http://fenbil.trakya.edu.tr/tujs
Trakya Univ J Sci, 6(2): 75-82 , 2005
ISSN 1305-6468
DIC: 175AHTT620512050106

Research Article/Araştırma Makalesi

FIRE TESTS ON CONCRETE FRAMEWORKS - ANALYSIS OF THE RESULTS

Ataman HAKSEVER
Civ. Eng, Dept., Trakya University, Çorlu/Türkiye, formerly Technische Universität Braunschweig (Ger.)
E-mail : ahaksever1@corlu.edu.tr

Alınış : 01.02.2005
Kabul Ediliş : 03.07.2005

Abstract: Traditionally the response to fire of a building will be estimated on the base of the fire resistance of its individual structural members. The paper presented deals with the fire resistance of a symmetrical half of a concrete framework as an integrated part of entire structural system, and derives results from experimental and theoretical investigations for fire engineering design.

Key words: Fire safety, framework, structural system, fire resistance.

Betonarme Çerçeveler Üzerine Yangin Deneyleri Ve Sonuçlarin Analizi

Özet: Genellikle bir yapının yangın davranışı, bu yapıyı oluşturan yapı elemanlarının bireysel yangın davranışına göre değerlendirilmektedir. Bu çalışmada, betonarme çerçeve taşıyıcı sistemlerin yangın davranışı teorik ve deneysel olarak analiz edilmiştir

Anahtar Kelimeler: Yangın güvenliği, betonarme tasarım, çerçeve sistemler, yangın direnci

1. Introduction

1.1 Status of the realisations, output questions

Facilities for fire testing of entire load bearing systems, combined of vertical columns and walls and corresponding horizontal beams and slabs have been missing both in Germany and abroad. The column-framework test stand of this *special fire research area* at Braunschweig Technical University makes it now however possible to close this gap. Thus, both *buckling* and *bending* of monolithical load-bearing elements under fire attack can be examined experimentally. The cross-section of the special furnace for these fire tests is shown in Fig. 1.1. Investigations of complex load-bearing structures are in the case of fire of certain special importance, because their mutual *interaction* determines the *fire resistance* and the type of failure of these systems.

The mechanical loading combined with the heating changes the behaviour model of the structure:

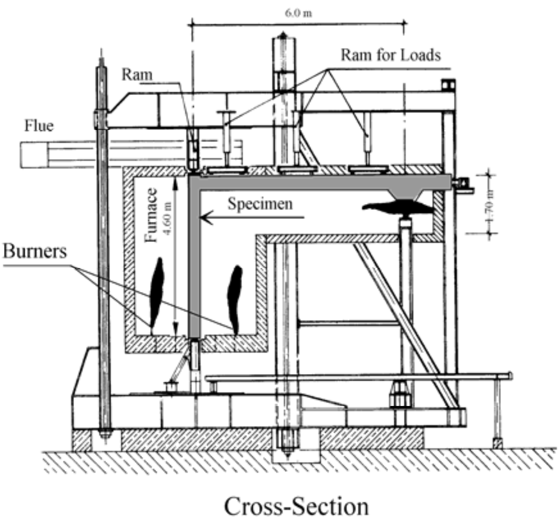


Fig. 1.1: Special furnace for structural fire tests

a) Redistribution of internal forces in slender compression members changes the *buckling length*
b) In elements exposed to bending, plastic deformations take place resulting in mechanisms.

In complicated frame structures, these effects change the load-bearing system. For example, when the thermal expansion is even partially restrained, additional normal forces appear during the heating period. Important results can therefore, be obtained by studying statically *indeterminate structures* in fire. Theoretical investigations for these systems have been carried out in many places during passed decades. Developing computing codes have not proven to be however, due to restrictive assumptions fully reliable [1, 2].

In the context of SFB148[1], a new code [3] enables also the theoretical investigation of the framed systems under fire attack with consideration of material and geometrical non-linearity. In this contribution, test results will be presented, performed for a half of framework in the special furnace of SFB 148. The theoretical investigations are shown as well. The results are compared with each other proving an excellent agreement between them.

