Large Scale Fire Tests of 4 - Story Type Car Park

Part 1:

The behavior of structural frame exposed to the fire at the deepest part of the first floor

TAKAYUKI KITANO*1, OSAMI SUGAWA*2, HIDEAKI MASUDA*3, TAKEO AVE*4 and HIDEKI UESUGI*5

*1 Sanken Setsubi Kogyo Co., LTD
(1-35-8, Nihonbashi kakigaracho, Chuou-ku, Tokyo 103-0014, Japan)

*2 Assoc.Prof., Center for Fire Science and Technology, Science University of Tokyo
(2641, Yamazaki, Noda-shi, Chiba-ken 278-0022, Japan)

*3 Building Research Institute, Ministry of Construction
(1, Tatehara, Tsukuba-shi, Ibaraki-ken 305-0802, Japan)

*4 Assoc.Prof., SERC, Tokyo Institute of Technology
(4259, Nagatuta-cho, Midori-ku, Yokohama-shi, Kanagawa-ken 226-0026, Japan)

*5 Prof., Graduate school of Science and Technology, Chiba University
(1-33, Yayoicho, Inage-ku, Chiba-shi, Chiba-ken 263-8522, Japan)

ABSTRACT

The requirement for car parks is constantly growing and car parks have become higher and bigger. The quality and quantity of combustible materials in car parks is limited, and exterior wall and windows are not required. As a result, if a fire breaks out in this type of car park, the combustion type is not ventilation-controlled one but fuel-storage-controlled fire type. Currently, car parks are designed based on the premise that a fire initiated in one car in a car park does not spread to the neighboring cars[1]. However, this premise was arrived at on the basis of the results of experiments performed using the small car parks. In this study, in order to examine the hypothesis that a car fire initiated in one car in a large car park does not spread to neighboring cars, an experiment is conducted using a large-sized multistory car park by setting fire to a car in the parking lot. Contrary to the premise, the fire spreads from one car to another in succession.

KEYWORDS : Large Scale Test, Spreading Fire of Cars, MultiStory Car Parks, Open Car Parks

1. INTRODUCTION

In recent years, there has been an increase in the size of commercial facilities such as department stores and shopping centers, and the number of facilities located in suburbs are increasing. It is well known that these facilities have a severe shortage of parking spaces, although the number of urban and suburban dwellers using vehicles increases each year. There is a notable shortage of parking space in residential areas, particularly in apartment housing complexes. It would be impossible to provide sufficient parking space for all households within their building sites. The parking situation will worsen as more and more single-family households own multiple vehicles. The shortage of parking space around shopping centers leads to lines of waiting vehicles on the road and causes far worse conditions of traffic congestion. The shortage of parking space in residential areas promotes serious social problems such as illegal roadside parking and increases traffic accidents. Indeed, it will be difficult to maintain a peaceful residential environment under these circumstances.

As a solution, the Minister of Construction approved the use of prefabricated car park systems. Two story prefabricated car park system was devised in February 1991[2] and three-story car park system was devised in 1993[3]. These developments provided an opportunity to examine a wide variety of car park systems as well as in relation to the traffic conditions and other car parks in the vicinity. Unfortunately, there has been insufficient improvement in the traffic problems and in the shortage of parking space. The number of urban and suburban residents with vehicles that require parking space has increased in pace with the increase in size and number of commercial facilities and residential areas. It is essential to respond to these changes by increasing the number of car parks or by constructing taller and larger car parks. Examination of the structural safety of the four-story prefabricated car park system has just begun and the safety measures and standards have not yet been established. In view of the limited supply and the expected increase in demand for parking space, it is important to immediately examine the feasibility and safety of multistoried car parks such as a four-story system.

The following items are issues to be investigated regarding the prefabricated, open-type multistoried car parks in view of fire resistance properties.

1. Prefabricated open-type car parks have been designed under the premise that fires would not spread to surrounding vehicles[1]. However, this premise was based on experiments that were performed using small car parks with an area of approximately 100 m². The premise may not apply to prefabricated car parks with areas as large as 4000 m² per floor.
2. For fires that spread among vehicles, the structural frame temperatures are not clarified.
3. The quantity of structural frame deformation is not clarified.
4. It is not clarified whether or not structural frame collapse occurs.

