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DAMAGE TO WOODEN HOUSES DUE TO THE 1995 GREAT HANSHIN-AWAJI EARTHQUAKE DISASTER

TADASHI DOI *, HIROYUKI KITAMOTO * and LU HENG JIAN **

* Department of Environmental Design,Faculty of Human Life Science,Osaka City University,
3-3-138 Sugimoto,Sumiyosi-ku,Osaka,558,JAPAN

** Technical Research Laboratory,Pacific Consultants Co.,Ltd.
1-7-5,Sekido,Tama-shi,Tokyo,206,JAPAN

ABSTRACT

The 1995 Great Hanshin Earthquake disaster that struck Hyogo prefecture on January 17, 1995 at 5:46 A.M. with magnitude 7.2 on the Richter scale by Japan Meteorological Agency brought about such devastating damages as 5,502 deaths, 2 missing persons, 100,209 buildings collapsed or severely damaged and 107,074 buildings partially damaged (as of May 10, 1995). 86 percent of deaths took place in their homes, because a great number of wood-frame buildings collapsed. Many of the victims are believed to have died from suffocation caused by falling ceilings, beams and columns that crushed their chests and abdomens(The Sankei Shimbun,1995).

We conducted a survey in Kobe city and a part of Hokudancho of Awajishima island, in order to determine the causes and distribution of damage based on the degree of damage sustained by wood-frame buildings and their attributes. We focused our investigation on the biological degradation of structural members of buildings, and found that partial loss of cross sectional area of structural members such as sill and column due to biological degradation contributed to the collapse of houses as one of major causes.

KEYWORDS

The 1995 Great Hanshin-Awaji earthquake disaster;damage;wooden houses;termite;decay;
biological degradation;hokudancho;awajishima;higashinada;kobe.

OUTLINE OF THE SURVEY

Survey Area

The survey was conducted in central part of East Higashinada ward, Kobe city and a part of Hokudancho of Awajishima island. In Hokudancho, Awajishima, five areas near the seismic fault (Nakata *et al.*,1995)identified after the earthquake were surveyed as shown in Fig.1.In Higashinada ward,entire survey area was divided into areas [a], [b] and [c] as shown in Fig.2.

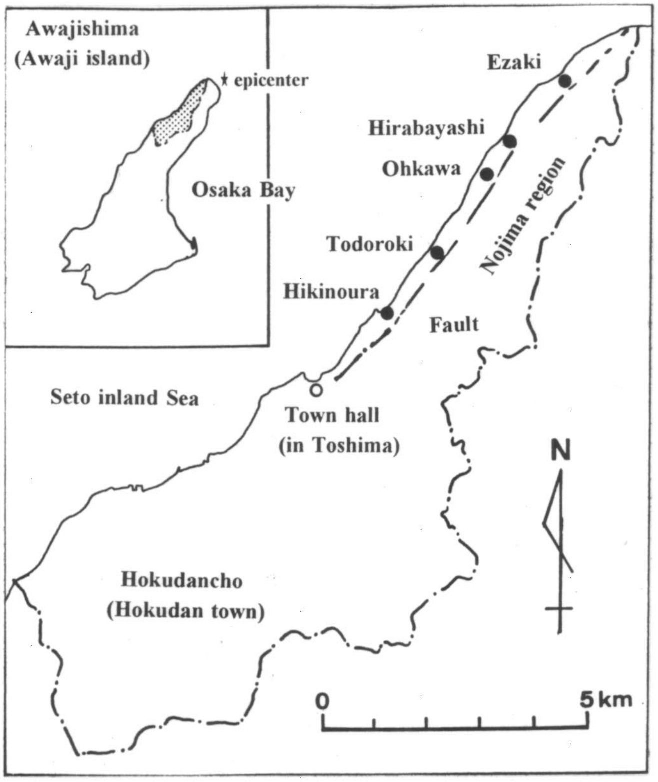

Fig.1. Map of survey area in Hokudancho, Awajishima island.

