Review of Indonesian Standard for Concrete Building Subjected to Fire

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Review of Indonesian Standard for Concrete Building Subjected to Fire

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Abstract

Fire safety engineering design of concrete structures in Indonesia is principally based on individual member from results of isolated beams, columns, and slabs tested in small furnaces. However, researchers identify that the behaviour of individual isolated members is significantly different from behaviour of complex structure connected together when subjected to fire. Although the current guidance is conservative when the entire building performance is considered, it should be noted that the beneficial and detrimental effects in complete structures should be taken into account. The effect of concrete spalling in fire has also not been enclosed sufficiently in the code. It should also be noted that the reduction of steel reinforcement cover could generate premature collapse of the structures. Since designers and engineers need to understand the behaviour of entire structure in fire, developing engineering guidance based on realistic structural behaviour is essential.

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Keywords: building-code; safety; concrete; fire; spalling.

1. Introduction

Modern concrete structures often require special consideration for their fire performance. The special consideration may include the ability of building to fulfil its assigned function in the event of fire. The consideration may also include the stability of building which provides adequate time for the occupants to escape and for fire fighting.

During the past decades, considerable attention has been given to the use of structural building components as physical barriers to prevent or delay the growth and

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spread of fire. Since concrete is a non combustible material and a good insulator, this phenomenon also applies to concrete structures which traditionally have a favourable position in the building industry. Consequently, the understanding of the behaviour of concrete building subjected to fire is essential for reliable analysis and safe design.

The Institute of Structural Engineers [The Institute of Structural Engineers 2003] explained that there are two primary ways of achieving an adequate standard of fire safety in building including the fire performance of structures. First is the simple application of the building codes and standards and secondly is a fire safety engineering solution. The application of the building codes and standards gives little flexibility and require only a limited engineering approach. The second way gives greater design flexibility to achieve a particular performance of the building and requires greater skills involving the analysis, risk assessment and engineering judgement.

This paper is mainly concerned with the review of Indonesian Standard as guidance for concrete structure subjected to fire. Since the removal of concrete cover to steel reinforcement could direct to premature collapse of the structures, special attention is given to the effect of concrete spalling in fire [Khoury 2000, Malhotra 2000, Connoly1995] which is not covered in the standard.

2. Standard Fire Test

The Indonesian standard fire test has been in existence since 1987 [SKBI 1987]. The thermal exposure of time versus temperature used in the standard is based on ISO 834 [ISO 1975] which is also adopted as the basis for most national fire resistance procedures. The thermal exposure is based upon an air temperature measured nominally 100 mm from the fire exposed face of the element is presented in the following formula:

$$T = T_0 + 345 \log(8t + 1) \quad (1)$$

Where: T= furnace temperature (^{o}C),

T_o = ambient temperature (^{o}C), and

t=time (minutes).

The mathematical relationship in Eq.1 exists to help programming the control function rather than have been derived from any specific predictive fire growth model [Jackman 2004].When the ambient temperature T_o is assumed to be 20^{o}C, then the Eq.1 can be written as:

$$T = 20 + 345 \log(8t + 1) \quad (2)$$

This formula create a curve in Fig.1 with a very steep initial rise in temperature which slows down as time progresses making a smooth transition into a near steady state heating relationship. Throughout the test, the furnace environment continues to increase in temperature at a reducing rate but at no time does the temperature decrease.