An area of 4000m² is approximately a square with a side of 60 m. For this study, the first floor of the experimental rectangular structure is 30 m x 20 m in size. The two sides of the structure are thermally insulated using autoclaved-aerated concrete boards and the other two sides remain open. Large-scale fire test is carried out setting fire at the deepest part of the thermally insulated corner on the first floor.

2. EXPERIMENTAL METHOD

2.1 Outline of structure used in the experiment

Table 1-1 lists the parameters and dimensions of the structure used in the experiment. Fig.1-1 and Fig.1-2 show external photos of the structure, and Fig.1-4~Fig.1-7 show the first story plan and elevations of the structure. Table1-2 lists the cross-sectional dimensions of the structure.

Table1-1 Parameters and Dimensions of the Structure Used in the Experiment

Scale	*Story*	4-Story	
	Building Area	621.6m²	
	Total Floor Area	1080.5m²	
	Max Height	10.15m	
Outline of Structure	*Standard Story Height*	1-Story	2.9m
		2-Story	2.9m
		3-Story	2.9m
	Strauture	Steel Structure	
	Frame	Moment Resisting Frame	
	Footing	Continuous Footing and Individual Footing	
	Floor Slab	Composite Slab and Steel Plate Slab	
	Insulating Wall	Autoclaved-aerated Concrete board	
ParkingCar	*1-Story*	Weight 2.5 (t) and under 2.0(t)	12 cars
	2-Story	Weight under 2.0(t)	12 cars
	3-Story	Weight under 2.0(t)	12 cars
	4-Story	Weight under 2.0(t)	12 cars

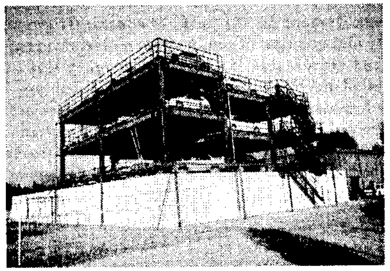


Fig.1-1 External view of car park from SouthWest side

Fig.1-2 Internal view of car park from East side

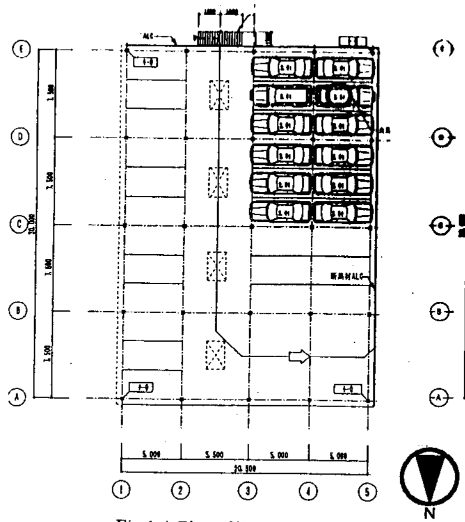


Fig.1-4 Plan of the First Story

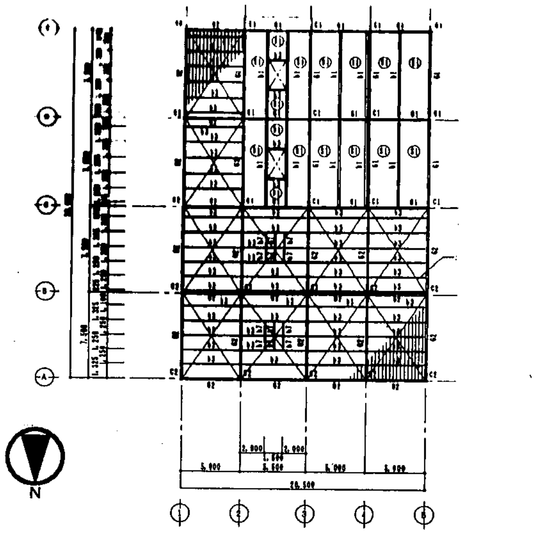


Fig.1-5 Beam Plan of the Second Story

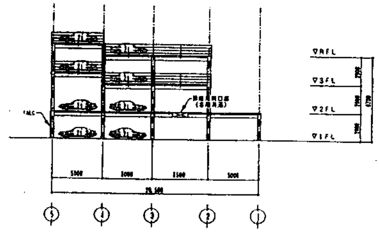


Fig.1-6 Side Elevation of E-Frame

Table1-2 Cross-Sectional Dimensions of the Structure

	Column		
	1-Story	2-Story	3-Story
C1	□-300x300x12	□-300x300x9	□-300x300x9
C2	□-200x200x6	-	-

