Some Testing Problems in Structural Fire Engineering : Part 1

testing facilities at the AUC fire research laboratory

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PART 1: TESTING FACILITIES AT THE AUC FIRE RESEARCH LABORATORY

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REPORT NO. 7801

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PREFACE

The present paper gives an account of the preliminary result of the work which has been carried out in recent years to build up a fire research laboratory at Aalborg University Centre. The work began in 1973 with some provisional set-up of facilities for structural fire testing, however, the developing and completion of the laboratory equipment to the present form has mainly taken place from the summer of 1975 to the summer of 1977.

The construction of the laboratory equipment has been carried out with the financial support of

Information Council of the Timber Trade

Danish Council for Scientific and Industrial Research

Aalborg University Centre Research Committee

with the additional support from the Institute of Building Technology and Structural Engineering in the form of project contributions, manpower, laboratory facilities, and other equipment.

It might seem a bit awkward that the paper on the laboratory facilities is published already now, when the construction has just been finished and a comprehensive work on analysis of the equipment still remains, before it can be fully utilized in qualified experimental work. This has been done due to our wish to inform as early as possible of the completed and current work, so that the further work may profit from the criticism, which we hope the paper will give rise to. Furthermore, it can be hoped that some of the construction ideas realized during the work might be utilized by colleagues working with related tasks.

Aalborg, March 1978

Niels Jørgen Hviid　　　　Frits Bolonius Olesen

INTRODUCTION

The present paper, Part 1: Testing Facilities at the AUC Fire Research Laboratory, deals with the design and construction of laboratory equipment to investigate the strength and deformation properties of load-bearing structures under and after fire exposure. This paper marks the end of phase 1, the construction phase, of the total project: »Structural Fire Testing» at the Institute of Building Technology and Structural Engineering at Aalborg University Centre. The next phase, the phase of analysis, which to some extent overlaps the first phase, comprises an intensive analysis of the functioning and capacity of the equipment, solution of a number of still not fully clarified practical testing problems, and on this basis correction, adjustment and specific completion of the measuring equipment.

Parallel with this it is planned to carry out some specific investigations of load-bearing structures exposed to fire. These investigations primarily aim at supplementing the already existing experimental foundation for introducing methods for structurel fire engineering design into the Danish codes for load-bearing structures. Efforts in this field have been made during recent years within the code organization of the Danish Society of Engineers, cf. ref. [1].

It has been aimed at making this paper as brief as possible with the main stress on illustrative system- and construction drawings and limiting the text to the minimum of technical specification which is necessary for the description of the main data and applications of the equipment.

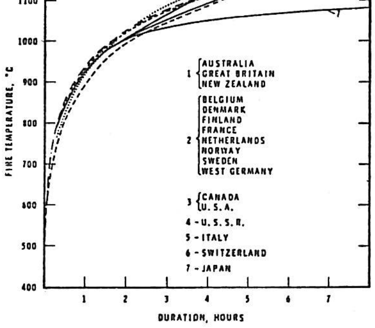
PURPOSE OF THE PROJECT

The purpose of the project, Structural Fire Testing, is to make a contribution to solve some of the testing problems involved in structural fire research. It seems natural and necessary to keep up with the development in recent years towards procurement of methods for a differentiated structural fire engineering design in trying to develop suitable principles and methods for experimental verification of the results of the theoretical fire research. Furthermore, it can be hoped that the analysis and development work that must be carried out to solve some of the testing problems in this context will also be useful in future work with development of classification test methods of more traditional kind.

BACKGROUND FOR THE PROJECT

It has been a characteristic feature of the last 10-15 years' intensive structural fire research that the applicability of for that matter very valuable experimental work has been limited due to inadequately well-defined test conditions, especially with regard to the thermal loads. The fire test methods developed in the USA and UK about half a century ago, which are used in principle unchanged in to day's fire classifiaction tests in most countries, have mainly functioned satisfactorily for their purpose, because the reproducibility has in itself been of main importance, to some extent even more important than the analysis and control of the physical mechanisms under the testing. As a practical, convenient and for the purpose reasonably reliable control parameter the gas temperature of the furnace has been used so far, expressed by a standardized

Standard temperature-time curves used in various countries for fire testing of building components, cf. ref. [9].



temperature-time curve, e.g. the ISO Standard Curve, cf. ref. [2], or a similar almost identical curve.

However, as pointed out by Knublauch, ref. [3], Paulsen [4], and numerous other authors, control according to the gas temperature of the furnace gives far from unique thermal exposure and consequently, great differences from one furnace to another, all dependent on their geometry, construction, and heating method - and besides, also dependent on the test specimens. And by comparison between furnace tests and experimental fires the gas temperature is not usable either as a parameter for the thermal exposure, as pointed out by e.g. Butcher and Law [5]. And finally, as proved by Ödeen [6], Magnusson and Thelandersson [7] and numerous other authors, there is no correspondence whatsoever between the standard time-temperature curves and the development of a real fire, dependent on the fire load, the ventilation properties and the thermal and geometrical properties of the fire compartment.

Though these standard test methods must thus be characterized as generally less suitable for research purposes a great deal of experimental work on structural fire research has been carried out in accordance with similar principles, among other things because often traditional fire testing equipment has been the only equipment available. And though in most cases proper recording of the many different data determining the time progress of the thermal load has been made so that the test can be reproduced in principle, many test results have been published in a form which strongly limits their information value because very often the fire development has been characterized only by the temperature curve of the furnace. Morover, it is often a drawback to research purposes that furnaces of traditional design (generally heavy structures of great thermal inertia) do not have so great manoeuvrability that the desired degree of dynamic thermal control can be obtained. Still, in the course of time various efforts have been made to define a »fictitious time of fire duration» on the basis of standard fire resistance tests, but as shown by Pettersson [8], predicting the fire behaviour requires a calculation work to about the same extent as a functional design procedure if it shall be realistic.