2. Applied numerical method

The global principles and the applicability of the computing procedure are described in [3, 4]. In this context, only short introduction is presented.

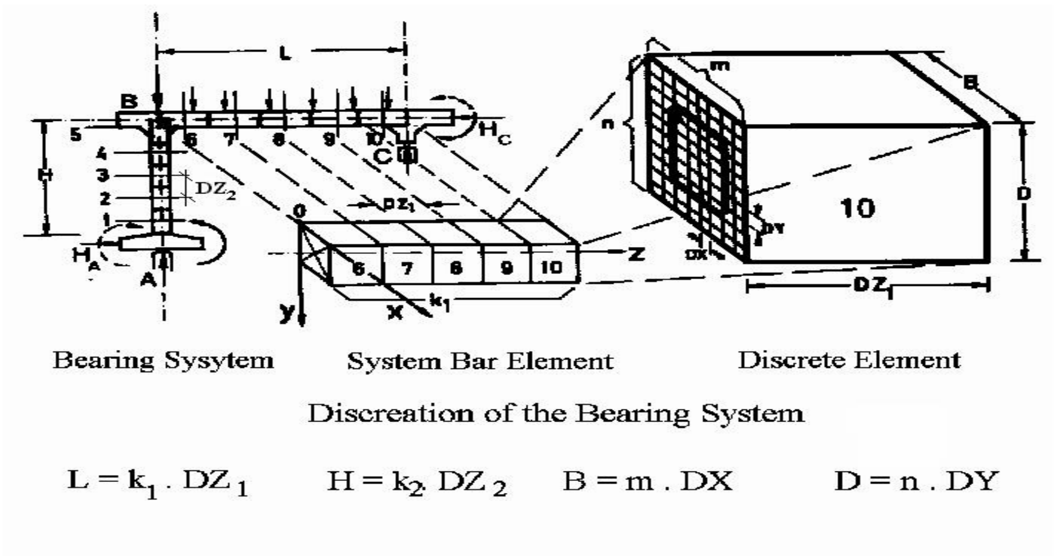


Fig. 2.1: Axial and cross-sectional discretisation of a bearing system in case of fire

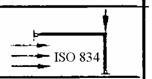
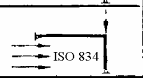
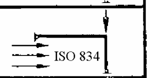
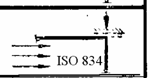
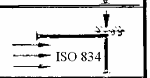
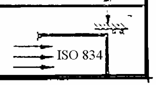
To get meaningful approximations in the analysis of non-linear structures, the piecewise linearization in the axial direction of each beam and column is adopted. When refining the linearization steps the consideration tends to the exact solution. This linearity creates the effect called *High-Temperature Rigidity*. When the linearization of the strain field is extended to the cross-section plane, traditional calculation methods can be utilised.

The procedure is based on the determination of the stable equilibrium state of the structure. This condition is checked at discrete points of the elements. In the computerised calculation the iteration is continued, until equilibrium is obtained. In each iteration cycle, a new cross section analysis is performed at the discrete points along the bar axis due to modified demands of the equilibrium.

---

[1] Sonderforschungsbereich 148, Brandverhalten von Bauteilen. TU-Braunschweig. (Ger.)

Table 3.1: Parameters varied in the test program

TEST PROGRAM					
Nr	Geometry l, h, b/d, A_s	Loading Conditions	Flaming Conditions	Boundary Conditions	Statical System
1,2	unvaried	High axial Force on the frame column P = 568 kN	Column allsided Girder 3 sided	Hinged Support at column end	
3	"	Small Axial Force on the column P = 85 kN	"	"	
4	"	High axial Force on the frame column	Column and Girder 3 sided	"	
5	"	"	Column allsided Girder 3 sided	Thermal Expansion restricted	
6	"	"	Column and Girder 3 sided	"	
7	"	Small Axial Force on the column	Column allsided Girder 3 sided	"	

Finally the failure state in the framework is achieved either by theoretically increasing deformations tending to infinity, in case of a *stability failure* or by the failure of a discrete element as consequence of exceeding the *load bearing capacity*.

