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DAMAGE TO MASONRY BUILDINGS FROM THE 1995 HANSHIN-AWAJI (KOBE, JAPAN) EARTHQUAKE
- Preliminary Report -

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INTRODUCTION

Normally, one would not associate "masonry construction" with "Japan". Indeed, the author has frequently heard from Japanese colleagues that masonry construction does not exist in Japan. While this may be true in some aspects, what has been forgotten is the existence of a few decades, at the turn of the century, during which masonry buildings of western style have been constructed in parts of Japan such as Kobe. Hence, and somewhat surprisingly for those not familiar with Japanese history, a small number of unreinforced masonry buildings existed in Kobe prior to the Hanshin-Awaji earthquake.

The author conducted extensive earthquake reconnaissance visits to the Kobe area, starting on January 21, 1995, sometimes on his own initiative, at other times joining either the efforts of the Kyoto University Disaster Prevention Research Institute team, the Architectural Institute of Japan investigation task force, or the official Canadian delegation. A brief overview of the various forms of damage suffered by unreinforced masonry buildings and non-structural masonry elements, as observed during these site visits, is presented here.

HISTORICAL OVERVIEW

In 1853, following centuries of self-imposed isolation from external and international influences, with the arrival in Tokyo Bay of four ships led by the American Commodore Matthew Perry, Japan embarked on its first era of large scale international trade. Under

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the rule of Emperor Meiji (1868-1912), the Japanese were captivated by all aspects of the western "modern" life, and attempted to import as many technologies as possible. It is during this era that the Japanese political, educational, medical and military institutions (to name a few) were either developed or modified to resemble the European and American models, and that numerous aspects of architectural and engineering technology were imported. The first Western style structure in Japan, the British No. 1 House, was apparently constructed in Tokyo in 1860 (by the carpenter Iwakichi Kajima, whose small business then eventually grew to become the well-known Kajima Corporation), and the demand for this new architecture grew exponentially.

In this early period of trade, when all goods were shipped by boat, the port of Osaka suffered greatly due to its rather shallow surrounding waters, and since port-reconstruction and dredging were not completed until the near-end of the nineteenth century, Kobe rapidly developed to become the most important fully accessible deep water port of eastern Japan. Hence, western influence was pro-eminent in Kobe, and not surprisingly, many prestigious buildings were constructed using the same unreinforced masonry material, architectural and engineering details found in the North American practice. And, their seismic performance during the Hanshin-Awaji earthquake of January 17, 1995, resembled that which had been observed until then following North American earthquakes.

OVERVIEW OF DAMAGE TO UNREINFORCED MASONRY BUILDINGS

Within the scope of this preliminary report, only a brief presentation of the damage to unreinforced masonry buildings is possible. More technical details regarding these failures will be provided in a forthcoming publication. Masonry buildings have been identified to generally fail in a well-defined number of ways; the terminology for these failure modes has been already presented elsewhere (Bruneau 1994a), and will be used here.

Unreinforced Masonry Buildings

Interestingly, wherever unreinforced masonry buildings could be found by the author, they suffered extensive damage, whether or not they were surrounded by damaged buildings constructed of other materials. For example, a sake-distillery near the shoreline, east of Kobe, suffered from the collapse of a large number of its buildings (Figure 1), while none of the adjacent reinforced concrete and steel buildings showed signs of apparent damage. These failures appear to be dominantly of the out-of-plane type, although some severe in-plane shear cracks could also be observed in the remaining uncollapsed buildings.

By contrast, another building which suffered significant out-of-plane failure of its walls at the higher stories and the "caving-in" of its central portion (Figure 2), was located in downtown Kobe, and surrounded by numerous heavily damaged buildings of other construction types.

Interestingly, some buildings which appeared to have suffered no damage when seen from their main entrance side, were actually found to have lost significant portions of their higher-story walls in an out-of-plane manner when inspected on the other sides. For example, this happened to the building shown in Figure 3, located in downtown Kobe near one of the expressways that collapsed. Given the otherwise excellent in-plane behaviour of these buildings, this out-of-plane failure could have easily been prevented by adding vertical reinforcement braces or other simple and inexpensive retrofitting techniques developed in California (Bruneau 1994b).

