Description of the STVF Programme No 11.

models for structural materials

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DESCRIPTION OF THE STVF PROGRAMME NO. 11

MODELS FOR STRUCTURAL MATERIALS

1. INTRODUCTION

During most of this century Denmark has been one of the leading countries regarding development of new theories and calculation methods for building materials and building constructions.

In this context theories of plasticity and fracture used at structures of concrete, as f.ex. plates, beams, discs and shells together with the whole development inside the modern soil mechanics can be mentioned. I.a. this has meant that Danish thoughts and Danish ideas have left an appreciable finger-print on the coming European concrete-standard, Eurocode 2.

It is the idea with this programme to continue and extend the work with material models for the important building structural materials: concrete, wood, masonry, and soil. This leads to the use of calculation methods and calculation principles, as f.ex. theory of plasticity, fracture mechanics, dynamic calculations together with experimental mechanics for providing this new knowledge about the behaviour of the materials and the structures.
This is described in further details in the next paragraph.

The programme is carried out in a co-operation between the staff from 3 departments, namely
The Department for Structural Engineering, DtH
The Department of Civil Engineering, AUC
The Department of Building Technology and Structural Engineering, AUC.

2. PURPOSE AND CONTENT OF THE PROGRAMME

The materials which have so far been used for building structures are the *metals*

steel and aluminium

and the *non-metals*

concrete, wood, masonry, and soil, which in this connection will be considered as a building material.

On account of the more regular structure of the metals (homogeneity and isotropy) more simple material models and calculation methods in many ways can be used instead of the more complicated models for non-metals, which are more irregular, and which make them more difficult to describe.

This programme is mainly referring to extend the knowledge to the static and the dynamic behaviour of the non-metals: concrete, reinforced concrete, wood, masonry, and soil by arrangement of new and improved *models of materials*, new and improved *calculation methods* together with *experimental investigations*, which among other things are going to serve as calibration of the theoretical models and calculation methods.

The theoretical work will be based partly on analytical solutions and partly on numerical solutions, for which reason use of computers will find extensive use. Computer power has in 1992 become rather cheap together with that greater and more complicated problems than earlier can be solved. In this way it gives the possibility for more advanced material descriptions and calculation methods. Therefore, an example in the programme will be included to prepare a fully modern computer-program, which can be used for calculations in the limit stage for concrete structures.

The idea of the programme is primarily to be able to make a better description of the material and to make better calculation methods of the materials above-mentioned.
By this a good foundation is made for practically all dimensioning and planning of building structures, namely to create structures with an *optimal material consumption*, an *optimal price of construction* and an *optimal price of maintenance.*

The area of concrete

New materials inside the area of concrete have during the last years seen the daylight. In this connection it is meant *concrete with high strength* (compressive strength of 75-100 MPa or more) and *good durability* ("compact concrete"), and concrete added with many different kinds of fibres, the so-called *fibre concrete.*

A number of investigations have been made for these materials of concrete, but answers to a lot of questions are still missing.

High-strength concrete and fibre concrete together with structures of these will in this way play a central part in this programme.

Beside the description of the materials by using different models of materials the theories of plasticity and fracture mechanics will be central areas of research. For fracture mechanics especially theories of crack growth will be looked at.

The area of masonry

Besides high-strength concrete, fibre concrete and reinforced concrete the programme will also include some investigations with a related material, namely masonry. It can also be reinforced masonry together with structures, where unreinforced materials as f.ex masonry and concrete are connected, which happens in combination walls.

The area of wood

Natural wood has for thousands of years been used to building structures and nowadays it is still used in a great extent together with the product of wood which is improved, namely: laminated wood.
Wood is "the most natural" building material, but at the same time one of the most difficult to describe. This is due to the inhomogeneous structure of the wood, knots,

failure in growth, different qualifications in different directions, influence of moisture content, the effect of long-acting load together with many other things.

In this programme earlier work with the material wood will be extended.

The area of soil

The coming big international connections require a new and better understanding of soil behaviour especially because new soil types will effect the foundation of the structures. Therefore a new constitutive model for soil will be developed in the programme. The model should describe the soil behaviour from the newest theories in a way, which fits for numerical calculations.

Summary

The purpose and the content of this programme is to give a better material description for the non-metals:

concrete, masonry, wood, and soil

and to make better calculation methods for structures, in which these materials are included.

The result of this will be structures with a minimum material consumption .

In the following paragraph a more detailed description of the projects, of which the programme exists, will be given.

3. THE PROJECTS OF THE PROGRAMME

In the following a short description of the projects, which are meant to be used in the programme, is given. It could be a question of decrease or increase the number a little or change a little in the various projects, if some changes in the expected budget will turn up. Likewise some small changes at the final presentation of the programme could be made.

