"St. CIRIL and METHODIUS" UNIVERSITY

FACULTY OF CIVIL ENGINEERING
SKOPJE - MACEDONIA

NUMERICAL AND EXPERIMENTAL ANALYSIS OF RC COLUMNS EXPOSED TO FIRE

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Experimental investigation by T.D.Lin, R.I.Zwiers, R.G. Burg, T.T. Lie & R.J.McGrath

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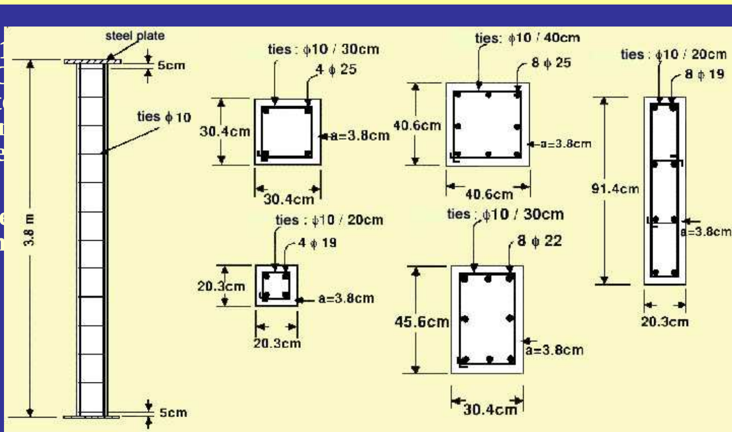
- The ... by T.D. Lin



- All columns were 3.8m long, and had 38mm concrete cover to the tie bars. They were fabricated with either siliceous or carbonate aggregate concrete with different compressive strength, different cross sectional geometry and the load/strength ratio was varied.

Experimental investigation by T.D.Lin, R.I.Zwiers, R.G. Burg, T.T. Lie & R.J.McGrath

According to American codes the load/strength ratio was defined as:

$$N_d = 0.8\Phi\left[0.85 f_c^{'}\left(A_g - A_s\right) + f_y A_s\right] \qquad \alpha' = N / N_d$$

In the above equation:

- $f_c^{'}$ is the strength of the concrete,
- f_y is the specified yield strength of the reinforcement,
- A_g is the gross area of the section,
- A_s is the area of the reinforcement,
- Φ is the strength reduction factor which is equal to 0.7, for members with tie reinforcement, and to 0.75, for members with spiral reinforcement.

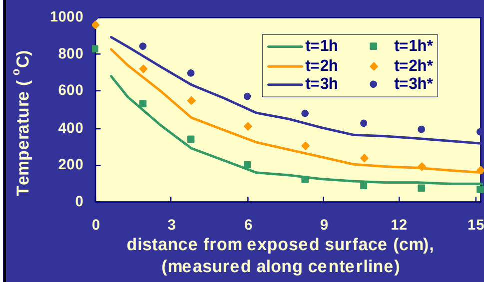
Benchmark study for validation the FEM programs "FIRE" and "Built Soft-Power Frame"

The results from this investigation were used as benchmark example for validation the finite element program FIRE (homemade program) and the commercial program Build Soft-Power Frame.

There were no data for the temperature dependent thermal and mechanical properties of concrete and steel, so they were taken as it was recommended by different authors (given in literature) and by Eurocode 2, part 1.2.

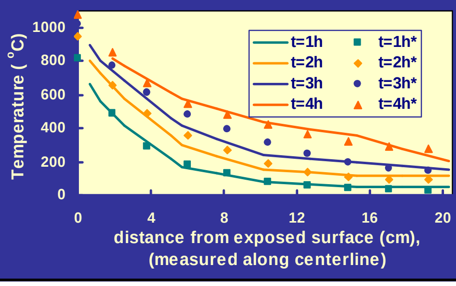
Benchmark study for validation the FEM program "FIRE"

Predicted and measured temperatures in the cross section of siliceous aggregate columns



COLUMN 304×304 mm

COLUMN 406×406 mm



* Predicted by program FIRE

Test data for centrically loaded columns compared with the predicted fire resistance

