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Composite columns subjected to fire and static loading, review paper

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Abstract

Concrete filled steel tube (CFST) column has been widely used in multi-storey buildings, towers and bridges due to its exceptional structural capacity and high load bearing. As a result of the increase in human activity within the building space and the recent increase in the rate of fires, it is important to research the behavior of this important type of columns under the influence of the combined load of static and fire loads. In this research, an introduction to CFST columns and an overview of published studies on the fire performance of CFST columns is presented. In this research, the focus was on the mechanical properties of steel and concrete and its effect on the column under the influence of high temperatures. To learn about CFST columns and their characteristics, and to diagnose the scientific gap in the behavior of these columns and the characteristics that need to be studied more deeply. Through research, it was found that the yield strength of steel does not have that important effect on the column's resistance to fire compared to the resistance of concrete. It was also found that increasing the percentage of thinness negatively affects fire resistance. The double-skin column is the least studied for its mechanical properties and behavior under high temperatures.

***Keywords**: Composite columns, fire loading, static and fire loading, numerical simulation, concrete-filled steel column, CFST, numerical simulation, Abaqus 2017.*

1. Introduction

Concrete-filled steel tube (CFST) sections have benefits like being strong, flexible, and able to dissipate a lot of energy. Multi stories buildings and long-span bridges use CFST sections as compression and bending members. Both steel and concrete add to the strength of CFST sections. The steel skin stops the concrete from deforming outward, and the concrete stops the steel skin from deforming inward. However, the steel of CFST sections can buckle locally in a way that is either elastic or inelastic when compressed or bent. But there is a lot of strength after buckling in the local mode, and this should be taken into account when figuring out how strong the steel skin is. Estimating the ultimate strength of CFST sections should also take into account the fact that the triaxial confinement of concrete by the locally buckled steel skin makes it stronger [1].

In this paper, a survey of the literature on CFST columns was conducted, and then a survey of the published literature on the fire behavior of these columns was presented. Its purpose is to learn deeply about this important type of columns and understand its mechanical behavior. To know the areas of weakness in understanding his behavior for the purpose of conducting future research to cover this gap.

2. Development of CFST Columns

Composed columns consisting of concrete and steel section especially consisting of a steel tube filled with concrete (CFST), used a lot. Many properties have been studied by experimental and numerical studies, such as: section shape, thickness of the steel, dimensions of the section, strength of material, load eccentricity, length of column, and so on [2].

Recently, some research has been emphasis on developing different kinds of CFST columns to meet different design requirements and enhance structural performance even further. One approach is to use contemporary alloys or alter the design of conventional CFST columns in order to increase the structural strength of composite columns. Concrete-filled double skin steel tube columns (CFDST) were created using two concentric steel tubes with an annulus filled with concrete between them. These were lighter and more cyclically efficient than typical CFST columns, yet they still provided almost all the same advantages [3, 4].

The stiffened columns of CFST, one of the more advanced columns, have been studied for the improvement of thin-walled steel tubes. In order to minimize the effects of local buckling on the thin-wall steel tubes, welding stiffeners were employed since they were affordable [5].

In an effort to conceptually actualize these constructions that can meet architectural requirements, a number of experiments on bent, tapered, and straight-tapered-straight CFST columns were recently carried out [6]. Furthermore, tests were conducted on the tapered CFDST columns as reported in [7]. Proving that a transmission tower cold be built out of this novel, innovative composite column.

Utilizing high-performance steel is another method for producing CFST columns in the present era. For CFST column steel tubes, premium steel with a yield strength of at least 700 MPa has been utilized, and in recent years, a great deal of experimental work has been done [8, 9].

Researchers have been studying stainless steel for almost ten years as an external component for CFST columns. It is another high-performance steel with higher strength, better hardness, and resistance to corrosion [10, 11]. However, since concrete is still a crucial component of CFST columns, various researchers and engineers have worked to create composite columns using different type of concrete instead of regular concrete. For instance, high-strength concrete may significantly increase the load-carrying capacity of CFST columns [12-14].

Recycled aggregate concrete was used to create CFST columns, which reduce the need for landfills and protect natural resources [15]. It was proposed to significantly reduce the structural weight of CFST columns by using lightweight concrete [16, 17].

3. Exposure to high temperature

This section discusses the mechanical characteristics of concrete and steel at elevated temperatures, as well as the behaviour of reinforced concrete columns subjected to high temperatures and fire models.

3.1. Materials mechanical properties

3.1.1. Concrete

Concrete's compressive strength has traditionally ranged between 21 and 51 MPa, classifying it as standard Normal strength concrete (NSC). Concrete with a compressive strength ranging from 51 to 121 MPa has been commonly accessible in recent years and is known as high-strength concrete (HSC). When the compressive strength of concrete reaches 121 MPa, it is known as ultrahigh performance concrete (UHP). Concrete strength declines with temperature, and the rate of strength deterioration is heavily determined by concrete compressive strength.

