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OVERVIEW OF BUILDING DAMAGE AND DAMAGE TO WOOD HOUSES FROM THE 1995 HYOGOKEN-NAMBU EARTHQUAKE

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ABSTRACT

The January 17, 1995, Hyogoken-nambu, magnitude 7.2 earthquake, with its epicenter near the Japanese city of Kobe, produced a phenomenal amount of damage. Although by far not the most powerful or deadly earthquake of this century, preliminary estimates indicate that it may be the most costly earthquake in recorded history. A brief report on the general building damage observed immediately after this earthquake is given.

1. INTRODUCTION

Although neither the most powerful nor deadly earthquake of this century, the Hyogoken-nambu earthquake wreaked havoc throughout the Kobe area, destroying or damaging a large percentage of the building infrastructure. As of February 4, 1995, 5243 persons were confirmed dead and 26,804 reported injured, and more than 107,388 buildings and homes destroyed or damaged beyond repair, rendering more than 300,000 people homeless. According to the Hyogo Prefectural Police, nearly 90% of the people killed by the earthquake were crushed to death by the collapse of their homes, which is largely a consequence of the earthquake occurring at 5:46 am. According to the latest estimates, the direct cost of damage is at least ten trillion yens ($100 billion U.S.), and there is speculation that a higher figure may be more realistic. Indirect costs obviously will be far greater although difficult to accurately quantify. Based on the Northridge experience, it appears that these may be as much as three times the direct costs. Damage to houses and buildings is reported to account for 60% of the total losses due to this earthquake. These figures may make the Hyogoken-nambu earthquake the most costly natural disaster in recorded history. Immediately after the earthquake, the Japanese Meteorological Agency (JMA) ranked the intensity of the tremors

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in the most severely shaken regions as 6 on the Japanese intensity scale (equivalent to 8 to 9 on the modified Mercalli [MM] scale) but two weeks later it raised the intensity to 7 (equivalent to 9 or more on the MM scale).

The writers visited the devastated area shortly after the earthquake, initially from January 17 to 19 and again from January 24 to 26. This paper provides a brief overview of the damage spread throughout the populated areas near the epicenter, and, using examples, documents the observed poor seismic performance of some types of residential dwellings.

2. SEVERITY OF THE EARTHQUAKE

It is important to gage the severity of the earthquake in order to appreciate the significance of the reported damage. Its epicenter was located at the north end of Awaji Island, approximately 25 km from downtown Kobe; Houses were found to have suffered extensive damage as far as 40 km from the epicenter. Seismographic data, when available for the areas where severe damage occurred, indicate that the peak horizontal ground accelerations exceeded 0.5g in many areas, reaching 0.85g. High peak vertical accelerations also have been reported. The peak horizontal ground velocity data, which more appropriately reflects the seismic energy imparted to structures, often exceeded 0.40 m/s.

3. DISTRIBUTION OF DAMAGE TO BUILDINGS

Damage to and the collapse of wood residential buildings was excessive and broadly distributed over the all areas where severe ground shaking was felt. Figure 1 is a map of Chuo-ku (the downtown Kobe) area, where many buildings and houses are clustered, and Fig.2 illustrates the damage distribution for wood houses in several selected blocks (Blocks 4, 7, 8, 9, 18, and 19). The attenuation of damage from south to north (from the sea to the mountains) is clearly seen in Fig.2. This reduction in damage correlates with changes in soil conditions; from soft soils along the coast to progressively more shallow and dense soils, and eventually rock, at the foot and on the slopes of the mountain ridge. The reduction in damage, i.e., less severe damage on the mountains to the north also correlates well with the age of construction, as Kobe grew first along the railway then to the coast in the south, and eventually to the mountains in the north. Block 9 in Fig.1 is crowded with many small wood houses. The damage distribution in this block (Fig.2) indicates that approximately 30% of all the houses collapsed or were severely damaged in that part of Kobe, the ratio being closer to 70% in the parts of the block near the sea. It is notable that this average is considerably larger than any ever recorded over the last decades in Japan. For example, only 5% of all the houses suffered any kind of damage during the 1983 Kushiro-Oki earthquake (ranked 6 on the Japanese intensity scale) and only 0.45% of all the houses totally or partially collapsed.

