# The Calibration and Use
# of a
# Triaxial Cell

**Kaare K. B. Dahl**

**Juli 1992**

**The Calibration and Use of a Triaxial Cell**

Tryk:
Afdelingen for Bærende Konstruktioner
Danmarks Tekniske Højskole
Lyngby
ISBN 87-7740-105-0

# Preface

This report has been prepared as one part of the thesis required to obtain the Ph.D. degree.

The thesis consists of the following three reports:

- **The Calibration and Use of a Triaxial Cell**
- **A Failure Criterion for Normal and High Strength Concrete**
- **A Constitutive Model for Normal and High Strength Concrete**

The thesis has been carried out at the Department of Structural Engineering, Technical University of Denmark, under the supervision of Professor, Dr.techn. M. P. Nielsen.

I wish to express my sincere thanks to my supervisor and the entire staff at the Department for their help during the time I have been here.

Finally I gratefully acknowledge the financial support granted by the structural research program 'High Performance Concretes in the 90'ies', which in turn is financed by the Danish Industri- og Handelsstyrelsen.

Frederiksberg 1992

Kaare K. B. Dahl

# Summary

## The Calibration and Use of a Triaxial Cell

This report describes in detail the equipment and techniques used for testing concrete in a triaxial cell. In a triaxial cell it is possible to induce a well defined triaxial stress field in a cylindrical test specimen. Not all possible combinations of stress fields can be generated in a triaxial cell, only stress fields where two of the three principal stresses are equal.

The subjects described in this report are the observations and conclusions, concerning the test equipment, of a major research program aimed at testing concrete under triaxial stresses. The major problems encountered were primarily how to generate a well defined triaxial stress field in a concrete cylinder, with the minor principal stresses in the range 0 to 140 MPa, and secondly how to measure the concrete strains at the same range of stresses.

The report pays particular attention to the following subjects:

1/ Describing the equipment needed for testing.
2/ Calibration of the test equipment.
3/ Preparing test specimens.
4/ Describing the adopted testing procedure.

## A Failure Criterion for Normal and High Strength Concrete

This report deals with the strength of concrete subjected to stresses in more than one direction. The report describes a large test program aimed at determining a failure criterion for concrete, including high strength concrete. The concretes investigated were ordinary concretes with a varying uniaxial strength between 10 and 110 MPa.

A total of 240 test specimens were tested with the minor principal stress ranging between 0 and 140 MPa. All tests were conducted with all principal stresses compressive and the two minor principal stresses being equal. The tests were performed using a triaxial cell. The construction and use of this cell is described in detail in ***The Calibration and Use of a Triaxial Cell.***

The test results showed a large difference between the ultimate strength of low and normal strength concretes, especially for high relative stress loadings. The difference in ultimate strength of normal and high strength concrete was not large but still noticeable. The test results showed also a drastic change in the failure envelope when testing mortars and pastes, as compared to ordinary concrete.

The test results are compared to the Ottosen model, and the Mohr-Coulomb model. Both models are changed in order for them to reflect the new knowledge found in this investigation.

## A Constitutive Model for Normal and High Strength Concrete

This report deals with the deformations of concrete subjected to stresses in more than one direction. The report describes a large test program aimed at determining a constitutive model for concrete, including high strength concrete. The concretes investigated were ordinary concretes with a varying concrete strength between 10 and 110 MPa.

The experimental investigation is an integral part of an investigation into the strength of concrete under multiaxial stresses as reported in ***A Failure Criterion for Normal and High Strength Concrete.*** In this investigation a total of 240 test specimens were tested with the minor principal stress ranging between 0 and 140 MPa. Of these 240 test specimens 91 were tested with strain gauges mounted. All the tests were conducted with the principal stresses compressive and the two minor principal stresses being equal. The tests were performed using a triaxial cell. The construction and use of this cell is described in detail in ***The Calibration and Use of a Triaxial Cell.***

The test results showed a surprisingly plastic behavior of the concretes under triaxial stresses. In the case of low strength concretes, deformations of more than 20% were experienced, and in the case of very high strength concretes, deformations of more than 8% were experienced.

Based on these test results an improvement of the Ottosen constitutive model is presented. The model is based on the non-linear elastic theory and is very simple and easy to use. The model has also been compared to experimental results from other investigations. Although widely different concrete strengths, test rigs, and load paths have been used in these investigations, it has been found that the model predicts the deformational behavior of concrete well within acceptable limits.

# Resumé

## The Calibration and Use of a Triaxial Cell

Denne rapport indeholder en detaljeret beskrivelse af det udstyr, og de teknikker der behøves for at kunne prøve beton i en triaxial celle. I en triaxial celle er det muligt at udsætte en beton cylinder for en forud fastlagt tre-akset spændingstilstand. Det er dog ikke muligt i en sådan celle, at frembringe en hvilken som helst tre-akset spændingstilstand, idet cellens opbygning gør, at to af de tre hovedspændinger altid vil være lige store.

I denne rapport er beskrevet de observationer og de konklusioner vedrørende forsøgsopstillingen, der er fremkommet under et større forskningsprogram rettet mod betons styrke og tøjningsforhold under tre-aksede spændingstilstande. De største problemer der opstod var, dels at kunne sikre en forud fastlagt spændingstilstand, hvor de mindste hovedspændinger var i området 0 til 140 MPa, og dels at kunne måle de tilsvarende tøjninger i betonen.

Rapporten beskriver indgående følgende emner:

1/ Beskrivelse af forsøgsopstillingen.
2/ Kalibrering af udstyret i forsøgsopstillingen.
3/ Den nødvendige forberedelse af prøvelegemer.
4/ Proceduren for den egentlige prøvning.

## A Failure Criterion for Normal and High Strength Concrete

Denne rapport omhandler betons styrke, når denne er udsat for spændinger i mere end én retning. Rapporten beskriver et stort forsøgsprogram rettet mod at bestemme et brudkriterium for beton, inklusiv højstyrkebeton. De anvendte beton var normale betoner, med en én-akset styrke på mellem 10 og 110 MPa.

I alt blev 240 prøvelegemer afprøvet med den mindste hovedspænding varierende mellem 0 og 140 MPa. Alle forsøgene blev udført med trykspændinger overalt, og med de to mindste hovedspændinger lige store. Forsøgene blev udført i en triaxial celle. Opbygningen og brugen af denne celle er udførligt beskrevet i ***The Calibration and Use of a Triaxial Cell.***

Forsøgsresultaterne viste en afgørende forskel i den tre-aksede styrke for lavstyrke beton contra normalstyrke beton, specielt når de mindste hovedspænding steg i styrke. Forskellen mellem normal og højstyrke betoner viste sig ikke at være særligt stor, men dog ikke uden betydning. Sammenlignende forsøg med beton, mørtel og cement pasta viste, at der sker en drastisk forandring i brudfladens udseende når indholdet af det grove tilslag mindskes.

Forsøgsresultaterne er slutteligt sammenlignet med Ottosens brudkriterium, samt Mohr-Coulomb brudkriteriet. Begge brudkriterier er foreslået ændret, således at de nu reflekterer den nye viden fremkommet i dette projekt.

## A Constitutive Model for Normal and High Strength Concrete

Denne rapport omhandler betons deformationer, når denne er udsat for spændinger i mere end én retning. Rapporten beskriver et stort forsøgsprogram rettet mod at bestemme en konstitutiv model for beton, inklusiv højstyrkebeton. De anvendte beton var normale betoner, med en én-akset styrke på mellem 10 og 110 MPa.

De, i denne rapport beskrevne forsøg, er en integreret del af en undersøgelse af betons styrke under fleraksede påvirkninger, som rapporteret i ***A Failure Criterion for Normal and High Strength Concrete.*** I denne undersøgelse blev i alt 240 prøvelegemer afprøvet med den mindste hovedspænding varierende mellem 0 og 140 MPa. Af disse 240 prøvelegemer var 91 bestykket med strain gauges for at måle deformationerne. Alle forsøgene blev udført med trykspændinger overalt, og med de to mindste hovedspændinger lige store. Forsøgene blev udført i en triaxial celle. Opbygningen og brugen af denne celle er udførligt beskrevet i ***The Calibration and Use of a Triaxial Cell.***

Forsøgsresultaterne viste en overraskende plasticitet hos beton udsat for treaksede belastninger. Således blev der for lavstyrke beton målt deformationer over 20%, og for højstyrke beton målt deformationer over 8%.

På baggrund af resultaterne fra forsøgene er der foreslået en forbedring af Ottosens konstitutive model. Modellen er baseret på den ikke-lineære elasticitetsteori og er simpel i sin opbygning, samt nem at anvende. Modellen er også blevet sammenlignet med andre publicerede forsøgsresultater. Selvom der i disse undersøgelser er blevet benyttet meget forskellige betoner, forsøgsopstillinger samt belastningmåder, er det konstateret, at modellen forudsiger betons deformationer med meget begrænsede afvigelser.

