EARTHQUAKES AND RESIDENTIAL CONSTRUCTION IN JAPAN

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ABSTRACT

While much effort has been spent on analysis of individual structures, building class seismic damage estimators for earthen buildings in seismic zones, of value in disaster planning, code-writing, city planning, national hazards policy formulations etc., have been little investigated. First, details of the typical construction in Japan incorporating earthen elements are presented, with emphasis on those providing lateral resistance. Next, based largely on data from Sendai City, Japan in the 12 June 1978 Miyagiken -oki earthquake (M_L-7.4), estimators of seismic damage for low-rise buildings in urban Japan have been determined, based on damage to over 60,000 buildings. Damage ratios for onset of damage and collapse and for cost of damage are found to correlate best with response spectra at 0.75 s. Using published test data and average building properties, a seismic damage model explains the low-rise building behaviour and permits examination of the effect of structural changes on the estimated damage.

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Introduction

Although Japan is usually associated with earthquakes, its association with building construction is usually that of wood rather than that of earthen buildings. This is due to the well-known superb joinery of the typical Japanese house, as well as the abundant forests and prominent part wood plays in the architectural aesthetics of Japan. Closer examination however, reveals that earthen construction is actually a significant part of the typical Japanese house, and vis-a-vis earthquakes, provides a considerable portion of the lateral resistance. Thus, a review of typical Japanese residential construction is appropriate in any discussion of earthen buildings in seismic zones. The purpose of this paper is to briefly present an overview of Japanese urban regions and seismicity, to outline typical residential construction and then to present some research results of the author quantifying such construction's seismic resistance.

Within the overall seismic risk problem, one of the less researched topics has been that of regional damage estimation, although the aggregated damage that a region sustains in an earthquake is probably society's greatest concern, vis-a-vis earthquakes. One of the reasons for this lack of activity has been the lack of damage estimators (also termed damageability performance, or vulnerability functions) for the various classes and sizes of structures in today's urban regions. Even though extensive research has been devoted to the response of specific individual structures, little effort has been devoted to the average response of these classes of structures. While the value of the study of the response of individual structures goes without saying, the value of building-class seismic damage estimators in such fields as land-use and city planning, microzonation, building code evolution, natural hazards insurance, disaster planning, etc. is also very great, when faced with the problem of estimating the damage to tends of thousands of low-rise and hundreds or thousands of mid- and high-rise buildings. To adequately serve these fields' needs, damage estimation functions should nt only be descriptors or predictors of damage given ground motion but should also relate the response or damage tothe structural system in sufficient (and yet not too much) detail such that the effects of modifications to the structural system are readily apparent, thus permitting the application of cost-benefit analysis or other decision-making methodologies.

Such damageability functions are especially mandated in situations like Japan, with one of the highest degrees of urbanization in the world. In urban regions, such as Tokyo-Yokohama, Osaka, Nagoya, Hiroshima, etc., low-rise buildings, especially of wooden construction, constitute the great majority. In Osaka (the second largst city in Japan), of 408,000 buildings 80.4 percent are wood, 90 percent one or two storey and only 0.124 percent are 10 storeys or higher.

The primary reason for the high degree of urbanization of modern Japan is the fact that mountainous areas constitute about 90 percent of 142,706 square miles, thus forcing her approximately 112,000,000 people onto recent (in geologic terms) alluvial plains, such as the great Kanto plain of Tokyo.

Coupled with economic, transportation and other constraints, the result is that much of Japan's population is housed on deep, recent, alluvial deposits in an area of high seismicity. This seismicity is among the world's highest for a densely populated country, and is basically due to the subduction of the Pacific plate under the Asian plate along offshore Japan to the east, complicated by the convergence of the Philippine plate near Tokyo. The result is great, deep offshore and large, shallow inland earthquakes with relatively high frequency of occurrence. An idea of the hazard can be gained in Fig. 1, which estimates motions for Japan for 75 years.

Thus, we find in Japan a high degree of urbanization on deep alluvial fans in an area of high seismicity, so that we have a high expectation of strong ground motion of long duration and long period.