On the basis of the most important moment curvature relations of the reinforced concrete elements, computing procedure enables to consider also the influence of local plastic zones on the load-carrying behaviour of the system.

3.Test results and the numerical analysis

3.1.Test program

For experimental investigations a precise test program was performed as shown in Table 3.1. The program was planned to verify the computational results [3, 4] by varying the boundary conditions used generally. Thus, the geometry and the reinforcement were kept unchanged in separate 7 tests. Boundary conditions, the loading and the exposure to fire of the frame column were chosen to be the parameters.
First, the framework was designed after DIN 1045 for the admissible loads in *Service State* and the reinforcing in the corner was chosen in accordance with the recommendations in [5].

The tests 1 and 2 were performed with a high and the test 3 with a low vertical load on the column of the framework, in order to determine the influence of the axial force on the fire resistance. The theoretical investigations resulted with higher loads in the stability failure on the frame corner. In case of lower load, a higher fire resistance of the system was reached on. In this case, the fire resistance is attained when *plastic hinges* are arisen forming a mechanism.

In the test 4, the structural system represented an end framework and the frame column was exposed in addition to high loading to fire from three sides. One side of the column was insulated and protected against the fire attack. Computational investigations showed that the fire resistance was extended significantly, when the curvature of the frame column due to temperature development is in the different direction compared to the curvature due to the bending moment.

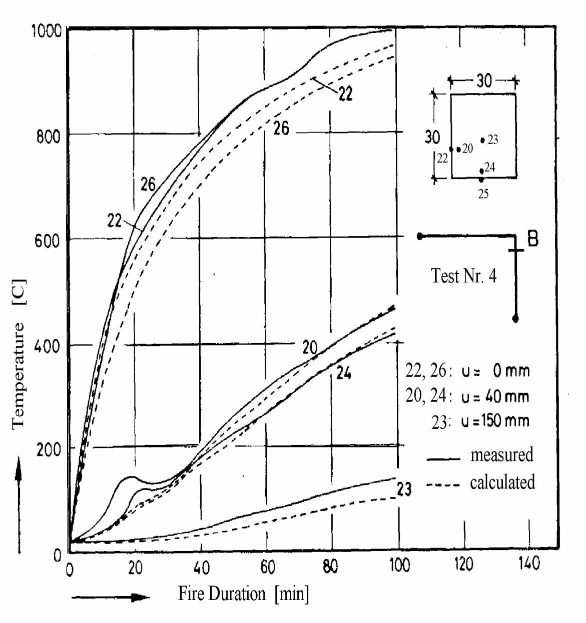


Fig. 3.1: Measured and calculated temperatures in case of ISO834-Fire

In the fire tests 5 to 7, the relaxation conditions in buildings are examined. In the tests 5 and 6, the influence of the magnitude of the axial force of the column, while in test 7 the positive influence of exposing the column to fire from three sides is examined when at the same time the thermal expansion is prevented.

3.2 Temperature development

In order to determine the temperature field in the elements of a frame, a *finite difference* method is used as presented in [6]. The heat transfer conditions are determined on the base of the detailed investigation of the SFB-Furnace. The calculated and measured values of temperatures are presented in Fig. 3.1. They are in a good agreement with each other. It is very important, particularly under a long fire exposure, because the computational procedure was corresponding to real fire temperatures and it is of greatest importance when predicting the load bearing capacity of the whole system.