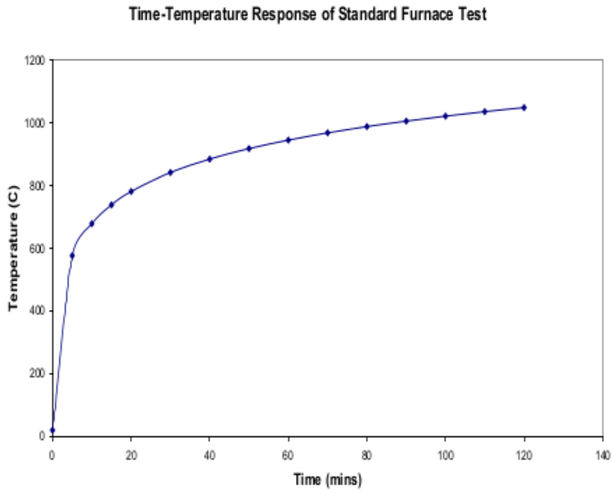

Figure 1. Time-temperature response of standard furnace test

3. Failure Criteria

Based on the fire resistance of individual members, failure criteria of the standard test depend on the type of the member. These failure criteria are simply identified as:

- Stability (R)
- Insulation (I)
- Integrity (E)

The terms in brackets are used in the UK and Eurocodes.

Stability (R), or load bearing capacity, is a measure of the element ability to resist the applied loading over the duration of the test. The criterion of load bearing capacity is an ultimate failure state signified by collapse.

Insulation (I) is a measure of ability to restrict heat transmission throughout the cross section of the element. The temperature on the unexposed face must not exceed an average of 140°C or the measured temperature of any point rises more than 180°C above the initial mean surface temperature. These limits have been set to prevent initiation of combustion of materials stored against that face.

Integrity (E) is ability of the element to resist the passage of flame and hot gasses from fire to unexposed face. The flame should not being able to reach unexposed face through any weakness in the construction or due to excessive deformation during the test. Failure by integrity is simply obtained by ignition of a cotton fibre pad held 25 mm in front of any gap or weakness (fissure, crack, etc.) in the construction. If integrity failure occurs before insulation failure, then insulation failure is considered to have occurred simultaneously with integrity failure.

The stability and insulation failure criteria are capable of being assessed on a calculation basis. However, the integrity failure criterion is not amenable to calculation and can only be determined by physical testing.

4. Perception of Current Standard

As previously stated, the current Indonesian standard is based on the standard fire test regulated on an international basis by ISO 834 which has been subject to amendments since 1975. The current standard is primarily based on the fire resistance of individual members tested in small furnaces. The assumption behind the standard is that the fire resistance of the connected members on the entire structure will be at least equal to the fire resistance of its individual members.

However, researchers identify that the behaviour of individual isolated members is significantly different from behaviour of complete structure connected together when subjected to fire. Although the current guidance is conservative when the entire building performance is considered, it should be noted that the beneficial and detrimental effects in complete structures should be taken into account.

5. Review of Current Standard And Discussions

5.1 Beneficial and Detrimental Effects of Entire Building Performance

Researchers [Bayley 2002, Chana and Price 2003, Izzudin and Moore 2002, Murtiadi 2008] determined that the individual member-based approach is not likely adequate for the majority of entire structure. In fact, the behaviour of the most structures has significant beneficial and detrimental effects during fire. The fire performance of complete structures is significantly different than that of single elements from which fire resistance is universally taken into account. Therefore, considerable attentions should be given to the performance of complete structures.

An obvious difference between whole building and individual member behaviour is that the structure will utilise actual load path mechanisms that cannot be identified from individual member testing [Bayley 2002]. Thermal expansion of a floor slab, for example, can induce high compressive stresses into a heated slab which can be beneficial by inducing compressive membrane action to support the applied load. The compressive membrane action of the floor slab is illustrated in Fig.2.

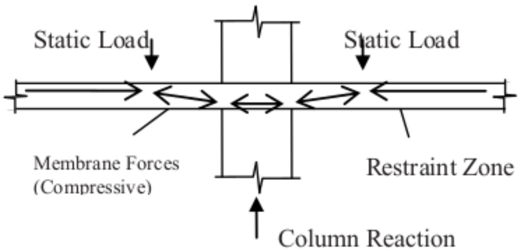

Figure 2. Compressive membrane actions

It is evident that the influence of membrane action in slabs can be very important to the ultimate integrity of compartment. The effect of compressive membrane action will significantly enhance the load-carrying capacity of the slabs provided the vertical displacements of the slabs do not reach greater than approximately half times of its depth.