Typical Residential Construction

The structure of the typical wooden low-rise in Japan has changed very little in this century (see Engel (2) for a detailed description). Fig. 2 shows a typical view of a nearly completed house in which the main elements are clearly discernible. These are heavy tile roofs (unlike many other localities, in Japan the tiles are seated in a bed of about 7 cm of mud, which adds enormously to the weight of the roof) supported on a vertical post and lintel constructions which carries the roof and second floor to the foundation. The foundation in the past consisted of stone or concrete seats and usually now are low perimeter concrete walls. Due to this feature, these structures are especially sensitive to ground movement. The vertical posts, being of wood joined into the sill or roof beams, provide virtually no lateral resistance due to the inability of the connections to develop any moment capacity. Thus, the lateral resistance is due solely to the walls and, if existing, bracing. Traditionally and until very recently, bracing was not typical, although now being increasingly mandated by code. In Fig. 2(a) some diagonal bracing can be seen, while the side wall, more clearly shown in Fig. 2(b), has no diagonal bracing and relies for lateral resistance solely on the mud infilled wall between vertical posts.

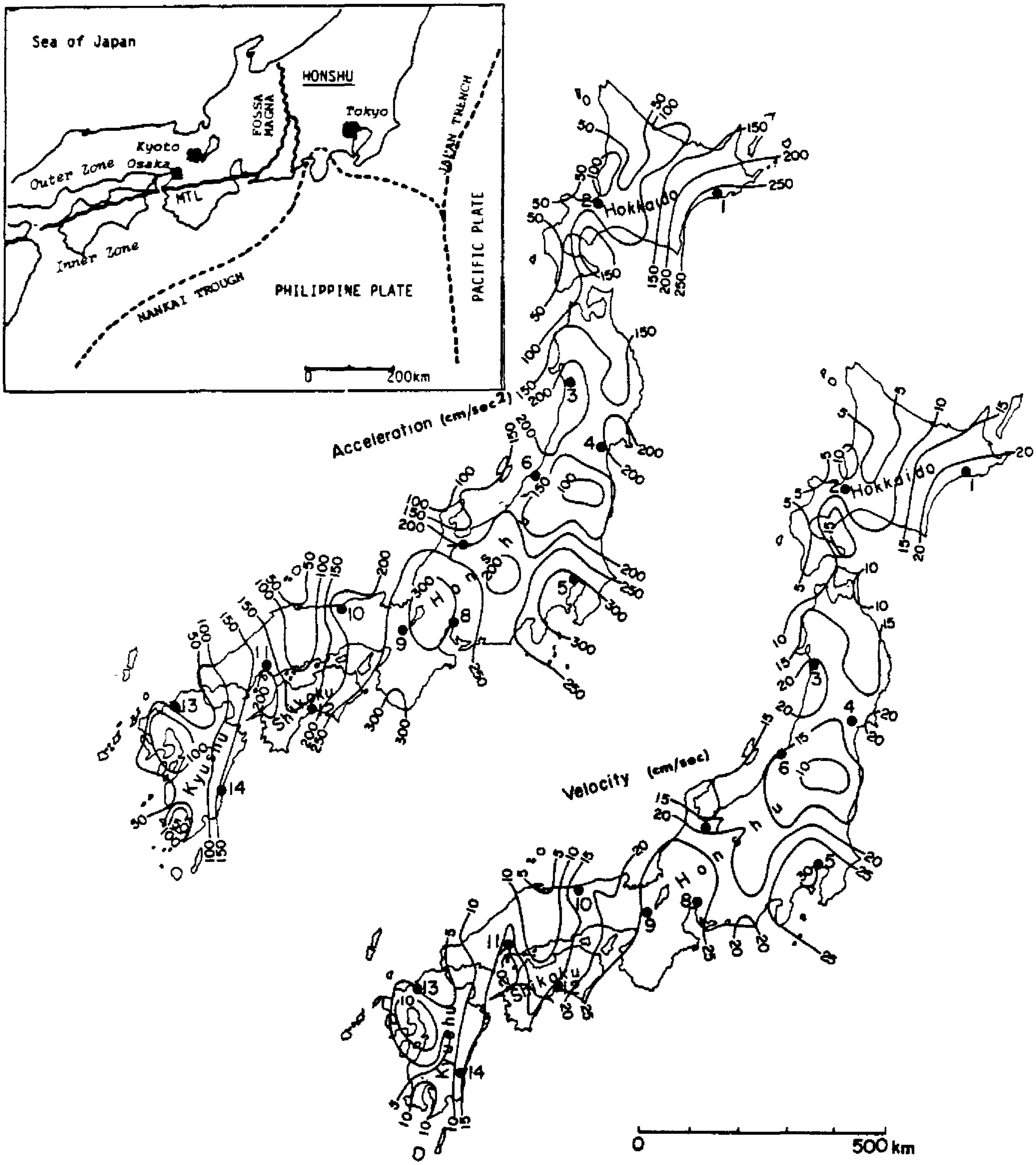

Fig. 1 Seismic map for the Expected Value of the Maximum Ground Motion to occur in 75 years (after Goto and Kameda (1)). Insert shows tectonic plates near Japan.

