Disasters Caused by Severe Local Storms in Japan

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Abstract

The occurrence probability of severe local storms in Japan is much smaller than that of typhoons. But such storms sometimes cause extremely severe damage to structures. The authors describe the necessity of taking the wind effects of such severe local storms into consideration in the design of important structures such as atomic reactor plants. Severe local storms, which cause severe damage in Japan, are Tatsumakis, thunderstorms, and small whirlwinds. However, knowledge of the characteristics of these severe local storms is at present quite insufficient to be applied to the design of structures, so the present authors propose a first approximation of the characteristics of such severe local storms in Japan from field studies of damage caused by Tatsumaki and thunderstorms which have occurred recently in the central part of Japan.

1. Introduction

In the design of wind resistant structures, a maximum wind speed which may be experienced once in fifty or a hundred years is usually chosen as the fundamental value of the design wind speed. In Japan, in most cases, this value is assumed to be caused by a high wind accompanied by a typhoon in summer or a severe extratropical cyclone in winter. However, although the maximum wind speed in severe local storms is sometimes much higher than the maximum wind speed observed in a typhoon or an extratropical cyclone, it has not yet been taken into consideration in the design of wind resistant structures because the expected occurrence probability of a severe local storm at any one point is extremely small, e.g. once in a million years or so.

It is also true that some structures, such as atomic reactor plant, must be constructed strongly enough not to be severely destroyed by any kind of environmental disaster. And networks of communication, transportation or electric power lines will also cause severe social damage if they are destroyed at crucial points. In the design of such principal structures, therefore, we should not disregard severe local storms even if their occurrence probability is extremely small. Under present circumstances, however, our knowledge of such severe local storms in Japan is quite insufficient for wind resistant structure design.

The present authors are now working for the establishment of design criteria for the extreme winds caused by severe local storms in Japan. This paper is a brief summary of their current knowledge and the results of detailed field studies of wind damage caused by such storms recently.

2. Severe Local Storms in Japan

"Severe local storm" is a general term representing severe storms in the meso-meteorological scale, whose meteorological features have been studied by many investigators (e.g. Donaldson[1], Fujita[2] and Kesller[3]); but their natures and methods of prediction are not yet established.

Severe local storms which cause severe damage in Japan are briefly surveyed by Mitsuta[4]. According to his study these storms are mainly thunderstorms, "Tatsumakis" and small whirlwinds.

"Tatsumaki" is a Japanese term for tornado, "a violently rotating column of air, pendent from a cumulonimbus cloud and nearly always observable as a funnel cloud", which is seen almost all over the world. There have been several studies on Tatsumaki climatology (e.g. Ibaraki and Tanaka[5], Shimada[6] and Mitsuta[4]). According to these studies most Tatsumakis occur near the sea coast, especially on the southern part of the ocean coast. The occurrence of Tatsumakis on land is about 7 per year and in an average year one person is killed, sixteen are wounded and 62 houses are damaged (Mitsuta[4]). The averaged characteristics and damages are shown in Fig. 1 and Table 1; they show that the amount of damage caused by Tatsumakis is not

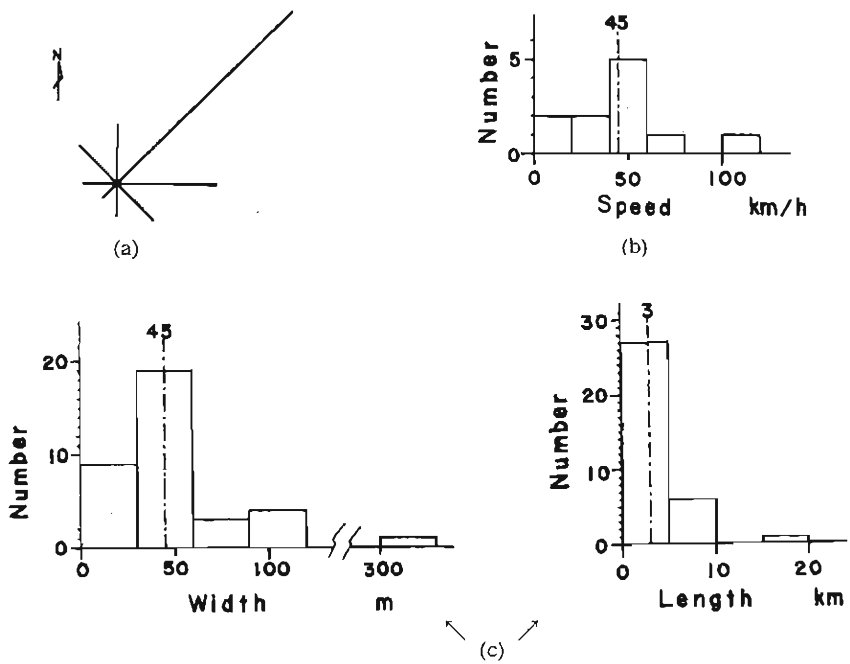

Fig. 1. The characteristics of Tatsumakis in Japan.
a) Direction of forward motion
b) Speed of forward motion
c) Width and length of area damaged by Tatsumakis

large. The averaged characteristics and damage of tornadoes in the United States, where most severe tornadoes are seen, are also shown in this table for comparison. The characteristics are almost the same for both Tatsumakis and tornadoes, but the intensity and scale of tornadoes are much larger and more intense than those of Tatsumakis. From these points some American meteorologists have suggested that Japanese Tatsumakis are comparable with waterspouts in the United States, as these

Table 1. Statistics of Tatsumakis in Japan and Tornadoes in the United States.

