IRIS-2010 - PART IV: NUMERICAL SIMULATIONS OF FLEXURAL VTT-IRSN TESTS

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ABSTRACT

The benchmark IRIS_2010 is an exercise in OECD/NEA/CSNI framework. This paper (part four over fives abstracts, see references [1] to [4]) proposes a synthesis of the results of all the simulations of the tests with punching failure and bending failure. The three different series of experiments (bending and punching) have been carried out before the computations (blind simulations); experimental results were not given to the teams except the principal characteristics (geometry of the specimens, boundary conditions with all the details of the experimental set-up) and some material characteristics for concrete and steel (both for the missile and the rebar). In a first step we read all the reports and opened all the files with the curves, the numerical values and technical comments (constitutive equations, numerical codes, material parameters). We had to gather all the data in order to compare the curves (and to correct some mistakes). In a second step we decided to build simple indicators related to the quality of the computations the ease the comparisons between the teams and also because the numerical strategies where sometimes very different. For this we considered the ultimate load, the maximal impulse, the deflection of the centre of the slabs (both the maximal and the residual), a strain given by a gauge stuck on a rebar and the duration of the shock (not all these data were given for the three tests). These values have been normalized by their experimental corresponding values or in some cases (the load for example) by the mean value of all the numerical data. The indicator is the sum over all these ratios (or there inverses if lower than one) divided by the number of quantities present in the sum. If equal to one the indicator reveals that the computation is perfect (for the quantities considered); a rosaceous presentation indicates that no team did good computations for the three tests.

INTRODUCTION

This presentation is organised as follows: we show the different input of the computations (load, momentum) and then analyse the different results produced by the authors: displacement (both maximal and residual), strain and damage pattern. The most difficult quantities to be obtained in the computations are the residual displacement and the strains on the rebars. On the contrary the other quantities are less dispersed and there mean value (over 28 teams) match the experimental data for the three tests. In a third step we have tried to exhibit a correlation between the quality of the numerical results and the code having been used, the complexity (or the simplicity) of the constitutive equations, the refinement of the mesh, the use of local improvements (sliding for example). It has been impossible to conclude from that analysis; this indicates that the experience of the teams in charge of the computations is more important than the technical elements they used. We have also shown that some quantities, even dispersed, are statistically more relevant to check the quality of the computations. For example the residual displacement is a quantity very difficult to obtain but when this value is reached by the computation it is much more related to the experimental one than the maximal displacement (probably more sensitive to the boundary conditions). In a last step we have compared the damage patterns given by the codes to the experimental ones. It is sometimes difficult to do these comparisons due to the variety of the representations (equivalent plastic strains, maximal eigen value of strains, cracking, damage,) but the main features have been obtained by, roughly speaking, a half of the teams (rupture with plastic lines for bending for example).

VTT-flexural

Loading

This test has been described in details in a previous paper. The loading history (between the missile and the target) is plotted in Fig. 1. It is important to notice (i) that some values given by the participants are probably incorrect (problem of units) and (ii) that six values are clearly out of range (not shown in the figure). We can see a large scatter for this value, scatter probably due to the different computation strategies.