Unreinforced Masonry Infills

In a few instances, damage was observed to reinforced concrete frames for which unreinforced masonry has been used as infills. For example, one church suffered a tremendous amount of damage to its lightly reinforced concrete frame and infills at the level where numerous window openings were present (Figure 3). Damage to the lower part of the church was actually slight, as the infills and smaller amount of openings provided a considerable amount of overstrength to the reinforced concrete frames. However, the gable of that church was a "pure" unreinforced masonry gable as opposed to an infilled gable. Being inadequately tied to the steel roof-frame, it partly collapsed in an out-of-plane manner. Some of the wall anchors, consisting of bent bars originally embedded in the masonry, were seen hanging from the steel frame (this can also be seen in Figure 3, but with some difficultly).

Another interesting example of infill failure occurred at the top of a modern church tower. The tower consisted of a multilevel reinforced concrete frame, infilled by slightly recessed unreinforced masonry. Solid bricks were used at all levels, except at the top where units with large voids were utilized to provide a striking architectural finish (Figure 4). The church and tower were both undamaged, except for the tower at its top level where the weaker masonry units were used. These were quickly crushed, providing no additional strength to the concrete frame which in turn suffered column damage at that level.

Non-structural Masonry

The seismic performance of non-structural masonry was not reviewed extensively by the author. However, damage was sometimes observed to non-structural masonry used in decorative architectural elements. For example, a circular reinforced glass-block wall which has been damaged is shown in Figure 5. Also shown on that figure is an example of the excellent behaviour of thin adhesive masonry coverings, frequently used in Japan as architectural finishes.

Many small masonry dividing walls also collapsed during this earthquake. Most were unreinforced masonry walls, although the presence of light reinforcement was sometimes observed, generally poorly anchored or even erroneously placed in ungrouted cells. Thicker dividing masonry walls were generally unreinforced. Some of these thicker walls which collapsed are shown in Figure 6. Incidentally, these particular walls were located in a part of town where adjacent buildings did not suffer visible damage.

North American style chimneys are rare in Japan. Nonetheless, one impressive failure was observed by the author in the "foreign" district were some old Western-style houses exist. A rather heavy chimney which collapsed is shown in Figure 7.

Also noteworthy was the failure of many small temples gateways. These portals, characteristically Japanese in their architecture, were sometimes constructed of piled stones. Small dowels were sometimes installed to connect these stones at their centre.

General Observation

Obviously, with some noteworthy exceptions, the real lesson of the Hanshin-Awaji earthquakes is that existing buildings, designed and built at a time when seismic-design requirements were still inexistent or in their infancy, remain the most vulnerable to earthquakes. Unless retrofitted, their level of seismic-resistance design force remains less than what is nowadays considered the necessary minimum, and their material detailing lacks the essential features which can ensure a reliable ductile behaviour.

In many aspects, this is not a new lesson, as the same statement could have been made following numerous earthquakes worldwide, including the recent California Loma-Prieta earthquake (San Franscisco) and Northridge earthquake (Los Angeles). However, this earthquake has "hit-home" in dramatically demonstrating the need for seismic retrofitting to the Japanese who, until now, had almost exclusively focused their structural engineering energies in the development of better seismic-resistant new constructions. Indeed, the author could not identify any building for which some of the recently developed seismic retrofitting procedures reported in the existing literature (Bruneau 1994b) had been used. Although it is possible that some unreinforced masonry buildings may have been retrofitted in the past, these would be rare instances, as Japanese engineers/researchers have indicated that the seismic retrofit of buildings has not received any attention in Japan in recent years. Now, following the Kobe earthquake, retrofit will undoubtedly become an important consideration in Japan, for buildings of all construction materials, including, in spite of their small proportion of the total building inventory, unreinforced masonry buildings.

CONCLUSION

Contrary to what has often been thought about Japanese construction, some unreinforced masonry buildings and structures were found to exist in the Kobe area which has been hit by the January 17, 1995, earthquake. In many instances, the existence of these buildings was revealed by their damage during this earthquake.

Prior to this earthquake, the seismic retrofitting of buildings was not a priority on the Japanese agenda, but as damage during the Hanshin-Awaji earthquake damage was almost exclusively confined to older buildings constructed with non-ductile material detailing, the responsible Japanese agencies are now under pressure to urgently start addressing the seismic rehabilitation needs to avoid similar disasters in future Japanese earthquakes. In that perspective, the few unreinforced masonry buildings that still exist in Japan will undoubtedly need to be included in that rehabilitation effort. However, because of the small number of these buildings, the profile of their owners, past Japanese construction practice, and the Japanese philosophy regarding seismic resistant design, it is quite possible that such retrofit will proceed using conservative procedures without much regards for the heritage value of these buildings.