	Tatsumakis, Japan 1955-1964	Tornadoes, US 1916-1958
Occurrence (per year)	7.2	213.2
Number of Deaths		
(per year)	1.0	214.9
(per Tatsumaki)	0.14	1.0
Number of Wounded		
(per year)	15.9	
(per Tatsumaki)	2.2	
Number of Damaged Houses		
(per year)	62.1	
(per Tatsumaki)	8.6	
Path Width m	45	250
Length km	3	10
Forward Motion		
Speed km/hr	45	60
Direction	to NE	to NE
Maximum Wind Speed m/sec	60(0)	250(E), 125(R)
Probability at any given point per year	10^{-6}	10^{-4}

sometimes go ashore and cause some damage on land.

The maximum wind speed of Tatsumakis has never been measured nor estimated. We have only one report obtained by an anemograph near the path of a Tatsumaki whose speed exceeded 60m/sec, as a clue to the maximum wind speed of Tatsumakis. In the United States, the maximum wind speed of tornadoes has been a subject of study, and a maximum wind speed of 125 m/sec has been observed by a Doppler radar and 250m/sec has been estimated from the analysis of damage to structures.

The occurrence probability of a Tatsumaki at any one point in Japan during a year is on the order of 10^{-6} (Mitsuta[4)]), which means that the return period of a Tatsumaki wind is as long as a million years at a given point. But the occurrence probability of a tornado at any one point in the United States is about 10^{-4} per year and 10^{-3} on the tornado belt in the center of the United States (Thom[7)]).

Clearly, the Japanese "Tatsumaki" is less severe and less frequent than the American tornado, hence less serious; but more detailed knowledge of its characteristics, especially its maximum wind speed estimate, is required for the purpose of disaster prevention.

Strong winds caused by thunderstorm downdrafts also occurs in confined areas, as in the case of tornado-type storms. But in such cases the winds are all in one direction which usually agrees with the direction of the thunderstorm's motion. These winds are sometimes referred to as plow winds. We can see this plow-type strong wind also in Japan, but sometimes it is confused with "Tatsumaki". Strong winds of this type can be seen even in inland Japan (Mitsuta[4),8)]), unlike the Tatsumakis. But their detailed characteristics have never been studied. We can only estimate that the maximum wind speed might be less than that of Tatsumakis, but that its width may be a little broader than that of Tatsumakis.

The small whirlwind described above was first observed and analyzed by Mitsuta[9] on the Pacific coast of Japan using more than 10 sets of anemometers in a small area. The diameter of the maximum wind zone was found to be about one or two kilometers and the maximum rotating wind speed to be 10 m/sec or so. This type of whirlwind is often observed in typhoons, therefore it might be recommended that in the wind-resistant design of important structures the design wind speed should be set at 10 m/sec above the maximum wind speed of typhoons at the area where this type of wind is often observed.

As such a severe local storm is small in size, it is rarely detected by instrumented observing points. And its maximum wind can only be estimated from the structural failures which it produces. However this estimation of maximum wind of severe local storms in Japan has never been done before. Fortunately the present authors recently had a chance to make field studies on wind damage caused by such severe local storms and some estimates of their maximum wind speeds were obtained from the analysis of damage to structures. The results are summarized in the following sections.

3. Tatsumaki at Toyohashi, Dec. 1969

In the evening of Dec. 7, 1969 a Tatsumaki caused severe damage in the city of Toyohashi, situated on the coast of Ise Bay in the central part of the Japanese main island. One person was killed, about 70 persons were wounded, more than 10 houses were totally destroyed and more than 100 houses were damaged. The statistics of the damage are shown in Table 2 (Ishizaki et al.[10]). Moreover, the Tokaido and New

Table 2. Statistics of damage caused by the Tatsumaki at Toyohashi on 7th December 1969 (from the publication of Toyohashi City Hall dated December 8).

Item	Quantity	Estimated Cost (1000 yen)
Personnel damage		
Dead	1	
Seriously injured	12	
Slightly injured	57	
Buildings		130,000
Totally destroyed	18	
Badly damaged	60	
Slightly damaged	56	
Agricultural facilities	8	2,850
Stores and factories	41	51,324
Power lines		5,000
Railroads		1,000
Telephone lines		1,000
Total		191,174

Tokaido Lines of JNR and highway Route 1 connecting Tokyo and Osaka were stopped for a long time, therefore indirect social damage extended throughout in the main part of Japan.

