JCSS Workshop on Semi-probabilistic FEM calculations

Delft, December 1 and 2, 2009

1. Introduction

On December 1 and 2 the Joint Committee on Structural held a Workshop in Delft on the topic of Semi-probabilistic FEM calculations. It is generally known that the use of FEM calculations in relation to the codified partial factor method is not an easy task. Both general as well as material specific problems may arise. Some of the typical problems are:

- Handling of load combinations and load arrangements
- Over/under proportional non-linear behaviour
- Imperfections and residual stresses
- Brittle materials and softening behaviour
- c-φ-reduction techniques / drained versus undrained geotechnical analysis
- Soil Structure interaction
- Mean values versus characteristic values
- Global resistance factors versus partial material factors
- (Simplified) full probabilistic FEM

Of course one can always develop computer programs that consider the code rules as a starting point and do precisely what else should have been done by hand. In such an analysis, however, the global analysis is often a linear elastic one and the actual verification is carried out on a local (member) scale. It is however more interesting to include directly all geometrical, physical nonlinearities, spatial material fluctuations and uncertainties in the analysis and check explicitly for combined overall and local stability, redistributed stresses and deformation capacity. For such an analysis one needs a clear strategy on how to deal with load arrangements, arrangements of geometrical imperfections, material properties and so on. In particular in soil structure interaction the STR and GEO ultimate limit states as defined in the Eurocode have to be combined in one coherent analysis.

The JCCS found it worthwhile to organise a workshop on this item. The objectives of this workshop were to find out how proper procedures could be formulated for the present day design standards (in particular the new suite of Eurocodes) and to formulate recommendations for changes in future codes.

2. Summary of the presentations and discussions

The summary was attended by about 30 participants and a total of 18 presentations were given in the fields of steel, concrete and geotechnical structures, both on full probabilistic calculations as in partial factor design. Presentations and participants are listed in the Annex.

The uncertainties and scatter for all materials were considered to be related to:

- loads and load models
- material properties and material behaviour models
- dimensions and geometrical configurations
- global schematisation and model

We will shortly discuss these

-load and material models
It was generally felt that the uncertainties in loads (and load models) and material properties (and material models) could best be treated on loading side or on the resistance side themselves. It is the

best guarantee to find correctly the most dangerous failure mechanisms (which is not always the most frequently occurring mechanism). A typical problem for reinforced concrete structures is the presence of two materials. For frame type of structures it has advantages to have one partial factor for the cross sectional resistance. This asks for an adjustment of the characteristic values for steel and concrete. For geotechnical structures the spatial scatter in the material properties also asks for a differentiation in the definition of the characteristic values. If the scale of fluctuation is high compared to the scale of the mechanism, the definition could be the same as for steel and concrete. However, in the reverse case, averaging will occur and only a 5% fractile for this average should be considered. Another typical geotechnical issue is the value of the water pressures and the related material parameters.

-*geometrical models*
Geometrical uncertainties turned out to be completely different for all materials considered. For slender steel structures especially the geometrical imperfections in stability calculations are important. In many cases it might be convenient or even necessary to consider these uncertainties already in the overall analysis. For concrete the position of the reinforcement is relevant and for soil the exact shape, thickness and position of soil layers. The uncertainty is large and in some cases soil layers may locally even vanish completely. It is then difficult to model these layers as random fields and some additional scenario presentation may be more helpful.

-*overall calculation model*
Most of the attention during the workshop was on the uncertainties related to the global model and schematisation. The main decisions concern the choice between 1D, 2D and 3D models, the boundary conditions, the element size and the nonlinear material properties. For soil the subdivision into layers may also be very important. There was even a proposal to add a special schematisation uncertainty, next to a model uncertainty. From a philosophical point of view it is a question whether these two could really be distinguished. But the point is clear: ask two bureaus to schematise a structure or system and results may differ substantially. In some cases this may have to do with a deliberate conservative choice in order to avoid cumbersome calculations, but not always. Apart from that, it may be difficult to give meaningful definitions of model uncertainties, in such a way that they actually could be measured in practice and inserted in the FEM analysis. The same holds for the corresponding partial factors. Possible options are (as already pointed out by Eurocode EN 1990):

a- increasing the representative unfavourable load values X_S
b- increasing the calculated load effect values S
c- decreasing the favourable representative values of the materials X_R.
d- decreasing the final resistance model R

Typical problems related to the choice are: (1) one should not disturb the equilibrium in the system (e.g. in a combined sheetwall-soil calculation one cannot increase the soil pressure on the sheetwall) and (2) one may shield some mechanism by cutting off some values (e.g. a reduced plastic moment lead to lower maximum shear forces, shielding a dangerous brittle mechanism). The choice may depend on the over- or under proportional effect of the safety margins. In general options **b** and **d** are to be preferred as being the most realistic.

Some other observations during the Workshop were:

- The degree of uncertainty related to the several models used in practice or research is often not (explicitly) known. The JCSS has given some indications in the Probabilistic Model Code, but this is far from complete. Only the standard procedure (linear elastic overall analysis in combination with member resistance modelling) is considered.