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Bruneau, M., 1994b. "Seismic Evaluation of Unreinforced Masonry Buildings - A State-of-the-Art Report", Canadian Journal of Civil Engineering, Vol.21, No.3, pp.512-539.

Figure 1a: Rubble masonry from collapsed buildings of a sake-distillery blocking an alley (close-up)

Figure 1b: Rubble masonry from collapsed buildings of a sake-distillery blocking an alley (global view)

Figure 1c: Walls partly collapsed in out-of-plane manner from a building of a sake-distillery complex

Figure 1d: Wall with visible in-plane cracking from an uncollapsed building of a sake-distillery complex

Figure 2a: Severely damage unreinforced masonry building in Downtown Kobe (global view)

Figure 2b: Close-up view of simply supported gravity structure for damaged unreinforced building in downtown Kobe

Figure 3a: Global view of out-of-plane damage to an unreinforced masonry building in downtown Kobe

Figure 3b: Additional global view of out-of-plane damage to an unreinforced masonry building in downtown Kobe

Figure 3c: Close-up view of out-of-plane damage to an unreinforced masonry building in downtown Kobe

Figure 3d: Additional close-up view of out-of-plane damage to an unreinforced masonry building in downtown Kobe

Figure 4c: Close up view of damaged level of church where more openings existed in the infilled reinforced concrete frame

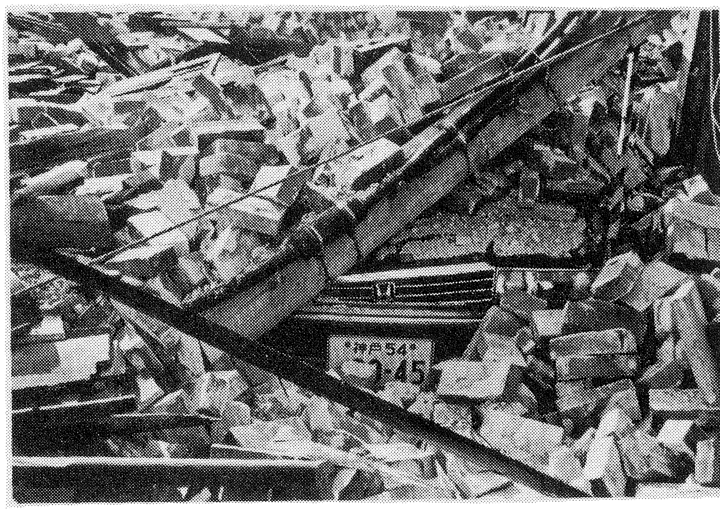
Figure 4d: Out-of-plane failure of poorly anchored unreinforced masonry church gable

Figure 5: Damage to non-structural masonry elements (a) Glass-block reinforced masonry; (b) decorative infill masonry

Figure 6a: Collapsed thick unreinforced masonry property wall

Figure 6b: Collapsed thick unreinforced masonry property wall

Figure 7: Large fallen unreinforced masonry chimney



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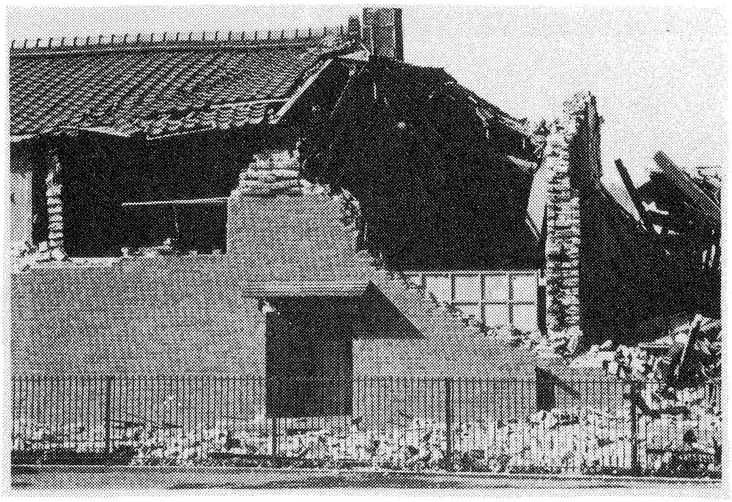