At the time of the occurrence of this Tatsumaki, Toyohashi was in the warm sector of a cyclone traveling from west to east along the coast of the main island. A well defined cloud echo, moving from SW to NE at 60 km/sec, was seen on the radar scope of the Nagoya Weather Station at about 50km NW from Toyohashi. And the Tatsu-

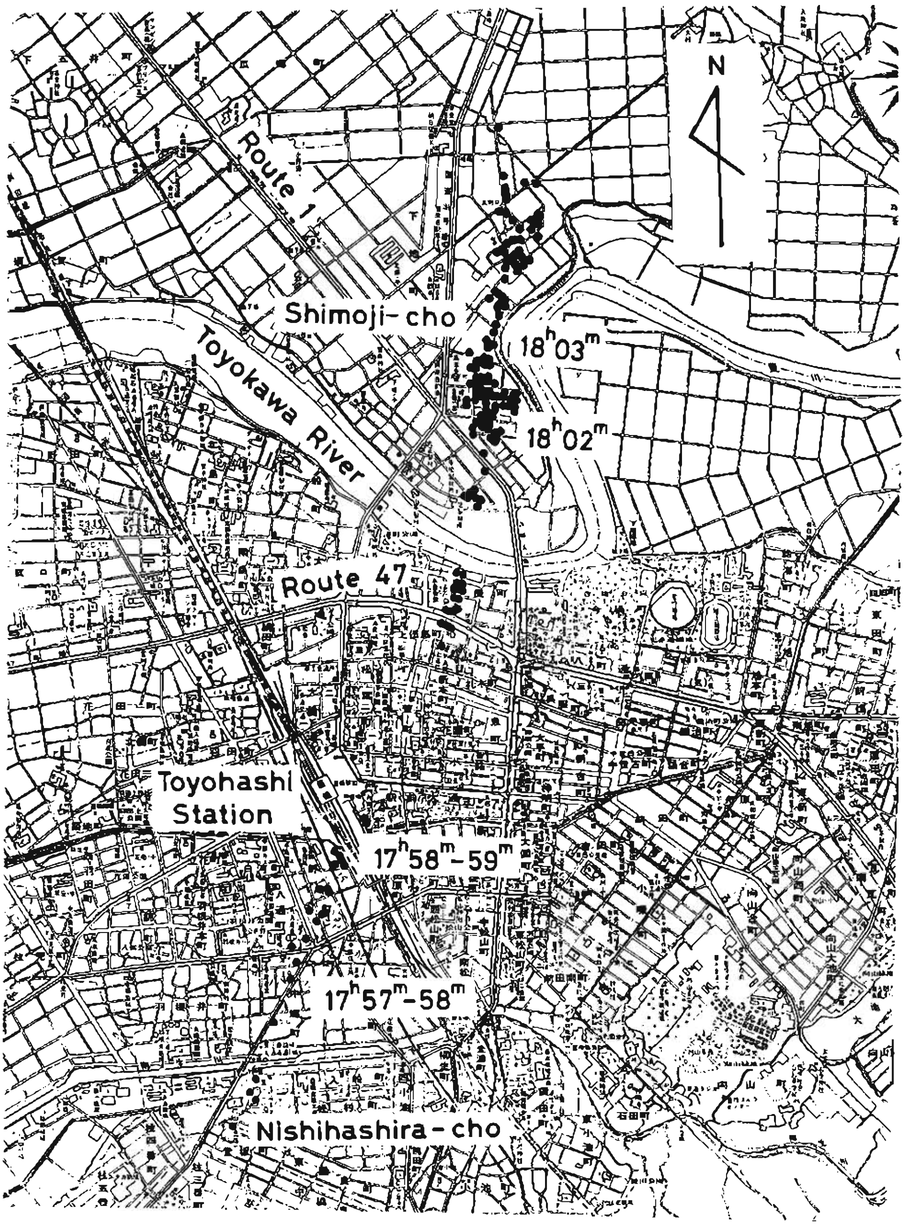

Fig. 2. Distribution of buildings damaged by the Tatsumaki.

maki developed when this echo was just over Toyohashi. However the characteristic echo shape which accompanies tornadoes (Donaldson[2] and Fujita[3]) could not been found.

Buildings damaged, mainly private residences, appear along a strip about 200 m wide at maximum and about 4 km long, extending from Nishihashira-cho to Shimoji-cho, from SSW to NNE, as shown in the street map of Toyohashi, Fig. 2. The beginning of the disaster is about 5km from the west coast and about 10km from the south coast.

Features of the areas near the strip are the following:

(A) Area extending from Nishihashira-cho to Toyohashi Station.
This is a closely settled section and most buildings do not exceed 10m in height.

(B) Area extending from Toyohashi Station to the Toyokawa River.
This is the city center of Toyohashi. Commercial buildings such as an 8-storey department store and hotels are crowded and the surface roughness is larger in this section.

(C) Shimoji-cho Area
This is a sparsely-settled residential section newly-developed in a rural district.

