Real Fire and Fire Modeling

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ABSTRACT

The system fire research in Japan was started after World War II. One of the main objectives was the diagnosis of the strength remaining in buildings burnt out during the as against a future earthquake. The fire behavior in compartments and the structural behavior of building in the fully developed stage were studied by carrying out full scale fire tests in compartments during the 1950s. Later the objectives became the study of the flashover in a room and the smoke movement inside a building. Actual buildings scheduled for demolition were used for investigation of many items during the 1960s and 1970s. In the first half of this period the main purpose was the observation of real fire behavior. In the later half, a comparison between the test and the simulated results became the main objectives. It can be said that research on building fire in Japan has advanced through such full scale fire tests.

Key Words : Real Fire Test, Simulation, Burning Rate, Smoke Behavior Structural Behavior, Modeling and Design

1.INTRODUCTION

In the last fiscal year, full scale gasoline pool fire inside a compartment were performed on the campus of the Science University of Tokyo. The compartment was fully open in the front, which was 15m wide 5m long. The depth of the compartment was 24m. In some the 20 tests, a surprising phenomenon could be seen. Soon after the ignition of gasoline in a $10m^2$ or $15m^2$ pool near the opening, the gasoline vapor flows out from the compartment close to the floor surface and a big fire whirl appeared outside of compartment just as if there was another gasoline pool at the bottom of the fire whirl. These fire whirl could be seen only when the compartment was receiving the weak wind from behind. The Karman vortex in the front of opening might exist, but nobody could expect the appearance of such a fire whirl. The test results of this project are reported by Dr. T. Mizuno and Dr. O. Sugawa in the 5(B) session in this symposium.[1]

It can be said that the research on building fires in Japan has always advanced through such full scale fire tests.

Just as in Europe and U.S.A, serious research on the building fire was started just after World War II. The purpose of its starting was to assist the diagnosis of the remaining strength of burnt out buildings against a future earthquake. Many cities had received heavy air raid by the American air force during the War and as a results conflagrations they became burnt out fields in which multi-story buildings remained only here and there. Compared with European or most U.S. building, the structure in Japan which was mainly made of reinforced concrete was designed to resist the strong earthquake. Consequently, structural members had a large section to fire and the building did not collapse even after severe exposure to fire. Then after the War people begun to re-use them, after reparations only of windows, doors, electricity and internal lining, because the original shape was preserved having a little deformation. However some researchers were very afraid of the possible reduction of earthquake resisting capacity against a future earthquake. The diagnosis for the remaining strength of building structure and development of reinforcement design became important research items in the Building Research Institute (B.R.I.).

At the beginning, the temperature history of the fire to which the building was exposed received was assessed. We could guess qualitatively that where the window area was large, the gas temperature inside building might be high and the fire duration might be short. Where the window area was small, the gas temperature might be low and the duration might be long. However, we had no tool to estimate the fire duration quantitatively even if the amount of combustible could be estimated quantitatively.

Concerning the structural performance, we had no fire test furnaces for beams or columns, and little test data was available to estimate the remaining strength of structural members.

The methods we could use for the diagnosis were as follows [2,3],

i) From the melted metals collected inside building the maximum temperature was estimated.

ii) Cement powder, collected at points 1 - 10 cm depth from the surface by chiselling, was heated in an electric furnace to measure the combined water content remained. From this the temperatures received at those points were estimated.

iii) Using a wood rod, a jack and a load meter inserted between girders, load was applied to girders so that the maximum deflections and residual were measured to estimate the strength of the girder.

iv) The frequency of the natural vibration of a building was measured by a seismograph put on the roof, so that the rigidity of total structure could be estimated.

Looking through these results with the engineering eyes, the remaining earthquake resisting capacity of the total structure was roughly estimated and a reinforcement method to increase the rigidity of total structure depending on the degree of fire damage was proposed .

Parallel with the work of diagnosis, the fire research was started to assist diagnosis by making it more scientific and quantitative.

2.FIRE TEST IN FULL SCALE COMPARTMENTS

The model test results and the ventilation theorem suggested us that the compartment fire must be controlled by the ventilation [4], but as the scale effect was not clear, it was necessary to perform full scale compartment fire tests, not only to know the fire behavior in the compartment but also to know the structural one. After the War a lot of fire resisting construction such as the concrete block one for dwellings were developed in various places. For the reconstruction of burnt out cities it was desirable to replace the traditional wooden house with them. To confirm the earthquake resisting capacity of them, one or two story full scale test structures having 9 - 25 m^2 floor area were built one after another on the B.R.I campus. After the completion of structural tests, these structures were used for compartment fire tests. It was fortunate for us to be able to make more than 20 full scale tests including a ship cabin during 1950's decade.

