

Institut for Bærende Konstruktioner og Materialer  
Department of Structural Engineering and Materials  
Danmarks Tekniske Universitet • Technical University of Denmark

**BKM**

## Resuméoversigt 1995

Afdelingen for Bærende Konstruktioner

## Summaries of Papers 1995

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RESUMÉOVERSIGT

AFDELINGEN FOR BÆRENDE KONSTRUKTIONER 1995

\*Summaries of Papers. Department of Structural Engineering 1995

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1996

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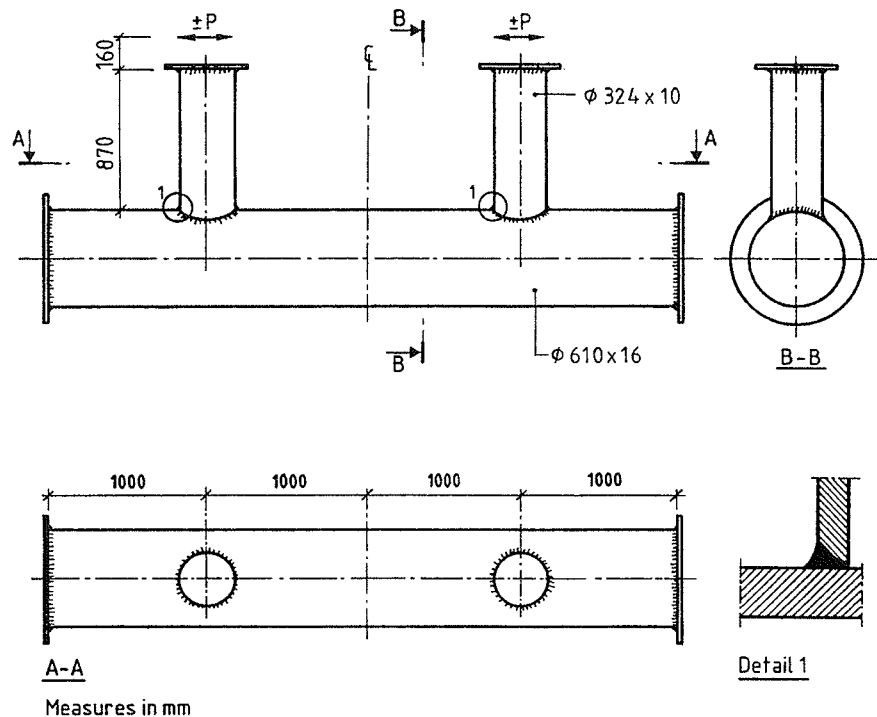
AGERSKOV, H., R.I. PETERSEN and L. LOPEZ MARTINEZ: \*Fatigue in High-Strength Steel Offshore Structures. (Udmattelse i offshorekonstruktioner i højstyrkestål). Proc. of the International Symposium on Offshore Engineering, Rio de Janeiro, Sept. 1995, pp. 361-375. (Reprints available).

\*In the present investigation, the fatigue life of offshore steel structures in high-strength steel is studied. The material used has a yield stress of 800-1000 MPa, and high weldability and toughness properties. Of special interest is the fatigue life under a realistic stochastic loading. In the experimental part of the investigation, fatigue test series have been carried through on both full-scale tubular joints and smaller welded plate test specimens, in high-strength steel as well as in conventional offshore structural steel. A comparison between constant amplitude and variable amplitude fatigue test results shows shorter fatigue lives in variable amplitude loading than should be expected from the linear fatigue damage accumulation formula. Furthermore, in general longer fatigue lives were obtained for the test specimens in high-strength steel than those obtained in corresponding tests on joints in conventional offshore structural steel.

AGERSKOV, H., se også NIELSEN, J.A., H. AGERSKOV og T. VEJRUM

AGERSKOV, H., se også PETERSEN, R.I., H. AGERSKOV, L. LOPEZ MARTINEZ og V. ASKEGAARD

ALWAN, J., se LI, V.C., H. MIHASHI, J. ALWAN, R. BRINCKER, H. HORII, H. STANG, M. MAALEJ og S.T. WU



Prøvelegeme med to fuldskala rørknudesamlinger.

\*Test specimen with two full-scale tubular joints.

Ref.: AGERSKOV, H., R.I. PETERSEN and L. LOPEZ MARTINEZ: \*Fatigue in High-Strength Steel Offshore Structures. (s. 5).

ASKEGAARD, V.: \*Applicability of Normal and Shear Stress Cells Embedded in Cohesionless Materials. SEM VI International Congress on Experimental Mechanics. Dec. 1995, pp. 315-321. (Reprints available).

\*A normal stress cell and a shear stress cell have been designed and tested under very varied conditions including permanent strain. Results pooled from nine different tests with the cells embedded in cohesionless materials (sand and wheat) showed that the coefficient of variation



of the normal stress-cell sensitivity was 0.04, while it was 0.10 for the shear cell. The agreement between predicted and measured sensitivity was considered to be good for the normal stress cell and reasonably good for the shear stress cell.

The shear cell showed a systematic dependence, within acceptable limits, of the total stress state in the surrounding material. A qualitative explanation of this phenomenon is given.

ASKEGAARD, V. and J. BROWN: \*Influence of Personal Factor on Cell Response when Mounting Embedded Pressure Cells. Bulk Solids Handling, Vol. 15, No. 2, April/June 1995, pp. 221-224. (Reprints available).

\*It is known that the mounting procedure influences the readings from pressure cells embedded in particulate media. This raises the question of repeatability of results obtained by the same person and also whether results obtained at different places by different persons following the same mounting procedure can be compared.

In this paper results are described from tests with 4 identical stiff pressure cells carried out by an experienced and an inexperienced person to answer the above stated problems.

Also tests with two of the cells are described in the paper demonstrating the behaviour of stiff pressure cells embedded in limestone powder under hydrostatic pressure at strains up to 13%.

ASKEGAARD, V., se også PETERSEN, R.I., H. AGERSKOV, L. LOPEZ MARTINEZ og V. ASKEGAARD

BAGGOTT, R., se BENTUR, A., S.T. WU, N. BANTHIA, R. BAGGOTT, W. HANSEN, A. KATZ, C.K.Y. LEUNG, V.C. LI, B. MOBASHER, A.E. NAAMAN, R. ROBERTSON, P. SOROUSHIAN, H. STANG og L.R. TAERWE

BAGGOTT, R., se REINHARDT, H.W., P. ROSSI, R. BAGGOTT, G. BALAZS,  
J. BOLANDER, A.M. BRANDT, M. CHEYREZY, K. CHONG, L. ERDELYI,  
H. KRENCHER, D. LANGE, C. LEUNG, V.C. LI, H. MIHASHI, A.E. NAAMAN,  
V.S. PARAMESWARAN og H. STANG

BALAZS, G., se REINHARDT, H.W., P. ROSSI, R. BAGGOTT, G. BALAZS,  
J. BOLANDER, A.M. BRANDT, M. CHEYREZY, K. CHONG, L. ERDELYI,  
H. KRENCHER, D. LANGE, C. LEUNG, V.C. LI, H. MIHASHI, A.E. NAAMAN,  
V.S. PARAMESWARAN og H. STANG

BANTHIA, N., se BENTUR, A., S.T. WU, N. BANTHIA, R. BAGGOTT, W. HANSEN,  
A. KATZ, C.K.Y. LEUNG, V.C. LI, B. MOBASHER, A.E. NAAMAN, R. ROBERTSON,  
P. SOROUSHIAN, H. STANG og L.R. TAERWE

BAWEJA, SANDEEP, se BAŽANT, ZDENĚK P., ANDERS B. HAUGGAARD og  
SANDEEP BAWAJA

BAŽANT, ZDENĚK P., ANDERS B. HAUGGAARD and SANDEEP BAWAJA: \*Micropre-  
stress-Solidification Theory for Concrete Creep, Report No. 95-12/603m, Department  
of Civil Engineering, Northwestern University, Evanston, Illinois 60208, USA,  
December 1995. (Reprints available).

\*A new physical theory for the effects of long-term aging and drying on concrete creep is proposed. The previously proposed solidification theory, in which the aging is explained and modeled by the volume growth (into the pores of hardened Portland cement paste) of a nonaging viscoelastic constituent (cement gel), cannot explain long term aging because the volume growth of the hydration products is too short-lived. The paper presents a revision of solidification theory in which the viscosity of the flow term of the compliance function is a

tangential viscosity of a nonlinear viscous power law governing very large and highly localized microstress in the hardened cement paste. This microstress is called the microprestress because it is produced during hydration by very large and highly localized volume changes, independent of loading. An essential aspect of the theory is that the applied external load or the macroscopic continuum deformation of concrete can cause only very small changes of the microprestress, such that the response to load is determined by tangential linearization. Relaxation of the microprestress causes the tangential viscosity to increase, which reduces long-term creep. A decrease of relative humidity in the pores causes (due to changes of capillary tension, surface tension and disjoining pressure) a large increase in the microprestress, which in turn reduces tangential viscosity and thus increases the creep rate. This explains the drying creep (Pickett effect). An improved constitutive law is formulated, verified and calibrated by comparisons of finite element solutions with test data.

BENTUR, A., S.T. WU, N. BANTHIA, R. BAGGOTT, W. HANSEN, A. KATZ, C.K.Y. LEUNG, V.C. LI, B. MOBASHER, A.E. NAAMAN, R. ROBERTSON, P. SOROUSHIAN, H. STANG and L.R. TAERWE: \*Fiber-Matrix Interfaces. I: "High Performance Fiber Reinforced Cement Composites - Volume 2 (HPFRCC-95)". Ed. Antoine E. Naaman and Hans Wolf Reinhardt. Department of Civil and Environmental Engineering, University of Michigan, USA, 1995, pp. 139-182.

\*The bonding mechanisms in FRC are reviewed, with reference to latest experimental and analytical studies. It is shown that bonding characteristics cannot be adequately accounted for by considering only the interfacial bond strength in aligned fibers. A variety of additional factors should be considered, such as bending effects (influencing the orientation efficiency), lateral stresses and the special characteristics of the interfacial microstructure. All these should be included in a comprehensive approach to advance high performance FRC.

BOLANDER, J., se REINHARDT, H.W., P. ROSSI, R. BAGGOTT, G. BALAZS,  
J. BOLANDER, A.M. BRANDT, M. CHEYREZY, K. CHONG, L. ERDELYI,  
H. KRENCHER, D. LANGE, C. LEUNG, V.C. LI, H. MIHASHI, A.E. NAAMAN,  
V.S. PARAMESWARAN og H. STANG

BRANDT, A.M., se REINHARDT, H.W., P. ROSSI, R. BAGGOTT, G. BALAZS,  
J. BOLANDER, A.M. BRANDT, M. CHEYREZY, K. CHONG, L. ERDELYI,  
H. KRENCHER, D. LANGE, C. LEUNG, V.C. LI, H. MIHASHI, A.E. NAAMAN,  
V.S. PARAMESWARAN og H. STANG

BRINCKER, R., se LI, V.C., H. MIHASHI, J. ALWAN, R. BRINCKER, H. HORII,  
H. STANG, M. MAALEJ og S.T. WU

BROWN, J., se ASKEGAARD, V. og J. BROWN

BYSKOV, ESBEN, se POULSEN, JOHANNES SAND, MICHAEL TONNESEN og ESBEN  
BYSKOV

BYSKOV, ESBEN, se TONNESEN, MICHAEL, JOHANNES SAND POULSEN og ESBEN  
BYSKOV

CHEYREZY, M., se REINHARDT, H.W., P. ROSSI, R. BAGGOTT, G. BALAZS,  
J. BOLANDER, A.M. BRANDT, M. CHEYREZY, K. CHONG, L. ERDELYI,  
H. KRENCHER, D. LANGE, C. LEUNG, V.C. LI, H. MIHASHI, A.E. NAAMAN,  
V.S. PARAMESWARAN og H. STANG

CHONG, K., se REINHARDT, H.W., P. ROSSI, R. BAGGOTT, G. BALAZS,  
J. BOLANDER, A.M. BRANDT, M. CHEYREZY, K. CHONG, L. ERDELYI,  
H. KRENCHER, D. LANGE, C. LEUNG, V.C. LI, H. MIHASHI, A.E. NAAMAN,  
V.S. PARAMESWARAN og H. STANG



CHRISTENSEN, CLAUS, se DITLEVSEN, OVE, CLAUS CHRISTENSEN og SØREN RANDRUP-THOMSEN

CHRISTENSEN, CLAUS, se MUNCH-ANDERSEN, JØRGEN, OVE DITLEVSEN, CLAUS CHRISTENSEN, SØREN RANDRUP-THOMSEN og PERNILLE HOFFMEYER

DAMKILDE, L., se JÖNSSON, J., S. KRENK og L. DAMKILDE

DAMKILDE, L., se POULSEN, PETER NOE og LARS DAMKILDE

DITLEVSEN, OVE: \*Codified Reliability of Structures. Proc. of the 6th IFIP WG 7.5 Working Conference on Reliability and Optimization of Structural Systems, Assisi (Perugia), Italy, Sept. 1994 (eds.: R. Rackwitz, G. Augusti, A. Borri). Published for IFIP by Chapman & Hall, London, 1995, pp. 25-44. (Reprints available).

