ROTATIONALLY RESTRAINT STEEL COLUMNS IN FIRE

Dr. Faris A. Ali

University of Ulster

The third part (phase 3) of the restraint test program started in May 1998. This phase involves applying rotational restraint on steel columns. The rotational restraint was imposed by connecting the top and the bottom of the column to horizontal steel plates forming an "I shape Frame". All the tested columns were 127X127UB13 and had a slenderness λ=98 if the column is considered as pin ended and a slenderness λ= 68 if the whole rigid frame was considered.

THE LEVEL OF ROTATIONAL RESTRAINT

The degree of rotational restraint ρ_K is defined as follows

$$\rho_K = \frac{\rho_S}{\rho_S + \rho_C}$$

where ρ_S is the flexural stiffness of the structure (the horizontal beams in this case) , ρ_C is the flexural stiffness of the column. In the steel frame tested a 40 mm plate was used to restrain the column. This plate gives a degree of rotational restraint ρ_K =0.93. Another thin plate 10mm was used also to give a degree of rotational restraint ρ_K =0.19 . During the tests an axial restraint degree was also imposed on the column. The stiffness imposed axially against the column expansion =58 kN/mm. This equivalent to an axial restraint degree =0.3.

LOADING LEVELS

The loading levels were calculated and applied by considering the column strength using slenderness l =68. Five loading levels were applied 0, 0.2, 0.4, 0.6, and 0.8.

Table 1. Parameters involved in the testing program of rotationally restrained columns

	Degree of Rot. Restraint r	Applied Rot. Restraint r_s kN.mm	**Column ref., applied loading levels and loads**				
Group 1 (H.R.R)	**0.936**	**3746**	P3UB1	P3UB2	P3UB3	P3UB4	P3UB5
			0 (0)	**0.2 (97 kN)**	**0.4 (145 kN)**	**0.6 (205 kN)**	**0.8 (284 kN)**
Group 2 (L.R.R)	**0.186**	**58.5**	P3UB6	P3UB7	P3UB8	P3UB9	P3UB10
			0 (0)	**0.2 (97 kN)**	**0.4 (145 kN)**	**0.6 (205 kN)**	**0.8 (284 kN)**

H.R.R.=High rotational restraint, L.R.R.=low.; for ρ see equation (1)