Furthermore, it has put a limit to the value of much experimental work that there were often no choice byt to carry out tests under more or less provisional conditions which in many cases do not sufficiently satisfy the requirements for well-defined test conditions that would be made of today's experimental work with load-bearing structures. In this respect too, the information value of many test results is limited due to less adequate and for the purpose not always suitable laboratory facilities with regard to support conditions, load- and deformation recording.

Finally, it appears to be a lack in connection with structural fire research that there are hardly any investigations of the response of load-bearing structures to momentaneous surface cooling under fire extinction, a matter which is specially relevant to prestressed concrete structures and lightweight insulated steel structures.

DESIGN CONDITIONS

On the above-mentioned background the following conditions for the design and construction of the fire laboratory have been set up:

1. The load equipment should allow combined load- and fire testing of

load-bearing structures - especially columns, beams, joints and similar structural members which it has not so far been possible to test in this country - under different and well-defined support conditions and with a high degree of accuracy of the load- and deformation measurings.

2. The furnaces should allow testing under well-defined thermal testing conditions and make possible a high degree of dynamic thermal control.
3. The equipment should make possible momentaneous extinction and cooling of test specimen and furnace under the tests.

Furthermore, it has been a prerequisite that the equipment is flexible and easily convertible to various tasks, that it is economical in design, operating and maintenance, and that to the greatest possible extent it can be combined with ordinary equipment for load- and deformation measuring.

On these conditions it has been chosen to built up the laboratory as a number of relatively traditional load equipment and load- and deformation measuring equipment. The furnaces, however, have been built as a flexible system of demountable lightweight modular components that can quickly and conveniently be combined to cope with any task within the limits of the capacity of the load equipment.

CONSTRUCTION OF THE LABORATORY

The fire laboratory is erected in the 200 m^2 test room of the institute. Figure 1 shows the arrangement of the about 60 m^2 area which is reserved for fire laboratory equipment. The laboratory comprises the following combined furnace/load equipment:

furnace/load equipment for columns

furnace/load equipment for joints

furnace/load equipment for beams

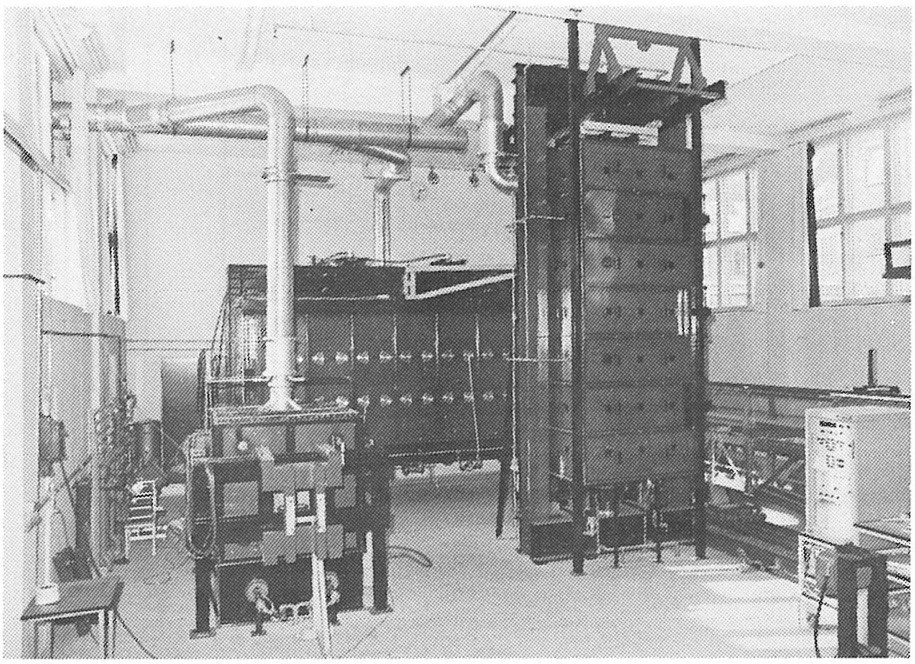


Figure 1. The disposition of the Fire Research Laboratory at AUC.

with the individual technical installations connected to the common installations of the laboratory for gas supply, extortion, extinguishing, outlets, etc. Also, to the greatest possible extent, load-, deformation- and thermal control, measuring equipment and data processing equipment are common to the three arrangements.

Figure 2 is a diagram which shows in principle the total composition of the laboratory. The equipment comprises the following components:

load equipment
furnaces
gas burner systems
extortion systems
extinguishing systems
security equipment
data processing equipment

that will be briefly described in the following.

LOAD EQUIPMENT

The load equipment comprises equipment for columns, equipment for joints, and equipment for beams.

The loading frame of the *load equipment for columns* (cf. fig. 3) comprises two verticals of sectional steel (HE 240 B) and an upper and lower

