Dynamics of Structures

progress report 1995

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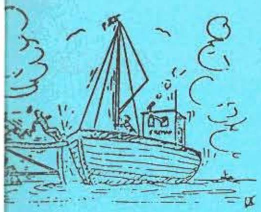
Publication date:
1995

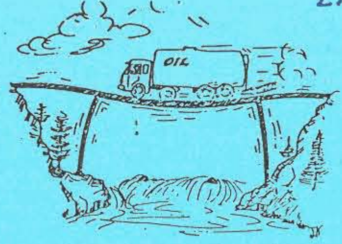
Document Version
Publisher's PDF, also known as Version of record

Link to publication from Aalborg University

Citation for published version (APA):
Hansen, L. P. (1995). *Dynamics of Structures: progress report 1995*. Dept. of Building Technology and Structural Engineering, Aalborg University.

LARS PILEGAARD HANSEN





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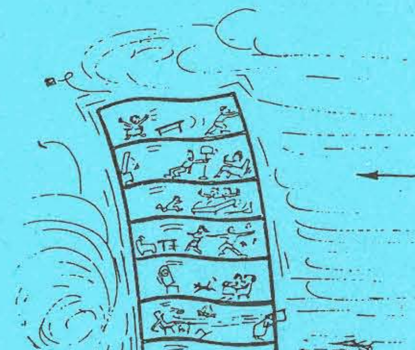

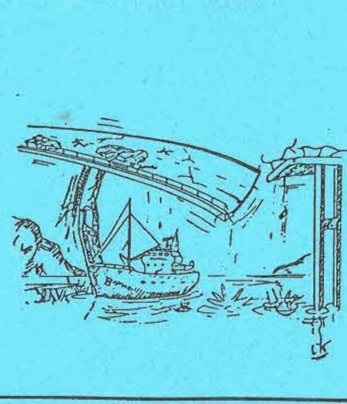

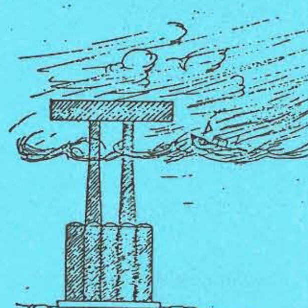

DYNAMICS OF STRUCTURES

Framework Programme at Aalborg University

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PROGRESS REPORT 1995

Contents

1. Introduction

Dynamics of Structures is a research programme sponsored by the Danish Technical Research Council. The programme started in 1993 and will continue to the end of 1997. It is a cooperative effort of the Department of Building Technology and Structural Engineering and the Department of Civil Engineering at Aalborg University and the Department of Structural Engineering at the Technical University of Denmark (until the end of 1995).

The purpose of the programme is to conduct research and to provide research education and results relating to dynamic loads and response of structures and foundations. Characterization and modelling of materials under time varying loads are also parts of the research programme. The research will develop and use both analytical, numerical and experimental methods.

The problem areas dealt with in the research programme are:

- Analysis of structures
- Wind and wave loads
- Soil mechanics
- System identification
- Damage detection
- Fatigue and crack propagation
- Man induced vibrations
- Experimental methods

This progress report for 1995 is organized according to the structure of the original proposal with the following project:

A. BASIC THEORY

- A1 Mode shape and reduced base techniques
- A2 Wind loads on structures
- A3 Dynamic response of structures with stochastic properties and excitation

B. EXPERIMENTAL TECHNIQUES

- B1 Damage detection in structures under random loading
- B2 Modal analysis based on the random decrement techniques
- B3 Fatigue and crack propagation

C. SELECTED DYNAMIC PROBLEMS

- C1 Behaviour of soil subjected to dynamic loads
- C2 Dynamic response of coarse granular materials to wave loads
- C3 Dynamics of sports stadiums
- C4 Dynamic measurements on the Frejlev mast

2. General Status

As described in the progress report 1993 - 94 the structure of the research programme confirms closely with that of the original proposal. Project C1 has been adjusted a little, and project A3 now covers the activities of an AAU - financed Ph.D. student relating to the subject. In 1995 the research programme has financed 5 Ph.D. students so a total of 6 Ph.D. students are working in the programme.

The expenses (excl. overhead) for the research programme in thousands of DKr. in 1995 are given in table 1.

Project	Ph.D. student	Salary	Other expenses	Total
A1	Steffen Vissing	185	145	330
A2			2	2
A3	Poul S. Skjærbæk		62	62
B1	Palle Andersen	315 NOTE 1	128	443
B2	John Asmussen	168	141	309
B3	Thomas Cornelius	101 NOTE 2	111	212
C1	Lars Bødker	206	335	541
C2		257 NOTE 3	117	374
C3				0
C4			23	23
Secretariat		57	34	91
Total		1289	1098	2387

NOTE 1: Includes also salary for Poul Henning Kirkegaard
NOTE 2: Ph.D. expenses for half of the year paid in 1994
NOTE 3: Salary for Finn Rosendahl Jacobsen

Table 1. Expenses for the research programme in 1995

Many of the projects have established international contacts as indicated in the sections in chapter 3.

A workshop similar to the one in 1994 was announced in the autumn of 1995 but was cancelled as only 5 (external) persons have signed up. A workshop is planned in the autumn of 1996 and an effort will be made to increase the number of external participants.

The programme leader, Steen Krenk, has left Aalborg University and is now working at Lund University in Sweden but has still connection to the research programme. The program leader from autumn 1995 is Lars Pilegaard Hansen, Aalborg University.

3. Description of Projects

3.1 Project A1. Mode Shape and Reduced Base Techniques

Content and status

The project deals with numerical techniques for reduction and subsequent eigenvalue analysis of models from structural analysis.