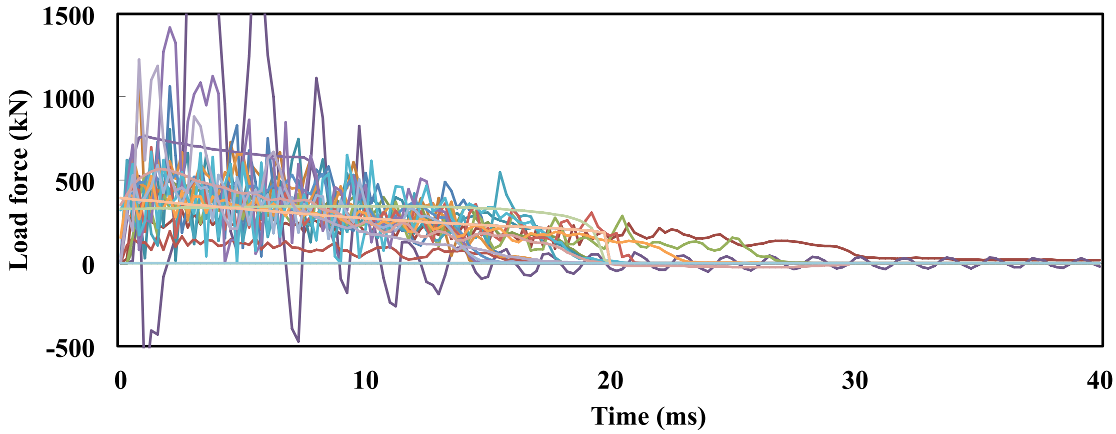

Fig. 1: VTT flexural: evolution of the loading.

The momentum is clearly a good result (considering the maximal value) for all the teams except two of them, which are without any explanation out of range. Some teams did not give this. The mean value is 5.27 kN.s (experimental one is equal to 5.5 kN.s). For one curve (the lower one in blue) we are quite sure that a multiplication by a factor four would give a good result (due to a calculation on a quarter of the specimen due to symmetry). It is sometimes possible to correct the given results but not always!

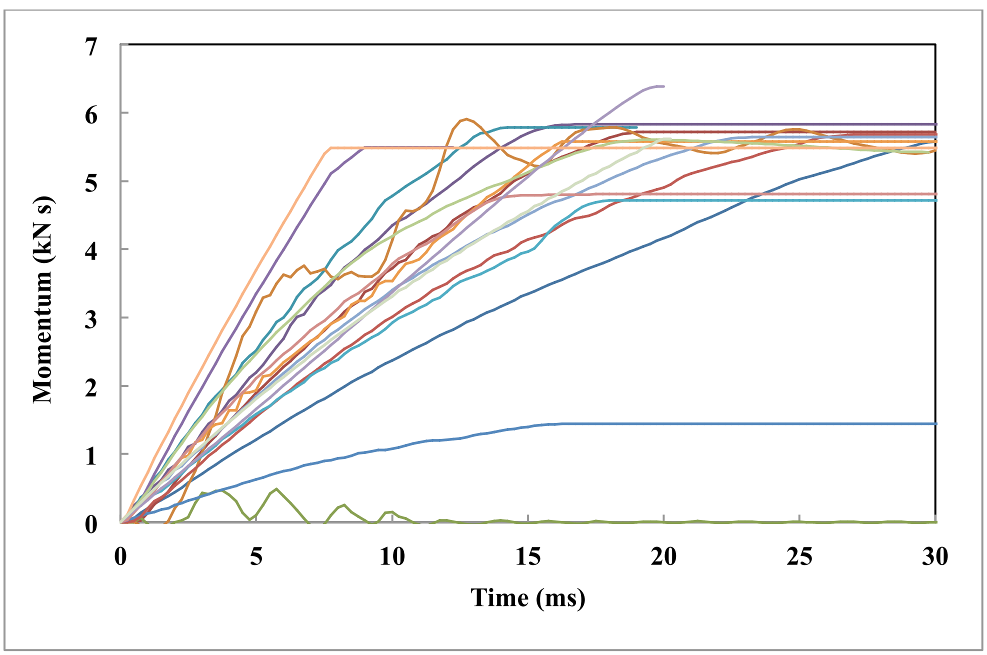

Fig. 2: VTT flexural: simulated momentum versus time.
The experimental curve is not represented in the figure due to the fact that this quantity is difficult to measure (the maximal value given by the experimental curve reaches 8 kN.s).

The load peak divided by the mean value is plotted against the momentum divided by the experimental value in Fig. 3. The results are very close to the one of Meppen test, i.e. a much more important discrepancy is found on the load peak rather than for the momentum.

