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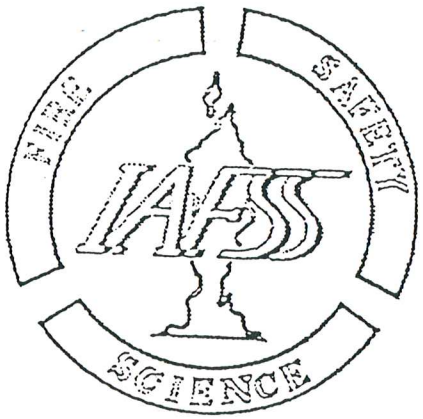

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A Straightforward Calculation Method for the Fire Resistance of Reinforced Concrete Columns

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EXPERIMENTAL BASE OF THE METHOD.

16 tests made in Belgium [1] at the universities of Gent (RUG) and Liège (ULg),
39 tests made in Germany [2] at the university of Braunschweig (TUBr).
21 tests made in Canada [3] at the National Research Council (NRC),

Section	Bars	Length	Supports	cover	ecc.	f_{cm}	f_{yk}	N	η	TEST	SAFIR	METH.	Lab.
(mm^2)		(m)		(mm)	(mm)	N/mm^2	N/mm^2	(kN)		(min.)	(min.)	(min.)	
300 x 300	4 ϕ 16	3.90	Free-Free	25	0	40.9	500	950	0.885	61	70	59	RUG
300 x 300	4 ϕ 16	3.90	Free-Free	25	0	42.7	500	622	0.564	120	85	90	RUG
300 x 300	4 ϕ 16	3.90	Free-Free	25	20	44.0	500	220	0.234	125	110	112	RUG
300 x 300	4 ϕ 16	3.90	Free-Free	25	20	40.2	500	664	0.640	128	84	83	RUG
300 x 300	4 ϕ 16	3.90	Free-Free	25	0	35.3	500	422	0.406	116	89	106	RUG
300 x 300	4 ϕ 16	3.90	Free-Free	40	20	44.1	500	349	0.372	123	105	115	RUG
300 x 300	4 ϕ 16	3.90	Free-Free	25	20	43.3	500	370	0.344	126	109	111	RUG
400 x 400	8 ϕ 16	3.90	Free-Free	25	20	35.7	500	1650	1.066	93	92	103	RUG
200 x 300	6 ϕ 12	3.90	Free-Free	25	20	37.5	500	300	0.641	60	31	68	RUG
200 x 300	6 ϕ 12	3.90	Free-Free	25	20	35.7	500	178	0.372	120	50	94	RUG
200 x 300	6 ϕ 12	3.90	Free-Free	35	20	39.2	500	283	0.666	60	36	76	RUG
200 x 300	6 ϕ 12	3.90	Free-Free	35	20	39.0	500	334	0.715	120	31	71	RUG
300 x 300	4 ϕ 16	2.10	Free-Free	25	0	35.3	500	1270	1.069	63	114	79	ULg
300 x 300	4 ϕ 16	2.10	Free-Free	25	0	34.5	500	803	0.693	123	153	117	ULg
200 x 300	6 ϕ 12	2.10	Free-Free	25	0	36.9	500	611	0.782	107	79	103	ULg
200 x 300	6 ϕ 12	2.10	Free-Free	35	0/0	32.9	500	620	0.910	97	76	102	ULg
300 x 300	6 ϕ 20	3.76	Free-Free	28	30	29.0	420	710	0.770	86	77	78	TUBr
300 x 300	6 ϕ 20	3.76	Free-Free	28	0	29.0	420	930	0.790	84	85	86	TUBr
300 x 300	6 ϕ 20	3.76	Free-Free	28	0	29.0	420	930	0.790	138	85	86	TUBr
300 x 300	6 ϕ 20	4.76	Free-Free	28	30	29.0	420	650	0.750	63	62	58	TUBr
300 x 300	6 ϕ 20	4.76	Free-Free	28	0	29.0	420	880	0.790	108	65	65	TUBr
300 x 300	6 ϕ 20	5.76	Free-Free	28	30	29.0	420	600	0.740	61	51	37	TUBr
300 x 300	6 ϕ 20	5.76	Free-Free	28	0	29.0	420	800	0.770	58	51	45	TUBr
200 x 200	4 ϕ 20	3.76	Free-Free	28	0	29.0	420	420	0.900	58	42	47	TUBr
200 x 200	4 ϕ 20	3.76	Free-Free	28	0	29.0	420	420	0.900	66	42	47	TUBr
200 x 200	4 ϕ 20	4.76	Free-Free	28	0	29.0	420	340	0.850	48	38	30	TUBr
300 x 300	6 ϕ 20	4.76	Free-Free	28	30	37.0	420	650	0.630	80	67	70	TUBr
300 x 300	6 ϕ 20	4.76	Free-Free	28	30	37.0	420	650	0.630	69	67	70	TUBr
300 x 300	6 ϕ 20	4.76	Free-Free	28	15	37.0	420	740	0.630	85	68	72	TUBr