The rate of burning

Through these experiments, we could find the following facts: the gas temperature was not so different between the upper part and lower parts of a compartment. The profile of pressure difference between inside and outside of compartment wall showed a straight line with an inclination that was dependent on the gas temperature. The neutral plane appeared at about 2/5 of the opening height from the bottom of opening, O_2 was almost consumed by combustion inside the compartment, the rate of burning was almost constant depending on the opening area. It was independent of the gas temperature and the heat transfer coefficient was very high compared with that in the fire test furnace, during the fully developed stage. The estimation model for the rate of burning under the ventilation control region was then developed by T. Sekine and K. Kawagoe [5,6]. In parallel with our study, P.H.Thomas also found out the same relation on the rate of burning from the model test results performed in the new model laboratory in the Fire Research Station[6]. To obtain the more knowledge about the effect of ventilation, CIB-W14 organized a big international cooperative project on the model compartment fire, to which 8 laboratories in 7 countries contributed from 1958 to 1962 [8]. Then the classical relationship of

$$R=(5.5 - 6.0)A\sqrt{H} \text{ (Kg/min)}$$

became widely recognized and a lot of new knowledge was obtained internationally.

The temperature field of projection flame from opening

S. Yokoi who had been studying on the theory of hot plume from point and line heat sources, measured the temperature field of the flame involving from the opening in some of full scale fire tests, and applied his theory to it. From wide windows, the flame rose closer to the wall and further than from narrow windows. At that a model of the trajectory of the emitted flame and its maximum temperature was proposed by him to estimate the necessary spandrel height to prevent spreading of fire from power to upper windows [9].

Time temperature curve

T. Sekine who was not satisfied with only to development of the estimation fire duration through full scale tests, considered the heat balance inside the compartment, so that the time temperature curve could be estimated step by step by hand calculation [6]. This model was verified by full scale test results as shown in Figure 1. In a compartment having small openings lined internally with non combustible mineral wool board, extreme high gas temperatures were observed compared with those in the same compartment lined with combustible plywood board. The heat conductivity of the enclosure and the opening factor $A\sqrt{H}/A_t$ were important factors determining the gas temperature. Then the primitive model was proposed by us [10]. Now more accurate models have been developed in many places.

Structural behavior

In each test the expansion and deflection of the compartment structure and in some tests the vibration of the structure before and after the fire were measured [11].

For the concrete block structures of Japan, it was necessary to insert the reinforcing bar and to pour in situ concrete inside the hole of joints and to cast the reinforced concrete beam on the top of concrete block wall together with the reinforced concrete floor. The difference of expansion between the concrete block wall and reinforced concrete beam caused breakage of, the concrete block wall creating big cracks at the upper part of the corner which behavior could not be seen in the usual wall furnace tests as shown in Figure 2. From the vibration tests the considerable reduction of rigidity of the total structure after the fire could be seen.

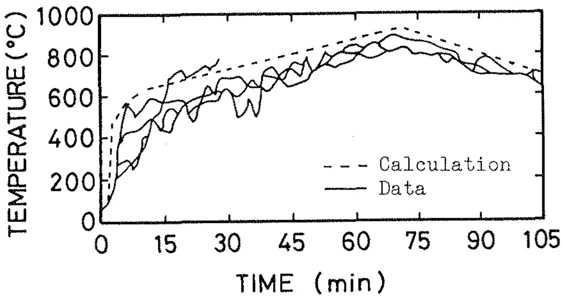

Figure 1

Estimation of time temperature curve.