The main focus has been on the development of the combination of a Lanczos reduction technique for linear and quadratic eigenvalue problems, and a generalized algorithm of QR-type for the final eigenvalue analysis. A modified format, using a tridiagonal matrix and a diagonal matrix with ± 1 elements, is introduced for indefinite problems that occur e.g. in connection with complex eigenvalues in damped oscillations of structures. The generalized QR-algorithm extracts the complex eigenvalues from this format by use of real arithmetic.

In 1995 the algorithms have been completed, and finite element routines have been developed, extending the MATLAB-based finite element program developed at AAU (Aalborg University) to dynamic analysis. The work has been presented at 'Svenska Mekanikdagar' and ' 8'th Nordic Seminar on Computational Mechanics '. Research assistant Hilda van der Veen from the Technical University of
Delft has visited the project for a week and presented related work. A Ph.D. thesis by Steffen Vissing entitled 'A generalized Lanczos-QR technique' has been completed, and submitted at the end of the year.

Participants

Steffen Vissing, Ph.D. student, Department of Building Technology and Structural Engineering, Aalborg University.

Steen Krenk, Professor, Division of Mechanics, Lund Institute of Technology, Lund University, Sweden

Publications

A1.1 S. Vissing and S. Krenk: *A generalized Lanczos-QR technique*. Paper 1.4, Svenska Mekanikdagar, Lund, May 31 - June 2, 1995.

A1.2 S. Vissing and S. Krenk: *A generalized indefinite QR algorithm*. Paper A.6.2, 8'th Nordic Seminar on Computational Mechanics, Göteborg, November 16 - 18, 1995.

A1.3 S. Vissing: *A generalized Lanczos-QR technique*. Ph.D. thesis, pp. 149, Department of Building Technology and Structural Engineering, Aalborg University, December, 1995.

3.2 Project A2. Wind Loads on Structures

Content and status

Two problems of structural wind loads have been considered: turbulent buffeting loads and vortex induced vibrations.

In engineering practice the spatial correlation is usually represented by an exponential function of separation distance. For large structures or high frequencies this representation overestimates the resulting wind load, because the correlation of along-wind fluctuations changes from positive to negative at sufficient distance. A simple theoretically founded improvement on the exponential format has been derived, reducing the resulting load on long slender structures with about 25\% in the high frequency range. The results were presented at the IUTAM Symposium on Nonlinear Stochastic Mechanics, organized in Trondheim by Arvid Naess with S Krenk as co-chairman and proceedings editor.

Michael Kleiser visited AAU from Munich financed by the EU Human Mobility Programme and worked on vortex-induced vibrations. The work included an analysis and reformulation of a recent model of single-oscillator type.

Plans for 1996

Wind

It is planned that S. Nielsen and S. Krenk work together on simplified models for vortex-induced vibrations, aiming at producing an alternative to the current Eurocode proposal for practical design. Recent data seem to indicate that the criteria for occurrence of vortex-induced vibrations need improvement, and also improved estimates of the maximum amplitude and its dependence on e.g. the wind turbulence are desirable. In addition an attempt will be made to simplify a recently published model for representation and simulation of turbulence in natural wind, and to derive relevant parameters from balance of the energy dissipation.

Water

A project entitled Active Vibration Control of Monopile Platforms will be initiated. At the exploitation of marginal fields in the Jutlandian sector of the North Sea monopile platforms have proved to be beneficial. In the original concept the platform was designed to water depths of 35-50 m, and was assumed to be operated unmanned. Vibrations of the structure under these conditions are unimportant in all cases. However, in later applications the concept is under consideration for a water depth up to 75 m, and the platforms are assumed to be manned. In this case significant dynamic amplification can arise in comparison to the quasi-statical response. The project, which is proposed together with Rambøll, Esbjerg, is aimed at developing an active vibration system for reduction of wave induced oscillations.

The system is based on control of the boundary layer flow, and hence of the loading on the cylinder. The wave load consists of a drag component and an inertial component. Only the drag component is under consideration. Normally, the drag coefficient is 0.6-0.9 for a circular cylinder. For a sharp edge body the drag coefficient can amount to 1.5-2.0. The cylinder will act effectively as a sharp-edged body, if the boundary layer is forced to separate before the natural separation points. The separation of the boundary layers will be ensured by blowing air from inside the cylinder whenever appropriate.

The idea is to ensure a large drag coefficient, when the velocity of the structure is opposite to that of the fluid. In this case the boundary layers are blown away. When the velocity of the structure and the fluid are unidirectional, no forced separation is impinged on the boundary layers. The velocity of the structure is measured by accelerometers on the platform, and the velocity of the boundary flow relative to the structure is measured by an ultrasonic velocity meter, attached to the structure. The advantage of the principle compared to other active vibration arrangements is that the power for vibration reduction is supplied primarily from the fluid itself. Only the power for blowing the boundary layers off needs to be supplied externally.
The applicability of the principle will be demonstrated by a series of tests in January and February 1996, in stationary flow and regular waves. The optimal control of air blowing has also been recognized. During the month of April a final test with a further optimized test setup will be performed.

Publications

A2.1 S. Krenk: *Wind field coherence and dynamic wind forces*. IUTAM Symposium on Advances in Nonlinear Stochastic Mechanics,Trondheim, July 3-7, 1995. (Proceedings published by Kluwer Academic Publishers, 1996)

A2.2 M. Kleiser, S.R.K. Nielsen and J.D. Sørensen: *Vortex-induced vibrations - Sensitivity and applicability of life-oscillator models*. (Manuscript), Department of Building Technology and Structural Engineering, Aalborg University, 1995.

Participants

Steen Krenk, Professor, Division of Mechanics, Lund Institute of Technology, Lund University, Sweden

Søren R.K. Nielsen, Reading Professor, Department of Building Technology and Structural Engineering, Aalborg University.

