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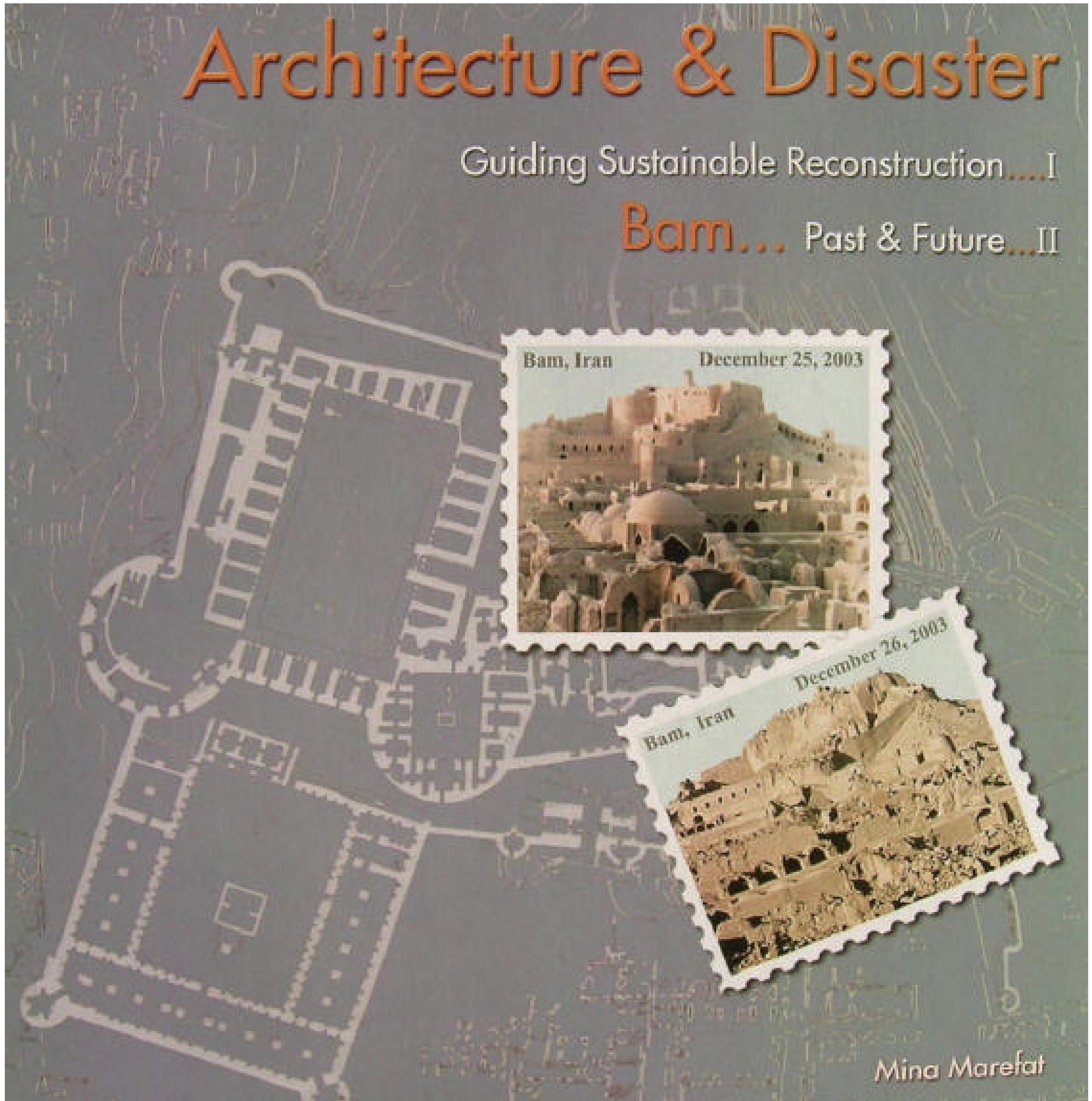
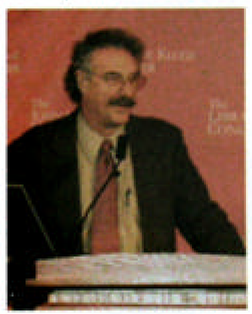


EARTHQUAKE AND THE CITADEL

By Randolph Langenbach

From an edited transcript of a lecture given at the Library of Congress, December, 2004.