Section	Bars	Length	Supports	cover	ecc.	f_{cm}	f_{yk}	N	η	TEST	SAFIR	METH.	Lab.
(cm^2)		(m)		(mm)	(mm)	N/mm^2	N/mm^2	(kN)		(min.)	(min.)	(min.)	
200 x 200	4 ϕ 20	4.76	Free-Free	28	10	37.0	420	280	0.620	49	41	47	TUBr
200 x 200	4 ϕ 20	4.76	Free-Free	28	20	37.0	420	240	0.590	36	44	45	TUBr
300 x 300	6 ϕ 20	4.76	Free-Free	28	90	37.0	420	460	0.660	75	63	67	TUBr
300 x 300	6 ϕ 20	4.76	Free-Free	28	150	37.0	420	362	0.680	65	59	65	TUBr
200 x 200	4 ϕ 20	4.76	Free-Free	28	60	37.0	420	170	0.580	49	45	46	TUBr
200 x 200	4 ϕ 20	4.76	Free-Free	28	100	37.0	420	130	0.560	53	43	48	TUBr
300 x 300	6 ϕ 20	3.80	Fixed-Free	28	30	40.0	420	845	0.717	111	128	107	TUBr
300 x 300	6 ϕ 20	3.80	Fixed-Free	28	50	40.0	420	780	0.763	125	121	102	TUBr
200 x 200	4 ϕ 20	5.76	Free-Free	28	10	39.0	420	208	0.550	40	42	33	TUBr
300 x 300	6 ϕ 20	4.76	Fixed-Free	28	15	37.0	420	735	0.627	160	119	118	TUBr
300 x 300	6 ϕ 20	4.76	Fixed-Free	28	150	52.0	420	355	0.562	89	129	122	TUBr
300 x 300	6 ϕ 20	4.76	Free-Free	28	15	38.0	420	735	0.550	93	82	88	TUBr
300 x 300	6 ϕ 20	4.76	Free-Free	28	30	46.0	420	645	0.430	135	93	100	TUBr
300 x 300	6 ϕ 20	4.76	Free-Free	28	5	46.0	420	1224	0.810	48	63	60	TUBr
300 x 300	6 ϕ 20	3.76	Free-Free	28	5	51.0	420	1695	0.950	57	78	68	TUBr
300 x 300	6 ϕ 20	4.70	Free-Free	28	5	42.0	420	1548	1.090	38	45	34	TUBr
300 x 300	6 ϕ 20	4.70	Free-Free	28	10	38.0	420	970	0.980	55	47	42	TUBr
300 x 300	6 ϕ 20	4.70	Free-Free	28	10	38.0	420	1308	1.040	57	45	36	TUBr
300 x 300	6 ϕ 20	4.70	Free-Free	28	150	38.0	420	280	0.820	49	41	52	TUBr
300 x 300	6 ϕ 20	4.70	Free-Free	28	150	38.0	420	465	0.860	50	49	48	TUBr
200 x 200	6 ϕ 14	5.71	Free-Free	23	100	50.0	420	140	0.725	31	29	16	TUBr
200 x 200	6 ϕ 14	5.71	Free-Free	23	10	50.0	420	245	0.608	40	30	33	TUBr
200 x 200	6 ϕ 14	5.71	Free-Free	23	50	50.0	420	172	0.646	35	31	23	TUBr
200 x 200	6 ϕ 14	5.71	Free-Free	23	10	50.0	420	175	0.434	49	40	50	TUBr
200 x 200	6 ϕ 14	5.71	Free-Free	23	50	50.0	420	122	0.459	52	43	42	TUBr
200 x 200	6 ϕ 14	5.71	Free-Free	23	10	50.0	420	128	0.317	72	51	61	TUBr
305 x 305	4 ϕ 25.5	3.81	Fixed-Fixed	48	0	44.5	400	1333	0.533	170	164	169	NRC
305 x 305	4 ϕ 25.5	3.81	Fixed-Fixed	48	0	41.2	400	800	0.343	218	219	188	NRC
305 x 305	4 ϕ 25.5	3.81	Fixed-Fixed	48	0	42.3	400	711	0.297	220	225	192	NRC
203 x 203	4 ϕ 20	3.81	Fixed-Fixed	48	0	51.0	400	169	0.195	180	165	182	NRC
305 x 305	4 ϕ 25.5	3.81	Fixed-Fixed	48	0	43.5	400	1067	0.436	208	193	178	NRC
305 x 305	4 ϕ 25.5	3.81	Fixed-Fixed	48	0	41.9	400	1778	0.750	146	132	147	NRC
305 x 305	4 ϕ 25.5	3.81	Fixed-Fixed	48	0	46.1	400	1333	0.516	187	164	170	NRC