Beam & Girder			
G1	H-400x200x8x13	b1	H-350x175x7x11
G2	H-300x150x6.5x9	b2	H-300x150x6.5x9
		b3	H-200x100x5.5x8

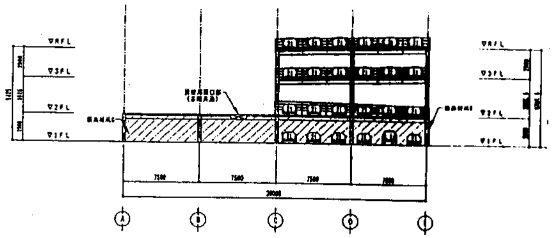


Fig.1-7 Side Elevation of 5-Frame

2.2 Outline of experiment

Experiment is performed by starting a fire at the deepest part of the thermally insulated corner on the first floor as shown in Fig. 2. The structure is covered with no fire protection, i.e., the car park is made of bare steel frames.

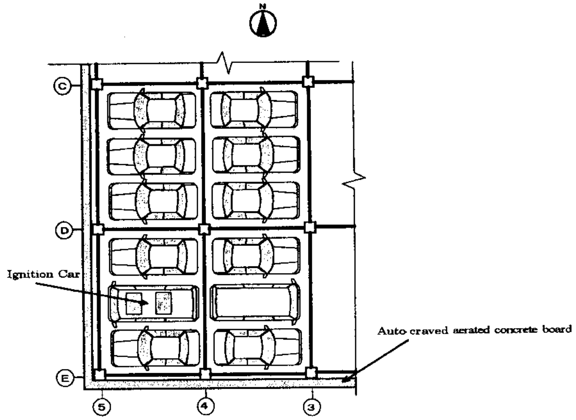


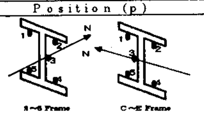
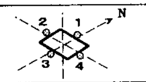
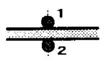
Fig.2 Allocation of Cars of Experimantal Frame

The maximum allowed floor area for prefabricated parking structures is 4000 m²/floor in Japanese specification. If the area is square, the dimensions are 63m x 63m. A fire started in the center of the first floor is thought as the most violent type possible.
In order to achieve the fire conditions described above, a thermally insulated structure is used to form a combustion space. This space is surrounded by the ceiling (floor of the second story), and walls. Combustion progress is considered more severely because of heat radiated from the floor and walls to the cars in the insulated space. Therefore, corner fires exhibits faster combustion and spread wider than open side fires. The purpose of the experiment is to understand the behavior of car combustion and structural frames under this extreme condition.

2.3 Temperature measurement points

Temperatures are measured with CA thermocouples at the locations indicated by the symbol in the cross-sectional area of Fig. 3. Table 2 lists points of temperature measurement along one cross section. With respect to the designation of the temperature measurement points (m-n-p), n represents the number of measurement points in Fig. 3, and m and p are explained in Table 2.

Table2 Positions and Numbers of Measuring Temperature in section

Member (m)	Position (p)
Girder,Beam (1)	
Column (2)	
Slab (3)	

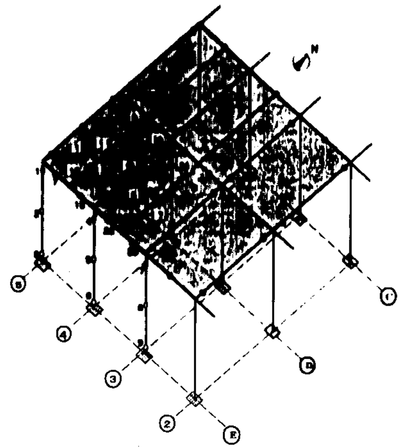


Fig.3 Positions and Numbers(n) of Measuring Temperature

2.4 Displacement measurement points

A tower is constructed as a reference point for displacement measurements. Displacement gauges are installed at the locations indicated in Fig. 4. In the measurement results (D-n), D indicates displacement at measurement point number n shown in Fig. 4. Table3 shows the directions of displacement measurements.

