Keynote Address

Back to the Future:

Lessons from the Past for a more Earthquake-Resistant City

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Abstract– **This Keynote Address focused on traditional construction typologies that have been found to be earthquake resistant. The presentation covered examples found in both Kashmir and Gujarat, documenting their performance in the 2001 Gujarat earthquake and the 2005 Kashmir earthquake. The talk then discussed examples of similar forms of construction in other parts of the world including Portugal, Turkey, Pakistan, and Afghanistan, showing comparisons of the performance of the traditional buildings with that of modern buildings of reinforced concrete. The talk concluded with a review of the urban design issues and development problems that have emerged with the almost universal adoption of reinforced concrete construction in urban areas in India and in other regions around the world.**

Keywords– **earthquake, vernacular architecture, masonry, timber, timber-laced masonry, *taq*, *bhatar*, *dhajji dewari*, reinforced concrete, Kashmir, Gujarat.**

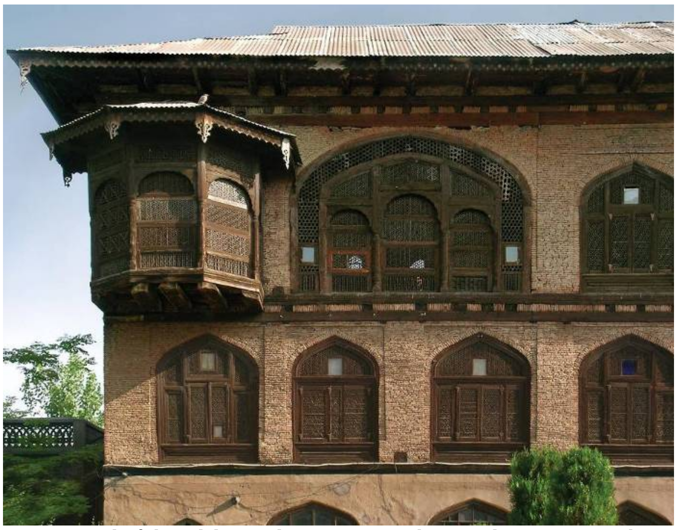

Fig. 1 Detail of the Jalali Haveli, Srinagar, Kashmir, India, ca. 1860. This is a timber-laced bearing wall masonry structure known as *taq* construction in India and *bhatar* construction in Pakistan. The timber lacing at the floor levels is visible on the exterior as part of the architectural expression.

The management of disaster risks imposes onto cities many particular challenges, of a kind that must be treated quite separately and uniquely from the day-to-day issues of planning and urban development. However, there are also many aspects of city planning and building construction that are directly related to disaster mitigation. In addition, however, natural disasters can be a metaphor for certain broader issues that extend well beyond such disasters themselves, touching upon and revealing a great deal about the health of cities and of their people – in ways that pertain very deeply to the history, culture and sense of identity of the people and the place.

Fig. 2 Detail of *dhajji dewari* construction in a building under demolition in Srinagar, showing the timber frame, with the single-layer brick masonry infill. The walls are thin and light, when compared to bearing wall masonry. Notice how the floor joists are sandwiched between timbers at the floor level. This gives a strong friction connection between the floor diaphragms and the walls.

Langenbach's Keynote Address dealt with this latter phenomenon, focusing on the issues connected to, and in many respects derived from, the built cultural heritage, rather than merely from the recent science and art of hazard mitigation. The specific risk discussed is earthquakes, with a focus on both old and new buildings – especially those old buildings that have proven to be resilient in earthquakes when compared to new buildings that, as many survivors have been distressed to find, have proven to be markedly less so.

The talk then turned to the recent earthquakes that have affected India and Pakistan – namely the 2001 Gujarat earthquake and the 2005 Kashmir earthquake. Both of these earthquakes demonstrated how the different types of timber-laced masonry construction found in both of these regions have proven to be more resilient than either ordinary unreinforced masonry construction or modern construction of reinforced concrete. [1]

Fig. 3 A view within the historic walled city area of Bhuj after the 2001 Gujarat earthquake. In this area of the city, most of the historic buildings were of rubble stone masonry construction and the modern buildings were of reinforced concrete. As can be seen in the photograph, the earthquake destroyed many of both types of construction.

