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Experience of Fires in Concrete Structures

by A. K. Tovey and R. N. Crook

Synopsis: This paper outlines the procedures adopted in obtaining information on fire-damaged concrete structures since 1975. Details are given on the information received from questionnaires and a summary of the building and construction types, damage and repairs are tabulated. The general conclusion is that concrete structures behave well under fire conditions with the majority of cases being repairable.

Keywords: buildings; concrete construction; damage; fire resistance; fires; performance; prestressed concrete; reinforced concrete; surveys

2 Experience of Fires

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INTRODUCTION

A small number of major fires in concrete structures have been well investigated and reported in various publications (1-5). These indicate the good fire resistance performance of both reinforced and prestressed concrete structures but, in order to gain a more comprehensive picture, the Fire Resistance Committee of The Concrete Society, England, decided to investigate a large number and variety of fire-damaged concrete structures within the UK.

An initial questionnaire, as given in Appendix A, was prepared and distributed to several hundred UK consultants in order to obtain contact with as many people as possible having experience of fire-damaged concrete structures.

Having obtained the contact, the next stage was to obtain detailed information on the structures concerned and, in order to be consistent, a comprehensive record summary sheet as given in Appendix B was developed. This is also to be issued as a questionnaire in future cases of fires.

RECORDING OF DATA

The record summary sheet is divided into six sections. The first part is concerned with the identification of the building and the contact point for information. Section 2 requires a description of the building, particularly its design and construction, in order to have a clear idea of the type of structure before the fire and its potential resistance to fire. Of particular interest is the question of structural continuity. If this was present, it could have had a significant influence on the structure's behaviour pattern and details or an estimate of this are requested. Section 3 aims to establish the type of fire that occurred. It may be that either the fire brigade or subsequent examination by an expert established the severity of the fire. Such information provides a base against which the actual behaviour of the construction can be judged. Section 4 asks primarily for the visual record of damage by spalling and its extent. Spalling occurs in most fires but it is necessary to establish the circumstances under which it may have serious consequences. Section 5 asks for data on structural damage to the parts affected by the fire and how the extent of the damage was established. This is followed by information in Section 6 on the repair work that had to be undertaken to put the building back into commission. A question is asked in the case of reconstruction as to whether the decision was based on the nature of the damage or because of other practical reasons.

BUILDINGS EXAMINED

As a result of this investigation, detailed information has been gathered on the performance, assessment and repair of over 100 fire-damaged concrete structures. The information was obtained from consultants and from the Cement and Concrete Association (England) whose staff have visited and advised on the reinstatement of many fires in concrete structures within the UK. The types of building examined, the type of construction together with the degree of damage and decision in respect to repair is summarized in Appendix C. From this, it will be seen that the structures covered include dwellings, offices, warehouses, factories and car parks of both single and multi-storey construction. Some fires under bridge structures were examined but only one is listed in Appendix C. The forms of construction examined included flat, trough and waffle floors and associated beams and columns of in situ and precast construction in both reinforced and prestressed concrete.

Examining the items under damage and repair shows that:

(1) most of the structures were repaired and many of those which were not could have been but were demolished for reasons other than the damage sustained;

(2) much spalling occurred but most structures still performed satisfactorily even those where supplementary reinforcement might now be required under current UK provisions;

(3) almost without exception the structures performed well during and after the fire.

It is hoped that these investigations will provide essential information on the behaviour of concrete structures in fire to enable recommendations given in the Codes and other relevant documents to be updated. The intention is to prepare a publication giving detailed findings of the investigation. The information gathered contains details of tests on components and methods used for repair. To date, the reports show the performance of concrete structures in fire is generally excellent.

An example of the information that is being obtained may be illustrated by reference to Figure 1. This shows an example of damage to the main structural beams to an in situ reinforced concrete warehouse built around 1930. The fire occurred in 1983 and there was noticeable separation of the floor slab and buckling of the main reinforcing bars over the central section of the beam. The omission of stirrups over the central section has clearly demonstrated a detailing deficiency. Such details would not generally be permitted under our current UK Codes but, despite this, the structure adequately withstood the fire. It is clear that examination of such cases can identify structural deficiencies and hence, when appropriate, be used to modify the Code provisions.