Tables 1 and 2 gives the number of damaged RC and steel buildings in the Chuo-ku area. The damage ratio with respect to the total number of buildings is not available at the time of this writing, but damage to more than 2,500 engineered buildings and serious damage (ranked moderate or more) to more than 350 buildings within the small area of 10 km^2 is clear evidence of the great severity of this earthquake. An example of the distribution of damage to engineered buildings is shown in Fig.3, for plots of Blocks 12 and 13: the downtown business district.

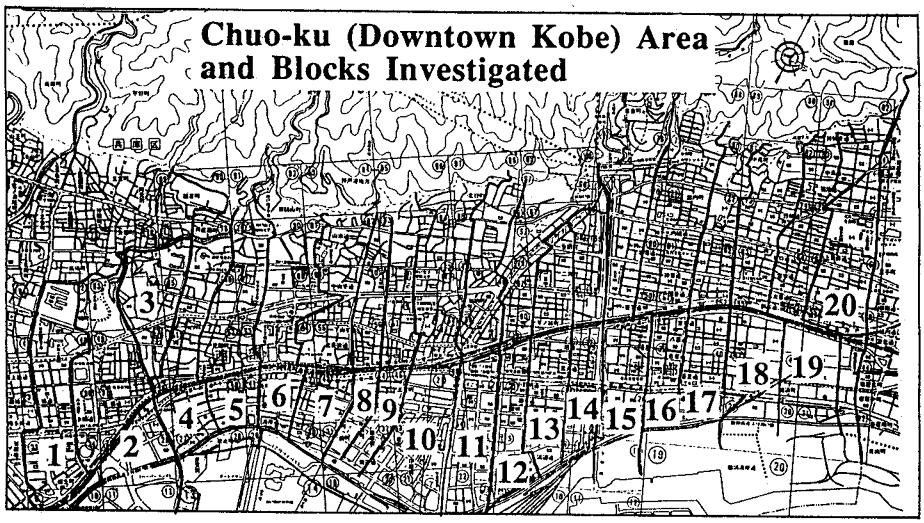


Fig. 1 Map of Chuo-ku (downtown Kobe) Area

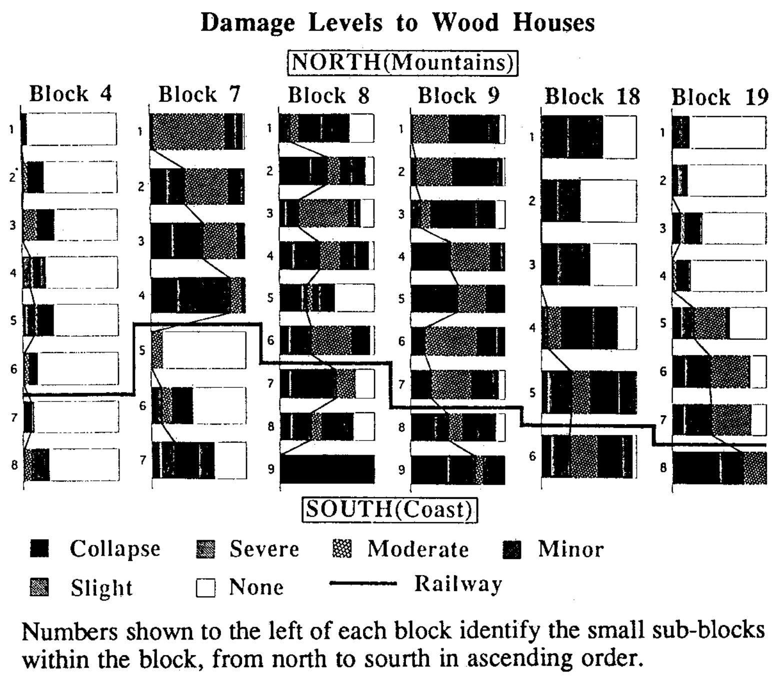


Fig. 2 Distribution of damage to wood houses (Blocks 4, 7, 8, 9, 18, and 19 in the Chuo-ku area)