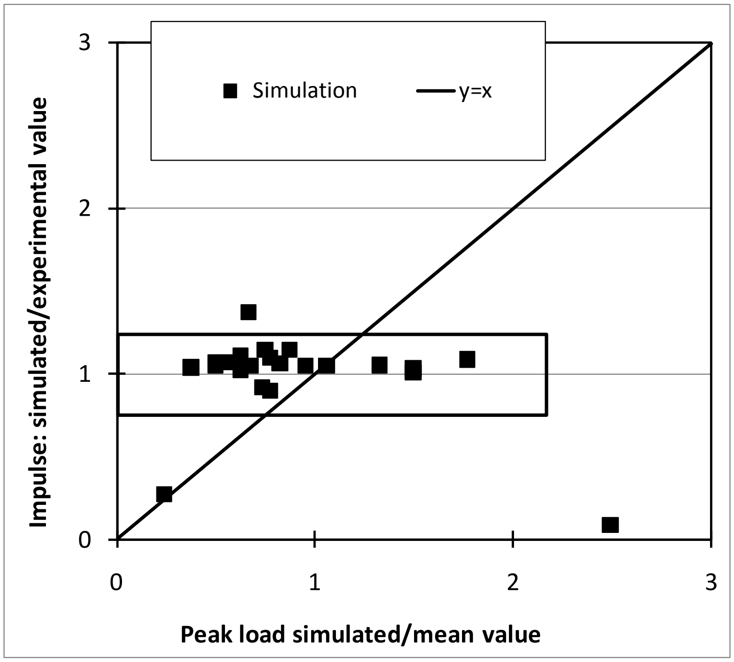

Fig. 3: VTT flexural: load peak with respect to momentum (impulse).
The rectangle is representative of the mean value minus the standard deviation.

Deflection

The figure 4 shows all the computed values of the W1 displacement compared to the experimental one (black curve). Indeed the displacement is not a good indicator of the quality of the computations.

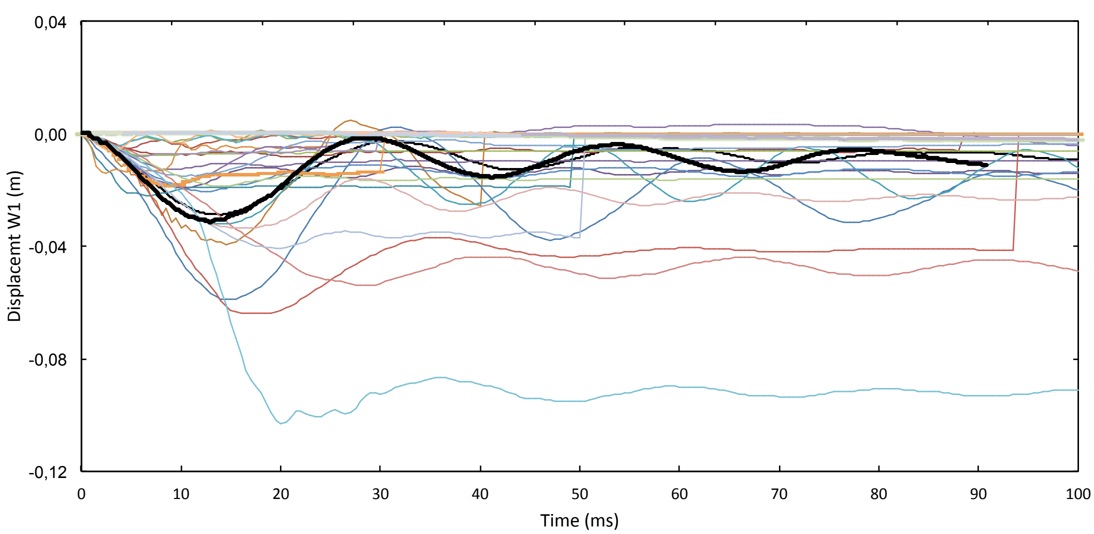

Fig. 4: VTT flexural: comparison between experimental and simulated evolution of the displacement W1 (in black the two experimental curves).