# List of contents

# Notation

In this report standardized SI units and European symbols have been used. Any deviations from this are described in the text when they occur. Furthermore will the convention that tension is assumed positive be used throughout the report. As a consequence, $0 > \sigma_1 > \sigma_2 > \sigma_3$ corresponds to a stress state where all stresses are compressive.

| | |
|---|---|
| D | Deformation, in mm |
| E | Young's modulus |
| F | Force |
| $K_{deformation}$ | Calibration constant, deformation transducer |
| $K_g$ | Gauge factor |
| $K_{pressure}$ | Calibration constant, pressure transducer |
| $K_{1000ton}$ | Calibration constant, 10 MN hydraulic jack |
| $K_{1000ton,TRIAX}$ | Calibration constant used in the TRIAX-program |
| $V_{ref}$ | Gauge signal, zero adjusted |
| $f_c$ | Uniaxial concrete strength |
| | |
| $\epsilon$ | Strain |
| $\epsilon_1,\epsilon_2,\epsilon_3$ | Principal strains (extension positive) |
| $\epsilon_{lef}$ | Strain from the left gauge |
| $\epsilon_{rig}$ | Strain from the right gauge |
| $\epsilon_{ver}$ | Strain from the vertical gauge |
| $\sigma_0$ | Hydrostatic stress |
| $\sigma_1,\sigma_2,\sigma_3$ | Principal stresses (tension positive) |
| $\varphi$ | Angle between an axis and the direction of one of the principal strains |
| $\varphi_1$ | Angle between an axis and the direction of the major principal strain |
| $\varphi_2$ | Angle between an axis and the direction of the minor principal strain |

# Chapter 1

# Introduction

In recent years an ever increasing effort has been directed towards research in high strength concrete. In this report high strength concrete is defined as concrete having an uniaxial strength of more than 50 MPa. An increasing number of countries have been extending their codes to allow the use of this, in many ways, new material. Most recently the Finish code have been extended to include concrete up to 100 MPa. In other countries, i.e. Norway and USA, high strength concrete has already been used for a number of years. The most spectacular examples of use of high strength concrete structures are probably the Norwegian offshore oil rigs, where concrete with strengths up to 80 MPa have been utilized.

In order to understand high strength concrete more thoroughly, a huge research program was launched in Denmark in 1989, with financial support from the Danish 'Industri- og Handelsstyrelsen'. Among the projects in this program was an investigation of the constitutive laws governing high strength concrete.

The constitutive laws for concrete have posed a challenging problem for many researchers the last 200 years. It started in 1773 when Coulomb formulated his very famous failure criterion. Although extremely simple, it is still much used due to its simplicity, and its relatively good accuracy when applied to concrete. Since then, and especially in the last 50 years, a number of more accurate, and more complicated, constitutive laws have been proposed. It is common for all the previous investigations that they have only treated normal or low strength concrete, that is concrete with strengths up to 50 MPa, with most of the experiments performed on concrete with strengths between 10 and 25 MPa.

The scope of this project has therefore been, to extend the knowledge of the triaxial behavior of concrete to include high strength concrete.

Testing concrete triaxially poses some interesting experimental problems. The first problem normally encountered, is the question of how to apply the load to the test specimen, in such a way, that the test equipment will not influence the test results. Many different test procedures have been used, and of principal interest are the cube test rig, and the cylinder test rig. Both test arrangements have been discussed in detail in [90.1]. The secondary problem normally encountered, lies in measuring the strains in the concrete. This problem is caused by two elements. The first part of the problem is how to measure strains in the concrete, when you have no part of the concrete exposed to place your measuring equipment on. The second part, is to be able to measure the very high strains encountered, strains of more than 20% have been reported by other investigators, and confirmed by this investigation.

After considerable research the test rig was decided. The choice was a test rig where the test specimen is a massive concrete cylinder. The hydrostatic load, that is, equal stress in all directions, is applied by an oil pressure, and the deviator stress is applied by an external jack in the axial direction of the test cylinder.

This report concerns the description of the equipment used. Also included are the calibration results, and the observations and conclusions leading to the adopted testing procedure.

# Chapter 2

# Description of the test equipment

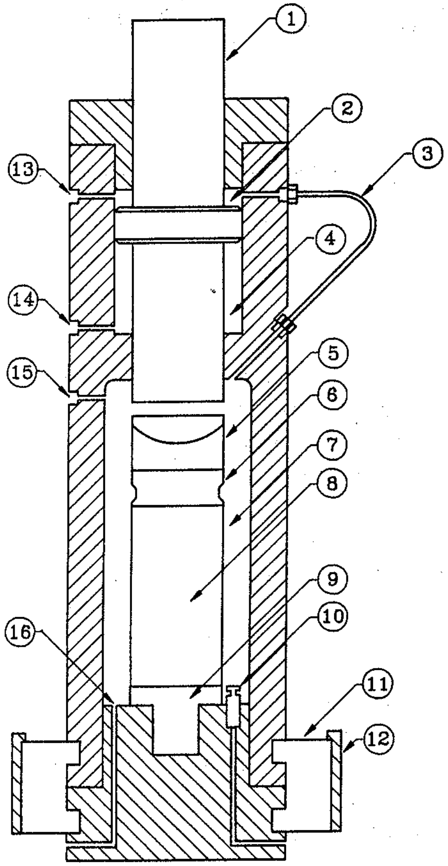
In this chapter the triaxial cell, and the external equipment necessary to run the test, will be described.

## 2.1 The triaxial cell

The triaxial cell is of the oil pressure type, that is, two of the three stresses are equal, and are supplied by an oil pressure acting directly upon the face of the test specimen. The third stress is supplied by an external jack, and is acting on the specimen by means of a piston. The specimen itself is a cylinder Ø100·200, and the oil pressure is acting on the curved part of the cylinder.

This type of triaxial test rig has its advantages and disadvantages. Many of these are described in detail in [90.1], however a few will be mentioned here. The main advantage of this kind of cell, is the absolute friction free loading of the two major principal stresses. Since these stresses are applied by an oil pressure acting directly onto the specimen, there can be no friction in the loading arrangement. This is a definite advantage when compared to other types of triaxial test equipment, i.e. test rigs for cubes, where the stresses are generated by jacks acting on the cube faces by means of some sort of steel plate. The third principal stress, applied via the piston, will of course induce some friction in the interface between the concrete and the piston, however, the specimen has a height of 200 mm, and, as shown by previous researchers [60.1] and [64.1], the influence of friction at the ends of a cylinder will virtually be nonexisting in the middle third of the cylinder.

The main disadvantage of this kind of test rig is, that two of the three principal stresses will always be equal. It is therefore not possible to explore every combination of principal stresses. However, the general agreement today is that the influence of the intermediate principal stress is rather small, therefore this limitation is not as great as it seems.



1: **Balanced piston**
2: **Upper oilchamber**
3: **Connecting oilpipe**
4: **Lower oilchamber**
5: **Top cap**
6: **Top plate (pore pressure outlet)**
7: **Main oilchamber**
8: **Concrete speciment**
9: **Base plate (pore pressure outlet)**
10: **Electrical outlet**
11: **Clamp**
12: **Clamp ring**
13: **Deairing port A**
14: **Deairing port B**
15: **Deairing port C**
16: **Oilpressure inlet**

**Fig. 2.1:** The triaxial test cell.

The triaxial cell is shown in Fig. 2.1, to which all numbers in the following refer. The cell consists of three major parts: a base unit, a barrel section enclosing the main pressure chamber, and a piston to apply the axial load from the external jack.

The base unit has a number of functions. Primarily it acts as the base plate (9) for the concrete specimen (8), and as the bottom cap of the main oil chamber. Furthermore the base unit has a number of ducts in order to provide the filling of the cell with oil (16), and lead-outs for electrical wiring (10). The base unit has a total of 6 lead-outs, each with 4 wires. It is therefore possible to have a total of 12 strain gauges mounted on the specimen at any one time. In addition the base unit have two ducts for relieving the pore pressure from the specimen.

After the test specimen (8) has been placed on the base plate (9), and has been fitted with a number of rubber sheaths, the top plate (6) is added. Both the top and base plate have facilities for relieving pore pressure. The pore pressure facilities consist of small pipes leading from each of the plates to the base unit. In each plate, the corresponding pipe is connected via internal ducts to a small opening in the center of the plate, where the plate is in contact with the specimen. The specimen is therefore connected to the outside atmosphere via these pipes, and a number of ducts in the base plate. As a result pore pressure cannot occur inside the specimen. On top of the top plate a spherical unit (5) is mounted in order to ensure that the specimen is centrically loaded. It is on this unit that the piston (1) acts.

The barrel section is lowered down over the base plate, and is locked by three clamping sections (11). The clamps are in turn locked by a clamp ring (12). The ring ensures correct placement of the clamps by preventing them from moving sideways. The interface between the barrel section and the base unit is sealed by means of a rubber O-ring, and a mitred brass ring. The brass ring has a triangular cross section, and is seated on an angular shoulder around the top surface of the base unit. Under pressure the brass ring is forced downwards, against the base section, and outwards, against the barrel section, and thereby forming an effective seal. The tests have shown this seal to be completely effective at all pressures.

The cell features a 'balanced' piston. The piston moves through two oil chambers, the main chamber (7) where the test specimen is placed, and the upper chamber (2). Inside the upper chamber the diameter of the piston is increased, so that the resulting area of the collar equals the area of the face of the piston that enters the main chamber. The main and the upper chamber are linked with a high pressure pipe, so that equal pressure exists in the two chambers. This design ensures that no resultant force is acting on the piston when the oil pressure is raised. Access to the upper oil chamber is reached through a cap on top of the cell. The cap is clamped to the barrel section by 12 high-tensile screws. This cap is only removed for maintenance purposes.

Finally the barrel section is fitted with various inlet/outlet ports (13), (14), and (15). The port into the main oil chamber (15) is used to raise the oil pressure during tests. Port (13) is used as a deairing port to ensure that all air has been excluded from the cell during filling. Port (14) is normally vented to the atmosphere, but can be used to supply a back-pressure to reduce the axial load, and thereby creating a stress field where $\sigma_1 > \sigma_2 = \sigma_3$ (tension positive), as opposed to the normal tests where $\sigma_1 = \sigma_2 > \sigma_3$. This, however, requires a slightly modified top plate system, which is described in detail in [74.1] and [90.1].