Phan and Carino, 2000 [18] demonstrated that, In the unstressed residual property tests, the specimen is heated without preload at a specified rate to the target temperature, which is maintained until the thermal steady state is reached. The specimen is then allowed to cool, at a specified rate, to the laboratory temperature. Poon et al., 2001 [19] Said that the unstressed test, and unstressed residual strength test are the three techniques available for determining the concretes residual compressive strength at high temperatures. The last approach is great for figuring out the residual qualities after exposure to high temperatures, whereas previous two ways prefer to determine the strength of the concrete at high temperatures. It was found that the third approach provides less strength and is, thus, more suited for determining limiting values.

Fletcher et al., 2007 [20] comments included, that due to the exposure to high temperature, concrete may undergo a variety of physical and chemical changes. Some of these changes are reversible through cooling, but others are non-reversible and may devitalize the concrete structure after the exposure period. Concrete includes porous which contains an amount of water. When the temperature exceeds 100 °C this water begins to vaporize, usually motiving a build-up of pressure inside the concrete. In practice, due to the pressure effects the boiling temperature range tends to extend from 100 to about 140 °C. Beyond the probability of vaporization deterioration, when the temperature reaches about 400 °C, the dehydration of calcium hydroxide in the cement will begin, generating more water vapour and also causing an additional significant reduction in the physical strength of the material. Aggregates also suffer from changes which may occur at higher temperatures. As a result, these chemical and physical changes in concrete will have a worse effect in reducing the strength of compressive of the material. The researchers concluded that the critical temperature of strength reduction is heavily dependent on the type of aggregate, and the estimated values are siliceous (430 °C), carbonate (660 °C), and sand lightweight concrete (650 °C).

The conventional structural mechanic's techniques may be used to estimate the fire resistance ability of a structural part with information on deformations and characteristic changes. The availability of material characteristics at extreme temperatures enables a quantitative method to estimate structural beam fire resistance [21].

Koksal et al., 2012 [22] showed that a variety of variables influenced the behavior of concrete that had been exposed to high temperature. These include the following: the duration of exposure, the rate at which the temperature rises, the highest temperature at which the concrete mass will reach, the initial temperature of the concrete prior to exposure to high temperature, the degree of water saturation in the concrete, the concrete’s maturity, the type of aggregate and cement used, the ratio of aggregate to cement, and finally the loading status of the concrete at the time of exposure. A rise in external temperature generally causes a progressive decrease of mechanical strength in mature concrete.

The performance of a concrete structural member exposed to fire is influenced by the thermal, deformation, and mechanical characteristics of the concrete used to make the member. Concrete's thermos-physical, mechanical, and deformation characteristics, like those of other materials, vary significantly within the temperature range related to building fires. These qualities change with temperature and are determined by the composition and features of the concrete. Concrete's strength has a major effect on its characteristics at both room and elevated temperatures. The characteristics of high-strength concrete (HSC) change with a temperature different from those of normal-strength (NSC). This difference is more evident in mechanical characteristics, which are influenced by strength, moisture content, density, temperature range, silica fume concentration, and porosity [23].

The mechanical characteristics that determine the fire behaviour of reinforced concrete elements are compressive strength, tensile strength, elasticity modulus, and stress-strain curve of constituent materials at high temperatures.

a. The compressive strength of concrete at high temperatures is of fundamental importance in fire-resistant design. At room temperature the concrete compressive strength is determined by the transition zone between the paste and aggregate, water-cement ratio, the aggregate type and size, the curing circumstances, the admixture kind, and the kind of stress [24]. Compressive strength at high temperatures is heavily controlled by temperature-increasing rate and binders in the batch mix (like silica fume, and slag). According to several publications, the strength deterioration in HSC is not uniform, and there are considerable variances in strength loss. A temperature of up to 400°C has a minimal effect on the compressive strength of normal-strength concrete. NSC is typically extremely permeable and enables simple pore pressure transfer as a consequence of water vapour, Figure (1).