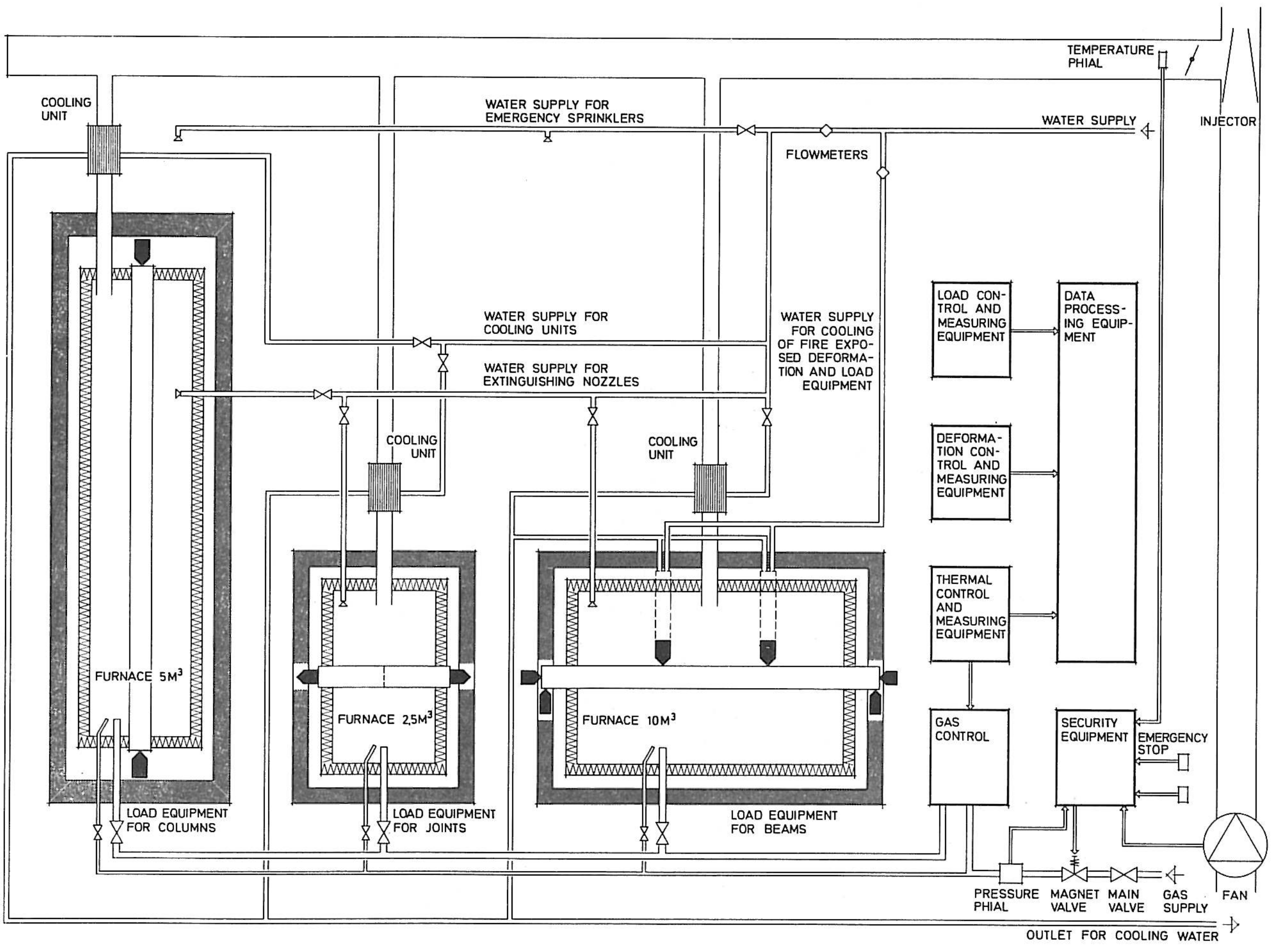


Figure 2. Diagram showing the composition of the laboratory in principle.

cross-member, each of which is composed of two sectional steels (HE 400 B), coupled to box sections. For the purpose of leaving as much room as possible for the test specimen the upper and lower bearing is inserted into the cross-members.

The loading frame is designed for a central load of 2000 kN.

The lower bearing consists of a 2000 kN hydraulic press of the make Bahco, type CX 200-100, at the surface of which a ø 200 mm cylinder of hardened steel is placed with its surface turned as a spherical surface (r = 400 mm), from which the force is transmitted to the test specimen through a distribution board (h = 125 mm).

The upper bearing consists of a 2000 kN load cell of the make Bofors, type LPM-1-T10, from which the force is transmitted to the test specimen through a spring-suspended distribution board (h = 125 mm). At

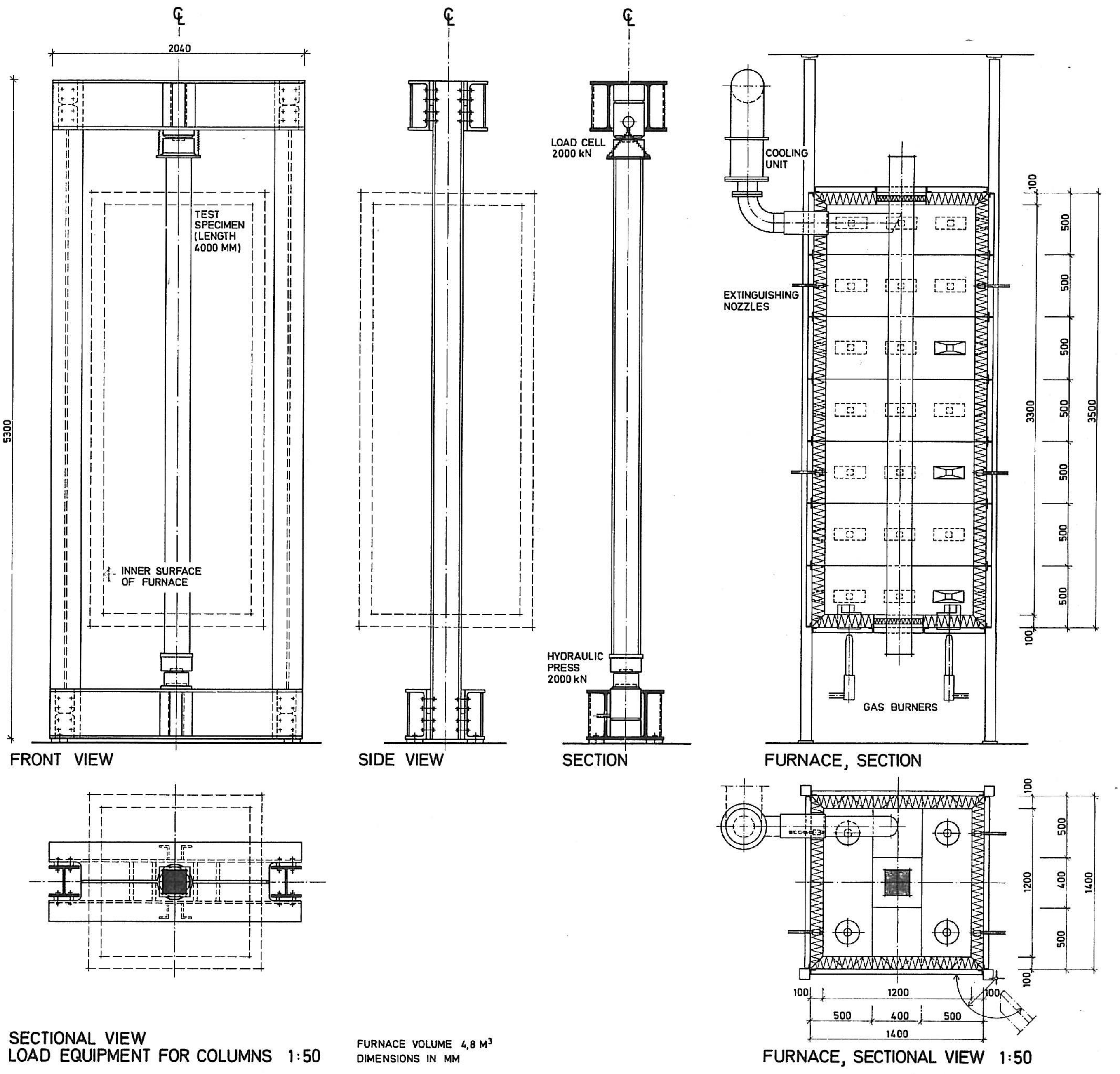
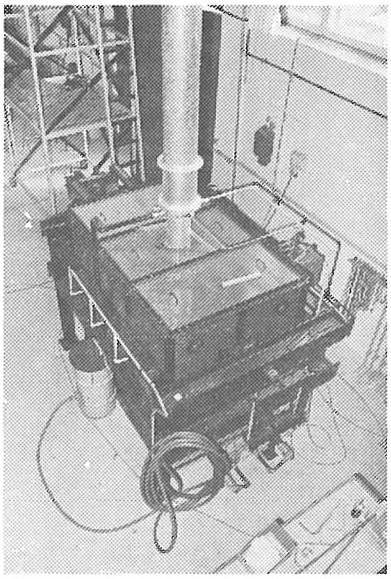