Table3 Direction of Measuring Displacement

Member	Measuring Displacement
Girder	Vertical Displacement
Beam	Vertical Displacement
Column Base of the First Floor	Vertical & Horizontal Displacement
Column Base of the Second Floor	Horizontal Displacement

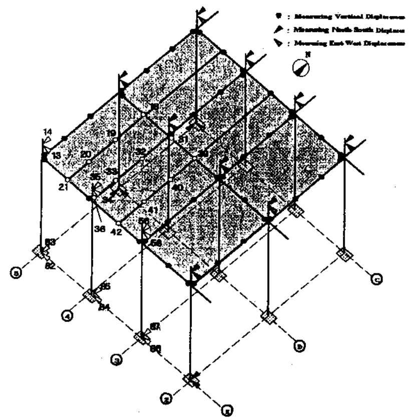


Fig.4 Positions and Numbers(n) of Measuring Displacement

2.5 Strain measurement points

A total of 36 strain gauges are installed on the four sides at the top of the second floor columns. The strains in the axial direction of the columns are measured. In the strain measurement results (S-n), S represents the strain at gauge number n shown in Fig. 5.

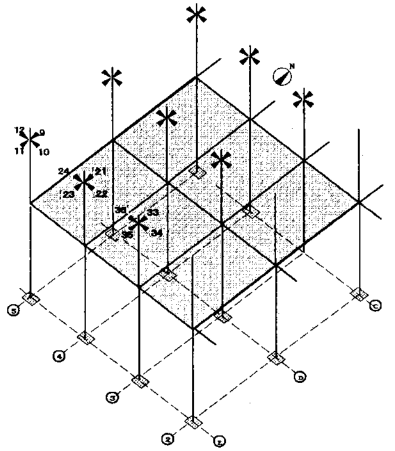


Fig.5 Positions and Numbers(n) of Measuring Strain

3. EXPERIMENYAL RESULTS

3.1 Fire spreading

Fig.6 and Table4 show events that occurred during the experiment. In the figure, ① denotes the car number set on fire and the symbols ②～⑧ show the order of spread. The time notation in the figure indicates the time at which a particular car catches fire. The car numbers range from 101 to 110. Fig.7-1～Fig.7-8 show photographs of the events during the experiment.

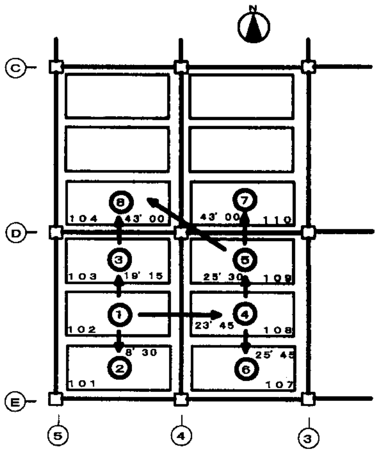


Fig.6 Passage of Fire Spreading

Table4 Whether Condition of the Experiment Time and Passage of Fire Spreading

Date: 26 January 1999	
Time of Starting Experiment: 10:54 a.m.	
Weather: Fine	
Temperature: 5 ℃	
Direction and Velocity of Wind : NNW2～3m / sec	
Time	***Record***
00'00"	Start of Ignition
08'30"	Fire Spread to Left Side Car (No.101)
19'15"	Fire Spread to Right Side Car (No.103)
23'45"	Fire Spread to Tail Side Car (No.108)
25'30"	Fire Spread to No.108's Right Side Car(No.109)
25'45"	Fire Spread to No.108's Left Side Car(No.107)
43'00"	Fire Spread to Cars (No.110 and No.104)
43'45"	Start of Fire Fighting