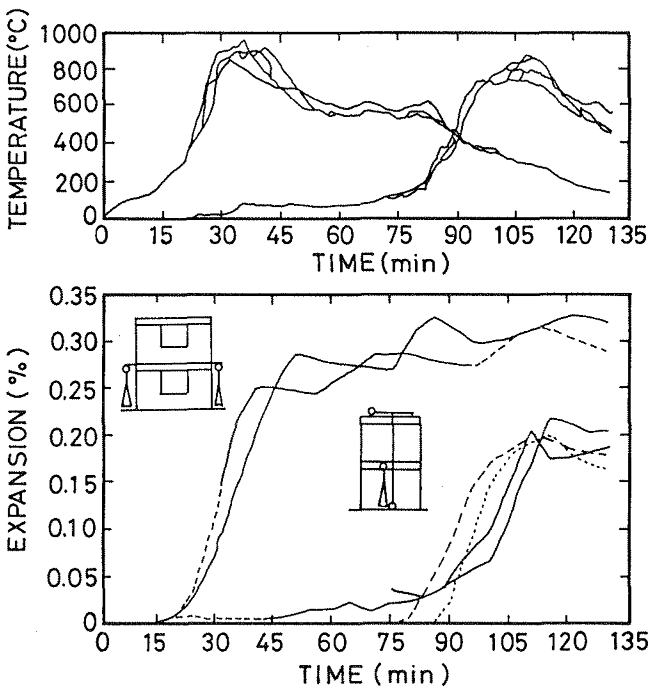

Figure 2

Expansion of Building.

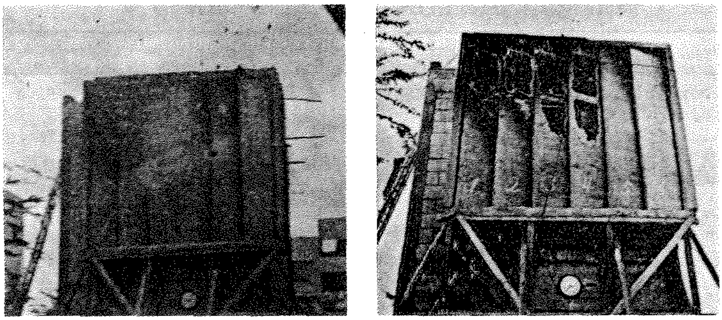

Figure 3 Explosive Spalling.

Unexpected phenomenon

Through these full scale fire tests we could obtain a lot of knowledge unexpected before the test such as the explosive spoiling of thin concrete panel (Figure 4) or the melting down of the wired glass window caused by the heat transfer coefficient being higher than that in the testing furnace.

The traditional attitude

Thus it has become the traditional attitude in Japan that the full scale fire test should be done first to observe the real behavior carefully. This is accompanied by the development of its modeling, if some unknown problem was brought to light.

3.FIRE TESTS IN ACTUAL BUILDING

In late of 1950s the most important problem to be studied was the explosive flashover in a room lined internally with combustible boards and the rapid smoke fill inside a building after flashover in the room. There were very dangerous for human life when its door was opened. It was a completely new subject to study such problems. Instead of carrying out a lot of small scale laboratory tests on materials, on model compartments and on small model buildings, full scale tests using the actual building were required to know the real behavior of flashover and smoke movement. Then in 1960s' and 1970s, a lot of fire tests using actual buildings scheduled for demolition or in some cases using new ones, were performed as shown in Table 1. Full scale compartment fire tests were also continued.

Items on which knowledge was gathered in the building fire tests were the flashover phenomenon in the rooms with or without combustible internal lining, the detection of fire, the fire spread along the combustible ceiling in the office room, the smoke density, the smoke spread inside building, gas composition of smoke, the behavior of animals inside smoke, the effect of smoke control measure and the structural behavior under fire.

Flame spread along the combustible ceiling and flashover

The flame spread tests along the combustible ceiling in a office room of 7m width, 20m long was carried out in one of the tests in Mitsubishi Naka 15 Building [12]. The ceiling was the perforated wood fiber board which had been classified with a flame spread index of about 90, tested by the tunnel furnace in The South West Research Institute in