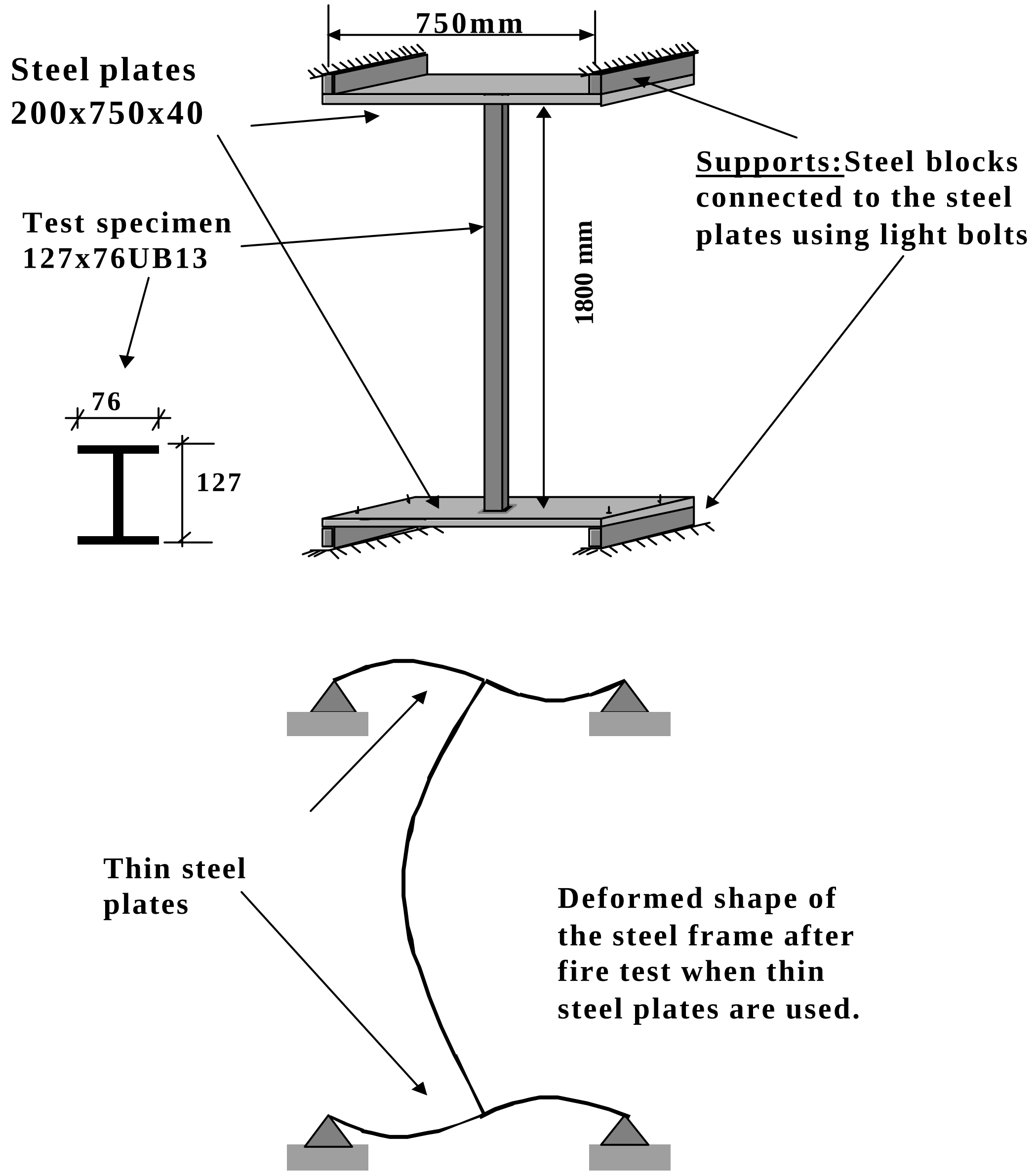
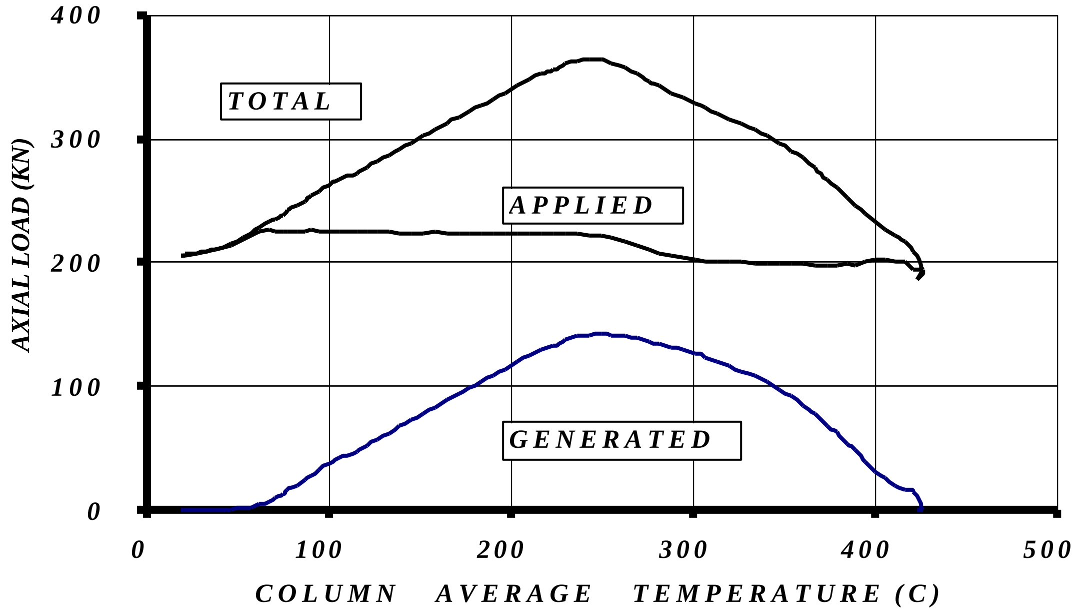