Figure 3. Combined furnace/load equipment for columns.



Combined furnace/load equipment for joints.

both upper and lower bearing fixing arrangements have been placed to ensure immediate exact positioning of the test specimen.

The compression force in the test specimen is measured by the load cell which makes it possible to record the test load at a maximum error of about ±0.5%.

To hoist and mount the 4000 mm long test specimens mounting equipment comprising electric winch (capacity 5 kN), a trolley and two running rails have been made in connection with the loading frame.

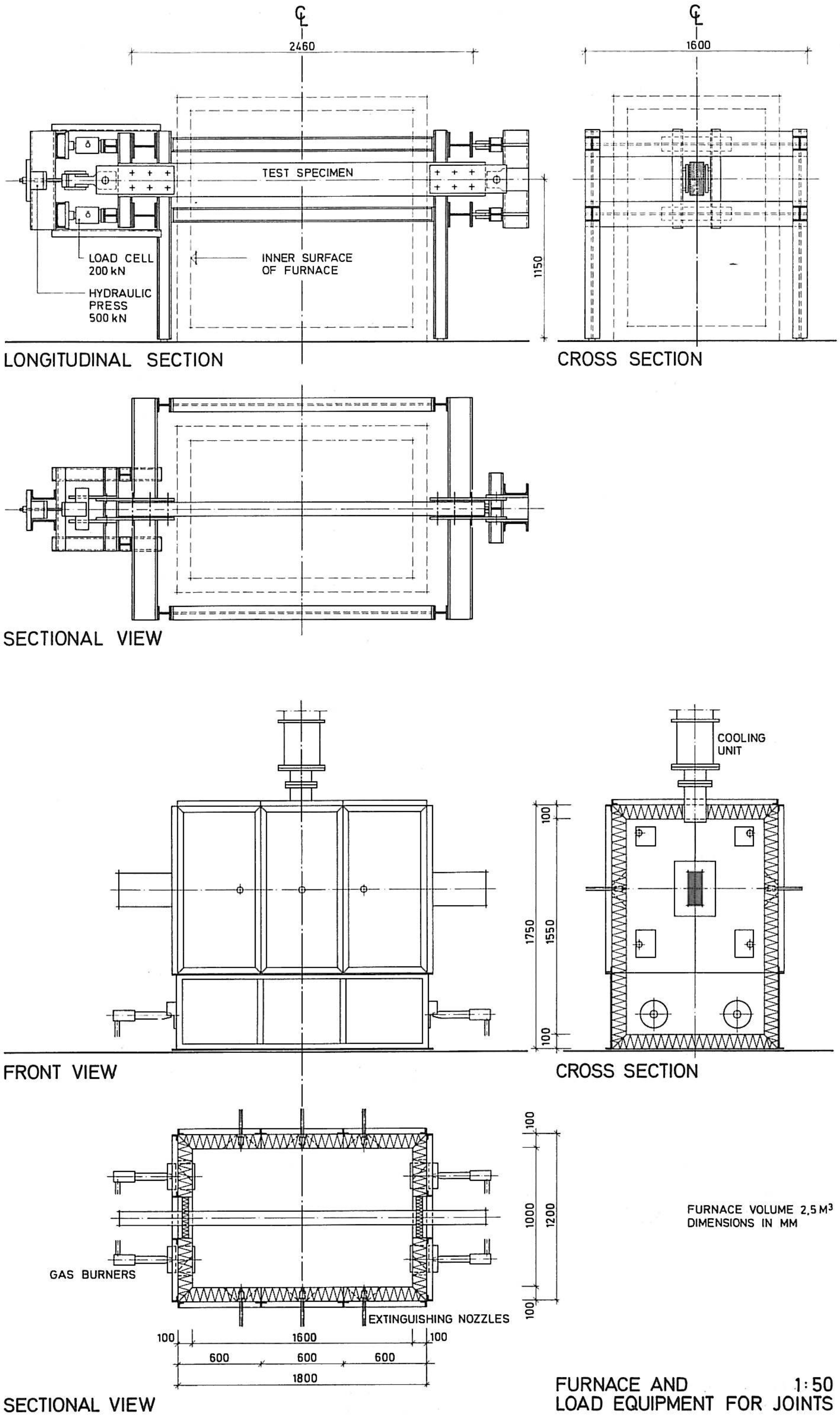
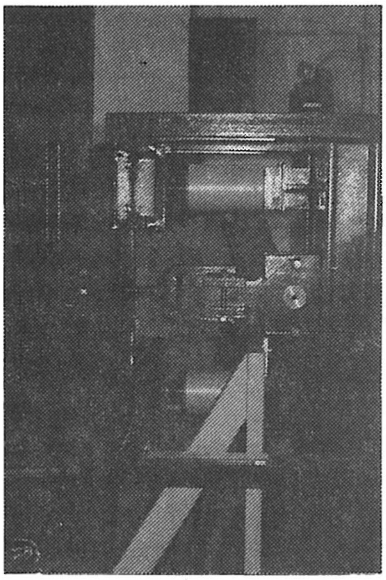