Table 1 Number of damaged RC buildings in Chuo-ku area

Number of Damaged RC Buildings (Chuoku Area of Kobe City)

Block	Collapse	Severe	Moderate	Minor	Slight	Total
1	4	4	12	37	51	108
2	0	4	4	14	9	31
3	0	1	0	7	14	22
4	1	0	4	0	18	23
5	1	0	0	16	188	205
6	0	3	4	7	36	50
7	2	15	29	78	91	215
8	2	8	19	24	26	79
9	4	13	6	7	36	66
10	20	21	27	40	144	252
11	21	22	9	18	44	114
12	3	10	12	6	32	63
13	2	7	21	33	85	148
14	3	2	5	8	14	32
15	0	2	1	4	3	10
16	0	0	7	8	67	82
17	0	2	0	2	9	13
18	5	7	10	21	49	92
19	9	3	2	2	5	21
20	3	2	1	5	1	12
Total	80	126	173	337	922	1638

Table 2 Number of damaged steel buildings in Chuo-ku area

Number of Damaged Steel Buildings (Chuoku Area of Kobe City)

Block	Collapse	Severe	Moderate	Minor	Slight	Total
1	1	4	33	26	29	82
2	1	0	4	15	4	24
3	2	2	7	10	9	30
4	0	0	1	7	6	14
5	1	2	3	12	34	52
6	1	2	3	3	13	22
7	2	12	33	46	21	114
8	6	13	21	25	32	97
9	1	8	8	12	16	45
10	11	13	12	35	63	134
11	5	5	6	12	33	61
12	6	6	11	15	17	55
13	1	5	13	22	29	70
14	1	1	5	7	12	26
15	0	0	1	5	4	10
16	0	9	6	10	45	70
17	2	2	3	4	16	27
18	11	7	18	25	20	81
19	3	2	0	2	0	7
20	0	0	0	2	9	11
Total	55	93	177	295	412	1032

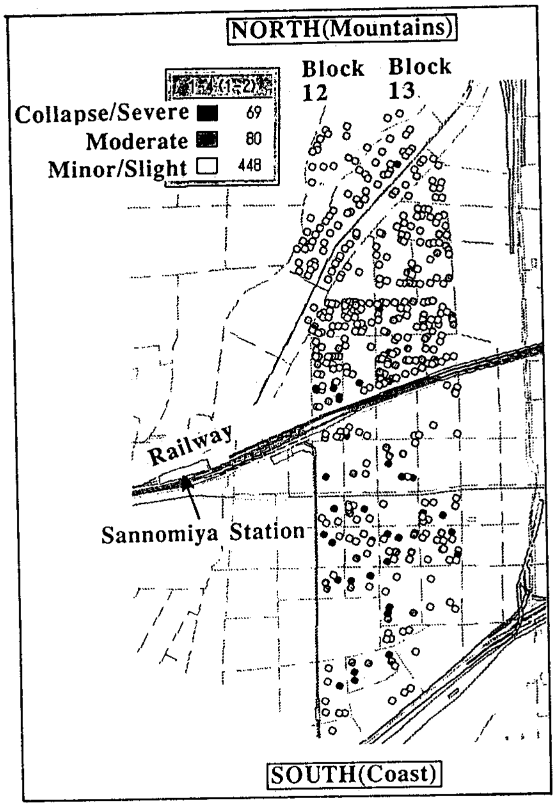


Fig. 3 Distribution of damage to engineered buildings (Blocks 12 and 13 in the Chuo-ku area)

4. DAMAGE TO WOOD HOUSES

The seismic performance of residential wood constructions varied greatly throughout the affected region, from no damage to total collapse. In order to make a comprehensive survey of all the communities reported to have experienced damage, the Architecture Institute of Japan (AIJ) quickly assembled and coordinated a large reconnaissance team of 110 engineers and architects. Extensive observations disclosed that in general older constructions suffered the most damage. A number of noteworthy construction features, some of which are reviewed hereafter, compounded to render many of these older houses subject to collapse.