We have computed the ratio between the displacement max denoted W1 and the corresponding experimental value (0.03 m) and the ratio between the maximal load deduced from the computations and the mean value (0.8 MN) supposed to be a good indicator of the correct value. This curve is very interesting because even if a team predicts a non-correct value for the normalized displacement (0.5 for example) a corresponding value should be obtained also for the load indicating that a non-correct identification or some problems in the FE procedure have occurred. It is not the case at all as the results are strongly dispersed.

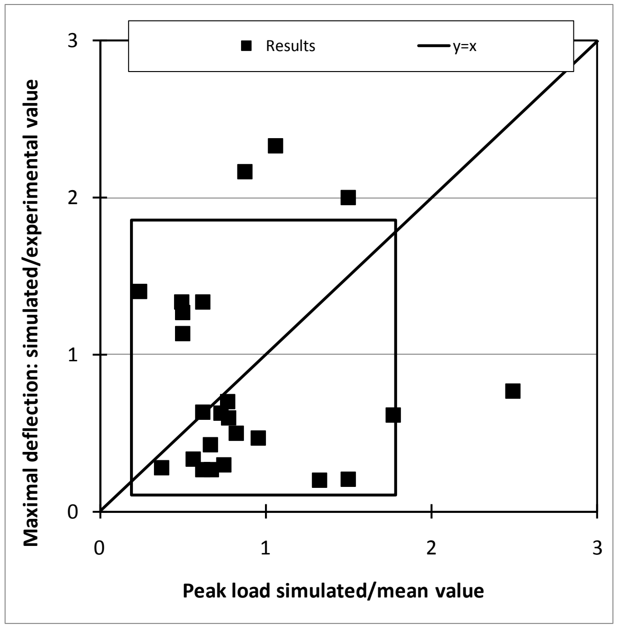

Fig. 5: VTT flexural: comparison between experimental and simulated maximal displacements W1 and load peak. The rectangle is representative of the mean value minus the standard deviation.

Reinforcement strain

The strains given by stain gauges stuck either on concrete or one rebar are not a good indicator of the performance of the computations as there is a great effect of the hypothesis: friction or not between steel and concrete, slip or not.

Damage pattern

Damages measured on B1 (left) and B2 (right) slabs, in terms of permanent (or residual) displacement (in mm).

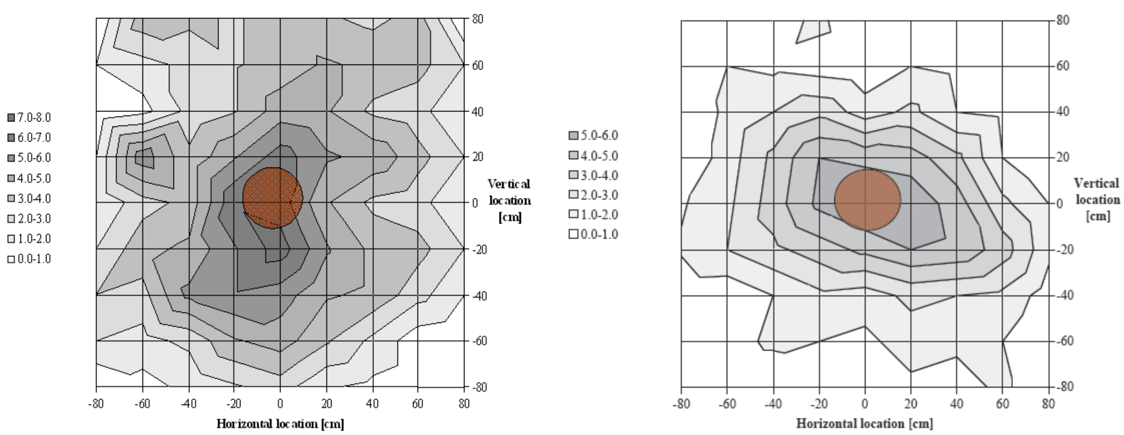

Fig. 6: VTT flexural: Damage measured on B1 (left) and B2 (right) slabs.

The Fig. 7 shows the different pictures given in the numerical results. They represent damage, cracking or maximal values of strains. The damage to target is more complex to analyze due to the difference between the models (plasticity or damage) and to the representation. We can say that for 4-5 teams a typical result can be viewed as the development of diagonal plastic lines. But the other results give either a confined plasticity or damage under the contact zone or diffuse all over the specimen.