The occurrence of damage appears to change according to the change of city features along the strip. In Area (A), about 20 buildings were damaged. They were distributed uniformly along a strip about 50 m wide.

In Area (B), about 20 buildings were damaged, but they were confined to the north part near the Toyokawa River. On the strip extending from Toyohashi Station to Route 47, only a few buildings were damaged. It is worth noting that some people waiting for a bus near Toyohashi Station at the time when the Tatsumaki was passing over them did not feel anything unusual but saw a black cloud over their heads.

In Area (C), more than 80 buildings were totally destroyed or badly damaged. There, the width of the damaged area became about 200 m at maximum. The aerial view of this area after the Tatsumaki is shown in Photo. 1.

From the reports of many residents, the wind force of the Tatsumaki has a strong impact like an explosion blast and the duration time is very short.

Wooden or steel structures were more seriously damaged (Photos 2, 3 and 4). Reinforced-concrete buildings suffered damage only at openings. The general features of the damage were similar to those caused by the strong winds of typhoons, but severe local damage caused by heavy debris, as shown in Photo. 5 was often observed.

Estimates of wind speed could be made in several cases by analysis of the effect of wind on damaged buildings and structures. Details of this analysis can be seen in the survey report (Ishizaki et al.[10]), so only the results are noted in Table 3.

The characteristics of this Tatsumaki have been summarized in Table 4 and its estimated wind distribution is shown in Fig. 3, which indicates the maximum wind speed estimate to be about 100 m/sec or so. It can be said, in comparison with the intensity of damage of past Tatsumakis, that this Tatsumaki was not extraordinarily strong but that it had comparable scale and intensity with past severe Tatsumakis and its characteristics can be accepted as a first approximation of Japanese Tatsumaki to be considered in the design of wind resistant structures.

Photo. 1. Aerial view of the damage in the Shimoji-cho area after the Tatsumaki. (by courtesy of the Chunichi Newspapers)

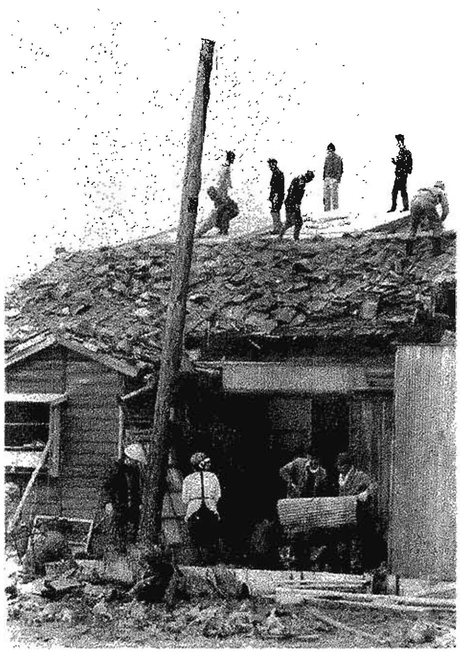

Photo. 2. Damage to a wooden house. Removal of roof-tiles, doors and windows. (by courtesy of the Mainichi Newspapers)

Photo. 3. Wreckage of a light-gauge-steel structure. Bodily removal of the structure from its foundations. (by courtesy of the Mainichi Newspapers)

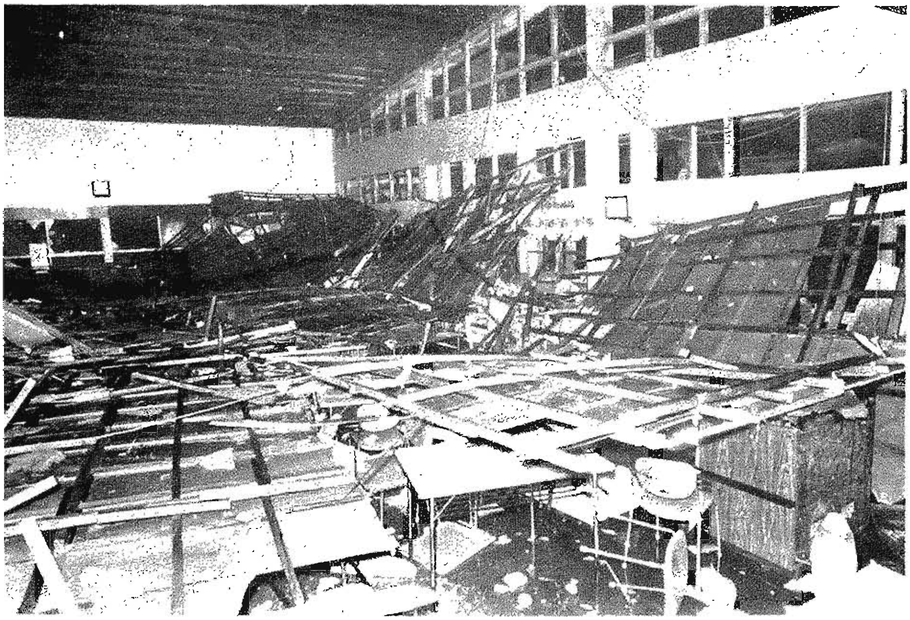

Photo. 4. Damage to a steel structure. Complete removal of the roof and collapse of the ceiling. (by courtesy of the Chunichi Newspapers)