Section	Bars	Length	Supports	cover	ecc.	f_{cm}	f_{yk}	N	η	TEST	SAFIR	METH.	Lab.
(cm²)		(m)		(mm)	(mm)	N/mm²	N/mm²	(kN)		(min.)	(min.)	(min.)	
305 x 305	4 ϕ 25.5	3.81	Fixed-Fixed	48	0	52.5	400	1044	0.359	201	187	186	NRC
305 x 305	4 ϕ 25.5	3.81	Fixed-Fixed	48	0	42.7	400	916	0.380	210	200	184	NRC
305 x 305	4 ϕ 25.5	3.81	Fixed-Fixed	48	0	63.7	400	1178	0.340	227	219	188	NRC
305 x 305	4 ϕ 25.5	3.81	Fixed-Fixed	48	0	59.6	400	1067	0.327	234	223	189	NRC
305 x 305	8 ϕ 25.5	3.81	Fixed-Fixed	48	0	51.3	400	978	0.276	252	228	204	NRC
305 x 305	8 ϕ 25.5	3.81	Fixed-Fixed	48	0	44.7	400	1333	0.414	225	188	190	NRC
406 x 406	8 ϕ 25.5	3.81	Fixed-Fixed	48	0	46.7	400	2418	0.504	262	287	250	NRC
406 x 406	8 ϕ 32.3	3.81	Fixed-Fixed	48	0	46.3	400	2795	0.499	285	272	254	NRC
406 x 406	8 ϕ 32.3	3.81	Fixed-Fixed	64	0	55.7	400	2978	0.464	213	305	275	NRC
305 x 305	4 ϕ 25.5	3.81	Fixed-Free	48	0	47.7	400	800	0.413	242	197	164	NRC
305 x 305	4 ϕ 25.5	3.81	Fixed-Free	48	0	47.3	400	1000	0.520	220	169	153	NRC
305 x 305	4 ϕ 25.5	3.81	Free-Free	48	25	48.1	400	1000	0.547	181	107	115	NRC
305 x 457	8 ϕ 22.2	3.81	Fixed-Fixed	48	0	51.2	400	1413	0.331	356	269	240	NRC
305 x 305	4 ϕ 25.5	3.81	Fixed-Free	48	25	45.7	400	1178	0.460	183	126	148	NRC

f_{cm} : average value of the compressive cube strength of concrete at the date of the test

f_{yk} : characteristic value of the yield strength of reinforcing steel

η : load level

TEST : Fire resistance obtained during the experimental test.

SAFIR: Fire resistance calculated by the numerical code SAFIR

METH.: Fire resistance calculated by the proposed calculation method.

Note Compare the experimental results on lines 18 and 19 of this table, see p. 2
Identical specimen sometimes produce significantly different results.
This variation, inherent to the experimental process, can hardly be taken into account in a calculation method and it must be realised that the objective of a method representing exactly every available test result is therefore utopian.

NUMERICAL BASE OF THE METHOD.

The numerical code SAFIR [4, 5], which had already been used for determination of the loads to be applied in the Belgium test series, was used in the analysis of the results of the 76 tests in order to clarify the influence of certain parameters. This code accounting for large displacements, non linear material laws, non uniform temperature distribution (but not spalling) can be considered as a general calculation model in the sense of § 4.4. of Eurocode 2, part 1.2. [6].

In order to judge from the quality of the proposed simple calculation method, the experimental tests have been calculated with the general calculation model (here the code SAFIR). Figures 1 and 2 give an idea of the correlation that could be obtained.

