rehabilitation Circle, but the Circle still had other projects in addition to the retrofit work. The preparations for the 2010 Commonwealth Games were a major source of competing pressures. The Delhi PWD was (and is) under immense pressure from the government to complete the Games infrastructure in time. Accordingly, the Retrofit Circle's lead engineer was assigned the design and construction of a netball arena. These competing pressures meant GHI had to continue to encourage timely completion of work, and to continue holding peer review panel meetings to create deadlines for progress.

3.3 Teaching a Radically Different Approach to Engineering Design
The project also faced a major ideological challenge when trying to introduce performance-based and displacement-based earthquake engineering approaches. Engineers who have primarily designed new buildings according to prescriptive, force-based, linear building code provisions must change their approach significantly in order to address the seismic vulnerabilities of existing buildings. They must think in terms of structural behavior – how the building might deform and be damaged in an earthquake – rather than whether the building meets code criteria or is simply strong enough. Explicitly assessing and accounting for nonlinear building behavior and using performance-based and displacement-based methodologies are now the state of the practice for existing buildings in most developed countries with high earthquake hazard. In the United States and elsewhere, this state of the practice did not appear overnight, and the new ideas and approaches were met with significant resistance in many cases. It took time for practicing engineers to develop the very different skills and experience they needed to understand seismic behavior and apply solutions to control deformations and failure mechanisms, and India's engineering community will need to go through a similar process. One of the goals of this project is to shorten that process and help India's engineers avoid the mistakes made elsewhere.

Researchers and academics accustomed to searching for new ideas and teaching malleable students may not fully appreciate the paradigm shift required. In prescriptive design, there is generally one way to design a certain type of structural system. In seismic retrofit, there are usually several alternate ways to address a given vulnerability in a particular structural system. Practicing engineers have had to be creative to balance technical constraints with the needs of the owner regarding cost, disruption and desired performance. Encouraging this creativity was easier than achieving the paradigm shift required by performance-based earthquake engineering. A study trip to California to visit retrofitted buildings and hear presentations on retrofit technologies helped tremendously by providing participants with first-hand knowledge of the variety of possible approaches.

3.4 Allowing Time for the Diffusion of New Ideas
The project introduced Delhi PWD engineers and other participants to the new ideas described in the previous section. The spread of new ideas takes time, and follows a well-documented process (Rogers, 2003). Project participants needed to go through this process, which included evaluating new ideas by talking to their peers with similar backgrounds and experiences, and determining whether the new ideas benefited them. Participants quickly adopted some new ideas, such as base isolation for very important buildings. Other ideas, such as the importance of involving building users and planning for the disruption caused by retrofit construction, met much more resistance. Some ideas suggested by the American engineers, such as making stiff but weak structural elements more flexible so they would deform compatibly with the rest of the structure, were regarded as too radical by some. Also, the need to show tangible project results sometimes clashed with the need to allow enough time for ideas to diffuse amongst the participants.

3.5 Reconciling Differing Styles of Practice Regarding Involvement of Stakeholders and Other Disciplines
The states of practice in several areas of critical importance to seismic retrofit projects differ substantially between India and the United States. Current practice in the Indian public works sector appears to be quite structural engineer-focused. Involving owners and other stakeholders in the decision-making process is rare.

Site-specific analyses and the inclusion of earth scientists in multidisciplinary project teams are not common, even for important buildings of the type addressed in the project. Conversely, it is standard in United States practice for the project team for an important building to include an engineering seismologist, geologist, and geotechnical engineer to address ground shaking and ground failure hazards through site-specific studies. These differences in practice led to a lack of consensus amongst peer review panel members on several important issues. GHI had to work very hard to try to build consensus, and was not entirely successful. As a result, some panel members were not satisfied with the level of attention given to site-specific seismic hazard, the potential for ground failure, and disruption planning. Conversely, other members thought the attention paid to these issues wasted valuable project time.