Another case which illustrates a detailing deficiency is shown in Figure 2. In this case, the structure consisted of a continuous reinforced concrete waffle floor slab that was detailed to cater for the appropriate negative and positive bending moments along the span. In accordance with the bending moment envelope, the bottom reinforcement can be stopped short of the spans. This is adequate for strength conditions but the effect of the fire caused the unsupported bottom bars to buckle away from the support zone. The Joint Report (1) recommends that 50% of the bottom reinforcement should continue to the support and that 20% of the top bars should be continued across the span. Again, the structure performed adequately in the fire but had all reinforcement be taken to the support then the element would ultimately have performed better and there would probably have been less spalling and damage.

The building fires investigated varied from minor fires of short duration through to major fires reaching, and at times exceeding, the designed fire period. The equivalent fire period was determined, where possible, from examination of debris, tests on the elements and consideration of the fire load.

The evidence to date shows all structures to have behaved well, even those having less than satisfactory details. Improving detailing can significantly improve the performance under fire and thus, if these are incorporated into the Codes, it should be possible to relax some of the Code provisions in respect to notional fire resistance requirements and yet still maintain a sufficient factor of safety in the event of a fire.

INVESTIGATION OF BEHAVIOUR OF STRUCTURE

The working group responsible for the review is seeking to obtain data on the overall performance of the structures and, in particular, on items which have prompted some concern in the past.

One such area being investigated is the overall effect of expansion and contraction on the complete structure. Although expansion of a hot suspended floor of a building can cause bending and shear to be developed in supporting columns and other members, significant problems arising from such are indeed rare within the UK. In fact, the data already collected has not yielded a single instance where significant damage has been noted in a concrete frame remote from the fire. The only collapses recorded were those resulting from instability of other structural materials.

Another area of concern in the UK is the loss of strength or restraint on cooling which according to the Joint Report (1) "could lead to rapid collapse". Some loss of strength of concrete on cooling is not in dispute but the essential point is that the beneficial restraint due to the effects of expansion obtained when hot is additional to the strength normally expected during a fire. If such benefit is lost on cooling then, according to the severity of the fire, the member still has the appropriate proportion of strength due to its normal methods of carrying load at normal temperature. Once again, no immediate evidence has been obtained which shows adverse or unacceptable behaviour on cooling. Nevertheless, the data is to be re-examined to identify those fires where restraint may have had a major influence on the structural behaviour.

The evidence so far indicates that the major reserve in strength comes from continuity reinforcement at supports rather than from expansive restraint during the fire. The former has the benefit in that the strength is also retained on cooling.

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APPENDIX A

INITIAL QUESTIONNAIRE

1. Have you had experience of a fire-damaged structure since 1975? Yes/No

2. What type of structure was involved:
   a) Shed type
   b) Multi-storey
   c) Other

3. What was the type of construction:
   a) Reinforced concrete
   b) Precast concrete
   c) Other

4. What type of concrete was damaged:
   a) Dense
   b) Lightweight

5. How much of the structure was damaged:
   a) All
   b) Part

6. Was the structure:
   a) Demolished
   b) Repaired

7. Please give the name and address of a contact for further details:

   Name ....

   Firm ....

   Address ....

   ....

   ....

   Tel.No. ....

8. Are there any other comments you wish to add.

APPENDIX B

FIRES IN CONCRETE STRUCTURES

Summary Record No.....