## 2.2 The confining pressure control system

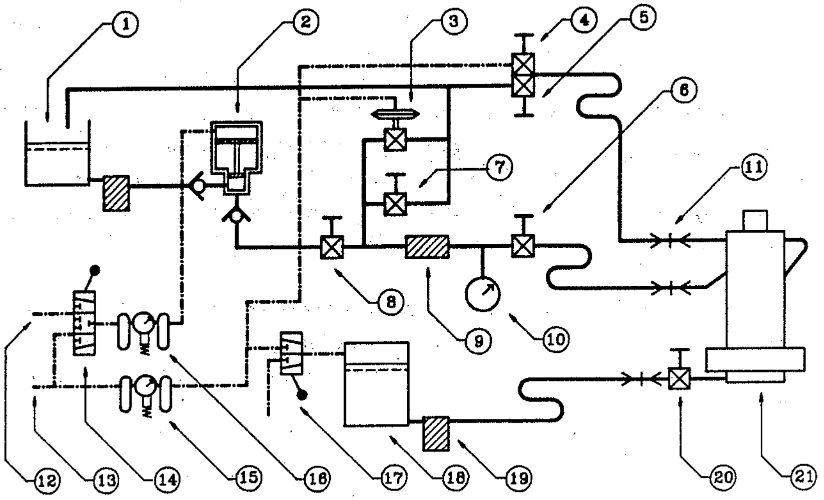
The system to control the confining pressure, along with filling and emptying the cell is shown in Fig. 2.2, to which all numbers in the following refer.

The control system is built around an air-hydro pump (2). This pump is capable of supplying an oil pressure of 140 MPa, and is driven by normal compressed air. The control system is capable of:

1/ Filling the cell with oil prior to testing.
2/ Increasing, maintaining, and decreasing the oil pressure during testing.
3/ Draining the oil from the cell after testing.

The control system has two reservoirs for oil (1) and (18). Reservoir (1) is used to supply the pump with oil, and to receive any surplus oil, i.e. from lowering the oil pressure. Reservoir (18) is used as a reservoir for containing the oil needed to fill the cell. The cell is filled by putting reservoir (18) under pressure by manipulating the selection switch (17). The air inside the cell is bled through valve (5), and any surplus oil is drained to the reservoir (1). The reverse procedure is used in emptying the cell, meaning that the cell is put under pressure by opening valve (4), and depressurizing the reservoir (18) by manipulating switch (17).

The oil pressure inside the cell is raised by means of the air-hydro pump (2). The pump is driven by compressed air. The pump requires an air pressure of 8 bar to deliver a working oil pressure of 140 MPa. This air pressure is delivered by bottled air, however, due to the need for minimizing the operation costs, the pump is driven by the in-house compressed air system (max 6 bar) for oil pressures below 100 MPa. The switch between the two systems is done by manipulating the air selection switch (14), and can be done, without any interruption or drop in oil pressure, at any time during testing. This setup greatly reduces the expenditure of bottled compressed air.



1: Oil reservoir (oil pump)
2: Air driven oil pump
3: Blow-out valve
4: Air-to-drain-cell valve
5: Air-relief valve (filling)
6: Valve to close oil flow
7: Valve to lower oil pressure
8: Valve to increase oil pressure
9: High pressure filter
10: Pressure transducer
11: Quick release coupling
12: Air inlet (max 10 bar)
13: Air inlet (max 6 bar)
14: Air selection switch
15: Air reduction valve (oil pump)
16: Air reduction valve
17: Air-to-fill-cell/air-relief switch
18: Oil reservoir
19: Low pressure oil filter
20: Valve to drain oil from cell
21: Triaxial cell

——— Oil pressure line
-·-·-·- Air pressure line

**Fig. 2.2:** Confining pressure control system.

The actual pressure of the air that reaches the pump, and thus the oil pressure on the high pressure end of the pump, is controlled by the air reduction valve (16). The actual oil that reaches the cell is controlled by the throttle valve (8), and is continuously monitored by the pressure transducer (10). If the oil pressure has become too large, it is then possible to lower the pressure by means of the throttle valve (7).

As a security measure, a blow-out valve (3) has been incorporated. The blow-out valve uses an air pressure of 5 bar to close the blow-out circuit. When the oil pressure exceeds 140 MPa the monitoring system cuts the air flow to the blow-out valve, and the oil pressure in the cell is lowered by bleeding oil from the cell. The threshold (140 MPa) is user specified, but should not exceed 140 MPa, which is the maximum design pressure for the components in both the cell and the oil control system.

Throughout the system low- and high-pressure filters have been incorporated to ensure that no foreign particles enter the delicate parts of the machinery. Finally all pressure lines are connected to the cell by means of quick-release couplings, in order to ease setting up and dismantling of the cell.

Through a skilled operator the control system is capable of increasing the oil pressure at a maximum rate of 0.4 MPa/s, with a deviation from the load path of less than 0.5 MPa at any time. It is also possible to maintain a given oil pressure with a deviation of less than 0.3 MPa, which is considered satisfactory in the tests here performed.

The test rig setup is shown in Fig. 2.3 and 2.4, and the confining pressure control system is shown in Fig. 2.5.

## 2.3 The data logging program TRIAX

The complete setup for data retrieval and test control, consists of an IBM PC-AT, a HP 3497A datalogger, and a balancing box for the strain gauges. A program, TRIAX, has been developed to communicate between the datalogger and the computer, and to facilitate the operator with a number of ways to control the testing.

The program is written in the ASYST language. The facilities for logging include converting the transducer and gauge signals as described in chapter 3, as well as saving these signals in a data file. The control part of the program is developed for the load path normally used in triaxial test, which is: an increasing hydrostatic load, all three principal stresses equal, until a predetermined level, after which the axial stress is increased until failure.