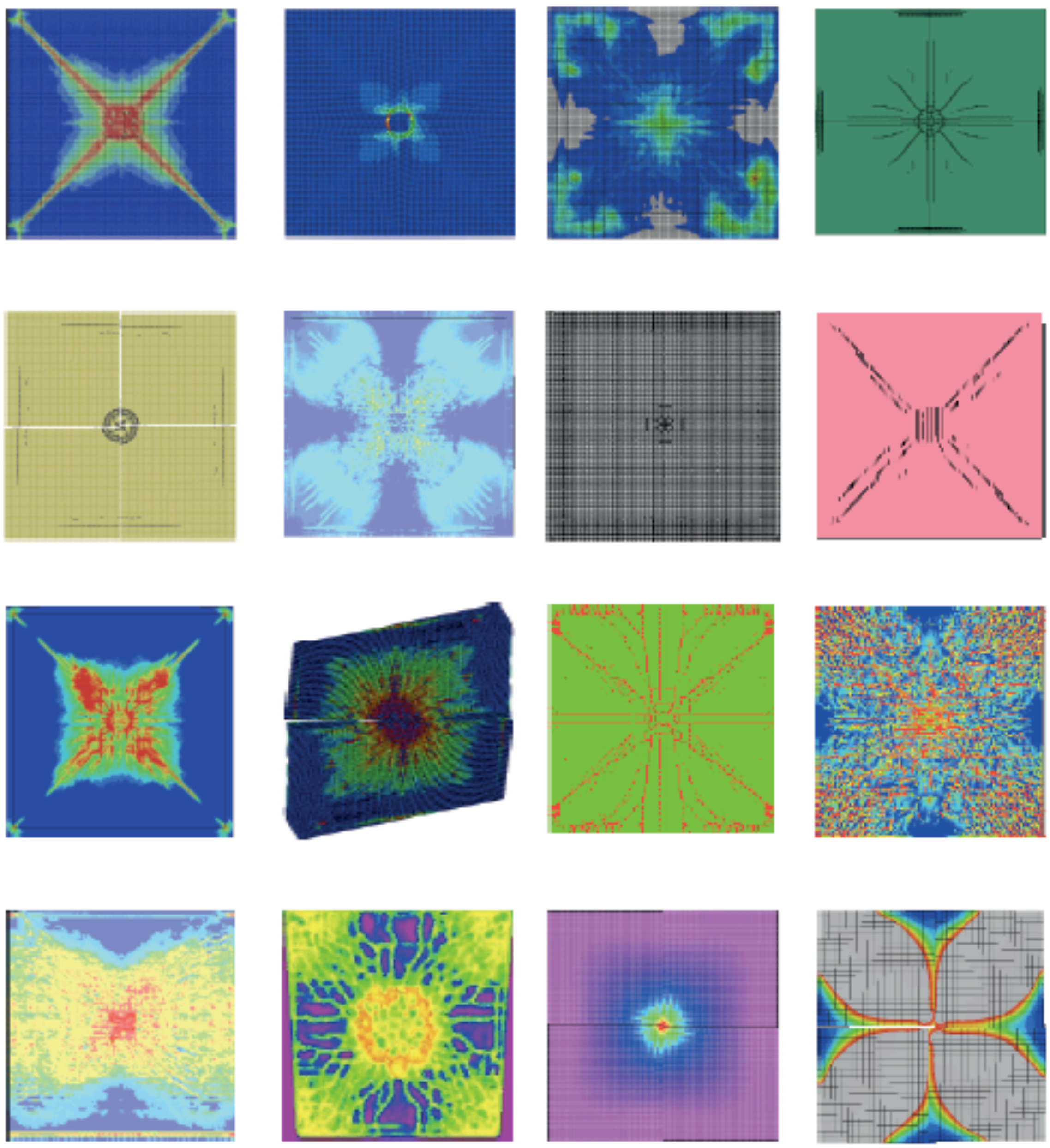

Fig. 7: VTT flexural: damage or cracking patterns.