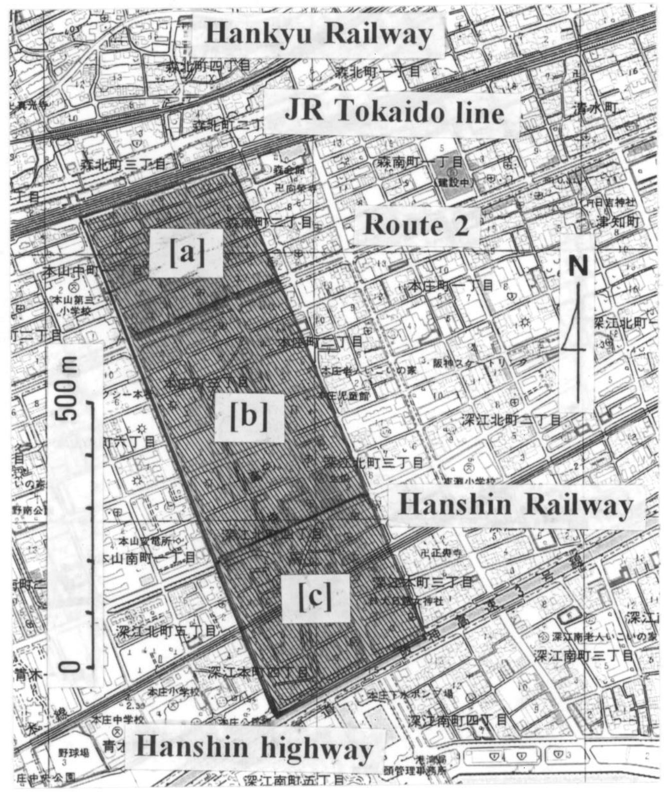

Fig.2. Map of survey area in Higashinada ward, Kobe city.Shaded area were investigated.

Check Points and Method of the Survey

We limited our survey to wood-frame buildings located within the survey area, while registering some attributes of the buildings as follows. Purpose of the building was classified into four categories: exclusively for dwelling, dwelling house combined with shop, wooden apartment and others. Buildings for other purposes include those for purposes other than dwelling, such as workshop and clinic. Type of roofing was classified into tile roofing and sheet metal roofing, except for Higashi-Nada ward where tile roofing was sub-divided by the kind of tile. Buildings were further classified by the years elapsed after construction. Conditions of major structural members such as sill, column and girder were checked by the appearance, to see whether they were deteriorated by termite attack and/or wood decaying fungi.
Damage to the building was classified into three ranks: collapse or severe damage, partial damage and slight or no damage.The survey was conducted over several times from January 27 to March 6, 1995.

Table 1. Damage to the Wooden building was classified into three ranks.

Damage rank	Criteria
A:Collapse or Sever damage	Collapse:building or story collapse Sever damage:sever,unrepairable damage to building frames, large residual story displacement
B:Partial damage	moderate or minor damage to building frames,small residual story displacement, substantial damage to roof tiles
C:Slight or No damage	Slight:cracks in non-structural walls No damage:no cosmetic or structural damage

RESULTS AND DISCUSSION

Damage to Buildings and Their Attributes in Hokudancho,Awajishima Island

We surveyed 266 wood-frame buildings distributed over the entire survey area of Hokudancho. Among these, useful data were obtained from 263 buildings. When classified by the degree of damage by the criteria shown in Table 1, 121 buildings (46.0%) collapsed or were severely damaged, 51 (19.4%) were partially damaged and 91 (34.2%) were slightly or not damaged. Very high proportion of the buildings in this area were damaged due partly to its location near the seismic fault. As can be seen from Fig.3, however, damage to the structures was not uniformly distributed among different places. The difference may be attributed to the differences in the distance from the fault and in the ground conditions.