4.1 *Heavy roof construction*

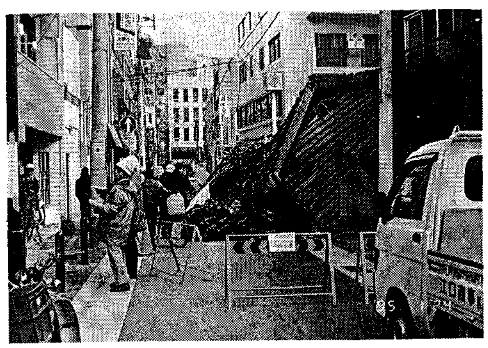
Heavy ceramic tile roofs are widely used in Japan as they provide excellent resistance to the strong gusty winds of typhoons which frequently sweep across the country. As the seismic forces imparted to a structure, however, are inertial forces induced by the ground shaking, heavy constructions such as buildings with heavy tile roofs sustain larger seismically-induced forces (Photo 1). Thus, houses with light roof systems, such as asphalt tiles or light metal sheets rather than heavy ceramic tiles, generally performed better during this earthquake.

Photo 1 Collapse of wood houses roofed with heavy ceramic tiles

4.2 *Open first story*

For many years, structural engineers have known that buildings with large open first stories that have fewer partitions than the above stories are very sensitive to a severe concentration of damage in that first story. Unfortunately, such damage-prone softer stories are characteristic of Japanese residential constructions, in which a large tatami room surrounded by sliding doors (hence large openings) is customary. In older and smaller homes, this room may be the dominant feature of the first story, with detrimental effects during earthquakes. Soft-story failures frequently result in a sway-mode type of failure, the second story typically moving sideways while falling down. During the Hyogoken-nambu earthquake, the homes that collapsed in that manner frequently blocked the narrow city streets, thus blocking access to numerous neighborhoods (Photo 2).

(a)



(b)

Photo 2 Collapsed wood houses blocking streets [(a) Chuo-ku area, (b) Hyogo-ku area)]

4.3 *Lack of structural integrity*

The most important cause of residential house collapses, however, is the absence of structural integrity. It has been the practice for many years in Japan to construct wood houses using interlocking wood parts (tenons and mortices) without the use of nails or other positive non-wood connectors. Examples of beam-ends prepared for this purpose are shown in Photo 3. More complex, but equally ineffective connections, are shown in Photo 4. At best, a few but insufficient number of nails were found in the members of collapsed structures. Thus, during severe shaking, the beams frequently pulled out of their socketed supports in the columns or beams, causing the immediate caving-in of the supported story.

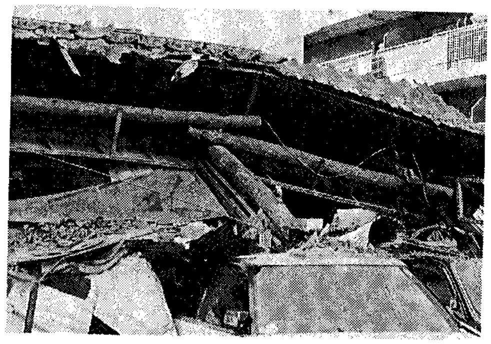
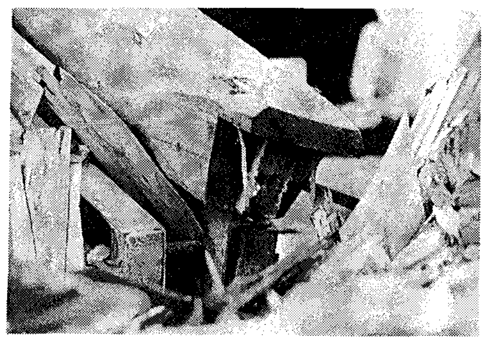


Photo 3 An example of old beam-to-column connections used in wood houses

(a)



(b)

Photo 4 Examples of tenons and mortices used for beam-to-column connections [(a) overview, (b) close-up]

4.4 *Poor shear-resistance of partitions*

Walls of old Japanese style dwellings typically are constructed of beams and columns covered with separated horizontal planking. These horizontal planks frequently are thin, making the nailed connections unable to resist a considerable moment before the nails split the planks and are pulled-out. As a result, the wood frames unrestrainedly deform in the shape of a parallelogram when swaying during earthquake excitation. Although any one of the above deficiencies can lead to a disastrous seismic performance, in many instances, a combination of these undesirable features produces the observed damage.