\*For the practical applications of probabilistic reliability methods it is important to make decisions about the target reliability level. Presently calibration to existing design practice seems to be the only practicable and politically reasonable solution to this decision problem. However, several difficulties of ambiguity and definition show up when attempting to make the transition from a given authorized partial safety factor code to a superior probabilistic code. For any chosen probabilistic code format there is a considerable variation of the reliability level over the set of structures defined by the partial safety factor code. Thus there is a problem about which of these levels to choose as target level. Moreover, if two different probabilistic code formats are considered, then a constant reliability level in the one code does not go together with a constant reliability level in the other code. The last problem must be accepted as the state of the matter, and it seems that it can only be solved pragmatically by standardizing a specific code format as reference format for constant reliability.

By an example this paper illustrates that a presently valid partial safety factor code imposes a quite considerable variation of the reliability measure as defined by a specific probabilistic

code format. Decision theoretical principles are applied to get guidance about which of these different reliability levels of existing practice to choose as target reliability level. Moreover, it is shown that the chosen probabilistic code format not only has strong influence on the formal reliability measure but also on the formal cost of failure to be associated if a design made to the target reliability level is considered to be optimal. In fact, the formal cost of failure can be different by several orders of size for two different by and large equally justifiable probabilistic code formats. Thus the consequence is that a decision theoretical code format formulated as an extension of a probabilistic code format must specify formal values to be used as costs of failure.

A principle of prudence is suggested for guiding the choice of the reference probabilistic code format for constant reliability. To the author's opinion there is an urgent need for establishing a standard probabilistic reliability code. This paper presents some considerations that may be debatable but nevertheless point at a systematic way to choose such a code.

DITLEVSEN, OVE: \*Strength Increase Due to Consolidation of Clay Till. Proc. of XI European Conference on Soil Mechanics and Foundation Engineering, Vol. 5, Copenhagen, May 1995, Danish Geotechnical Society, dgf-Bulletin 11, pp. 5.103 - 5.113. (Reprints available).

\*Triaxial tests made at DGI on till clay sampled from Storebælt along the bridge line have been investigated in order to extract information about the effect of reconsolidation on the undrained shear strength to be used for the anchor block reliability studies. The standard interpretation appears not to make much sense. However, the statistical analysis of the data revealed the existence of a surprising fit to a power law by which the undrained shear strength is related to the existing consolidation stress both in dimensionless form. It is crucial that the two quantities are made dimensionless by division by the last consolidation stress after which unloading took place in the triaxial test before the compression tests were made. The proportionality constant and the exponent of the power law varies randomly from soil sample to soil sample. For the reliability analysis only the distribution of the exponent is of relevance.

DITLEVSEN, OVE: \*Discretization of Random Fields in Beam Theory. Proc. of ICASP7: Seventh International Conference on Applications of Statistics and Probability in Civil Engineering, (eds.: M. Lemaire, Favre, J.-L., and A. Mebarki), Paris, July 1995. Published for CERRA (International Association for Civil Engineering, Reliability and Risk Analysis) by Balkema, Rotterdam, 1995, pp. 983-990. (Reprints available).

\*Stochastic finite element discretization of random fields needed for practicable first or second order reliability analysis causes problems, in particular if the correlation scale is smaller or comparable to the finite element scale. The weighted integral method of Deodatis and Shinozuka avoids this problem. However, the weighted integral method is tailored for certain types of problems and is not generally applicable. Der Kiureghian et al suggested that the well known more general direct kriging method (stochastic interpolation method) be used for stochastic finite element discretization. The kriging method is attractive, but it is not sufficiently sensitive to capture the effect of the rapid local fluctuations that may occur in random fields of small correlation extension. This paper describes a discretization method that mends this defect. It is called the method of regression on linear functionals and it is a generalization of both the weighted integral method and the kriging method. As an extreme test illustration the method is applied in the paper to discretize such a highly singular field as a compound Poisson field. When used with care the method gives a quite satisfactory accuracy for the considered purpose.

DITLEVSEN, OVE: \*Risk Acceptance Criteria in the Light of Decision Analysis. 22nd WEGEMT Graduate School: Accidental Loadings on Marine Structures: Risk and Response. Technical University of Denmark, April 1995. (Reprints available).

\*The most common formulations of acceptance criteria applied in practical risk analysis are introduced. The concept of risk profile associated to a given time interval of active operation plays an essential role for checking the acceptance. The risk profile is defined simply as the complementary distribution function of the loss accumulated during the operation time due to

the occurrence of adverse events. The convenience of the compound Poisson process as a tool for modelling the accumulated loss process is illustrated, and asymptotic expressions for the corresponding risk profile are given.

The current practice of acceptance criteria formulation is discussed from a decision theoretical point of view after introducing the axiomatic elements of the decision theory. The decision problem of the risk acceptance criteria setting authority is emphasized. In particular it is argued that the phenomenon of risk aversion rather than being of concern to the authority should be of concern to the owner. Finally, it is discussed whether there is an ethical problem when formally capitalizing human lives with a positive interest rate, implying that future casualties have a smaller loss value than present casualties.

DITLEVSEN, OVE and JØRGEN MUNCH-ANDERSEN: \*Empirical Stochastic Silo Load Model. I: Correlation Theory. Journal of Engineering Mechanics, ASCE, Vol. 121, No. 9, September 1995, Paper No. 8516, pp. 973-980. (Reprints available).

\*During the emptying phase silo wall pressures show large random fluctuations in time and space. The nonuniform variations of the pressure along the wall have a decisive influence on the bending moments in the silo wall. It seems difficult to formulate continuum mechanical models to explain these fluctuations that turn out very sensitive to the random geometrical imperfections of the silo wall. This empirical evidence calls for random process and field descriptions of the pressure variations. On the basis of the philosophy of stochastic interpolation, a parametric covariance model with a minimal number of parameters is formulated. The choice of model is guided by the property that in linear regression interpolation the covariance function acts analogously to an interpolating spline function. The covariance model is required to satisfy the equations of equilibrium in any horizontal layer of the silo medium assuming as a reasonable approximation that the horizontal cross section of the medium is without shear force. In the first of two companion papers, the model is adapted to a specific set of measurements from pressure cells situated along a horizontal



perimeter of a circular cylindrical concrete silo. In the third paper the model is applied in a reliability analysis example.

DITLEVSEN, OVE, CLAUS CHRISTENSEN and SØREN RANDRUP-THOMSEN:

\*Empirical Stochastic Silo Load Model. III: Reliability Applications. Journal of Engineering Mechanics, Vol. 121, No. 9, September, 1995, Paper No. 8518, pp. 987-993. (Reprints available).

\*Pressure data obtained in experiments with an existing grain silo in the second paper were used to estimate the parameters of an empirical stochastic silo load model formulated in the first paper. The obtained silo load model is investigated in this paper with respect to its structural reliability implications. Before considering the silo wall as a cylindrical shell structure, a reliability analysis with respect to first yield hinge formation is made for a circular reinforced concrete beam imagined to be a ring cut out from the silo by two consecutive horizontal planes of infinitesimal mutual distance at a place far away from the end regions of the silo. The beam is subjected normal to the beam axis by the Gaussian silo pressure field that corresponds to an assumption of horizontally ideally smooth silo wall. The analysis rests on a special discretization technique made necessary because of limitations of the computational capacity. This technique has general applicability as a stochastic finite-element method for beam structures. The reliability analysis leads to a simple deterministic design rule for the combined tension and bending capacity of the ring beam.

DITLEVSEN, OVE, GUNNAR MOHR and PERNILLE HOFFMEYER: \*Integration of Non-Gaussian fields. Proc. of Second International Conference on Computational Stochastic Mechanics, Athens, Greece, 12-15 June 1994, (ed.: P.D. Spanos), Balkema, Rotterdam, 1995, pp. 19-27. (Reprints available).

\*The limitations of the validity of the central-limit-theorem-argument as applied to definite integrals of non-Gaussian random fields are empirically explored by way of examples.

The purpose is to investigate in specific cases whether the asymptotic convergence to the Gaussian distribution is fast enough to justify that it is sufficiently accurate for the applications to shortcut the problem and just assume that the distribution of the relevant stochastic integral is Gaussian. An earlier published example exhibiting this problem concerns silo pressure fields, Ditlevsen et al (1994).

The numerical technique applied to obtain approximate information about the distribution of the integral is based on a recursive application of Winterstein approximations (moment fitted linear combinations of Hermite polynomials of standard Gaussian variables). The method uses the very long exact formulas for the 3rd and 4th moments of any linear combination of two correlated four-term Winterstein approximations. These formulas are derived by computerized symbol manipulations. Some of the results are compared with some special exact results for sums of Winterstein approximations, Mohr & Ditlevsen (1994). For decreasing correlation extension including negative correlation, problems of increasing sensitivity to the recursive approximations show up. For practical use of the method it may therefore in special situations with negative correlation be necessary to introduce numerical integration checks or simulation checks of the results.

DITLEVSEN OVE, se også JOHANNESSEN, JOHANNES, M. og OVE DITLEVSEN

DITLEVSEN, OVE, se også MOHR, GUNNAR og OVE DITLEVSEN

DITLEVSEN, OVE, se også MUNCH-ANDERSEN, JØRGEN, OVE DITLEVSEN, CLAUS CHRISTENSEN, SØREN RANDRUP-THOMSEN og PERNILLE HOFFMEYER

DYRBYE, C.: Opgaver i bygningsdynamik, 7. udg. (\*Problems in Structural Dynamics, 7th ed. In Danish). Afdelingen for Bærende Konstruktioner. Serie F, nr. 142, 1995. 131 s. Kr. 45,- excl. moms.

Opgavesamlingen indeholder øvelses- og eksamensopgaver i Bygningsdynamik.

\*The collection of problems consists of training- and examination problems in Structural Dynamics.

ERDELYI, L., se REINHARDT, H.W., P. ROSSI, R. BAGGOTT, G. BALAZS, J. BOLANDER, A.M. BRANDT, M. CHEYREZY, K. CHONG, L. ERDELYI, H. KRENCHER, D. LANGE, C. LEUNG, V.C. LI, H. MIHASHI, A.E. NAAMAN, V.S. PARAMESWARAN og H. STANG

HANSEN, THOMAS CORNELIUS: \*Triaxial Tests with Concrete and Cement Paste. (Triaksiale forsøg med beton og cement pasta). Afdelingen for Bærende Konstruktioner. Serie R, nr. 319, 1995. 19 s. + bilagsrapport. Gratis.