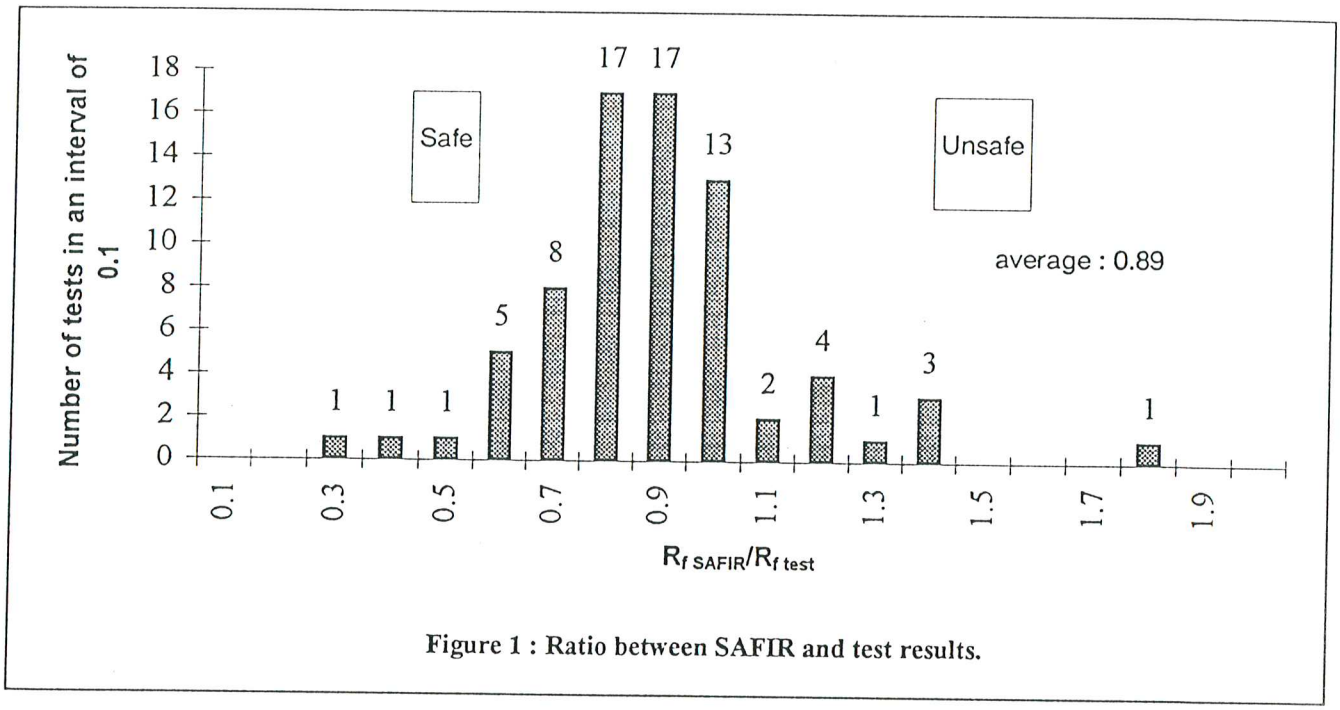

Figure 1 : Ratio between SAFIR and test results.