Table 1 Field Fire Tests in Real Building

Building		Testing Bodies	Fire room	Principal objects of experiment
1956	Shibuya Yamaichi Co. Building (Shibuya Tokyo) 130 m^2 3 story	B.R.I. & Tokyo Fire Brigade	1st(ground) floor 105 m^2	1. Fire growth in an offive room. 2. Structural behavior during the fire. 3. Remaining structural strength after fire.
1961	Mitsubishi Naka 15 Building (Marunouchi Tokyo) 1350 m^2 4 story	Tokyo Fire Brigade B.R.I. and F.R.I.	basement floor 52 m^2 2nd floor office rooms 133 m^2 244 m^2	1. Fire Spread & Flashover in two office rooms where opening are large and are covered with combustible and non-combustible lining. 2. Smoke move,ent through an open stair.
1962	Apartment Building (Akabane Tokyo) 420 m^2 5 story	JAFSE B.R.I. & Tokyo Fire Brigade	2nd floor one dwelling 35.1 m^2	1. Fire growth in a dwelling 2. Structural behavior during the fire. 3. Remaining structural new strength after fire
1964	Daiun Building (Yokohama 212 m^2 4 story	B.R.I. & Kajima Construction Co. Ltd.	2nd floor office room 150 m^2 3rd floor dwellings 32 m^2 and 38 m^2 4th floor dwellings 40 m^2 & 32 m^2	1. Effectiveness of a smoke tower. 2. Fire growth in rooms finished in different linings. 3. Fire growth in an office room of which opening is very small and ceiling is covered with combustible lining.
1966	Osaka Central Telephone Office (Osaka) 1600 m^2 6 story	Association of Building Contracters Universities of KAnsai area and B.R.I.	1st floor 51 m^2 (8 tests)	1. Fffectiveness of a smoke tower changing position (height) and area of opening for smoke outlet and inlet and opening condition of lobby's door.
1966	Tokyo Kaijo Building (Marunouchi Tokyo) 2370 m^2 7 story	Tokyo Fire Brigade and B.R.I. and F.R.I.	2nd floor 3 romms 24 m^2 4th floor 24 m^2 4th floor 270 m^2	1. Smoke movement along a long corridoe (100 m). 2. Smoke fills in a big room. 3. Smoke spread to upper floor through an open stair. 4. Effectiveness of pressu- rization in a corridor. 5. Effectiveness of a smoke tower.
1968	Central Hospital of Japan Nat'l Railway (Shinjuku Tokyo) 650 m^2 4 story	B.R.I. J.N.R. and Taisei Construction Co., Ltd.	2nd floor 4 rooms 25 m^2 14 m^2 3rd floor 242 m^2	1. Rate of smoke generation from fire rooms lined with various internal linings. 2. Smoke spread to upper floor through an open stair and through barriers of rolling shutters in 3rd and 4th floor.

				3. Structural behavior during the fire. 4. Remaining structural strength after fire.
1968	Relay Station of Japan Telephone Co. (Honda Tokyo) 500 m^2 1 story	B.R.I. & J.T.T.	1st floor 2 rooms 48 m^2	1. Effectiveness of rolling shutters for smoke barrier and fire barrier. 2. Smoke fill in adjacent room.
1970	New Car Park Building (Bare steel frame) 84 m^2 1 story	New Nippon Steel Co., Ltd.	1st floor 84 m^2	1. Behavior of car fires. 2. Stuructural behavior of bare steel frame.
1972	Aprtment Building (Chishima Osaka) new 3832 m^2 11 story	B.R.I. and J.H.C.	2nd floor one dwelling 45 m^2	1. Effectiveness of smoke barrier doors in a corridor. 2. Effectiveness of pressurization in a staircase to be kept free from smoke. 3. Effectiveness of smoke extraction from fire room.
1973	Test House Japan Housing Corporation testing Center (Hachioji Tokyo) new, 45 m^2 dwelling with a long corridor	B.R.I. and J.H.C.	1st floor one dwelling 45 m^2	1. Fire growth in a dwelling 2. Smoke movement along a long corridor
1973	U.S.Army Hospital (Oji Tokyo) 2625 m^2 2 story	JAFSE	1st floor 530 m^2 34 m^2	1. Smoke fill in a large room under the smoke extraction 2. Effectiveness of the smoke extraction system. 3. Compartmentation of a large room.
1973	Office Building, Ministry of Health and Welfare (Kasumigaseki Tokyo) 512 m^2 5 story	B.R.I. and F.R.I.	2nd floor 227 m^2	1. Smoke movement in the buildings. 2. Pressurization in a stair 3. Comparison between calculated and measured value
1974	Mitsubishi Bank Building (Kanasugi Tokyo) 470 m^2 2 story	Tokyo Fire Brigade	1st floor 290 m^2	1. Smoke fill in a room of high ceiling height, changing the opening area.
1975	Fukoku Seimei Building (Hibiya Tokyo) 1003 m^2 8 story	Tokyo Fire Brigade	2nd floor 32 m^2, 42 m^2 270 m^2 3rd floor 42 m^2	1. Smoke movement inside building under several boundary conditions. 2. Effectiveness of pressurization.

U.S.A.. Waste lumber of 3 tons was scattered about 40m high and at the end of room near the fire origin the waste lumber was placed along the wall. All outside windows in the long side were opened. Their total area was 21.6 m^2. The flame spread very rapidly across the ceiling. It took only 70 seconds to spread 18m. Then the explosive flashover inside the whole room followed. The flame emitted through the windows reached the top of windows in 2 upper floors, and broke the window pane through which the fire spread to the upper floor. Unexpected sudden high radiation intensity from flame outside and the rapid smoke fill inside the building caused much difficulty in making observations and measurements. We had thought illusion before the test that the ceiling material might have its own flame spread rate as shown by the result of tunnel test, but we noticed that it was the violent upward current of plume and the adequate air that supported such rapid flame spread.