\*The main purpose of this paper is to present some triaxial tests with concrete and cement paste, and to examine the failure criterion of these materials. The report is subdivided into 5 sections:

- 1) A short theoretical introduction.
- 2) Description of the test equipment and the test procedure.
- 3) Presentation of the test results.

- 4) Discussion.
- 5) Conclusion.

The main issue is to examine whether Coulombs failure criterion is sufficient to describe the failure behavior of concrete and paste under triaxial loading. The main conclusion is that the parameters in Coulombs failure criterion are not constant, and that the angle under which failure takes place is varying with the magnitude of the side pressure. Therefore, it is necessary to modify the Coulomb failure criterion for concrete and cement paste.

Hovedformålet med denne rapport er at præsentere nogle triaksiale forsøg med beton og cementpasta, og at undersøge brudkriteriet for disse materialer. Rapporten er inddelt i 5 afsnit, som indeholder:

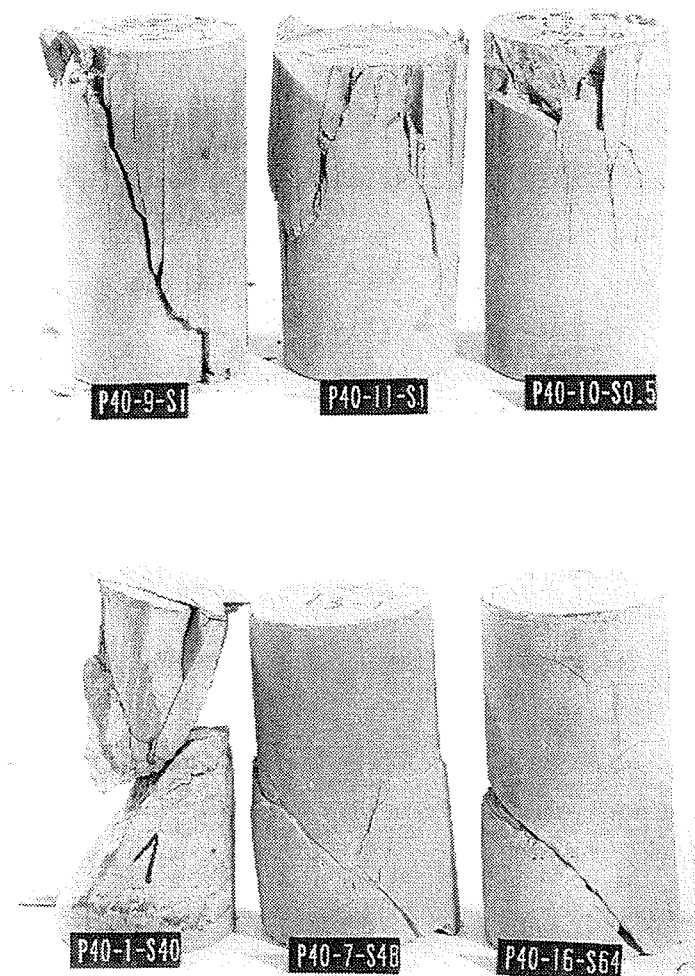
- 1) En kort teoretisk introduktion.
- 2) Beskrivelse af forsøgsudstyret og forsøgsgangen.
- 3) Præsentation af forsøgsresultaterne.
- 4) Diskussion.
- 5) Konklusion.

Hovedformålet er at undersøge, om Coulombs brudkriterium kan benyttes til at beskrive brudopførslen af beton og pasta under triaksial belastning. Hovedkonklusionen er, at parametrene i Coulombs brudkriterium ikke er konstante, samt at vinklen, under hvilken brud indtræffer, varierer med sidetrykkets størrelse. En modifikation af Coulombs brudbetingelse for beton og pasta er derfor nødvendig.

HANSEN, W., se BENTUR, A., S.T. WU, N. BANTHIA, R. BAGGOTT, W. HANSEN, A. KATZ, C.K.Y. LEUNG, V.C. LI, B. MOBASHER, A.E. NAAMAN, R. ROBERTSON, P. SOROUSHIAN, H. STANG og L.R. TAERWE

HAUGAARD, ANDERS B., se BAŽANT, ZDENĚK, P., ANDERS B. HAUGAARD og SANDEEP BAWEJA





Brudplaner i cementpasta,  $f_c = 40 \text{ MPa}$  .

\*Fracture planes in cement paste,  $f_c = 40 \text{ MPa}$  .

Ref.: HANSEN, THOMAS CORNELIUS: \*Triaxial Tests with Concrete and Cement Paste.  
(s. 17).

HOFFMEYER, PERNILLE, se DITLEVSEN, OVE, GUNNAR MOHR og PERNILLE HOFFMEYER

HOFFMEYER, PERNILLE, se MUNCH-ANDERSEN, JØRGEN, OVE DITLEVSEN, CLAUS CHRISTENSEN, SØREN RANDRUP-THOMSEN og PERNILLE HOFFMEYER

HORII, H., se LI, V.C., H. MIHASHI, J. ALWAN, R. BRINCKER, H. HORII, H. STANG, M. MAALEJ, og S.T. WU

IBSØ, JAN BEHRENDT: \*Fatigue Life Prediction of Welded Joints Based on Fracture Mechanics and Crack Closure. (Bestemmelse af udmattelseslevetiden for svejste samlinger baseret på brudmekanik og luknings-/åbningsmekanismer for udmattelsesrevnen). Afdelingen for Bærende Konstruktioner. Serie R, nr. 322, 1995. 218 s. hoveddrapport + bilagsrapport. Gratis. /Ph.D./.

\*In the present report a crack closure mechanism-related and generally applicable model is presented. The analytical crack closure model is applied for the calculation of fatigue crack growth under various load conditions and different stress states using fracture mechanics.

The crack closure model is based on the Dugdale-Barenblatt model with modifications to allow plastically deformed material to be left along the crack surfaces as the crack grows. The crack closure model accounts for load interaction effects, such as retardation and acceleration, under variable amplitude loading. The model may be used to simulate fatigue crack growth under both constant amplitude and variable amplitude loading taking into account the influence of crack closure upon fatigue crack growth.

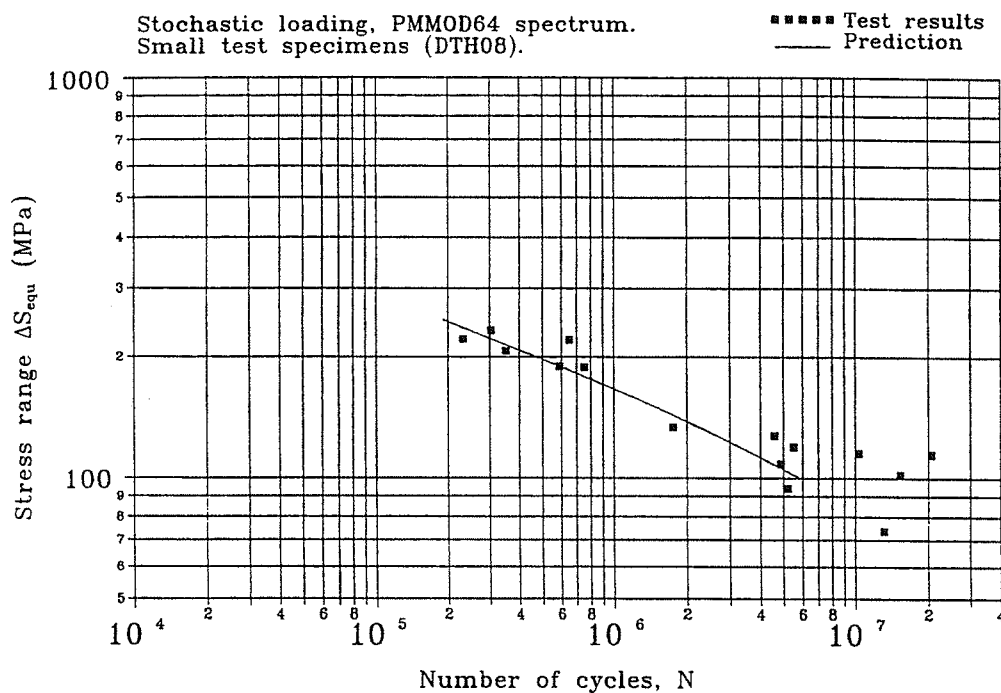
Methods to include the effect of stress concentrations and welding residual stresses on crack closure and crack growth have been developed in the present study and several examples are given showing different applications of the methods.

Based on the crack closure model, a computer program FAWS (Fatigue Analysis of Welded Structures) has been developed in the present study. The program has been developed in order

to simulate the fatigue crack growth under general load histories. The program is especially suited for calculation of fatigue crack growth in welded details including the effect of stress concentrations, welding residual stresses and crack shape.

During the last 5-6 years, an investigation of the fatigue life of offshore steel structures has been carried through at the Dept. of Structural Engineering of the Technical University of Denmark. This investigation comprises mainly experimental works.

In the present study theoretical analyses are emphasized in order to find possible explanations to the experimental results obtained.



Sammenligning mellem eksperimentelt og analytisk bestemte udmattelseslevetider.

\*Comparison between experimentally and analytically determined fatigue lives.

Ref.: IBSØ, JAN BEHRENDT: \*Fatigue Life Prediction of Welded Joints Based on Fracture Mechanics and Crack Closure. (s. 20).

I den foreliggende rapport præsenteres en generel anvendelig model, der er baseret på luknings- og åbningsmekanismer for en udmattelsesrevne (crack closure). Den analytiske model anvendes i brudmekaniske beregninger af revnevækst for forskellige lasthistorier og for forskellige spændingstilstande.

Modellen er baseret på Dugdale-Barenblatt modellen, som modificeres for at kunne tage hensyn til det plastisk deformerede materiale, som efterlades bagved revnespidsen, langs revnens overflader, når revnen vokser. Modellen tager højde for lastinteraktionseffekter, så som retardation og acceleration, under variabel amplitude last. Modellen kan anvendes til simulering af revnevækst under konstant amplitude last og under variabel amplitude last, idet indflydelsen af lukningen og åbningen af revnen for revnevæksten er inkluderet i modellen.

Der er i studiet udviklet metoder, hvormed effekten af spændingskoncentrationer og svejseegenspændinger på revnelukning og revnevækst kan inddrages i analysen. Der gives i rapporten en del eksempler, som viser anvendelser af metoderne.

I studiet er der udarbejdet et computerprogram, FAWS (Fatigue Analysis of Welded Structures), som er baseret på den analytiske model. Programmet er udviklet med henblik på at kunne simulere revnevækst for en vilkårlig lasthistorie. Computerprogrammet er specielt velegnet til revnevækstberegninger for svejste samlinger, idet indflydelsen af spændingskoncentrationer, svejseegenspændinger og revneformen er inkluderet i beregningen.

Der er igennem de seneste 5-6 år gennemført et stort forskningsprojekt på Afdelingen for Bærende Konstruktioner, Danmarks Tekniske Universitet med henblik på at undersøge offshore stålkonstruktioners udmattelsesstyrke. Der har i dette projekt primært været tale om eksperimentelle undersøgelser.

I det foreliggende studium er hovedvægten lagt på teoretiske analyser med henblik på at finde mulige forklaringer på de opnåede eksperimentelle resultater.



JOHANNESSEN, JOHANNES M. and OVE DITLEVSEN: \*Reliability Analysis of Large Bridge Box Girder by Model-Correction-Factor Method. Proc. of ICASP7: Seventh International Conference on Applications of Statistics and Probability in Civil Engineering, (eds.: M. Lemaire, Favre, J.-L., and A. Mebarki), Paris, July 1995. Published for CERRA (International Association for Civil Engineering, Reliability and Risk Analysis) by Balkema, Rotterdam, 1995, pp. 1079-1086. (Reprints available).