Figure 4. Combined furnace/load equipment for joints.

The loading frame of the *load equipment for joints* (cf. fig. 4) comprises two horizontal frames each of which is composed of two load rods (HE 100 B) and two cross-members (HE 180 B) and carried by four columns in the corners. The loading frame is designed for a central load of 200 kN.



The active bearing of the load equipment for joints.

The tensile force is transmitted to the test specimen through special jaw fittings mounted at either end of the test specimen. Through special gear fittings, which make possible turning about both vertical and horizontal axes, an almost moment free transmission of forces between test specimen and loading frame is ensured.

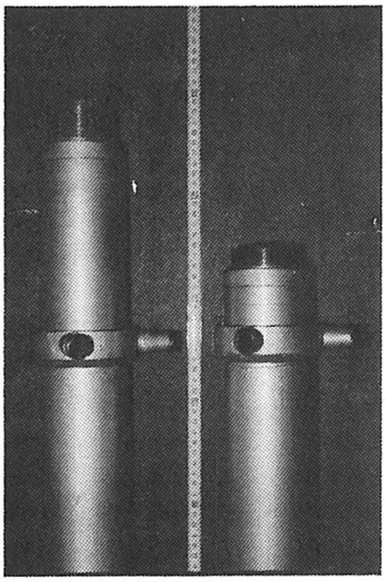
The test specimen is secured at the passive bearing, and at the active bearing a 500 kN hydraulic press of the make Bahco, type CH 50-40, with 40 mm stroke is inserted. Between the cross-members on which the press is mounted and the cross-members of the loading frame two 200 kN load cells of the make HMB, type C1, making is possible to record the test load at a maximum error of about ±0.5% are inserted. The measuring of the axial deformations of the test specimen is made by inductive displacement transducers mounted on a gauge bar at either end of the test specimen. The gauge bar is independent of the loading frame.

The loading frame of the *load equipment for beams* comprises two vertical portal frames. Each of these is composed of a top girder (IPE 500) rigidly connected with the frame legs (HE 200 B) which are held together by a bottom girder (IPE 200).

The loading frame is thus arranged that vertical loads can be applied on the test specimen at intervals of 300 mm. Inside the furnace these loads are downwards directed and outside the furnace they are both upwards and downwards directed, because each end support is designed for a maximum reaction force of 300 kN upwards as well as downwards directed. Thus it will be possible to create varied support conditions corresponding to the test specimen being simply supported, single-sided or double-sided restrained. An axial compression force up to 300 kN can be applied on the test specimen independently of the vertical load.

For each downward vertical load applied on the test specimen a double cross-member (HE 120 B), on which a 200 kN hydraulic press of the make Bahco, type CX 20-150, is mounted, can be placed on the top girders of the loading frame.

Water-cooled load rods for the load equipment for beams.



On the plunger of the press a 200 kN load cell of the make HBM, type C1, is applied. From the spherical head of the load cell the force is transmitted to the test specimen through a water-cooled load rod. The water-cooling ensures that the load-carrying capacity of the lod is maintained during the exposure to fire and that its temperature can be kept so constant that the rod can be used to measure the deflections of the test specimen. Between the load rod and the load cell an extension joint can be inserted which in steps of 10 mm can be adjusted to test specimens of various dimensions. Deformation measurements in additional measuring points are made correspondingly with water-cooled gauge sondes.

To create an axial force in the test specimen a hydraulic press of the make Bahco, type CH 50-40, is mounted on one set of frame legs from which the force is transmitted to the test specimen through a 500 kN load cell of the make HBM, type C2M, with a distribution board mounted on the spherical head.