Fig.7-1 The View Just After Ignition

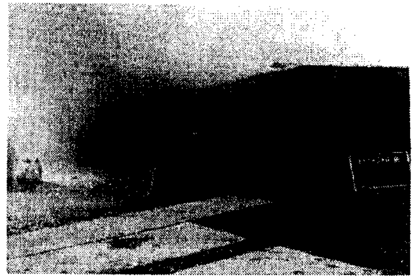


Fig.7-2 The View of Smoke Flow from North-East Side

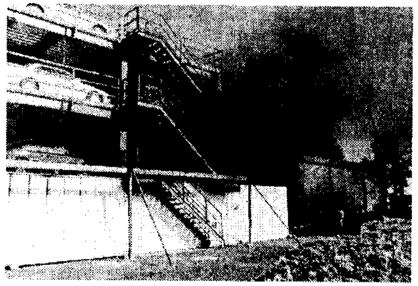


Fig.7-3 The View of Smoke Flow from South Side

Fig.7-4 The View of Spreading Car Fire from North-East Side

Fig.7-5 The View of Spreading Car Fire from East Side

Fig.7-6 The View of Fire Fighting

Fig.7-7 The View of Beam and Deck Plate After Fire Fighting

Fig.7-8 The View of Cars After Fire Extinguishment

3.2 Temperature of structural member

Fig.8-1 ~ Fig.8-13 show girder and beam temperatures. Fig.9-1 ~ Fig.9-9 show column temperatures and Fig.10-1 ~ Fig.10-4 show temperatures along the front and back surfaces of slabs.

During the 44 minute time span from ignition to initiation of fire fighting, the steel temperature tended to increase with time at most measurement points. The maximum temperature of a beam, 700°C, positioned immediately above the ignited car is reached at 10 minute after ignition (Fig.8-2). The temperature then decreases for up to 20 minute and remain approximately at 500°C until 35 minute after the start of ignition. Thereafter, the temperature increased again until the time of fire fighting. The temperature reaches 600°C at the lower flange and web. The ignited car is tall (wagon) and contains a sunroof. It is considered that the sections of the beam are in a region of continuous fire and resulting in the occurrence of the sudden temperature increase. The increase in temperature at 35 minute after ignition appears to result from the combustion of car No. 101. Fig.8.8 shows that the temperature immediately above a wagon (without a sunroof) remain at 600°C. Fig.8-4 ~ Fig.8-6 show the temperature of a girder surrounded by six cars (car numbers 101 ~ 103 and 107 ~ 109). The temperature at the lower flange and the web part of the beam reaches approximately 500°C and may rise further if the fire is not extinguished.

Fig.9-1~Fig.9-9 show the steel column temperature. The maximum temperature reached is slightly below 500°C before the fire is extinguished.

As shown in Figs.10-1 ~ Fig.10-4, the temperature of the heated-side deck plate of the floor slab reaches 500°C ~ 600°C just prior to fire fighting. The temperature on the back surface of the deck plate slab is approximately 70°C at the most.

3.3 Deformation of columns and beams

Fig.11-1 shows the degree of deformation of a beam immediately above the ignited car. The difference in deformation between the central point and the edge point is 55 mm. The critical deflection ($\delta = l^2/800d$, where l= span length, d= beam depth) is 200 mm. The structure exhibits a sufficient margin of safety for fire.

Fig.11-4 shows the westward deformation of the tops of the columns of E-frame. The maximum deformation at the top of the column reaches 30 mm. The critical deformation ($\delta = h/30$, where h= height of story) is 100 mm. Thus, the safety margin is sufficient. Fig.11-6 shows that the westward deformation reaches 60 mm at the bottom of the column of E-frame. The column bottom exhibits greater displacement than the column top because the column bottom is not restrained and flexible.

3.4 Strain at the column top on the second floor

Fig.12-1 ~ Fig.12-3 show the degree of strain at the top of the column on the second floor on the E-frame. The strain gauges are attached to the four sides of the column top, 10 cm from the lower flange of girder. The tensile and compressive strain increase with time due to thermal expansion of the second floor girder, which is exposed to fire. However, the strain tends to decrease after initiation of fire fighting. A tensile strain value close to 1500 μ is observed and it is confirmed that the steel material enters into the tensile yield region. The strain value in Fig. 12-2 is small because the placement of the strain gauge is attached under 140-cm from the girder.

