IJASRM International Journal of Advanced Scientific Research and Management, Volume 4 Issue 4, April 2019
www.ijasrm.com
ISSN 2455-6378

Size Effect on Fire affected Columns and Beams A Literature Review

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Abstract

Generally during fire accidents in buildings, columns and beams are exposed to fire and these structures are expected to perform well during such extreme conditions. This shows the importance of study of concrete structures when they are exposed to fire. The objective of this limited study is to provide an overview of the effects of size and fire on columns and beams. In meeting this objective previous investigations done by various researchers are summarized.

Keywords*: Column, Beam, Fire and Size Effect*

1. Introduction

1.1.1 Reinforced concrete structures consist of two separate materials with very different characteristics, namely, concrete and steel. Concrete is a very complex composite material includes aggregate, cement mortar, micro-cracks, voids and all kinds of mixtures and it presents obvious size effect. The size effect in quasi-brittle materials like concrete is a well known phenomenon and there are a number of experimental and theoretical studies which confirm the existence of size effect. It can be found in different RC members for different types of loading. Concrete is a composite material widely used in construction sector. When used in buildings and industries it is likely to be subjected to fire of different intensities. Structural members in buildings have to satisfy certain fire safety requirements specified in building codes. Behavior of concrete in fire has observed that, properties of concrete such as compressive strength, tensile strength, modulus of elasticity, etc. are adversely affected at elevated temperature when exposed to fire. The change of mechanical properties also depends on several factors e.g. rate of heating, type of aggregate used, size of specimen, moisture content, age of specimen, etc. Approximately 65% to 75% of concrete volume is occupied by aggregates. The commonly used aggregates are stable up to a temperature range of 300 ^{0}C–350 ^{0}C but when the temperature rises to 500 ^{0}C –600 ^{0}C the physical and chemical changes in the aggregate occur which result in increase in volume of aggregates.

2. Literature Review

2.1 Size Effect on Column

Yongping Xie et al., (2018)[21] : Studied about flexural behavior and size effect of normal strength RC columns under monotonic horizontal loading. The cross-sectional sizes of the columns ranged from 300 to 700 mm. These specimens are tested after 28 days of water curing. These columns are tested under monotonic horizontal loading. Parameters studied are compressive strength and Young's modulus. From the study it has been concluded that the larger the axial compression ratio, the more obvious the size effect in the bending capacity and the ultimate compression strain of concrete.

Yuyin Wang et al., (2017)[22] : Studied based on size effect of circular concrete-filled steel tubular short columns subjected to axial compression. Three concrete columns are with a size of 150 × 150 × 300 mm are used to determine the elastic modulus of the concrete. Columns are cured in wet conditions for 28 days. All specimens are tested until failure under axial compression using a 50,000kN hydraulic

testing machine. Parameters studied are axial stress, peak axial strain, composite elastic modulus and ductility coefficient. From the study it is concluded that size effect exists in CFST columns with the steel ratio in the range of 4.1–10.3%, the peak axial stress decreases by 6.2–9.7% when the diameter varies from 150 mm to 460 mm.

Chengshun Xu et al., (2016)[3] : The Study is to examine the possibility of existence of size effect in eccentrically loaded high-strength reinforced concrete (RC) columns. All specimens are cast from the same batch of continually mixed concrete. The widths of the square cross-section of the RC columns are between 200 mm and 800 mm and the lengths are 900 mm to 3600 mm. Parameters under study are compressive strength, peak load, and nominal strength. From the study, it is concluded that existence of the transversal reinforcement could minimize the size effect behavior of eccentrically loaded RC columns, but could not make it disappear.

Liu Jin Dong Li and Xiuli Du (2016)[9] : The Study focused on mechanical behavior and size effect of moderate high-strength RC structural members under cyclic loading. 16 high-strength RC columns have been tested. The cross-sectional size of the columns are between 200 and 800 mm and the length varied from 600 to 2400 mm. Columns are cured in wet conditions for 28 days. Parameters studied are stress-strain response, hysteretic behavior. From the study it is concluded that RC columns under cyclic loading pronounce a more obvious size effect, which should be caused by the separation of the bonding between steel bars and the surrounding concretes due to fatigue loading.