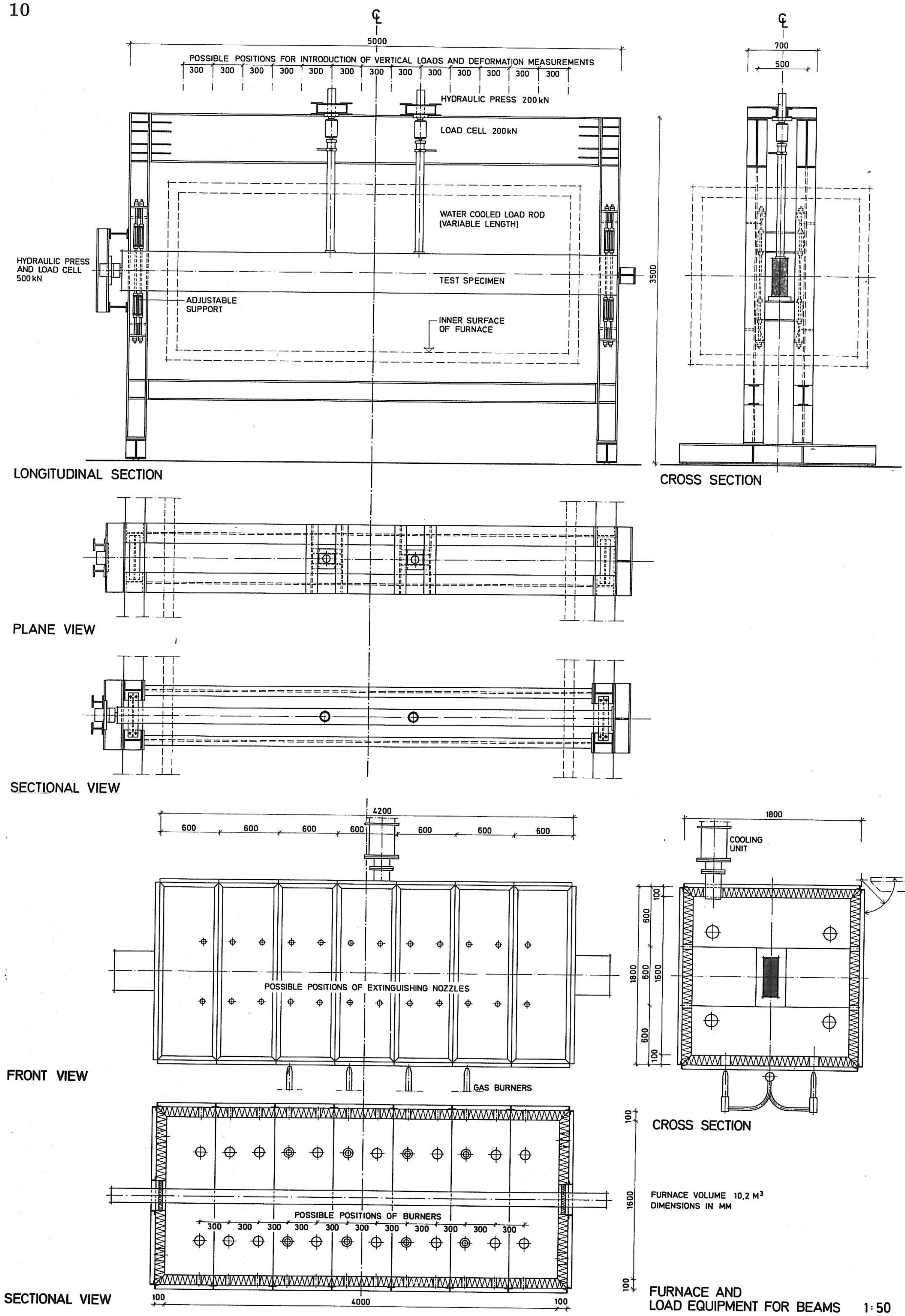


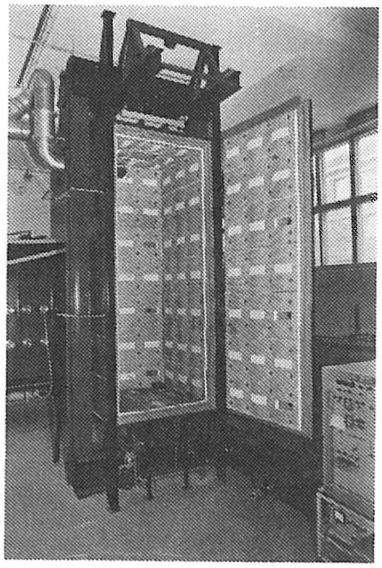
Figure 5. Combined furnace/load equipment for beams.

FURNACES

The furnace of the *load equipment for columns* is composed of mineral-wool insulated steel elements and has the inner dimensions

$$h \cdot b \cdot \ell = 3300 \cdot 1200 \cdot 1200 \text{ mm (volume } 4.8 \text{ m}^3)$$

Apart from a few special elements at the top and bottom of the furnace the elements have the dimensions 500·1400 mm and are composed of an outer steel plate with angle iron edges and insulated with 75 mm heat-resistant rock wool and 25 mm kaolin wool and at the inner surface a 1 mm perforated steel plate secured to the front plate with 8 steel binders. Each element is supplied with three square observation holes. The furnace is built up of elements mounted on four corner columns, secured to floor and ceiling. The elements at one side of the furnace are side-hinged so they form one coherent gate.



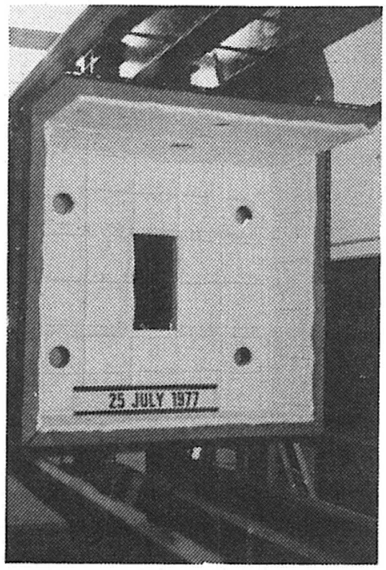
Furnace of the load equipment for columns.

Correspondingly, the furnace of the *load equipment for joints* is composed of mineral-wool insulated steel elements (building dimensions 600·1200 mm) mounted on an about 550 mm high base of a similar construction as the elements. The inner dimensions are:

$$h \cdot b \cdot \ell = 1550 \cdot 1000 \cdot 1600 \text{ mm (volume } 2.5 \text{ m}^3)$$

The furnace of the *load equipment for beams* is constructed in the same way as the other two, however, without the inner perforated steel plate, and instead the insulation is secured by a network of 1.5 mm Kantal-wire. The furnace is built in accordance with a spatial modulus system with the basic modulus of 6M (= 600 mm). Thus it has been possible to build the furnace of 32 elements of the same building dimensions, 600 · 1800 mm, and 4 smaller special elements at the gables. The inner cross-sectional dimensions of the furnace are h·b = 1600·1600 mm, while the inner length can be varied from 1600 mm to 4000 in steps of 600 mm, corresponding to a volume varying from 4.1 m^3 to 10.2 m^3. The purpose of this variable longitudinal dimension of the furnace is to permit support of the test specimen at a number of points outside the furnace so that different conditions of support can be obtained. On account of the modest weight of the elements (about 30 kg per element) it will be possible to adapt the length of the furnace quickly and conveniently to the actual jobs.