Randolph Langenbach is an expert in the field of seismic vulnerability and methodologies for the strengthening of historic buildings. He has investigated the damage after major earthquakes in India, Turkey, Yugoslavia, Greece, and Central America, and documented the resistance of certain types of traditional construction to earthquakes. He received a Master's of Architecture from Harvard University and a Diploma in Conservation Studies from the Institute of Advanced Architectural Studies in York, England. Until recently he was employed at FEMA where he worked on the technical analysis and cost estimation for the rehabilitation of significant historical buildings. He has published numerous works and received a number of awards for his work on traditional buildings in earthquake areas, including the 2003 National Endowment for the Arts Rome Prize Fellowship at the American Academy in Rome. He has been to Bam after the earthquake and has made some important new earthquake discoveries



I wish to begin by saying that it is now a sensitive time to reach out to Iran. In April, 2004, on receiving the invitation from UNESCO for the international conservation workshop in Bam, I visited Iran for the first time. I can say from my experience that I have not been to another country where people treated me as well as in Iran. Prior to my journey to Iran, while working for FEMA (Federal Emergency Management Association) on the earthquakes in California, I had come to know engineers who had immigrated from Iran, so I had already become familiar with a number of Iranians – giving me some idea of what to expect, but I was still impressed with how open and welcoming people were, not just at the professional level, but among the general public as well. My experience stood in sharp contrast to the situation that exists between the governments of our two countries. I was reminded while in Iran that people are people, and Iran and the Iranians are very much like we Americans, in many significant ways.

Earthquakes have had a history of bringing people together. We have seen this happen after the 1999 earthquakes that struck both Turkey and Greece. Now there has been a similar opportunity for both the United States and Iran. After such events, people's goals around the world should be one and the same, which is to help the victims recover from such an overwhelming personal tragedy.

My training is in architecture and building conservation, and thus I will offer instead some observations about the causes of the collapse of structures from the earthquake.

There is a tendency among many engineers to identify the earthquake shaking itself as the cause of the extraordinary destruction, and to simply stop there. The buildings are of weak unfired earthen construction, and the shaking at the ground level was severe. To many observers, this is the end of the story. Nothing more needs to be said. But, from a perspective of conservation science, and also from the comparative experience of a study of prior earthquakes, one can see that this isn't a sufficient explanation. In earthquakes in general, it isn't always the oldest buildings that fall down first. In fact, in many recent large-scale events, it has been quite the opposite.

Once we examined the pattern of destruction in Bam, we observed that, if the collapse of the structures within the Arg (as the ancient citadel is called) were a forgone conclusion, why, for example, did those structures that had not been maintained or rebuilt during the last 150 years come through the earthquake practically unscathed? I will now lead you through the series of counter-intuitive points that I observed when I examined the ruins of the Arg and offer a hypothesis for the causes of the collapse.

On arriving in Bam in April, four months after the earthquake, the first challenge in the Arg-e Bam was to make sense out of chaos of formless debris stretching as far as the eye could see. In less than 12 seconds, this shallow earthquake killed 30,000 people and annihilated a large part of the small city, including Arg-e Bam, the archeological open air museum of the remains of the ancient walled city that was the original settlement on the site.

Most people assumed, based on the news that spread around the world following the disaster, that most of the 30,000 people who were killed died in ancient earthen buildings. In fact, they did not. The death toll was, in fact, primarily caused by the collapse of buildings constructed in the last 30 years. Only two people died in the Arg-e Bam, as, except for the guards, it is vacant at night,.