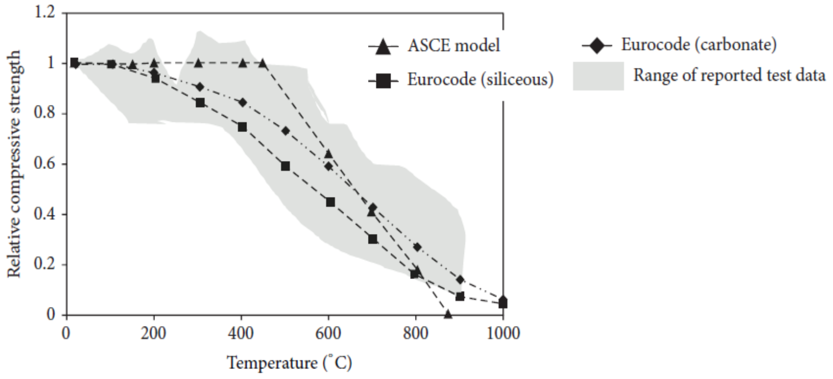

Fig. 1: Temperature effects on the compressive strength of (NSC) normal strength concrete, [23].

b. Concrete Tensile strength is controlled by the same factors that determine the concrete compressive strength [25]. Due to the ease with which cracks spread under tensile stresses, concrete's tensile strength is significantly lower than its compressive strength. Tensile strength for NSC is just 10% of compressive strength, and for HSC, the tensile strength proportion is much lower. As a result, the concrete tensile strength is normally overlooked in strength estimations at high and ambient temperatures. Nevertheless, it is an essential characteristic since cracking in concrete is typically caused by tensile strains and major damage to tension members is frequently caused by the advancement of micro-cracking [26]. The tensile strength of concrete is especially important in situations of fire-induced spalling in a concrete structural element under fire exposure [27]. See Figure (2).

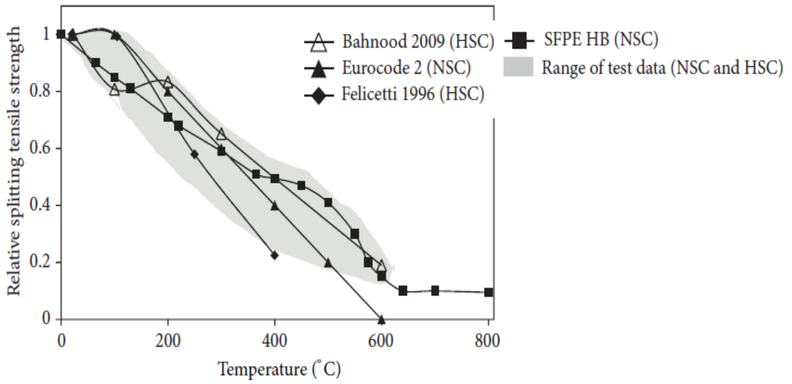

Fig. 2: Concrete's relative splitting tensile strength at elevated temperature, [23].

c. The concrete modulus of elasticity, which reduces with temperature, is another characteristic that impacts fire resistance. The breakdown of hydrated cement materials and the breakdown of bonds in the microstructure of cement paste diminish elastic modulus at high temperatures, and the amount of reduction relies on moisture loss, elevated temperatures creep, and aggregate kind, Figure (3).

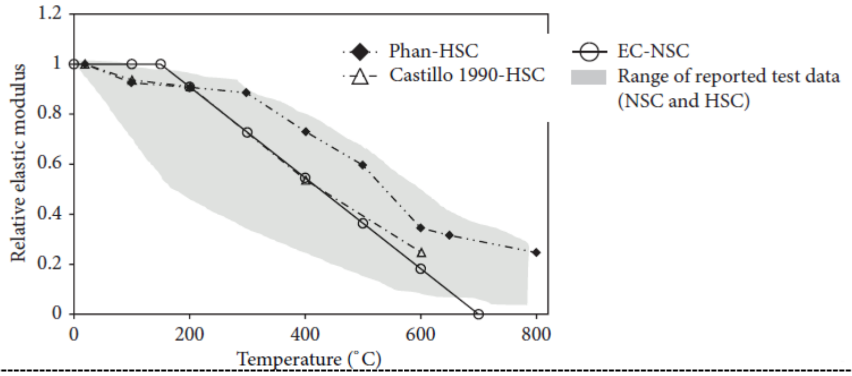

Fig. 3: Concrete modulus of elasticity at elevated temperature, [23].

d. Concrete's mechanical responses are often described in the form of stress-strain relationships, which are frequently utilized as input information in mathematical models for assessing the fire resistance of concrete components, Figure (4). At high temperatures, the stress-strain relation of concrete is normalized. Concerning the influence of the tensile strength of concrete on the tensile membrane effect of reinforced concrete members, [28] showed that for high deformations, concrete tensile strength contributes significantly to slab resistance. As a result, a suitable constituent model for concrete tensile strength at high temperatures is required. Nevertheless, if a more complex computation approach, such as the finite element approach, is utilized, a component model is required. The tensile stress-strain relation given by [29] is used as it can account for the decrease in tensile resistance and bonding strength as demonstrated in Figure (5).