3.2 Developing of the member forces

3.2.1 Developing of the bending moments at frame corner

In Fig. 3.2, the computed moment developments at the frame corner are illustrated on the base of the test series 1 by applying the theory of the first and second order. The computational investigations resulted in following consequences:

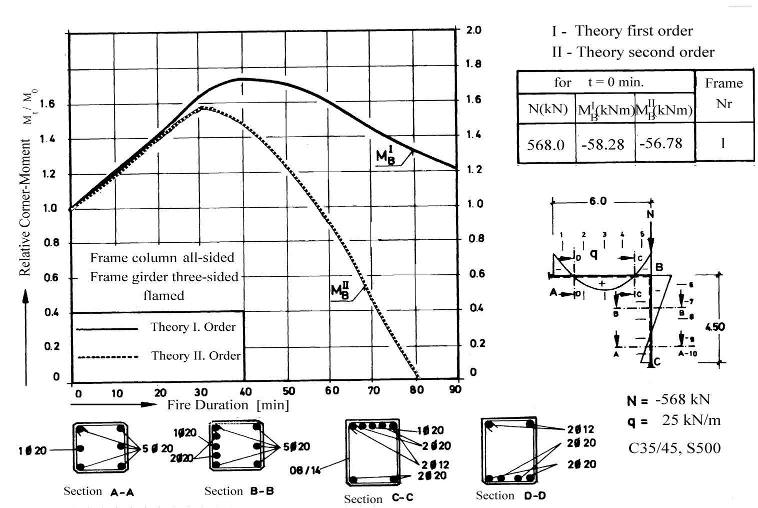


Fig. 3.2: Development of the calculated corner moments of the frame-work in case of fire

Fig. 3.3: Failure of the frame corner in test No. 4 in case of fire

1. The corner moments increase with continuing fire duration; after reaching the maximum value they decrease again steadily, it means that the bending stresses move towards the span. This effect is discussed in paragraph 3.2.2 and proven also experimentally (Fig. 3.2).
2. The framework in the test 1 shows clearly that the corners with negative bending moment (tensile at the outer face) are releasing down steadily during continuing fire duration. It is even to be noticed that this moment changes its sign before the final fire resistance is reached (tensile at the inner face). The agreement between calculation and tests regarding this process is shown in Fig. 3.3, where tensile cracks occur due to insufficient reinforcement on this side.
3. The calculations show also that plastic deformations occur on the inner side of the corner when the final fire resistance is reached, due to exceeding of the yield stress. This effect is also confirmed in the test (see Figs. 3.5 & 3.6).

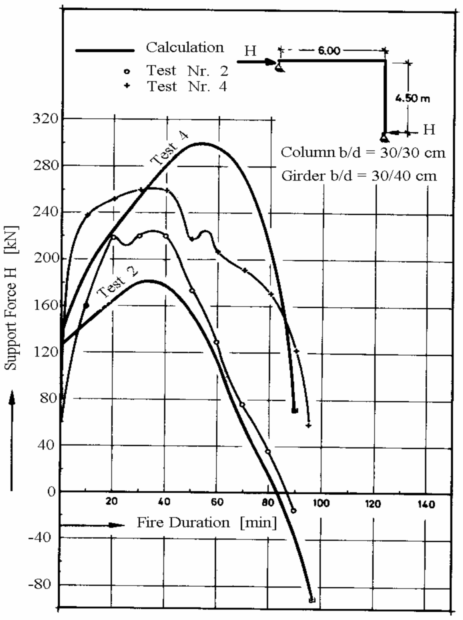


Fig. 3.4: Measured and calculated horizontal support reactions

3.2.2 Developing of the support reactions

The horizontal support reaction H at the column end, presented in Fig. 3.4, shows a typical development process during the fire. Test 2 presents the development of the H-force when all four sides of the column are exposed to fire. Test 4 shows the same on the other hand, when three sides of the column are exposed only. The two presentations enable to identify the same tendencies in the development of the corner moments as in Fig. 3.2.

The good agreement between calculated and measured data becomes particularly distinct in the following aspects: Both processes have an ascending and after reaching the maximum a descending branch. The descending branch shows in particular the *loss of stability* of the frame column with progressive fire exposure.