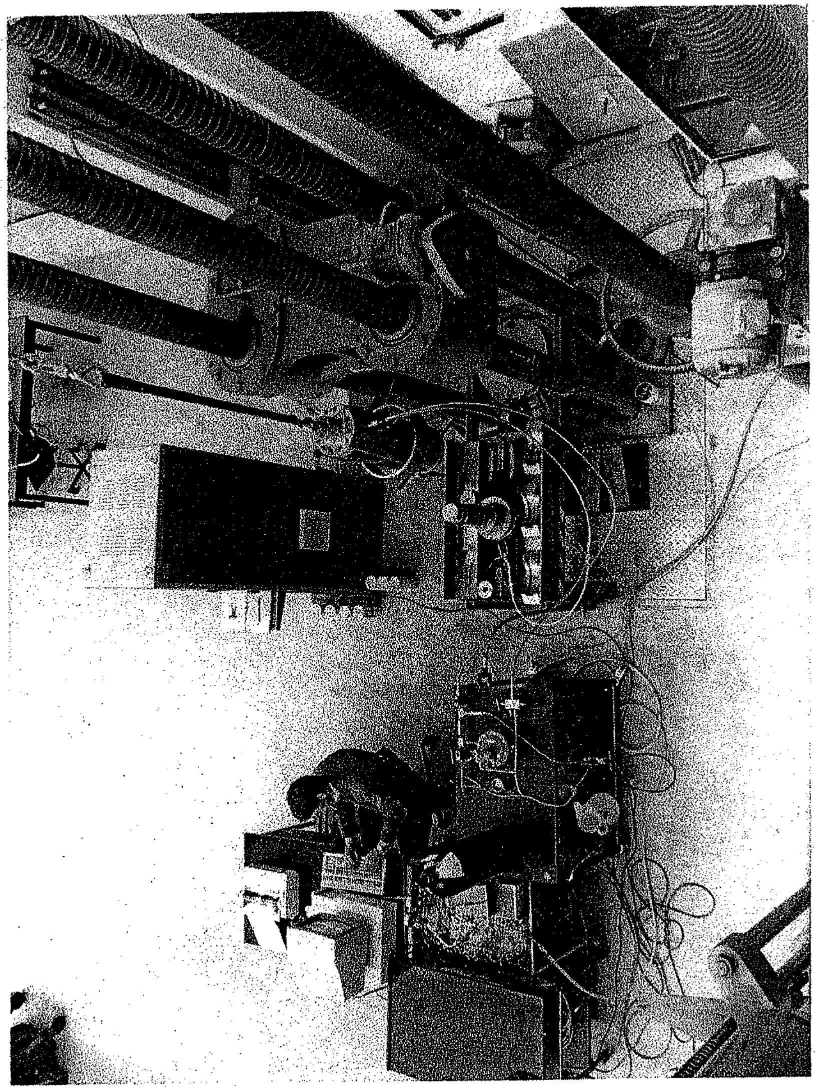


**Fig. 2.3:** The complete test rig seen from above.

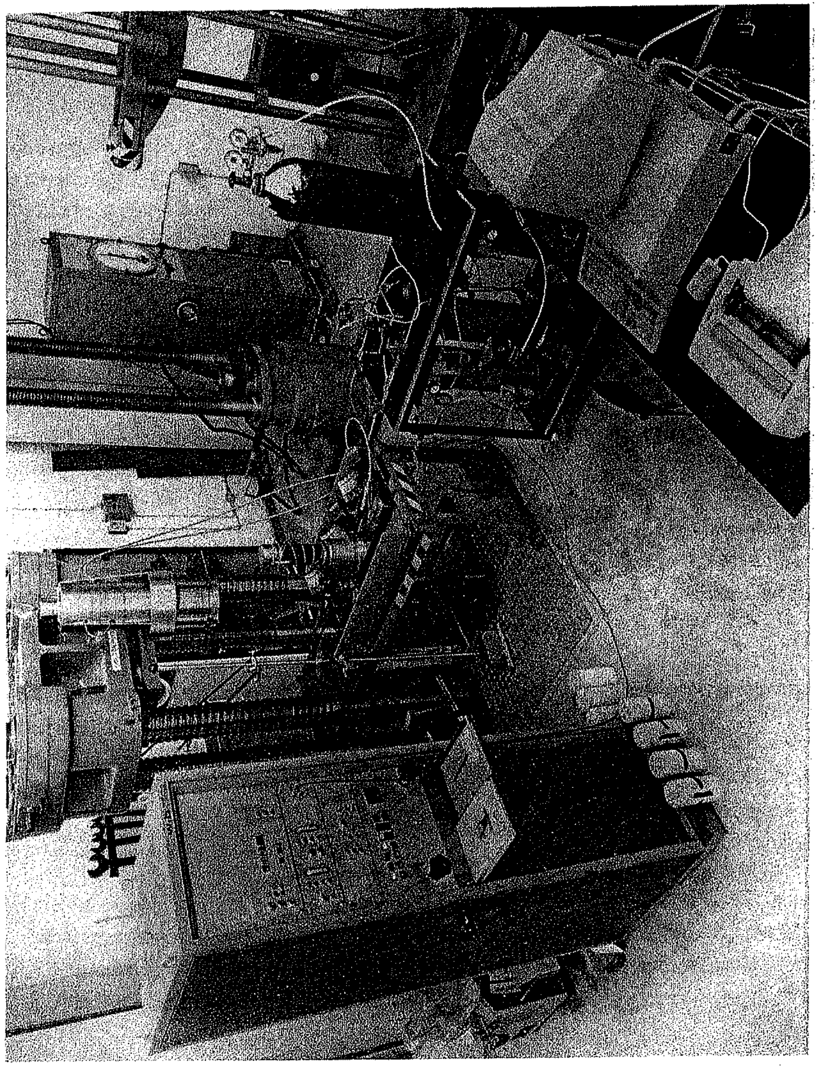


Fig. 2.4: The test rig seen from the side, the barrel unit is raised by the crane to gain access to the test specimen.

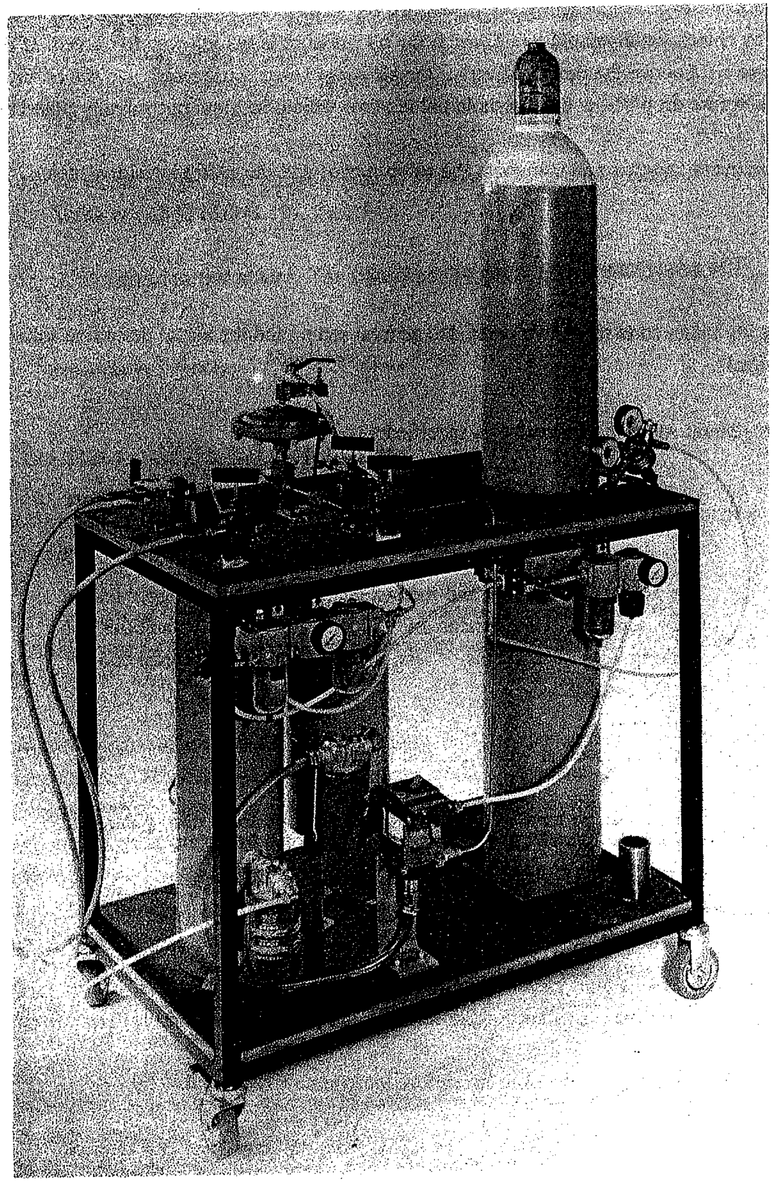


**Fig. 2.5:** The confining pressure control system.

Furthermore does the program, as a security measure, control the blow-out valve. This is done by entering a threshold value which the oil pressure is not allowed to exceed. If the oil pressure rises above the threshold value, the blow-out valve is triggered, and the oil pressure will therefore drop below the threshold value, after which the blow-out valve is closed again.

The program has two major menus: the setup menu, and the data acquisition menu.

### 2.3.1 The setup menu

The setup menu consists of two parts, the general setup, and the actual definition for each of the signals.

In the general setup the following is specified:

1/ The disk drive, and the filename of the data file where the logged data are to be saved.

2/ The number of the first and the last channel in the datalogger that is to be scanned. This version of the program has only facilities for working with 20 channels or less, however, this is more than enough for the present.

3/ The load speed at which the test is run.

4/ The maximum level of hydrostatic confining pressure during the test.

5/ The maximum oil pressure that is allowed in the system before the blow-out valve is triggered (threshold value).

The next step is to assign measuring equipment to each of the channels, and to specify the appropriate calibration constant for the selected equipment. 5 possibilities are covered:

1/ The bridge excitation, no calibration constant is needed.

2/ The pressure transducer. The signal from the transducer is converted to a pressure-reading using eq. (3.4) along with the calibration constant specified.

3/ The vertical force. The signal from the jack is converted to a force reading using eq. (3.2). However, since the control unit of the jack is giving the signal in percentage of the maximum load, the calibration constant to be supplied is not the one specified in eq. (3.1), but rather as given in eq. (2.1).

4/ A strain gauge. The gauge signal is converted to a strain reading using eq. (3.9) and (3.10).

5/ A deformation transducer. The transducer signal is converted to mm using eq. (3.7).

$$K_{1000ton,TRIAX} = K_{1000ton} \cdot Max\ load_{1000ton}\ (ton) \qquad (2.1)$$

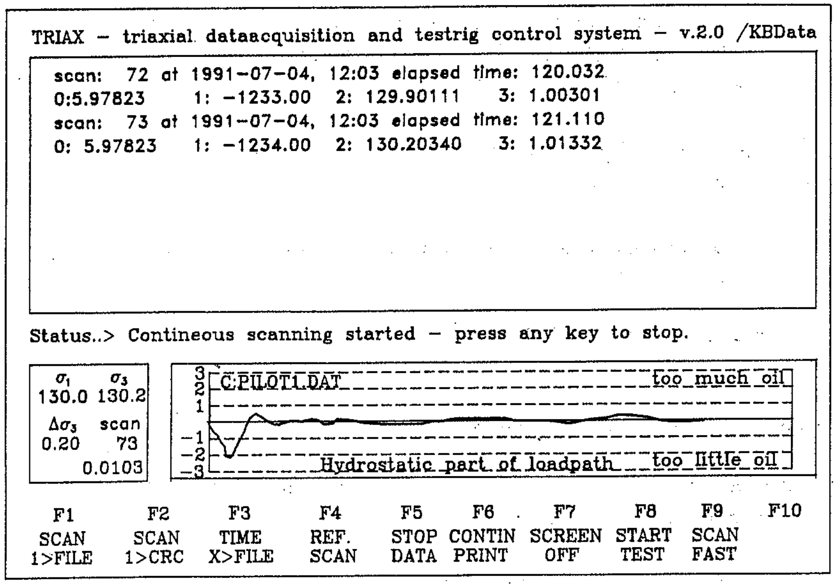
### 2.3.2 The data acquisition and control menu

After completing the setup menu, it is possible to continue with the actual data logging. The logging screen is shown in Fig. 2.6.

The screen consists of 3 main windows. The first window is located in the upper half of the screen. In this window the converted signals from the scans are shown. All data shown are in Volts, MPa, N, mm, or as a strain reading.

The last two windows are located in the bottom half of the screen, and are used for controlling the test. The left window is a summary of the information in the upper window. The data shown are the vertical stress, the confining pressure, the scan number, and the two important control parameters: the deviation of the confining pressure from the load path, and the downwards speed of the piston in mm/s. The deviation from the load path is used by the operator to determine, if the confining pressure should be increased or decreased. The changing of the confining pressure is performed using the valves (8) or (7) in Fig. 2.2. The downwards speed of the piston is measured by the deformation transducer, and is used in determining if failure in the test specimen is imminent. This is seen by a rapid rise in the downwards speed of the piston.

The right window is used by the operator to control the loading along the hydrostatic part of the load path. Inside the window is a graph showing the confining pressure versus the deviation from the load path. This graph is continuously updated and the operator can, by manipulating valve (8) and the reduction valve (16) in Fig. 2.2, keep the confining pressure within 0.5 MPa of the load path.



```
TRIAX - triaxial dataacquisition and testrig control system - v.2.0 /KBData
scan:  72 at 1991-07-04, 12:03 elapsed time: 120.032
0:5.97823    1: -1233.00  2: 129.90111    3: 1.00301
scan:  73 at 1991-07-04, 12:03 elapsed time: 121.110
0: 5.97823   1: -1234.00  2: 130.20340    3: 1.01332

Status..> Contineous scanning started - press any key to stop.
```

**Fig. 2.6:** The data logging and test control screen.

In the bottom of the screen is a ruler for the function keys. Their functions are:

F1 Perform one scan, show it on the screen, and save in the data file.

F2 Perform one scan, and show it on the screen, but do <u>not</u> save it in the data file.