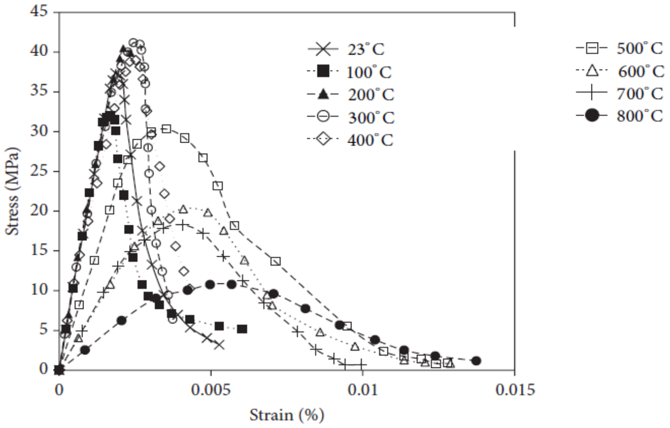

Fig. 4: Stress-strain curves of normal strength concrete (NSC) at high temperatures.

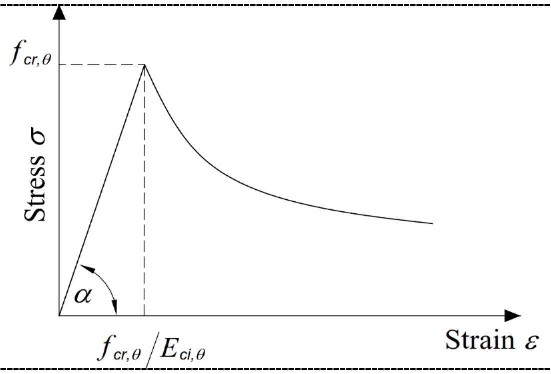

Fig. 5: Tensile stress-strain relation suggested by [29].

e. Thermal expansion coefficient, concrete creep, and reinforcement properties at high temperatures are the deformation qualities that govern the fire performance of RC elements. Furthermore, the transient strain that develops in concrete at high temperatures can amplify deformations in fire-exposed concrete structural components. The thermal expansion coefficient, which measures the expansion or shrinkage of a material unit length when the temperature of the concrete increases by one degree, describes the expansion or shrinkage of the material caused by the heating process. The percentage change in specimen length for each degree of temperature rise is known as the thermal expansion, which is determined by the dilatometric graph a representation of the linear dimension’s proportional change at a certain level [30]. The thermal expansion coefficient is an essential feature in the prediction of thermal stresses induced under fire in a structural part. The concrete thermal expansion coefficient is usually determined by the kind of cement, water content, temperature, aggregate kind, and age [31]. Lie, 1992 [32] gives a curve representing the thermal expansion coefficient of normal-strength concrete at elevated temperatures, Figure (6).

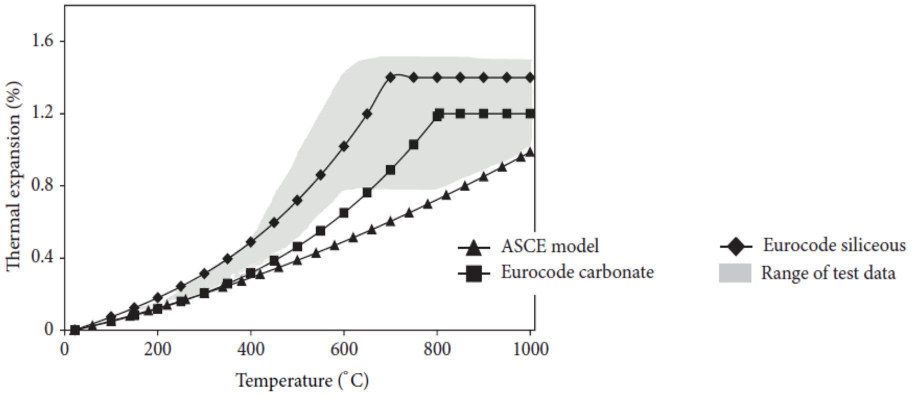

Fig. 6: The thermal expansion coefficient of normal strength concrete at elevated temperature, [32].

For the first time, transient strain is produced and it is time-independent. It is mostly due to the thermal incompatibility of the aggregate with the cement paste [33]. The transient strain of concrete is complicated and is specified by parameters like temperature, moisture level, strength, stress, and mixing proportions.

f. Spalling is specific to concrete and can be a key element in evaluating a reinforced concrete structural member's fire resistance. Spalling is described as the separation of concrete slices from a concrete member's surface which is subjected to elevated temperatures such as those found in fire and fast increases in temperature. Spalling may occur shortly after exposure to quick heat, with powerful explosions, or in future fire stages when concrete becomes so weak after heating that those bits of concrete fall from the surface of the concrete component when cracks develop. Comprehensive spalling can cause early stabilization and integrity loss. In addition, deep layers of concrete are exposed to fire temperatures and therefore the transmission rate of heat to the inner component layers, including reinforcement, is increased. When the reinforcement is exposed directly to fire, the reinforcement temperatures rise extremely high, resulting in a quicker loss in the strength of the structural component. The fire resistance of a structural part is considerably reduced by the loss of reinforcement strength, along with the degradation of concrete related to the spalling [34, 35].