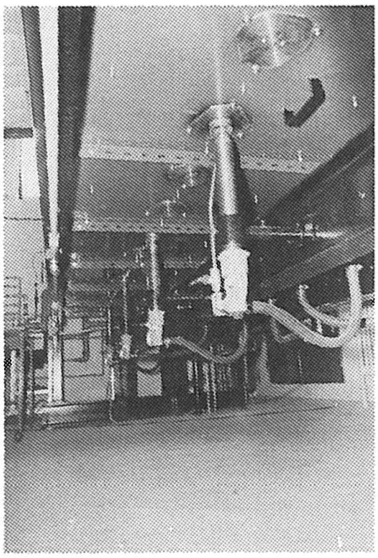
Erection of furnace elements of the load equipment for beams.



At the top of the furnace holes are made in the vertical symmetry plane, which allow introduction of loads or deformation gauge sondes per 300 mm, The elements at one of the vertical longitudinal sides are top-hinged so they form one coherent gate. Each element of the vertical longitudinal sides is supplied with 4 observation holes and each of the gables also with 4 holes.

GAS BURNER SYSTEM

The furnace of the *load equipment for columns* (cf. fig. 3) is heated by 4 gas burners of the make AMAL 354/6 for city gas, at a total input of maximum 200 kW. The burners are inserted at the bottom of the furnace turned vertically upward and placed at the quarter points of the diagonals symmetrically about the vertical axis of the furnace. The burners are lit by 4 manually operated igniters.



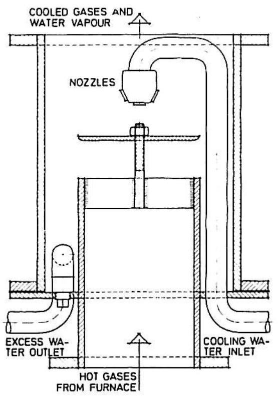
Gas burners mounted under the furnace of load equipment for beams.

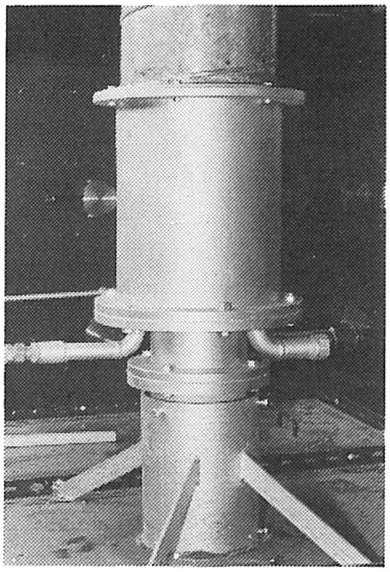
The furnace of the *load equipment for joints* (cf. fig. 4) is heated correspondingly by 4 small gas burners of the make AMAL 354/5 mounted two and two at both of the short sides of the base of the furnace and led into the furnace at a height of about 150 mm above the bottom.

The furnace of the *load equipment for beams* (cf. fig. 5) is heated by a number of gas burners of the make AMAL 354/5 mounted under the furnace under fire holes in its bottom elements. With a mutual distance of 300 mm between them the holes are arranged in two longitudinal rows 900 mm apart. From these 24 possible positions for placing the burners a number only limited by the 13 coupling spots on the distributing main under the furnace is chosen according to the nature of the task. Unused fire holes are covered.

Each of the three burner systems can be connected to a common control board where the gas supply is controlled by 4 ball valves mounted parallelly.

On account of the low thermal inertia of the furnaces it is possible with this equipment to control the gas supply in accordance with a desired thermal development of which a wide range can be chosen, e.g. with considerably higher heating speed than that corresponding to the standard temperature-time curve in relation to ISO 834.





Cooling unit of the extortion system for waste gas.

EXTORTION SYSTEMS

Directly outside each furnace the waste gas is led into a cooling unit consisting of an about 50 cm long vertical steel duct to which atomized water is led through a number of nozzles. The passage of the waste gas through the water fog will result in so much vapour that the temperature of the waste gas will decrease to about 100°C. Water is sprayed in in such quantity (10-20 ℓ/min.) that a certain surplus is always running through the outlet of the cooling unit.

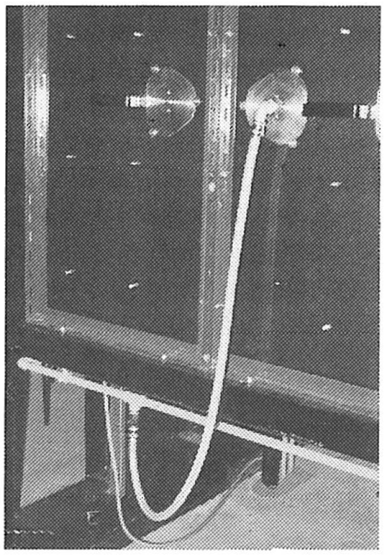
Through galvanized steel ducts the waste gas is led to a 280 mm circular main duct which is suspended under the ceiling of the test room. The main duct is led to an injector in an exterior vertical 315 mm outlet duct led up above the edge of the roof. The injector is supplied with air through a 280 mm vertical duct from an exterior ventilator with a capacity of 3600 m^3/h at a total pressure of 160 mm VS. The arrangement is seen in figure 2.

EXTINGUISHING EQUIPMENT

Extinguishing equipment in the form of nozzles for spraying atomized water is mounted on each furnace to make it possible to extinguish combustible test specimens and to cool test specimens and furnaces instantaneously.