D.Y. Wang et al., (2016)[5] : Study is on axial compressive behavior of carbon fiber-reinforced polymer confined concrete columns. Cross-sectional dimensions of columns are 350, 250, 100, and 50 mm. Columns are cured in wet conditions for 28 days. Tests are conducted in universal test machine of 5000kN capacity. Parameter studied is compressive strength. From the study it is concluded that axial stress-strain response exhibited significant difference with an increase of specimen size, especially for large-scale columns.

Kedar Kirane et al., (2014)[8] The purpose of this study is about using three-dimensional stochastic finite-element analysis to determine the size effect type. By experimental study similar to plain concrete beams, the flexural strength of disks suffers from a significant size effect. Fracture patterns of disks of thicknesses 30, 48, and 75 mm have been used. The disks are tested using micro-plane model M7. Parameter under the study is young's modulus. From the study it is concluded that with realistic boundary conditions and random material properties, the fracture patterns observed in the tests are correctly reproduced for the disks of all sizes.

Varol Koc and Sıddık Sener (2009)[17] The study is done on columns which are built with normal and high-strength concrete. The columns are cast with mix proportion of 0.5:1:2. The maximum length of a circular columns diameter and effective lengths are 37.5 X 75, 75 X 150 and 150 X 300 mm, the middle-sized columns are 25 X 100 mm, 50 X 200 mm, 100 X 400 mm and 200 X 800 mm, and large sized columns 25 X 200 mm, 50 X 400 mm and 100 X 800 mm. The specimens are cooled in air and cured under room temperature of 20 °C until 70 days. From this study, it is concluded that size effect is observed on strength of concrete under peak loads. It is reduced in the deep notch columns of small slenderness.

Sıddık Sener et al., (2004)[15] The purpose of this study is to determine the size effect in axially loaded RCC concrete columns. The cross sections of the concrete columns of sides 50, 100 and 200 mm, and varied in length from 0.14 m to 2.08 m. The columns are cast in plywood mould with a smooth hard varnish-painted surface. These specimens are cured in a water tank at 20 °C until 28 days. All columns are tested using displacement controlled method. The parameters under study are compressive strength, splitting strength and modulus of rupture. From the study, it is concluded that larger size columns exhibited larger imperfections and with increase slenderness of the column. The size effect becomes stronger as the brittleness number increases.

Michele Brocca and Zdenek P. Bazant (2001)[14] The work done in this study is to presents a finite-element study of the size effect of compressive failure of geometrically similar concrete columns of different sizes. The concrete is made of Type I Portland cement. The square cross sections are 12.7, 25.4, 50.8 mm and the effective lengths are 73, 136.5, 200 mm for the smallest cross section, 146 mm, 273 mm, 400 mm for the middle cross section, and L = 292, 546, 800 mm for the largest cross section. Columns are simply supported. The Young's modulus of the steel bars is Es = 200GPa and the specified yield strength is fy=552MPa. The parameters under study are Nominal strength and Yield strength. From the study, it is concluded that when similar columns of different sizes, made of the same concrete, are considered, all the design codes predict the same nominal strength P/D.

2.2 Fire Effect on Column

Asif H. Shah and U.K. Sharma (2017)[1] : Studied about the fire resistance and spalling performance of confined concrete columns. Fire resistance

experiments on 8 different types of reinforced columns were conducted. The RC columns are heated in a furnace of dimensions 2.5 X 1. 5 X 1. 5 m. The length of the column is up to 4 m with an exposed length of 2 m. A 300 ton capacity hydraulic jack is used to load the columns under compression loading frame. Parameters studied are concrete strength and confining reinforcement. From the study it is concluded that increasing the confinement by 50% increased the fire resistance by 12 and 3.5% respectively in normal strength and high strength concrete columns respectively.

