RESEARCH ARTICLE

SIZE EFFECT ON RESIDUAL LOAD CARRYING CAPACITY OF UN-STRESSED RC COLUMNS UNDER FIRE

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Abstract
It is critical to examine the effect of cross-section size andthickness of concrete cover on the residual load carrying capacity of concrete columns, as fire endurance generally improves with member size of cross-section and thickness of concrete cover at the same load level. It is extremely rare to do research on the effect of size on the residual load carrying capacity of unstressed Reinforced Concrete (RC) columns exposed to fire. There are only a few studies available on this concept. To determine the effect of size of cross-section and thickness of concrete cover on percentage residual load carrying capacity, experiments were conducted at increased temperatures of 300,500, and 800°C on 150x150mm, 200x200mm, and 230x230mm square RC columns with an L/D ratio of 4, concrete covers of 20,30, and 40mm, and fire durations of F30 (0.5hr), F60 (1.0hr), F90 (1.5hr), and F120 (2.0hr) in an unstressed condition. At all temperatures, it was discovered that when the column size and cover thickness increase, the percentage residual carrying capacity increases as well. Maximum loss of residual load carrying capacity occurred at 800°C, the loss being 63.20%, 41.60% and 32.10% for 150,200 and 230mm size columns respectively at 2.0 hours with 20mm cover. The minimum cover was determined to be 30mm for all three column sizes.
Keywords: Size effect, cover thickness, fire duration, Residual load carrying capacity, RC column

Introduction

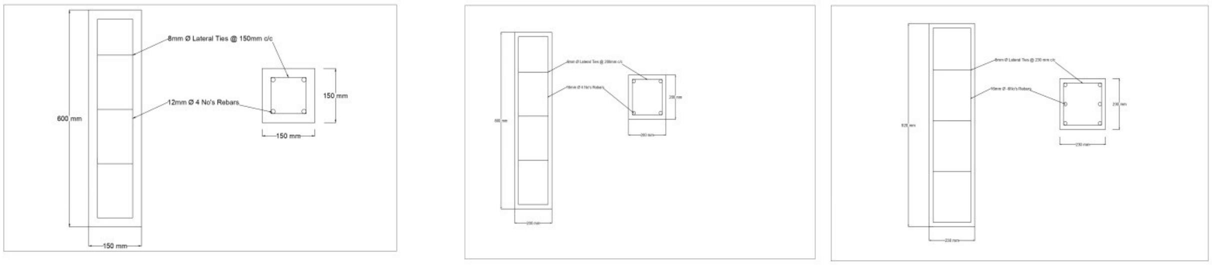
Along with other natural calamities, fire is one of the most destructive forces capable of destroying structures. When a structure catches fire, the temperature rises and the structural materials fail as a result of differential thermal expansion coefficients. Reinforced concrete is a frequently utilised structural material across the world.If the primary components of RC structures and bridges, such as slabs, beams, and columns, are exposed to an accidental fire, they may crack and lose bearing capability. A component member's failure can result in the partial or complete collapse of a structure;thus, RC columns are critical components in a large number of structures. Numerous parameters, including the area of cross-section, the temperature, thecover thickness, the main reinforcement diameter,the fire duration, the grade of concrete, the percentage of main reinforcement, and the applied load during the fire, all have an effect on thecapacity of load carrying of RC columns when exposed to fire [1]. If a structure is damaged by fire, it can be used to evaluate if it should be retrofitted or demolished and rebuilt. There is no evidence of a size effect in any strength deterministic theory's anticipated structural load capacity (e.g., elastic, plastic, or elasto-plastic strength criterion) [2]. However, it has been established that the effect of size occurs theoretically [3–7] and may be demonstrated experimentally and numerically for concrete in plain and reinforced concrete members havingbeams,columns,and column-beam connections [8–18]. Numerous researches have been carried on the effect of the size of concrete members at room temperature.However, a detailedliteraturereview reveals that little consideration has been paid to the size effect on the residual capacity of load carrying of RC members during a fire. The influence of column and beam size on the ofRC columns and beamsfire resistance was researched by Liu Lixian (2010)[19]. This article discusses the impacts of size of cross-section on the RC column's and beam'sfire resistance, as well as the influence of cover thickness of concrete on the resistance of fire of reinforced concrete beams. They concluded that as the cross-sectional area of the member and the thickness of the concrete cover increases, theresistance of fire at similar load ratios increases as well. [20] AneeshaBalaji (2016) investigated thereinforced column's axial capacity subjected to fire and discovered that the column's axial capacity rises as the concrete strength and cross-section increase. Capacity increases by a greater percentage in columns with a larger cross-section.

