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## **BEHAVIOR OF WIND BLOWN CRIB FIRES**

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### **INTRODUCTION**

City fire has been one of the most significant disasters that Japan had to fought against throughout its industrialization. The two big earthquakes which attacked the greater Tokyo area during the Japanese modernization, Ansei Earthquake(1855) and Kanto Earthquake(1923) caused over 10,000 and 100,000 victims only by postearthquake fires. Even after the World War II, big city fires were rather frequent, say at least one time a year, until 1960's, most of which occurred by strong wind. Since late 1960's, big city fires became rare partly as the fire defense had been modernized. However, recent two big earthquakes in Japan, Hokkaido Southwest-off Earthquake in 1993 and Hyogo-Nambu Earthquake in 1995, revealed risk of city fires especially at the occasion of big earthquake.

Since establishment of BRI in 1946, considerable efforts have been made on the analysis of city fires and fire spread in urban district. Early works on city fires by BRI staff include characterization of fires of wooden structures from fire-spread point of view in 1940's(Fujita), probabilistic formulation of fire spread in urban fires in early 1950's(Yokoi), and modeling of meteorological aspect and fire plumes in city fires in 1950's(Yokoi and Sekine). Also a research project on the prevention and mitigation of city fires through city planning was organized at BRI in 1969~1972 while the late Prof.Kawagoe served BRI's Director General. This research project was combined with another governmental investigation project for the redevelopment of the Koto district, east of Sumida River, where city fires were the most significant at the occasion of Kanto Earthquake and the postwar reconstruction was done with weak wooden structures. A series of model fire tests were carried out at the Tokyo Bay landfill area in fiscal 1969~1972 as a part of these projects under the cooperation of BRI, Tokyo Fire Department, Tokyo Metropolitan Material Inspection Office, and Architectural Institute of Japan(AIJ). This report tries to summarize this experiment project and its outcome.

### **THE EXPERIMENTS**

Two different series of fire tests with wood cribs were carried out. One series were run in 1969~1971 with AIJ as the secretariat and the other were done in 1970 and 1971 with BRI as the secretariat. Although numbers of research organizations and individual experts joined the tests, the two test series will be referred to as the AIJ tests and BRI tests respectively only for simplicity. The two test series were coordinated with each other and some of the AIJ tests were even carried out at the same time with the BRI tests for efficiency, but the AIJ tests featured analysis of the effectiveness of a "fire wall" against the spread of fire in urban district, while the BRI tests dealt with more general aspects of fire behavior in urban area. Summary of the AIJ tests were reported by Sekine(1971) and the BRI tests were reported by Takahara and Sekine(1973) both in the Japanese language.

#### **AIJ Tests**

Numbers of tests were made in the winter of 1969 - 70, 1970 - 71, and 1971 - 72. Five out of the

tests in 1969 - 70 and 1970 - 71 were analyzed by Sekine(1971). A material prepared by Sekine at a seminar in 1983 and 1984 compares results from the 1971-72 winter tests with those from the former tests. A city block of wooden buildings were simulated with cribs of 7 layers of twelve 2 m long 4 cm x 4 cm wood sticks. Table 1 summarizes the test conditions, and Figure 1 demonstrates a typical layout of the fuel and the fire wall. Temperature field was monitored with thermocouples mounted on 6 m tall poles, and wind velocity was monitored basically windward to the fuel. All cribs were ignited simultaneously.

Table 1 AIJ Tests Conditions, Summary

Identification	Date	Number of cribs	Height of wall	Wind velocity(direction)
Test B	Dec 1969	36(9 x 4)	1.5 m(single)	U= 1.2 m/s(N)
D	Dec 1969	72(9 x 8)*	3.0 m(single)	4.7 m/s(N)
E	Jan 1970	54(9 x 6)	1.5 m(double)	2.1 m/s(N)
H	Jan 1971	36(9 x 4)	1.5 m(double)	5.0 m/s(N)
I	Jan 1971	36(9 x 4)	none	4.0 m/s(N)
M	Feb 1972	15(5 x 3)	1.5 m(double)	3.5 m/s(N)
N	Feb 1972	15(5 x 3)	1.5 m(single)	3.5 m/s(N)

\* 14 layers of sticks were used while 7 layers were used in other tests.

