TEMPERATURE INDUCED FAILURE OF STEEL COLUMNS UNDER SUSTAINED AXIAL LOADING

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Introduction

Collapses of the World Trade Centre (WTC) towers were attributed to the heating of the columns at a particular floor of plane impact, due to fire which resulted in sudden failure of these columns. Due to the sudden fall of total mass of upper blocks lead to a very high impact load on the lower columns. (Bazant, Z. P. And Zhou, Y, 2002, NIST 2005). When steel is heated, its mechanical properties such as strength and the modulus of elasticity will change. At 500^{0}C, the ultimate and yield stresses (σ_u and σ_y) of steel drop by 60% and 40% respectively from their values at room temperature. At 600^{0}C, the elastic modulus (E) of steel drop by 60% (Ref-Faris A Ali et al.) These changes are not sudden but gradual as temperature increases. So when columns under axial load are heated and are free to move, it is questionable whether a sudden onset of failure will occur.

Moreover, under normal conditions, the short columns fail by squashing and the slender columns fail by overall buckling. Therefore when columns are heated also similar type of failure modes should occur, but the slenderness ratio at which transisiton from squashing to overall buckling may be different from that for a normal column under room temperature. It can be noted that the squashing failure will be slow compared to the unstable overall buckling failure.The objectives of this paper are, to identify whether the collapse of axially loaded columns under heating lead to a sudden failure; and then to identify the region of slenderness ratio at which a slow failure process can occur.

Methodology

An experimental setup as shown in Fig.1 was fabricated in which a column under axial load can be heated. To make heating efficient, the column is kept horizontally and by means of cables axial compression is applied to the column. The column section used is a 12.7 mm X12.7 mm square hollow seam welded cross section with wall thickness of 0.78 mm. As the load carrying capacity of columns are high, smallest available square hollow section was used in order to reduce the load handling. The load on each column was kept to the half of its load carrying capacity and. the columns were heated until failure. Variation of axial shortening and temperature increase were noted with time. Collapse was recorded with video camera to identify approximate collapse speeds.

Two sets of samples were tested. The lenderness was increased from 15 to

30. Additional columns were tested where the collapse mode changed from the squashing to overall buckling.

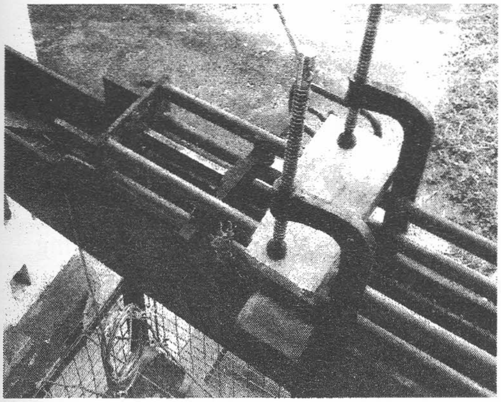

Fig1: Experimental setup

Results and discussion

Figure 2, shows photographs of the first set of samples after the test. For λ=15 and 17 samples did not undergo any change for long exposure at temperatures over 600□C, for 17 < λ <26 samples underwent crippling kind of partial collapse and the failure temperatures varied in the range of 590□C to 620□C. All the samples with λ value above 26 collapsed in overall buckling mode with very high speed of collapse. The temperatures of collapse varied in the range of 5850C to 595□C. Table 1, summarises the details of samples tested in the first set. The second set had additional samples for λ = 26, 27 and 29 to capture the exact transition point. Highest λ value for cripple failure was noted at λ = 26.

Conclusions

For the cross section under consideration, the crippling failure is observed for column slenderness λ ≤ 26, which absorb large amount of energy and therefore the speed of collapse is reduced and collapse is partial. For λ > 26 rapid collapse was observed with energy absorption only at points of plastic hinges.

At the level of plane impact, the WTC tower core columns were of λ < 27. Therefore assumptions of rapid column buckling leading to the total collapse of towers under fire needs further experimental or theoretical justifications.

References

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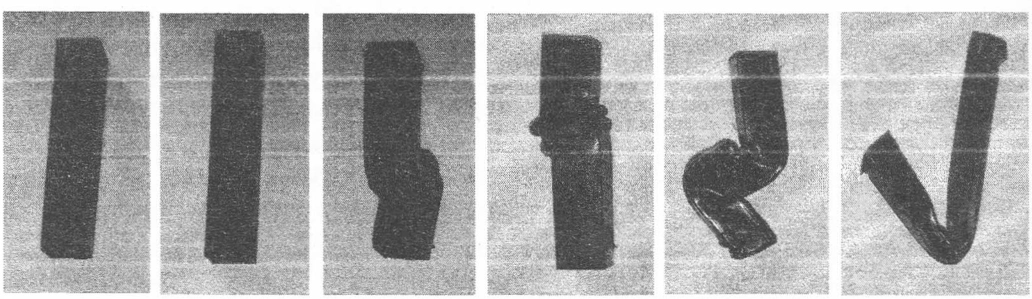
Table 1. Details of the first set of the experiment

SLENDERNESS RATIO	LOAD/kg (50% of the capacity)	MAXIMUM TEMPERATURE/^{0}C	FAILURE MODE
15	553	620	Not failed
17	553	610	Not failed
20	549	590	Squashing
22	547	615	Squashing
25	543	620	Squashing
28	538	560	Overall buckling
30	536	580	Overall buckling



λ=1 λ=1 λ=2 λ=2 λ=2 λ=2

Fig.2. First set of samples after the test