F3 Start timed scanning. In timed scanning, scans are performed constantly, with the specified time interval between the scans.

F4 Perform a reference scan. This reference scan will later be subtracted from any subsequent scans.

F5 Stop data acquisition, and return to the main menu.

F6 Start continuous printing of the scanned data.

F7 Turn off showing the scanned data in the top window. This is done when the scanning interval is at a premium.

F8 Start the test timer. The test timer is used for calculating the load path along with the load speed entered in the setup menu.

F9 Perform scanning as fast as possible.

# Chapter 3

# Calibration of the test equipment

In the following chapter the calibration of the triaxial test cell and the auxiliary equipment will be scrutinized, and the calibration results discussed.

## 3.1 Calibration of the 1000 tons hydraulic jack

The hydraulic jack used for generating the vertical force for the deviator stress is a Walter+Bai hydraulic jack, capable of supplying a force of 10 MN. The hydraulic jack is controlled by a servo unit also manufactured by Walter+Bai. It is possible by means of this servo unit to control, among other things, the load speed, the minimum load, the maximum load, and the error sensitivity of the jack.

The calibration was performed by applying a steadily increasing force from the hydraulic jack on a 1000 kN load cell, and at the same time storing the signals supplied by both the servo controller and the load cell.

The hydraulic jack was calibrated up to 800 kN. The calibration result is shown in Fig. 3.1, and the calibration constant was found to be:

$$K_{1000ton} = 0.986201 \tag{3.1}$$

The signal from the jack is converted to the corresponding load by the following formula:

$$Force_{1000ton}\ (N) = \frac{signal_{1000ton}\ (V)}{10\ (V)} \cdot Max\ load_{1000ton} \cdot K_{1000ton} \tag{3.2}$$

Where $\boldsymbol{Max\ load}_{1000ton}$ is the maximum load for the jack. This can be set to 10 MN, 5 MN, 2 MN, or 1 MN.

The calibration consists of 4 loadings up to 800 kN. It can be seen in Fig. 3.1 that, apart from the region 0 to 100 kN, the calibration constant is very much linear, and with a very small deviation from the mean value. It can also be seen that for very small loads there is a

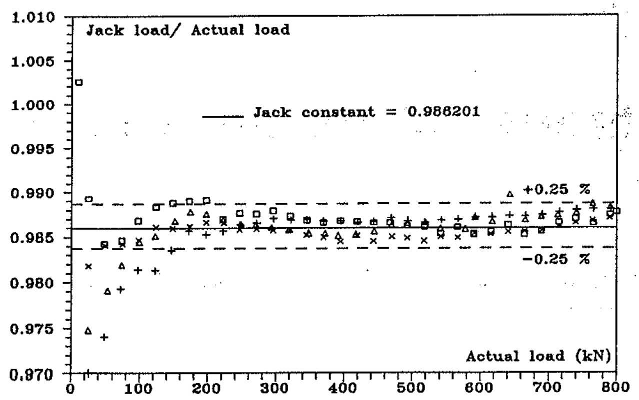


**Fig. 3.1:** Calibration result for 10 MN hydraulic jack.

large scatter in the results. This is normal behavior for a calibration test, and is due, among other things, to the internal friction in the jack, and to the numerical error normally experienced when working with small signals. This deviation is therefore disregarded when determining the calibration constant.

The hydraulic jack is used to supply a force up to 5000 kN. It is therefore obvious that this calibration cannot be more than a guideline to show the deviation between the jack force and the real force. However, as can be seen in Fig. 3.1 there exist a very good correlation between the 2 signals. Therefore it was decided not to perform any further calibration test on the hydraulic jack, and instead use this calibration constant, eq. (3.1), in the region 0 to 5000 kN.

## 3.2 Calibration of the pressure transducer

The pressure transducer used in the test rig is a HBM P3MA with a pressure range of 0 to 2000 bar (= 0 to 200 MPa). The precision of the transducer is ±0.20 %. In order to calibrate the transducer, a Budenberg pressure calibration unit was used. The Budenberg instrument is a dead-weight type instrument, and it is therefore possible to maintain a constant, exact pressure during calibration.

The pressure transducer was calibrated in this way for pressures in the range 0 to 60 MPa. The calibration factor for the transducer was found by minimizing the mean error between the calculated pressure (from the transducer), and the actual pressure. The calibration factor was found to be:

$$K_{pressure} = 0.00197 \ V/V \tag{3.3}$$

The transducer signal is converted to the corresponding pressure by the following formula:

$$Pressure\ (MPa) = \frac{Signal_{transducer}\ (V) \cdot 200\ (MPa)}{Excitation_{Bridge}\ (V) \cdot K_{pressure}} \tag{3.4}$$

The calibration result is shown in Fig. 3.2.

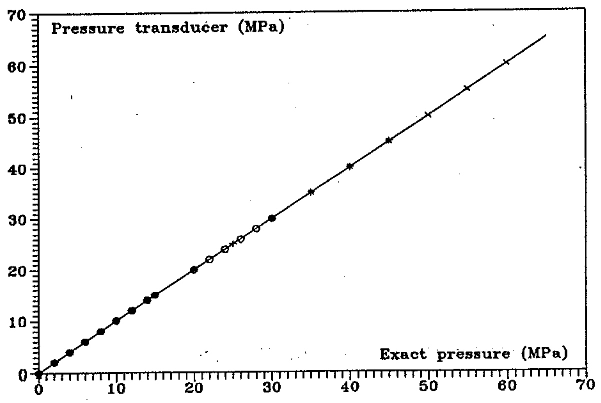


**Fig. 3.2:** Calibration result for the pressure transducer.

As was the case with the hydraulic jack, the pressure transducer was not calibrated for pressures up to 140 MPa, only for pressures up to 60 MPa. However, as can be seen in Fig. 3.2, there is a very good correlation between the transducer signal and the actual pressure when using the calibration constant eq. (3.3). Therefore no further calibration has been undertaken, and the calibration constant given in eq. (3.3) has been used.

## 3.3 Dynamic friction in the triaxial cell

When the concrete specimen inside the triaxial cell deforms axially, the piston has to follow the specimen. The piston is therefore subject to frictional restraint at the internal seals. The main factors that affect the magnitude of this friction are:

1/ The rate of movement of the piston. In this investigation a speed of ~0.01 mm/s has been chosen, because the initial tests showed this speed to correspond well to the speed in the actual tests.

2/ The magnitude of the oil pressure inside the cell. When the oil pressure changes, it will cause the various components of the cell to change. This will affect the clearance between the piston and the seals. Furthermore any difference between the area of the piston in the main chamber, and the area of the piston collar in the upper chamber, will also create an upwards or downwards force on the piston. This extra force will be included in this calibration.

3/ The temperature of the oil inside the cell. There is virtually no flow of oil when the tests are running. Therefore, the temperature of the oil will be fairly constant, and as a consequence the temperature effect is considered to be insignificant.

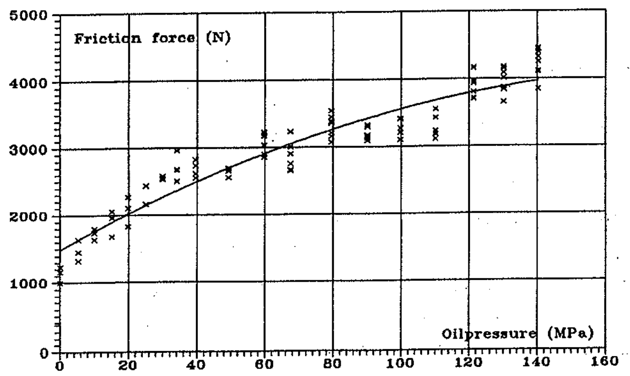


**Fig. 3.3:** Dynamic friction restraint of the piston, as a function of cell pressure.

The calibration was performed by establishing the desired oil pressure inside the cell. The piston was then loaded by an external force until it reached a speed of more than 0.2 mm/s. The external force was then diminished until the piston stopped moving. Throughout the test

displacement transducers were used to measure the piston movement. The friction force was determined as the force necessary to move the piston at a speed of 0.01 mm/s. The results, as shown in Fig. 3.3, show an increasing frictional restraint for increasing oil pressure. The results also show a rather large scatter of the results, but still the overall picture is clear.

A formula, based on the least square method using a second degree polynomial, has been adopted to describe the dynamical frictional restraint of the piston (3.5).

$$\mathit{Friction}\ (N) = -0.075\ \mathit{Oilp}^2 + 28.174\ \mathit{Oilp} + 1490.44 \qquad (3.5)$$

where ***Oilp*** is the oil pressure in MPa.

## 3.4 Calibration of the deformation transducer

In order to measure the movement of the piston during the tests, a deformation transducer was used. The transducer was of the type HP 1000 with a maximum deformation of 50 mm.

The transducer has mostly been used as an indication of when failure is imminent in a concrete specimen, rather than to measure the axial strain in the specimen. The calibration result is shown in Fig. 3.4, where also the calibration constant, eq. (3.6), is shown.

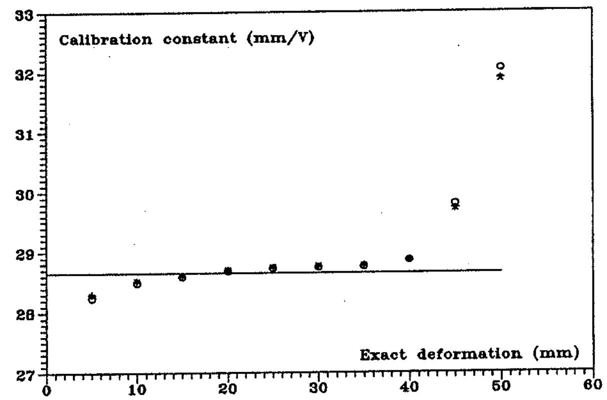


**Fig. 3.4:** Calibration result for the deformation transducer HP 1000.

It is clearly seen in Fig. 3.4 that the calibration constant is only valid for deformations smaller than 40 mm, however again, the transducer is only used as an indication of imminent failure, and exact measurements are therefore not needed.

$$K_{deformation} = 28.6524\ mm/V \tag{3.6}$$

The deformation is calculated using the calibration constant (3.6) and eq. (3.7)

$$D\ (mm) = \frac{Signal_{deformation}}{Excitation_{bridge}} \cdot K_{deformation} \tag{3.7}$$

## 3.5 Calibration of strain gauge

In order to measure the strains in the concrete, foil-type strain gauges were used.