### BRI Tests

The test project started with smaller models in FY 1970 and then was extended to a larger test in FY 1971.

At the FY1970 tests, two different scale models for city fire experiments were built with wood cribs, and temperature field in the wind direction was monitored with thermocouples mounted on 6 m tall poles (Figure 2 (a) and (b)). The larger model(model-A) consisted of 20 cribs of 14 layers of twelve 2 m long 4 cm x 4 cm wood sticks. The most leeward row of the cribs was located 0.30 m away from the other cribs to study the fire spread across a vacant space such as a street. The smaller model(model-B) consisted of 20 cribs of 7 layers of six 1 m long 4 cm x 4 cm wood sticks. The most leeward row of the cribs was located 0.15 m away from the other cribs. Wind direction and velocity were measured windward to the fuel. At the two tests, ignition was made on the most windward row of the cribs.

At the FY1971 tests, 32 cribs of 7 layers of 2 m long 4 cm x 4 cm wood sticks were arranged with interval of 0.50 m to make a 20 m x 10m total burning area(Figure 3). Measurements were made on temperature with thermocouples mounted on 6 m tall steel poles and wind direction and velocity windward and leeward to the fuel. Although it had been planned that only the most windward row of the cribs, the two windward rows were ignited by accident. Also weather was somewhat unstable because of the low pressure passing near the Tokyo Bay on that day.

### SUMMARY OF TEST RESULTS AND DISCUSSIONS

Figure 4 summarizes temperature field measured at several of the AIJ tests. The inclined straight line in each drawing demonstrates the trajectory axis of the plume estimated from the maximum temperature at each distance. Interestingly, the trajectory axis is practically straight, and is found not to be very dependent on test conditions including wind velocity. The height for the maximum temperature rise at each distance  $x$ ,  $z_m$ , has been summarized as a function of  $x$  as shown in Figure 5. The angle of the trajectory axis,  $\phi$ , was between  $30^\circ$  and  $35^\circ$  and  $\tan \phi$  was approximately 0.6

$\sim 0.7$  independent of the size and wind velocity. This tendency has also been confirmed by the BRI tests. However, the plume stops to rise or even starts to decline in the far field, say for  $x/H \geq 30$  in the AIJ tests where  $H$  is the height of the fuel. At the BRI tests, the plume started to decline even earlier, at around  $x/H=20$ . Further analysis has been made using another parameter,  $(x/L_x)(R/U)$ , where  $L_x$  is the horizontal length of fuel in the wind direction and  $R$  is the mass consumption rate of fuel per unit area.  $z_m/L_z$  where  $L_z$  is the fuel height has been correlated against  $(x/L_x)(R/U)$  as seen in Figure 6.  $R$  was estimated from the weight of the cribs measured before each test and the time from ignition to the autonomous extinction.  $z_m/L_z$  is nearly proportional to  $(x/L_x)(R/U)$ , which suggests the following relation for the trajectory axis angle.

$$z_m/x \propto (L_z/L_x)(R/U) \quad (1)$$

Temperature along the trajectory axis,  $\theta_{\max}$ , was found to be nearly inversely proportional to the distance measured along the trajectory,  $x_t$ , divided by wind velocity as summarized in Figure 7, and can be approximated by

$$\theta_{\max}/L_x \propto (x_t/U)^{-1} \quad (2)$$

#### ACKNOWLEDGMENT BY THE EDITORS OF THIS REPORT

This report in English is summarized by Y.Hasemi and Y.Hayashi for the Kawagoe Memorial Symposium held at the 13th Joint Panel Meeting of UJNR, 1996, from previous publications and unpublished notes of Prof.Sekine. The experimental description and its analysis is essentially a contribution by Prof.Sekine, and the report does not include any personal opinions nor analysis by the editors. The drawings in this report were taken from his publication and his unpublished notes. Prof.Sekine worked at Building Research Institute from 1946 to 1979, and was one of the closest colleague to the late Prof.Kawagoe. Prof.Sekine is known also as the author of the first paper deriving the ventilation factor,  $AH^{1/2}$  as the dominant parameter for postflashover fires in 1959.