3.1 Calculation using plasticity theory of the bearing capacity of concrete structural elements

Danish researchers have for many years been among the best inside some areas of the research of structures. F.ex. Ingerslev's theory for reinforced plates of concrete, followed by K. W. Johansen's work of yield line theory, Lundgren's theory of cylindrical shells, Brinch Hansen's theories inside soil mechanics together with M. P. Nielsen's great work with theory of plasticity of many kinds of structures of concrete.

In this way new strength theories for structures of concrete by use of the theories of plasticity among other things has been created.

However, this "old" area of research still contains a lot of unsolved problems, and it is the plan to solve some of these problems in the programme.

I.a. we think of the following

* Dome effect on unreinforced and reinforced plates of concrete. The practice which is used to-day, is very much on the safe side and these elements are made with great reserves of bearing capacity included. Great economic savings are possible at a calculation with new methods.
* The bearing capacity of non-shear reinforced beams and plates. There is also a lot of unsolved problems in this area, which i.a. the accident with the Norwegian oil-drilled platform "Sleipner" was an evidence of.
* Problems of stability in concrete discs and concrete shells.
* The effect of fibre reinforcement on bending-, shear- and punching shear strength of structures of concrete.

3.2 Calculation using plasticity theory of structures of masonry

The project is very much attached to the project as described above, as it has turned up during starting investigations that a part of the developed theories for structures of concrete also can be used to determination of bearing capacity of other construction materials as f.ex. masonry.

The most topical investigations inside the structures of masonry will be:

* Determination of bending- and shear-strength of reinforced masonry.
* Determination of the strength of combination walls as f.ex. masonry/masonry or masonry/concrete with binders.

3.3 Calculation of reinforced structures by use of computers

Formerly, computer-programs were made for use to calculations in the limit stage for reinforced structures of concrete, and the interaction of the structures with soil. To-day the programs are considered as out of date. Partly new knowledge has been created since the programmes were made and partly the development inside the computer-technic has been explosive during the last years.

As an example the great development which has happened inside the area optimization can be mentioned.

You have to consider the change of the crack direction with the load. If you do not take this into consideration very large failures on f.ex. stress of concrete and crack openings will arise. Further you have to consider the curved stress strain relation and a possible yielding in the reinforcement.

3.4 Examinations of strength of cracked concrete

This very important subject demands further investigations. During the last years there has been made a great work (i.a. through the existing programme "High Performance Concretes in the 90'ies") with understanding of the importance of the cracks for the strength of concrete both with regards to micro-cracks and macro-cracks.

These investigations have a great importance to the society, because a good base of decision is obtained through these investigations for either a renovation or a demolition of a number a alkali-silica-damaged bridges of concrete. A general theory for cracked concrete is being made. The first results seem to be very encouraging, but as previously mentioned there is still many unsolved problems and the research so far should be continued during this programme.

In this connection projects with the following content should be made:

* A further examination of one of M. P. Nielsen's new-developed crack growth formula at different types of loading: bending, compression and shear problems, see also project 3.6.
* Theoretical and experimental determination of the importance of cracks for the shear strength of non-shear reinforced beams and for reinforced discs.
* For damaged structures of concrete it is of great importance to know the strength parameter of a crack as a function of crack opening and the composition of the concrete, first of all the size of the stones.

3.5 Constitutive equations containing micro-crack addition

It is very important to be able to reduce a creation of the crack, which arises on account of the hardening heat of the concrete.
To be able to calculate the stresses coming from the hardening heat, quite new constitutive equations, which contain the so-called micro-crack addition, must be used, otherwise it will not be possible to obtain agreement with the test results.

In the project the work with such new constitutive equations will be made, after which they will be implemented into a finite-element programme.

After this a number of situations of common occurance can be calculated and practical used simple rules can be formulated.

3.6 Theories of crack growth for concrete

As mentioned in project 3.4 a new theory for crack growth has resently been made. The crack growth occurs i.a. at the fatigue process, at which a material or a structural element is exposed to many repeated actions. Besides the description of the crack growth also other descriptions of the fatigue process will be considered. F.ex. ultra-sound tests, acoustic emission, change of dynamic parameters as frequencies and damping. Fracture mechanical considerations will be used, and i.a. examinations of high-strength concrete

and different types of fibre concretes will be considered.
The project is based on the work which i.a. has been made under the programme "High Performance Concretes in the 90'ies".

3.7 Fibre reinforced concretes

Modelling of Tensile Stress-Strain behaviour of high performance FRC (Fibre Reinforced Concretes) with high volume fraction of main reinforcement.
A framework will be developed for designing high performance FRC with tensile strain capacity similar to that of steel, and load-carrying capacity several times that of conventional reinforced concrete.
Theory of elasticity/plasticity and fracture mechanics principles will be used to develop new constitutive relations between load (stress) and deformation capacity of heavily reinforced (fibres and main reinforcement) high strength concretes.
An important aspect in the design of these new composites will be crack control.