Poul H. Kirkegaard, Ph.D., Associate Professor, Department of Building Technology and Structural Engineering, Aalborg University.

3.3 Project A3. Dynamic Response of Structures with Stochastic Properties and Excitation

Content and status

From March 1995 Poul S. Skjærbæk has been engaged in developing a method for localizing damages in severely damaged buildings exposed to earthquake. The prerequisite of the method is that the building has been instrumented so that the surface ground acceleration and the top-storey displacements are measured, which is the most applied setup in practice. Based on this input-output relationship it is further assumed that at least the two lowest time-varying smoothed circular eigenfrequencies, $\omega_1(t)$ and $\omega_2(t)$, can be identified. The damage of a certain substructure or beam element is assumed to be reflected by the relative reduction of the stiffness matrices of such substructures. An algoritm for localization of the indicated damage measures has been derived.

The applicability of the method has been demonstrated using simulated data obtained by the SARCOF program (Stochastic Analysis of Reinforced Concrete Frames), see [A3.1] and [A3.9].

The problem of identifying the smoothed 1st circular eigenfrequencies, $\omega_1(t)$, which form the basis for the so-called maximum softening damage indicator, was investigated using discrete wavelet anlysis, see [A3.2] , and using short-time Fourier transform, continuous wavelet transform and Wigner-Ville distribution, see [A3.4]. These papers were written in June-August 1995 during a 3-month stay by Ray Micaletti in Aalborg, financed by the research programme.

The cooperation on stochastic response of uncertain structures exposed to random loads with Professor A. S. Çakmak, Princeton University, and Assistant Professor H.U. Köylüoğlu, was further developed during the year. S.R.K. Nielsen visited Princeton Universty for a fortnight in January 1995, and H.U. Köylüoğlu visited Aalborg University for one week in August 1995. During a year a paper on faster Monte-Carlo simulation schemes for hysteretic structures, based on an extension of the Ermak-Allen algoritm from molecular dynamics, was suggested, see [A3.3]. An Ermak-Allen type of algoritm was also suggested for the integration of moment equations of geometrically non-linear structures, see[A3.5]. The capabilities of a previously developed model for analysis of RC-structures, based on sequential updating, was further investigated,and it was demonstrated that the localization of damage is highly dependent on the frequency contents of the excitation, see [A3.6]. A method for dealing with the buckling load and reliability of structures with uncertain properties based on stochastic finite elements was also derived, see [A3.7]. Finally, some further results for a previously devised perturbation method for dealing with structures with random properties was addressed, see [A3.8].

Plans for 1996

Poul Skjærbæk is visiting the Department of Civil Engineering and Operations Research, Princeton University as a guest of Professor A. S. Çakmak during the period January 1 to June 15. During the stay he is supposed to improve the damage localization method for severely damaged RC-structures by introducing auxiliary measurements providing both time-averaged circular eigenfrequencies and mode shapes. Besides, he will deal with the identification of such quantities on real time measurements.

The developed localization procedure has only been tested with simulated data optained by the SARCOF FEM program. The applicability of this program has only been demonstrated for predicting the non-linear displacement response of RC-frames, whereas the capability for predicting the damage development in elements and substructures is unknown. For this reason a series of preliminary tests will be performed at the return of Poul Skjærbæk on two 6-storey 2-bay reinforced concrete frames in the scale 1:6 exposed to earthquake loading.

Finally, a new project entitled Dynamic Amplification Factors in Relation to Traffic Loads at Reinforcement Projects on Minor Highway Bridges will be initiated. The background of the project is, that during the recent years it has been nescessary to upgrade smaller highway bridges to heavier loads, partly because heavy trucks are driving with higher velocities, and partly because the highway authorities are inclined to allow transportation of especially heavy goods over a larger part of the highway net. This calls for reinforcement of the bridges in most cases. To keep the expenses for this reinforcement project at a minimum it is necessary to perform accurate calculations of the dynamic amplification factor, so its magnitude is neither over- nor underestimated.

The critical load scenario occurs, when two heavy vehicles are passing the bridge simultaneously. According to Danish standards these two heavy vehicles are made up of a "lighter" vehicle (up to 50 ton) and a heavier vehicle (100-150 ton). For both vehicles a dynamic amplification factor of 1.25, acting simultaneously, is assumed, which is an expensive generalization for reinforcement projects, and emphasizes the need for a better specification of the dynamic reinforcement for highway bridges. Since the bridges are relatively small, these are assumed to respond quasi-statically. Only the vehicle dynamics is considered. The highway irregularities are modelled stochastically, and the obtained amplification factors are interpreted as a random variable with distribution depending on the speed of the opposite approaching vehicles, the variability and wave length distribution of the highway surface, and the dynamics of the involved vehicles.

The primary gain of the project is a considerable reduction of the expenses of such reinforcement projects. At present 100 existing highway bridges are under consideration for upgrading to heavier loads.

Participants

Poul S. Skjærbæk, Ph.D. student, Department of Building Technology and Structural Engineering, Aalborg University. Financed by Aalborg University.

Ray C. Micaletti, Jr., Ph.D. student, Department of Civil Engineering and Operations Research, Princeton University, Princeton, NJ 08544, USA.

Søren R.K. Nielsen, Reading Professor, Department of Building Technology and Structural Engineering, Aalborg University.

Poul H. Kirkegaard, Ph.D., Research associate, Department of Building Technology and Structural Engineering, Aalborg University.

H.U. Köylüoğlu, Ph.D., Assistant Professor, College of Arts and Sciences, Koc University, Istinye, 80860 Istanbul, Turkey.