The construction of these walls is of some interest. The first step is usually the assembling on the ground of the pre-fabricated main posts and lintels, and tilting these up into place. By this method, the main posts and heavy roof timbers, Fig. 3, can usually be entirely erected in a day, with temporary bracing. This is followed by the installation of bamboo lath first on a coarse grid (labeled mawatashi -dake in Fig. 5) and then on a finer grid (komai-dake) tied to the coarser grid. Fig. 4 shows a close up of this, prior to applications of the mud, while Fig. 5 is a schematic, with Japanese terms, etc.

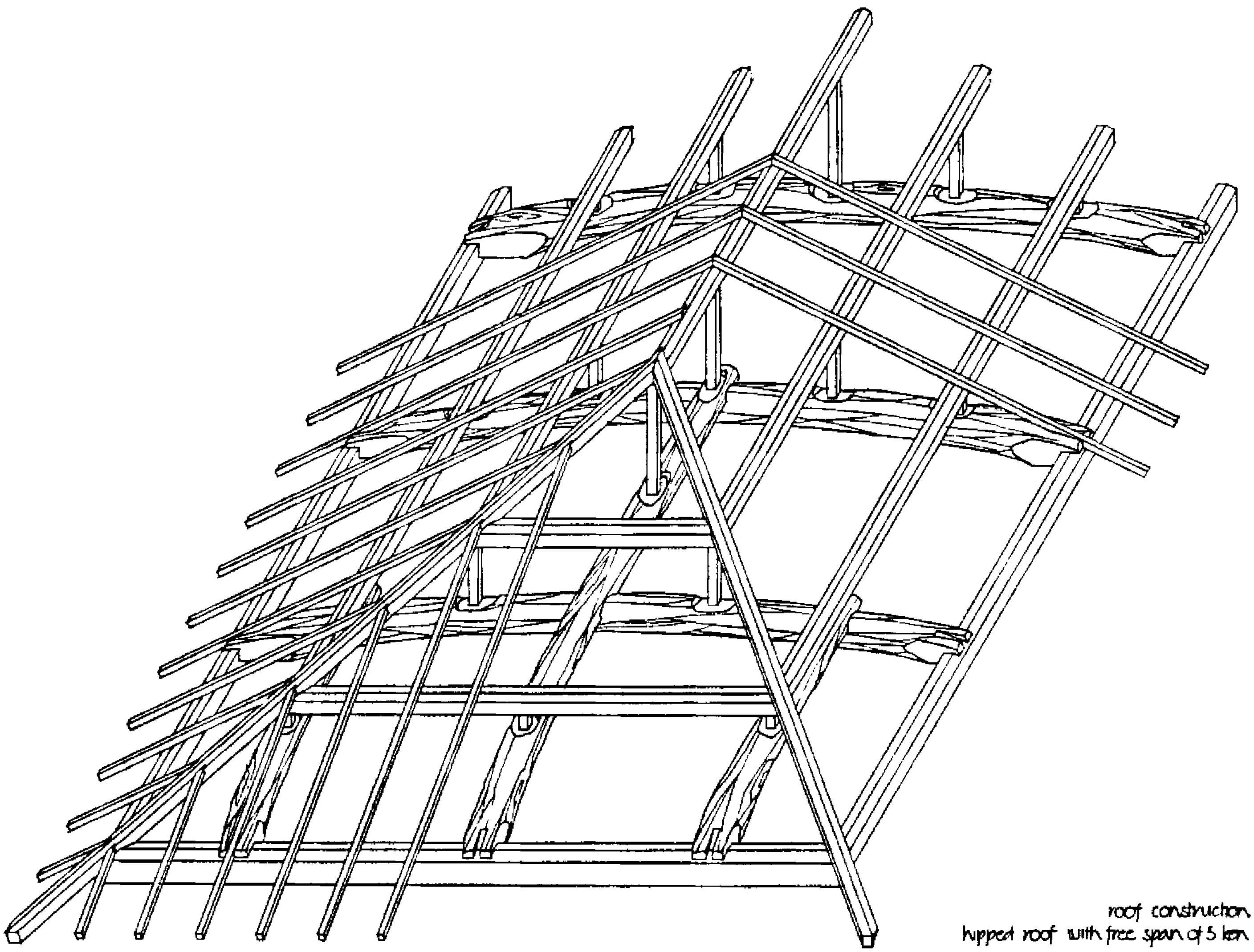

Fig. 3 Hipped-roof construction (after Engel 2)).