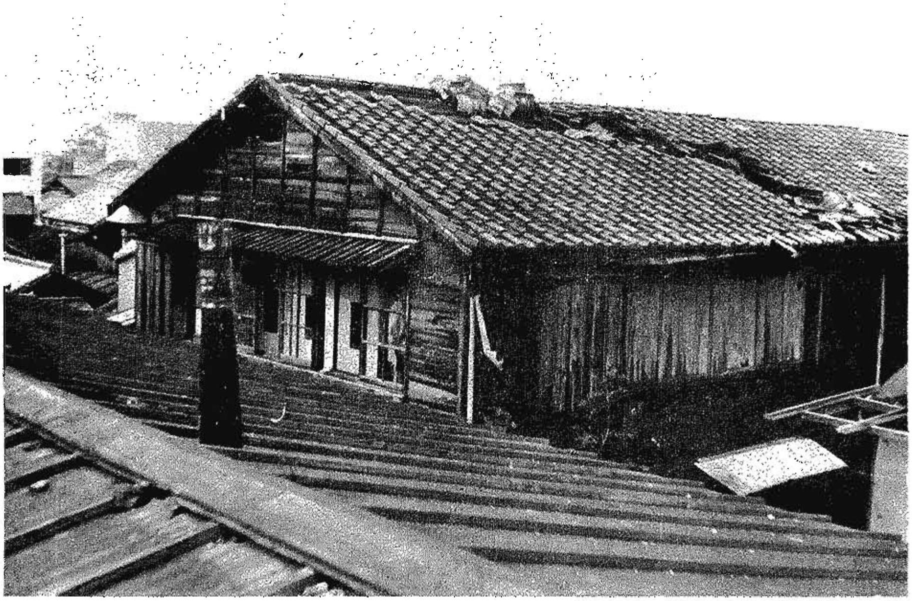

Photo. 5. Local damage to a tiledro of caused by heavy debris. (by courtesy of Mr. K. Chikada)

Table 3. Estimated wind speed (V) and distance from the center of the Tatsumaki path (D).

D (m)	V (m/s)	Damage
0-20	87-100	Power line steel-trussed tower. Buckling of diagonal members.
10-20	63-119	Restaurant "Tsuboya". Inclination of a 2-storey steel building.
30-40 30-40	47-60 42-54	Inclination of 7m high sign towers.
40-60	32, 51	Bodily removal of automobiles

Table 4. Characteristics of the Tatsumaki at Toyohashi, Dec. 7, 1969.

Time of occurrence		1800 JST
Maximum wind speed	m/sec	100
Forward motion		
Speed	km/h	30-40
Direction		NNE
Path		
Width	m	50-200
Length	km	4
Rotation		anti-clockwise

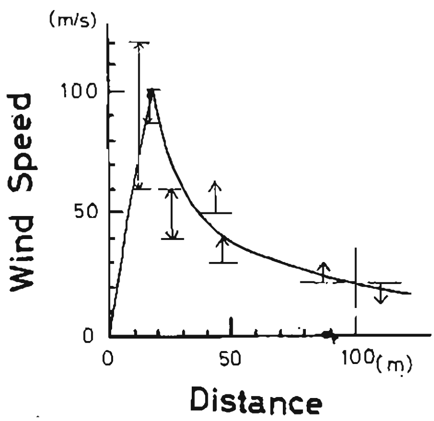

Fig. 3. Estimated wind speed distribution of the Tatsumaki.

4. Thunderstorm at Hikone, Sept. 1970

On the afternoon of Sept. 15, 1970, a thunderstorm caused severe wind damage to houses and other structures in the suburbs of Hikone City, situated on the coast of Lake Biwa in the central part of the Japanese main island. The damage was caused by a northerly strong wind accompanied by heavy hail in a narrow area of about a few square kilometers on the lake shore. Wind damage totalled 5 houses totally destroyed, 9 houses badly damaged and more than 30 greenhouses in farms blown down.

The most prominent damage was the bodily removal of a hotel roof. The hotel is on the edge of the urban area and its north, windward, side faces open flat rice field. A light-gauge-steel roof of a reinforced-concrete hotel building, whose area is about 1,000 m^2 and estimated weight was about 6 tons, was blown off and collided with a house about 100 m away from the hotel.

The evidences of uniform wind direction and relatively wide high wind zone show that this wind was not a Tatsumaki but a plow-type wind. Fortunately at the Hikone Weather Station in the urban area of Hikone City, about a kilometer away from the severely damaged area, a sudden gale of 33.2 m/sec (N) in peak gust was observed at 16:16 JST. At the same time the atmospheric pressure suddenly rose by about 2 mb and the air temperature dropped by about 5°C. The traces are reproduced in Fig. 4. Hail and thunderbolts were also observed during this storm.