Ib Enevoldsen, Ph.D., Rambøll, Nørregade 7A, 1165 Copenhagen K. Financed by the Danish Technical Research Council.

Publications

A3.1 P.S. Skjærbæk, S.R.K. Nielsen & A. S. Çakmak: *Damage Localization of Severely Damaged RC-Structures based on Measured Eigenperiods from a Single Response.*

Structural Reliability Theory, Paper No. 149, Aalborg University (to be presented at the Localized Damage Conference, Fukuoka, Japan, June 1996).

A3.2 R.C. Micaletti, A. S. Çakmak, S.R.K. Nielsen & P.H. Kirkegaard: *Construction of Time-Dependent Spectra using Wavelet Analysis for Determination of Global Damage*. Structural Reliability Theory, Paper No. 147, Aalborg University (to be presented at the Noise and Vibration Conference , Leuven, Belgium, September 1996).

A3.3 H.U. Köylüoğlu, S.R.K. Nielsen & A. S. Çakmak: *A Faster Simulation Method for the Stochastic Response of Hysteretic Structures subject to Earthquakes.* Structural Reliability Theory, Paper No. 127, Aalborg University (submitted to Earthquake Engng. Struct. Dyn.).

A3.4 P.H. Kirkegaard, S.R.K. Nielsen, R.C. Micaletti & A. S. Çakmak: *Identification of a Maximum Softening Damage Indicator of RC-Structures using Time-Frequency Techniques.* Structural Reliability Theory, Paper No. 146, Aalborg University (to be presented at the EURODYN'96 Conference , Florence, Italy).

A3.5 H.U. Köylüoğlu, S.R.K. Nielsen & A. S. Çakmak: *Approximate Forward Difference Equations for the Lower Order Non-Stationary Statistics of Geometrically Non-Linear Systems subject to Random Excitation.* Structural Reliability Theory, Paper No. 131, Aalborg University. To appear in Proc. 3rd. Int. Conf. Stochastic Struct. Dyn. , San Juan, Puerto Rico, January, 1995 (in press). Also in review for the J. Int. Nonlinear Mech. .

A3.6 H.U. Köylüoğlu, S.R.K. Nielsen, J. Abbott & A. S. Çakmak: *Local and Modal Damage Indicators for Reinforced Concrete Shear Frames subject to Earthquakes.* Structural Reliability Theory, paper No. 145, Aalborg University (submitted to J. Eng. Mech., ASCE).

A3.7 H.U. Köylüoğlu, S.R.K. Nielsen & A. S. Çakmak: *Uncertain Buckling Loads.* Structural Reliability Theory, paper No. 141, Aalborg University (to appear in Bulletin of the Technical University of Istanbul).

A3.8 H.U. Köylüoğlu, S.R.K. Nielsen, & A. S. Çakmak: *Solution Methods for Structures with Random Properties subject to Random Excitation.* Proc. ASCE Specialty Conf. ,Ed. Stein Sture, Colorado, June 1995, pp. 1131-1134.

A3.9 P.S. Skjærbæk, S.R.K. Nielsen & A. S. Çakmak:*Assessment of Damage in Seismically Excited RC-Structures from a Single Measured Response.* Fracture and Dynamics, Paper No. 64, Aalborg University (to appear in Proc.14th Int. Modal Analysis Conf., Michigan, February 1996).

3.4 Project B1. Damage Detection in Structures under Random Loading

Content and status

In the period from January 9 to May 31, 1995 Palle Andersen was on maternity leave from his

Ph.D study. In the end of April 1995 professor Bruno Piombo from Torino, Italy, visited the participants of the project at Aalborg University. During this visit the use of Auto-Regressive Moving Average Vector (ARMAV) models for discrete-time modelling of structural systems was discussed.

From June 1 to October 1, 1995 Palle Andersen visited Prof. G.C. Manos, Department of Civil Enginering at Aristotle University of Thessaloniki, Greece. During this visit he was attached to the EU founded EURO SEIS-Test programme. His job was primarly system-identification of EURO SEIS-Test structure. The results of the work are described in [B1.1], which is to be completed in the spring of 1996. During the visit a hybrid identification routine, combining the accuracy of the ARMA model with a high-speed unbiased FFT-estimation of sampled covariance functions was developed. This hybrid approach has made it possible, by means of a univariate ARMA model, to estimate all modal parameters, including scaled modeshapes. In [B1.2] the approach has been tested on offshore data supplied by Intervep A.S.

From October 1 to December 31, 1995 Palle Andersen's work has mainly concerned time series modelling using different state space realizations, implementation of different algorithms for on-line and off-line calibration of full-polynomial ARMAV models, see [B1.3]. These algorithms are now a part of the STDI toolbox. Both on-line and off-line algorithms have been used for system-identification of different systems. They have shown promissing results in the case of systems containing closely space modes, see [B1.4], [B1.5] and [B1.6]. The software of the STDI toolbox has also been used in the development of the publications [B1.7], [B1.8] and [B1.9].

Plans for 1996

The more practical aspects of damage assessment will be considered. In relation to this a large number of measurements of a 20 m. laboratory lattice steel mast is planned. During the measuring period damages will be artificial introduced. The measurements will be spread over a long period, in order to make the environmental conditions change significantly. This will result in disturbance of the estimated modal parameters. It is the idea to filter this disturbance out using an on-line regression analysis. The detection of damages will be based on modal parameters using the software of the STDI toolbox. The localization and quantification of the damages will be based on already well proved methods.

The cooperation with G.C. Manos and the EURO SEIS-test project will be continued. This cooperation will probably result in further analysis of earthquake excited structures. Also the cooperation with Intervep A.S. is planned to continue. This company has proved to be a valuable source in obtaining response data from ambient excited offshore structures.