Fig. 4 This building in the Bhuj branch of the Ahmedabad-based Swaminarayan Temple is located in the heart of the walled city of Bhuj, yet it survived almost undamaged, while the modern concrete pavilion seen on the right collapsed. The construction is of timber frame with masonry infill, like that otherwise common in Ahmedabad, but rare in Bhuj.

Particularly relevant in India is the fact that the buildings in the walled city of Bhuj were largely of rubble stone construction, which is particularly vulnerable to earthquake collapse, while almost all of the historic buildings in the walled city of Ahmedabad were of timber-laced bearing wall masonry or timber frame with infill masonry construction. In both cities, by comparison with the pre-modern construction, many modern reinforced concrete buildings collapsed. A comparison of the performance of these two cities, both affected by the earthquake, provides a good opportunity to see the resilience of both timber-laced bearing-wall masonry and timber frame with masonry infill construction.

The 2005 Kashmir earthquake killed approximately 80,000 people on the Pakistan side of the Kashmir Line of Control. After this earthquake, the Government of Pakistan first mandated that in order to be eligible for government support, all new home construction had to be of reinforced concrete or concrete block.

As can be seen in Figure 5, there were some owners who nevertheless reconstructed their houses using the traditional *dhajji* form of construction after seeing that older houses of this type survived while the newer ones of rubble stone and also even of concrete construction failed. In addition, the cost and difficulty of transporting the materials for concrete construction into the rural countryside made such construction almost impossible to undertake, regardless of the government grants.

One year after the earthquake, the government of Pakistan approved *dhajji* construction for financial assistance, and some months later also approved *bhatar* construction. Now, UN-HABITAT has reported that 250,000 new *dhajji* houses have been built in the earthquake damage district in Pakistan, as well as an unknown number of ones of *bhatar*.

Fig. 5 New house being constructed in *dhajji dewari* by owner-builder in Pakistan Kashmir after the 2005 earthquake destroyed the prior house, which was of unreinforced rubble stone masonry. This family embarked on this construction after seeing that the one house to survive in the village was of *dhajji* construction. At the time they began construction, the Pakistan government would only provide reconstruction assistance for concrete construction, but one year after the earthquake, the government approved *dhajji* construction for assistance.

Langenbach then showed the effects of earthquakes in other parts of the world where similar historic construction systems exist. The most important of recent earthquakes to affect both traditional and modern buildings are the two in 1999 near the Sea of Marmara in Turkey, and a smaller one that followed in 2000 near Orta in central Anatolia, Turkey. In both the cities of Gölcük and in Düzce, these 1999 earthquakes affected many structures of timber frame with infill masonry construction, which in Turkey is known as *hımış*. Almost all of the buildings of this type remained standing in the midst of collapsed reinforced concrete buildings. The 2000 Orta earthquake was instructive because it caused more damage to the traditional structures than it did to the reinforced concrete frame with infill masonry buildings.

Langenbach's research on a comparison between the damage seen in 1999 and that seen in Orta in 2000 provided an opportunity to show why the concrete frame construction is often perceived as more *pucca* (strong) than it often really is. Timber and masonry buildings will often show damage to exterior and interior plaster and to some of the infill masonry at low levels of shaking, while the onset of damage in concrete buildings at that same level of shaking his largely inconspicuous, but ultimately more dangerous, hairline cracking. In the higher levels of shaking experienced in the 1999 Marmara earthquakes, the traditional buildings demonstrated their resilience over many strong-motion cycles, where the slow progression of damage helped to dissipate the energy of the earthquake, while the lack of such energy dissipating capacity was demonstrated by the rapid collapse of many of the reinforced concrete buildings.

The death toll in the Marmara earthquakes was in the range of 40,000 people, almost all of whom died in modern concrete buildings that collapsed. A Turkish research team has revealed that in one district in the hills above Gölcük where 60 of the 814 reinforced-concrete, four-to-seven-storey structures collapsed or were heavily damaged, only four of the 789 two- or three-storey traditional structures collapsed or had been heavily damaged. The reinforced-concrete buildings accounted for 287 deaths, against only three in the traditional structures.[2]