3.8 Models of long-term strength for wood

During the last years many tests with wood have been made in order to determine how the long-term strength is influenced by the type of the load (load level, load amplitude) and by the mechanical qualities of the wood (short-time strength, creeping). It is of great practical value to get this connections illustrated and modelled, as existing standard rules both are relatively rude and conservative. In the examination it is staked on combining crack mechanical models for damage development with damages on account of creeping, damage on account of fatigue and damage from the enviromental effect. The models are calibrated by the carrying out both for short-time and long-time tests.

The project is carried out in co-operation with researchers from i.a. DtH (Lauge Fuglsang Nielsen) and continues i.a. a greater experimental examination of fatigue qualities of laminated wood carried out at the Department of Building Technology and Structural Engineering, AUC.

3.9 Constitutive equations for soils

The behaviour of a soil element subjected to static or dynamic loads depends mainly on the soil type, the geological history of the soil layer, preshearing, the stress level and the stress state. The soil is unelastic and exhibits hysteresis, anisotropy and creep. Much research work has been done to understand the behaviour of soils and many complicated stress-strain relationships have been presented. But these theories do not all fit the Danish experiences and special soil types so well and they are not developed for numerical calculations. Furthermore, a review of the Danish experiences is initiated because of the Storebælts-bridge and the coming big international connections, and some new ideas have been introduced.

A new constitutive model for soil should therefore be developed. It should be as simple as possible and for use in numerical calculations. However, the new ideas should also be studied and put into the model or be rejected. Test series with selected soil types should be carried out to clarify the limitations of the constitutive equations.

4. THE TECHNICAL POWERS AND BACKGROUND OF THE PARTICIPANTS

The following persons at the Department for Structural Engineering, DtH, the Department of Civil Engineering, AUC, and the Department of Building Technology and Structural Engineering, AUC, are taken part in this programme.

For each person the two most important subject areas are stated.

Professor, dr. techn. M. P. Nielsen: Concrete structures and theory of plasticity.

Professor, Ph.D. Will Hansen: Technology of concrete and fibre concrete.

Professor, lic. techn. Moust Jacobsen: Geotechnic and experimental work.

Senior Lecturer, lic.techn. Rune Brincker: Fracture mechanics and experimental mechanics.

Senior Lecturer, civ. eng. Gert Heshe: Concrete structures and concrete technology.

Docent, lic.techn. Lars Pilegaard Hansen: Experimental mechanics and dynamic.

Owing to lack of space CV for the above-mentioned persons will not be attached, but it can be required if it is wanted.

Owing to lack of space any survey of publication so will not be attached too. However, it can be informed that all participants have taken active part in the research inside their special subject of the area of the programme, and that all the subjects areas of the programme are covered by the persons mentioned above.

5. PROPOSALS TO THE PROGRAMME LEADER AND THE PROGRAMME COMMITTEE

Lars Pilegaard Hansen, the Department of Building Technology and Structural Engineering, AUC, is taken care of the administrative management of the programme and with that the responsability of the economy of the programme.

The mentioned persons under item 4, who in a close co-operation are to coordinate the research work (the synergy effect), are taken care of the scientific part of the programme.

This group, probably supplemented with other technical qualified researchers inside the subject area of the programme, will form the programme committee of the programme.

Inside the single projects it is considered to establish groups with members from other research institutions, consulting engineering companies, contractors and producers at home and abroad.

6. BUDGET AND INTERNAL RESOURCES

The programme is considered to last 3 years.

It is aimed to the fact that 5 projects out of 9 are carried out as Ph.D. studies, while the last 4 projects are carried out of other collaborators who are active in the research work.

This gives the following budget per year:

5 Ph.D. studies:	Salaries	dkr. 1,250,000.-
	Expenses	250,000.-
Other project collaborators,	Scientific personal	550,000.-
	Non scientific personal	150,000.-
Equipment		200,000.-
Travels, publication, adm.		100,000.-
		dkr. 2,500,000.-

The collaborators at the 3 departments mentioned under item 4, who participate in the programme, are considered to contribute a considerable work performance, which can be estimated to 2 men per year.

Besides there will be some profit by the computer-facilities which the 3 departments have and not less the 3 department's laboratories for building technology material - and structural research both for static and dynamic investigations.

In this programme it is aimed at a close cooperation between theoretical and experimental work.

In this connection it can be informed that a strong extension of the laboratory facilities at the Department of Building Technology and Structural Engineering, AUC, is made, as it has just been granted a building of about 600 m^2 for a new laboratory area for concrete research and another structural research.

7. THE COLLABORATORS

Inside this programme there will be a collaboration with a number of single persons, research departments, consulting engineering firms and producers at home and abroad.

In this connection can be mentioned:

Rambøll, Hannemann & Højlund
COWI
Vejdirektoratet
Spæncom
Murværkscentret, DTI
AEC, Rådgivende Ingeniører A/S
Vattenfall, Sverige
Lunds Tekniske Højskole, Sverige
Chalmers Tekniske Højskole, Sverige
Cement- og Betonlaboratoriet, Aalborg Portland