A series of tests was planned and conducted in this workto determine the column size effecton the residual load carrying capability of RC columns exposed to axial loading under fire. One objective was to determine the probable RC column size effect on residual load carrying capacity, and the other objective was to determine the effect of RC column concrete cover thickness on residual load carrying capacity.

Experimental study

Casting

Inthis experimentalwork, three sizes of columns, 36 numbers of each size having three different covers, each cover column exposed to three different temperatures for a period of four different fire durations, total of 108 columns with a dimensions of 150x150x600mm(C150), 200x200x800mm(C200), 230x230x920mm(C230)and a longitudinal reinforcement of 2% were cast to determine the residual load carrying capacity after a fire. The columns were reinforced longitudinally with HYSD (Fe500) and transversely with mild steel (Fe250) grade of steel. Figure 1 illustrates the details ofreinforcement of all the three columns. The columns were horizontally cast with the aid of wooden moulds.



(a) (b) (c)

Fig.1 Reinforcement details of a)C150 b) C200 c)C230

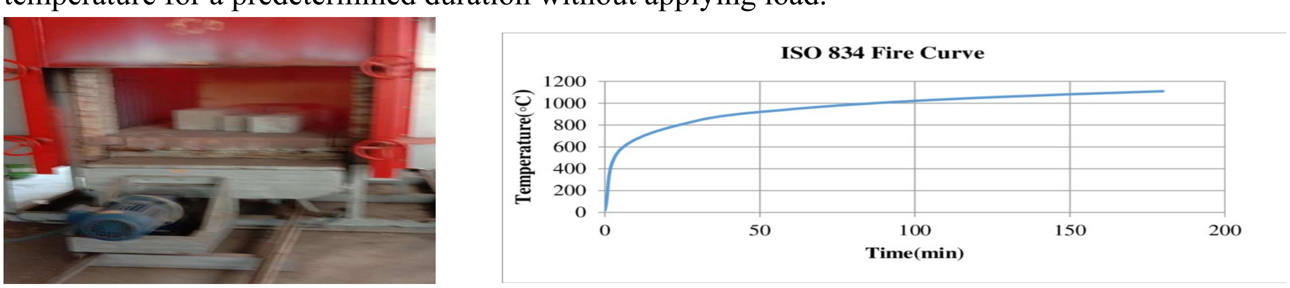
Three columns and three cubes were cast simultaneously from a single batch of concrete and for 28 days curing was done under water to determine the strength of the concrete.The concrete mix consists of river sand, 10mm and 20mm crushed stone aggregate, and Ordinary Portland Cement (OPC) of 53-grade. The mix fraction was adjusted after 28 days to attain a typical compressive strength of 25MPa. The concrete mix contains 300 kg cement per m^3, 150 kg water per m^3, 752 kg sand per m^3, and 1236 kg crushed stone aggregate per m^3.

(a) **(b)** **(c)**

Fig.2 (a) Reinforcement cages (b) casting in wooden moulds (c) curing under water

Heating

In this work, RC columns were heated for 0.5, 1.0, 1.5, and 2.0 hours at 300°C, 500°C, and 800°C in a Bhogie Hearth Furnace.The heating chamber is 750x600x2000mm in size. The furnace operates between 25 and 1200°C. The furnace's heating profile complies with the ISO 834 fire rating requirement. Three columns and three cubes are heated simultaneously to a specified temperature for a predetermined duration without applying load.



(a) (b)

DOI: 10.5281/zenodo.6972694
Journal of East China University of Science and Technology
Volume 65, Issue 3, 2022 (ISSN: 1006-3080)

Fig.3 (a) Bhogie Hearth Furnace (b) Time- Temperature Curve

Testing

The load carrying capacity of the unheated and heated columns was determined using axial concentric loading in a 1000kN UTM. During the tests, the first load of crack, maximal crackload, and breaking load were all documented.