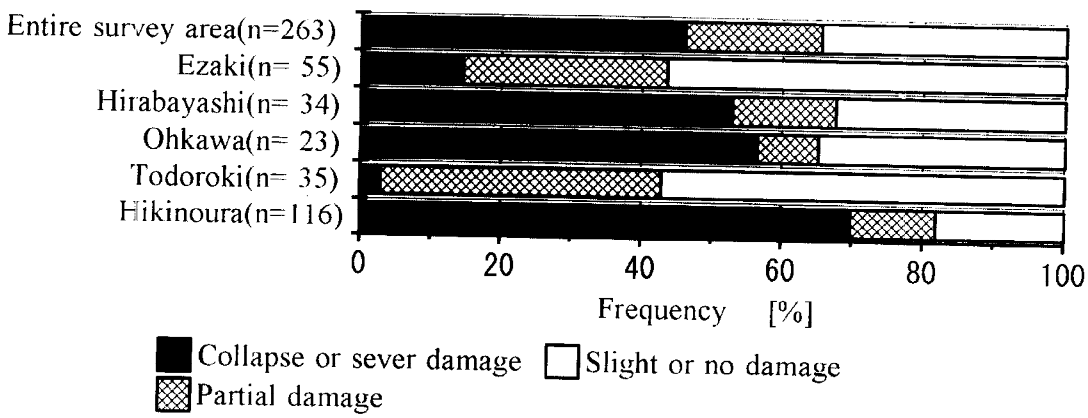

Fig.3. Proportion of damage to wooden -frame buildings in Hokudancho,Awajishima Island.

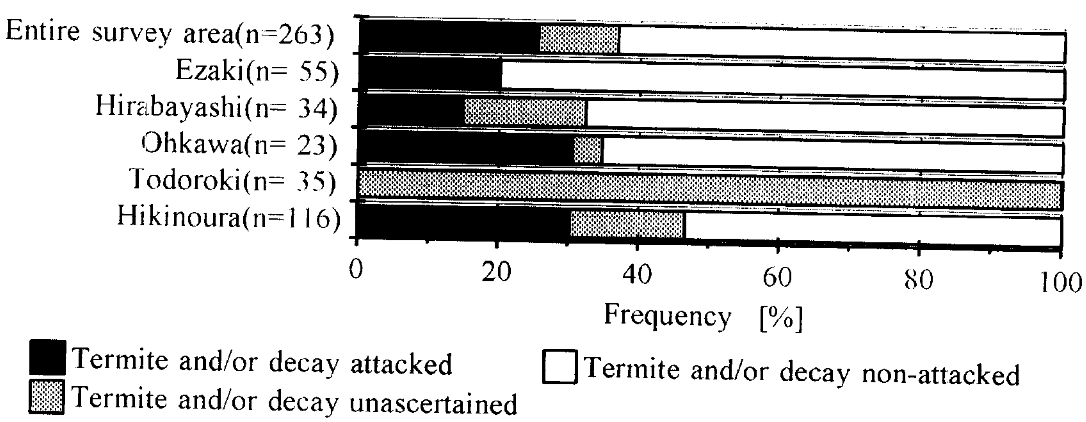

Fig.4. Proportion of wooden-frame buildings affected by termite and/or decay in Hokudancho

In Hikinoura, for example, over 80% of the buildings were severely or partially damaged. Such a devastating damage may be blamed on the ground condition, because most of the buildings of this area are concentrated in low-lying level land near coastline, in contrast to other areas. When classified by the purpose, 299 (87.1%) buildings were exclusively for dwelling, 8 (3.0%) were houses combined with shops, 2 (0.8%) were wood-frame apartments and 24 (9.1%) for other purposes. As for the roofing material, tile is predominantly used on 255 buildings (97.0%), while sheet metal roofing was used only on 7 buildings (2.7%). This may be due to the fact that Awajishima is a major roofing tile producing area, and also to the preparation for typhoons.Proportion of buildings affected by termite attack and decay is shown in Fig.4. Although the climate is relatively warm in this region, proportion of buildings affected by termite attack/decay is not necessarily high, indicating good practice of caring the houses by the owners.

Correlation of Earthquake Damage to Houses Affected by Termite Attack in Hokudancho

Most of the buildings in the survey area of Hokudancho were tile-roofed, as described above, and therefore it is difficult to tell whether the difference in roofing material caused differences in the earthquake-induced damage. Thus contribution of termite attack and decay to the degree of damage to the buildings will be discussed. Fig.5 shows that 58 of the buildings located in the survey area showed degradation due to termite attack and/or decay. Among these, 75.9% collapsed while 10.3% were partially damaged and 13.8% sustained only slight or no damage at all. Meanwhile, 144 buildings showed no sign of termite attack. Among these, 38.2% collapsed while 19.4% were partially damaged and 42.4% sustained only slight or no damage at all. These figures clearly show that buildings affected by termite attack and/or decay collapsed at a higher rate.