Figure 1c: Walls partly collapsed in out-of-plane manner from a building of a sake-distillery complex

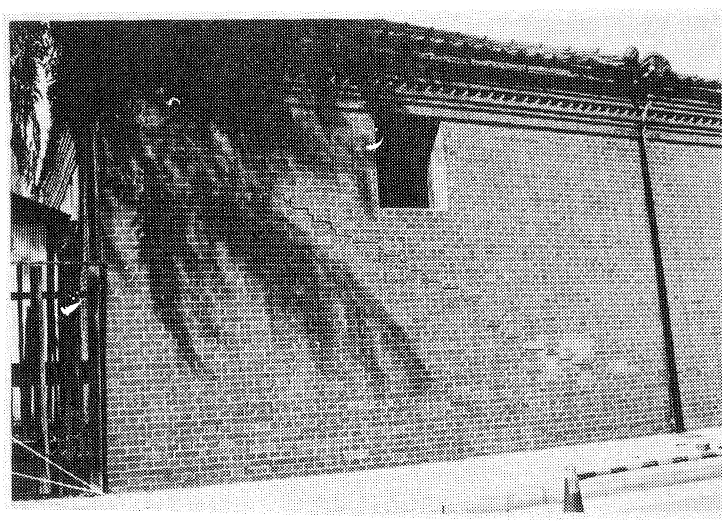


Figure 1d: Wall with visible in-plane cracking from an uncollapsed building of a sake-distillery complex

Figure 2a: Severely damage unreinforced masonry building in Downtown Kobe (global view)

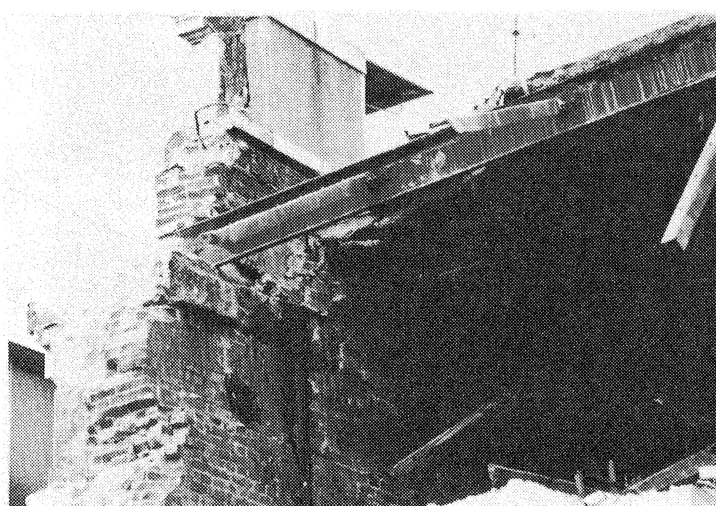


Figure 2b: Close-up view of simply supported gravity structure for damaged unreinforced building in downtown Kobe

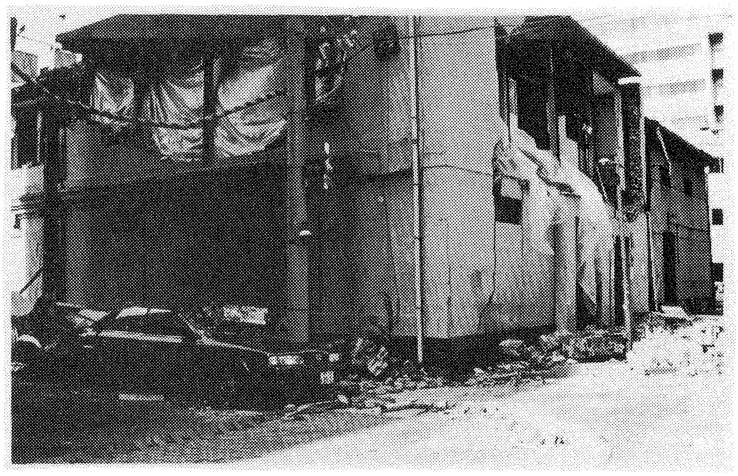


Figure 3a: Global view of out-of-plane damage to an unreinforced masonry building in downtown Kobe