The work with on-line calibration algorithms will be continued and be related to the project A.3, and the work with the STDI toolbox will be completed. The work is now concentrated around the development of a user-friendly graphical interface.

Participants

Palle Andersen, Ph.D. student, Department of Building Technology and Structural Engineering, Aalborg University.

Rune Brincker, Associate Professor, Department of Building Technology and Structural Engineering, Aalborg University.

Lars Pilegaard Hansen, Senior Associate Professor, Department of Building Technology and Structural Engineering, Aalborg University.

Poul Henning Kirkegaard, Associate Professor, Department of Building Technology and Structural Engineering, Aalborg University.

Publications

B1.1 J.C. Asmussen, P. Andersen, R. Brincker & G.C. Manos : *Identification of the EURO SEIS Test Structure*, 1996. Fracture & Dynamics No. 76, Aalborg University.

B1.2 R. Brincker, P. Andersen, M.E. Martinez & F. Tallavó : *Modal Analysis of an Offshore Platform using Two Different ARMA Approaches*. 14th International Modal Analysis Conference, February 1996, Dearborn, Michigan USA. Fracture & Dynamics No. 66, Aalborg University.

B1.3 P. Andersen, R. Brincker & P.H. Kirkegaard:*Theory of Covariance Equivalent ARMAV Models of Civil Engineering Structures* 14th International Modal Analysis Conference, February 1996, Dearborn, Michigan USA. Fracture & Dynamics No. 71, Aalborg University.

B1.4 P.H. Kirkegaard, P. Andersen & R. Brincker: *Identification of the Skirt Piled Gullfaks C Gravity Paltform using ARMAV models* 14th International Modal Analysis Conference February 1996, Dearborn, Michigan USA.Fracture & Dynamics No. 69, Aalborg University.

B1.5 P.H. Kirkegaard, P. Andersen & R. Brincker: *Identification of Civil Engineering Structures using Multivariate ARMAV and RARMAV models*. International Conference of Engineering Systems, March 27 - 29, 1996, Swansea, Wales. Fracture & Dynamics No.70, Aalborg University.

B1.6 P.H. Kirkegaard, P. Andersen & R. Brincker: *Identification of an Equivalent Linear Model for a Non-Linear Time-Variant RC-Structure*. International Workshop on Structural Damage Assessment using Advanced Signal Processing Procedures, May 1995, Pescara, Italy. Fracture & Dynamics No. 68, Aalborg University.

B1.7 Sørensen, N.B. & P.H. Kirkegaard: *Dynamic Parameters as Damage Indicators for Fibre Reinforced Matrices*. Nordic Concrecte Research, Publication NO. 17, Vol. 2, 1995.

B1.8 Sørensen, N.B. & P.H. Kirkegaard: *A Comparative Evaluation of Three Damage Indicators in Flexural Fatigue of CRC matrics*. Submitted to Experimental Mechanics, SEM , 1995.

B1.9 Rytter, A., P. Negro & P.H. Kirkegaard: *On-Line Estimation of Stiffness Matrices* *during a Pseudo-Dynamic Test*, Joint Research Center, Ispra, Italy, 1995.

3.5 Project B2. Modal Analysis Based on Random Decrement Signatures

Content and status

The project is carried out as a Ph.D.-project. The project will be finished according to the original project. The aim of this project is to investigate the applicability of the random decrement technique for estimation of modal parameters.

During 1995 the Ph.D.-student John Christian Asmussen has spent 4 months at the University of Thessaloniki, Greece. The aim was identification of a 5 storey model structure used in a project on eartquake financed by the EEC. The work is reported in [B2.4].

The applicability of the random decrement technique for identification of structures from ambient response has been investigated with good results, see [B2.2]. Furthermore, the problem of identification of structures to general forces has been investigated theoretically and on simulated data, see [B2.3].

The problem of estimating frequency response functions by random decrement has been investigated, see [B2.1]. The work is based on simulated data. The results from the random decrement technique has been compared with the traditional method based on Fourier transformations. The investigations show that the random decrement technique has some advantages. Therefore, this work will be continued in 1996 with respect to the speed and quality of different approaches.

Plans for 1996

In the first part of 1996 a laboratory bridge model will be built. The purpose of the work with the bridge model is: to get experience and to produce software to measure the response of a bridge. Later in this project the plan is to measure and analyse the response of a real bridge. Furthermore, the influence of the vehicle load will be investigated. The bridge model is under construction, and an initial modal analysis of the response of the bridge by both Random Decrement and Fourier transforms will be performed. This work is planned to be presented at the ISMA 21 conference, Leuven Belgium, in September 1996.

Another work in the first part of 1996 is estimation of covariance functions of multi degree-of-freedom systems. The purpose of this work will be a comparison of speed and quality of two different approaches: random decrement and Fourier transformations.

During the summer of 1996 Professor Ibrahim, Old Dominion University Virginia USA, will wisit Aalborg University. The plans for this are investigation of a vector formulation of the trig conditions. This new approach will be tested on both simulated and real data of an offshore platform. This work is planned to be presented at the 15th IMAC Conference in February 1997.

Participants

John Christian Asmussen, Ph.D.-student, Department of Building Technology and Structural Engineering, Aalborg University. Ph.D.-study financed by the research programme.

Rune Brincker, Associate Professor, Department of Building Technology and Structural Engineering, Aalborg University.

Poul Hennning Kirkegaard, Associate Professor, Department of Building Technology and Structural Engineering, Aalborg University.

Publications

B2.1 J.C. Asmussen & R. Brincker: *Estimation of Frequency Response Functions by Random Decrement.* Proceedings of the 14th International Modal Analysis Conference, February 1996, Dearborn, Michigan, USA.