Figure 1. Steel frame involved in the tests

TEST RESULTS

The test results were reasonably logical. The tests showed that increasing the loading levels reduced the forces generated in the columns. The failure temperature were also reduced when increasing the loading levels. The test results are shown in Table 1



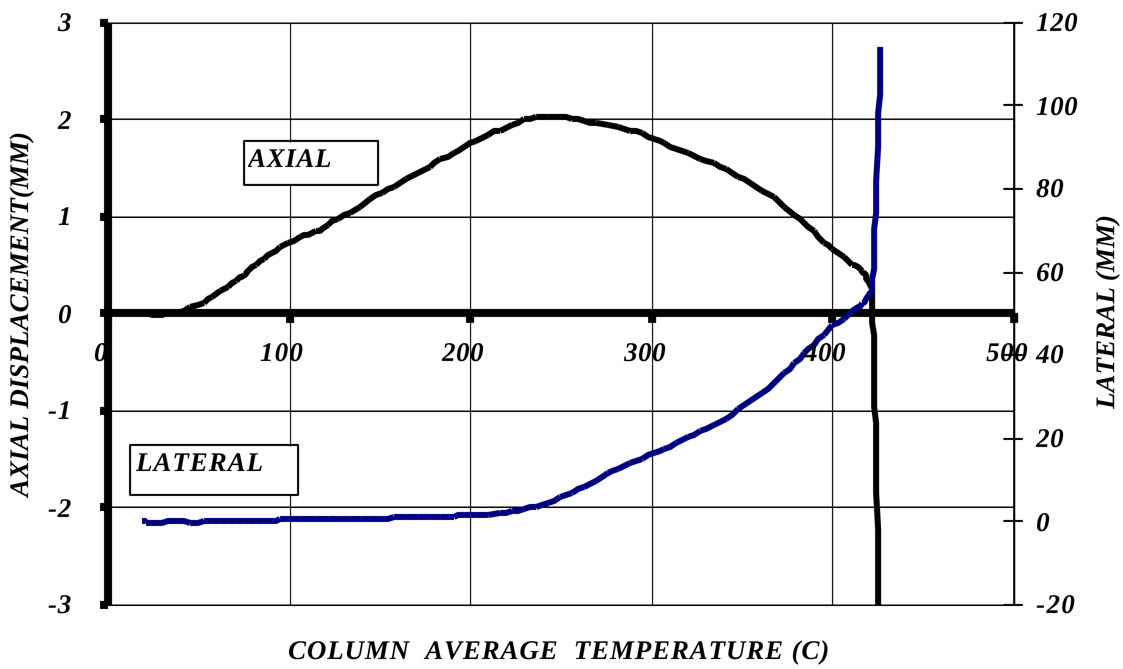


Figure 5. Curves of applied and generated forces, lateral and axial displacements of column P3UB4 tested under rotational restraint.