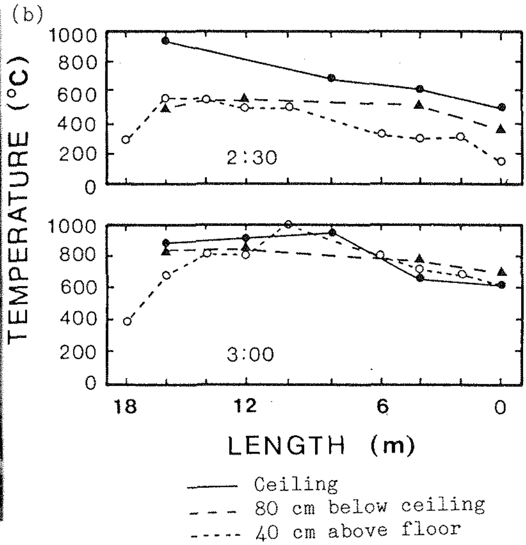

Figure 4-a Flashover in a Big room.

Figure 4-b Horizontal distribution of temperature in the first test room.

A flame spread test along a similar ceiling was also performed in one of tests in Daiun Building. The room was 7.5m width, 21m long similar to the former test room. In this case only 3 windows with an opening area of 5.7 m^2 at the front of room were opened. The waste lumber of 500 Kg was scattered, and a wood crib piled up to 9 layers of 17 pieces of 2x2x100 cm near the end of room was used for fire source. The ceiling was ignited by the crib fire but the flame did not spread, and after a while it went out. As the crib fire and the lumber fire around the crib became weak, after 25 minutes the fire was set again in the waste lumber at the middle of room and at 30 minutes the ceiling caught fire which spread very slowly. When the ceiling flame spread to near the windows, the fire became active. At last, after 51 minutes flame emerged from windows.

The distinct difference between these two tests showed us that the fire spread was depended on the intensity of fire source and the opening area. In fact, $A\sqrt{H}/A_t$ is the former case was 0.078 $m^{1/2}$ and in the later case 0.016 $m^{1/2}$.

The smoke filling of a corridor

Smoke spread tests along a corridor and to upper floor through open or closed stair were made in many buildings. In one of the tests in The Central Hospital Building of Japan National Railway, a room of fire origin having an open door of 1.7m width, 1.9m height was 5.5m width, 4.5m long lined with the plywood board without any furnishing [14]. The fire was set in a crib of 31 layers of 12 pieces of 2x2x60cm located at one corner. The smoke emitted through the door spread along the non combustible ceiling of the corridor of about 35m length consisting of two zones in the beginning. After 5 minutes the smoke layer gradually went down about 1.3m to from the floor. Suddenly black smoke filled the corridor up to the floor level caused by the rapid expansion of air in the room heated by the steep temperature rise just after the violent flashover. We were astonished that observers inside corridor who were escaping under the smoke layer bending forward their body, suddenly disappeared inside black smoke. After a while the two layer zone was gradually formed again, and remained in the steady state. In many cases, in the corridor two layer zone was kept the test, but the same immediate smoke filling inside a whole corridor section just after violent flashover could also be seen in the tests in Daiun Building [13], in Tokyo Kaijo Kasai Building [15] and some other buildings.

The smoke movement to the upper floors

The test of smoke movement to upper floors through an open stair or an open stair closed by rolling shutter in the upper floors were made in many buildings. In 5 tests performed in the Center Hospital Building, corridors in the 3rd and 4th floor were filled with smoke through the open corridor, one minute after the smoke filled the corridor of the 2nd floor. Where the rolling shutters were used in the 3rd and 4th floors, the smoke entered through the lower part of shutter and at about 10 minutes an observer on the 3rd floor could not