Global indicator

We give below the global indicator for the flexural test for all the teams. It is the sum of the ratio of the six quantities given in this analysis (duration of impact, reinforcement strain, residual displacement, maximal displacement, momentum and load peak). The scale is logarithmic between one and ten and the scale is inverted. This indicator (a value close to one means a good prediction) takes into account the following normalized quantities: maximal load (note that it is obtained experimentally from the support structure legs), maximal displacement W1, residual displacement W1, maximal momentum and duration. The mean is arithmetic. Of course some coefficient should modify the indicator because for example the reinforcement strain is more difficult to obtain than the maximal displacement that is a global quantity.

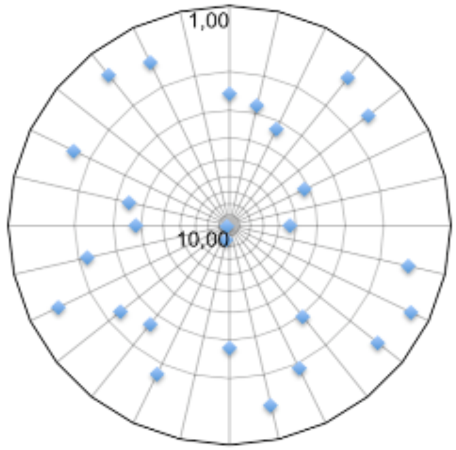

Fig. 8. VTT Flexural: Indicator of the performance of the calculations
(the performance decreases as this indicator increases).

An analysis of the better results shows that different strategies exist to get good results. Rough models (two - three teams) or much more complicated to handle and to identify (three - four teams) permit to obtain low values of the indicator (around 1.4). The other teams have indicator between 2 and over 10.

The different ratios are given below in normal scale in Fig. 9

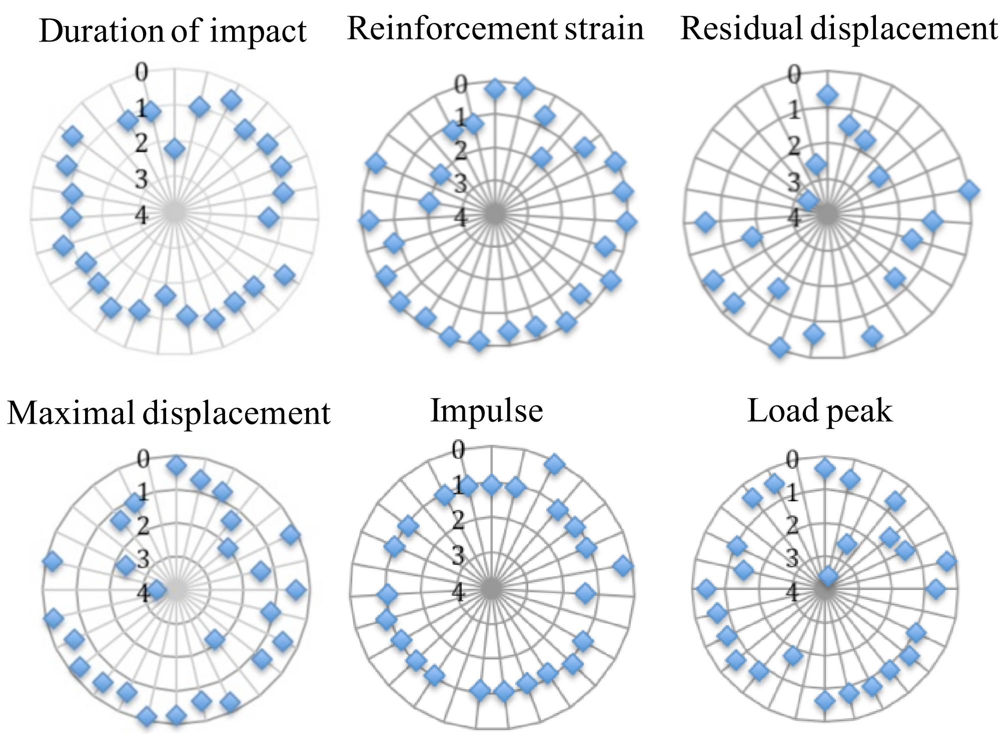

Fig. 9: VTT flexural: ratios between numerical results and experimental data.
The ratios are concerning the different quantities: (top from left to right) the duration,
the strain, the residual displacement (bottom from left to right)
the displacement maxi, the momentum (impulse) and the load max.

