# 3rd CIB/W14 WORKSHOP

# "MODELLING"

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## PROCEEDINGS

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# TIME HISTORY VERSUS ULTIMATE STATE DESIGN IN STRUCTURES SUBMITTED TO THE FIRE.

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## I. INTRODUCTION.

The normal course of events for a structure which is submitted to a fire is first to be loaded at ambient temperature and later to suffer the fire. This is also the way that work most (but not all) of the numerical program which have been written for the simulation of the fire behaviour of structures. The load is applied at ambient temperature in one or several load steps (from A to B on Fig. 1). The structure is then heated and the evolution of the situation is tracked from time step to time step (from B to C on Fig. 1 if the load remains constant).

If, for instance, the structure is first heated without any load up to the same failure time (from D to E on Fig. 2) and the load is then applied without any further variation of the temperature field, i-e. considering that the time is fixed (from E to F on Fig. 2), the failure load is likely to be different from the one that had been applied in the first calculation. There is a path dependency.

The first strategy is called "time history" because it simulates the true history of the structure during its life time. We will call the second strategy "ultimate state design" because the calculation of the load bearing capacity is made at the desired time of, for example, 60 or 90 minutes.

The appealing side of the second strategy is that it can tremendously reduce the computing time. This reduction comes from two facts.

1. Reduction of the C.P.U. time for each calculation.
   If the ultimate design strategy is accepted, it is possible to adopt some computing techniques which allow to pass from D to E (see Fig. 2) in one single step. The number of load steps to pass from E to F (Fig.2) is then likely to be much smaller than the number of load and time steps required to pass from A to B to C (Fig. 1).
   In this paper the code SAFIR developed at the university of Liège is used as a comparison tool. As this code has been originally foreseen to follow the first strategy, it is necessary to pass quietly from D to E (Fig. 2) when the code

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is used to mimic the second strategy, in order to support the out of balance forces caused by each temperature increase. In this particular case where the concept of ultimate state design is utilised in the strategy of the calculation but was not foreseen during the development of the program, the reduction of C.P.U. time for each calculation is small.

2. Reduction of the number of calculations.
One might be interested, instead of the resistance time corresponding to an applied load, in the applied load that would lead to a desired fire resistance time. Using the first strategy obliges to make a first guess concerning the load to introduce in the first calculation, then to make a second calculation with an increased or decreased load depending whether the first resistance time was too long or to short. A few more successive calculations must be performed up to the moment when the obtained resistance time is judged to be sufficiently close to the aimed resistance time. The number of calculation is highly dependent on the quality of the first guess but an average of four trials is not uncommon, which is the number by which the C.P.U. time is reduced when the second strategy is used. The reduction in terms of total effort is even much higher if one think of the time that is needed by the human being to analyse the results of each calculation, to decide what the load will be in the next calculation and to prepare and start the next calculation.

The disadvantage of the second approach is that the result might not be the same as the one obtained by the first approach which is probably the most realistic. This is mainly due to creep, which is very low during the heating without load of the ultimate state design calculation.
Now, for various reasons that will not be discussed here, we very often end by using material laws where creep is implicitly introduced in the stress-strain relationship. In this particular case, the path dependency is reduced, but there remains a difference between both strategies because of the non linear material laws and because of second order effects. How big is the difference ? Does it really still exist ? This paper tries to give a partial view of what the answer could be.

## II. AXIALLY LOADED STEEL COLUMNS.

The code SAFIR has been used successively with the two strategies described by Fig. 1 and 2. The material laws are those of the part 10 of Eurocode 2 for concrete and of Eurocode 3 for steel, i.e. creep is implicitly introduced in the stress-strain relationship. When the stress related strain decreases, the relationship between stress and strain is linear and parallel to the tangent at the origin. The material law therefore considers the unloading.

In a research project concerning the buckling curves of hot rolled profiles at elevated temperature, it was investigated whether the second strategy (i.e. ultimate state design) could not be used in order to save time.