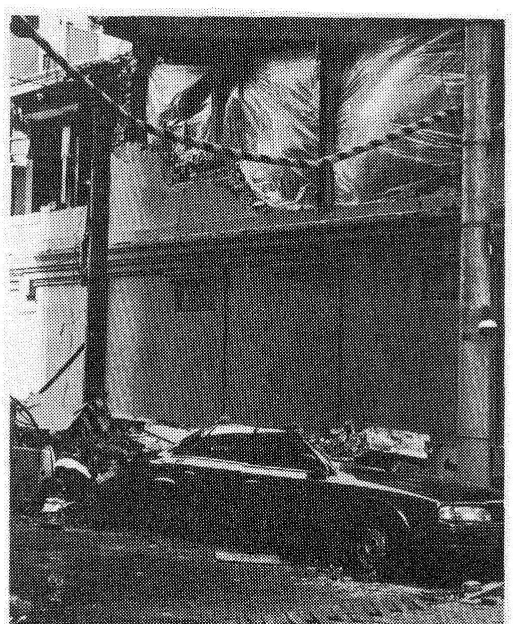


Figure 3b: Additional global view of out-of-plane damage to an unreinforced masonry building in downtown Kobe

Figure 3c: Close-up view of out-of-plane damage to an unreinforced masonry building in downtown Kobe

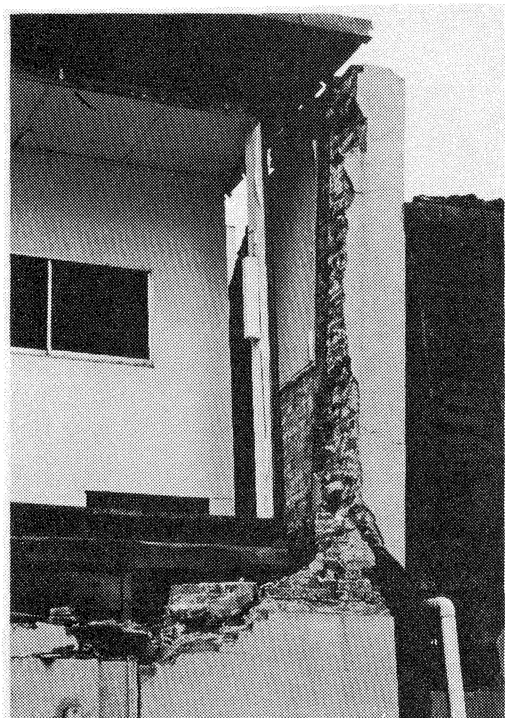


Figure 3d: Additional close-up view of out-of-plane damage to an unreinforced masonry building in downtown Kobe

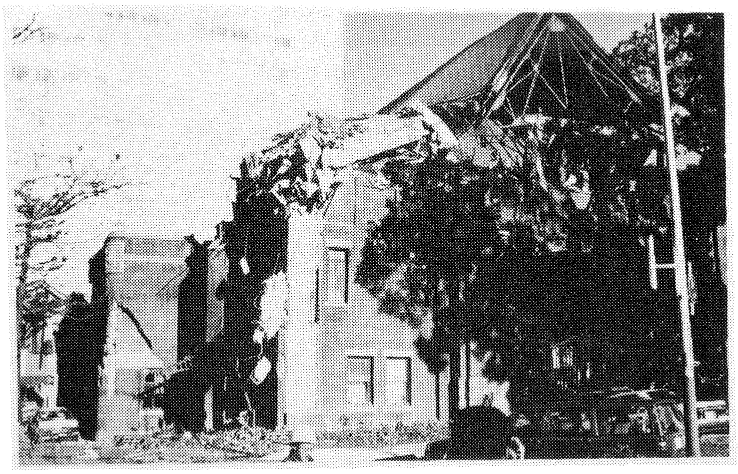


Figure 4a: Damaged church having reinforced concrete frame infilled with unreinforced masonry