1. REFERENCE DATA

1.1 Name of the building:
1.2 Address:
1.3 Contact:
1.4 Firm:
1.5 Telephone No:

2. BUILDING DESCRIPTION

2.1 Type of occupancy:
2.2 Contents:
2.3 Plan size:
2.4 Height / No. of storeys
2.5 Type of construction (reinforced, prestressed, in situ, etc):
2.6 Brief description:
2.7 Aggregate type:
2.8 Cover to reinforcement (design / actual):
2.9 Supplementary requirement:
2.10 Detailing for continuity:
2.11 Structural design by and construction date:
2.12 Fire resistance requirement:

3. FIRE DETAILS

3.1 Date of fire:
3.2 Fire duration:
3.3 Fire brigade:
3.4 Estimation of fire severity (e.g. BS 476 equivalence):
3.5 Examination of debris for fire damage assessment:

4. FIRE EFFECTS

4.1 Extent of fire spread (No. of storeys, floor areas involved):
4.2 Extent of structure affected:
4.3 Extent of spalling (localized or extensive):
4.4 Reinforcement exposed (locally or extensively):
4.5 Spalling damage to floors:
beams:
columns:
walls:

5. STRUCTURAL DAMAGE ASSESSMENT

5.1 Name of assessor:
5.2 Brief description of damage floors:
beams:
columns:
walls:
5.3 Method of damage assessment:
5.4 Residual deformation:

6. REPAIR

6.1 Was the damaged part repaired or replaced?
6.2 Method of repair:
6.3 If replaced, the reason:

7. GENERAL

7.1 Has there been a previous fire in the building?
7.2 Is a report or photographs of the incident available?
7.3 Can all or some of the information given be published?

APPENDIX C

CONCRETE SOCIETY - FIRE RESISTANCE COMMITTEE

Working Group A

SUMMARY OF INFORMATION ON
FIRES IN CONCRETE STRUCTURES

Ref No.	Type of Building	Type of Construction	Damage	Repaired ?
1	Office block	In situ hollow pot	Localized spalling	Yes - reconcreted
2	Supermarket	Prestressed double tee beams. In situ frame	Spalling of beams	Yes - gunite/ reconcreted
3	Office block	In situ waffle	Spalling to ground floor soffit	Yes - gunite
4	Office block	In situ RC	Spalling to soffit one floor	Yes - reconcreted
5	Information not received *			
6	Department Store	In situ RC	Spalling to soffit one floor	Yes - bonded mortar
7	Office block	In situ RC		Yes
8	College	Precast Prestressed	Localized to service shaft	Yes steel sub-frame
9	Bus Garage	Steel frame + concrete	Severe	No - demolished
10	Office block	Steel frame + concrete	Spalling of beams	Yes - reconcreted
11	Furniture shop	In situ RC	Spalling to ground and first floor	Load test Yes - epoxy mortar
21	Multi-storey	RC and PS	Local damage	Yes
22	Office block	Steel frame + concrete	Spalling of beams	Yes - gunite
23	Warehouse	In situ + prestressed pot floor	Spalling of beams	No - demolished
24	Office block	In situ RC frame hollow pot floor	5 floors damaged	Yes/no Part demolished repair by gunite

APPENDIX C (continued)

Ref No.	Type of Building	Type of Construction	Damage	Repaired ?
25	Warehouse	Precast portal	Damage to single unit	No - demolished Replaced with PC units
26	Hospital	In situ frame	Basement	Yes - gunite
27	Tunnel	In situ RC	Spalling to entire soffit	Yes - major gunite - minor epoxy
28				
29	Office block	In situ	Spalling to soffit 25 mm hard soot	Yes/no demolished bad areas
41	Library	In situ	Limited	Not required
42	Office block	In situ	Basement soffit	Yes/no some demolished gunited areas columns jacketed
44	Power Station	Steel frame + concrete	Thermal expansion Distortion of steelwork Spalling to concrete	Yes
45	Oil jetty	Concrete on steel piles	Severe damage to superstructure Deck burnt through (hydrocarbon fire)	No - demolished and replace superstructure
46	Office block	In situ	Spalling of beams	Yes - bonded mortar
47	-	Steel frame	-	-
48	Office block	In situ	Whole building to some degree Fire burnt for one week	Yes/no some members replaced others repaired
61	Warehouse	In situ	Considerable	-
62	School	In situ + Precast	First floor soffit	Yes structural steel stiffeners
63	Market	Steel frame + precast/prestressed units	Steel - bad damage conc - minimal	Yes/no steel replaced concrete - gunited