B2.2 J.C. Asmussen, S.R. Ibrahim & R. Brincker: *Random Decrement and Regression Analysis of Traffic Responses of Bridges.* Proceedings of the 14th International Modal Analysis Conference, February 1996, Dearborn, Michigan, USA.

B2.3 S.R. Ibrahim, J.C. Asmussen & R. Brincker. *Modal Parameter Identification from Responses of General Unknown Inputs.* Proceedings of the 14th International Modal Analysis Conference, February 1996, Dearborn, Michigan, USA.

B2.4 J.C. Asmussen, P. Andersen, R. Brincker & G.C. Manos: *Identification of the EUROSEIS Test Structure.* Fracture & Dynamics No. 76, Aalborg University.

3.6 Project B3. Fatigue and Crack Propagation

Content and status

The project is separated into two fields. The first field concerns dynamic fatigue investigations of metals and the second field is concerning crack propagation in concrete.

The main purpose is to verify a newly developed crack propagation formula.

A test series on metals with the purpose to investigate the dependence of the critical stress intensity factor K_{IC} on the fatigue intensity K_I and a series of fatigue tests are analysed using the crack propagation formula. It is shown that crack propagation under fatigue loading depends on the fatigue intensity factor K_{IC}. The results have been presented in a report published in 1994, see [B3.1].

A test series on high strength steel with the purpose to investigate the dependency of the critical stress intensity factor K_{IC} on the fatigue intensity K_I and a series of fatigue tests are hereby further verifying that the results from the project carried out in 1994 [B3.1] were carried out during 1995. A report will be published [B3.4].

An investigation of concrete under triaxial compression was carried out in 1994. A report on the triaxial test results has been performed [B3.2].

An investigation of crack propagation in welded metal structures has been performed.The crack propagation formula has been used to predict the crack growth in welded joint test specimens and welded center cracked test specimens. A report is under preparation and will be published in 1996 [B3.5.].

An investigation on notched concrete beams has been carried out using the crack propagation formula. The results will be presented in a report which will be published in 1996 [B3.3].

Both the results from the concrete investigations and the results from the metal investigation are very promising. It seems likely that the crack propagation formula in a very simple way is able to predict fracture in general for various materials under varying loading conditions.

Plans for 1996

The project was finished in December 1995. Some remaining work on the reports in the project will be carried out and the reports will be published during 1996.

Participants

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Publications

B3.1 T.C. Hansen: *Fatigue and Crack Propagation*, R316. Department of Structural Engineering, DTU, 1994.

B3.2 T.C. Hansen: *Triaxial Tests on Concrete*, R319, Department of Structural Engineering, DTU, 1995.

Pending:

B3.3 T.C. Hansen and D.H. Olsen: *Fracture of Concrete*, Department of Structural Engineering, DTU, 1996.

B3.4 T.C. Hansen: *Fatigue in High Strength Steel*, Department of Structural Engineering, DTU, 1996.

B3.5 T.C. Hansen: *Fatigue in Welded Connections*, Department of Structural Engineering, DTU, 1996.

3.7 C1. Behaviour of Soil Subjected to Dynamic Loads

Content and status

The project deals with determination of the elastic properties of different kinds of soils, such as Young's modulus, shear modulus , Poisson's ratio, and damping of both frictional soils and cohesive soils. These parameters are required in analyses of foundations exposed to dynamic loadings, resulting from high speed trains, earthquakes and engine foundations where small strain deformations occur. These parameters will be determined experimentally in the laboratory by tests at very small strain levels partly by torsion and longitudinal resonant column tests and partly by tests with piezoceramic bender elements. The objective is to obtain a large data base for the elastic parameters for frictional and cohesive soils. Beyond the actual research program the project also entails a close cooperation with the LITASEIS project which is an international and interdisciplinary project dealing with field- and laboratory measurements of the dynamic properties of soil. The LITASEIS project is sponsored by EU.
At present new laboratory equipment has been developed to be used in conventional test set-ups at the Soil Mechanics Laboratory at Aalborg University by means of bender elements for testing at isotropic as well as anisotropic stress states. This equipment has been used for test series with Yoldia clay as well as two types of sand to determine the maximum shear modulus, G_{max}. New methods for interpretations of the measurements from the tests have been studied intensively. Furthermore, during 1995 a comprehensive test program for Yoldia clay has been carried out in which Young's modulus, G_{max}, and the damping ratio have been determined by longitudinal resonant column tests fitted with bender elements.
In connection with the project a research period of 4 months has been completed at the Norwegian Geotechnical Institute in the beginning of 1995. During this period tests with bender elements and torsional resonant column tests were performed on two types of clay, two types of sand and one silt. The results from the research period are presented in [C1.2].

Plans for 1996

During the autumn of 1995 a new resonant column apparatus was installed at the Soil Mechanics Laboratory, Aalborg University for the purpose of performing torsional and longitudinal resonant column tests. Thus, it is possible to work with different strain levels when determining the shear modulus. The apparatus is being commissioned in the beginning of 1996 and the built-up of the large data base will continue during 1996. A model to describe the elastic properties of soils depending on stress levels, strain levels, soil characteristics such as void ratio, water content, plasticity index, overconsolidation ratio etc. will be worked out.

Participants

Lars Bødker, Ph.D. student, Department of Civil Engineering, Aalborg University.

Lars Bo Ibsen, Assistant Professor, Department of Civil Engineering, Aalborg University.

Publications

C1.1 L. Bødker : *G_{max} determined by bender element at anisotropic stress states*. Submitted to Nordisk Geoteknikermøde, NGM-96, Reykjavik, June 26-28, 1996.

C1.2 L. Bødker : *Resonant column calibration and testing at NGI.* Report No. 515139-1, Norwegian Geotechnical Institute, Oslo.