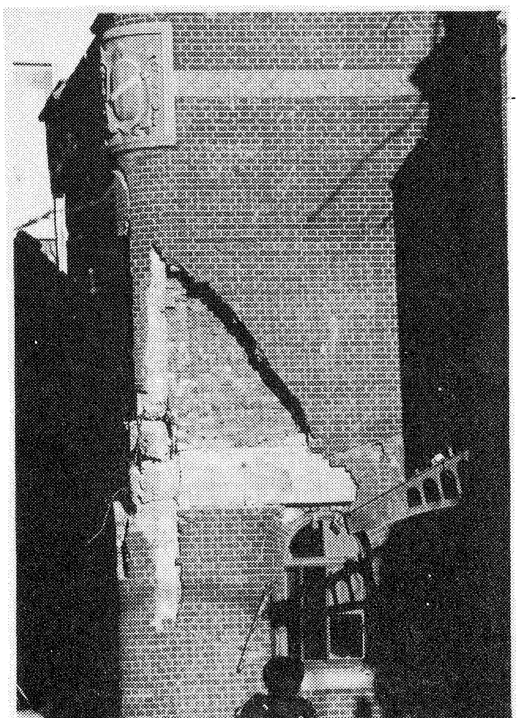


Figure 4b: Minor damage to covering masonry wythe covering the infilled frames at church's lower level

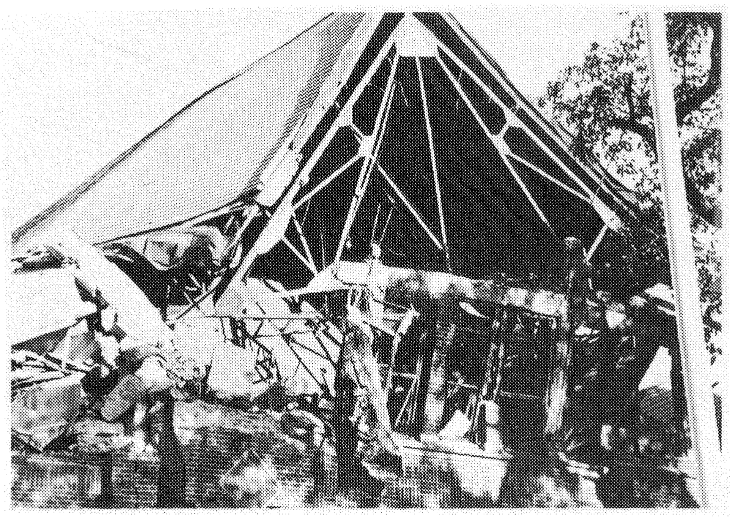


Figure 4c: Close-up view of damaged level of church where more openings existed in the infilled reinforced concrete frame

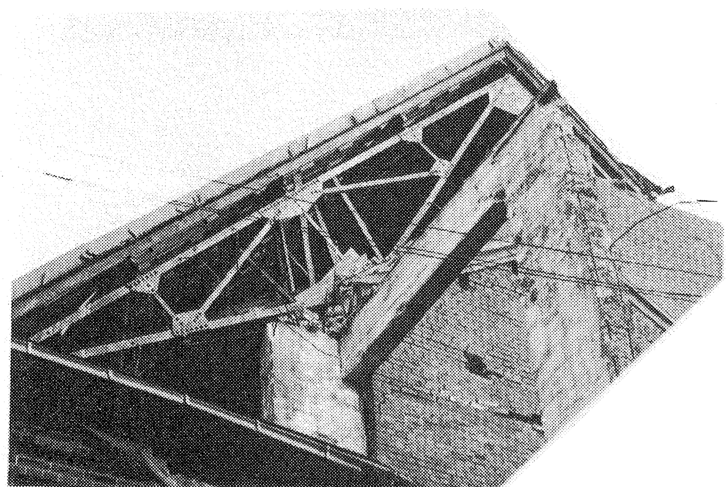
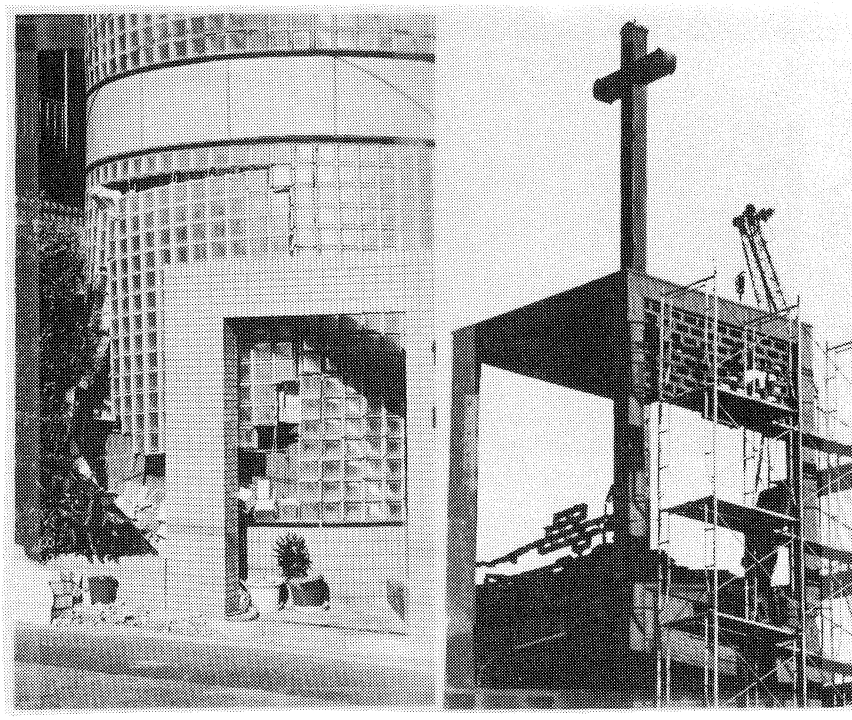


