DELHI EARTHQUAKE SAFETY INITIATIVES FOR LIFELINE BUILDINGS

Brief progress report

By

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Prepared Under

GoI – UNDP Disaster Risk Management Programme

MINISTRY OF HOME AFFAIRS

Government of India

New Delhi

August 2007

Delhi Earthquake Safety Initiative for Life Line Buildings

1. AIM

The project aims at developing an approach towards identifying and reducing the earthquake risk of lifeline buildings by building capacity on earthquake evaluation and Retrofitting.

It is expected that this initiative, would form the precursor to a larger nation-wide movement to reduce earthquake risk in India. More than 58% of the country is prone to shaking of intensity VII (MSK) and above. The country has more than 5000 urban areas and a burgeoning building stock. While recent initiatives would guide and facilitate incorporation of seismic safety in new structures, the real challenge would be to address the risk of existing ones. Seismic retrofitting is one strategy that can help mitigate earthquake risk in existing buildings. Seismic retrofitting, means upgrade of the lateral force (earthquake force) resisting system of a building so that the building can resist higher level of forces where not considered in the original design.

2. CONTENTS

In Delhi, the project would be piloted in five "life-line" buildings. These are buildings that would be needed after a major earthquake. The following buildings have been identified for the project:

(i) Government School, Ludlow Castle

(ii) Guru Tegh Bahadur Hospital

(iii) Delhi Police Headquarters Building

(iv) Office of Blocks Divisional Commissioner

(v) Delhi Secretariat/ Players Building

The project is preparing design for retrofit of these life-line buildings. It will develop decision-making procedures and build capacity for similar work elsewhere. Experiences from US is being shared and adapted for implementation in India. This is being supported by USAID assisted by GHI (USA) through technology support.

A Peer Review Panel has been constituted comprising Indian and US experts. On the Indian side the panel consists of Dr. A.S. Arya (Chairman), Dr. Jose Kurien, Dr. Mahesh Tandon and Dr. D.K. Paul (Members). On this side Thomas Tobin of GHI chairs the panel. The members being W.J. Holmes, Melvyn Green, K. Edwards and I.M.Idriss. The Divisional Commissioner of Delhi leads the project with the Engineer-in-Chief and the SE's incharge of the life-drive buildings play the most important engineering role on behalf of the Delhi Government.

3 PROGRESS AND PRESENT STATUS

3.1 Ludlow Castle School

The Ludlow Castle School is a government school located at 5 Sham Nath Marg. Both the classroom block and the multipurpose room are being seismically retrofitted to the life safety plus damage control performance level for the DBE, and collapse prevention for the MCE. The classroom block building is a 3-story Load bearing wall building. The building was constructed in two phases, with two blocks being constructed in 1965, and the third block being constructed in 1978. The retrofit solution involves providing seismic belts, corner reinforcement, and other prescriptive measures as per the Indian code provision IS:13935. The Multipurpose Hall is tall one-story brick structure that can accommodate assemblies of students and sporting events. The retrofit scheme involves measures per IS: 13935 and addition of new exterior elements. Fire safety and functional improvements will be made at

the same time as the retrofit to minimize disruption. Indian peer panel members requested that PWD ensure that adequate sanitary facilities are provided, due to recent concerns about school sanitation in the city.

The Delhi PWD and Delhi Government have approved construction documents and estimates, solicited bids, and are in the process of selecting construction contractors. Delhi PWD estimates that the contract will be awarded in September and construction activities will begin soon thereafter. The engineering team intends for most construction on the classroom block to take place during the vacation period, but that any construction activities necessary before or after that will be accommodated by moving students to the multipurpose room temporarily. Delhi PWD estimates that construction on the classroom block will take approximately six months, followed by another six months for the Multipurpose Hall. The Engineer-in-Chief also informed meeting that the Delhi Government intended to upgrade the Multipurpose Hall so it could also serve as a practice facility for the 2010 Commonwealth Games.