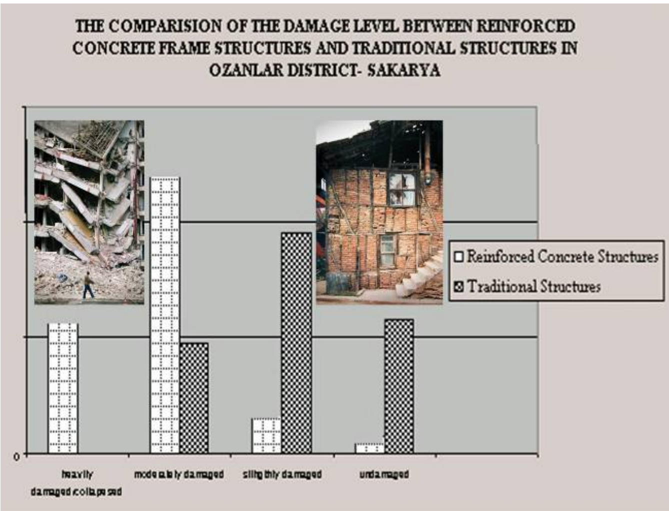

Fig. 6 A graph from the report by Turkish researchers D. Gulhan and I.Ö. Gunay showing a statistical comparison between the performance of buildings of traditional forms of masonry construction and reinforced concrete frame construction in one district in the heart of the damage district after the first of the 1999 earthquakes in Turkey. [2] (The photos of examples were added.)

This same team showed that in the heart of the damage district in Adapazari, where the soil was poorer, research showed that 257 of the 930 reinforced concrete structures collapsed or were heavily damaged, and 558 were moderately damaged. By comparison, none of the 400 traditional structures collapsed or were heavily damaged, and 95 were moderately damaged [2].

Langenbach then addressed the subject of modern reinforced concrete construction and explored some of the reasons for the repeated failures of reinforced concrete frame construction – this supposedly *pucca* building system. By describing "Armature Crosswalls," a technology that he has proposed, Langenbach explained how the pre-industrial, pre-modern traditional buildings systems found in Srinagar, Kashmir and Ahmedabad, Gujarat may actually hold the key to reducing the threats to life safety and severe economic losses posed by these supposedly strong and modern structures.

Fig 7 *left:* A view of a collapsed infill masonry wall in a reinforced concrete building in Gölcük, Turkey after the 1st 1999 earthquake, showing how the brittle masonry wall can collapse out of the concrete frame soon after it begins to crack when the frame deforms from the earthquake forces. *right:* A view of a *hımış* construction wall showing how the timber frame has held the masonry panels in place for the duration of the earthquake, despite the shedding of the plaster surface.

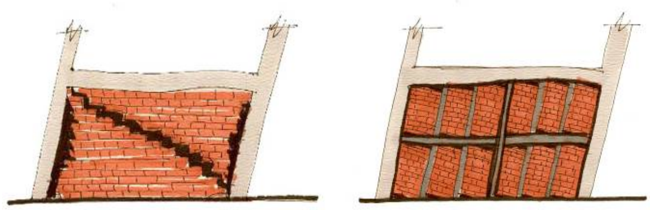

Fig. 8 These diagrams show the conceptual difference between the earthquake performance of a standard masonry infill wall (*left*) and an Armature Crosswall (*right*) in reinforced concrete frame construction. The sub-frame (which in modern construction can be of any material including concrete or steel, not only timber), holds the brick masonry panels in place, allowing the deformation of the system without the likelihood of the development of diagonal tension "X" cracks that can lead to the rapid collapse of the wall. An important component of the Armature Crosswall system is the use of mortar that is soft and weaker than the masonry units, such as lime or clay mortar rather than cement mortar. The initial stiffness of the standard infill wall, which is usually laid up with cement mortar, also can cause the surrounding frame to be broken leading to its collapse, while the Armature Crosswall is much less stiff at the onset of shaking, allowing "frame action" to take place.

The Keynote Address then turned to the 2010 earthquake in Haiti, a catastrophe which resulted in the collapse of over 40% of the buildings in the city center of the capital city of Port-au-Prince, and killed as many as a quarter of a million people. Ironically, this earthquake was not even as strong as many other earthquakes in recent history, either in total energy output or surface shaking in Port-au-Prince, yet it was mainly the newer buildings of reinforced concrete that collapsed onto this vast number of people, while the many older structures, even those of unreinforced brick and rubble stone masonry, remained standing. [3]

Fig.9 Remains of a collapsed multi-storey building in Port-au-Prince Haiti after the 2010 earthquake that devastated the city. The pancake collapse of reinforced concrete buildings is usually lethal to most of the occupants, and because of the strength of the concrete floor slabs, the finding and extraction of the survivors in time is exceedingly difficult.