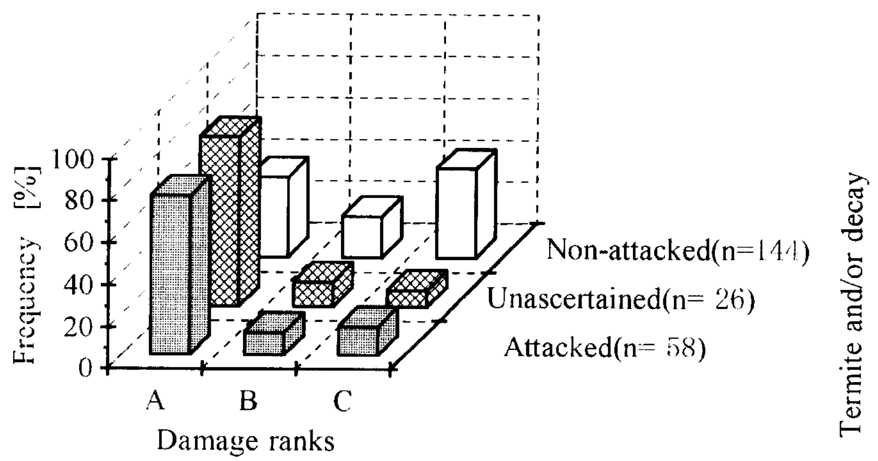

Fig.5. Correlation of damage to wood -frame buildings affected by termite and /or decay . Damage ranks are shown in Table 1.

Attributes of Buildings Located in the Survey Area of Higashinada Ward, Kobe city

Data of 709 buildings were obtained from the survey area of Higashinada ward. To avoid being injured by buildings collapsing by after shocks, survey was limited to buildings located along streets. Thus we did not survey all wood-frame buildings in the survey area, except for area [a] where nearly all buildings were surveyed. Buildings other than wood-frame were excluded from the scope of the survey. Among the 333 buildings in area [a]. 267 (80%) were exclusively for dwelling, near 10% were dwelling houses combined with shops and near 10% were wood-frame apartments. Most of non-wood buildings such as reinforced concrete buildings and steel-frame buildings were collective houses, with only a small proportion being shops and factories. Areas [b] and [c] included about 20% of dwelling houses combined with shops. Area [c] is a small block crowded by wood-frame houses and shops, with 29 non-traditional, simplified wood-frame buildings built several decades ago among the 165 buildings (18%), showing the highest proportion among the three survey areas. Area [b] was occupied by many non-wood collective housing buildings and factories with relatively less wood-frame buildings.

About 70 to 80% of the buildings in this area were roofed with tiles including clay tiles on shingle bed and clay tiles with batten. Batten was used in more buildings than shingle bed in all the areas. Even in area [c] where the proportion of shingle bed was relatively high, shingle bed was used in only 41 (34%) among 120 tile-roofed buildings.

Buildings were classified into old and new, with 30 years after construction as the borderline, based on the surface conditions of the lumber, appearance of the building and interview of the dweller. In all areas, about 60% were wood-frame buildings built later than 30 years ago. Many buildings were observed to have been changed from clay tiles on shingle bed to those with batten, although their structures were rather old.

Damage to Buildings in the Survey Area of Higashinada Ward

The survey area is within the region registered at 7 on the Japanese closed seismic scale, and over 50% of the buildings collapsed as shown in Fig.6. In area [a] which is bordered by the Japan Railway Tokaido line and the national highway No.2 on both sides, in particular, 60% of the buildings collapsed and 80% of wood-frame buildings collapsed or sustained partial damage. In area [c] to the south which is penetrated by the Hanshin Railway, in contrast, only 30% collapsed. When collapse and partial damage are combined, proportion of damaged buildings is 50%, while half of the buildings sustained only slight or no damage. Extent of damage in area [b] which is located in between is near the average of the entire survey area. In the survey area, degree of damage is found to become less southward from near the mountainous area toward seaside area.