It is notable that, in many cases, new houses that were undamaged or had sustained at most minor damage were found adjacent to totally collapsed dwellings (e.g., Photo 5). Some of these new houses were pre-fabricated structures with light-gage steel beams and columns, bar braces, and light asphalt sheet roofing. Others were constructed of 2″ by 4″ walls, a practice imported from

North America several decades ago. Furthermore, the traditional houses that now are being constructed must comply with specifications which require extensive nailing, the use of steel connections, and walls prescribed as a percentage of the total floor area. The satisfactory seismic performance of the new houses built using one of these construction techniques is encouraging.

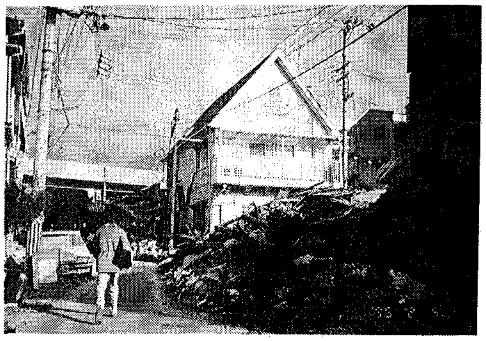


Photo 5 A relatively new house that sustained minor damage, whereas adjacent old houses collapsed

5. FIRES

The rapid spread of earthquake-triggered fires further compounded the seismic-related problems inherent to residential constructions in the dense Japanese urban environment. A large number of fires triggered by this earthquake devastated many of the neighborhoods that had a dense inventory of wood houses (e.g., Photo 6). Figure 4 gives the number of fires which had to be fought by emergency units in the days following the earthquake. Fortunately, most fires were brought under control within a few days, but sometimes not before spreading to significant areas.

Photo 6 Remains of houses destroyed by fire

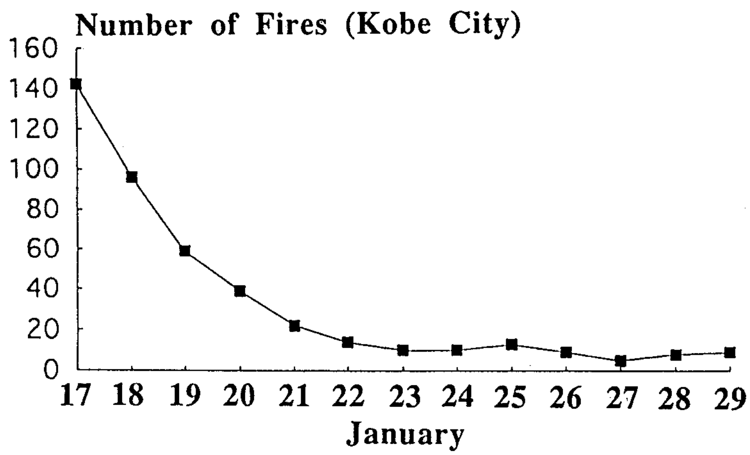


Fig. 4 Number of fires on and after January 17, 1995 (City of Kobe)

6. CONCLUSIONS

The greatest tragedy resulting from the Great Hanshin earthquake is directly related to the total and partial collapse of a phenomenal number of residential houses which became deadly prisons for their occupants. The numerous collapses can be attributed to various causes that include heavy roof construction, open first stories, lack of structural integrity, and poor shear-resistance of partitions and walls. When compared to newer construction, older residential buildings clearly suffered the most damage during this earthquake. This incontrovertibly shows the need for the seismic retrofit of residential dwellings in Japan. More research is immediately needed to develop cost-effective measures to reach that objective.