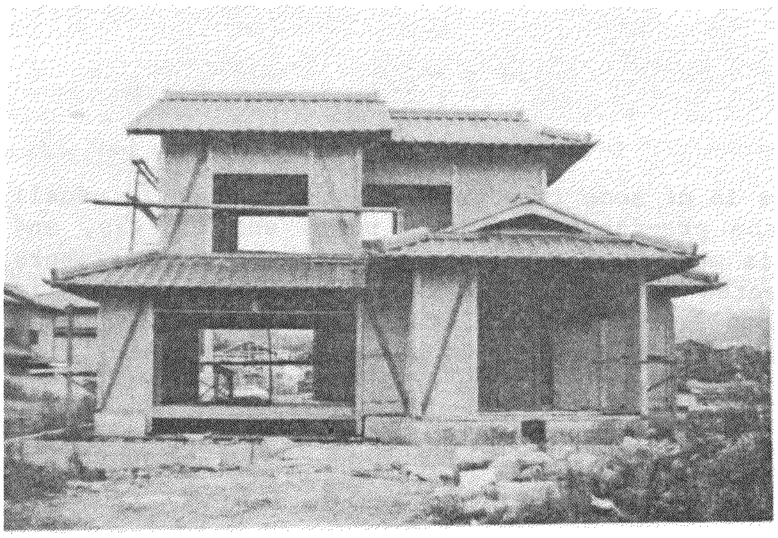

Fig. 2(a). Nearly-completed typical Japanese house - front view

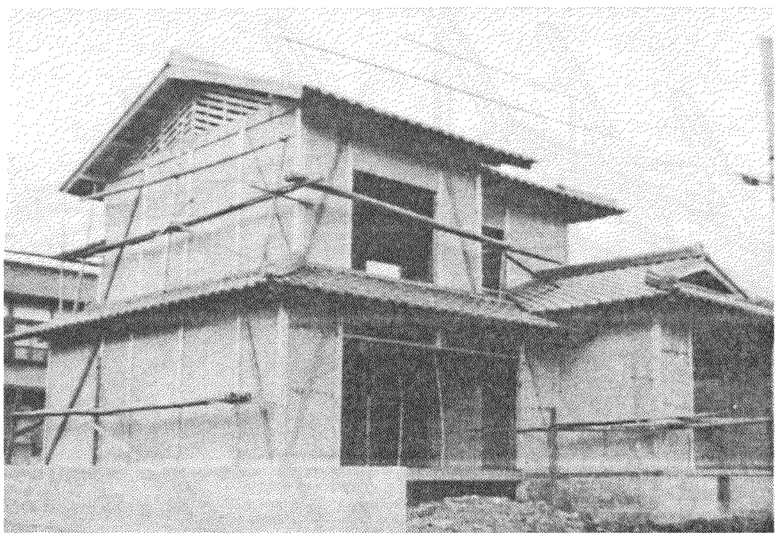

Fig. 2(b). - side view

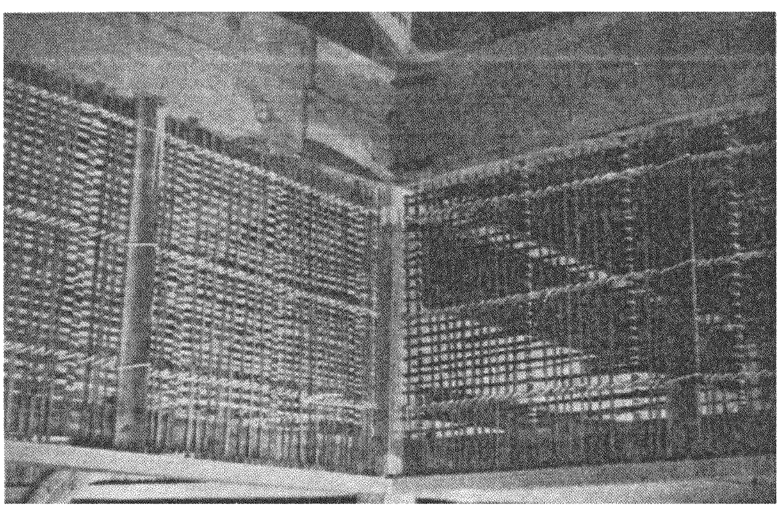

Fig. 4 Close-up of bamboo lath, showing tying of various elements and setting into the eaves beam.