It has been reported, [74.1], that concrete can undergo deformations exceeding 20% at very high confining pressures. Since a normal strain gauge is capable of measuring deformations in the range 1-2% is it necessary to use gauges of the post-yield type. It is possible to buy these gauges, however they are rather expensive. It was therefore decided to develop and manufacture the gauges at the Department of Structural Engineering (ABK). The resulting gauge was a 60 mm long foil-type post-yield gauge.

The calibration of the strain gauge falls into two parts.

1/ An investigation to determine the gauge factor for the gauge.

2/ An investigation to determine if the strain gauge is sensitive to the large pressure that will be exerted on the face of the gauge.

The length of the gauge was not chosen arbitrarily. Previous researchers, [56.1] and [74.1] have stated that the length of the strain gauge has to be taken into account when measuring strains on concrete. In [56.1] it is reported that the gauge length should not be less than 3-4 times the maximum aggregate size, for the measured strain to be within 5% of the actual strain.

Other investigations [64.1] have shown that the middle third of a concrete cylinder with a height/diameter ratio of 2, is relatively unaffected by the friction between the concrete and the load platens. The use of 60 mm long strain gauges, in cylinders Ø100·200 mm, with a maximum aggregate size of 16 mm, therefore seems to be a good compromise between these two demands.

### 3.5.1 Determining the gauge-factor for the ABK post-yield gauge

The ABK post-yield strain gauge (ABK-PY) was calibrated against a commercially available gauge, Micro Measurements gauge no. EP-08-20CBW-120 (MM). The MM gauge is capable of measuring deformations of ±20 %, and is linear within this deformation range.

The calibration was performed by mounting 2 MM gauges, each flanked by 2 ABK-PY gauges, vertically on opposing sides of 2 low-strength mortar cylinders Ø100·200 mm. The type of mortar was chosen to ensure extremely large deformations in the cylinders. The cylinders where loaded with a hydrostatical pressure of 135 MPa, and a vertical force was added, until the total deformation of the cylinder reached 45 mm. The ABK-PY gauges were then calibrated by minimizing the deviation of the ABK-PY gauges from the MM gauges by varying the gauge-factor, $K_g$. The resulting gauge factor was found to be:

$$K_g = 2.14 \tag{3.8}$$

the strains are then calculated by the equations (3.9) and (3.10).

$$\varepsilon = \frac{4 \cdot V_{ref}}{K_g\ (1 + 2 \cdot V_{ref})} \tag{3.9}$$

$$V_{ref} = \frac{Gauge\ signal_{scan}}{Bridge\ exitation_{scan}} - \frac{Gauge\ signal_{reference}}{Bridge\ exitation_{reference}} \tag{3.10}$$

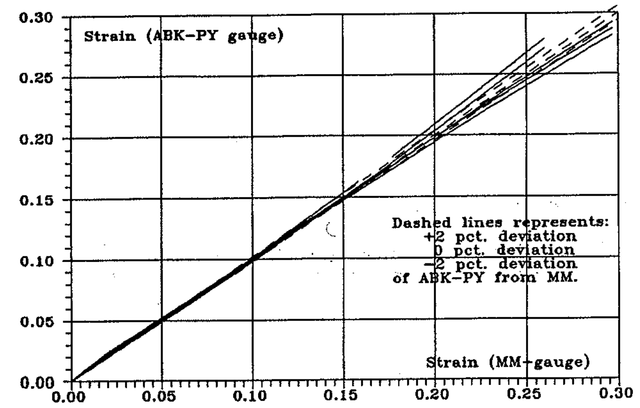


**Fig. 3.5:** ABK-PY gauge versus MM gauge.

The calibration result is shown in Fig. 3.5.

The calibration shows that the ABK-PY gauge is quite linear for strains in the range 0 to 20%, and is in very good agreement with the MM-gauges.

### 3.5.2 Effect of oil pressure on the strain gauge

During a test of a specimen in the triaxial cell there exists a fluid pressure upon the curved part of the test cylinder. This part of the specimen is also the part where a strain gauge would be mounted. An investigation was therefore performed in order to asses the effect of such a pressure upon the strain gauge signals.

The investigation was undertaken in the following way:

1/ A cylinder Ø100·200, made of mild steel, was manufactured. On this cylinder were mounted 4 ABK post-yield strain gauges (ABK-PY), and 2 Micro Measurements EP-08-20CBW-120 strain gauges (MM).

2/ The steel cylinder was tested in uniaxial compression in order to determine the E-modulus. The maximum stress in the steel was kept below 150 MPa in order to prevent yielding in the steel.

3/ The same cylinder was then subject to a hydrostatic pressure of 135 MPa inside the triaxial cell. A vertical force was added until the vertical stress reached 270 MPa. Throughout this, the signals from the 6 gauges were monitored. On basis of these recordings the E-modulus for the deviator stress was calculated.

The results of the investigation are shown in table 3.1 and 3.2.

From the results it can be seen that there seems to be a slight increase in the Young's modulus when the oil pressure is raised. However, it is also obvious that this increase is so small that, for the range of pressures used here, the effect of pressure on the face of the strain gauge can be neglected. The same conclusion regarding the sensibility of the strain gauge has been reached in [74.1]. Although the gauges are not the same, these two results indicates that normal foil type strain gauges are not sensitive to pressure on the face of the gauge.

| Gauge type | E test 1 (MPa) | E test 2 (MPa) | E test 3 (MPa) | E Mean val. (MPa) | S.dev. % |
|---|---|---|---|---|---|
| ABK-PY 1 | 198032 | 203637 | 203454 | 205135 | 2.35 |
| ABK-PY 2 | 196865 | 204874 | 205925 | | |
| ABK-PY 3 | 213655 | 208246 | 206762 | | |
| ABK-PY 4 | 211401 | 206126 | 202643 | | |
| MM 1 | 193756 | 201885 | 204131 | 203477 | 2.93 |
| MM 2 | 212035 | 205955 | 202920 | | |

**Table 3.1:** Young's modulus from uniaxial tests.

| Gauge type | E test 1 (MPa) | E test 2 (MPa) | E test 3 (MPa) | E Mean val. (MPa) | S.dev. % |
|---|---|---|---|---|---|
| ABK-PY 1 | 207302 | 200437 | 201107 | 208558 | 4.45 |
| ABK-PY 2 | 192168 | 221150 | 218237 | | |
| ABK-PY 3 | 213964 | 210444 | 212212 | | |
| MM 1 | 192008 | 201151 | 204473 | 205976 | 5.75 |
| MM 2 | 227579 | 204968 | 205678 | | |

**Table 3.2:** Young's modulus from triaxial tests.

# Chapter 4

# Preparatory work on the test cylinders

The work needed for preparing the concrete cylinders for a test will be described in this chapter. The reason for this preparatory work on the cylinders is due to the need of preventing oil from entering the concrete. If that occurs the failure criterion will be different from the one investigated in this project, due to the rise in the local pore pressure. The effect of oil being in direct contact with the concrete is discussed in detail in [81.1] and [90.1].

The preparatory work falls into two parts: the use of rubber membranes around the concrete, and preparing the concrete cylinders so that the rubber membrane will not puncture during testing.

## 4.1 The manufacturing and use of rubber membranes

In order to ensure that no oil leaked into the specimen before, during and after test, the specimen was placed inside a rubber membrane. The rubber used was a 1 mm thick synthetic oil resisting rubber called NITRIL-rubber. The membrane was manufactured by gluing the ends of a rubber sheet 260·340mm together, so to form a tube. The glue used, was a glue called NEOTOL-glue, specially made for gluing rubber together.

It was soon discovered that using only one of these membranes caused an excessive number of aborted tests, due to puncturing of the membrane. Therefore the following procedure was adopted: for confining pressures below 100 MPa, 3 membranes were used, and for pressures above 100 MPa, 4 membranes were used. This caused the number of aborted tests to drop from ~50 % to less than 10 %.

## 4.2 Surface preparation of the specimens

During the testing period it became clear, that it was most critical to prepare the specimens the right way. The problem lies in the nature of concrete itself. In all concrete there are a number of macroscopic pores and voids. Some of the voids are located in the outer layer of the concrete, sometimes covered only by a thin layer of hardened cement paste. Such voids are dangerous in triaxial testing, because they will implode when subject to the confining pressure. This is critical, partly because such an implosion easily could cause the membrane to puncture causing oil to be in direct contact with the concrete, and partly because an implosion under a strain gauge will cause the gauge signal to be erroneous.

The procedure finally adopted to overcome this obstacle was as follows:

1/ The concrete cylinders were sandblasted in order to expose all voids near the surface.

2/ The cylinders were then lightly brushed with a diluted water based glue in order to close the microscopic pores in the surface. Afterwards the voids were filled a with ready-mix filling compound. The 'gluing' was done in order to minimize the water absorption from the filling compound, so to ease the stopping process. After the filling compound had hardened, the cylinders were sanded in order to remove excessive filling material. Much testing was needed to find the right filling compound. The compound needs to be workable for a long time, which rules out gypsum, and it should not shrink during hardening, which rules out cement paste. The compound finally used was a ready-mix compound by the commercial name 'HUS-FIX', which contains cement, lime, and very fine sand.