(a)C150(30) (b) C200(40) (c) C230(20)

(a)C150(30) Column150x150x600 with 30mm cover

(b)C200(40) Column200x200x800with 40mm cover

(c)C230(20) Column200x200x800with 20mm cover

Fig.4. column testing

Results and Discussions

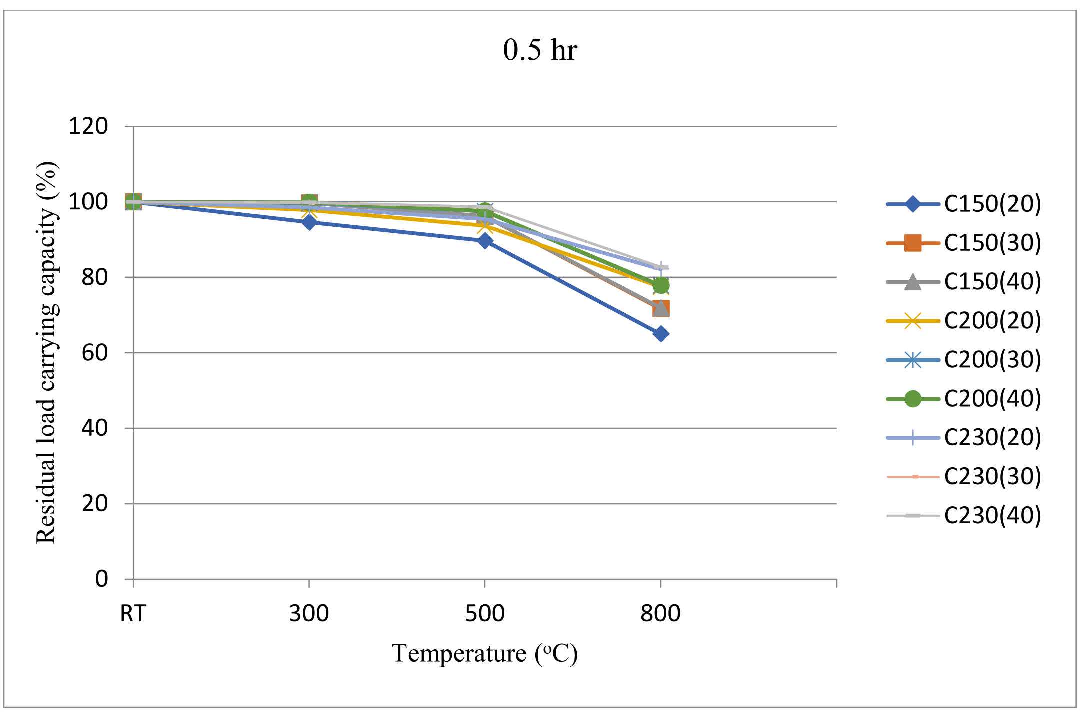


Fig.5Percentage residual load carrying capacity variation with temperature for all column sizes and covers with respect to 0.5hr fire duration

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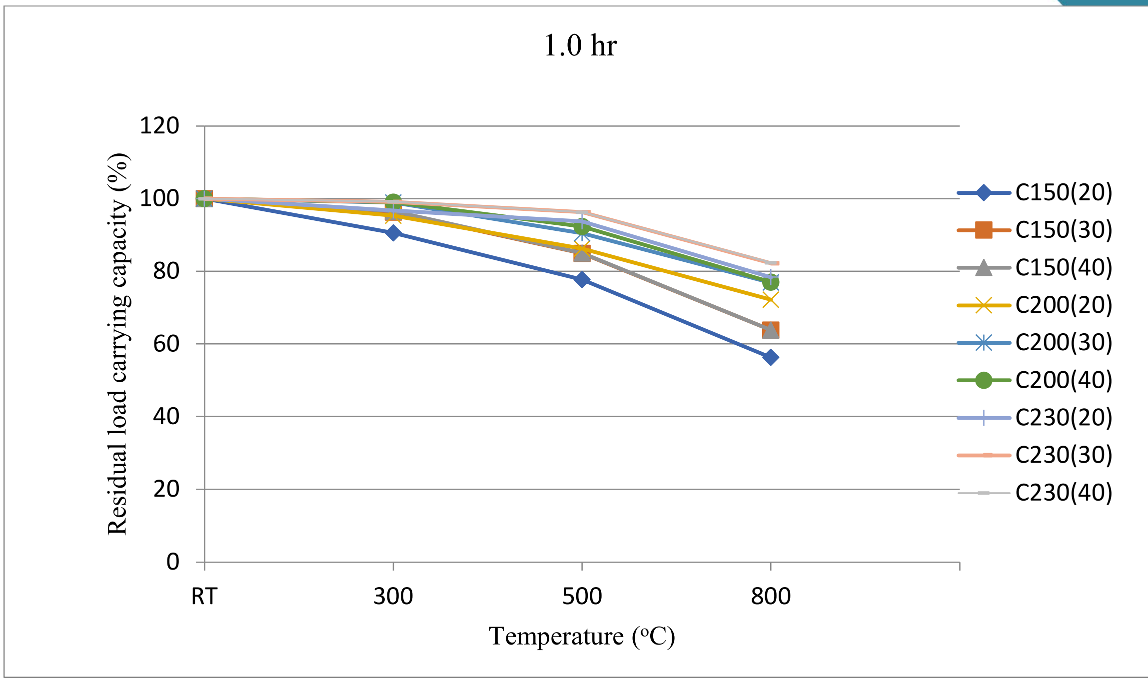