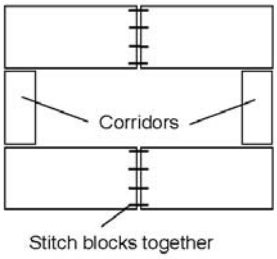
The American panel members recommended that despite the prescriptive nature of the retrofit scheme, the engineering team perform a computational analysis of the building to document the demand on and capacity of the walls. This exercise would provide additional understanding of the building type and would be helpful if engineers wanted the option of using of other non-prescriptive methods on other buildings in the future. Peer panel members also initiated discussion on proposed details of seismic belt construction, including surface preparation and lap splice locations, as well as on the construction quality control plan. PWD expressed confidence in their quality control process due to past earthquake performance of PWD-constructed buildings.

3.2 Guru Tegh Bahadur (GTB) Hospital

The Guru Tegh Bahadur (GTB) Hospital is a large public hospital in the Trans-Yamuna area of Delhi that serves a large population, including many low-income people, from both east Delhi and the neighboring state of Uttar Pradesh. The hospital is under tremendous pressure, and though it has approximately 1000 beds, there are up to 1500 inpatients daily, along with 4000-4500 outpatients and approximately 300 emergency cases per day. GTB Hospital also serves as a teaching hospital for Delhi University. The project initially covered several buildings at the hospital, but efforts to this point have focused on the Ward Block, the only building discussed.

The proposed retrofit scheme includes tying the two blocks on each side together (see below), and preventing collapse of infill walls. Issues remaining were identified as detailing of the stitching and selection of appropriate infill wall retrofit details. Analysis determined that a possible soft story at the plinth level was not an issue. The American panel members raised questions about the corridors not being included in either the proposed retrofit scheme or the issues remaining. Indian panel members replied that the corridors should be considered separately to avoid delaying the retrofit of the hospital. The American panel members stated for the record that in their opinion, not dealing with the seismic deficiencies of the corridors

meant that the retrofit solution was incomplete, since the corridors provided exits for the building. They recommended that the corridors be dealt with as soon as possible.



Plan layout of Ward Block

Discussions related to tying the blocks together ensued. The American panel members raised the issue of how much force the stitching elements should be designed for, since the analysts considered the only best case (in-phase behavior of attached blocks), but the real behavior will probably lie somewhere in between the best case and the worst case of out-of-phase behavior. The panel members recommended a simple calculation to determine forces, which should be somewhat higher than in the best case, and that the connection be designed for shear and tensile chord forces in the diaphragm (i.e. beams be adequately connected at chord locations). Panel members also recommended that it would likely be possible to stitch only every other floor to reduce cost and disruption.

What to do with the thicker (9-inch) brick infill walls was another major point of discussion. Panel members pointed out that it was important to keep the walls from falling out of plane without making them stronger in plane, since making them stronger would require new analysis. Top angles were suggested as the most likely solution for resisting overturning from out-of-plane forces. Possible suggestions to prevent out-ofplane collapses or spalling due to in-plane shear cracking included vertical steel channels (these would also serve as attachment points for bracing equipment), plastic coated chicken wir e covered in weak plaster, and cutting around walls and filling gap with Corridors rubber or other pliable material. The thinner (4.5-inch) brick partition walls were considered more cumbersome, since approximately 70-80 percent of the walls in the building are thin brick partitions. Options included replacement with gypsum partitions and aluminum partitions, though Indian engineers pointed out that aluminum partitions may not meet fire safety standards. Disruption was a major concern for the replacement of these infills. However, the Engineer-in-Chief related new information that local authorities were likely to authorize an upgrade for the hospital. The upgrade would take two floors at a time out of service, and retrofit measures could be constructed at the same time as the upgrade, greatly reducing the disruption.

The issue of fire safety in the hospital also generated much discussion. Concerns were raised by the Delhi PWD that perhaps fire safety and seismic safety were at odds, and that it would be difficult to satisfy both sets of design constraints. The American panel members related that in their experience, it was necessary to design for both simultaneously, and that designers had come up with appropriate solutions. Some Indian engineers expressed concerns that solutions used in American hospitals, such as gypsum board partitions with continuous plastic bumpers to prevent damage, would be impractical in the Indian context.