The results of the research projects introduced in this report were applied to the design of the Shirahige Disaster Mitigation Position in the Koto district of Tokyo in 1970's, which consists of a large refuge on Sumida River and wall-like high rise apartment buildings between the refuge and urban blocks.

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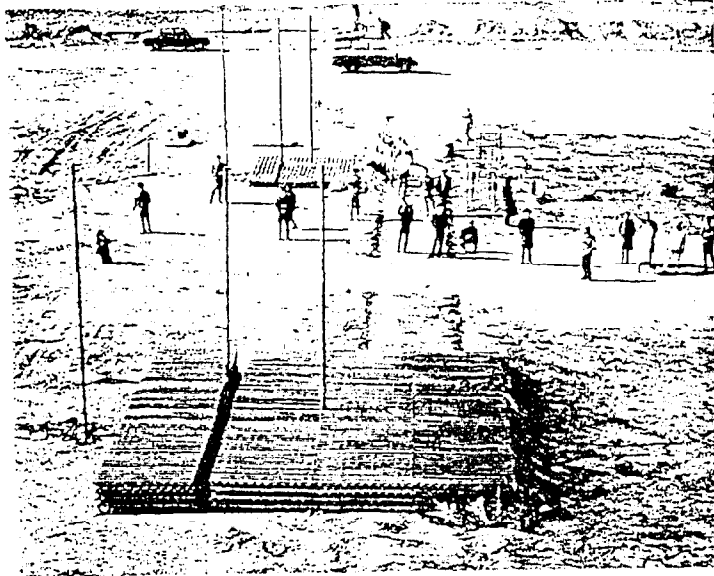


Photo 1 BRI FY 1970 Test-A Arrangement (before ignition)  
 The small cribs behind the Test-A cribs are for Test-B.

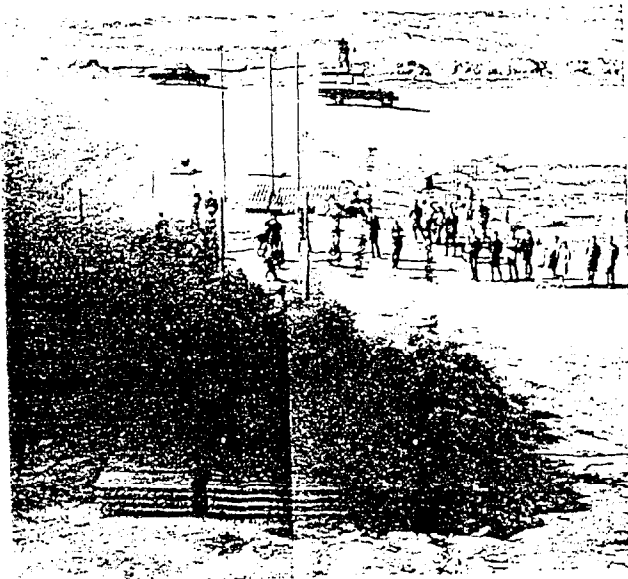


Photo 2 BRI FY 1970 Test-A (just after ignition)