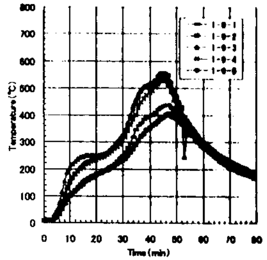


Fig.8-1 Beam Temperature

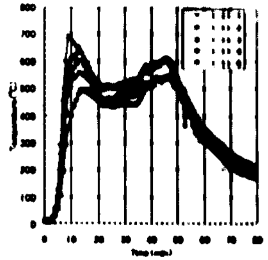


Fig.8-2 Beam Temperature

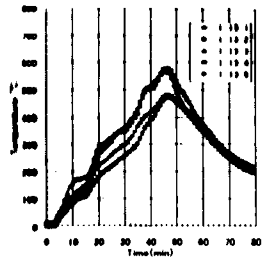


Fig.8-3 Beam Temperature

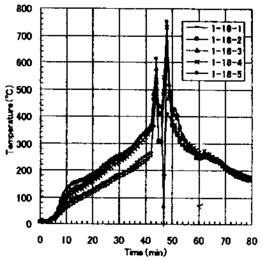


Fig.8-4 Girder Temperature

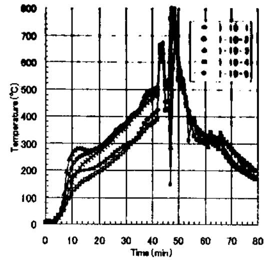


Fig.8-5 Girder Temperature

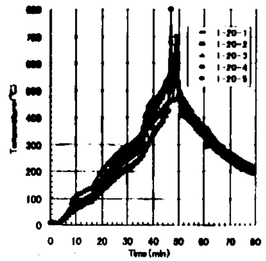


Fig.8-6 Girder Temperature

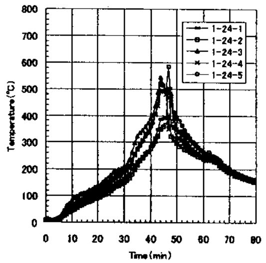


Fig.8-7 Beam Temperature

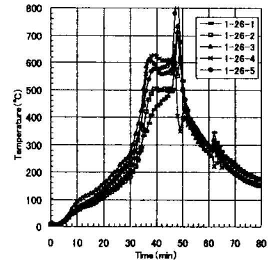


Fig.8-8 Beam Temperature

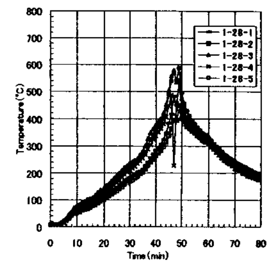


Fig.8-9 Beam Temperature

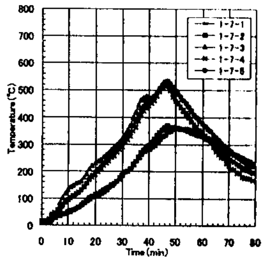


Fig.8-10 Girder Temperature

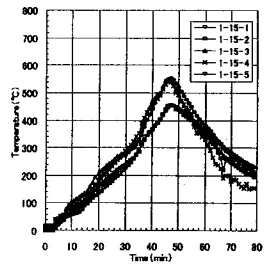


Fig.8-11 Girder Temperature

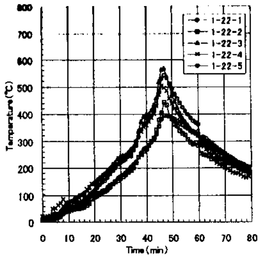


Fig.8-12 Girder Temperature

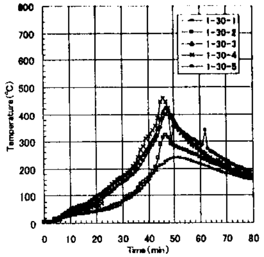


Fig.8-13 Girder Temperature

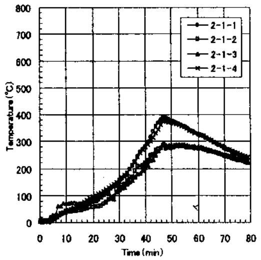


Fig.9-1 Column Temperature

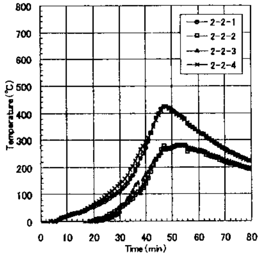


Fig.9-2 Column Temperature

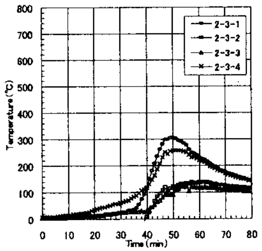


Fig.9-3 Column Temperature

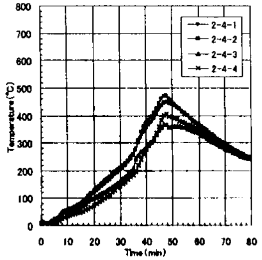


Fig.9-4 Column Temperature

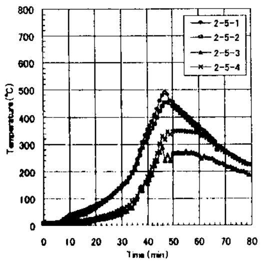


Fig.9-5 Column Temperature

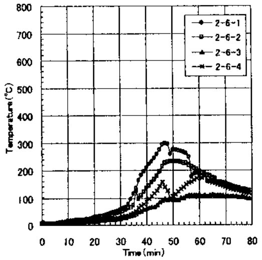


Fig.9-6 Column Temperature

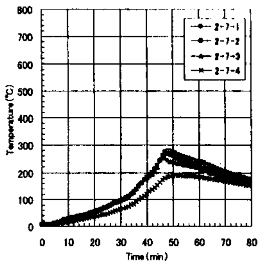


Fig.9-7 Column Temperature

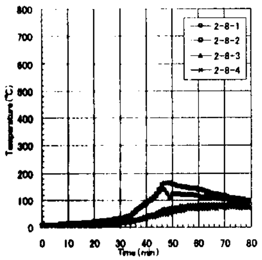


Fig.9-8 Column Temperature

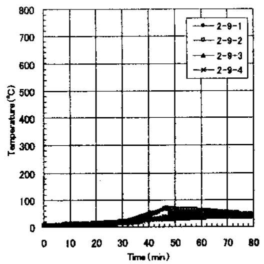


Fig.9-9 Column Temperature

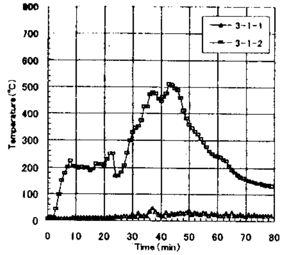


Fig.10-1 Slab Temperature

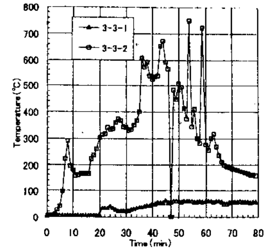


Fig.10-2 Slab Temperature

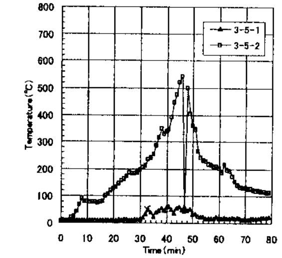


Fig.10-3 Slab Temperature

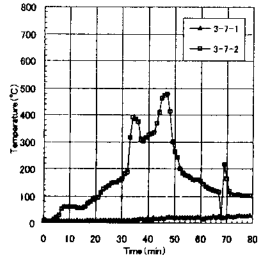


Fig.10-4 Slab Temperature

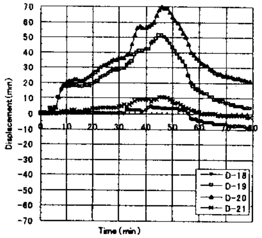


Fig.11-1 Displacement

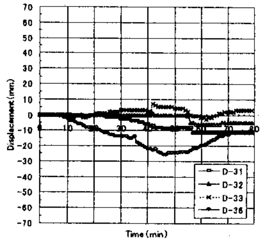