Another example, as a result of the large lateral movement caused by thermal expansion of floor slab in concrete building under localised fire scenarios, the whole building can lead to premature collapse. These forms of behaviour are not covered in the current standard.

The lateral displacements due to thermal expansion of the floor slab induced additional moment to the vertical members such as columns and walls. The lateral movement of the vertical members have been identified as the cause of failure of concrete structures. This form of behaviour is not covered in current standard and has been highlighted as the main reason for structural collapses of concrete structures in fire. Design engineer should be aware of this behaviour and ensure that the vertical members can resist the lateral displacement during fire.

5.2 Concrete Spalling

Spalling is the breaking off of pieces of concrete from the surface of the structure when it is heated due to thermal stresses or high pore pressures or both. The behaviour of spalling is very difficult to predict although large amount of researches have been carried out into it. This is probably the reason why Indonesian Standard provides no definitive guidance into spalling.

Connolly [Connoly 1995] presented the categorisation suggested by Gary [Gary 1916] that spalling can be grouped as follows:

a) Aggregate spalling, which is defined as a splitting of aggregates at the heated surface. This spalling occurs to areas on the heated surface within the first 20minutes of exposure to the standard heating test with maximum depth of the removed section of about 5 to 10 mm. Aggregate spalling has minor effect on the fire resistance of concrete structures.

b) Corner spalling, which defined as a gradual disintegration of parts of heated concrete at the corner of member such as beams and columns. This type of spalling occurs after 30 minutes of exposure to the standard test. Corner spalling attributed to the loss of tensile strength leading to bond failure. Fortunately, corner spalling can usually be repaired easily after fire.

c) Surface spalling, which defined as the violent removal of sizeable lumps from the heated surface up to 100x100 mm. The loss of sizeable parts of concrete means the effective area of concrete is reduced and the exposure of the steel-reinforcement to fire causes result in rapid rise of steel temperature. Therefore, the fire resistance of concrete structures decreases significantly.

d) Explosive spalling, which is described as a very violent bursting of large parts of heated concrete. This type of spalling is extremely dangerous and may cause sudden and complete failure accompanied by a large release of energy and produces a typical explosive noise.

Concrete exposed to fire causes spalling of the concrete cover and exposure of the reinforcing steel. This exposure will definitely cause a reduction in the resistance strength of the reinforcing steel, and thus reduce the ultimate capacity of the structural element. High-strength concrete is thought to be particularly susceptible to spalling. The incorporation of synthetic fibres such as polypropylene fibres which melt at approximately 160°C during the fire to produce channels where steam can escape is recommended [Connoly 1995].

The design guidance on spalling of concrete has now been codified at European Code [Purkiss 2000]. The addition minimum value of 2.0 kg/m^3 polypropylene to the concrete mix has been specified at this Code to reduce spalling in fire. The Code also provides design guidance which states that the detrimental effect ofspalling can be ignored when the moisture content of concrete is less than 3%.

6. Conclusions

The main conclusions that can be drawn from the above discussion are:

- The results and study from analysis on a complete frame concrete structure indicated that the current Indonesian Standard is based on an incorrect model of structural behaviour.
- The current standard does not incorporate the beneficial effects of compressive membrane action.
- The detrimental effect of lateral displacement of the vertical members such as columns and walls due to large thermal expansion of the heated floor has also not been accommodated.
- Development of fire engineering method is required from the study of whole concrete structures rather than individual member behaviour.
- In order to prevent the concrete members from spalling, minimum value of 2.0 kg/m^3 polypropylene added to the concrete mix recommended at European Code can be suggested to Indonesian Standard.
- As also guided by the European Code, the detrimental effect of concrete spalling during fire can be ignored when the moisture content of concrete is less than 3%.

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