- Simple models are often used in practice with a relatively low margin for the model uncertainty. The justification may be in the long experience there is using these models. For FEM, and in particular for the full nonlinear case, this degree of experience is much less. It may lead that, at least for the time being, to the curious result that the uncertainty related to the use of the more advanced model is larger. On top of that there may be the uncertainty related to the extra parameters as often present in advanced FEM calculations.

- Model uncertainties may be so large that experiments are needed to calibrate the model. As usually experiments are more expensive than calculations, a proper mix of calculations and experiments may be helpful.

- For different failure types (e.g shear versus bending) different values for the safety level are sometimes required. There is a need for an economical and practical calculation procedure to deal with such a safety differentiation.

- In the FEM analysis one often keeps the structural properties fixed at the design values, while the loads are raised form zero to the failure level. However, this does not always work properly, especially in soil mechanics calculations. In that field it might be better keep the loads constant and reduce the resistance parameters (c-phi-reduction). From a probabilistic point of view an intermediate solution seems to be the most appropriate: start with all variables on a mean (or representative) value level and increase (or decrease) them proportional to the standard deviation till the limit state is reached. This solution may be the only way out for solving properly nonlinear soil structural interaction problems.

3. Conclusions
The workshop agreed on the following statements:

1) There is a need for a consistent non-linear-FEM oriented Partial factor format for all materials.

Partial factors should realistically take into account the uncertainties in geometrical properties, loads and load models, material properties, local resistance models (point, section, member or mechanism-level) and global load distribution model.

3) The format should lead to a design that fulfils a specified safety target (e.g. $\beta = 3.8$ according to EN 1990).

4) Full probabilistic non-linear FEM may and should be used to check the safety levels obtained by the partial factor method. Sufficiently developed operational methods are available.

5) The main difficulty in both full and semi probabilistic analysis is the uncertainty in the global load distribution; the position of the model uncertainty factor should depend on over/under proportional behaviour; global model uncertainty factors may never destroy equilibrium

The following follow up activities are foreseen:

-All presentations will be made available on the web for JCSS members and Workshop participants.
-All participants agree to stay in touch and exchange experiences; relevant papers will be listed and or distributed; interesting is especially the fib-guideline under preparation
-Guiseppe Mancini will prepare a bench mark example in order to check numerical differences

Finally it may be concluded that the problems within the various field of application (steel, concrete and geotechnics) are very similar and ask, on the main lines, for the same type of solution.

Annex A: Overview of the Presentations

Ton Vrouwenvelder and Raphael Steenbergen
Design rules according to Eurocode and ISO 22394

Gerhart Sedlacek and Frans Bijlaard
Steel Frames design and EC3

Vladimir Cervenka Jan Cervenka
Verification of Global Safety of Resistance of Reinforced Concrete Structures based on Non-lin FEA

Max Hendriks
Nonlinear FEM for concrete structures

Michael Hicks
FEM and stochastic analysis in geo-engineering, with application to EC7

Hans Teunissen
Uncertainties in modeling of frictional materials

Bruno Sudret and Thierry Yalamas
Advanced methods for FE-reliability analysis

Alfred Strauss
Probabilistic modeling of degradation and corrosion processes with respect to ULS and SLS

Guiseppe Mancini and Diego Allaix
Actual safety level with different safety formats used in non-linear analysis

Milan Holicky and Miroslav Sykora
Global resistance factors for reinforced concrete members

Bruno Sudret
Comparing Eurocodes designs with full probabilistic designs for RC beams

Hendrik Schlune
Evaluation of Safety Formats for Nonlinear FEA of Concrete Struct

Ane de Boer and Cor Van der Veen
FE nonlinear analysis, unity check and reliability index in two civil engineering applications

Henk Bakker
FEM in design of Water defense systems

Timo Schweckendieck
Probabilistic FEM analysis for a sheet wall

John Sorensen and Lars Anderson
Reliability of (wind turbine) foundations using non-linear analysis

Sebastian Thöns
Buckling reliability of steel shells utilizing the EC3 methodology

Wim Courage
Demonstration Reliability software tool Prob2B

Participants

Ton Vrouwenvelder	Netherlands
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Vladimir Cervenka	Chech Republic
Jan Cervenka	Chech Republic
Max Hendriks	Netherlands
Michael Hicks	UK/Netherlands
Hans Teunissen	Netherlands
Bruno Sudret	France
Thierry Yalamas	France
Alfred Strauss	Austria
Guiseppe Mancini	Italy
Diego Allaix	Italy
Milan Holicky	Chech Republic
Sykora	Chech Republic
Bruno Sudret	France
Hendrik Schlune	Sweden
Ane de Boer Cor	Netherlands
Van der Veen	Netherlands
Henk Bakker	Netherlands
Timo Schweckendieck	Netherlands
John Sorensen	Netherlands
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Sebastian Thöns	Germany/Switzerland
Maximilian Huber	Germany
Gerard Canisius	UK
Geoffrey Decan	Belgium
Robby Caspeele	Belgium
Celeste Barnardo	South Africa
Chris Roth	South Africa
Beatrice Belletti	Italy
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Anneke Hommels	Netherlands
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