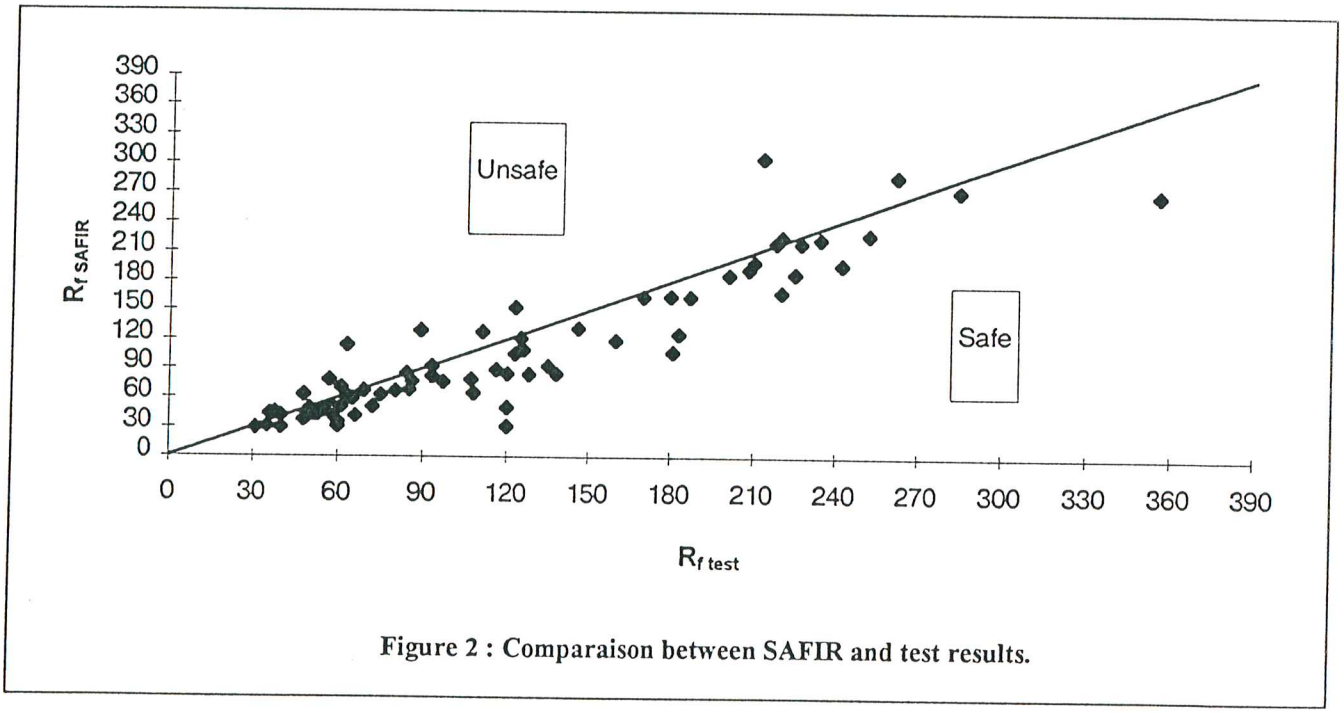

Figure 2 : Comparaison between SAFIR and test results.

METHODOLOGY LEADING TO THE ESTABLISHMENT OF THE CALCULATION METHOD.

1. The influence of different parameters has been analysed, considering the experimental results and/or the results of the numerical calculations. The following parameters were found to have a significant influence
   - the load level,
   - the massivity of the section,
   - the buckling length of the specimen,
   - the number off re-bars,
   - the cover of the longitudinal bars,
   - the eccentricity of the load.

2. Considering that the parameters have no interaction, an analytical expression was chosen for the influence of each parameter [1].

   Example : The influence of the buckling length L is linear

   $$Rf = A1 + A2 \times L$$

3. A regression analysis lead to the determination of the constants which are present in the analytical expressions, in order to give the best correlation with the experimental results.

[1] An attempt was made to obtain a better correlation with the test results by the introduction of coupling between some parameters. No significant improvement could be achieved.

THE CALCULATION METHOD.

The following equation allows a straightforward determination of the fire resistance of a reinforced concrete column.

$$R_f = R_b + R_a + R_L + R_e + R_n + R_\eta$$

where

R_f	is the fire resistance in minutes.
$R_b = 0.68 \times 1.13^b$	is the term accounting for the massivity of the section, b = perimeter/4 , in cm
$R_a = 1.08(a - 25)$	is the term accounting for the position of the bar, a from the *centre* of the bar to the nearest exposed edge, in mm
$R_L = 21.7(5 - L)$	is the term accounting for the buckling length of the column, L in m
$R_e = 0.54(20 - e)$	is the term accounting for the eccentricity of the load, e in mm. This term can not be negative.
$R_n = 10$	if there are more than 4 longitudinal re-bars in the section, R_n =0 if not.
$R_\eta = 99(0.77 - \eta)$	is the term accounting for the load level, $\eta = N/N_d$ [2]

[2] In the calculation of the design load of the column at ambient temperature N_d ,
the strength of concrete is $f_c = \alpha f_{ck} / \gamma_c$,
the strength of steel is the design strength f_y / γ_s ,
buckling must be considered if necessary.

Comparison between the calculation method and the experimental tests.

Figure 3 gives the distribution of the ratio between the fire resistance calculated by the proposed method and the fire resistance given by the tests.
The smallest value is 0.50 and the highest one is 1.37. The average is 0.89 which means that the proposed method is rather safe.
The distribution compares favourably with the distribution obtained by a general calculation method, see figure 1.

