Fire Rating Questioned on Post Tensioned and Prestressed Concrete Slabs

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Introduction

A recent United Kingdom fire test of a post tensioned slab designed for a 2 hour fire rating achieved only a 66 minute fire resistance. Spalling began after 11 minutes and after 20 minutes spalling exposed the tensioning ducts which resulted in a significant loss of strand strength. While care must be taken in extrapolating test results from one form of construction to another without assessing differences in thermal and restraint conditions (Kelly, Purkiss, 2008), it also raises concern over the elevated temperature performance of prestressed concrete floor systems used in New Zealand. Factors which affect spalling at elevated temperatures are concrete moisture content, permeability and the presence of compressive stresses. (Kelly, Purkiss, 2008) The prestressed products in New Zealand have a higher strength of concrete than the concrete strength of the post tensioned slab in the fire test. Concrete permeability deceases with an increase in concrete strength. Therefore high strength concrete is more susceptible to spalling at elevated temperatures. Further investigation is required to allay these concerns.

The fire test is presented in an article on '*Reinforced concrete structures in fire: A review of current rules*' by Fergal Kelly from Peter Brett Associates and John Purkiss formally of Aston University and was published in The Structural Engineer magazine on 7th October 2008. This article describes the fire test carried out on the post-tensioned concrete slab, the conclusions of the test and subsequent UK discussions following the fire test.

Recent Fire Test of a Post-Tensioned Concrete Slab

In 2006 a test was carried out on a post-tensioned concrete slab to assess the vulnerability of this shallow form of flooring system to the effects of spalling and compression from restrained thermal expansion. The post-tensioned slab consisted of a one way spanning slab with a 250mm deep RC40 slab with plan dimensions of 8.5m long x 3.6m wide. The slab was prestressed with four 15.7mm diameter bonded prestressing strands inside each of four ducts spaced at 1.2m centres, 16 strands in total. The slab was cured for 111 days before testing and the moisture content at the time of testing was 4.6% by mass.

The slab was designed in accordance with TR43 Post-tensioned concrete floors – Design Handbook (Concrete Society, 2005) for an imposed load of $5kN/m^2$ and $0.85kN/m^2$ superimposed dead load. The requirements of TR43 are similar to those given in the British Standard BS 8110 Part 1(BSI, 1997). The concrete was RC40 normal weight Ordinary Portland Cement (OPC) concrete made with 5-20mm Thames valley gravel aggregate. Cube test results averaged $45.7N/mm^2$. Cylinder strength is used is New Zealand. A cube strength of 45.7 N/mm^2 is approximately equal to a cylinder strength of 36 N/mm^2.

The slab was designed for a fire resistance of 2hrs and had a minimum cover of 40mm from the soffit to the underside of the ducts giving 52mm minimum distance to the centre of the strands.

The slab was exposed to the standard 2hr fire test as defined in BS 476 Part 20 (BSI, 1987) with temperatures monitored using 20 Type K wire thermocouples.

To model the effect of restraint from a real structure the slab was restrained in the direction of span with an initial force of 120kN, giving an additional compressive stress of $0.13N/mm^2$. During the test this was allowed to increase to a maximum value of 1200kN after which it was maintained at this level. An imposed load of $3.3kN/m^2$ was applied during the fire test.

Observations
Spalling of the slab began after 11min and sections of post-tensioning ducts became visible in the furnace after about 20min. The temperature in the ducts reached a maximum of 350-400˚C, but where spalling removed the full cover to the ducts the temperature reached about 920˚C.

Vertical deflection of the slab was initially relatively steady at about 3mm/minute, reaching 180mm after 60mins. Runaway deflection started at about 60min with a maximum deflection of 246mm recorded just before collapse. Collapse of the slab occurred at 66mins. The brittle failure mechanism is most likely the result of the weakened post-tensioned strands as a result of high temperatures strained up to a point where the compressive stress in the top of the slab exceeded capacity and caused sudden collapse.

Conclusions
The authors stated that some of the conclusions from the work are:

'There are obvious discrepancies between the fire data in BS 8110: Part 2 and tests carried out on continuous post-tensioned prestressed slabs. This discrepancy is highlighted by the failure due to severe spalling of a restrained post-tensioned fire test specimen. The specimen achieved only 66min fire resistance against a design fire resistance of 2hr from TR43.'

'… extrapolation of historical levels of spalling to provide concrete cover for modern concretes is both unconservative and potentially unsafe'

'A fundamental review of the basis of the current rules and a programme of fire testing of modern structural components is required to restore confidence in the behaviour of reinforced concrete structures.'

New Civil Engineer (NCE) Website News Items
The conclusions from the Kelly and Purkiss paper were picked up by New Civil Engineer (NCE) magazine which published a news item on its web site (www.nce.co.uk) on Wednesday 15th October 2008. The NCE has brought the results from this fire test to the attention of the Standing Committee on Structural Safety (SCOSS). The secretary of this committee said *'This paper throws up some concerning issues'* and *'Post-tensioned floors may be particularly vulnerable and specifically so if not constructed correctly.'*

Further news items were published on the NCE website on 23rd October and 29th October. Professor Colin Bailey of the University of Manchester blamed the premature collapse of the slab's on "unrealistically" high moisture content of 4.6%. However Kelly rejected criticism and said *'The design amounts of concrete and water determines the initial water content'* and *'Over time concrete dries out, but it can take several years to reach a low moisture content'* and *'With regard to moisture content, Bailey states that 2.5% is a realistic moisture content but offers no evidence to prove this'* and *'Bailey's own paper on the large scale Cardington test pointed out that the moisture content of that building was 3.8% at the time of testing, when the building was already 3.5 years old. Unfortunately, Bailey relies on this assumption rather than evidence'*

The Structural Engineer – Debate Continues
The Structural Engineer magazine has published a number of responses and comments concerning Kelly and Purkiss article. Andrew Minson at the Concrete Centre criticises the article in the 4th November 2008 magazine. Kelly and Purkiss respond in the 18th November 2008 issue. Professor Colin Bailey of the University of Manchester responds to criticisms by Kelly and Purkiss on fire tests conducted on post tensioned slabs at Manchester in the 6th January 2009 issue. In his response Bailey suggests that D49 mesh to the bottom of slab could be used if designers were concerned about spalling. Also in this issue Allan Todd of Corus joins the debate and suggests that full scale fire testing is required and consideration be given to imposing a moratorium on post-tensioned floor construction. Kelly responds in the 3rd March 2009 issue by summarising various points of view and concludes further research is required.

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