The stational front was running along the northern coast and it moved southward in the afternoon of 15th. A very distinct radar echo was observed near the front and it passed over Hikone from north to south at the time of the disaster.

The damage caused by this storm was surveyed by the present authors just after the disaster and the detailed description of the meteorological situation and the damage is reported in another paper (Ishizaki et al.[11]). The distribution of the damage is summarized in the map shown in Fig. 5. The shaded area is the severely damaged area, but fortunately there were only a small number of houses in it. Some of the pictures of the damage are shown in Photos 6 and 7.

The maximum wind speed of the storm was not observed. At the Hikone Weather Station, indicated as W in Fig. 5, a peak gust speed of 33 m/sec was recorded, and at the point P in the map, which is the Harbour Police Station, a maximum peak wind speed of 45 m/sec (NW) was read on the anemometer. These are the only values of wind speed observed by instruments near the severely damaged area. At the point T in the map, tomb stones and a stone monument were blown down. From these, maximum wind speed estimations in several cases are more than 62 or 55 and less than 57 m/sec.

From the damage to stone and concrete-block fences (F_1 and F_2) the maximum wind speed was estimated to be more than 20 or 15 m/sec, while the analysis of a distorted steel door bar at point D led to maximum wind speed estimates of less than about 50 but larger than about 35 m/sec. From these maximum wind speed estimates, it may be concluded that the maximum wind speed of this storm might be 50 to 60 m/sec near the ground.

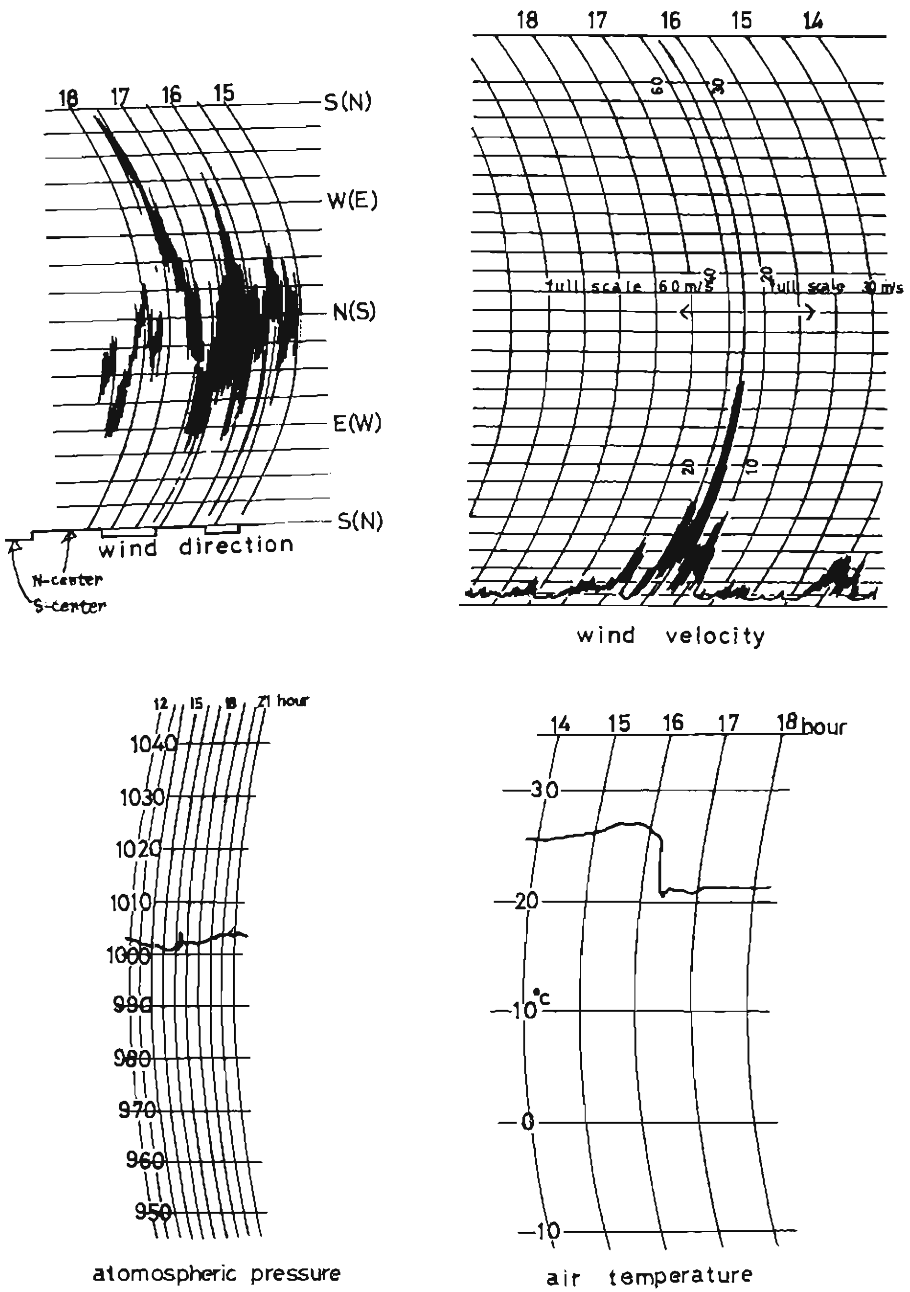

Fig. 4. Records of wind velocity, wind direction, atmospheric pressure and air temperature of the thunderstorm downdraft at Hikone.