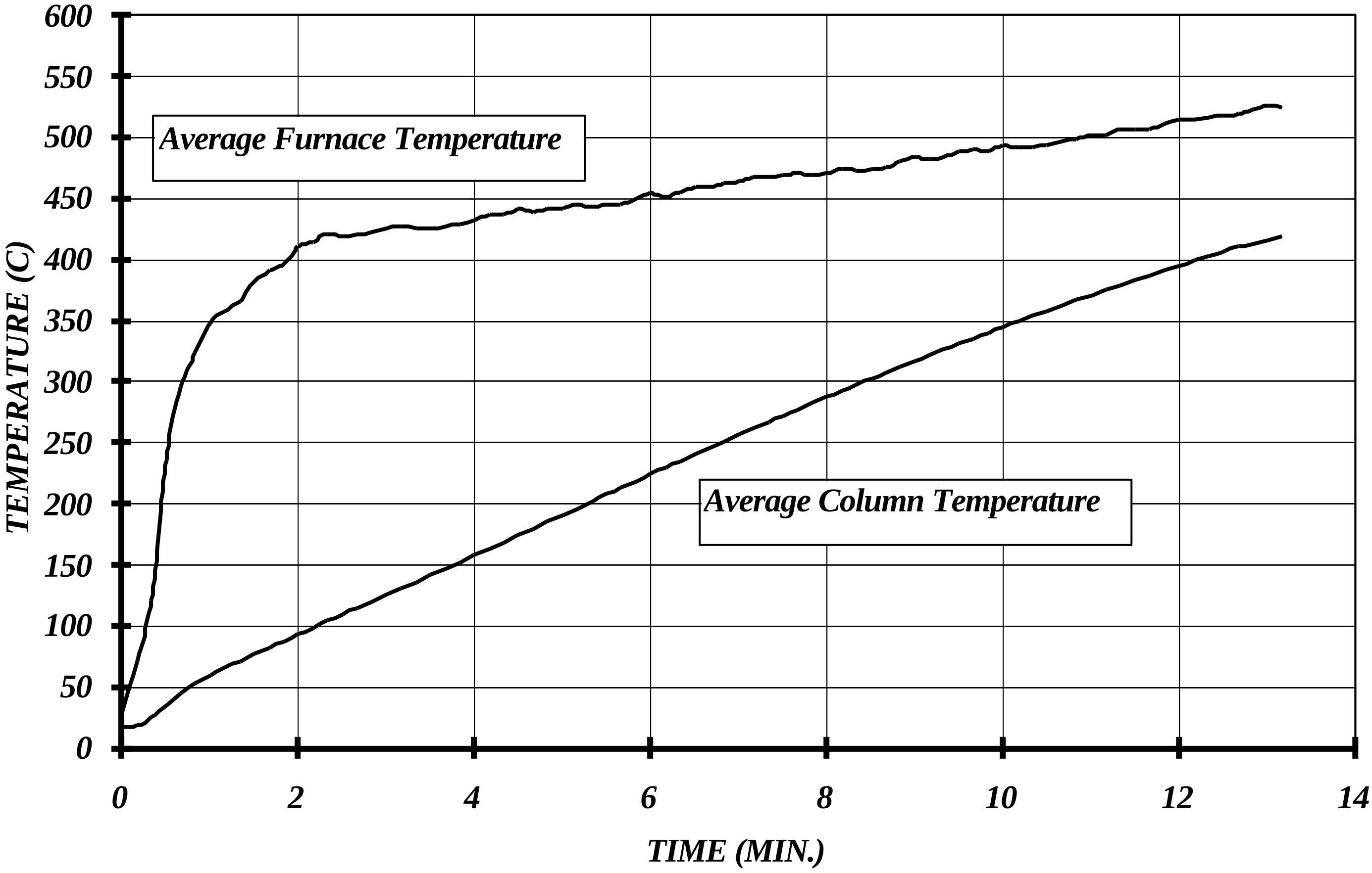


Figure 2. Typical fire curves adopted in the tests.

Table 2. Summery of the results of the fire tests.

	Column Ref.	Loading Level	Failure Temp. °C	Max. Axial Force Generated in Columns (kN).	**Applied load / Generated force**
Group one, High rotational Restraint	**P3UB1**	**0**	**648**	**260**	**0**
	P3UB2	**0.2**	**589**	**220**	**0.44**
	P3UB3	**0.4**	**525**	**179**	**0.81**
	P3UB4	**0.6**	**421**	**142**	**1.44**
	P3UB5	**0.8**	**277**	**69**	**4.11**
Group Two, Low Rotational Restraint	**P3UB6**	**0**	**652**	**290**	**0**
	P3UB7	**0.2**	**509**	**256**	**0.37**
	P3UB8	**0.4**	**379**	**192**	**0.75**
	P3UB9	**0.6**	**271**	**143**	**1.43**
	P3UB10	**0.8**	**200**	**97**	**2.92**

Table 3. Effective lengths of the tested columns

	Column Ref.	Effective length
Group one, (High Rotational Restraint)	**P3UB1**	**N/A**
	P3UB2	**0.56L**
	P3UB3	**0.57L**
	P3UB4	**0.58L**
	P3UB5	**0.52L**
Group Two, (Low Rotational Restraint)	**P3UB6**	**N/A**
	P3UB7	**0.61L**
	P3UB8	**0.60L**
	P3UB9	**0.65L**
	P3UB10	**0.61L**