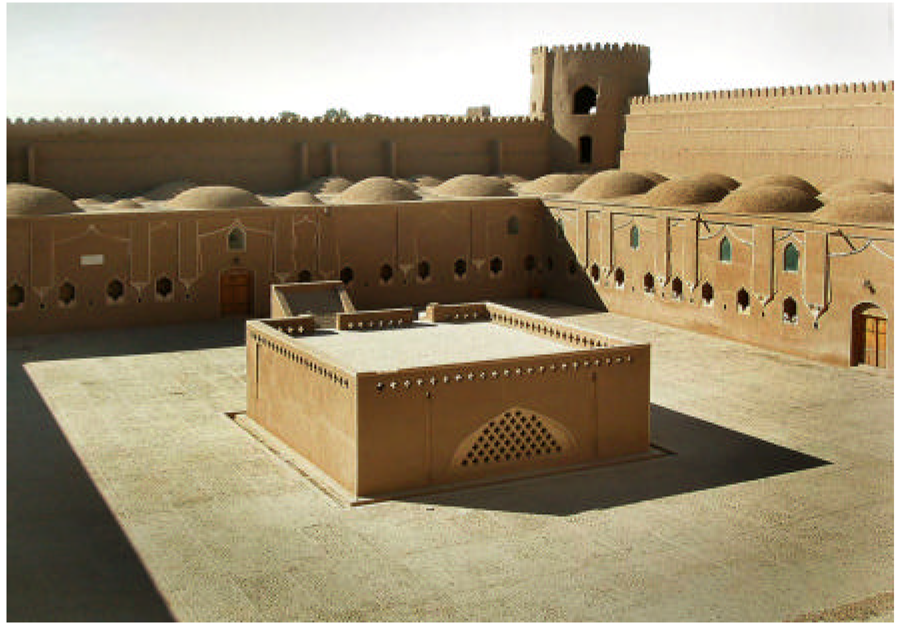
Specifically turning to the Arg-e-bam, a study of photographs over the years shows the citadel was not just a fort, but was the entire settlement of Bam before people migrated some 100 years ago outside the walls to build houses among the orchards. These photos also illustrated the fact that the growth of the settlement surrounding the Arg-e-bam has seen an ebb and flow as opposed to a simple trajectory of expansion. This means that Bam had originally been larger than it was at the time when the restoration work on the Citadel was started in the 1950's.

The first counter intuitive observation is that unsupported garden walls of thin monolithic earth construction did not fall down in the earthquake to the degree that one would have expected. These walls, of a construction called "chineh" in Persian, are constructed of loosely compacted earth piled up on site without being cast into blocks first. To most observers, these unbuttressed clay walls would appear to be particularly vulnerable, but they proved to be more resilient than the houses.

The second observation is that those structures in the Arg that had the thickest, and thus seemingly the most stable and robust, walls, turned out to be the most vulnerable to collapse in the earthquake. This even included the turrets and ramparts that surrounded the site. This observation stands in contrast to those made by the researchers at the Getty Conservation Institute in the North and South America, who concluded in their multi-volume report that in earthquakes, thick walls, even of unfired earth, can prove to be quite stable even after cracking because they simply rock back and forth because of their thickness. Why then, it must be asked, did the thickest walls in Bam simply collapse in 12 seconds?

Even more profound, perhaps, is the observation that those parts of the Arg that had been either maintained, or had been strengthened and restored back into buildings from the pre-existing ruins, were most often the ones that collapsed. Remarkable as it may seem, there were many structures of ancient origins that had not been restored during the past century that survived the earthquake with comparatively little damage. Some with very high unsupported walls that would normally be considered quite vulnerable remained unimpacted. By contrast, those buildings that had been restored or reconstructed crumbled first. These observations challenged our common presumptions.

The first clue to an explanation of the dilemmas presented by the observations came from an unexpected discovery during my first day at the site of a cracked and spalled section on one of the more intact sections of rampart walls surrounding the inner citadel. Curiosity about this evidence of the onset of damage from the earthquake led to the discovery of bore holes and a large amount of frass – evidence of extensive insect infestation. I learned from the Iranian archeologists that the insect damage observed was from termites which are quite common in Iran. Termites live in the unfired earthen walls, consuming the organic material (kehqel) that was used as reinforcement.