There are some differences between both approaches, but they are not the same for all the buckling lengths or for all the ultimate temperatures. The differences vary from 0 to 3 %, the ultimate state design giving the highest values. For example, in one particular case (HE 200B, $f_y$ = 235 MPa, buckling around the weak axis, H = 4 m., ISO curve) the ultimate state design at 576 seconds provides a buckling load of 652,25 kN (see Fig. 3). This load, applied on the same column in a time history calculation leads to a fire resistance of 569,75 seconds. The relative difference is $\frac{576-569,75}{569,75}=1,1\%$
After 4 different trials, it could be found that the load of 646,70 kN leads to the same fire resistance of 576" that had been obtained by the ultimate state design approach. The relative difference concerning the loads is
$\frac{652,25-646,70}{646,70}=0,9\%$.

Although differences of up to 3 % were considered as unacceptable in a research project and the ultimate state design strategy was eventually rejected, one could consider it as possible to live with such a small difference in a situation of practical design.

## III. REINFORCED CONCRETE COLUMNS.

The path dependency was also investigated in a research project concerning the fire resistance of reinforced columns. Fig. 4 concerns an axially loaded column which exhibits buckling because of a sinusoidal imperfection equal to H/1000 that has been introduced. The doted line gives the ultimate load as a function of time and has been derived by the ultimate state design strategy, whereas the full line gives the fire resistance as a function of the load and has been derived by the time history strategy. The relative differences are this time more important with, for time ≅ 50 minutes, a maximum difference of 15 %. It must be noticed that for times beyond 40 minutes, the ultimate design strategy is this time conservative. This could be due to the high tension thermal strains which appear in the centre of the section when it is heated without any load.

Fig. 5 concerns a slightly different column (the cover on the rebars is 40 mm. and there is no geometrical imperfection) which is calculated as submitted to a load applied with an eccentricity of 2 cm., i.e. b/15. In this case, no difference at all could be observed between the two approaches.

## IV. CONCLUSION.

The term of "conclusion" is probably too ambitions, concerning the limited view that has been given of the problem. The author wanted to say that, in his own experience with time history simulations, it is not easy to find cases where the path dependency can be highlighted. This is true only if, and that is a big if of course, we accept to use implicit creep in our stress-strain relationships. But if we accept that, we could perhaps consider to go one step further and to accept the philosophy of ultimate state design in our modelling.

The problem is that for other types of structures, it is not possible to know whether the path dependency can be neglected or not, unless a comparison like those that have been presented here has been mode.

There is at least one case where the time history seems to be unavoidable, it is the case of the so-called natural fires, i.e. with a cooling down phase.