3.1.2. Steel

Holmes et al., 1982 [36] studied the effect of high temperature on the stiffness and strength properties of four steel bars of varying sizes. The test program was designed to provide data on three major parameters [(yield stress (fy), ultimate strength (fu), and elastic modulus (Es)]. They found that the normalized results for the fy, fu and Es for all sizes are as follows:

a. There was no significant change in the normalized value below 300°C.

b. A 50% reduction in both the yield stress and ultimate strength was obtained between (520°C – 580°C), and between (540°C – 700°C) for the elastic modulus.

Edwards and Gamble, 1986 [37] investigated the behaviour of grade 60 reinforcing bars of diameter 12.7 mm after exposure to fire. The bars were burned to temperatures of 500 °C – 800 °C. The furnace was held at peak temperature for about one hour and then slowly cooled. After cooling, the bars were examined in tension. The yield stress was lowered to at least 73 per cent of the unburned one and the ultimate strength was lowered to at least 83 per cent of the unburned one. The heating and cooling of the reinforcement did not change the nature of the stress-strain curves.

Abramowicz and Kowalski, 2007 [38] revealed, that when a temperature increase occurs, the value of steel yield strength and the steel modulus of elasticity drop significantly. However, after the fire, when the structure is cooled down, reinforcing steel usually recovers a majority of its material properties. The true degradation results from these alerts, since certain structural parts’ reinforcement may fail to hold up after being exposed to fire, rendering them worthless.

4. Fire models

4.1. Standard fire resistance tests

A gas, oil, or electric furnace is often used to conduct a fire test. The temperature curves used in these tests include the ASTM E119 curve in North America [39], the JIS A1304 curve in Japan [40], and the international curve ISO834 [41], which is stated in Eq. (1). A comparison of them is presented in Figure (7). There is a small variation between the different fire curves, as the graphic illustrates.

$$T_f = 345 \log (8t + 1) + T_0 \tag{1}$$

Where T_f = the furnace temperature in °C , t = fire duration time in min and T_0 = the initial room temperature. Two criteria are used to determine whether the test CFST column fails in the fire test: 1- the heated column must have contracted axially by 0.01 L mm, where L is the test column's height in millimeters; and 2- the contraction rate must reach 0.03 L mm/min. It is considered that the column has failed when the axial deformation caused by the fire effect reaches one of the aforementioned criteria.

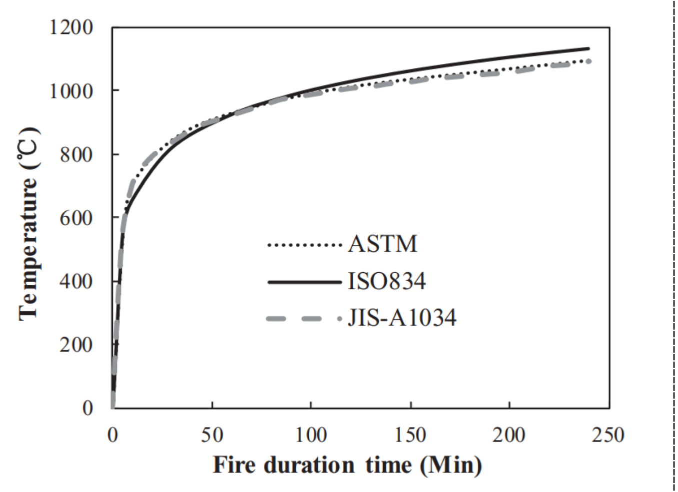

Fig. 7: Standard fire test curve.

4.1.1. Non-standard fires

Moore, 2008 [42] reported that the flame temperature in flames generated by gasoline or explosives will be greater and will occur faster than stated by the conventional time-temperature curve. Because in the standard, no information is available for these circumstances. To mimic these scenarios, manual calculations and computer models must be employed.