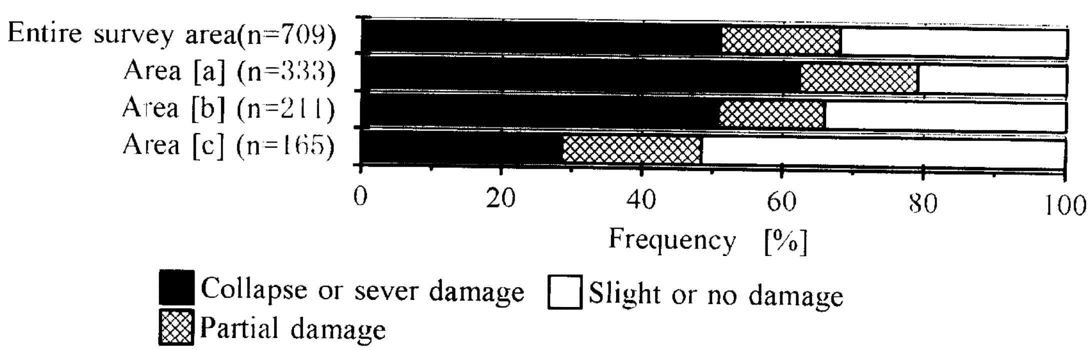

Fig.6. Proportion of damage to wooden-frame buildings in Higashinada ward,Kobe city.

Termite Attack and Decay in the Survey Area in Higashinada Ward

In the wake of the Great Hanshin Earthquake, a number of surveys were conducted by many researchers in urgency to investigate the damage. Based on these surveys, many including mass-media have pointed out that old housing buildings collapsed. The term "old house" implies a house built before the Building Code was put into effect. It cannot be denied that old houses had weakness in the foundation and in the main structure such as lack of braces, adding second story on a one-story structure and extending a house by removing walls and columns. As for the lumbers used as the structural members which bear the load, however, decrease in their strength is negligibly small however they are old. Aging of lumber is physical and chemical changes of the material which proceed very slowly over an extended period of time, except for the case of fire. These changes can be neglected in practice for the roof and structural members covered by interior and exterior walls. Biological degradation caused by wood decaying fungi and termite, on the other hand, proceed remarkably faster than aging, and therefore results in significant reduction of the strength. Thus lumbers not affected by biological degradation normally maintain sufficient strength even if they are old. Decay and termite attack are often observed at the same time in the same building. The region struck by the Great Hanshin Earthquake was anticipated to be the habitat of the Japanese termite,*Reticulitermes speratus* KOLBE, and, because the mean temperature in January is not lower than 4 ℃ and the average of the lowest temperatures does not fall below 0 ℃ , the habitat of the Formoson subterranean termite,*Coptotermes formosanus* SHIRAKI. Slightly higher rate of termite attack and decay was observed in Higashinada ward than in Hokudancho.

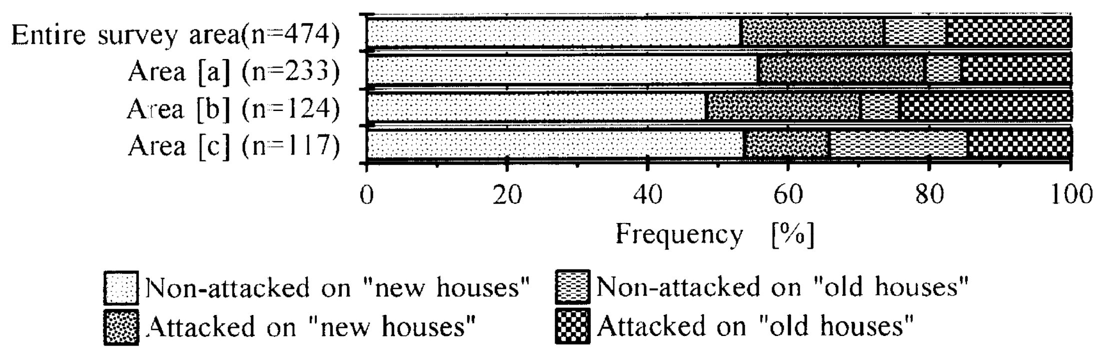

Fig.7. Proportions of wooden buildings affected by termite and/or decay in the survey area on Higashinad ward,Kobe city.