\*The model-correction-factor method for reliability analysis has in previous papers been demonstrated to be very effective for small textbook type structural examples. In this paper the mechanical properties of a large steel box girder of an actual bridge project is modelled by a non-linear FE-program that in direct use makes any type of reliability analysis extremely computer time consuming. Thus limit state simplifying techniques have to be employed. The model-correction-factor method is based on a principle of replacement of a complicated limit state surface by an adapted limit state surface that originates from a suitably simple mechanical theory such as the rigid-plastic theory. The adaptation is made by applying a calculated correction factor (effectivity factor) to those material parameters of the problem that in their physical units contain the unit of force (yield strengths, for example) such that the two limit state surfaces give approximately identical failure probabilities. This correction factor is calculated by a single or some few applications of the FE-program. The input to the FE-program is determined by a first order reliability analysis on the basis of the simple model. It is found that also in this large structure example the model-correction-factor method is fast and accurate and that it by intelligent simplifying engineering modelling cuts the computer efforts drastically down.

JÖNSSON, J., S. KRENK and L. DAMKILDE: \*Recursive Substructuring of Finite Elements.  
Computers & Structures, Vol. 54, No. 3, pp. 395-404, 1995. (Reprints available).

\*Recursive substructuring takes advantage of the simple repetition of substructures of identical geometry. In each recursive step the problem is transformed into a new problem involving half the number of identical substructures. The computational work involved in factorization only grows logarithmically with an increasing number of substructures as opposed to conventional methods which grow linearly. For some vector problems the efficiency of recursive substructuring may be further improved by use of symmetry relations. In the present paper the technique is applied in linear buckling analysis of thin-walled beams.

KATZ, A., se BENTUR, A., S.T. WU, N. BANTHIA, R. BAGGOTT, W. HANSEN,  
A. KATZ, C.K.Y. LEUNG, V.C. LI, B. MOBASHER, A.E. NAAMAN, R. ROBERTSON,  
P. SOROUSHIAN, H. STANG og L.R. TAERWE

KRENCHER, H., se også REINHARDT, H.W., P. ROSSI, R. BAGGOTT, G. BALAZS,  
J. BOLANDER, A.M. BRANDT, M. CHEYREZY, K. CHONG, L. ERDELYI,  
H. KRENCHER, D. LANGE, C. LEUNG, V.C. LI, H. MIHASHI, A.E. NAAMAN,  
V.S. PARAMESWARAN og H. STANG

KRENCHER, H., se STANG, H., V.C. LI og H. KRENCHER

KRENK, S., se JÖNSSON, J., S. KRENK og L. DAMKILDE

LANGE, D., se REINHARDT, H.W., P. ROSSI, R. BAGGOTT, G. BALAZS,  
J. BOLANDER, A.M. BRANDT, M. CHEYREZY, K. CHONG, L. ERDELYI,  
H. KRENCHER, D. LANGE, C. LEUNG, V.C. LI, H. MIHASHI, A.E. NAAMAN,  
V.S. PARAMESWARAN og H. STANG

LEUNG, C.K.Y., se BENTUR, A., S.T. WU, N. BANTHIA, R. BAGGOTT,  
W. HANSEN, A. KATZ, C.K.Y. LEUNG, V.C. LI, B. MOBASHER, A.E. NAAMAN,  
R. ROBERTSON, P. SOROUSHIAN, H. STANG og L.R. TAERWE

LEUNG, C., se REINHARDT, H.W., P. ROSSI, R. BAGGOTT, G. BALAZS,  
J. BOLANDER, A.M. BRANDT, M. CHEYREZY, K. CHONG, L. ERDELYI,  
H. KRENCHER, D. LANGE, C. LEUNG, V.C. LI, H. MIHASHI, A.E. NAAMAN,  
V.S. PARAMESWARAN og H. STANG

LI, V.C., H. MIHASHI, J. ALWAN, R. BRINCKER, H. HORII, H. STANG, M. MAALEJ  
and H.C. WU: \*Micromechanical Models of Mechanical Response of HPFRCC. I: "High Per-  
formance Fiber Reinforced Cement Composites - Volume 2 (HPFRCC-95)". Ed.  
Antoine E. Naaman and Hans Wolf Reinhardt. Department of Civil and Environmen-  
tal Engineering, University of Michigan, USA, 1995, pp. 43-95.

\*The state-of-the-art in micromechanical modeling of the mechanical response of HPFRCC is reviewed. Much advances in modeling has been made over the last decade to the point that certain properties of composites can be carefully designed using the models as analytical tools. As a result, a new generation of FRC with high performance and economical viability is in sight. However, utilization of micromechanical models for a more comprehensive set of important HPFRCC properties awaits further investigations into fundamental mechanisms governing composite properties, as well as integrative efforts across responses to different load types. Further, micromechanical models for HPFRCC behavior under complex loading histories, including those in fracture, fatigue and multiaxial loading are urgently needed in order to optimize HPFRCC microstructures and enable predictions of such material in structures under realistic loading conditions.

LI, V.C., se også BENTUR, A., S.T. WU, N. BANTHIA, R. BAGGOTT, W. HANSEN, A. KATZ, C.K.Y. LEUNG, V.C. LI, B. MOBASHER, A.E. NAAMAN, R. ROBERTSON, P. SOROUSHIAN, H. STANG og L.R. TAERWE

LI, V.C., se også REINHARDT, H.W., P. ROSSI, R. BAGGOTT, G. BALAZS, J. BOLANDER, A.M. BRANDT, M. CHEYREZY, K. CHONG, L. ERDELYI, H. KRENCHER, D. LANGE, C. LEUNG, V.C. LI, H. MIHASHI, A.E. NAAMAN, V.S. PARAMESWARAN og H. STANG

LI, V.C., se også STANG, H., V.C. LI og H. KRENCHER

LOPEZ MARTINEZ, L., se AGERSKOV, H., R.I. PETERSEN og L. LOPEZ MARTINEZ

LOPEZ MARTINEZ, L., se PETERSEN, R.I., H. AGERSKOV, L. LOPEZ MARTINEZ og V. ASKEGAARD

MIHASHI, H., se LI, V.C., H. MIHASHI, J. ALWAN, R. BRINCKER, H. HORII, H. STANG, M. MAALEJ, og S.T. WU

MIHASHI, H., se REINHARDT, H.W., P. ROSSI, R. BAGGOTT, G. BALAZS, J. BOLANDER, A.M. BRANDT, M. CHEYREZY, K. CHONG, L. ERDELYI, H. KRENCHER, D. LANGE, C. LEUNG, V.C. LI, H. MIHASHI, A.E. NAAMAN, V.S. PARAMESWARAN og H. STANG

MOBASHER, B., se BENTUR, A., S.T. WU, N. BANTHIA, R. BAGGOTT, W. HANSEN, A. KATZ, C.K.Y. LEUNG, V.C. LI, B. MOBASHER, A.E. NAAMAN, R. ROBERTSON, P. SOROUSHIAN, H. STANG og L.R. TAERWE

MOHR, GUNNAR and OVE DITLEVSEN: \*Partial Summations of Stationary Sequences of Non-Gaussian Random Variables. Proc. of Second International Conference on Computational Stochastic Mechanics, Athens, Greece, 12-15 June 1994, (ed.: P.D. Spanos), Balkema, Rotterdam, 1995, pp. 379-385. (Reprints available).

\*The distribution of the sum of a finite number of identically distributed random variables is in many cases easily determined given that the variables are independent. The moments of any order of the sum can always be expressed by the moments of the single term without computational problems. However, in the case of dependency between the terms even calculation of some few of the first moments of the sum presents serious computational problems.

By use of computerized symbol manipulations it is practicable to obtain exact moments of partial sums of stationary sequences of mutually dependent lognormal variables or polynomials of standard Gaussian variables. The dependency structure is induced by specifying the autocorrelation structure of the sequence of standard Gaussian variables. Particular useful polynomials are the Winterstein approximations that distributionally fit with non-Gaussian variables up to the moments of the fourth order, Winterstein (1988) . A method to obtain the Winterstein approximation to a partial sum of a sequence of Winterstein approximations is explained and results are given for different autocorrelation functions of the generic Gaussian sequence.

The primary purpose of the investigation is to provide a tool for judging the validity of the central-limit-theorem-argument in specific applicational situations occurring in stochastic mechanics, that is, to judge the speed of convergence of the distribution of a sum (or an integral) of mutually dependent random variables to the Gaussian distribution.

The paper is closely related to the work in Ditlevsen et al (1994).

MOHR, GUNNAR, se også DITLEVSEN, OVE, GUNNAR MOHR og PERNILLE HOFFMEYER

MUNCH-ANDERSEN, JØRGEN, OVE DITLEVSEN, CLAUS CHRISTENSEN, SØREN RANDRUP-THOMSEN and PERNILLE HOFFMEYER: \*Empirical Stochastic Silo Load Model. II: Data Analysis. Journal of Engineering Mechanics, Vol. 121, No. 9, September 1995, Paper No. 8517, pp. 981-986. (Reprints available).

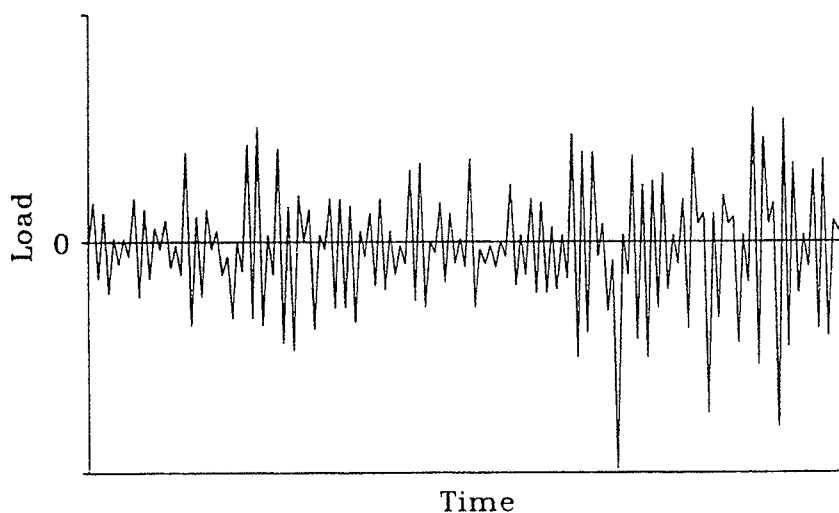
\*Pressure data obtained in experiments with an existing grain silo are used to estimate the parameters of a stochastic silo load model formulated by the first two authors in the first of three papers. The estimation procedure is based on the method of maximum likelihood as applied to point observations of a Gaussian random field with unknown distribution parameters. The justification of this method is not based on superior scientific reasoning, but rather on a pragmatic principle: The family of interpolation curves between the measured data are required to satisfy whatever given regularity conditions (continuity differentiability, etc.) in as simple a way as possible without being in conflict with the data. If by visual inspection these interpolation curves are judged to be reasonable from an engineering point of view, then also the corresponding silo load model should be acceptable as the basis for a reliability analysis of the silo wall. Generally, this procedure leads to a conservative assessment of the reliability. This is demonstrated in the third paper.

MUNCH-ANDERSEN, JØRGEN, se også DITLEVSEN, OVE og JØRGEN MUNCH-ANDERSEN

MAALEJ, M., se LI, V.C., H. MIHASHI, J. ALWAN, R. BRINCKER, H. HORII, H. STANG, M. MAALEJ og S.T WU

NIELSEN, J.A., H. AGERSKOV and T. VEJRUM: \*Fatigue Damage Accumulation in Steel Bridges under Highway Random Loading. (Udmattelse i stål vejbroer ved stokastisk last). Proc. of the 1st European Conference on Steel Structures, Athen, Maj, 1995, pp. 375-382. (Reprints available).