3.6 Addressing Differences in Priorities for Project Emphasis

Project participants came from diverse backgrounds, which contributed to differing opinions on what the project should emphasize. Some participants were most interested in building the capacity of Delhi PWD engineers to understand the seismic behavior of complex buildings and apply creative retrofit solutions. Others wanted to demonstrate simple, inexpensive solutions, both to avoid retrofit being viewed as complicated or costly and to promote widespread adoption. Still others were most interested in transferring an understanding of the full retrofit process and thus emphasized management, decision-making, and owner and stakeholder participation. These differing emphases occasionally led to friction. GHI had to balance all these valid points of view and empower Delhi PWD to achieve appropriate retrofit solutions. This involved making tradeoffs between technically advanced solutions and prescriptive minimum solutions, and addressing concerns that interest in retrofit could be destroyed by high costs and perceptions that highly specialized expertise is required.

3.7 Outsourcing of Project Analysis and Design Tasks

At the project outset, GHI planned to build Delhi PWD's capacity to do their own advanced analyses and develop their own retrofit designs. However, it quickly became apparent that the competing demands on the Delhi PWD engineers' time made it impossible for them to take the time to learn the required theory and techniques. Delhi PWD ended up outsourcing the analyses to three IITs and three local consulting firms. This provided an opportunity for the project to impact the private and academic sectors in addition to the government sector. This opportunity was not without significant drawbacks. Outsourcing to six different outside organizations it more difficult and time consuming to analyze and design retrofit measures, and raised the level of coordination needed by an order of magnitude. In addition, Delhi PWD's contracting mechanisms seemed to have difficulty accommodating projects like this, where many analyses and iterations are required. Payment delays and scope issues further postponed the work.

4. LESSONS LEARNED

Through experiences with the challenges described above, the project team learned several lessons. These lessons are most applicable to future projects in India, but provide insight for capacity building and technology transfer projects elsewhere.

Design the project to prevent transfers and mitigate the resulting effects on career advancement. This requires agreement with the top-level officials in the government partner agencies before the project begins, documented in writing and placed in the project file. The agreement should prohibit transfers for a set period of time (the project duration plus a handover period when replacements are trained). The agreement should also include provision for either promotion without transfer or accelerated promotion after the period when transfers are prohibited, so that participants don't have to choose between advancement and gaining new technical skills. Project participants should cultivate relationships with government officials to maintain support for the project and these agreements. Very little can be done about rivalries or politically motivated attacks; perhaps the best defense is doing a good job with honesty and integrity, thereby winning the support of allies in responsible agencies.

Require dedicated personnel. For projects such as this one that require major design work or other tasks to be done by government partners, it is necessary to have personnel devoted entirely to the project, without other competing responsibilities. It won't be possible to dedicate very many people, but even one person who spending all of their time and energy on your project can have a tremendous impact.

Emphasize hands-on learning. Site visits and first-hand experiences can be very important when communicating new ideas during capacity building. The diffusion process can be accelerated by providing shared first-hand experiences for a peer group, who can then evaluate the new ideas based on mutual understanding.

Be flexible and willing to accommodate other points of view. Local project participants may have very valid policy or contextual concerns that need to be addressed.

Anticipate the time needed for diffusion of new ideas and develop a diffusion strategy. It will take time for project participants to adopt radically different ideas, and some may never adopt such ideas. Plan the project so that participants have the necessary information and the opportunity to adopt new ideas, and include activities, such as shared first-hand experiences, that can support or accelerate diffusion.

Capacity-building is a worthwhile endeavor despite all these challenges. Accelerating the natural process by which a country's earthquake engineering practice develops is beneficial in several ways. The most significant benefits include the opportunity for local engineers and officials to learn from the experience gained in other countries and avoid their mistakes, and to thus make more people safer more quickly. As a result of this project and others, the Delhi government has begun the process of reducing their substantial earthquake risk and making Delhi's millions of residents safer.

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