Column No.	Concrete strength (Mpa)	Concrete relative Humidity, %	Test Load (Kn)	Load/strength ratio α	Test duration Hr : min.	Predicted fire resist. Hr : min.	Deviation In %	Type of failure (test)
Cross section: 304×304mm, steel: 2.19% (4ϕ25), siliceous aggregate								
S1	34.1	5	0	0.00	4:00	>6:00	/	None
S13	40.3	65	340	0.15	5:40	5:45	+1.5	Compres.
S4	35.0	63	710	0.36	3:40	4:00	+9.1	Compres.
S25	39.6	60	800	0.37	4:02	4:00	-0.8	Compres.
S17	50.3	75	1070	0.41	3:54	3:51	-1.3	Compres.
S3	34.0	70	800	0.41	3:38	3:42	+1.8	Compres.
S16	52.9	75	1180	0.43	3:47	3:45	-0.9	Compres.
S31	41.5	/	1024	0.45	3:41	3:36	-2.3	Compres.
S26	39.3	67	1000	0.46	3:40	3:30	-4.5	Compres.
S7	36.0	74	1070	0.53	3:28	3:12	-7.7	Compres.
S9	38.3	/	1335	0.63	3:07	2:51	-8.6	Compres.
S2	36.8	15	1335	0.65	2:50	2:43	-4.1	Compres.
S8	34.8	/	1780	0.90	2:26	1:57	-19.8	Compres.

Column No.	Concrete strength (Mpa)	Concrete relative Humidity, %	Test Load (Kn)	Load/strength ratio α	Test duration Hr : min.	Predicted fire resist. Hr : min.	Deviation In %	Type of failure (test)
Cross section: 304×304mm, steel 2.19% (4ϕ25), carbonate aggregate								
S10	40.8	75	800	0.36	8:30	5:00	-41.2	Compres.
S11	36.8	75	1070	0.52	6:06	4:06	-32.8	Compres.
S12	40.0	75	1780	0.81	3:35	3:00	-16.3	Compres.
Cross section: 304×304mm ,steel: 4.38% (8ϕ25), siliceous aggregate								
S20	42.5	61	980	0.36	4:12	3:54	-7.0	Compres.
S21	37.0	80	1335	0.53	3:45	3:10	-15.5	Compres.
Cross section: 203×203mm, steel: 2.75% (4ϕ19), siliceous aggregate								
S6	42.3	29	169	0.16	3:05	3:27	+11.9	Buckling
Cross section: 406×406mm, steel: 2.47% (8ϕ25), siliceous aggregate								
S5	40.7	9	0	0.00	5:00	>5:00	/	None
S22	38.8	70	2420	0.62	4:22	4:20	-0.8	Compres.
Cross section: 304×456mm, steel: 2.22% (8ϕ22), siliceous aggregate								
S27	42.4	65	1415	0.41	5:56	4:50	-18.5	Compres.
Cross section: 203×914mm, steel: 1.22% (8ϕ19), siliceous aggregate								
S28	42.0	/	756	0.16	5:35	5:12	-6.8	Compres.

Benchmark study for validation the FEM program “FIRE”

Test data compared with the predicted fire resistance (siliceous aggregate columns)

Column No.	Concrete strength (Mpa)	Load ratio α '	Test duration Hr:min.	Predicted Fire resist. Hr:min.	Deviation in%	Type of failure (test)
Cross section: 304 ×304mm, Steel: μ=2.19% (4 ϕ 25), siliceous aggregate						
S1	34.1	0.00	4:00	>6:00	/	none
S13	40.3	0.15	5:40	5:45	+1.5	compres.
S4	35.0	0.36	3:40	4:00	+9.1	compres.
S25	39.6	0.37	4:02	4:00	-0.8	compres.
S16	52.9	0.43	3:47	3:45	-0.9	compres.
S26	39.3	0.46	3:40	3:30	-4.5	compres.
S8	34.8	0.90	2:26	1:57	-19.8	compres.
Cross section: 203 ×203mm, Steel: μ=2. 75% (4ϕ 19), siliceous aggregate						
S6	42.3	0.16	3:05	3:27	+11.9	buckling
Cross section: 406 ×406mm, Steel: μ=2. 47% (8ϕ 25), siliceous aggregate						
S22	38.8	0.62	4:22	4:20	-0.8	compres.
Cross section: 203 ×914mm, Steel: μ=1.22% (8 ϕ 19), siliceous aggregate						
S28	42.0	0.16	5:35	5:12	-6.8	compres.