\*In the present investigation, fatigue damage accumulation in steel bridges under highway random loading is studied. In the experimental part of the investigation, fatigue test series on welded plate test specimens have been carried through. The fatigue tests are carried out using load histories, which correspond to one week's traffic loading, determined by means of strain gage measurements on the orthotropic steel deck structure of the Farø Bridges in Denmark. The results that have been obtained until now in the test series carried through indicate that the linear fatigue damage accumulation formula, which is normally used in the design against fatigue in steel bridges, may give results, which are unconservative.



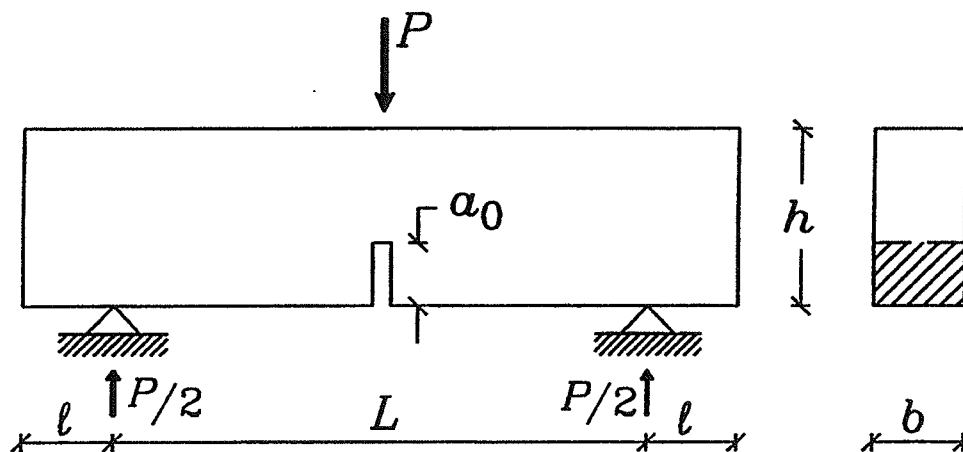
Typisk spændingshistorie bestemt ved strain gage målinger på Farø broerne.

\*Typical stress history determined from strain gage measurements on the Farø Bridges.

Ref.: NIELSEN, J.A., H. AGERSKOV og T. VEJRUM. \*Fatigue Damage Accumulation in Steel Bridges under Highway Random Loading. (s. 29).

NIELSEN, CLAUS VESTERGAARD: \*Ultra High-Strength Steel Fibre Reinforced Concrete. Part I: Basic Strength Properties of Compresit Matrix. (Ultrahøjstyrke beton med stålfibre. Del I: Grundlæggende styrkeegenskaber af Compresit matrix). Afdelingen for Bærende Konstruktioner. Serie R, nr. 323, 1995. 162 s. + appendiks 26 s. Gratis. /Ph.D./.

\*The present report contains the basic material properties of the fibre reinforced matrix compresit. Compresit matrix is an ultra high-strength, steel fibre reinforced cementitious matrix, that shows remarkable strength and deformational results. The cement matrix is very dense with a water to binder ratio of 0.18 together with a high content of fibres (up to 10% by volume), which give it compressive strengths above 150 MPa.



Bjælke med kær, udsat for tre-punktsbøjning.

\*Notched beam under three-point bending.

Ref.: NIELSEN, CLAUS VESTERGAARD: \*Ultra High-Strength Steel Fibre Reinforced Concrete. (s. 30).



The scope of this report is to collect the strength properties of compresit matrix to be used in a structural design analysis. Both test results obtained throughout the last decade and new results from the present project are included. Furthermore, the material properties are related to similar results observed from conventional fibre reinforced concrete and high-strength concretes. The properties include complete stress-strain curves in both uniaxial tension and compression, triaxial compressive tests to determine the strength criterion and finally the fracture energy.

The conclusion of the report is, that even though compresit matrix acts like a high-strength concrete its deformational behaviour is rather like normal-strength concrete, because of the fibres. The uniaxial compressive and tensile strength is satisfactory predicted by direct proportionality with the fibre content and the aspect ratio.

Denne rapport indeholder de basale materiale parametre for fiber armeret compresit matrix. Compresit matrix er betegnelsen for et stålfiberarmeret cementbaseret produkt, som udviser forbløffende styrke- og deformationsegenskaber. Cement matricen er meget tæt med et vand - cement forhold på 0.18, som sammen med et højt indhold af fibre (op til 10 volumen-%) giver trykstyrker over 150 MPa.

Rapportens formål er at samle compresit matricens styrkeegenskaber til brug i design af bærende konstruktionselementer. Forsøgsresultater fra det sidste tiår er medtaget sammen med nye resultater opnået i forbindelse med dette projekt. Derudover er materialeegenskaberne sammenlignet med de tilsvarende for fiberarmeret beton og højstyrke beton. De egenskaber der behandles er enakset tryk og træk med komplette arbejdskurver, treaksede trykforsøg til fastlæggelse af brudbetingelse samt brudenergi.

Hovedkonklusionen er, at selvom compresit matrix er et højstyrke produkt, så opfører det sig i høj grad som normal beton mht. deformationer pga. fibre. Styrken i enakset tryk og træk er desuden fundet proportional med fiberindholdet samt fibrenes længde - diameter forhold.

NIELSEN, CLAUS VESTERGAARD: \*Ultra High-Strength Steel Fibre Reinforced Concrete. Part II: Structural Applications of Compresit. (Ultrahøjstyrke beton med stål-fibre. Del II: Anvendelse af Compresit i bærende konstruktioner). Afdelingen for Bærende Konstruktioner. Serie R, nr. 324, 1995. 122 s. + appendiks 32 s. Gratis. /Ph.D/.

\*The present report contains structural considerations of the steel fibre reinforced matrix compresit. Compresit matrix is an ultra high-strength, steel fibre reinforced cementitious matrix. The properties of the matrix are investigated in Part I of the thesis. The structural applications focus on bridge design, i.e. especially the behaviour of slender beams.

First the report treats the triaxial failure criterion for compresit matrix, which has been experimentally observed. This investigation is based on the theory of plasticity and a modification of the normal Coulomb friction criterion is proposed. It appears that the presence of steel fibres does not influence the triaxial strength behaviour significantly.

The main part of the investigation concerns the behaviour of slender beams made of high-strength concrete, fibre reinforced concrete or compresit. First, the bending behaviour is analyzed in both the ultimate and the serviceability limit state. Then the beam shear strength is considered with basis in the theoretical plastic solution to the problem. Especially the effect of steel fibre reinforcement on the beam shear strength is treated. Finally, an example of compresit bridge design is given together with a comparison with an existing concrete solution. The conclusions are, that relatively small fibre contents are significant for the shear strength. The plastic effectiveness factor is significantly raised by the fibres. Furthermore, the investigation shows that compresit seems competitive in bridge structures.

Denne rapport indeholder konstruktionsmæssige overvejelser for compresit matrix. Compresit matrixen er betegnelsen for et cementbaseret produkt, som er armeret med stålfibre og udviser ekstrem høj trykstyrke. Matrixens egenskaber er behandlet i Del I af den foreliggende afhandling. Konstruktionstyperne sigter primært mod brodesign, dvs. den mekaniske opførsel af lange slanke bjælker.

Først er den treaksede brudbetingelse for compresit behandlet vha. egne forsøgsresultater. Denne undersøgelse er baseret på plasticitetsteorien og giver en modifikation af den normale Coulomb brudbetingelse. Fibrene synes ikke at influere den treaksede trykstyrke i nogen særlig høj grad.

Hovedparten af afhandlingen omhandler slanke bjælker af højstyrkebeton, fiberarmeret beton eller compresit. Først er bøjningsopførslen undersøgt i både brud- og anvendelsestilstand. Dernæst er bjælkers forskydningsstyrke behandlet ud fra en plastisk løsning, især mht. fibrenes effekt. Til slut gives et konkret broeksempel med compresit design. Konklusionen er,



Eksempel på fodgængerbro med compresit løsning.

\*Example of footbridge with compresit solution.

Ref.: NIELSEN, CLAUS VESTERGAARD: \*Ultra High-Strength Steel Fibre Reinforced Concrete. (s. 32).

at selv små fiberindhold øger forskydningsstyrken markant, hvilket ses på effektivitetsfaktoren. Ydermere viser broeksemplet, at compresit er et konkurrencedygtigt materiale.

NAAMAN, R., se BENTUR, A., S.T. WU, N. BANTHIA, R. BAGGOTT,  
W. HANSEN, A. KATZ, C.K.Y. LEUNG, V.C. LI, B. MOBASHER, A.E. NAAMAN,  
R. ROBERTSON, P. SOROUSHIAN, H. STANG og L.R. TAERWE

NAAMAN, A.E., se REINHARDT, H.W., P. ROSSI, R. BAGGOTT, G. BALAZS,  
J. BOLANDER, A.M. BRANDT, M. CHEYREZY, K. CHONG, L. ERDELYI,  
H. KRENCHER, D. LANGE, C. LEUNG, V.C. LI, H. MIHASHI, A.E. NAAMAN,  
V.S. PARAMESWARAN og H. STANG

PARAMESWARAN, V.S., se REINHARDT, H.W., P. ROSSI, R. BAGGOTT, G. BALAZS,  
J. BOLANDER, A.M. BRANDT, M. CHEYREZY, K. CHONG, L. ERDELYI,  
H. KRENCHER, D. LANGE, C. LEUNG, V.C. LI, H. MIHASHI, A.E. NAAMAN,  
V.S. PARAMESWARAN og H. STANG

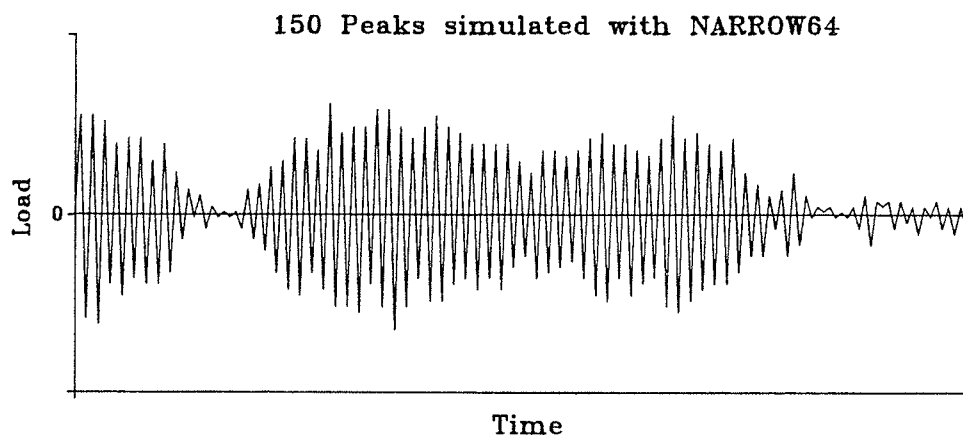
PETERSEN, R.I., H. AGERSKOV, L. LOPEZ MARTINEZ and V. ASKEGAARD: \*Fatigue  
Life of High-Strength Steel Plate Elements under Stochastic Loading. (Udmattelsesle-  
vetiden af pladeelementer i højstyrkestål ved stokastisk last). Afdelingen for Bærende  
Konstruktioner. Serie R, nr. 320, 1995. 109 s. Gratis.

\*The fatigue life of high-strength steel structures under stochastic loading is studied in the present investigation, with special view to applications in offshore structures. Of special interest is the problem of fatigue damage accumulation.