Figure 4d: Out-of-plane failure of poorly anchored unreinforced masonry church gable



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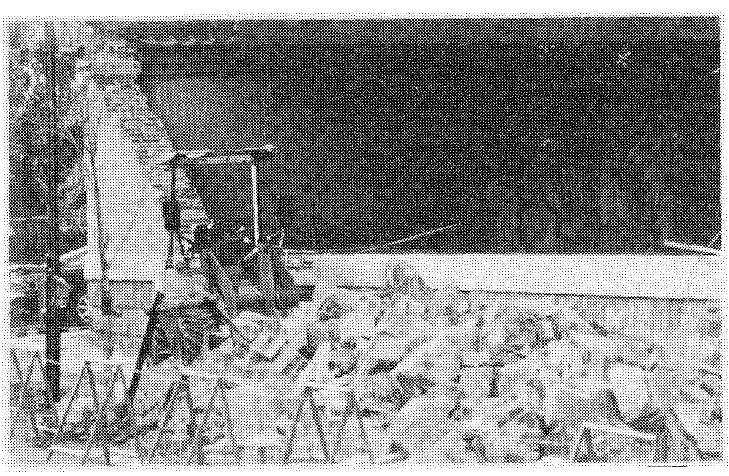

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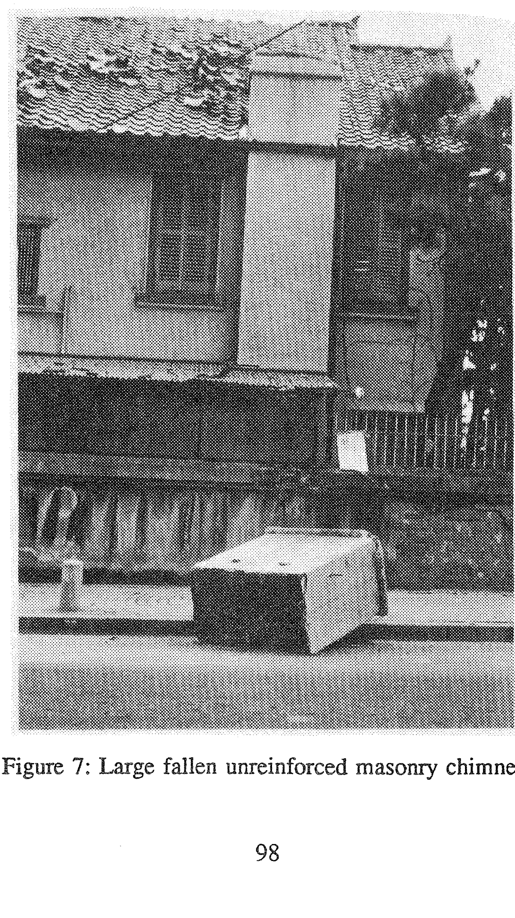

Figure 7: Large fallen unreinforced masonry chimney