Lila M. Abdel-Hafez et al., (2014)[11] : The present work is to study the behavior of reinforced concrete Carbon Fiber Reinforced Plastic strengthened columns exposed to fire under axial load. A furnace and a loading frame allow the application of the axial load driven from a hydraulic jack on the fired specimens at the same time. 14 CFRP columns 15 X 15 cm cross section, 160 cm length with different protection layers subjected to 900 °C for 30 min. Parameter studied is loading capacity of a column. From the study it is concluded that the some materials used for protection have low thermal conductivity and good resistance to fire.

M. Mohamed Bikhiet et al., (2014)[13] : Studied about the behavior of reinforced concrete short columns exposed to fire. The first part is experimental testing of 15 column specimens 15 X 15 X 100 cm exposed 600 °C fire and second part is performed using three-dimensional nonlinear finite element program. Columns are cooled by jet water. Columns are tested using a hydraulic loading machine of 500 ton capacity and 0.5 ton accuracy. Parameters studied are concrete strength, fire duration, level of applied loads, longitudinal reinforcement yield strength, percentage of longitudinal reinforcement and bar diameters. From the study it is concluded that columns not exposed to fire shows first crack load nearly at 80% of column failure load and columns exposed to fire shows about 50% of column failure load.

Wen-Chen Jau and Kuo-Li Huang (2008)[20] : Studied about the behavior of corner columns under axial loading, biaxial bending and asymmetric fire loading. columns of size 300 X 450 X 2700 mm. The columns are tested after 1.5 years of casting and are dried in air. The residual strength ratios of column after fire loading for 2 hrs is 67% and 4 hrs is 57%, 10% reduction in strength is due to time variation. Reduction in reinforcing steel ratio decreases residual strength ratios. Parameters studied are K-type thermocouples, axial strength. From the study, it is concluded that dimensions of the core of the column are very important for the residual strength and the column strength depends mainly on the core of concrete.

V. K. R. Kodur and M. A. Sultan (2003)[18] : This study is about type of aggregate has a significant influence on the thermal properties of high strength concrete. General purpose port-land cement is used to fabricate the four batches of concrete. The concrete mix in batches 1 and 3 are made with siliceous stone aggregate and batches 2 and 4 are made with carbonate stone aggregate. For each concrete mix, 152 X 304 mm cylinders and bricks 200 X 100 X 80 mm in size are fabricated. These specimens are soaked in for 7 days and cured at a temperature of 20 °C for 28 days. The measurements are made in the temperature range between 20 °C to 800 °C. The parameters under study are mass loss, thermal conductivity and thermal expansion. From the study, it is concluded that type of aggregate has a significant influence on the thermal properties of high strength concrete at elevated temperatures. The presence of carbonate aggregate in HSC increases fire resistance.

V.K.R. Kodur et al., (2004)[19] : Study is about the behavior of high performance concrete (HPC) columns exposed to fire. Each column is 3810 mm long, 305 mm of square cross-section and it is subjected to a load of 2000kN. Compressive cylinder strength of the concrete is measured after 28 days of curing. Parameters studied are load, section dimensions, column length, concrete strength, aggregate type, and fiber reinforcement. From the study it is concluded that fire resistance of HPC columns can be evaluated for any value of the significant parameters.

L.T.Phan et al., (2000)[12] : The purpose of this study is to focuses on effects of elevated temperature exposure on residual mechanical properties of HPC. Heating the cylinders of 102 x 204 mm to steady state thermal conditions at a target temperature and loading them to failure after the specimens are cooled to room temperature. The exposed temperatures to be 100 °C, 200 °C, 300 °C, 450 °C at a heating rate of 5 °C/min using a furnace heating. Parameters studied are compressive strength. From the study, it is concluded that effects of thermal exposure on HPC's mechanical properties have been found to be more pronounced than the effects on conventional concrete.

G.A Khoury (1992)[7] : Studied about Compressive strength of concrete at high temperature. Concrete containing brick aggregate has no loss in the residual compressive strength for temperatures up to 600 °C but the results of Portland cement specimens showed loss in compressive strength for temperatures above 300 °C compared with the initial cold strength. Parameters studied are compressive strength. From the study it is concluded that choice of an appropriate concrete mix can make the difference between a

concrete structure being repairable and remaining serviceable.