3/ Finally the cylinders were ground accurately plane by use of a diamond-impregnated grinding wheel.

## 4.3 Strain gauging

The strain gauges were mounted using an epoxy-resin glue. 4 gauges were used per cylinder, 2 vertical and 2 horizontal, mounted symmetrically about the center circumference.

Ordinary plastic insulated electrical wires, approximately 1.5 mm in outer diameter, and 200

mm long were soldered to the end terminals of the gauges. Trial tests with these wires have shown that it is possible to make an effective seal at the top cap, and at the same time ensuring that any left-over hole or void in the outer layer of the cylinder will not disrupt the electrical connection due to implosion during testing.

Other researchers [74.1] have used lacquer covered copper wires guided along prepared 'routes' on the cylinder face. However, using normal insulated wires seems to ensure a greater chance of survival of the electrical connection to the gauge throughout the entire test period.

# Chapter 5

# Using the triaxial cell

In this chapter the procedure for testing a concrete cylinder under triaxial states of stress will be explained.

## 5.1 Preparing and mounting the test cylinder

The cylinder is first checked for any holes or voids on the surface, which are not completely filled with the stopping material. If any holes are found, they are stopped with a quick setting epoxy compound.

Ordinary plastic insulated wires, approx. 1.5 mm in diameter, and 200 mm long are soldered to the end terminals on the gauges.

After connecting the gauges, 3 or 4 membranes are fitted over the cylinder. The number of membranes is depending on the confining pressure the cylinder is to experience. If the confining pressure exceeds 100 MPa, 4 membranes are fitted, otherwise only 3 membranes are used. The membranes are fitted so that none of the overlaps of the individual membrane is directly on top of an overlap of an underlying membrane. If two overlaps are placed on top of each other, problems with the sealing of the cylinder around the top and the base plate might occur.

The cylinder is placed on the base plate of the triaxial cell, and a heavy duty torque clip is firmly tightened around the rubber and the base plate to form an effective seal, as shown in Fig. 5.1.

The torque clip has been another area of extensive research. When the triaxial cell is pressurized, the pressure will help keeping the seal intact, providing that no oil can seep in between the membranes and the base or top plate. It is not a problem at the base plate. At the top plate, however, wires are guided out between the plate and the membrane. The torque clip therefore has to deliver a force large enough to fold and seal the rubber around the wires,

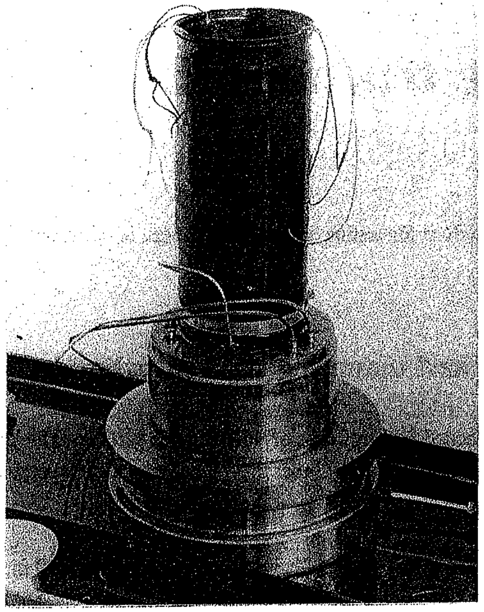


**Fig. 5.1:** Mounting the cylinder on the base plate.

as well as compressing the membranes and the wires tightly against the top plate. In order to ensure the tightness of the seal, groves were cut in the top plate, so that the wires were guided over a knurled surface. The modified top plate is shown in Fig. 6.2. The torque clip has to deliver a normal stress large enough to ensure sealing. Torque clips come in many sizes and shapes, however, heavy-duty clips tend to have a very wide band. This means that the actual normal stress experienced is small, as compared to normal torque clips. The normal clips cannot, on the other hand, be used again and again. A compromise was found in a heavy duty clip with a rather narrow band, fabricated by ABA, Sweden.

After securing the seal at the base plate, the top plate is placed on top of the cylinder. The wires from the strain gauges are spaced around the entire circumference and a torque clip is tightened around the membranes and the top plate. The wires are then soldered to a soldering board which is connected to wires leading outside the triaxial cell. Thereupon the pore pressure outlet from the top plate is connected to the base unit, and the spherical unit is placed on top of the top plate. This is shown in Fig. 5.2.

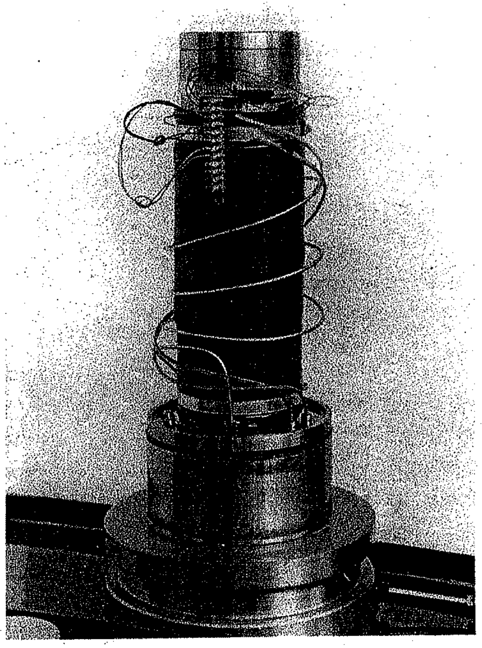


**Fig. 5.2:** A concrete cylinder ready for testing.

Finally, before the concrete cylinder is ready for testing, the cylinder is checked for centrical placing between the plates, and the electrical system is checked for proper connection.

## 5.2 Preparing the triaxial cell for a test

After the test specimen has been mounted, the cell is closed by lowering the barrel unit down on top of the base unit, ensuring that the seals between the two units are in their proper position. The two units are then locked together by the clamps and the clamp ring, (11) and (12) in Fig. 2.1.

After closing the cell, it is placed under the hydraulic jack by means of the small cart attached to the jack, this is shown in Fig. 5.3. A small force (6-7 kN) is then applied on the piston to establish contact between the piston and the spherical unit on top of the test specimen. The deformation transducer is placed, as shown in Fig. 5.3, to measure the movement of the piston. Actually the transducer is measuring the upwards movement of the barrel unit. This because the plunger of the jack is placed on the floor, and the stroke is therefore upwards. This means that instead of moving the piston downwards into a fixed cell, the cell is moved upwards with a fixed piston.

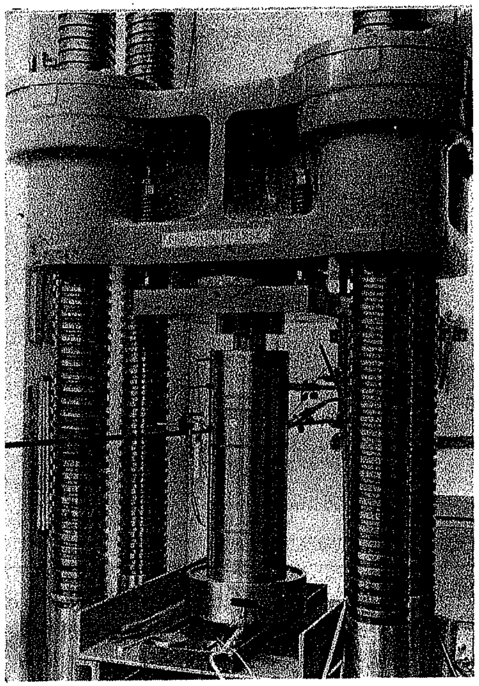


**Fig. 5.3:** Placement of the triaxial cell on the hydraulic jack.

Finally, the cell is filled with oil. This is done by pressurizing the oil reservoir (18) via the switch (17), all numbers here, and in the following, refers to Fig. 2.2. Oil is then allowed to enter the cell by opening valve (20). The air trapped inside the cell is allowed to escape by closing the air-to-drain-cell valve (4), and opening the air-relief valve (5). Finally, the close-oil-flow valve (6) is closed in order to prevent air from entering the main part of the pressure system.

Valve (20) is closed when oil is overflowing in the low-pressure spill pipe, leading from valve (5) to reservoir (1). The flow of oil is allowed to stop before valve (5) is closed, thereby ensuring that all air has been bled from the cell, and testing can now commence after valve (6) has been opened.

## 5.3 Testing a concrete cylinder

Testing and logging of data is controlled by the program TRIAX, as described in chapter 2.3. The program is started and the appropriate test data is entered. TRIAX assumes a normal load path, which consists of increasing the hydrostatic stress until a predetermined level is reached, followed by an increasing deviator stress in the axial direction. Since the oil pressure acts both radially and on top of the concrete cylinder, a hydrostatic stress field is achieved by increasing the oil pressure alone. Prior to this, a reference scan is recorded by activating the function key <F4>, next the timer is started by the function key <F8>, and the continuous scanning started by the function key <F9>.

The operator then manipulates valves (8) and (16) in order to follow the load path shown on the graph on the screen, as described in chapter 2.3. When the predetermined hydrostatic stress level is reached, the operator starts the hydraulic jack, in order to supply the deviator stress in the concrete. During this last part of the test, the oil pressure has to be kept constant.

Since the volume of the concrete changes during a test, oil either has to be added when the volume decreases, or drained when the volume increases. The TRIAX program continuously displays the difference between the predetermined pressure, and the actual pressure. By manipulating valves (7), (8), and (16), and using the displayed pressure difference, the pressure can be kept within 0.3 MPa of the predetermined pressure level at all times.

Typical load paths are shown in Fig. 5.4 and 5.5. Fig. 5.4 shows the load path from the first part of the test, where the load path follows the hydrostatic axis. Fig. 5.5 shows the deviation of the confining pressure from the predetermined stress level in the last part of the test, where the confining pressure is to be kept constant.