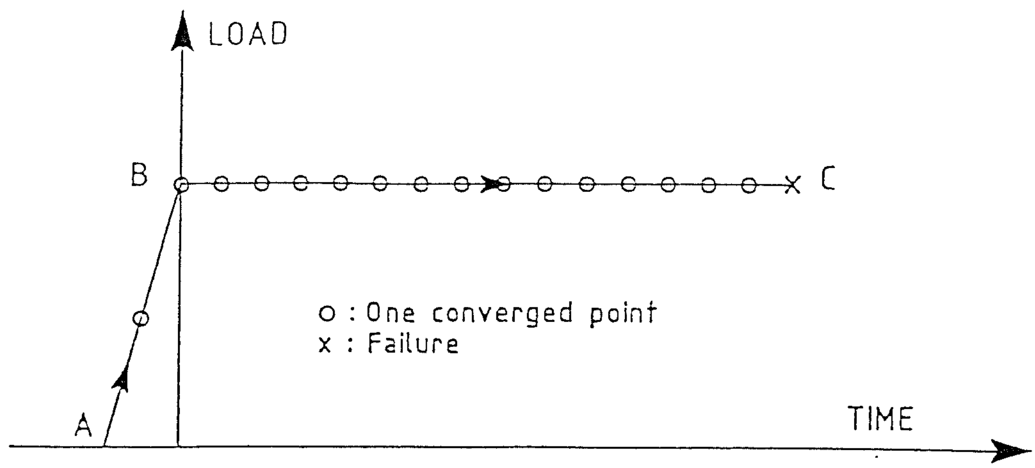


Fig. 1 TIME HISTORY

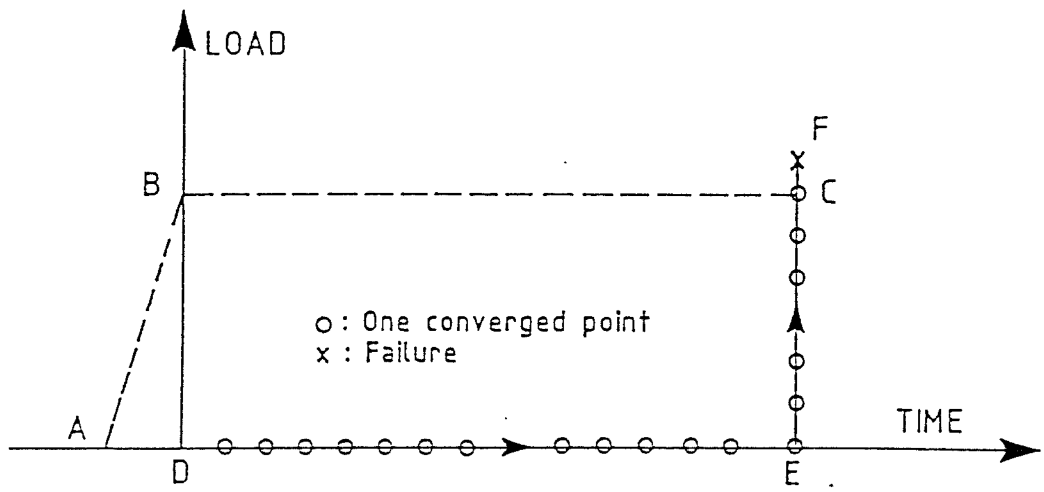


Fig. 2 ULTIMATE STATE DESIGN

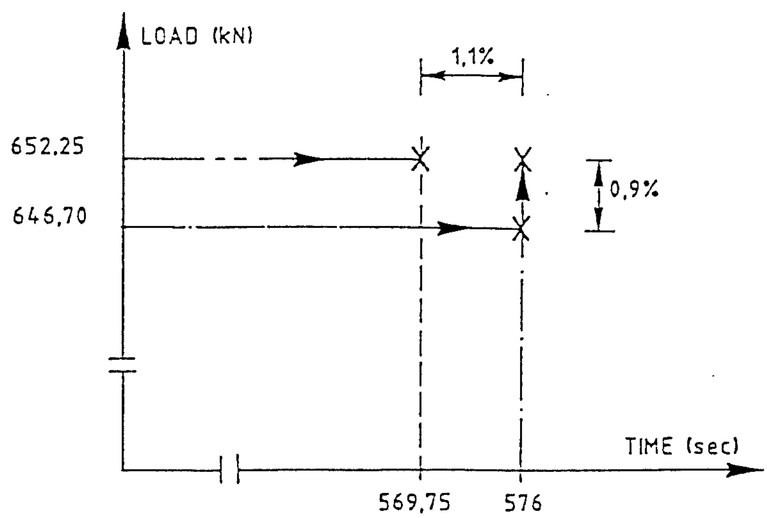


Fig. 3 Axially loaded steel column.