Fatigue test series with various types of stochastic loading that are realistic in relation to offshore structures have been carried through. Three different load spectra with irregularity factors ranging from ~ 0.70 to 1.00 have been applied. The experimental investigation

comprises both test series on full-scale tubular joints and test series on smaller welded test specimens. The present report concentrates on the investigation on the latter type of test specimens. The materials that have been used in this investigation have been high-strength steels with a yield stress of  $\sim 800\text{-}1000$  MPa. However, for a comparison, a similar investigation has been carried through on test specimens in ordinary offshore structural steel, with a yield stress of  $f_y \sim 360\text{-}410$  MPa. Thermoelastic measurements were in the present investigation used to estimate the stress concentration factor and to follow the initial crack development.

The test series that have been carried through show a significant difference in fatigue behaviour between plate elements with transverse and longitudinal attachments. Furthermore, in general longer fatigue lives were obtained on the welded plate test specimens in high-strength steel than from the similar investigation with the test specimens in ordinary offshore structural steel.



Typisk lasthistorie anvendt ved undersøgelse af udmattelseslevetiden af offshore konstruktioner i højstyrkestål.

\*Typical load history used in investigation on the fatigue life of high-strength steel offshore structures.

Ref.: PETERSEN, R.L., H. AGERSKOV, L. LOPEZ MARTINEZ and V. ASKEGAARD.

\*Fatigue Life of High-Strength Steel Plate Elements under Stochastic loading. (s. 34.).

I det aktuelle projekt undersøges udmattelseslevetiden af stålkonstruktioner i højstyrkestål under påvirkning af stokastisk last, med særligt sigte på anvendelse i offshorekonstruktioner. Af særlig interesse er udmattelsesskade akkumulering.

Der er i projektet gennemført udmattelsesforsøgsserier med forskellige typer stokastisk last, som er realistiske i relation til offshore konstruktioner. I forsøgene er anvendt tre forskellige lastspektre med irregularitetsfaktorer fra  $\sim 0.70$  til  $1.00$ . Der er gennemført forsøgsserier med såvel fuldskala rørknudesamlinger som mindre svejste pladeprøvelegemer. I rapporten er gjort rede for de resultater, der er opnået i forsøgsserierne med pladeprøvelegemer. De materialer, der er anvendt til prøvelegemerne, er højstyrkestål med en flydespænding på  $f_y \sim 800-1000$  MPa. Til sammenligning er gennemført et tilsvarende projekt med prøvelegemer i sædvanligt offshore konstruktionsstål med  $f_y \sim 360-410$  MPa. Der er i projektet anvendt termoelastisk måleteknik til bestemmelse af spændingskoncentrationsfaktoren og til at følge revneudviklingen i prøvelegemet.

De hidtil gennemførte forsøgsserier viser en betydelig forskel i udmattelsesegenskaber mellem pladeelementer med påsvejste langsgående og tværgående afstivningsplader. Endvidere fandtes generelt længere udmattelseslevetider for pladeprøvelegemerne i højstyrkestål end for de tilsvarende prøvelegemer i sædvanligt offshore konstruktionsstål.

PETERSEN, R.I., se AGERSKOV, H., R.I. PETERSEN og L. LOPEZ MARTINEZ

PEDERSEN, C., se STANG, H. og C. PEDERSEN

POULSEN, JOHANNES SAND, MICHAEL TONNESEN and ESBEN BYSKOV: \*Localized Failure in Clear Wood, in CANCAM95 (ed B. Tabarrok & S. Dost). Proceedings of the Fifteenth Canadian Congress of Applied Mechanics, University of Victoria, Victoria, British Columbia, Canada 1995, pp. 200-201. (Reprints available).

\*When wood is exposed to compression parallel to the grain, strain localization will occur at some point during the load history. This strain localization is known as a kink band. The stress-displacement curve as well as the kink band angle on the tangential-longitudinal face has been determined experimentally. The morphological behavior of compression failure is described.

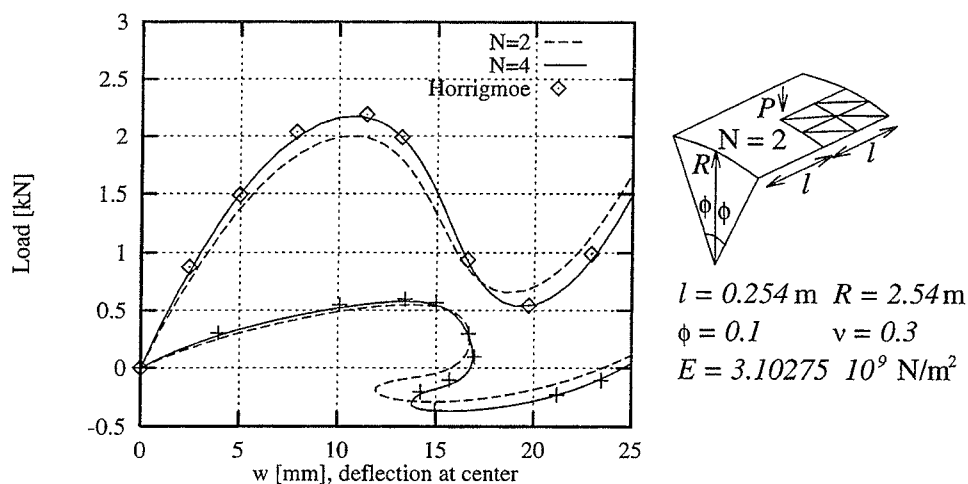
A two-dimensional continuum model and an Euler column model are investigated in order to model the peak stress. The two-dimensional continuum model can predict the peak stress using the transverse tensile strength as a limiting failure criterion. If we introduce the actual dimensions of a fiber into the Euler column model this also gives us an estimate of the peak stress. However, neither of the models can provide us with the kink band angle nor the kink band height.

POULSEN, JOHANNES SAND, se også TONNESEN, MICHAEL, JOHANNES SAND  
POULSEN og ESBEN BYSKOV

POULSEN, PETER NOE and LARS DAMKILDE: \*A Flat Triangular Shell Element with Loof Nodes. DCAMM Report No. 495, February 1995. 25 p. (Reprints available).

\*In the formulation of flat shell elements it is difficult to achieve inter-element compatibility between membrane and transverse displacements for non-coplanar elements. Many elements lack proper nodal degrees of freedom to model intersections making the assembly of elements troublesome. A flat triangular shell element is established by a combination of a new plate bending element DKTL and the well-known linear membrane strain element LST, and for this

element the above mentioned deficiencies are avoided. The plate bending element DKTL is based on discrete Kirchhoff theory and Loof nodes. The nodal configuration of the element is similar to the SemiLoof element, and the formulation is an improvement of a previous formulation. The element is used for both linear statics, linear buckling and geometrical non-linear analysis and numerical examples are presented to show the robustness, accuracy and rapid convergence of the element.



Geometrisk ikke-lineær skalberegning.

\*Geometric non-linear shell analysis.

Ref.: POULSEN, PETER NOE and LARS DAMKILDE: \*A Flat Triangular Shell Element with Loof Nodes. (s. 37).

RAMAKRISHNAN, V., se VAN MIER, J.G.M., H. STANG og V. RAMAKRISHNAN

RANDRUP-THOMSEN, SØREN, se DITLEVSEN, OVE, CLAUS CHRISTENSEN og SØREN RANDRUP-THOMSEN



RANDRUP-THOMSEN, SØREN, se MUNCH-ANDERSEN, JØRGEN, OVE DITLEVSEN, CLAUS CHRISTENSEN, SØREN RANDRUP-THOMSEN og PERNILLE HOFFMEYER

REINHARDT, H.W., P. ROSSI, R. BAGGOTT, G. BALAZS, J. BOLANDER, A.M. BRANDT, M. CHEYREZY, K. CHONG, L. ERDELYI, H. KRENCHER, D. LANGE, C. LEUNG, V.C. LI, H. MIHASHI, A.E. NAAMAN, V.S. PARAMESWARAN and H. STANG: \*Future Research Needs in the Field of HPFRCC. I: "High Performance Fiber Reinforced Cement Composites - Volume 2 (HPFRCC-95)". Ed. Antoine E. Naaman and Hans Wolf Reinhardt. Department of Civil and Environmental Engineering, University of Michigan, USA, 1995, pp. 401-406.

\*Future research needs are presented and discussed. They address mechanics of materials, performance, production, structural design and testing. Although much knowledge on HPFRCC is available there is still a lot to do to facilitate the acceptance of HPFRCC in practical engineering. Research should help overcome this problem.

RESUMÉOVERSIGT 1994: "Summaries of Papers 1994". Afdelingen for Bærende Konstruktioner. Serie R, nr. 321, 1995, 63 s. Gratis.

Resuméer af 35 videnskabelige publikationer m.v., af 1 rapport over eksperimentelle undersøgelser og af 9 eksamensarbejder.

\*Summaries in Danish and English of 35 scientific papers etc., of 1 report on experimental investigations, and of 9 final projects.

ROBERTSON, R., se BENTUR, A., S.T. WU, N. BANTHIA, R. BAGGOTT,  
W. HANSEN, A. KATZ, C.K.Y. LEUNG, V.C. LI, B. MOBASHER, A.E. NAAMAN,  
R. ROBERTSON, P. SOROUSHIAN, H. STANG og L.R. TAERWE

ROSSI, P., se REINHARDT, H.W., P. ROSSI, R. BAGGOTT, G. BALAZS, J. BOLANDER,  
A.M. BRANDT, M. CHEYREZY, K. CHONG, L. ERDELYI, H. KRENCHER, D. LANGE,  
C. LEUNG, V.C. LI, H. MIHASHI, A.E. NAAMAN, V.S. PARAMESWARAN og  
H. STANG

SOROUSHIAN, P., se BENTUR, A., S.T. WU, N. BANTHIA, R. BAGGOTT,  
W. HANSEN, A. KATZ, C.K.Y. LEUNG, V.C. LI, B. MOBASHER, A.E. NAAMAN,  
R. ROBERTSON, P. SOROUSHIAN, H. STANG og L.R. TAERWE

STANG, H.: "Micromechanical Parameters, Fracture Processes and Application of Fiber Reinforced Concrete". I: Fracture of Brittle Disordered Materials. Concrete, Rock and Ceramics. Ed. G. Baker and B.L. Karihaloo. E & FN Spon, 1995, pp. 131-148. (Reprints available).

\*The present paper describes a network of models used to predict mechanical behaviour of fiber reinforced concrete structures. The models cover the micro-scale in terms of descriptions of the fiber-matrix bonding mechanisms, the meso-scale in terms of the so-called stress-crack width relationship and the macro-scale in terms of structural models taking the stress-crack width models as input. Emphasis is placed on the description of the micro-mechanical parameters, the possibility of independent determination of these and the final structural response to changes in these parameters.

STANG, H., V.C. LI and H. KRENCHER: "Design and Structural Applications of Stress-Crack Width Relations in Fibre Reinforced Concrete". Materials and Structures, Vol. 28, No. 178, 1995, pp. 210-219. (Reprints available).

\*The stress-crack width relationship has been shown to be the key to the understanding of fracture propagation in and mechanical behaviour in tension of fiber reinforced concrete materials and structures. A model for the stress-crack width relationship for randomly oriented short fiber composites which takes hybrid fiber systems and possible fiber rupture into account is derived. It is shown how this stress crack width relationship can be included in a structural model for prediction of crack widths in reinforced concrete structures. With this combination of models a rational design tool for the design of composite materials and structures has been established. It is shown how different fiber systems can be tested for structural applicability and how a combined material and structural optimization can take place.

STANG, H. and C. PEDERSEN: "Using the  $\sigma$ - $\delta$  Relationship in the Design of FRC Structures". I: Nordic Symposium on Modern Design of Concrete Structures. Aalborg University, Denmark. May 3-5, 1995. Ed. Kirsten Aakjær. Institutet for Bygningsteknik, Aalborg Universitet, 1995, pp. 235-246. (Reprints available).