3.3 **Delhi Police Headquarters 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 Public Works Department (PWD), including the offices of the Engineer-in-Chief and the four zonal Chief Engineers. The 14-story building was constructed in three phases, and is essentially three different reinforced concrete buildings separated by expansion joints 150 mm wide. Phase 1 has a core with two massive H-shaped shear walls from foundation to roof, 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. In particular, ties do not continue through joints and 90o hooks are used throughout. The performance goal for the retrofit is life safety plus damage control in the DBE, with a collapse prevention check for the MCE.

Arriving at a technical solution for this building has proven to be quite challenging, despite general agreement from almost the very beginning that the retrofit scheme would include tying the three phases together to avoid pounding and adding shear walls. The difficulties stem from the incompatibility between the stiff shear walls in Phase 1 and the flexible moment frames in the other phases. The shear walls in Phase 1 were not properly detailed and as a result are very stiff but weak. The analysts from IIT Kanpur were unable to add enough new shear walls, given architectural constraints, to keep the Phase 1 walls from experiencing shear failure, a highly undesirable brittle failure mode. Mr. Holmes had suggested making the H-shaped shear walls more flexible by making cuts in them. The analysts had tried several cutting schemes, none of which softened the wall enough, and recommended trying to add shear strength to the wall instead.

Peer panel members recommended that the analysts pursue the strategy of tying the phases together and adding new shear walls along with softening the existing walls at the lower floors until they no longer failed in shear, and adding new boundary elements and/or coupling beams as necessary. Peer panel members recommended that the phases could be tied together at every other floor or perhaps every third floor to minimize disruption. New exterior shear walls should also be located outside the columns if possible to improve constructability, especially for foundations.

Engineer-in-Chief Subramanian expressed concerns about disruption to the operation of elevators (lifts) in Phase 1 if work was done to the existing shear walls. Engineers expressed opinions that regardless of the final retrofit scheme, disruption of the elevators could be minimized by careful planning, working on only one or two shafts at a time, and using elevators in the other parts of the building.

3.4 Divisional Commissioner's Office Complex

The office complex located at No. 5, Sham Nath Marg, houses a number of government offices, including the offices of the Divisional Commissioner, the Labour Department, and the Delhi Disaster Management Authority. The complex has four separate but closely spaced buildings: Blocks A, B, C, and D.

Blocks A and B, which are unreinforced masonry buildings, may be demolished and replaced with a single, larger building that better satisfies the space and functional needs of the Delhi Government. However, when apprised of this possibility, the Divisional Commissioner seemed to be opposed to the demolition of the office and stressed the need for the office to be able to function following a disaster and communicate with officials throughout Delhi. Engineers related that it would be very difficult for Block A to provide this of level performance since it is an older unreinforced brick building, even with a very expensive retrofit solution, and that for this reason emergency operations centers are generally new buildings specifically designed to remain operational. There was significant disagreement among some participants

as to whether replacement would be cheaper than retrofit, however. Some peer review panel members recommended that this might be a good opportunity to construct a new state of the art emergency operations center for Delhi.

The Delhi Government plans to retrofit Blocks C and D for Life Safety plus Damage Control for the DBE, and Collapse Prevention at the MCE. Block C is a 4-story reinforced concrete frame with load-bearing unreinforced stone and brick masonry, a system known as the Bombay pattern. Block D, a reinforced concrete frame with masonry infills, has four stories plus a basement. Both buildings will be retrofitted using external reinforced concrete shear wall schemes. Construction documents have been prepared for both buildings. Block C has been tendered out.

3.5 Delhi Secretariat Building

The building housing the Delhi Secretariat, or Delhi Sachivalaya (or the Players Building), is a rehabilitated building originally designed for use as housing for athletes in the 1982 Asian Games, but left in an incomplete and disused state for approximately 20 years. The building has a non-ductile reinforced concrete frame structure. The performance goals for the building are Life Safety plus Damage Control for the DBE (PGA = 0.18g), and Collapse Prevention for the MCE (PGA = 0.24g). Seismic analysis in the elastic as well as plastic stage through push-over methods has been carried out which clearly indicate that the existing building is not so strong enough and needs retrofitting. The following retrofitting alternatives are being considered:

- Strengthen deficient columns by jacketing;
- Removing the top three stories; and
- Adding new structures at end of each wing that enhance lateral resistance and provide added floor space.
- Options for the core included:
- Adding shear walls or strengthening existing walls;
- Softening shear walls to make them more compliant with the flexible frames in the wings; and
- Widening seismic joints to eliminate pounding.