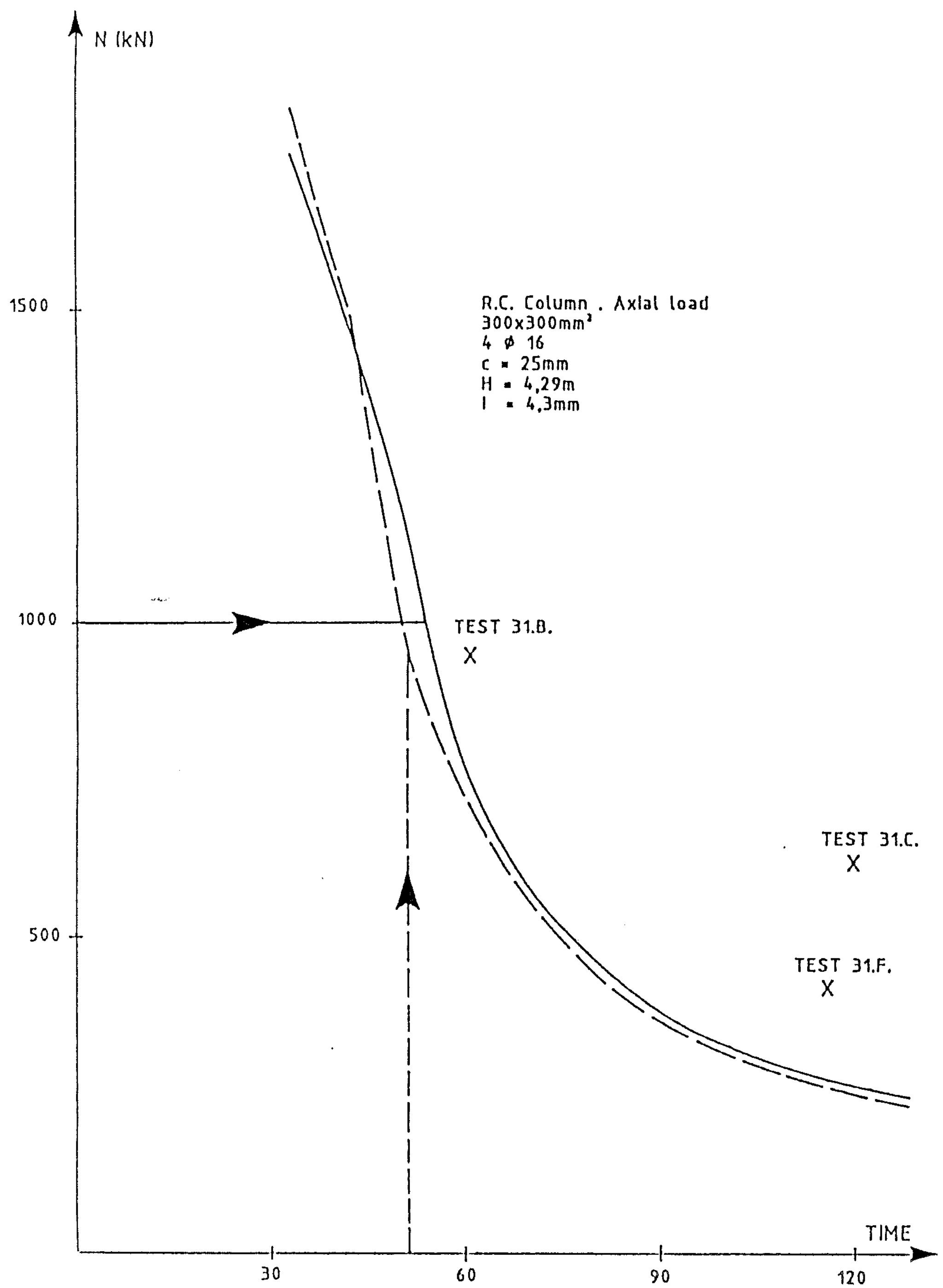
N (kN)
1500
1000
500
R.C. Column . Axial load
300x300mm²
4 ø 16
c = 25mm
H = 4,29m
I = 4,3mm
TEST 31.B.
X
TEST 31.C.
X
TEST 31.F.
X
TIME
30
60
90
120