Correlation of the years after construction and termite attack/decay was studied by using the estimated age of the building and data excluding those of buildings with termite attack and decay unascertained. As shown in Fig.7, buildings that were less than 30 years after construction (indicated as "new" in the figure) and showed no termite attack and decay formed the largest group. Among buildings that were less than 30 years after construction, 69 to 82% showed no termite attack. Among buildings that were older than 30 years after construction (indicated as "old" in the figure), on the contrary, 43 to 81% showed termite attack.

Correlation of Earthquake Damage with Termite Attack/Decay , Years after Construction and Roofing Material in Higashinada Ward

Degrees of damage to buildings with and without termite attack and decay are shown in Fig.8, being classified by the years after construction. It can be seen from this figure, that most of buildings with termite attack and decay collapsed regardless of the years after construction. Those indicated as termite attack and decay being unascertained are buildings so severely damaged that their foundations and sills could not be observed, or had been cleared for the purpose of rescue activities. Among buildings not affected by termite attack in area [a], more buildings older than 30 years were heavily damaged than those less than 30 years in which slight damage is relatively dominant. In areas [b] and [c] to the south of national highway No.2, slight damage to buildings without termite attack and decay is predominant. As these observations suggest, termite attack made major contribution to the damage to buildings.

About 70 to 80% of buildings in the survey area were tile-roofed with shingle bed or batten. Among buildings which were tile-roofed with batten, 194 (50.3%) collapsed, 83 (21.5%) were partially damaged and 109 (28.2%) were slightly or not damaged. Among buildings with old tile roof applied on shingle bed, on the other hand, 95 (71.4%) collapsed, 17 (12.8%) were partially damaged and 21 (15.8%) were slightly or not damaged. Buildings with tile roof on shingle bed sustained relatively heavier damage.

This result clearly shows the significance of the effect of termite attack and decay, as the proportion of collapse or severe damage is less than slight or no damage among tile-roofed buildings, including those tile-roofed on shingle bed which was blamed as the cause of collapse for its weight as well as those tile-roofed with batten which is relatively light-weight.

Presence of termite attack and decay showed the highest correlation with the degree of damage, 0.620, followed by 0.277 of the roofing material, in line with the discussion given in the preceding sections.

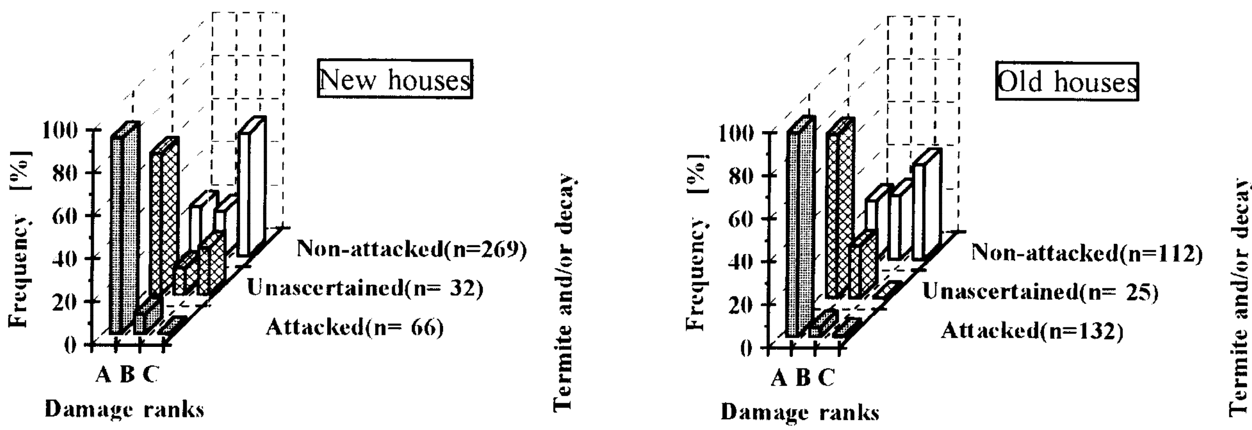

Fig.8. Degrees of damage to wooden buildings with and without termite attack and decay, classified by the years after construction.