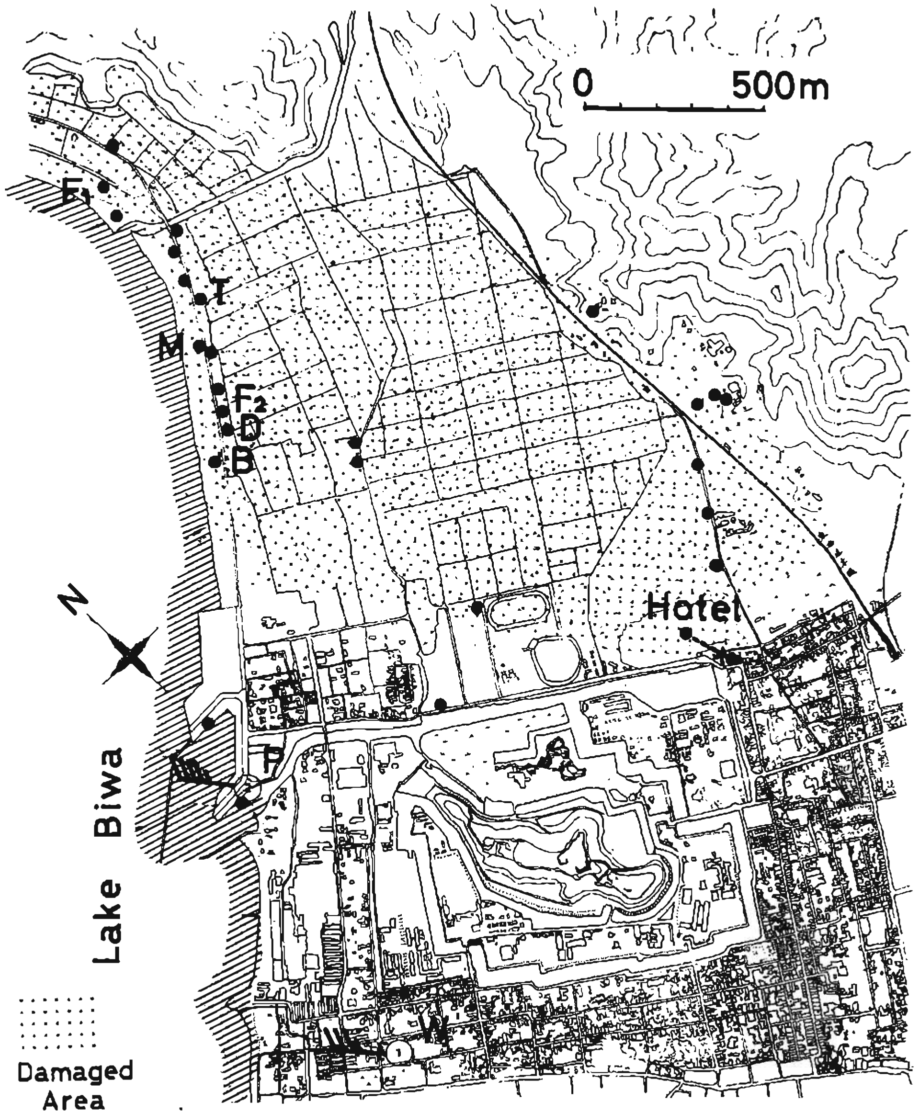

Fig. 5. Distribution of the damage caused by the thunderstorm downdraft at Hikone.