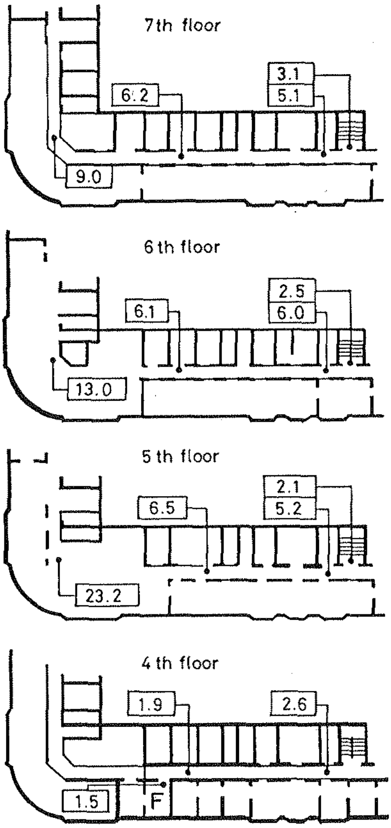

Figure 5 Smoke spread to upper floors. "F" is fire room. Number shows the time(min). when smoke(Cs=0.1/m) reached each place.

stay there because of the black smoke [13]. In one of the tests in the Tokyo Kaijo Kasai Building the black smoke reached the open stair 32m apart from the fire room in 2 minutes and reached the middle of the corridors in the upper 3 floors in 5 minutes as shown in Figure 5.[15]

The smoke density and toxicity

The measurement of smoke density by F. Saito in corridors just after flashover in many building tests indicated very high values of 20 - 30 1/m of extinction coefficient [14,16]. As the allowable smoke density for escape is only 0.1 - 0.2 1/m proposed as by T. Jin [17], these test results clearly indicated to us the importance for very high accuracy of smoke control measures. Many mice inside round cages were used to survey the toxicity inside smoke together with gas analysis of CO, CO_2 and O_2.

Smoke tower tests

The first smoke control measure for a high-rise building, a smoke extract tower was studied in a series of tests in the Osaka Central Telephone Office Building [18]. An elevator shaft was modified into a smoke tower in which a roof ventilator and fans were placed at the top. The smoke was produced in a room next to the elevator lobby. Tests were made with various boundary conditions. The importance of air supply was recognized. As a result of these tests T. Maeda developed the calculation model for the smoke tower [18].

Similar smoke tower tests were made in Daiun Building [13], Tokyo Kaijo Building [15] and other Building. The effectiveness of smoke towers became widely recognized.

The test on smoke barrier doors inside a corridor

A test on smoke barrier doors inside a corridor was made in a new Chishima Apartment Building having a central corridor [16]. The fire room was protected by incombustible insulation board to protect the new structure. When a corridor was open and the entrance door of an apartment was closed, a lot of smoke leaked into the corridor through the door gap. When 3 barrier doors were closed a little smoke leaked into the corridor because of the multi resistance for air movement although the temporary doors had a considerable gap around the edges. Thus we confirmed the effectiveness of confirmed multiple smoke barrier doors inside a corridor to maintain compartmentation.

The test on the pressurization

In one of the tests in Kaijo Building, we studied the effectiveness of pressurization inside the corridor [15]. A big scale pressurization test was made in a Office Building of Ministry of Agriculture, Forestry and Fisheries [19]. The room of 8.4m width 26.8m long having 3 windows of 1.06x2.39m and 3 doors of 0.79x2.5m in 2nd floor was used for the fire room. The fire load was 4 tons, half of wood and half of plastic textile. A big room of about 500 m^2 in 5th floor was connected to the fire room through a corridor and a stair. A big fan with a capacity was 1000 m^3/min was set in the stair of first floor. In 30 minutes, the first half of the test, the smoke movement to the 5th floor room was investigated and in the latter half the effect of pressurization was examined, T. Wakamatsu who had developed the model of smoke movement model inside a building [20] was satisfied that the calculation results of smoke filling in the 5th floor room agreed satisfactory with the test results as shown in Figure --. After 30 minutes the fan was operated at its full capacity of 1000 m^3/min. As the fire room was suddenly fed by excess air, the maximum temperature increased 1300 °C and flame together with black smoke spouted out horizontally from windows like jets. Inside the building heavy smoke was soon ejected out from the stair up for one and half minutes. Then gradually the air flow was reduced to 300 m^3/min so that to find the critical value at which the smoke will not come beyond the swing door inside the open corridor of 0.76m width 1.9m high.

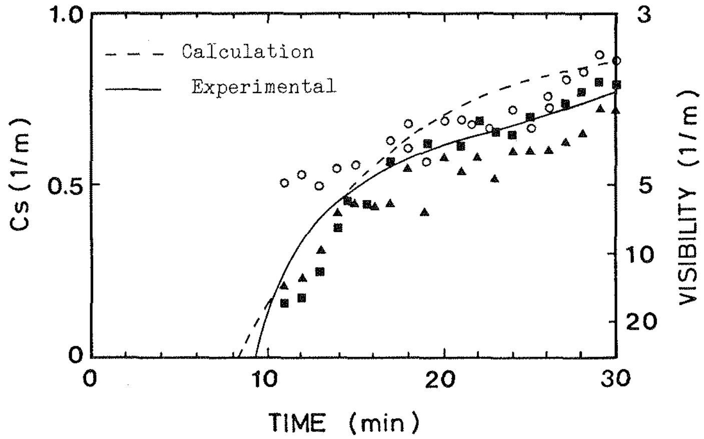

Figure 6 Smoke filling in the room of 5th floor.