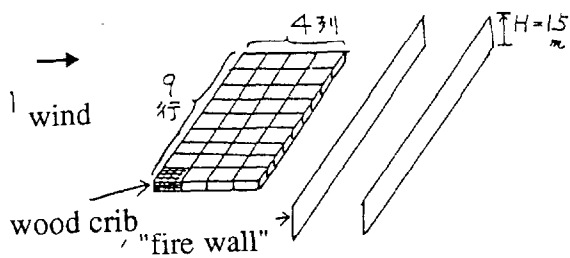


Figure 1 Layout of Wood Cribs and "Fire Walls", AIJ Tests

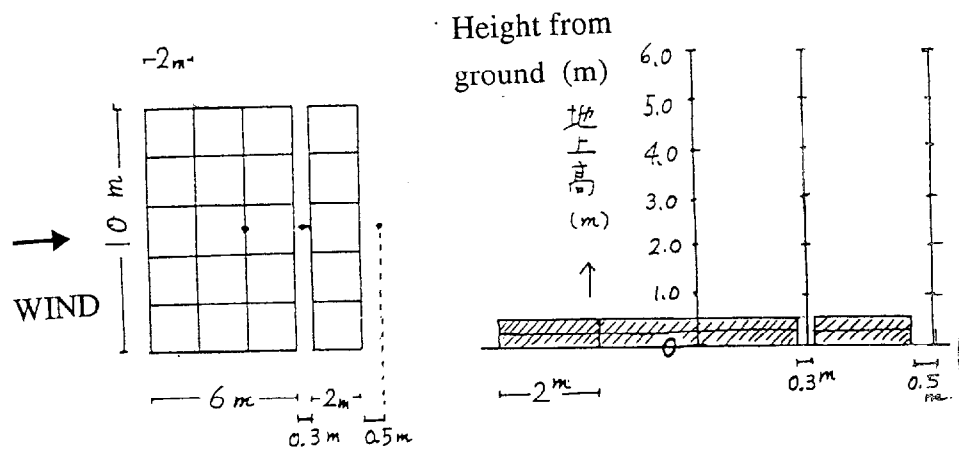


Figure 2 (a) Layout of Wood Cribs and Instrumentation, BRI FY 1970 Test A

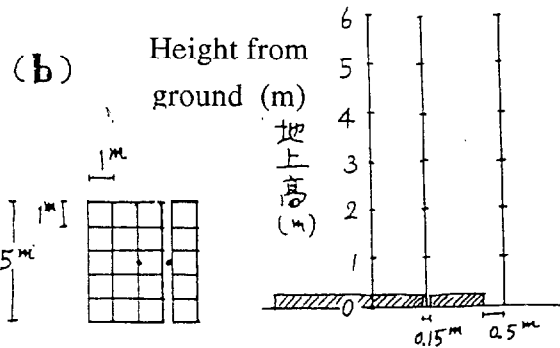


Figure 2 (b) Layout of Wood Cribs and Instrumentation, BRI FY 1970 Test B

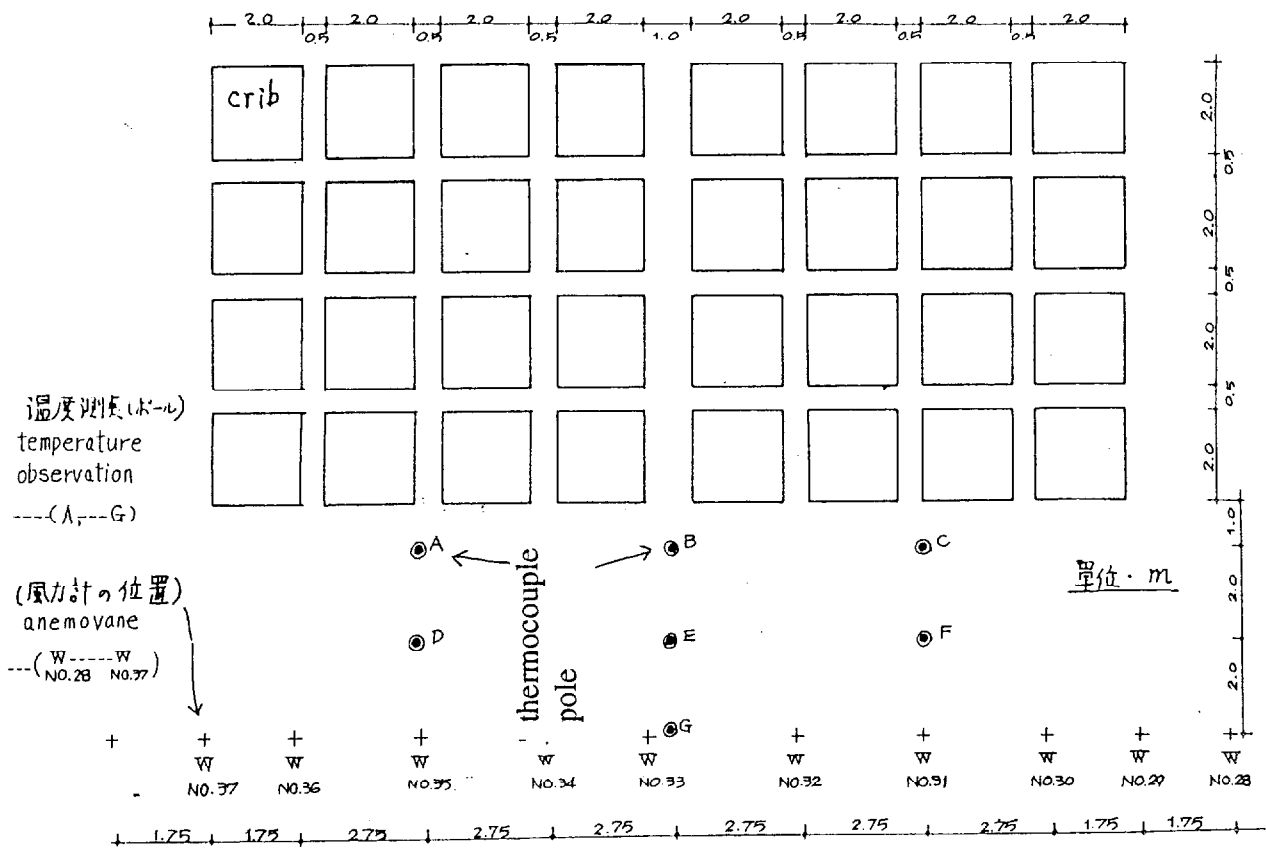


Figure 3 Layout of Wood Cribs and Instrumentation, BRI FY 1971 Test

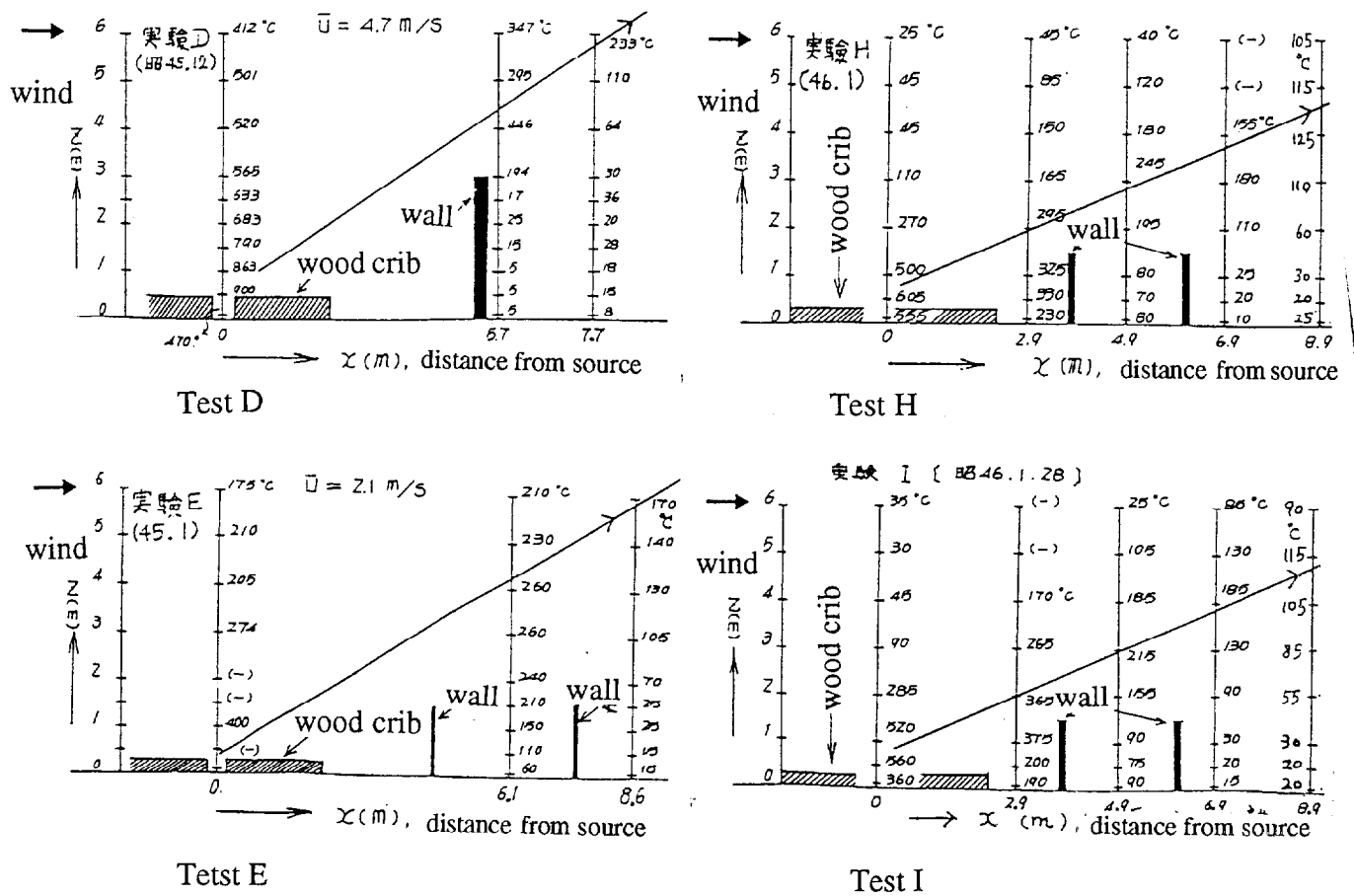


Figure 4 Temperature Field in AIJ Tests, average for 3~5 minutes after ignition

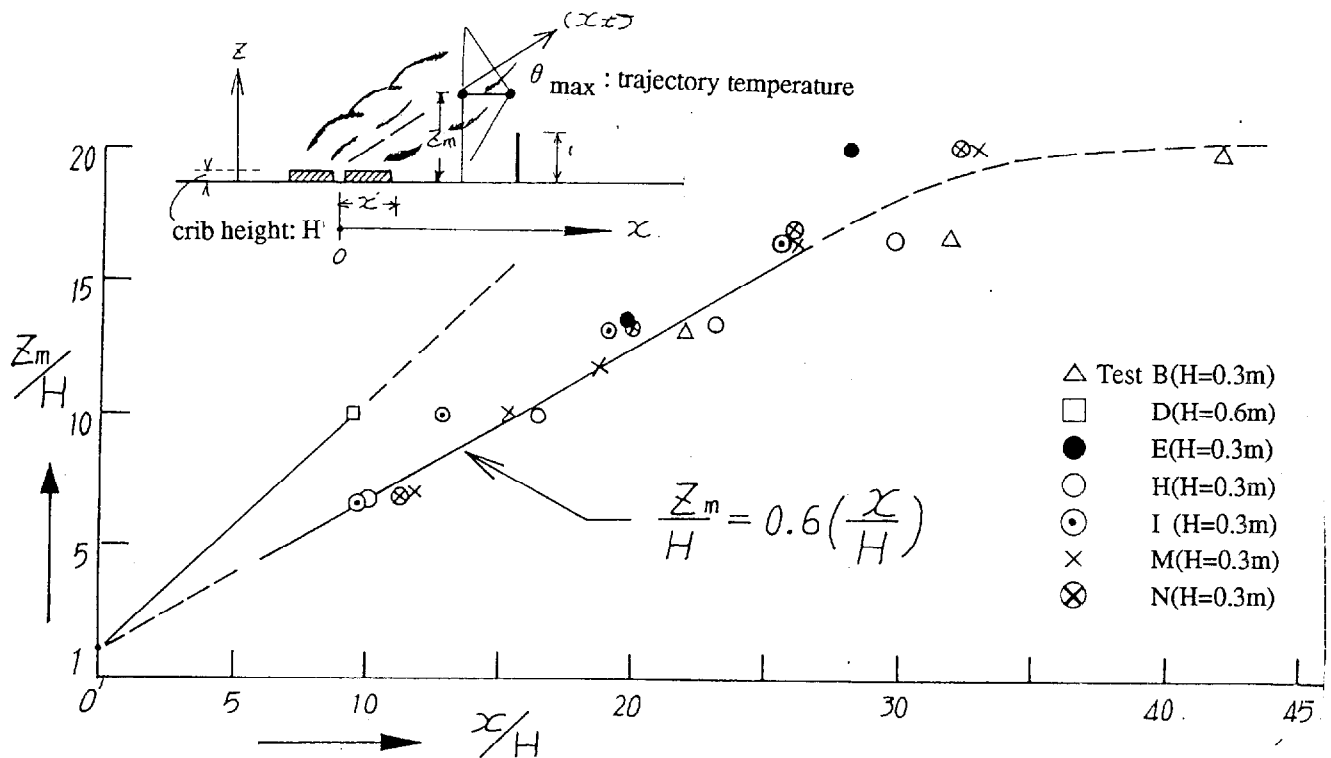