1. When three sides of the column are exposed to fire the maximum horizontal force is delayed when compared to the case of four side exposure (about 20 min) when the horizontal force achieves its maximum value clearly sooner. This emphasises again the fast loss of rigidity when all sides of the column are exposed to fire.
2. The magnitudes of support reactions differ also clearly from each other. When three sides of the column are exposed only, the support reactions are developing faster, since substantial restraining occurs in the system. This can be explained by realising the curvatures due to the external loading and fire to be of various sign.

3.3 Total deformation picture of the frame system

In the initial stages of the fire attack the curvature due to the bending moments predominantly determine the deformation behaviour. This influence goes down in the column with progressive fire exposure, and it outweighs the influence of the non-linear temperature distribution over the cross-section. This effect will be obvious in case of three-side fire exposure of the frame column, in particular under low-intensity vertical loads on the frame corner.

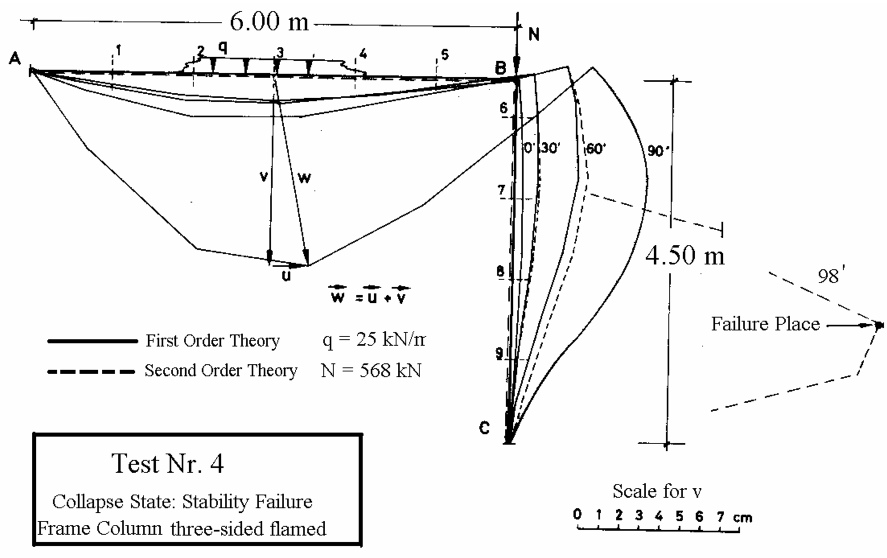


Fig. 3.5: Calculated deformation of Frame Work No. 4 in case of ISO-Fire

In Fig. 3.5, the computationally determined deformation modes of the framework No. 4 are presented, when three sides of the column are exposed to fire. The deformations are drawn both according to first and second order theory. The positive influence of the three-side exposure of the column becomes obvious in smaller difference between deformation curves. The curvatures are noticeably changing in the framework with progressive fire exposure.

The collapse is taking place as stability failure after 98 minutes exposure, as it was also predicted (see Fig. 3.5). The computational deformation mode in the 90 minutes shows clearly the development of a critical zone at the column mid span. The correctness of this prognosis is acknowledged in the experimental collapse failure of the same framework, where this zone is situated approximately at mid span of the column height shown in Fig. 3.6.