Benchmark study for validation the FEM program "FIRE"

Test data compared with the predicted fire resistance (carbonate aggregate columns)

Column No.	Concrete strength Mpa	Load ratio α'	Test duration Hr:min.	Predicted Fire resist. Hr:min.	Deviation in %	Type of failure (test)
Cross section: 304 × 304mm, Steel: μ=2.19% (4ϕ 25)						
S10	40.8	0.36	8:30	5:00	-41.2	compres.
S11	36.8	0.52	6:06	4:06	-32.8	compres.
S12	40.0	0.81	3:35	3:00	-16.3	compres.

The difference between the measured and predicted fire resistance for the columns S10, S11 and S12 indicates that the values for the thermal conductivity and the specific heat of the carbonate aggregate concrete, recommended in EC2, are not adequate, but the predicted results are on the side of safety.

Benchmark study for validation the FEM program "FIRE"

Test data compared with the predicted fire resistance (carbonate aggregate columns)

Column no.	Load/strength ratio α	Test duration hr : min.	Predicted using EC2 hr : min.	Deviation in %	Recommend. by Harmathy hr : min.	Deviation in %	Recommend. by T.T.Lie hr : min.	Deviation in %
S10	0.36	8:30	5:00	-41.2	7:06	-16.5	5:50	-31.4
S11	0.52	6:06	4:06	-32.8	6:18	+3.3	4:40	-23.5
S12	0.81	3:35	3:00	-16.3	4:20	+20.9	3:15	-9.3

In the literature there is a considerable scatter in the recommended values for these two parameters.

If the fire resistance is predicted using the recommendations given by T.Z.Harmathy, the results are more close to the measured, and if it is predicted using the recommendations given by T.T.Lie the results are between the previous two .

Benchmark study for validation the FEM program "FIRE"

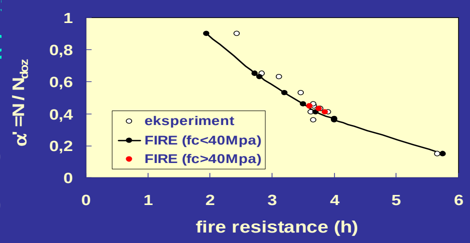
Test data for eccentrically loaded columns compared with the predicted fire resistance

Column No.	Concrete strength (Mpa)	Axial Force (Kn)	Moment (Knm)	Load/strength ratio α	Test duration Hr : min.	Predicted Fire resistance Hr : min.	Deviation In %	Type of failure (test)
Cross section: 304×304mm, steel: 2.19% (4ϕ25), carbonate aggregate								
S1	39.3	1000	25.4	0.46	3:02	3:24	+12.1	Compres.
Cross section: 304×304mm, steel: 2.19% (4ϕ25), siliceous aggregate								
S2	42.0	1023	25	0.45	2:50	2:40	-5.9	Ex. Defl.
S3*	42.7	1037	25	0.45	3:45	3:39	-2.7	Ex. Defl.
S4*	44.8	940	25	0.39	3:30	3:54	+11.4	Ex. Defl.
S5	38.6	980	22.6	0.46	2:47	2:39	-4.8	Ex. Defl.

* Restrained to initial rotation

Benchmark study for validation the FEM program "FIRE"

A fire resistance relationship of 304×304mm siliceous aggregate columns to load/strength ratio



A fire resi… …m siliceous
agg… …ratio
α' =N / Ndoz
0,4
eksperiment
FIRE (fc<40Mpa)
FIRE (fc>40Mpa)
0 1 2 3 4 5 6
fire resistance (h)

Significant factors affecting the fire resistance of centrically loaded columns:

- CROSS SECTIONAL GEOMETRY
- LOAD/STRENGTH RATIO
- TYPE OF THE AGGREGATE