Fig. 10 A late 19th century house of *colombage* construction in Port-au-Prince after the 2010 earthquake. This house, despite its age, suffered only minor damage. *Colombage* is the French word for timber frame with infill masonry construction, similar to that found in Turkey, as well as in India in Srinagar and Ahmedabad.

The damage in Haiti from this earthquake only serves to show that the issue of construction safety and quality has not been resolved by the introduction of the modern strong, seemingly *pucca*, materials of steel and concrete. There are many other considerations that affect life-safety beyond engineering. The socio-economic environment needs to be taken into account in a profound way. In addition, the wholesale reliance on a single form of construction for almost all buildings – particularly one that is as dependent on training and extensive knowledge and quality control of the design and craftsmanship as reinforced concrete – inevitably leads to situation where a significant proportion of the buildings fall below acceptable earthquake-resistant standards.

Fig 11 A late 19th century house in Port-au-Prince after the 2010 earthquake. The construction of the masonry walls in this house is a combination of brick and rubble stone. Despite the use of extensive internal sections of rubble stone, the house remained standing, although extensively damaged – thus showing a better performance than at least 40% of the reinforced concrete buildings in Port-au-Prince, which collapsed.

This would be true regardless of whether the construction takes place in a developed country or a developing one. In a country like Haiti, where there are limited resources, limited numbers of educated professionals, no building code, and no governmental oversight, the results of an earthquake can be extreme, but the same situation has been found to a lesser extent in Turkey, Pakistan and India, and also in Italy. It is the still-standing pre-modern buildings of traditional masonry construction of the different types which must be studied because they have demonstrated resilience to these very same earthquakes. In fact, they can provide lessons for the future mitigation of these modern-day risks.

The address closed with examples from a recent trip to Bhutan and also to India. These demonstrated how the issue of structure and architecture are culturally interconnected – and how it is impossible to understand the culture and architecture of a place without understanding the construction systems used. This is particularly pertinent in Bhutan because of the government's effort to preserve elements of the traditional architectural style in new buildings.

Fig 12 A traditional rammed earth and timber Bhutanese house on the edge of Thimphu next to a new multi-story house of reinforced concrete construction. [4]

Fig 13 A comparison of a traditional rural Bhutanese house of rammed earth and timber construction (*left*) next to a new hotel in downtown Thimphu of reinforced concrete frame construction. The traditional *rabsel*, or projecting window-wall can be found on both buildings, but it appears tacked onto the side of the modern structure, rather than an integrated and culturally consistent part of its architecture. [4]

As so many of the world's cultures have moved headlong into an age where reinforced concrete has become the default system of construction, people and governments have too easily accepted it as an essential extension of contemporary life, like bathrooms and indoor plumbing. Yet, earthquakes teach us that this construction system is, in a very real and tragic sense, an ill-digested phenomenon.

Fig. 14 A view in 2005 of a traditional building in Srinagar, Kashmir where part has been demolished and replaced with a new concrete block, probably after the building was subdivided between two members of the same family.

By looking at the traditional structures which has often been found around the ruins of these modern concrete buildings after each recent earthquake, one can find the proof that the concrete structural system does not have to be accepted as universal, nor should it necessarily be relied on as *pucca*, at least not unless the proper design and construction can be guaranteed to have been carried out. The older buildings often reflect a craftsmanship that is accessible, understandable, and yet resilient. They possess a culturally time-honored connection to the people of each place in ways that many of the newer concrete buildings located in traditional cultures do not. This address has attempted to shine some light on the importance of this understanding of the traditional building systems of the past as a window into strategies to maximize the health of our cities in the future.

Fig 15 A view over a new housing complex in New Delhi. Reinforced concrete construction cannot be blamed for such prison-like and culturally insensitive housing complexes, but the introduction of an industrial and corporate approach to the provision of housing for urban populations, if devoid of creativity and cultural sensitivity, can easily lead to such results.

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