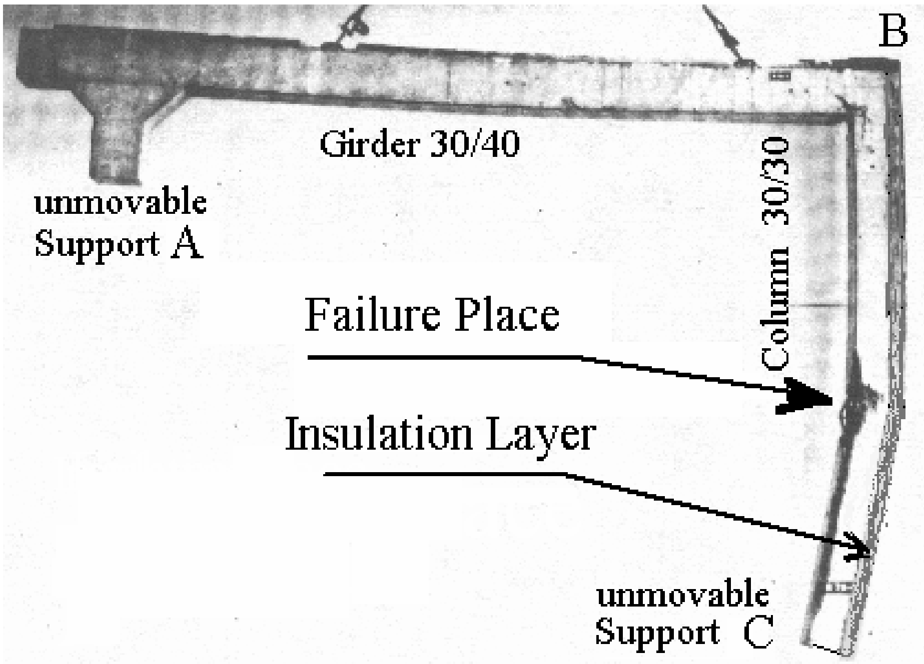


Fig. 3.6: Collapse of frame work No. 4 in case of ISO-Fire

Conclusions

The fire tests performed for the half of reinforced concrete frame in SFB148 supplied valuable results though their number in the first stage of the research work was small. The geometry of a monolithical frame clearly defined the behaviour of the whole structure in the fire. The fire tests gave at the same time an important possibility for critical examination and verification of the computing code, developed for this purpose.

The following results from the tests can be drawn:

1. The deformation sensitivity of the reinforced concrete framework increases with the increasing fire exposure.
2. The total deformation of the structure consists of three components in plane; each point takes a vertical and horizontal translations accompanied by a rotation component.
3. The vertical support reaction has a stiffening effect for the deformations.
4. The meaning of the geometrical non-linearity becomes more important under increasing fire exposure and normal force of the column.
5. In some cases, plastic hinges occur in the overloaded places of the column.
6. The high normal force loading of the column leads sometimes to a premature collapse of the system as stability failure.
7. The continuity at the corner of the system plays a stiffening role for the load carrying behaviour of the framework

A good agreement between calculation and fire test results became obvious overall, both with respect to the critical fire duration and the deformations of the system.

The investigations are carried out at the **Technical University of Braunschweig** (Germany.), in Institute of Fire Technology **(iBMB)**, where the author was active as a scientific collaborator for many years. German Research Foundation **(DFG)**[2] deserves many thanks for the financial support.

References

1. BECKER, J. etal, A computer program for the Fire Response of Structures - Reinforced Concrete Frames. Uni. Of Calif., Berkeley, 1974.
2. AKHTARUZZAMAN, A., etal, Calculation of the deflections of reinforced concrete members during transient heating. Imperial College of Science and Technology, London, 1974.
3. HAKSEVER, A., Zur Frage des Trag-und Verformungsverhaltens von einfach statisch unbestimmten Stahlbetonrahmen im Brandfall. Diss. TU-Braunschweig. 1977 (in German).
4. HAKSEVER, A., Stahlbetonstützen bei natürlichen Bränden. Habil. İ.T.Ü & (print. TU-Braunschweig), 1982 (in German).
5. KORDINA , K., Bewehrungsführung in Rahmenecken und Rahmenknoten. Vortrag, gehalten auf dem Deutschen Betontag in Hamburg, 1975 (in German).
6. HAKSEVER, A, Kapalı hacimlerdeki tabii yangınların analizi için yeni bir model.(A new model for the analysis of natural fires in enclosures). Diss. İ.T.Ü., 1989 (Turkish)

[2] Deutsche Forschungsgemeinschaft.