Fig.6Percentage residual load carrying capacity variation with temperature for all column sizes and covers with respect to 1.0 hour fire duration

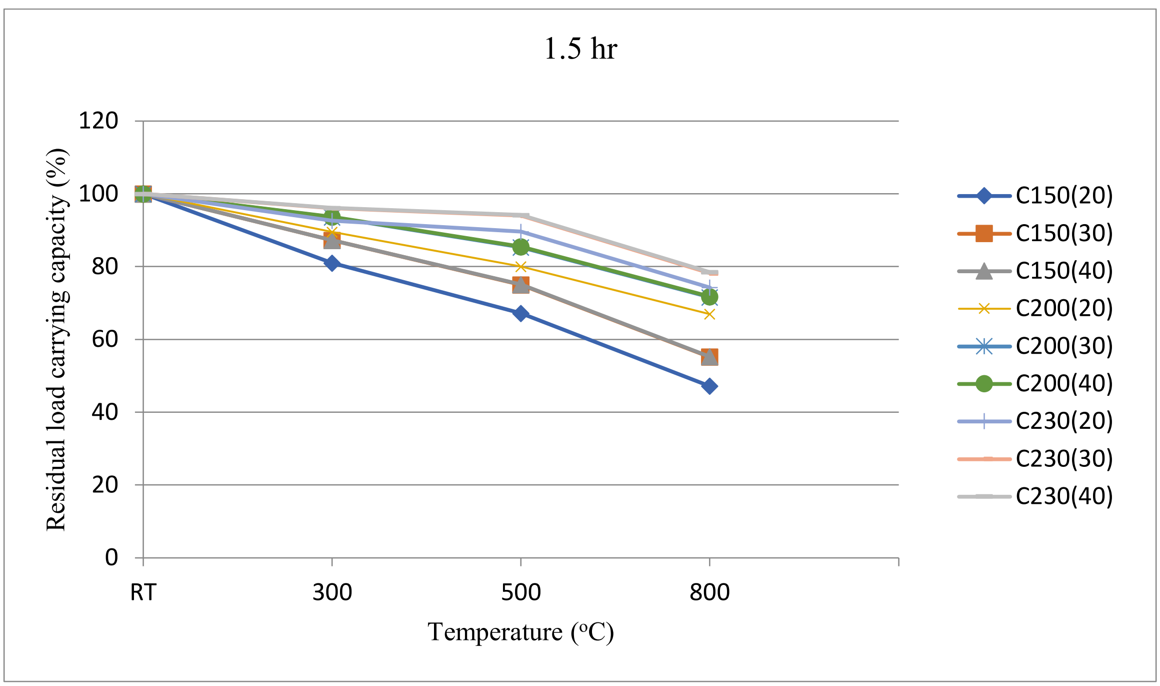

Fig.7Percentage residual load carrying capacity variation with temperature for all column sizes and covers with respect to 1.5 hour fire duration