There was some discussion about how important of an issue pounding would be, given that the retrofit solutions would be quite different if the building were tied together than if it were not. Panel members pointed out that it would be nearly impossible to obtain a reliable analysis of the building with pounding. Thus, tying the building together or increasing the seismic gaps sufficiently were the recommended options, with connecting the building preferred since it would increase redundancy. If the building were tied together, the core would need to be softened and upper story columns jacketed. Some peer panel members recommended that removing the problematic stories would be very disruptive to the occupants and unlikely to receive approval from the government. In this building in particular, the functional needs of politically important users and the architectural appearance will be very important, and any retrofit activities are likely to take place while the building is occupied. The Divisional Commissioner Ms. Jayaseelan reiterated at the end of the session that users should be involved in the decision-making process.

4 DISCUSSIONS ON PERFORMANCE CRITERIA, USER INVOLVEMENT

Several users were present at the meeting and again brought up the issue of performance. The Divisional Commissioner raised concerns that the users had not been sufficiently involved in determining the performance goals. The Deputy Police Commissioner brought up the issue of performance for the Police Headquarters building and asked if the building would be functional after the design earthquake. Several peer panel members then explained the definition of the performance goal for the building (Life Safety plus Damage Control), and said that the building would likely not be operational immediately. The police official was expressed his opinion that the building really needed to perform at the
Immediate Occupancy level. Several peer review panel members recommended that Delhi construct a separate emergency operations center that could be designed for continued operation in the event of an earthquake, since it would be very costly to retrofit the entire building to the IO level when the actual space needed for IO would be small. They explained that it would be very difficult and expensive to get the necessary performance out of an older, existing building even with state-of-the-art retrofit strategies.

Disruption considerations were discussed since several buildings are nearing the construction phase. This discussion focused on GTB Hospital since disruption would be most critical there. Prof. Paul related his experience with the retrofit of the All Indian Institute of Medical Sciences (AIIMS), and that it was very difficult to get the doctors there to agree to a retrofit scheme due to disruption considerations. Peer panel members agreed that many times replacement is preferable, but that space constraints make this difficult, and the issue is more of a hospital planning issue than an engineering issue.

Peer panel members considered the facility update, in which two floors of the ward block would be closed at a time for modernization, a perfect opportunity to carry out retrofit measures with little additional disruption. However, not enough was known about where the patients from the two floors would be housed. Participants discussed possible solutions for infill partitions, and agreed that ‘dry’ constructed solutions were less disruptive and therefore preferable. In addition to the infill partitions, participants discussed anchoring equipment and retrofitting other non-structural items. Prof. Arya asked participants to help review a handbook he is developing for nonstructural mitigation in hospitals.

5 RECOMMENDATIONS FOR NEXT STEPS

Peer panel members made a number of recommendations regarding the next steps necessary to move the project forward. These next steps include:

- Proceeding with retrofit construction at Ludlow Castle School and using it as an example to train other engineers;
- Preparing construction documents for Blocks C and D at 5 Sham Nath Marg (the Divisional Commissioner’s office complex);
- Determining in conjunction with Delhi government whether Blocks A and B will be retrofitted or replaced with a new, larger and more functional building;
- Preparing construction documents for GTB Hospital Ward Block and coordinating retrofit efforts with the planned renovation;
- Determining the required amount of softening for the existing shear walls in the Police Headquarters to make the scheme of adding new shear walls and tying the three phases together work;
- Determining whether the preferred retrofit scheme of tying the buildings together, jacketing the columns, and softening the central core shear wall will work;
- Performing a temperature analysis to determine if tying the Secretariat wings to the core would work.