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While walking out of the complex, I randomly stopped to inspect the broken edges of the standing ruins. The results of this observation established that the initial discovery was not unique. The entire Arg had been infested with termites at various points in its recent history, raising the question: *Did the Arg collapse because the damage caused by termites?*

This question of the importance of the termites as a factor in the earthquake induced collapses was debated during the UNESCO, ICOMOS (International Council on Monuments and Sites), and ICHO (Iranian Cultural Heritage Organization, since changed to ICHTO: Iranian Cultural Heritage and Tourism Organization) meeting of the experts that took place that week, without arriving at a single consensus. My discovery of the termites, however, did serve to focus my own attention onto the nature of the earthen material itself in my further studies. It did not seem adequate to treat this material as a generic material which, in engineering terms, can be assumed to have a certain strength and structural capacity. The earth in the Arg may have been in a seriously degraded state going into the earthquake – a degradation that was largely hidden from view by the subsequent layers of new material and surface earth plastering from the recent restorations. As the modern clay plaster was itself extensively reinforced with straw that the termites had consumed, it became apparent that this modern work may actually have encouraged the proliferation of the termites.

Earth is not just a generic material. In fact, of all construction materials, it is the most variable. It is a living material. It swells; it shrinks; it grows; and it also can become home for insects and animals. But the most important observation was not just the termites. What was also revealed by the earthquake was the eclectic composition of the walls. Looking closely, it was possible to see many layers and styles of construction imbedded into a single wall. Thus, instead of being the kind of horizontally-bedded adobe bricks or uniform “chineh” found in the garden walls, many of the restored walls of the Arg were composed of a series of unbonded vertical layers of earthen material, some of which were compromised by prior erosion or termite damage.

This proved to be a devastating condition during the earthquake. This was particularly true in this earthquake because of its unusually high frequency and strong vertical shaking, a product of the fact that the earthquake’s hypocenter was shallow and immediately underneath the site. The combination of these factors increased the vulnerability of the already severely compromised earthen walls – with a particularly devastating effect on those walls that had vertical gaps and voids, as well as those with material that was already excessively dried out and of low cohesion. As a result, the walls of many of the structures collapsed from a separation of layers of construction and from the sudden loss of cohesion of the earthen material deep within the walls.

The appearance of the damage after the earthquake gave the impression that the modern restoration had been weaker than the ancient earthen construction at the core of the walls, but this was not necessarily the case. Rather, the modern layers often fell because they were resting above and beside the older layers, which were themselves sometimes overloaded by the later work. In any case, any loss of cohesion in the older layers that resulted in collapse carried the newer construction with it. There was extensive evidence that many of the walls, instead of cracking and falling over, simply collapsed in place. Their cores simply turn to loose sand which burst through the outer layers, imploding structures within their own footprints.

The lesson that may come out of this experience is that we have to start asking different questions of our ancient structures. We need to look at some structures in a different way, with a different eye. No longer can we assume that existing material will behave predictably based on engineering analysis of structures of a similar shape and size or of models newly constructed in a lab. The particular condition of the material deep within the walls has to be taken into account. The Getty Seismic Adobe Report is vitally important, but at the same time, there needs to be a risk assessment for some of the most significant monuments worldwide to evaluate their structural integrity. This is particularly pertinent in the Middle East and North Africa. It is equally important to take into account the factors such as those found in Bam that make adobe structures behave differently from those studied by the Getty project.

To foster seismic resistance we need to re-learn many of the things that people in prior ages who used earth understood well, and we must combine that knowledge with today's modern scientific understanding. Architecture, structure, and material have to be seen as one. Otherwise, when straw-reinforced stucco is superimposed over structure, or structural material is haphazardly joined to older work, the underlying structure will lack integrity, and the surface restoration becomes merely wallpaper. We need to seek a core understanding of what building systems are in order to appreciate why they look the way they did, rather than simply taking their architectural appearance as the starting point.

While many modern steel frame buildings did not survive the earthquake in Bam, it is clear that we should not blame the steel itself. It was, in this case, a problem of the field welding of the frames – an issue having to do with the construction system, rather than the material itself. The same fact is true with earthen construction. Many of the world's peoples continue to depend on simple unfired earth as a primary building material. At the same time, many of the world's most precious cultural artifacts are constructed of earth. The failures in Bam were failures specific to the construction system of the specific structures, rather than of the material itself. The many long abandoned and eroded structures of earth in and near the Arg survived the earthquake, while the heavily restored and modified ones collapsed. They remain mute testimony. It is important to learn from their example.