2.3 Size Effect and Fire Effect on Beams

Doo-Yeol Yoo et al., (2016)[6] : Studies on size effect in normal- and high-strength amorphous metallic and steel fiber reinforced concrete beams. Three different specimens of cross sections 50, 100, 150 of lengths 250, 400, 550 mm respectively has been taken. These specimens are tested after 28 days of water curing. Increasing load is applied using the UTM up to 3000 kN. Parameters studied are flexural strength, normalized deflection capacity, and normalized toughness. From the study it is concluded that higher strength concrete is more sensitive to the size effect than lower strength concrete.

Liu Jin et al., (2016)[10] : Studied about the seismic behavior of RC cantilever beams under low cyclic loading and size effect on shear strength. The cross-sectional sizes of the beams range from 80 X 200mm to 400 X 1000mm and the total length of the five beams ranges from 490 mm to 2360 mm. Cyclic displacement is applied to the specimen with the help of the servo hydraulic dynamic actuator. Parameters studies are shear strength, shear displacement, loading carrying capacity and Ductility capacity. From the study it is concluded that with increasing the structural size, the corresponding nominal shear strength and the safety reserve coefficient decrease.

Salim Barbhuiya and Abdul Munim Choudhury (2015)[16] : Studied about the size effect of RC beam column connections under cyclic loading. Ordinary Portland cement of 53 Grade is used. Reinforcing steel of diameters 20 mm, 12 mm and 8 mm are used, considering three types of beam–column connections with some specific deficiencies. Cyclic load is applied with displacement controlled load. Parameters studied are energy dissipation. From the study it is concluded that size effect is more pronounced in specimens exhibiting brittle mode of failure.

Ali Jihad Hamad (2017)[2] : studied about the effect of size and shape specimen on the compressive strength of High performance lightweight foamed concrete (HPLWFC) reinforced with glass fibers. The fresh properties of HPLWFC are measured by flow ability and fresh density tests. The size and shape of specimens used for compressive strength are cubes by size (150 X 150 X 150, 100 X 100 X 100 and 50 X 50 X 50 mm) and cylinders by size (150 X 300 and 100 X 200 mm). The small size of specimens gave higher compressive strength in comparison with other sizes. Parameters studies are compressive strength. From the study it is concluded that compressive strength of high performance lightweight foamed concrete increased with rising glass fiber content.

Cagatay M. Belgin and Sıddık Sener (2008)[4] : Studied about the size effect on failure of over-reinforced concrete beams. The specimens are made of concrete with a maximum aggregate size of 10 mm. The tests consisted of four groups with 1, 2 and 3 different size combinations. Three specimen sizes characterized by beam lengths of L = 1.15, 2.30 and 4.60 m are used. Beam lengths and widths are constant, 4.6 and 0.11 m respectively, for one-dimensional similarity (group I). Beam lengths of L = 1.15, 2.3, and 4.6 m beam widths of b = 0.055, 0.11 and 0.22 m, beam heights of h = 0.075, 0.15, 0.30 m are used for three-dimensional similarity (group II). For two-dimensional similarities two types of tests are carried out. For group III beam heights of h = 0.15, 0.30 and 0.6 m are used and the beam width is constant; b = 0.11 m. The reinforcement ratio is 3%. From the study it is concluded that the size effect is found to be stronger in 2 dimensional similarities than 1 and 3 dimensional similarities.

Zdengk P. Bazant and Siddik Sener (1987)[23] : The study is about the size effect law for failures of concrete beams due to distributed cracking, Brittle failures of structures that are made of heterogeneous materials like concrete. Considered rectangular beams with a constant cross section of depth d and width b subjected to torque T. Parameters studied are tensile strength and compressive strength. From the study it is concluded that torsional failure of unreinforced and longitudinally reinforced concrete beams of rectangular cross-section without stirrups shows size effect.

3. Conclusion Based on Review of Literature

In spite of a few investigations carried out on Size effect on columns and beams and fire resistance of different beams and columns, no investigations are found on size effect on columns when they are exposed to real fire. Further studies are needed on size effect of fire affected columns.

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