The test was successful. The people who watched the smoke inside the building were satisfied by the quick ejection of smoke by the operation of the fan. But the people who watched the test from outside of the building were astonished by the long horizontal flame jet with heavy black smoke suddenly emitted from the windows. As the air supply was gradually reduced to the critical value the flame length became short, but the long flame jet gave them the impression that the pressurization method seemed too dangerous. At present some fire experts still do not like to use the pressurization system. The first impression is very important. We have shown that we should operate the fan on the weakest power and then increase the power to find out a critical value.

<u>Structural behavior</u>

One of tests in the Central Hospital Building was a big room fire to examine the behavior of reinforced concrete structure conducted by H. Saito [14]. The fire room in the third floor was 11m width 22m long in which of 12 tons (50kg/m^2) wood was scattered. The fire temperature curve corresponded with about 1.5 hours of the standard one. The horizontal expansion of the upper floor structure was rather rapid corresponding to the gas temperature rise of fire room. Just after the gas temperature reached its maximum, the expansion of the structure also reached its maximum, after which it decreased slowly to almost zero after one day. The maximum expansion ratio was 3 - 5x10^{-3} which correspond with that of concrete at 300 - 500 °C. The expansion curve and the maximum expansion ratio suggested us that the expansion of floor structure was dominated by the temperature rise in the lower part of the floor slab which broke through the restraint of girders.

The maximum displacement of top the of a column in the width direction was more than 23 mm and its ratio to column height was 1/150, which was beyond the allowable one for earthquake resisting design. The displacement of the end column in the length direction was 66mm at which the glass panes of the window in the staircase wall attached to the fire room broke down, due to the deformation of its wall.

The behavior of floor slabs was interesting. The floor slabs of some bays were warped down, some were warped up as shown in Figure 7. Many cracks appeared on the floor surface, from which a lot of vapor spouted out to fill the upper floor, which prevented people from making measurements.

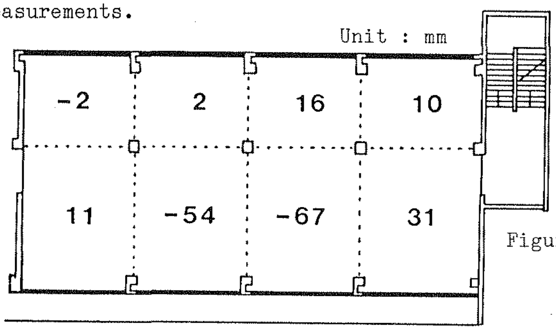

Figure 7 Deformation of floor (mm).

The loading tests and vibration measurements on girders and a floor slab before and after the fire test, revealed us that their rigidity decreased more than 50% of the original value as shown in Table 2. Although the outside appearance of structural surface seemed not so damaged after one day, the structure, in fact, received the rather sever damage that we expected. The re-use of it seemed dangerous a future earthquake without some considerable reinforcement.

Similar structural tests were made in Yamaichi Stock Company Building [21] and Akabane New Apartment Building [22].

Table 2 Reduction of Rigidity (Vibration Tests)

	floor	girder No.1	girder No.2	girder No.3
Before the fire	1.0	1.0	1.0	1.0
After the fire	0.35	0.60	0.38	0.60

New smoke test facility (building) in B.R.I.

Gradually it became difficult inside the city to make tests using an actual building scheduled for demolition, because of the social attitude against the air contamination. Since a new smoke test building of 7 story was completed in B.R.I. in the new Tsukuba site in 1976, the full scale smoke movement tests have mainly been made in it.

4.FULL SCALE TESTS IN RECENT DECADE

Recently many full scale fire tests on wooden detached and semi-detached houses were made in several places. As the construction of wooden houses has recently been considerably changed from the traditional open style, we had to learn how fire behaved in it so as to develop life safety measures and also to estimate any change in the development of configuration after a future earthquake. A lot of new knowledge has been obtained for the fire behavior in dwellings [23].