Figure 5 Trajectory Axis, AIJ Tests

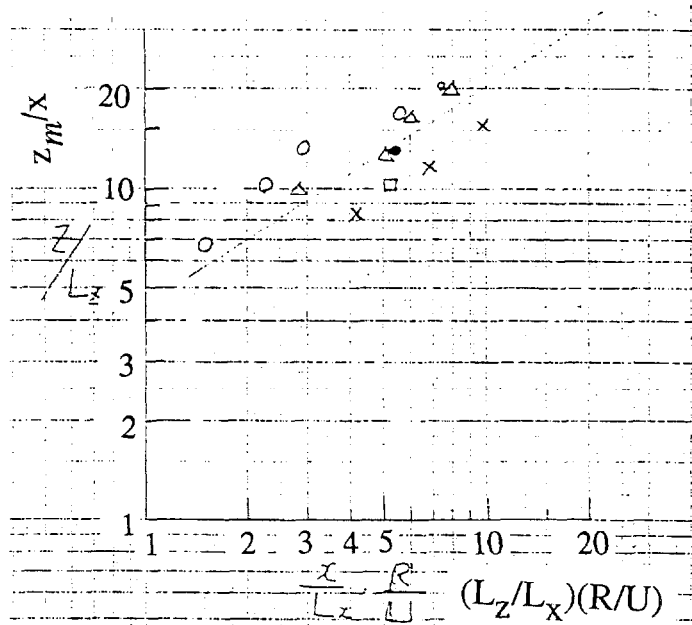


Figure 6  $z_m/L_z$  vs.  $(x/L_x)(R/U)$

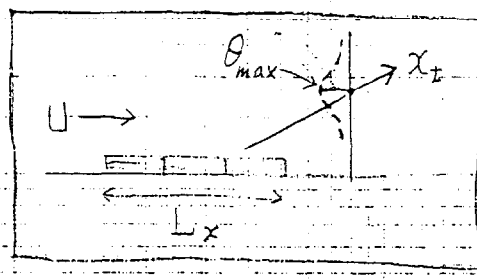
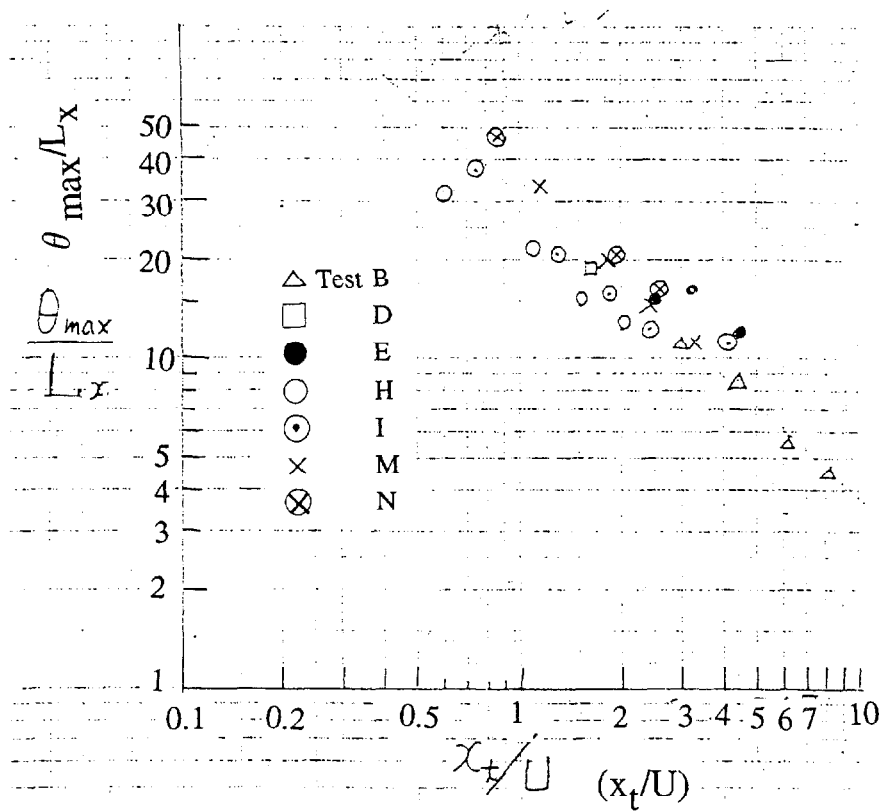


Figure 7 Relation between Temperature on the Trajectory and Distance along the Trajectory



## ***Discussion***

Robert Levine: Do I understand correctly that the long building that was shown in the first slide was actually designed as a fire break? Has that been done frequently in Japan? How many times?

Takashi Sekine: That is the only case.