4.1.2. Pool fires

If a fuel leak causes a fire, there are established standards for predicting the size and period of the fire. A set of equations has been established that change depending on the kind of chemical, the surface on which it is spilt, and the containment of the spill. Eq. (2) calculates the maximum diameter (D_{max}) of fire for an immediate unconfined spill [43]. In this equation, VL is the spill quantity, y is the fluid burning rate, and g is the acceleration of gravity. The SFPE Manual of Fire Protection Engineering provides measures for the fluid burning rate [44].

$$D_{max} = 2(VL^3 \times g/y^2)1/8 \tag{2}$$

Eq. (3), where v is the regression rate, may be used to calculate the time a pool fire will burn. Eq. (4) defines the regression rate, where m″ is the mass burning rate of fuel per unit of area and ρ is the density of fuel [45].

$$t = 4\ VL/\Pi D^2\ v \tag{3}$$

$$v = m''/\rho \tag{4}$$

Because of the non-uniformity of the flame, measuring its temperature might be challenging. Researchers have discovered that the flame is composed of two primary temperate zones: the bottom zone, which is generally constant, and the tip, which drops as one moves up the plume. Temperatures in the lower zone are generally about 1652 degrees Fahrenheit F° (900 degrees Celsius C°), while temperatures near the tip are typically around 842 F° (450 C°). Larger pools, on the other hand, may reach 2192 F° (1200 C°) in the bottom area, and. The temperatures of the chosen fuels' average flames are provided by [45-47]. The temperatures of the chosen fuels' average flames are provided by [45]. The typical flame temperature of gasoline is 1878 F° (1265 C°).

5. Finite element modeling

The usage of modelling in the applications of fire simulation has been rapidly growing in recent years. The race to produce techniques and solutions that properly and efficiently address engineering challenges is never-ending. Temperature distributions in concrete are often investigated using finite element modelling (FEM). Several techniques have been developed, however there has been very little study done to validate their correctness for elevated temperatures. Wickström, 1986 [48] generated one of the prototypes. This "extremely basic" model predicts the temperature profile inside concrete using data already obtained from traditional fire curves. This method can only be used to structures that experience temperatures that fall within the typical range of the time-temperature curve. A different method used by Wang and Tan, 2006 [49] to determine the temperature profile for I-sections surrounded by concrete was the "Residual Area Method." Using this method, a series of fomulas to calculate the critical temperature over the steel profile is provided.

Ellobody and Bailey, 2009 [50] investigated the structural performance of un-bonded post-tensioned one-way RC slabs in fires. ABAQUS has prepared and submitted a nonlinear numerical model for the study of un-bonded post-tensioned RC slabs at elevated temperatures. The tendons' contact with the surrounding concrete was moulded, allowing the tendon to maintain its profile figure slab deformation. Temperature distribution over the slab, time–longitudinal expansions, time–deflection response, time–stress performance of the tendon, and mechanism of failure have all been predicted and confirmed with experimental findings. The model can accurately predict the performance of un-bonded post-tensioned one-way RC slabs in fire conditions, according to a comparison of experimental and computational data.

6. Concrete filled tubular (CFT) columns performance while subjected to high temperature

Romero *et al.*, 2011 [51] Romero examined sixteen fire experiments conducted on thin hollow circular shafts filled with both conventional and high strength concrete axial stresses. The standard strength of the concrete (30 or 80MPa), the kind of filling (plain concrete, reinforced concrete, or steel fibre reinforced concrete), and the axial load level (20 or 40%) were the test criteria. The columns were tested using boundary conditions that were fixed and pinned. In all of the cases, the relative slenderness at room temperature was higher than 0.5. A computer model was checked against the results of the tests so that the results could be expanded and the way these columns failed could be understood. The goal of this paper is to look at how using high-strength concrete instead of normal-strength concrete affects a fire. The results showed that when high temperatures were put on thin columns, high-strength concrete behaved differently than when it was put on short columns. In the tests, spalling was not seen. Also, adding steel fibres to thin columns was not found to be very helpful, since the fire protection of the columns that had this type of support did not increase. However, adding reinforcing bars seems to be the answer in some cases where external fire protection is not wanted in the design of buildings. This is because the reinforcing bars make the tube able to withstand higher transverse load.

Tondini *et al.*, 2013 [52] showed an experimental-numerical study of how High Strength Steel (HSS) columns behave at high temperatures, both on Circular Hollow Sections (CHS) and on a Concrete Filled Tube (CFT). Around 820 MPa was the recorded stress strength of the circle pieces. In more detail, three HSS CHS and one HSS CFT were tested under the standard ISO fire with a constant eccentric compression load. Instruments like thermocouples and displacement sensors were used to measure how the temperature and deformation patterns changed over time. Numerical analyses were done and compared with experimental data by using stress–strain relationships of carbon steel at high temperatures given by the Eurocodes and two different sets of reduction factors: i) those given by the Eurocodes and valid up to S460 steel grades, and ii) those suggested in the literature and based on tests on HSS.