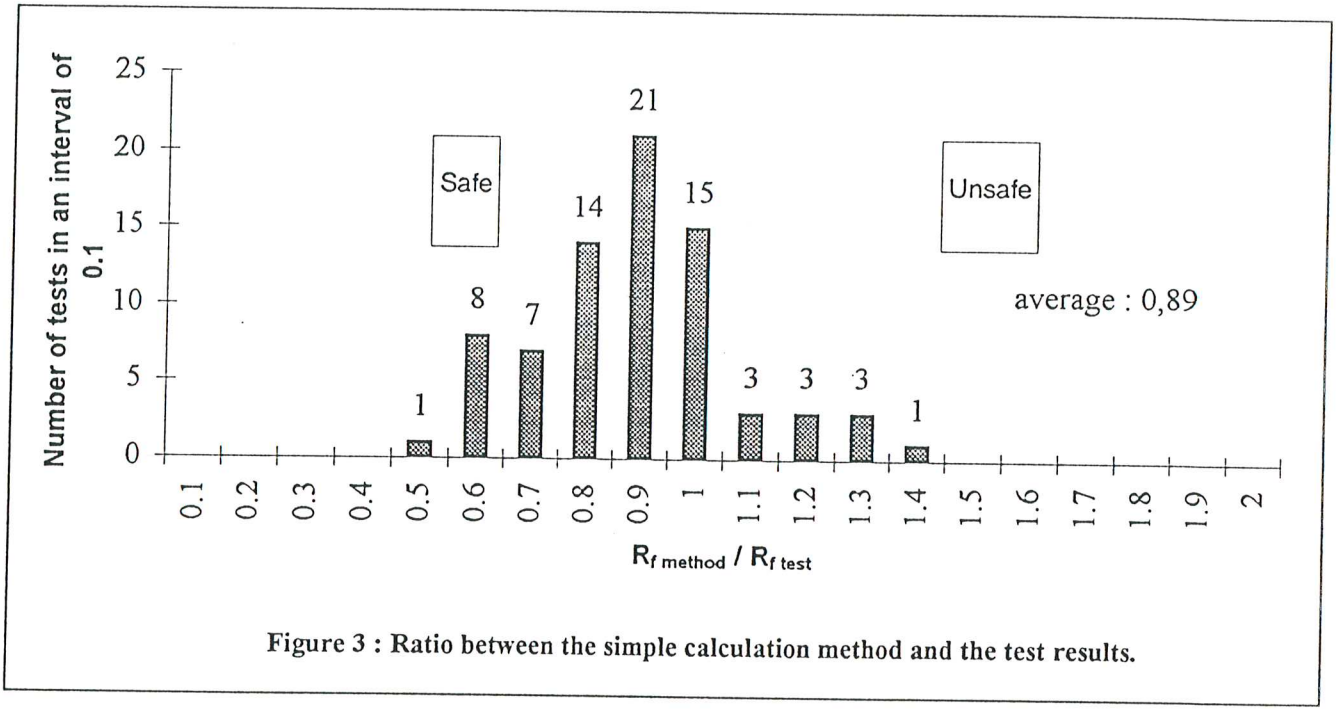

Figure 3 : Ratio between the simple calculation method and the test results.