Fig.11-2 Displacement

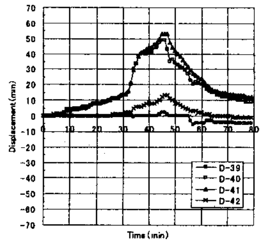


Fig.11-3 Displacement

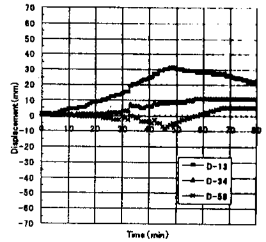


Fig.11-4 Displacement

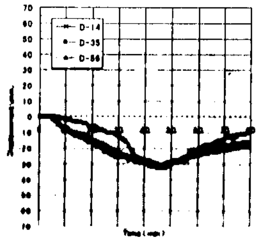


Fig.11-5 Displacement

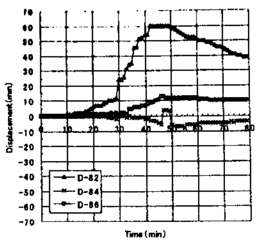


Fig.11-6 Displacement

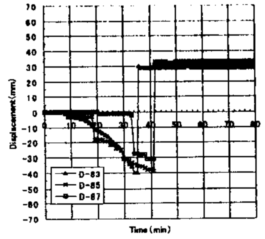


Fig.11-7 Displacement

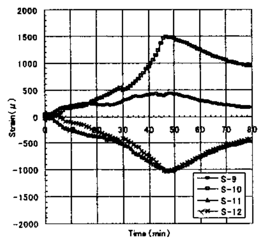


Fig.12-1 Strain

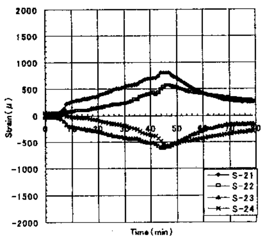


Fig.12-2 Strain

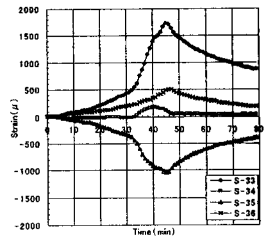


Fig.12-3 Strain

4. Conclusions

The experiment performed in this study yields the following results.

1) Car fires spread one after another.
2) The steel temperatures of a beam located immediately above the combusted vehicle reaches from 600°C to 700°C.
3) The degree of structural deformation is 1/4-1/3 of the critical deformation but the strain enters the plastic region.
4) The structure doesn't collapse even though it is subjected to severe fire conditions. Residual deformation, such as local buckling, is not observed.

The data reported in this paper are analyzed in the middle of the data collection process. Therefore, the results of more detailed data analysis will be reported in the future.

Acknowledgment

The experiments in this study were performed with the full support of the Prefabricated Parking Lot Industrial Association of Japan. The authors thank everyone involved in the study.

References

1) ECCS, Technical committee 3, Fire safety of steel structures technical note, "Fire safety in open car parks, Modern fire engineering".
2) Structural safety standard guidelines for two-story single layer garages, Prefabricated Parking Lot Industrial Association, Japan, 1991.
3) Structural safety standard guide lines for three story two layer garages, Prefabricated Parking Lot Industrial Association, Japan, 1993.

Experimental Study on Motorcycles Fire in the Arcade of the Building

BANG-LEE CHANG, CHUN-CHING CHEN and CHING YUAN LIN