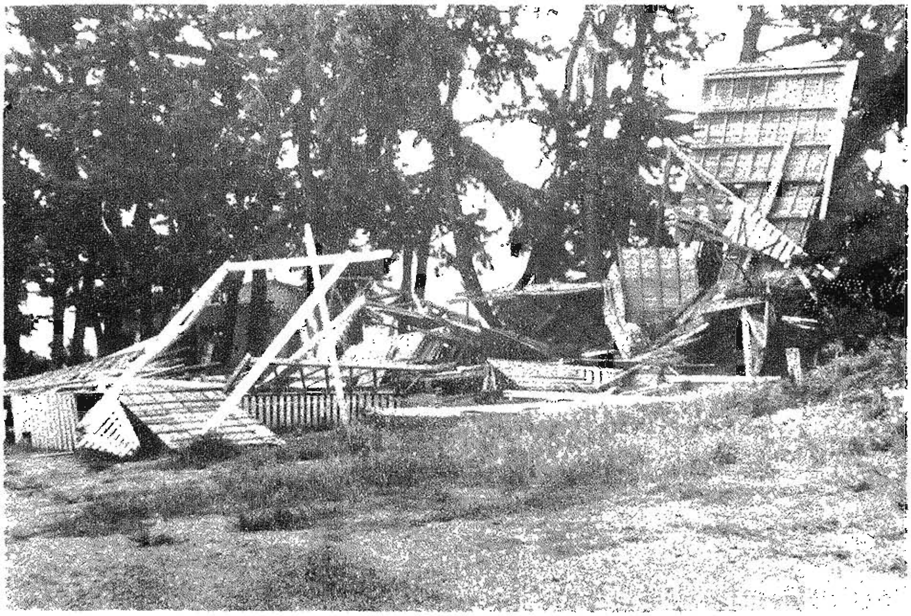

Photo. 6. Wreckage of a wooden bungalow near the lake.

Photo. 7. 30 cm diameter pine trees broken off at the roots.

5. Concluding Remarks

In the design of very important structures in Japan special consideration must be paid to the wind of severe local storms. These are Tatsumakis, thunderstorms, and small whirlwinds. However the maximum wind speed to be considered has never been estimated. From case studies of wind disaster caused by typical Tatsumakis and thunderstorms, estimates of their maximum wind speeds were obtained which could be used as first approximations of the minimum characteristic values for the design of structures against severe local storms.

Tatsumakis in Japan are normally seen near the coast of the ocean (Pacific, Japan Sea or East China Sea) and important structures in these zones should be designed against accidents caused by Tatsumakis even though their probability of occurrence at a given point is as small as 10^{-6} per year. As the area damaged by a Tatsumaki is a narrow strip about 100 m wide and a few kilometers long, the main arteries of communications, power lines, transportation, and the like should, if there are more than two alternatives, not be constructed side by side in coastal zones but should be separated by a few kilometers or so to prevent simultaneous break-down causing severe social damage. And if it is required to construct a structure to withstand a Tatsumaki wind, it must be made safe even in a Tatsumaki with a maximum (gust) wind speed of at least 100 m/sec or so. This value is comparatively lower than the value used in the design of nuclear power plant structures to withstand tornadoes in the United States (Doan[12]).

Small whirlwinds with about 10 m/sec of maximum rotating speed are also reported to develop even in typhoon conditions on the coast in the southern part of Japan, with relatively higher occurrence probability than that of Tatsumaki. Therefore to withstand them the design typhoon wind speed should be increased by 10 m/sec or so to allow for these phenomena. But more detailed studies are required to know the climatology of these small whirlwinds.

Strong winds caused by thunderstorms may occur any place in Japan. The probability of occurrence of winds of this kind at a given point may also be as small as that of Tatsumakis with the exception of areas of high thunderstorm occurrence. The characteristics of these plow winds are not well known, but the example shown in this paper shows a maximum peak wind speed of 50 or 60 m/sec. More detailed studies of the climatology of thunderstorms and the mechanism of high winds caused by down-drafts are necessary.

We must point out another type of wind disaster caused by severe local storms with extremely high wind speed. It is the damage caused by objects which are blown up and carried by high winds. The objects carried by winds have the same speed as the winds and much larger masses than the air itself, therefore their destructive force is extremely high in proportion to their density (e.g. by 10^3 times). They may be called storm-generated missiles. Even in the two cases shown in this paper, examples of storm-generated missiles are seen; one is a hotel roof of 6 tons in a thunderstorm, another is a motor car in a Tatsumaki. And the piece of wood thrust into the wall of a house (Photo. 8) in a Tatsumaki is the perfect image of a storm-induced missile. Therefore in the design of wind resistant structures, consideration of storm-induced missiles (size, shape and mass) should be taken into account. And continuous attention not to place any removable objects near important structures is necessary.

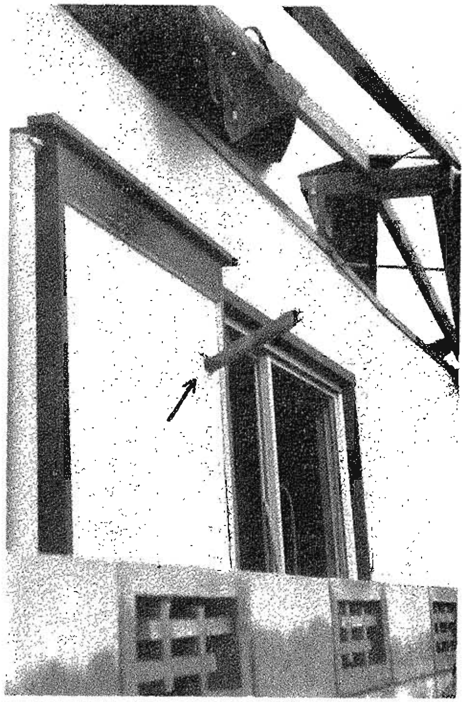

Photo. 8. Piece of wood thrust into a wall.

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