3.8 Project C2. Dynamic Response of Coarse Granular Materials To Wave Load.

Content and status

The project has been carried out as a combined theoretical - experimental project closely coordinated with the Marine Science and Technology II project: Monolithic Coastal Structures (EU - project). The main effort in 1995 was concentrated on preparing a general document describing design guidelines for the modelling of the structure - foundation interaction of monolithic caisson structures. [C2.13]. This document is the product of cooperation between several European Institutes. The foundation aspects of caisson breakwaters are described. Special attention is paid to dynamic response of the foundation to wave impacts, generation of pore pressures in the subsoil, degradation by repetitive loading and the interaction between all this aspects. The results of the theoretical work [C2.11] & [C2.12] are published in this general document.
The aim of the experimental part of the project has been to investigate the general mechanism guiding and controlling the response of the frictional soils subjected to static and dynamic loads [C2.3], [C2.8]. Drained as well as undrained static and dynamic triaxial tests have been performed on 5 different sand- and gravel materials. The tests have been performed with at least 3 relative densities for each material. The test material constitutes a unique data base which has formed the basis for Design Guidelines for Vertical Caisson Breakwaters. The results of the experimental work are published as data base in [C2.4],[C2.6], [C2.10].

The generalization of the Cam-Clay model started in 1994 has proceeded, and has now been formulated in a general invariant format. In addition the nonlinear elastic part of the model has ben extended to a more general form, also including nonlinear shear stiffness. A paper has been accepted for the IUTAM Symposium on Porous and Granular Materials, to be held in Cambridge in July 1996.

Plans for 1996

The plans for 1996 can be described in three parts

Part 1

The development of plasticity based models for granular materials commenced during the initial part of the program period will continue. A plasticity model will be developed and it will contain a numeric algorithm to describe triaxial stress-strain states in laboratory tests and engineering practice. The model requires only 3 rigidity parameters, namely the specific pore volume, the gradient of the "critical line", and a parameter to determine the dilatation in the state of failure. In spite of the few parameters, the model represents the qualitative behaviour of the material rather well including a stress-strain curve with top for over consolidated materials, a gradual transition from pressure to dilatation in a triaxial test as well as development of large stresses along the critical line before failure in an undrained triaxial test. The time dependent behaviour resulting from pore water movements will also be investigated. The data base concerning the behaviour of the material commenced during the initial part of the program period will be used to calibrate the model for different materials and to identify future necessary investigations.

Numerical algorithms will be developed for implementing the model into finite element programs. The key issue is the combination of nonlinear elasticity and the rather complicated mathematical form of the yield surface that makes an iterative plastic corrector procedure necessary in order to remain on the yield surface during plastic loading. Properties of the more general nonassociated form of the theory will also be considered.

Part 2

In order to develop the model described in part 1 the existing data base must be supplemented with tests investigating the position of the characteristic state during a stress path which deviates fundamentally from the stress paths normally described in triaxial tests.

Part 3

So far this part of the project has been carried out as a combined theoretical-experimental project closely coordinated with the MAST II project: Monolithic Coastal Structures. The research will continue under MAST III with a limited grant. An investigation of the deformation- and strength properties of soil, including gravel, influenced by dynamic loads and pore pressure caused by waves are part of the research.
During 1996 and 1997 the majority of the research will still be within this area in order to provide a reliable determination of soil parameters to be used in dynamic calculations. Also, wave loads are going to be further investigated, including:

Probability distribution of wave load frequencies (particularly high-frequency wave loads).
The load distribution along a vertical caisson wall.
Damping from the involved hydrodynamic and geodynamic mass.
The deformation states in the caisson itself.

The investigation will include theoretical calculations as well as hydraulic and geotechnical model tests.

Participants

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Publications

C2.1 L.B. Ibsen: *The Stable State in Cyclic Loading.* Soil Dynamics & Earthquake Engineering. 6th International Conference. Bath, UK. June 1993, pp 241-258.

C2.2 H.F Burcharth & L.B. Ibsen: *Response of Rubble Foundation to Dynamic Loading.* Proceedings of International workshop on Wave Barriers in Deepwaters, Port and Harbour Research Institute Yokosuka, Japan Jan 10 - 14 1994, pp 402 - 417.

C2.3 L.B. Ibsen: *The Stable State in Cyclic Triaxial Testing on Sand. Elsevier,* Soil Dynamics and Earthquake Engineering 13, 1994, pp 63-72.

C2.4 L.B. Ibsen, L. Bødker: *Baskarp Sand No 15.* Data Report 9301, Soil Mechanics Laboratory,Aalborg University ,August 1994, Denmark.

C2.5 M. Borup & J. Hedegaard: *Characteristic State Modelling of Friction Materials.* M.Sc Thesis, Aalborg University , January 1995, Denmark.

C2.6 M.Borup & J.Hedegaard. *Baskarp Sand No 15.* Data Report 9403, Soil Mechanics Laboratory, Aalborg University , January 1995, Denmark.

C2.7 A.Hansen & K.P.Jacobsen. *Fundamenters Stødbæreevne ved Plasticitetsteoriens øvreværdisætning.* M.Sc Thesis, Aalborg University, January 1995, Denmark.

C2.8 L.B. Ibsen: *The Static and Dynamic Strength of Sand.* XI ECSMFE ' 95 - European Conferance on Soil Mechanics and Foundation Engineering. Copenhagen, 28 May - 1 June, 1995, Volume 6 pp. 69 - 76.

C2.9 S. Krenk, M. Borup & J. Hedegaard: *Characteristic state model for sand.* XI ECSMFE '95 European Conference on Soil Mechanics and Foundation Engineering. Copenhagen, 28 May - 1 June, 1995. Volume 6 pp. 89 - 94.