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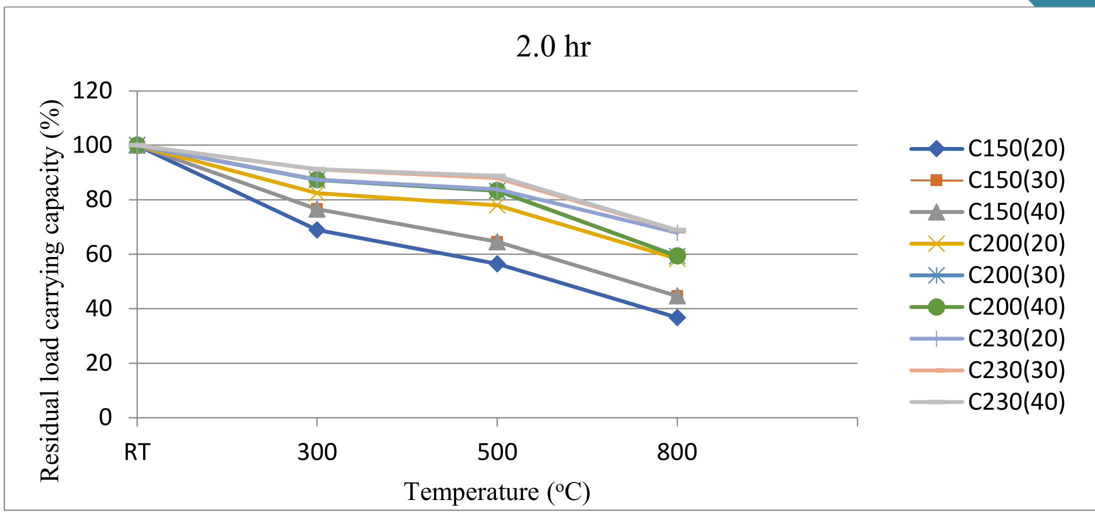

Fig.8Percentage residual load carrying capacity variation with temperature for all column sizes and covers with respect to 2.0 hour fire duration

Effect of Size on Residual load carrying capacity

As illustrated in Figures 5, 6, 7, and 8, the effect of size is most pronounced at F120 (2.0hr) with a 20 mm cover thickness. At 300°C, 500°C, and 800°C, the percentage residual load carrying capacity of the C150(20) column is 68.9, 56.5, and 36.80, respectively. At 300°C, 500°C, and 800°C, the percentage residual load carrying capability of the C200(20) column is 82.4, 78.0, and 58.40, respectively. At 300°C, 500°C, and 800°C, the percentage residual load carrying capacity of the C230(20) column is 87.4, 83.6, and 67.9, respectively. At all temperatures, it is noticed that as the column's size increases, the percentage residual load carrying capacity increases as well. The increase in residual load carrying capacity was found to be around 14%, 22%, and 22% at 300°C, 500°C, and 800°C, respectively, when the column size increased from C150(20) to C200 (20). The percentage increase in residual load carrying capacity was approximately 5%, 6%, and 10% at 300°C, 500°C, and 800°C, respectively, as the column size increased from C200(20) to C230(20). The percentage increase in residual load carrying capacity was approximately 19%, 27%, and 31% at 300°C, 500°C, and 800°C, respectively, as the column size increased from C150(20) to C230 (20). The percentage increase in residual load carrying capacity from C200(20) to C230(20) is determined to be relatively small at all temperatures.

Effect of Cover thickness on Residual load carrying capacity

The effect of cover thickness on residual load carrying capacity is illustrated in Figures 5, 6, 7, and 8. As the thickness of the cover increases, the percentage residual load carrying capacity increases as well, for any temperature and time, regardless of the column size. Although residual load carrying capacity rises with cover, the improvement is negligible for all three column sizes at 30 and 40mm coverings. As a result, the 30mm cover is optimal. For all three cover thicknesses, the lowest values of percentage residual load carrying capacity were recorded at 800°C and F120(2.0hours). The lowest percentage residual load carrying capacity values for C150 were found to be 36.80, 44.60, and 44.70 at 20mm, 30mm, and 40mm covers, respectively. The % residual load carrying capability of C200 was determined to be 58.40, 59.30, and 59.40 at 20, 30, and 40mm covers, respectively. The % residual load carrying capacity of C230 was determined to be 67.90, 68.80, and 68.90 at 20, 30, and 40mm covers, respectively. For C150, it is noticed that cover thickness has a noticeable effect on the % residual load carrying capability. It is minimal in the case of C200 and C230.

Conclusions

As the column's size increases, the proportion of residual load carrying capacity increases as well. At 300ºC, no significant effect of size on residual load carrying ability is observed for 0.5 and 1.0 hour fire durations.