\*The design of structures using Fiber Reinforced Cementitious (FRC) materials in general and fiber reinforced concrete in particular has for many years been done almost exclusively on an empirical basis. At this point in time, however, new design tools are emerging which can provide a rational approach to the design of FRC structures and materials. The key concept in these design tools is the  $\sigma$ - $\delta$  relationship which takes the pullout and possible breakage of short fibers into account. The present paper gives an overview of the models presently available for the prediction of the  $\sigma$ - $\delta$  relationship on the basis of micro-material parameters. These micro-material parameters are parameters describing the mechanical properties and geometry of the fibers, the mechanical properties of the matrix and the bond between fibers

and matrix. Furthermore, models which on a structural level takes the  $\sigma$ - $\delta$  relationship into account are described and evaluated.

STANG, H., se også BENTUR, A., S.T. WU, N. BANTHIA, R. BAGGOTT,  
W. HANSEN, A. KATZ, C.K.Y. LEUNG, V.C. LI, B. MOBASHER, A.E. NAAMAN,  
R. ROBERTSON, P. SOROUSHIAN, H. STANG og L.R. TAERWE

STANG, H., se også LI, V.C., H. MIHASHI, J. ALWAN, R. BRINCKER, H. HORII,  
H. STANG, H. MAALEJ og S.T. WU

STANG, H., se også REINHARDT, H.W., P. ROSSI, R. BAGGOTT, G. BALAZS,  
J. BOLANDER, A.M. BRANDT, M. CHEYREZY, K. CHONG, L. ERDELYI,  
H. KRENCHER, D. LANGE, C. LEUNG, V.C. LI, H. MIHASHI, A.E. NAAMAN,  
V.S. PARAMESWARAN og H. STANG

STANG, H., se også VAN MIER, J.G.M., H. STANG og V. RAMAKRISHNAN

TAERWE, L.R., se BENTUR, A., S.T. WU, N. BANTHIA, R. BAGGOTT,  
W. HANSEN, A. KATZ, C.K.Y. LEUNG, V.C. LI, B. MOBASHER, A.E. NAAMAN,  
R. ROBERTSON, P. SOROUSHIAN, H. STANG og L.R. TAERWE

TONNESEN, MICHAEL, JOHANNES SAND POULSEN and ESBEN BYSKOV: \*Strain Localization in Clear Wood in Compression, in Computational Mechanics '95 (ed. S.N. Atluri, G. Yagawa & T.A. Cruse), Proceedings of the International Conference on Computational Engineering Science, Hawaii, USA, 1995, Springer-Verlag, Heidelberg, 1995, pp. 1785-1790. (Reprints available).

\*Experimental tests have shown that the fibers will start to buckle in a localized band when wood is exposed to compression parallel to the fiber direction. The angle of this localized band (kink band) is found to be a straight line perpendicular to the fiber direction on the radial-longitudinal face while on the tangential-longitudinal face it slopes at an angle of 20°-25° with respect to a line perpendicular to the fiber direction. The load drops about 20% after peak and then remains constant even for very large deformations.

A small-strain finite element formulation is used to model the kink band evolution in a compression specimen. The stress-displacement relation and the kink band angle obtained from experiments are implemented in the model and calculations reproduce the experimental observations. The model is used to calculate the behavior of wooden beams in bending.

TONNESEN, MICHAEL, se også POULSEN, JOHANNES SAND, MICHAEL TONNESEN og ESBEN BYSKOV

VAN MIER, J.G.M., H. STANG, and V. RAMAKRISHNAN: \*Practical Structural Applications of FRC and HPFRCC. I: "High Performance Fiber Reinforced Cement Composites - Volume 2 (HPFRCC-95)". Ed. Antoine E. Naaman and Hans Wolf Reinhardt. Department of Civil and Environmental Engineering, University of Michigan, USA, 1995, pp. 387-399.

\*The paper gives an overview of the current state of fibre reinforced concrete applications, in particular of advanced high performance fibre concretes in structures. The materials which

have been developed to date, SIFCON, SIMCON, Polyolefin Fibre Reinforced Concrete (PFRC). Compact Reinforced Composite (CRC) are relatively new, and in most cases only premature ideas for new applications exist. For some of the materials (CRC and PFRC), structural applications in tools, tunnel segments and pavement overlays have been constructed on an experimental basis. Moreover, the application of CRC in structural joints is presently investigated. These full scale experiments are considered of utmost importance for further development of the high performance materials. For SIFCON structural applications other than floor overlays are non-existent. Recently a mecano system of linear structural elements containing high volumes of aligned steel fibres has been proposed, and is currently in the stage of laboratory testing. The most promising way to develop new applications for FRC and HPFRCC seems an integrated approach where material development and structural design are combined.

VEJRUN, TINA, se NIELSEN, J.A., H. AGERSKOV og T. VEJRUN

WU, S.T., se BENTUR, A., S.T. WU, N. BANTHIA, R. BAGGOTT, W. HANSEN,  
A. KATZ, C.K.Y LEUNG, V.C. LI, B. MOBASHER, A.E. NAAMAN, R. ROBERTSON,  
P. SOROUSHIAN, H. STANG og L.R. TAERWE

WU, H.C., se LI, V.C., H. MIHASHI, J. ALWAN, R. BRINCKER, H. HORII,  
H. STANG, M. MAALEJ og S.T. WU

## 2. EKSAMENSPROJEKTER

### \*Final year projects

Da disse afhandlinger kun findes i et enkelt eksemplar, må et nærmere studium af dem foregå på Instituttets bibliotek efter forudgående aftale. Fotokopier af hele afhandlinger eller dele heraf kan leveres til en pris af kr. 1,00 pr. side.

Yderligere oplysninger om afhandlingernes indhold fås ved henvendelse til den under resumeet angivne lærer.

Anmodning om kopiering kan ske telefonisk på tlf. 45 25 25 25.

\*As there is normally only one copy of each of these theses, anyone wishing to study them in detail must do so at the Department's library according to a previous arrangement. Photocopies of entire theses or parts thereof can, however, be supplied at a price of D.kr. 1.00 per page. Orders for copies must be accompanied by a cheque for the amount in question.

Further information on the content of the theses can be obtained by application to the project leader indicated under the summary.

ÁSGEIRSSON, HAUKUR: Alternativ udformning af en bro over Ellidaarosar. (\*Alternative designs for bridge over Ellidaarosar. In Danish). Eksamensprojekt, Afdelingen for Bærende Konstruktioner, 1995, 127 s. hovedrapport + 125 s. bilagsrapport. Fotokopi, kr. 252,-.

I projektet undersøges alternative udformninger af en bro over Ellidaarosar. Brotypen vælges som en skrånstagsbro, og afstivningsdrageren udformes som en kompositkonstruktion. Broen analyseres for forskellige lastkombinationer, herunder tages der hensyn til de særlige islandske forhold f.eks. jordskælv.

Lærere: Lars Damkilde og N.J. Gimsing.

\*The scope of the project is to investigate different designs for a bridge over Ellidaarosar. The result is a cable-stayed bridge, and the girder is a composite structure. The bridge is analysed for different load combinations which takes into account the specific conditions in Iceland e.g. earthquakes.

Project leaders: Lars Damkilde and N.J. Gimsing.

CHRISTENSEN, JACOB LØJTVED og JESPER PEDERSEN: Fleksible samlinger i stålkonstruktioner. (\*Flexible Connections in Steel Structures. In Danish). Eksamensprojekt, Afdelingen for Bærende Konstruktioner, 1995, 114 s. hovedrapport + 191 s. bilagsrapport. Fotokopi, kr. 305,-.

Projektets mål er at kunne analysere en samling i en stålkonstruktion med et element metode program, og dermed tage hensyn til selve samlingens fleksibilitet. Der tages hensyn til stabilitet, forhåndsudbøjninger og plasticitet. Undersøgelserne koncentrerer sig omkring tyndvæggede rammekonstruktioner, hvor der på SBI er lavet en del eksperimentelle undersøgelser. Beregninger viser, at der er en rimelig overensstemmelse mellem forsøg og beregninger.



Lærer: Lars Damkilde.

\*The aim of the project is to analyse a connection in a steel structure with a finite element program, and hereby take into account the flexibility of the connection. The analysis includes stability, geometric imperfections and plasticity. The investigation is concentrated around thin-walled frame structures for which several experimental investigations have been conducted at the Danish Building Research Institute (SBI). The calculation show a reasonable accordance between experiments and calculations.

Project leader: Lars Damkilde.

FEJÉR, TAMÁS: \*A program for limit state analysis of plates. (In English). M.Sc. project, Afdelingen for Bærende Konstruktioner, 1995, 96 p. report + 148 p. appendices. Fotokopi, kr. 244,-.

\*The scope of the project is to establish a Finite Element formulation of limit state analysis of plates. The method is based on the lower-bound theorem, and a triangular element based on Airy's stress function is formulated. The element is implemented in a program system. Some examples are given including a deep beam and a punch problem. The examples show that the element is effective.

Project leader: Lars Damkilde.

HAGSTEN, LARS GERMAN: Dimensionering af Fiberarmerede Betonrør. (\*Design of Fiber Reinforced Concrete Pipes. In Danish). Eksamensprojekt, Afdelingen for Bærende Konstruktioner, 1995, 144 s. + 119 s. appendix. Fotokopi, kr. 263,-.

I rapporten opstilles en teori til bestemmelse af den konstitutive betingelse - herunder revnetæthed og revneåbning - for et fiberarmeret cementbaseret materiale. Det forudsættes, at der tilsættes den fornødne mængde fibre, for at der kan opnås en tilnærmet plastisk

materialeopførsel (pseudo-strain hardening). Denne konstitutive betingelse danner herefter grundlaget for en beregningsmetode, som anvendes på cirkulære rør. Der gennemregnes dels en situation, hvor røret påvirkes af to linielaste (svarende til en prøvebelastning) og dels en situation, hvor røret belastes af et lodret og vandret jordtryk. Ved denne kombination af modeller for materialeopførsel og for konstruktionsopførsel bliver det muligt at bestemme et givet fiberarmeret betonrørs deformationsforhold, bæreevne samt revnetæthed og revnevidder i røret på et vilkårligt tidspunkt i belastningshistorien. Modellen, som benyttes til bestemmelse af materialets arbejdskurve, er verificeret ved sammenligning med forsøg. Der er desuden udført kontrol af beregningsmetoden ved hjælp af et FEM-program og ved brug af en analytisk lineær elastisk løsning.

Lærer: Henrik Stang.

\*In the report a theory is developed for the determination of the stress-strain relationship for a fiber reinforced cementbased material. The developed constitutive relationship also provides information about crack density and crack opening. In the model it is assumed that the material is fiber reinforced in such a way that a pseudo plastic material behavior (pseudo-strain hardening) is obtained. This constitutive relationship forms the basis for a design method for circular pipes. Two loading situations are considered: two opposite line loads (corresponding to a test loading situation) and a loading situation corresponding to an in-situ loading with vertical and horizontal soil pressure. This combination of models for material behavior and structural behavior makes it possible to determine the deformation characteristics and loading capacity of a given fiber reinforced concrete pipe. Furthermore, the design method provides information about crack density and crack width at any time in the loading history. The model for material behavior is verified by comparison with experimental data. Furthermore, the design method is verified by comparison with results from a FEM-program and an analytical linear elastic solution.

Project leader: H. Stang.

HANSEN, ANDERS STRANGE: CAD og CAE til plastisk beregning og optimering,  
(\*CAD/CAE for limit state analysis and optimization. In Danish). Eksamensprojekt,  
Afdelingen for Bærende Konstruktioner, 1995, 87 s. hovedrapport + 58 s. bilags-  
rapport. Fotokopi, kr. 145,-.

Projektets formål er at implementere et eksisterende system, LimitS, til beregning af armerede betonplader i et CAD-system. I CAD-systemet kan brugeren nøjes med at definere de overordnede data som geometri, last og understøtningsbetingelser. I CAD-systemet gennemføres automatisk elementinddeling m.m., og hermed opnås en rationalisering. I rapporten vises eksempler på optimering af armeringsarrangementer. Projektet er udført i samarbejde med Carl Bro A/S.