Also the new tendency of the buildings to have big open spaces such as the air-dome and the atrium has appeared. Full scale fire tests were performed in several of such buildings to confirm the escape safety [24].

5.MODELING AND DESIGN

With the development of the computer, mathematical fire modeling has been advancing very rapidly in various place in the world.

In 1977, N.B.S. the leading fire research body in the USA set up the ad hoc Working Group on Mathematical Fire Modeling, of which the objectives are mainly compartment fire studies. Since then it has continue to work very activity to promote more scientific modeling. Recently the Fire Simulation Laboratory has been established in which training course and work shops to study theoretical methods, based on fire dynamics, and also a sub-committee for fire modeling has been established in A.S.T.M.. C.I.B.W-14(fire) has held workshops for fire modeling.

The people are now tending to believe that sophisticated mathematical models could predict accurately real fire phenomena and could be used for the automatic design for fire protection. Computer protection is a very useful tool for the design of building never seen before. But the fire phenomenon is too complex to predict by computer precisely under the wide variety of conditions. Especially data of mathematical properties under high temperature are now very poor. The data base of materials for the fire modeling should be promoted as international work, parallel to the advance of modeling. Technology can be transferred very easily and rapidly, but not the experience obtained by people on a long time. Although the expert system is now developing rapidly, computer prediction making of the designers or consultants in select the better solution from many proposals under the wide range of conditions, should not be used to decide the design deterministically alternated with the designer or consultant who has the ability to do the engineering judgment for fire safety.

6. REFERENCE

1) Mizuno, T., and Sugawa, O.,"Experimental Study on Gasoline Station Fire" Proceeding of the Second International Symposium on Fire Safety Science
2) Diagnosis and Reinforcement of Burnt Building, Report of BRI No.2, (1948) (in Japanese)
3) Diagnosis and Reinforcement Concrete Building Damaged by Fire Exposure, Concrete Pamphlet No.4 Japan Cement Association, (1955) (in Japanese)
4) Fujita, T., "Fire in Fire Resisting Building and Fire Protection, Report of BRI, No.1 J-1 (1954) (in Japanese)
5) Kawagoe, K.,"Fire Behavior in Rooms" Report of BRI No.27 (1958)
6) Sekine, T.,"Room Temperature in Fire of a Fire Resistive Rooms" Report of BRI No.29, (1959)
7) Thomas, P.H."Research on Fire Using Models", Inst. of Fire Engineers Quart, (1961)
8) Thomas, P. H. and Heselden, A.J.M. Fire Research Note, No.923 (CIB Report No.20) (1972)
9) Yokoi, S., "Study on the Prevention of Fire Spread caused by Hot Upward Current", Report of BRI No.34 (1960)

10) Kawagoe, K., and Sekine, T., "Estimation of Fire-Temperature Curve in Rooms" BRI Occasional Report No.17, (1964)
11) Kawagoe, K.,"Damage of Structure in Full-Size Fires" Report of BRI No.29, (1959)
12) Fire Tests in Mitsubishi Naka 15 Building, "KASAI" JAFSE, Vol.12, No.3 (1962) (in Japanese)
13) Fire Test in Daiun Building "KASAI" JAFSE (in Japanese)
14) Fire Tests Report of the Central Hospital of Japan National Railway, Association for Railway Building, (1968) (in Japanese)
15) Fire Tests Report of Tokyo Kaijo Kasai Building, "KASAI" JAFSE Vol.17, No.3 (1967) (in Japanese)
16) Study on the Fire Protection of the Tall Apartments, Japan Housing Corporation, 74-363, (1974) (in Japanese)
17) Jin, T., Journal of Fire and Flammability Vol.9 (1978)
18) The Study on the High Rise Building, The Association of Building Contractors (1966) (in Japanese)
19) Wakamatsu, T.,"Smoke Movement in Building Fire-Field Experiment in Welfare Ministry Building and Analysis of Sennichi Building Fire", BRI Report Paper No.61 (1975)
20) Wakamatsu, T., "Calculation of Smoke Movement in Buildings", Second Report, BRI Research Paper No.46 (1971)
21) Report of Fire Test in Yamaichi Stock Company Building, "KASAI", JAFSE Vol.6,No.3 (1956) (in Japanese)
22) Report of Fire Test in Akabane New Apartment Building, "KASAI", JAFSE Vol.12, No.4 (1962) (in Japanese)
23) Tsukagoshi, I., and Itoigawa, E.,"External Radiation at a Full Scale Fire Experiment", Proceeding of the First International Symposium on Fire Safety Science (1985)