Maximum residual load carrying capacity losses were reported to be 63.20 percent, 41.60 percent, and 32.10 percent for 150mm, 200mm, and 230mm size columns, respectively, at F120(2.0hr), 800ºC, and 20mm cover thickness.

As the cover thickness increases, the percentage of residual load carrying ability increases as well. The improvement in % residual load carrying capacity is negligible for 30 and 40mm coverings. As a result, the 30mm cover is optimal.

References

1. Bikhiet M, El-Shafey NF, El-Hashimy HM (2014) Behavior of reinforced concrete short columns exposed to fire. Alexandria Eng.J 53:643–653. http://dx.doi.org/10.1016/j.aej.2014.03.011
2. Bazant ZP, Planas J. Fracture and size effect in concrete and other quasibrittle materials. CRC Press; 1997. p. 7–15.
3. Weibull W. A statistical distribution function of wide applicability. ASME J ApplMech 1951;18(2):293–7.
4. Bazant ZP. Size effect in blunt fracture: concrete, rock, metal. ASCE J EngMech 1984;110(4):518–35.
5. Carpinteri A, Ferro G. Size effects on tensile fracture properties: a unified explanation based on disorder and fractality of concrete microstructure. Mater Struct 1994;27(10):563–71.
6. Duan K, Hu X, Wittmann FH. Scaling of quasi-brittle fracture: boundary and size effect. Mech Mater 2006;38(1/2):128–41.
7. Hoover CG, Bazant ZP. Universal size-shape effect law based on comprehensive concrete fracture tests. ASCE J EngMech 2014;140(3):473–9.
8. Bazant ZP, Kwon YW. Failure of slender and stocky reinforced concrete columns: tests of size effect. Mater Struct 1994;27(2):79–90.
9. Sener S, Barr BIG, Abusiaf HF. Size effect in axially loaded reinforced concrete columns. J StructEng 2004;130(4):662–70.
10. Nemecek J, Bittnar Z. Experimental investigation and numerical simulation of post-peak behavior and size effect of reinforced concrete columns. Mater Struct 2004;37(3):161–9.
11. Hoover CG, Bazˇant ZP. Comprehensive concrete fracture tests: size effects of types 1 & 2, crack length effect and postpeak. EngFractMech 2013;110:281–9.

12. Syroka-Korol E, Tejchman J, Mróz Z. FE calculations of a deterministic and statistical size effect in concrete under bending within stochastic elastoplasticity and non-local softening. EngStruct 2013;48(48):205–19.
13. Syroka-Korol E, Tejchman J, Mróz Z. FE analysis of size effects in reinforced concrete beams without shear reinforcement based on stochastic elastoplasticity with non-local softening. Finite Elem Anal Des 2014;88(10):25–41.
14. Syroka-Korol E, Tejchman J. Experimental investigations of size effect in reinforced concrete beams failing by shear. EngStruct 2014;58(7):63–78.
15. Syroka-Korol E, Tejchman J, Mróz Z. FE investigations of the effect of fluctuating local tensile strength on coupled energetic-statistical size effect in concrete beams. EngStruct 2015;103:239–59.
16. Barbhuiya S, ChoudhuryAM. A study on the size effect of RC beam-column connections under cyclic loading. EngStruct 2015;95:1–7.
17. Jin L, Du X, Li D, Su X. Seismic behavior of RC cantilever beams under low cyclic loading and size effect on shear strength: an experimental characterization. EngStruct 2016;122:93–107.
18. Jin L, Li D, Du X. Mechanical behavior and size effect of moderate high-strength RC columns under monotonic and cyclic axial compression.EngStruct 2016;124:269–85.
19. Liu Lixian, Reddy D.V, Sobhan K. Size Effect on Fire Resistance of Reinforced ConcreteColumns and Beams. Engineering Structures 2015;99: 468–478.
20. AneeshaBalaji ,MuhamedLuquman K, Praveen Nagarajan, MadhavanPillai T.M.Studies on the behavior of Reinforced Concrete Short Column subjected to fire. Alexandria Engineering Journal 2016; 55: 475–486.
21. MohdZahid M Z A, Abu Bakar B H, MuhamadNazri F (2006) Behaviour of Post Heated Reinforced Concrete Columns. IOP Conf. Series: Earth and Environmental Science.244012006. https://doi.org/10.1088/17551315/244/1/012006
22. VenkateshKodur, Derek Hibner, AnkitAgrawal (2017) Residual response of reinforced concrete columns exposed to design fires. Procedia Engineering 210:574–581. https://doi.org/10.1016/j.proeng.2017.11.116
23. Shariq M, Masood A, Umar A, MasroorAlam M, Haiyan A (2020) Residual load carrying capacity of reinforced concrete cylinders after heating at elevated temperature. SN Applied Sciences 2:1671. https://doi.org/10.1007/s42452-020 03483-7
24. Anjaly Nair, Osama (Sam) Salem (2020) Experimental determination of the residual compressive strength of concrete columns subjected to different fire durations and load ratios. Journal of Structural FireEngineering11(4):529-543. https://doi.org/ 10.1108/JSFE-10-2019-0034
25. IS 1642-1989, *Indian Standard* Fire Safety Of Buildings(General): Details Of Construction codeof Practice.