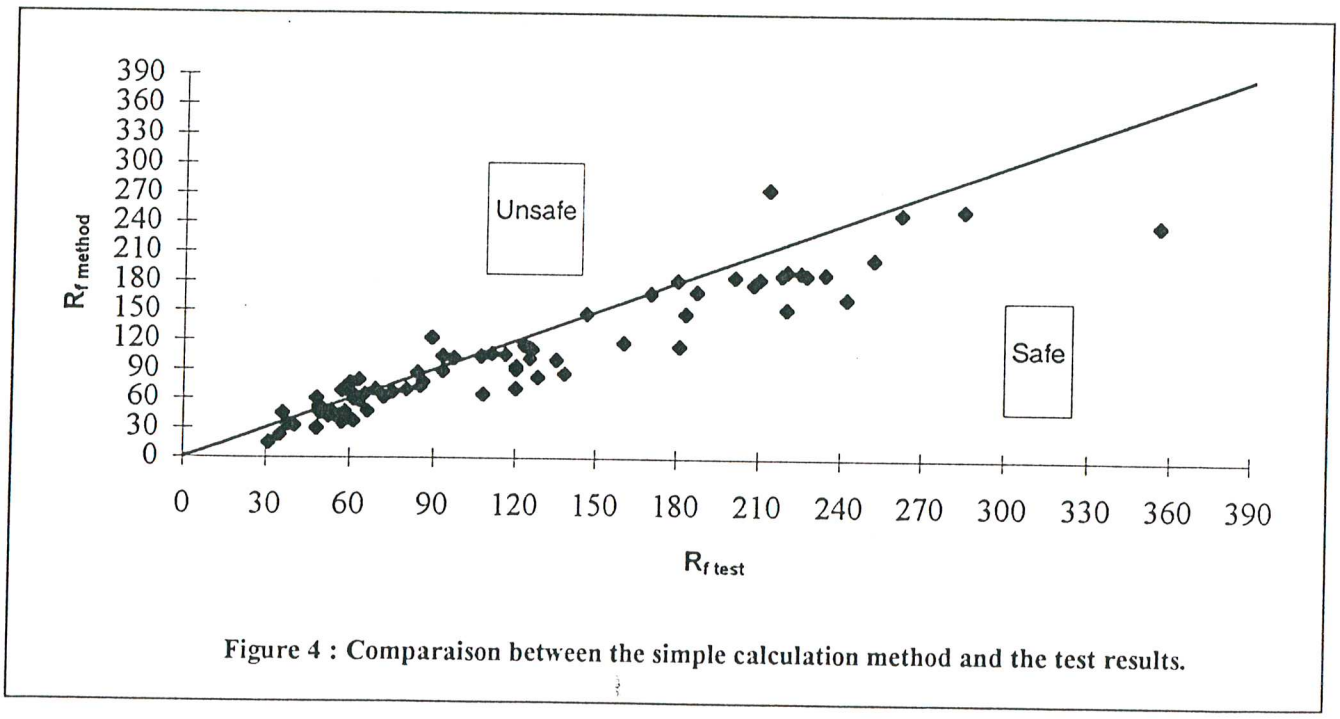

Figure 4 : Comparaison between the simple calculation method and the test results.

CONCLUSIONS.

Being established on phenomenological bases, the calculation method can be regarded as a level 1 method, in the sense of § **4.2. Tabulated data** of Eurocode 2, part 1.2. [6].

The main advantage of the method is that it is really straightforward. It takes only some minutes to calculate the fire resistance, or the ultimate load after a certain time, of a reinforced column.
There is no need to interpolate in tables.
The results compare with the experimental results as well as a general calculation method.

The calculation method should not be applied out of its field of validation which is;

- ISO 834 heating,
- the parameter b=perimeter/4 included **between 20 cm and 40 cm**,
- the buckling length not greater than 6 meters,
- eccentricity limited to ½ the width of the section.

The diameter of the longitudinal re-bars is not limited, but it is recommended to use a diameter smaller than 25 mm. Spalling appeared in some tests of the Belgian series with a diameter of the re-bars greater than 25 mm, leading to prematures ruptures. These tests were not considered to establish the proposed method

BIBLIOGRAPHY.

1. Dotreppe, J., C., Baus, R., Franssen J., M., and Bruls, A., " Dimensionnement des colonnes en béton armé en considérant le problème de la résistance au feu. " Rapport final, Convention F.R.F.C. N° 29010.90/F, Service des Ponts et Charpentes, Univ. de Liège, 1993.
2. Hass, R., " Zur Praxisgerechten Brandschutztechnischen Beurteilung von Sutzen aus Stahl und beton. ", Inst. für Baustoffe, Massivbau und Brandschutz der Technishen Universität Braunschweig, Heft 69, 1986.
3. Lie, T., T., and Woolerton, J., L., " Fire resistance of reinforced concrete columns - Test results. ", Report N° 569, National Research Council, Inst. for Research in Construction, Ottawa, 1988.
4. Franssen, J., M., et al. , " A comparison between five structural fire codes applied to steel elements. ", Fourth International Symposium on Fire Safety Science, Ottawa, June 94.
5. Franssen, J., M., " SAFIR applied to prestressed beams at ambient temperature", Association Française Pour la Construction, in *Ext. prestressing in struct. Non-Linear Calculation Tests of Prestressed beams*, 67-73, 1995
6. CEN TC 250/SC2/93-1, " Eurocode 2: Design of concrete structures. Part 1-2: Structural fire design.", prENV 1992-1-2, October 1993