Yang, Liu and Gardner, 2013 [53] showed an experimental and numerical study of how concrete-filled RHS beams react when they are exposed to fire on three sides. Three full-size concrete-filled RHS columns were tried until they broke. Two of the columns were burned on three sides, and the third was burned on all four sides. All of the temperature ranges, axial displacements, lateral displacements, and failure causes were recorded and talked about. After the tests, a sequentially linked thermal–stress computer model with heat transfer analysis and stress analysis was made. The FE model was checked against the test results, and it was used to help figure out how the failures happened and to look into a wider range of key factors. Some of these factors were the load ratio, the load deviation, cross-sectional measurements, the slenderness ratio, the steel ratio, and the values of the materials used. It was found that the size of the cross-section, load ratio, and the load eccentricity all have a big effect on fire protection. Based on the outcomes of parametric studies, a simple design formula was made to predict how fire-resistant concrete-filled RHS columns are when they are exposed on three sides. Also, a reduction factor method was suggested for the design of concrete-filled RHS columns exposed to 3-sided fire. This method was based on fire safety design methods for concrete-filled RHS columns in uniform fire, which may be easier for engineering uses.

Moliner *et al.*, 2013 [54] looked into a set of 24 fire tests that were done on thin hollow spherical shafts filled with normal and high-strength concrete and put under an eccentric axial load. It is a follow-up to an earlier study work Romero *et al.*, 2011 [51], which showed the results of tests on centrally filled columns. This fire testing program looked at the standard strength of concrete (30 & 90 MPa), the type of infilling (plain, reinforced, and steel fibre reinforced concrete), the axial load level (20% & 40%), and the load variation (20 & 50 mm). The goal of this paper is to look at how oddity and the type of concrete fill affect each other.

The results show that adding steel fibres to thin columns doesn't make them more fire-resistant than columns filled with plain concrete, even when the loads aren't the same. In this case, though, adding reinforcement bars makes the beams less likely to catch fire. Filling the steel hollow section columns with concrete makes them more resistant to fire. Columns filled with high-strength concrete can hold more weight after being filled with concrete. A comparison with present simple calculation model in Eurocode 4 part 1.2 shows that, while the method is safe for columns that are loaded in an odd way, it makes very bad estimates for columns that are filled with plain concrete or concrete with steel fibres in it.

Kamil, Liang and Hadi, 2019 [55] presented a mathematical model that uses the fibre method to measure the strength and fire resistance of narrow concrete-filled steel tube (CFST) columns with rectangular sections that are loaded in an irregular way. The model takes into account the interaction between local and global bending. The model uses a thermal simulator to find out how the temperature is distributed in cross-sections and a nonlinear global buckling analysis to predict how the local and global buckling of stressed CFST thin columns react to fire effects. The equation takes into account the initial physical flaw, the air gap between the concrete and the steel tube, the tensile strength of the concrete, the deformations caused by preloads, and how the material behaves depending on the temperature. There is a description of the computer theory, the modelling process, and the numerical solution methods. The practical and theoretical data that we already have confirm the computer model. When CFST poles with rectangular parts are put in a fire, the structural reactions and fire resistance are studied. The suggested mathematical model is shown to be a good computer predictor for the fire performance of thin CFST columns that are loaded in an odd way.

Liu *et al.*, 2019 [56] tested and calculated how the steel tube confined reinforced concrete (STCRC) beams behaved when they were subjected to both heat (fire) and structural loads. Four full-size STCRC columns and one concrete-filled steel tube (CFST) column were axially loaded and then put through the ISO 834 standard fire until they broke. The recorded temperatures of the furnace and the specimens, the axial movement versus time graphs, and the fire resistance of the columns are shown and talked about. Then, a sequentially coupled thermal stress analysis was used to make a nonlinear finite element model in ABAQUS. This model was checked against recent fire tests on STCRC columns and concrete-filled steel tube (CFST) columns that were reported in the press. After a lot of work studying the parameters, a simpler way of figuring out the temperatures of the steel tube, the reinforcement bars, and the concrete is suggested. Then, design rules are made for predicting the load-bearing capacity of STCRC columns exposed to the ISO 834 standard fire. These rules are the same as the design method for STCRC columns at room temperature.