Causes of Termite Attack and Decay

Causes of termite attack and decay will be discussed below. Termite is an insect of *Isoptera*, which is more closely related to cockroach, the native insect of tropical rain forest, than to ants of *Hymenoptera*. Thus termite prefers warm and humid environment, and feeds on lumbers with water content above the fiber saturation point (F.S.P.) that include free water. *Coptotermes formosanus*, however, can attack dry lumber by carrying moist to it by itself if necessary. Wood-decaying fungi, on the other hand, are mostly those classified into *Basidiomycetes* or, more particularly, those of *Polyporaceae* which are generally called by the name of mushroom. Wood-decay fungi have high decaying effect on lumbers with moisture content in a range from 30 to 60% in an atmosphere of 90% or higher relative humidity, but have no decaying effect on lumbers with moisture content lower than 20% or higher than 150%. They reproduce in a relatively wide temperature range from 5 to 40 °C , and are aerobes that require oxygen.

In sum, termite and wood-decay fungi require the following five conditions to live and reproduce: (1) nutrient, particularly carbon supply, (2) oxygen (air), (3) appropriate temperature (near the comfort zone of man), (4) moisture (relative humidity of 90% or higher, moisture content of lumber 30% or higher) and (5) space required to live. This means that biological decay can be impeded by removing any one of these five conditions. However, lumber is made up of cellulose as the major component made in a porous, cellar structure. Air and warm temperature are necessary for human, too, and it is difficult to remove these conditions. For these reasons, prevention of biological decay is carried out by means of treatment with chemicals such as wood preservative to make it difficult for the wood attacking organisms to take nutrient, or by directly exterminating the termite and/or fungi. Their activities can also be impeded by controlling the moisture content of lumber, which is the only controllable factor.

Sources of moisture supply to the lumber in wood-frame buildings are water vapor in the atmosphere, water included in the soil, water used in human life and rain. Architects employ such measures to shut off moisture supply as damp-proofing of soil, ventilation of the space below floor, prevention of dew condensation on the surface and the inside of walls, water-proofing of roof, balcony and wall surface, installation of roof gutter and prevention of leakage from water supply and waste pipings. Use of lumber with moisture content below 20% is naturally required. Thus legal regulation requires that waterproof paper is used on mortar finish bed and that anti-fungus measures and, if necessary, anti-termite measures be taken for structurally important portions within 1m above the ground. It is also stipulated that preservation-treated material be used for structurally important members.

Survey of damaged buildings and those slightly damaged with part of exterior wall mortar being fallen off in Higashinada ward, and interview with the dwellers showed that anti-fungus measures and anti-termite measures taken in this survey area did not meet the legal requirements. Poor water-proof management also contributed to the progress of termite attack and decay. Poor maintenance of the mortar-finished exterior wall allowed rain water to penetrate through cracks in the wall, causing the wooden lath to decay and leading to termite attack and decay of sills and base of column. Poor maintenance of roof gutter also led to conspicuous penetration of rain water through eaves. This caused the pole plate and top of column to be attacked not only by *Coptotermes formosanus* but also by *Reticulitermes speratus* which usually attacks only the part around sills where moisture is easily supplied from the soil.

Conclusion

Correlation of the degree of damage sustained by wood-frame buildings to some attributes of the building was investigated, based on the results of survey conducted in Higashinada ward, Kobe city and a part of Hokudancho, Awajishima. It was found that whether structural members such as sill, girder and column were affected by termite attack and decay had greater contribution to the destruction of houses than the building attributes such as roofing material and the purpose of building did. Improper treatment of sills and other members with chemicals, insufficient water-proofing of kitchen, bath room, exterior wall mortar, roof gutter and balcony floor, and other problems in the construction process and maintenance are suspected as major causes of the termite attack and decay. These findings suggest that wood-frame buildings which sustained slight or no damage in the Great Hanshin Earthquake require inspection and maintenance with regard to waterproofness, water leakage, dew condensation in the wall and moisture content of the structural members consealed in walls, thereby to prevent biological deterioration of structural members.

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