Fig. 4

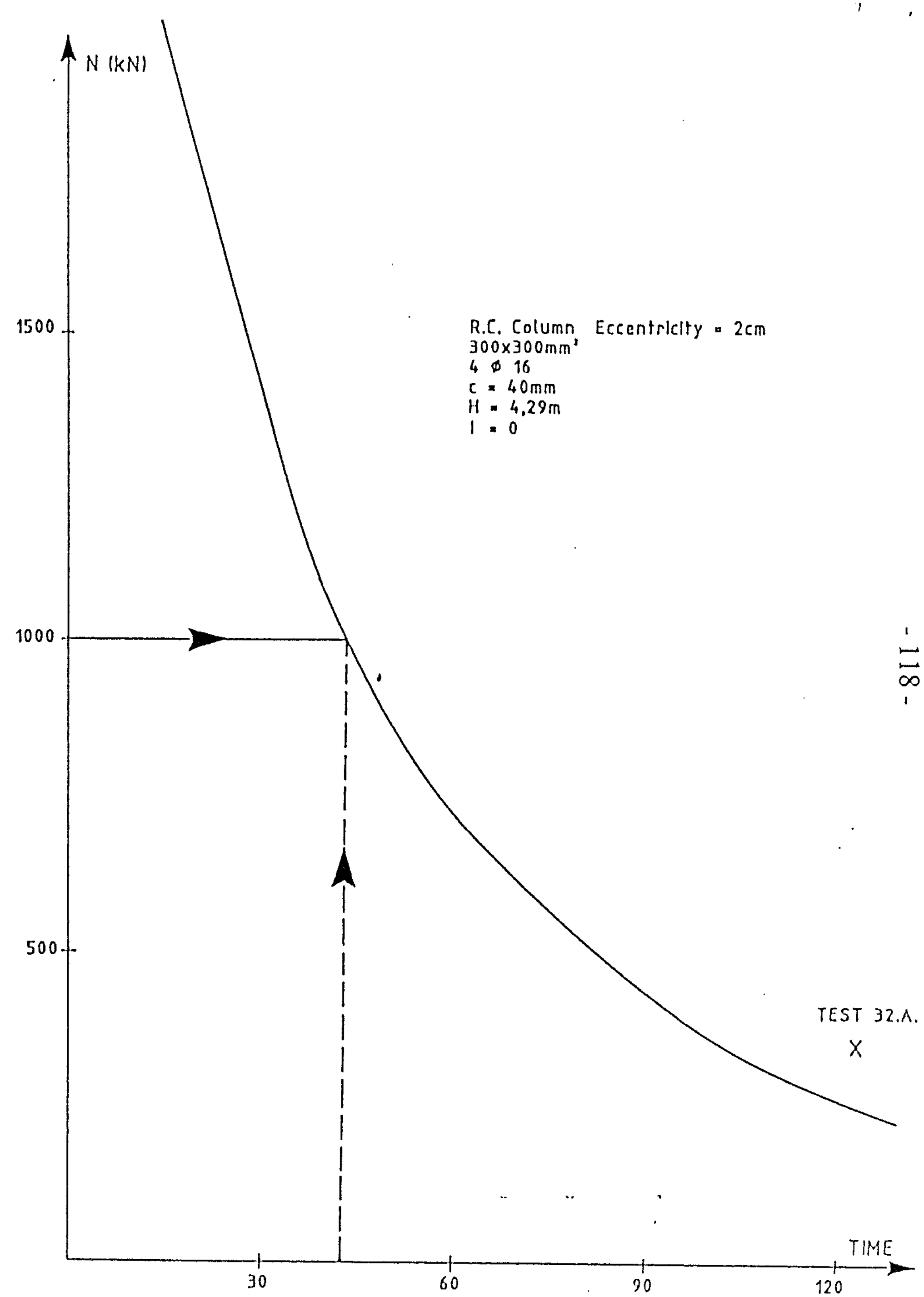
N (kN)
1500
1000
500
R.C. Column Eccentricity = 2cm
300x300mm²
4 ø 16
c = 40mm
H = 4,29m
I = 0
TEST 32.A.
X
TIME
30
60
90
120

Fig. 5