26. IS 456-2000, Indian Standard plain and reinforced concrete code of practice.
27. Lie T, Rowe T, Lin T (1986) Residual strength of fire-exposed reinforced concrete columns. ACI Struct J 92:153–74. https://doi.org/10.4224/40001373
28. Wu H, Wang Y (2015) Multiscalemodeling for compressive strength of concrete columns with circular cross-section. ComputConcr 15(6):865–878. https://doi.org/10.12989/cac.2015.15.6.865
29. Kodur V, Raut NK, Mao XY, Khaliq W (2013) Simplified approach for evaluating residual strength of fire-exposed reinforced concrete columns. Materials and Structures 46 (12): 2059-2075. https://doi.org/10.21041/ra.v10i2.483
30. Kodur VKR, Raut NK (2009) Design equation for predicting fire resistance of reinforced concrete columns. Struct. Concr. 10 (2): 73–86.
31. Kodur VKR, Raut NK (2012) Behavior of circular reinforced concrete columns under fire conditions. J. Struct. Fire Eng. 3(1):37–55. https://doi.org/10.1260/2040-2317.3.1.37
32. Ali FA, Nadjai A, Chois S (2010) Numerical and experimental investigation of the behavior of high strength concrete columns in fire. Engineering Structures 32(5);1236-1243. https://doi.org/10.1016/j.engstruct.2009.12.049
33. El-Fitiany S, Youssef M (2018) Practical method to predict the axial capacity of RC columns exposed to standard fire. Journal of Structural Fire Engineering 9(4):266-286.
34. Hibner DR (2017) Residual axial capacity of fire exposed reinforced concrete columns. M.Sc. Thesis, Civil Engineering. Michigan State University.
35. Kodur V, Agarawal A (2020) A numerical approach for evaluating residual capacity of fire damaged concrete members. RevistaALCONPAT*10*(2):230-242.
36. Ma Q, Guo R, Zhao Z, Lin Z, He K (2015) Mechanical properties of concrete at high temperature—a review. Constr Build Mater. 93:371–383. https://doi.org/10.1016/j.conbuildmat.2015.05.131.
37. Arioz O (2009) Retained properties of concrete exposed to high temperatures: size effect. Fire Mater. 33 (5): 211–222. https://doi.org/10.1680/macr.2005.57.8.445.
38. Kodur VKR (2014) Properties of concrete at elevated temperatures, ISRN Civ. Eng. 1–15. https://doi.org/10.1155/2014/468510.
39. Hertz KD (2005) Concrete strength for fire safety design. Mag. Concr. Res. 57 (8):445–453.
40. Ali F, Nadjai A, Silcock G, Abu-tair A (2004) Outcomes of a major research on fire resistance of concrete columns. Fire SafeJ39(6):433–45. https://doi.org/10.1016/j.firesaf.2004.02.004
41. Nayak, Vindhya, and Thushar Shetty. "Analysis of L Shaped RC Columns Subjected To Bending With Axial Load Using Moment-Curvature Relationship." International Journal of Mechanical and Production Engineering Research and Development (IJMPERD) 8.2 (2018): 195-206
42. Mehdi, Hayder A., and Maryam Sinan Rasheed. "Effect of Slenderness Ratio on the Behavior of Reinforced Concrete Column Confined with Carbon Fiber Reinforced Polymer Composites

Under Axial Load." International Journal of Civil, Structural, Environmental and Infrastructure Engineering Research and Development (IJCSEIERD) 7.6 (2017): 1-20.