At the furnace of the load equipment for columns 8 extinguishing nozzles are mounted in a firm position on two opposite walls of the inner surface of the furnace. When extinguishing or cooling is necessary at the furnace of the load equipment for joints 6 adjustable nozzles are led in through the observation holes placed at the longitudinal sides of the furnace.

In the furnace of the load equipment for beams an extinguishing nozzle is mounted on a number of the boards used to cover the observation holes at the longitudinal sides and the gables and unused holes in top and bottom elements. All cover boards and their fastening to the furnace elements are identical so in principle the extinguishing nozzles can be placed arbitrarily in these holes, only limited by the possibilities of connection to the pipe stubs (a total of 12) at the three supply strings which are placed along the top and longitudinal sides of the furnace.



Extinguishing nozzle mounted on a furnace element of the load equipment for beams.

SECURITY EQUIPMENT

The gas burner system is secured so that the magnet valve is turned off or cannot be activated

if there is no voltage on the motor of the fan or

if the gas phial records insufficient gas pressure in the pipe system or the magnet valve, or

if the thermal control records too high temperature in the outlet duct, or

if one of the two emergency stops switches is activated.

As a further security arrangement manually operated sprinklers are mounted on the ceiling above the furnaces.

Besides, there are various hand extinguishers in the laboratory.

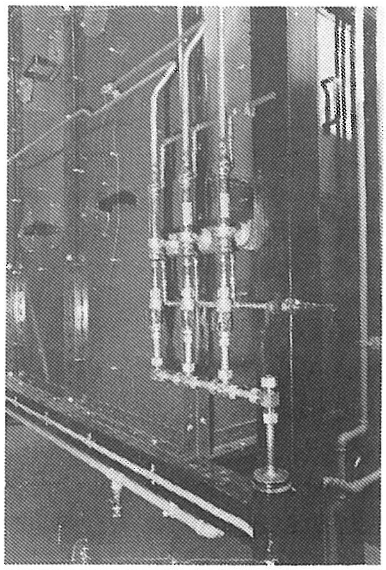
COLLECTION OF MEASURING DATA

The data processing equipment systems for load measuring, deformation measuring, thermal measuring, and a data recorder connected to a printer and tape puncher. In the following the parts are described individually.

Load control and measuring equipment

This equipment comprises three parts: power supply, load cells and control board. The individual load cell is supplied with voltage from a distributor box with connection possibilities for up to 12 load cells or other voltage-dependent transducers, and its output signal which is proportional to the input voltage and the imposed force is led to a control board built into the distributor box. Digital voltameters on the control board make it possible to watch the signals from up to three load cells at the same time and from here to control the supply of oil to the hydraulic presses. Besides it is possible on the control board constantly to control the supply voltage on a separate digital voltameter. From the distributor box both the input voltage and the signals from the connected load cells and other transducers, if any, are led to the data recorder.

Pipe and cooling system for waste gases before inlet into the oxygen analyser.



Deformation control and measuring equipment

This equipment comprises two parts: Power supply and displacement transducers. The individual displacement transducer is supplied with voltage from the above-mentioned distributor box, and its output signal, which is a rectilinear function of the displacement, is led through the distributor box to the data recorder.

Thermal control and measuring equipment

The thermal properties in the furnaces are detected by means of unprotected thermocouples, suction pyrometers and heat fluxmeters. The unprotected thermocouples are used for measuring temperatures in the furnaces as well as inside the test specimens and on their surface. Both these thermocouples and those in the suction pyrometers consist of Chromel-Alumel thermocouple wire designed and placed in accordance with the actual task. While the suction pyrometers give information only about the gas temperature in the furnace, the heat fluxmeters make it possible to measure the total thermal action on a specimen during the test.

The signals from the thermocouples are recorded either by twelve-channel point recorders, from which the output is used by the manual control of the gas burners, or via a digital temperaturemeter by a data recorder.

Further analysis equipment
For analysis of the chemical composition of the furnace atmosphere the laboratory is equipped with a system for measuring the oxygen content. In a number of positions at each of the furnaces outlets are mounted from which the sample is drawn through a heat exchanger to an oxygen analyser of the make Teledyne, type 9600AX.

The handy furnace elements make it convenient to arrange supplementary equipment for measuring further relevant parameters of the furnace atmosphere.

Data registration and processing
The signals of the thermoelements are recorded graphically on a 250 mm wide chart in twelve-channel point recorders with a measuring range from 0-1200°C and variable paper and scanning speed. The output voltage from other transducers used and other voltages, if any, which are to be measured are recorded by the printer or tape puncher connected to the data recorder.

Further treatment of the recorded measuring data will then be carried out manually from the printer output or by a computer using the tape from the puncher.

The output from the twelve-channel point recorders must always be treated manually.

ADDITIONAL REMARKS

Although no final conclusions can be drawn at present with regard to the detailed function of the fire test equipment the pilot tests carried out so far have given reasonable proof of the functional abilities of the equipment. The construction system with furnaces of demountable lightweight elements of low thermal inertia seems to allow the desired high degree of dynamic operating, to be adequately sturdy to repeated momentaneous coolings and on the whole to be extremely convenient to handle (the erection of the furnace of the load equipment for beams was thus made in 5 days by two men).

The most essential task to be dealt with now is a thorough analysis of the thermal conditions of the furnaces so that a set of thermal characteristics can be worked out which can allow control of the individual furnace subsequent to the desired thermal action on the test specimen. Probably this work will give rise to adjustments of the equipment and make it desirable to complete the measuring equipment especially with regard to analysis of the furnace atmosphere, radiation conditions, etc.

Dependent on the result of this phase of the project the structural principle developed here will make it possible for relatively modest means to supply existing structural research laboratories with proper and reliable equipment for structural fire testing. Especially for strong-floor structural laboratories the system holds good possibilities to create facilities for structural fire research at a reasonable investment.

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