It is clear from this figure that the momentum has been correctly modelled and that other quantities are more dispersed.

It is possible to calculate for each ratio the mean value and the standard deviation. We have represented on a unique figure the mean value (blue curve) and the mean plus (red) or minus (green) the standard deviation. In black the one value is displayed. It is interesting to note that for all quantities excepted the residual displacement W1 and the strain EPS 3 the mean value of the numerical data matches the experimental one.

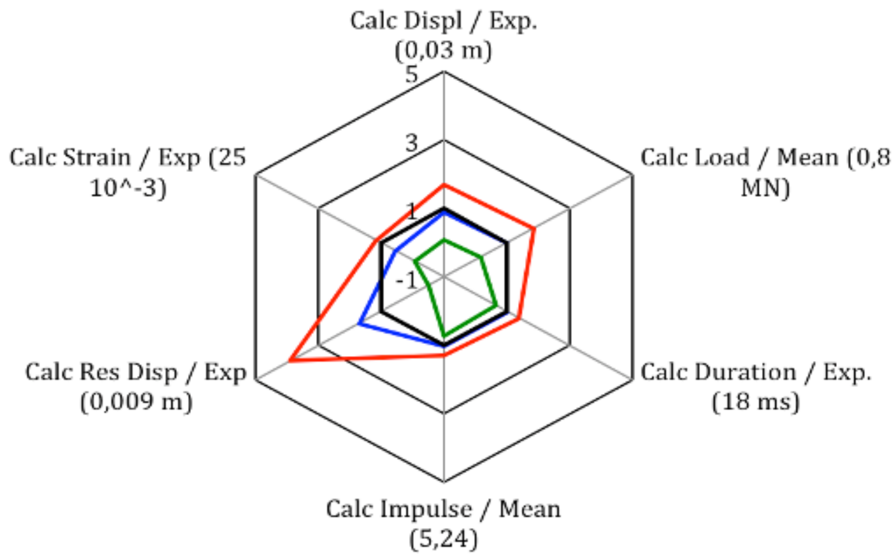

Figure 5-1 VTT Flexural: Indicator of the performance of the calculations
(the performance decreases as this indicator increases).

Conclusion

All the results are summarized in Table 1. The conclusions are different from the one drafted for the Meppen test. However, it is interesting to note that the global indicator shows that the results for the VTT-flexural are less in accordance with experimental ones than the Meppen test.

Table 1: Mean and coefficient of variation of different data.
Comparison to experimental results (VTT-flexural).

	Mean value	Coefficient of variation	Experimental value
Maximal displacement (centre of slab) [cm]	2.6	89 %	3
Residual displacement (centre of slab) [cm]	1.4	143.5 %	0.9
Maximal load [MN]	1.6	261 %	NC
Momentum [kN.s]	4.9	40 %	5.5
Performance Indicator	5.4	224 %	NC

We have tried to understand what would be a good strategy to model this flexural test (for example). For that we computed different ratio: computed W1 maximal (resp. residual) displacement to experimental ones, computed maximal load to the mean one, computed strain (eps 3) to the experimental one. The duration has been estimated as the time for which the load comes to zero in the computation and the maximal impulse has been compared to the mean value. The experimental data has been obtained through complex optical set-up. The value given by the system is equal to 18 ms. We have exactly the same representation but only for the teams considered to have chosen simple constitutive equations. Results obtained with modelling with kinematic hardening or damage law with complex evolution laws and a great number of materials parameters have been removed. It is not possible to see better results.

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