(L= Column Length=1800mm)

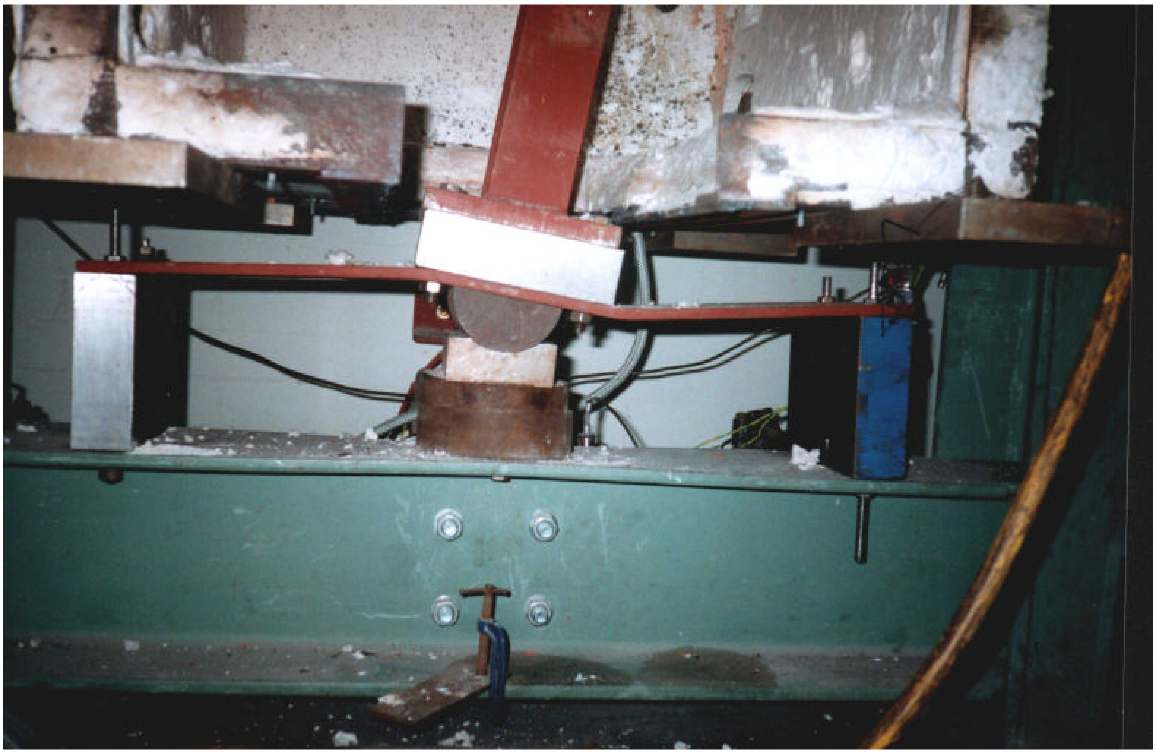


Figure 3. Deformation in the lower part of the steel frame after the fire test (when thin plates were used).

CONCLUSIONS

1. **Adding rotational restraint had a relatively minor effect on the value of generated restraint forces but failure temperatures were greatly increased under the same load.**
2. **Changing the value of the applied rotational restraint has an insignificant effect on the values of generated restraint forces.**
3. **The generated forces could increase the total imposed load to dangerous levels which may exceed the column's design load.**
4. **Increasing the load level from 0.2 to 0.8 caused a significant drop in the generated restraint forces by up to 45%.**

5. The failure stage in rotationally restrained columns has no sudden drop in the generated restraint force as in columns restrained axially only (excluding the cases mentioned in 6 below).

6. A sudden failure pattern was noticed in few cases where the applied load is significantly higher than the generated forces.

7. Increasing the loading level also caused a significant drop in the failure temperature.

8. Calculating the effective length of steel columns (using the geometrical data of the cool columns) gave an average value of 0.56L for highly restrained columns and 0.62 for low rotational restraint value.