Charles Scawthorn: Thank you very much for the talk. I should just mention that long building has many fire defense features, water curtains, and doors that come down and other features like that. The one question I have is that while that provides an excellent fire break and a barrier for high temperatures and so on, what about defects of branding? I think in the conflagration of 1923, brands were found many miles away. I was just curious about the potential or the effects of burning flaming fire debris being carried over that wall, perhaps two or three kilometers downwind or something like that.

Takashi Sekine: That fire break was built next to a very densely inhabited area. It is my personal opinion, not the opinion of a scientist, there is still some risk that the fire brands would fly over the building. But behind the building there is only open space, so unless people bring many things to the place, there is not a very big risk that any big fire would take place in that open space.

Charles Scawthorn: So the real purpose of it is not so much as a fire stop as a protective area?

Takashi Sekine: Yes.

Ai Sekizawa: This idea of creating a fire break is wonderful. However, it is very costly. This type of thing was built in 1970; since then, nothing similar has been built because it costs too much. So these days, they are establishing fire breaks along the main roads by using fire resistive materials. If I may make one comment, I have been involved in research on the flow field around buildings, and if there are many tall buildings, then air flow around those buildings would change because of those buildings. Depending on the air flow, the flight of the brand would also vary. So research on branding, I think, is a very important research subject to be addressed in the future.