Mao, Wang and Xian, 2020 [57] provided research on the fire performance of the square cross section steel reinforced concrete filled steel tube (SRCFST) shafts. To forecast the behavior of the fire, Abaqus builds up the computer models of SRCFST components, which comprise a heat transfer analysis model and a structural analysis model. The numerical models and the real data that has previously been recorded may be found to reasonably match in terms of temperature field, axial displacement vs. time curve, fire resistance, and failure mechanisms. Sensitivity investigations are conducted on the immediate thermals strain and contact thermal resistance. FE models are shown to be more realistic when they account both the concrete's quick thermal strain and the thermal resistance across the contact of concrete and steel tubes. The study examines and contrasts the fire performances of SRCFST columns with normal CFST in terms of temperature distribution, axial force distribution, axial deformation time (Δ-t) curves, and strain. The findings demonstrate that integrated steel can further improve the SRCFST supports' fire safety. Lastly, the impacts of several parameters on the fire resistance are examined, including material strength, tapered steel ratio, steel tube ratio, and slenderness ratio. It was discovered that, provided the overall steel ratio remains constant, SRCFST columns' fire resistance is improved by a higher shaped steel ratio. Conversely, fire resistance decreases significantly when the fire load ratio and slenderness ratio rise.

Meng *et al.*, 2020 [58] looked into how well square steel-reinforced concrete-filled steel tubing (SRCFST) worked. SRCFST columns were tried in fires on four sides, three sides, two sides, and one side. Six poles that were 1.8 m tall and had pinned-fixed edges. In laboratory studies, it was found that SRCFST columns were resistant to fire in both 3-sided and 4-sided fires, but their ways of failing were very different. Under two-sided and one-sided fires, SRCFT columns did better than expected because they did not fail before 4 hours. A nonlinear elastic-plastic finite element model is checked against the findings. Advanced forecast methods are used to compare validated numerical and actual findings. It is shown that none of these can accurately predict how well SRCFST columns will stand up to fire in a uniform or non-uniform fire.

Shintani *et al.*, 2021 [59] presented a set of four full-scale furnace tests that were done on concrete filled steel tube shafts that were not covered and did not have support bars. Three of the columns were exposed to compression and horizontal loads, taking into account the end supports given by the neighbouring cooler frame members and the forced movement caused by the thermal extension of the hot beam during a fire. For the goal of setting a standard, a circular load was put on one of the supports. The test set was made up of multiple-loaded specimens that were made up of two-story poles that were compressed. A standard ISO-834 fire was put in the bottom column, and a horizontal displacement control force was put on the top of the column until a horizontal displacement of 1/50th of the heating length of the column was reached after 120 or 240 minutes of fire . Due to the double bend in the core concrete, the test result showed that the failure times of the columns under compound loading conditions were lower than those of the columns under axial loading conditions. In the test where the furnace was loaded in an odd way , it was seen that the double curvature bending was worse than the single curvature bending.

Mao, Zhou and Wang, 2023 [60] Mao and others studied the fire performance of steel reinforced concrete filled steel tube (SRCFST) beams when they are exposed to fire in different ways. Four SRCFST columns are carefully tested under three-, two-opposite-, two-adjacent-, and one-face heating to find out how they fail, how the temperature changes over time, how they bend axially and laterally, and how resistant they are to fire. Models of finite element analysis were used to check and evaluate the results of the tests. The results show that curved steel makes SRCFST supports stronger and more resistant to fire. Uneven temperature distribution has a big effect on the cross-section's temperature distribution, which moves the stiffness centre towards the side that isn't visible when the temperature is high. Parametric studies are also done on a number of important factors to find out how they affect the fire resistance of SRCFST columns when they are exposed to a fire that is not regular. The fire resistance of SRCFST columns under different fire conditions, such as uniform fire, opposite, adjacent, and face heating, is predicted using a modified calculation method based on the extended Rankine method. Based on the quantitative differences between the actually observed data and the numerically expected results, the simpler method usually gives accurate forecasts of the final load capacity of SRCFST columns under non-uniform fire.

7. Conclusion

Among the most dangerous risks in engineering construction is fire, which may result in both human deaths and financial damages. Since the 1980s, a lot of buildings and bridges have made use of the concrete-filled steel tubular column due to its exceptional structural performance. It follows that a significant area of research is the fire behaviour of the CFST column. After reviewing published research on the subject, the following was concluded:

1. Regarding the impact of the concrete strength on the CFST column’s fire resistance, opinions differ. On the other hand, the experimental findings show that while a high concrete strength increases fire resistance, the fire resistance rate fall as normal concrete strength increases.
2. The yield strength and thickness of the tubular steel have no appreciable impact on the CFST column's fire resistance.
3. Although the effect of the column eccentricity is not evident, it is clear that the fire resistance declines as the slenderness ratio and axial stress applied rise.
4. As the duration of the fire increases, the axial load-bearing ability decreases dramatically.
5. The quantity of fire surfaces and the boundary condition affect the fire resistance capability.
6. When adding an additional steel section inside the concrete (double skin), the column’s fire resistance increases significantly.

It is also pointed out that extensive research is still lacking in a number of crucial areas. It is advised that additional research on the behaviour of CFST columns in multiple-hazard scenarios, such as fire.

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