C2.10 L.B. Ibsen & L. Bødker: *Blokhus sand.* Data Report 9501 part 1 & 2 ,Soil Mechanics Laboratory, Aalborg University,June 1995, Denmark .

C2.11 L.B. Ibsen & F.R Jacobsen:, *Soil Parameters.* Final proceedings MCS - Project MAST II, July 1995.

C2.12 C.S. Sørensen, L.B. Ibsen, A. Hansen and K.P. Jakobsen: *Bearing Capacity of Caisson*

Breakwaters on Rubble Mounds. Final proceedings MCS - Project MAST II, July 1995.

C2.13 General Document: *Foundation design of caisson Breakwaters.* Monolithic (vertical) Coastal structures, Final proceedings MCS - Project MAST II, July 1995.

C2.14 S. Krenk, M. Borup and J. Hedegaard: *A triaxial characteristic state model for sand.* Proceedings of the Eleventh European Conference on Soil Mechanics and Foundation Engineering, Copenhagen, May 28 - June 1, 1995, pp. 89-94.

3.9 Project C3. Dynamics of Sports Stadiums

Content and status

A small 800 mm x 800 mm measuring platform of concrete and equipped with 3 force transducers has been produced. This platform is used to measure the vertical load from one person performing different movements such as jumping. The person has been equipped with an accelerometer at the waist to monitor his movements. However, it was difficult to get suitable results from the accelerometer because the electrical integration of the acceleration to displacement did not work very well. It was then decided to drop the accelerometer as transducer and instead use a new type displacement transducer. Some introductory measurements with this new type transducer have been carried out and the measurements are being analysed. Also the theoretical part of the project has been continued a bit. One of the participants in the project has changed job from Aalborg University to a consulting firm in Copenhagen and for the half of 1995 no work has been carried out in the project.

Plans for 1996

The teoretical part of the project will be continued and include the following. A simple impulse based load model for human motion will be developed. Finite element analysis will be used to make comparison with the experimentally determined eigenfrequencies. It is the aim to formulate a simple impulse based recommendation for loads on grandstands and similar structures as an alternative to the current use of static loads.

The experimental part of the project will be continued. The aim is first to determine the relations between the vertical human motion and the load impulse and then to determine the influence of eigenfrequencies and displacement amplitude of the underlying structure. Finally, to determine the influence of the number og people in relation to the eigenfrequency. The first aim will be fulfilled in the first part of 1996 with measurements in the laboratory using the small concrete load platform. After this the concrete platform will be mounted at different positions on a steel I-beam with movable supports, thus, allowing investigation of the influence of eigenfrequency and the displacement amplitude. The last measurements in the laboratory will include different numbers of people jumping on the I-beam. If possible, measurements will be performed in a real situation at a grandstand.

Publications

C3.1 Jeppe Jönsson and Lars Pilegaard Hansen: *Man induced actions on a small concrete platform.* To appear in 1996

Participants

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3.10 Project C4. Dynamic Measurements on the Frejlev Mast

Content and status

The aim of this project is to make full-scale measurements on the Frejlev-mast which is a 200 meter high guyed steel mast located 10 km. from Aalborg. One of the goals will be to investigate the uncertainties of the modal parameters and mode shapes obtained by a practical application of time series models such as multi channel ARMA-models implementated in project B.1. Especially, problems concerning model reduction and separating closely-spaced modes will be investigated. Another goal is to estimate the cable forces from vibration measurements.

In June 1995 five cables of the Frejlev masts were instrumented in order to measure strains in the cables. However, it was found that the strain signals had a too low signal to noise ratio to be used for a further analysis. Since the strain signals could not be used the five cable became instrumentated with accelerometers. The accelerations in three directions were measured with 3 different types of excitation :

1. wind excitation
2. free-decays and
3 harmonic excitation by shaking the cables by the hand.

In order to establish the relationship between frequencies and cable forces different models of the dynamic response of a cable have been investigated.
The results of the measurements and the estimation of the cable forces will be presented in a report (Kirkegaard et al. [C4.1] and a paper (Kirkegaard et al. [C4.2]), respectively.

Plans for 1996

In 1996 it is planned to measure the response of one of the cables again, after accelerometers have been installed at the location where the cable is attached to the mast. These measurements will be used to investigate the influence of the motion of the cable support on the dynamic response of the cable.
In 1996 it is also planned to install accelerometers at the mast together with a cup-anemometer and wind vane in order to measure the response of the mast. These measurements will be analysed using techniques from the B.1. project.

Publications

C4.1 Kirkegaard, P.H & L.P. Hansen: *Vibration Measurements on the Frejlev Mast.* To appear in 1996.

C4.2 Kirkegaard, P.H & L.P. Hansen: *Estimation of Cable Forces of a Guyed Mast from Dynamic Measurements.* To appear in1996.

Participants

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4. Final Remarks

The main conclusion is that the research programme meets all of its objectives. In all the Ph.D. projects the activity is very high and the results obtained in the projects have been published internationally in a large number of papers or presented at international conferences. The activity in the projects A2, C3 and C4 is not so high and only very small amounts of money are spent on these projects, see table 1 on page 3. It is the hope that there will be more activity in these projects in 1996 and 1997.

The Ph.D. students in the projects A1 and B3 have stopped at the end of 1995 and the activities in these projects will not be continued. On the other hand many new activities have been suggested in many of the other projects as described in chapter 3.

The relations to Danish and foreign institutes and consulting engineering companies have been continued and some new established.

It is our hope that the programme will provide more knowledge and data to design dynamically sensitive structures in a more reliable and economic way.

Aalborg, March 29, 1996.

Lars Pilegaard Hansen