Department of Construction Engineering
National Taiwan University of Science and Technology
43, Section 4, Keelung Road
Taipei, Taiwan 106, R.O.C.

ABSTRACT

This paper describes motorcycles fire in the arcade of the building. Four tests for motorcycles burning were conducted in the arcade of a full-scale two-story building. Experimental results indicate the flames from the motorcycle with plastic body hull, in intense burning, may ignite any combustible materials in the arcade by radiation and flame touch, and their heating of the surroundings is quite dangerous. When there are three motorcycles fallen in a row in the arcade, and the motorcycles are fired, the flame heights from the floor is over 5m, the temperature and the radiant-heat flux of the ceiling in the arcade is separately equal to 576℃ and 8.7 W/cm^2.

KEYWORDS: motorcycles fire, arcade

INTRODUCTION

There are now about ten million (10,503,877) registered motorcycles in Taiwan: on average, one motorcycle for every two people. Motorcycle fires have caused serious damage in Taiwan because motorcycles are improperly managed and inadequately regulated, such as motorcycle fires happened recently in the arcade of a modern complex-use building (Taipei, 1996). [1] The traditional building with arcade is often constructed in Taiwan. Therefore, motorcycle fires happening in traditional Taiwanese arcades often develop into building fires, which often spread to other buildings, even cross the street. The flames tend to curl back, impinge upon ceilings and building facades above arcades, generating radiant-heat fluxes to ceilings and building facades. The density of the radiant-heat flux is high enough to make fire hazards to the facades above the arcades and to the surrounding buildings. [1] Thus data of motorcycles fire in the arcade of building, such as flame height, radiant-heat flux and temperature were useful for the assessment of fire hazards.