Lærere: Lars Damkilde og Kristian Hertz.

\*The aim of the project is to implement an existing system, LimitS, in a CAD environment. LimitS enables a limit state analysis or optimization of reinforced concrete slabs. In the CAD-system the user input is restricted to the engineering information such as geometry, loading and support conditions. In the CAD-system the finite element mesh is generated automatically etc., and hereby the calculation is done very effectively. In the report examples on optimization of reinforcement are given. The project is done in cooperation with the consulting firm Carl Bro A/S.

Project leaders: Lars Damkilde and Kristian Hertz.

HANSEN, PETER STEEN, se HÅKANSSON, SØREN og PETER STEEN HANSEN

HÅKANSSON, SØREN og PETER STEEN HANSEN: Spændingsbestemmelse og udmattelse i stålbrodæk. (\*Stress determination and fatigue in steel bridge deck. In Danish). Eksamensprojekt, Afdelingen for Bærende Konstruktioner, 1995, 205 s. + bilag 113 s. Fotokopi, kr. 318,-.

Grundlaget for projektet er, at der i ABK's forsøgshal udføres en række statiske forsøg og udmattelsesforsøg på et broanepanel med en ortotrop dækplade i fuld størrelse. Broanepanet svarer til den i Storebæltsforbindelsens østbro anvendte konstruktion. I dette eksamensprojekt forsøges spændingstilstanden i et tværsnit bestemt ved elementmetodeberegninger samt ved SPATE- og strain gage målinger. Ved et litteraturstudium undersøges mulighederne for at bestemme de individuelle hovedspændinger på baggrund af SPATE-målinger. En stumpsvejst stødsamling med permanent modhold undersøges for spændingskoncentrationer ved brug af SPATE-udstyr.

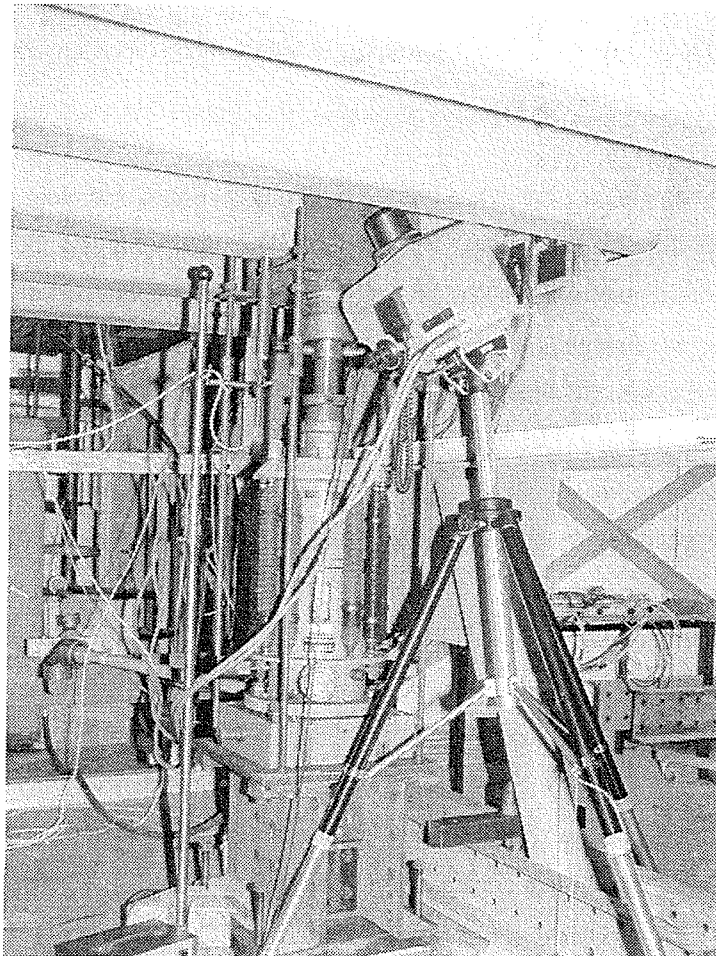
På baggrund af et litteraturstudium samt resultater fra spændingsbestemmelsen vurderes panelets levetid mht. udmattelse. Endvidere er der udført en forsøgsserie med 13 små prøvelegemer udsat for stokastisk brolast.

Lærere: V. Askegaard, H. Agerskov og L. Damkilde.

\*A full-scale bridge test panel with an orthotropic deck plate is subjected to a series of static and fatigue tests in the laboratory of the Department of Structural Engineering. These tests are carried out to support the design basis for the suspension bridge of the Great Belt Link. An attempt is made to determine the stress distribution in a cross girder by use of finite element analysis and by SPATE- and strain gage measurements. In the literature, the possibility of separating the individual principal stresses by use of SPATE-technique is studied. A butt welded connection with permanent backing strip is examined by use of SPATE equipment for stress concentrations arising from the backing strip.

From a study of the literature and from the results of the stress determination, the strength of the test panel against fatigue failure is estimated. Furthermore, a test series in which 13 small plate test specimens were subjected to stochastic bridge loading was carried out.

Project leaders: V. Askegaard, H. Agerskov and L. Damkilde.



Spændingsbestemmelse ved hjælp af SPATE-målinger.

\*Stress determination by use of SPATE-technique.

Ref.: HÅKANSSON, SØREN og PETER STEEN HANSEN: Spændingsbestemmelse og udmattelse i stålbrodæk. (s. 50).

KAMSTRUP, HENRIK og LARS PETERSEN: Beregning af skalkonstruktioner med finite elementprogrammet COSMOS. (\*Analysis of shell structures by means of the finite element program COSMOS. In Danish). Eksamensprojekt, Afdelingen for Bærende Konstruktioner, 1995, 191 s. hovedrapport + 696 s. bilagsrapporter. Fotokopi, kr. 191,-.

Projektet består af beregninger af en række typiske skalkonstruktioner med elementmetodeprogrammet COSMOS (lineære beregninger af cylinderskaller, omdrejningsskaller og dobbeltkrumme skaller, samt geometrisk ulineære beregninger af cylinderskaller og kugleskaller). De lineære beregninger er sammenlignet med analytiske løsninger, hvor de numeriske resultater er udregnet med programmet MATHEMATICA. Der er undersøgt forskellige elementtyper og forskellige elementinddelinger. Det viser sig, at især elementet SHELL9 giver fine resultater for cylinderskallerne og de dobbeltkrumme skaller, men faciliteterne til beregning af omdrejningsskaller er ikke imponerende. Den geometrisk ulineære analyse fungerer tilfredsstillende.

Lærer: Hugo Møllmann.

\*The project consists of calculations of a series of typical shell structures by means of the finite element program COSMOS (linear calculations of cylindrical shells, shells of revolution, and doubly curved shells, and geometrically nonlinear calculations of cylindrical and spherical shells). The linear calculations are compared with analytical solutions, where the numerical results are obtained by means of the program MATHEMATICA. Different types of finite elements and element divisions are studied. It is found that the element SHELL9 gives excellent results for the cylindrical and the doubly curved shells, but the facilities for analysis of shells of revolution are not impressive. The geometrically nonlinear analysis gives reasonably reliable results.

Project leader: Hugo Møllmann.

PEDERSEN, JESPER, se CHRISTENSEN, JACOB LØJTVED og JESPER PEDERSEN

PETERSEN, LARS, se KAMSTRUP, HENRIK og LARS PETERSEN

RAHIN, SLAVASH: Beregning af sammensatte omdrejningsskaller. (\*Calculation of combined shells of revolution. In Danish). Eksamensprojekt, Afdelingen for Bærende Konstruktioner, 1995, 136 s. hovedrapport + 65 s. bilagsrapport. Fotokopi, kr. 201,-.

Projektets formål var at udvikle et generelt PC-program til beregning af sammensatte omdrejningsskaller (f.eks. vandtårne). Membranløsninger kombineres med tilnærmede bøjningsløsninger. Beregningsomfanget bliver med denne metode væsentligt mindre end med en elementmetode. Samtidig får man en god beskrivelse af lokale fænomener i randzonerne (f.eks. kraftigt dæmpede bøjningsmomenter). Numeriske eksempler viser fin overensstemmelse mellem programmets resultater og analytiske løsninger.

Lærer: Hugo Møllmann.

\*The purpose of the project was to develop a general PC-program for the analysis of combined shells of revolution (such as water towers). Membrane solutions are combined with approximate bending solutions. The amount of calculations involved in this method is considerably smaller than that of a corresponding finite element calculation. At the same time, a good description is obtained of the local phenomena in the edge zones (such a heavily damped bending moments). Numerical examples show excellent agreement between the results of the PC-program and corresponding analytical solutions.

Project leader: Hugo Møllmann.

ROWE, JOHN: \*Numerical simulation of a bolted endplate connection and mechanical model derivation. (In English). M.Sc. project, Afdelingen for Bærende Konstruktioner, 1995, 85 p. report + 41 p. appendices. Fotokopi, kr. 126,-.

\*The scope of the project is to simulate the real behaviour of connections especially in thin-walled structures. The connections own flexibility have influence on the overall structural behaviour, and affects e.g. the stability load. In the project a specific connection is analysed with a Finite Element system, Cosmos. The calculation includes nonlinearities from geometry (large displacements) and plasticity. A simplified model is established in order to achieve a more simple design tool.

Project leader: Lars Damkilde.

STEC, CHRISTIAN ANDREAS: Et CAD/CAE værktøj til automatisering af konstruktionsberegninger. (\*A CAD/CAE program for automatization of structural analysis. In Danish). Eksamensprojekt, Afdelingen for Bærende Konstruktioner, 1995, 63 s. hovedrapport + 185 s. bilagsrapport. Fotokopi, kr. 248,-.

Målet med projektet er at effektivisere anvendelsen af finite element beregninger i forbindelse med konstruktionsberegninger. Netgenerering og belastningsberegninger tager traditionelt lang tid, og informationen er svær at genbruge ved ændringer i konstruktionen. I projektet er udarbejdet et system IDAS, som er i stand til at generere elementnet og belastninger på basis af en parametriseret geometri. Projektet er udført i samarbejde med Carl Bro A/S.

Lærer: Lars Damkilde.

\*The aim of the project is to make finite element calculations of structures more effectively. Generation of finite element mesh and loadings traditionally takes much time, and the ability to reuse the information after changes in the structure is small. In the project a system IDAS is developed, which is able to generate mesh and loading based on a parameterised geometry. The project is done in cooperation with the consulting firm Carl Bro A/S.



Project leader: Lars Damkilde.

TARP-JOHANSEN, NIELS JACOB: \*Non-linear Dynamics of Structures. M.Sc. thesis. (In English). Eksamensprojekt, Afdelingen for Bærende Konstruktioner, Juli 1995, 103 s. + 230 s. bilagsrapport. Fotokopi, kr. 333,-.

\*As technical skills and economical demands encourage engineers to design closer to the limit, more exact and refined methods of design are required. Often the refined methods implies nonlinearities.

This thesis has its background in cable stayed mast structures. These structures are extremely high and slender, and due to wind subjected to dynamical loads. Their slenderness and the large displacements of the cables introduce geometrical nonlinearities.

Though the starting point of the thesis is cable stayed masts the main subject is nonlinear dynamical analysis of structures and the thesis is mostly concerned with the establishment of the tools required to perform numerical nonlinear dynamical analyses.

An object oriented FEM program including a sparse technique implementation of matrices was build and verified. The nonlinear algorithm used was an implicit direct time integration algorithm for which some effort was made to allow introduction of more detailed damping models than the usual damping matrix model. To be able to model a cable stayed mast a shear flexible column beam element and a string element were implemented and some investigations of damping in cables conducted.

Project leader: Lars Damkilde.

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