In Fig. 5.4 it is seen that the deviation from the load path is rather large at the beginning of the test. This because the air-hydro pump has a little difficulty in creating the first slight pressure in the oil. This behavior has been experienced in all test, however, it should not influence the test results at all.

In Fig. 5.5 there is also seen some disturbances at the start of the graph. This is most probably due, partly to the settling of the piston onto the spherical unit, and partly to small

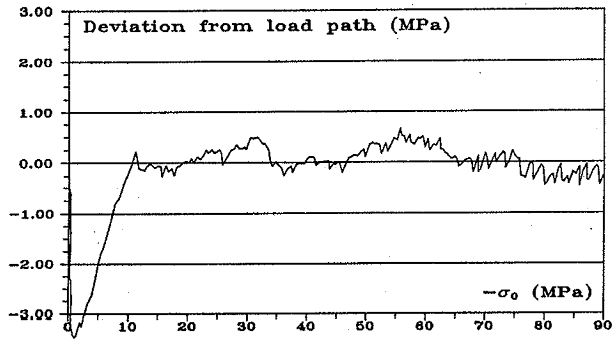


**Fig. 5.4:** Deviation of the oil pressure from the hydrostatic load path.

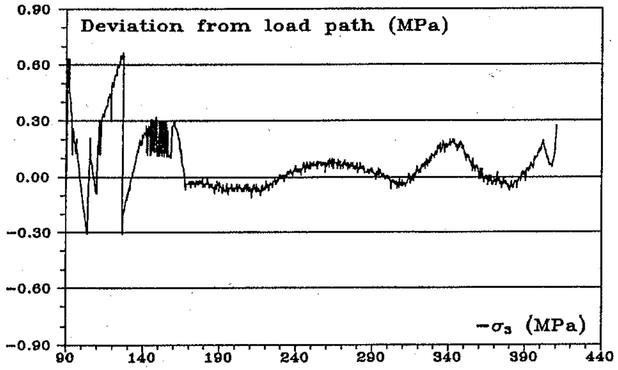


**Fig. 5.5:** Deviation of the oil pressure from the predetermined level during the application of the deviator stress.

pressure waves moving around in the system before they settle. No influence on the test results are attached to these disturbances.

## 5.4 Dismantling the triaxial cell

After the test has stopped, the following procedure is adopted in order to empty the cell of oil. The air switch (17) is placed in the position where there no longer is pressure in the oil reservoir (18). The confining pressure inside the cell is relieved, by **slowly** opening valve (20), and the oil inside the cell is allowed to **seep** back into the reservoir (18). When the oil pressure inside the cell has been lowered to almost zero, valve (4) is opened. By opening valve (4), an air pressure is established inside the cell, thereby forcing the oil back into the reservoir (18). If valve (20) is not opened slowly, rupture of the low-pressure pipe might occur.

While the oil is drained from the cell, the piston is raised back into the topmost position by a crane. The oil trapped in the upper chamber is thereby released back into the main chamber, and further on into the reservoir (18).

When all oil has escaped the cell, valve (4) is closed. Valve (5) is then opened to release the excess air pressure now inside the cell. The clamp ring and the clamps are removed, and access to the test specimen is gained by raising the barrel unit by the crane.

# Chapter 6

# Pilot tests

Prior to the actual testing program, a number of pilot tests were conducted in order to examine the operation of the cell. The following questions were posed:

1/ Is there a well defined triaxial stress field in the test cylinder?
2/ Do the grooves cut in the top plate influence the ultimate strength of the concrete specimen?
3/ Are there any serious disadvantages in using a proportional load path instead of the normal load path?

In this chapter the answers to the above questions will be given.

## 6.1 The stress field in the test cylinder

In order to examine the stress field in the test cylinder during testing, 4 concrete cylinders where prepared with 9 strain gauges each. The gauges were mounted in sets of 3. In each set one was vertical while the other two were placed at an angle of ±45°. The 3 sets of gauges were placed equidistant around the circumference of the cylinder, and the center of all of the gauges was at the mid height of the cylinder.

Measuring the individual strains from the gauges $\epsilon_{ver}$, $\epsilon_{lef}$, and $\epsilon_{rig}$, the strain from the vertical gauge, the strain from the left gauge, and the strain from the right gauge, respectively, the principal strains can be calculated using eq. (6.1) and (6.2).

$$\varepsilon_3 = \frac{1}{2}(\varepsilon_{rig} + \varepsilon_{lef}) + \frac{1}{2}\sqrt{(\varepsilon_{rig} - \varepsilon_{lef})^2 + (2\varepsilon_{ver} - \varepsilon_{rig} - \varepsilon_{lef})^2} \qquad (6.1)$$

$$\varepsilon_1 = \frac{1}{2}(\varepsilon_{rig} + \varepsilon_{lef}) - \frac{1}{2}\sqrt{(\varepsilon_{rig} - \varepsilon_{lef})^2 + (2\varepsilon_{ver} - \varepsilon_{rig} - \varepsilon_{lef})^2} \qquad (6.2)$$

The principal angle, $\varphi$ is then given by eq. (6.3).

$$\tan 2\varphi = \frac{2\varepsilon_{ver} - \varepsilon_{rig} - \varepsilon_{lef}}{\varepsilon_{rig} - \varepsilon_{lef}} \tag{6.3}$$

The solution of eq. (6.3) gives two values of $\varphi$, $\varphi_1$ and $\varphi_2$, where $\varphi_1$ is the angle between the direction of the right gauge and the direction of the maximum principal strain $\epsilon_3$, and $\varphi_2$ is the angle between the direction of the right gauge and the direction of the minimum principal strain $\epsilon_1$.

All four tests showed that the direction of the maximum principal strain varied ±0.5° from vertical at all times during the tests. Furthermore did the analysis reveal a very good correlation between the strains measured by the three sets of gauges on each cylinder. An example of this is shown in Fig. 6.1.

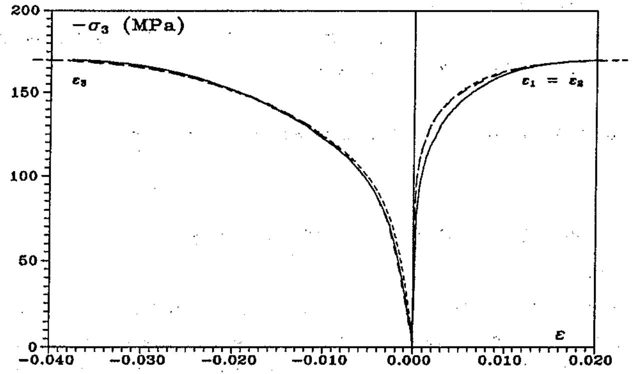


**Fig. 6.1:** Measured strains at three different points on the same concrete cylinder, proportional load path.

The conclusion is, that there exists a well defined triaxial stress and strain field in the test cylinders at all times during testing.

## 6.2 The influence of the grooves in the top plate

A number of grooves were cut in the top plate in order to ensure an effective seal against ingress of oil into the test specimen. This was done because wires from the strain gauges were to be lead through this seal, and extra precautions, as compared to the seal at the base plate, were needed. The grooves are shown in Fig. 6.2.

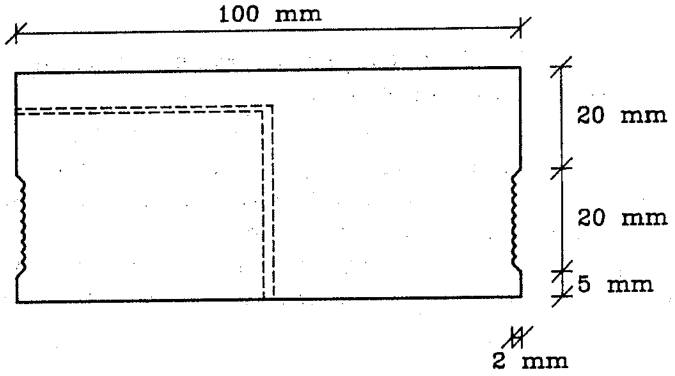


**Fig. 6.2:** Top plate with the grooves, and the pore pressure outlet.

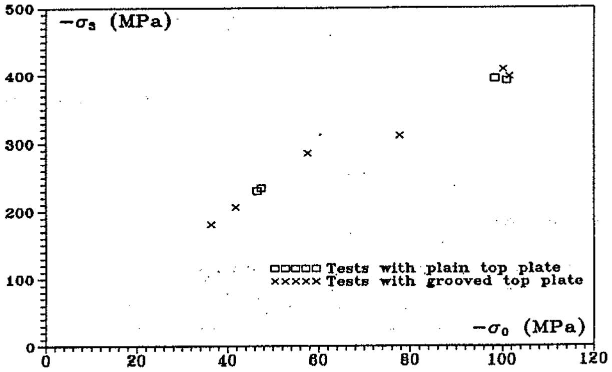


**Fig. 6.3:** Ultimate strength of concrete specimens with, and without grooves in the top plate.

The presence of the grooves will weaken the stiffness of the top plate at the end where it meets the test specimen. The use of this modified top plate might therefore lead to lower ultimate loads, when compared to test utilizing a top plate without grooves. A number of pilot tests were performed in order to evaluate the influence of the grooves. The results are shown in Fig. 6.3.

The investigation shows that the influence is negligible, and the effect is therefore disregarded when treating the test results.

## 6.3 Proportional loading versus normal loading

Many load paths have been used when testing concrete triaxially. The most commonly used load path is the so-called 'normal' load path. This load path consists of following the hydrostatic axis until a predetermined level is reached, and hereafter increasing the vertical stress until failure is reached. Many other load paths are used from time to time, however, the other path of interest is the proportional load path. Loading along this path consists of keeping the ratio of the principal stresses equal. The two load paths are shown graphically in Fig. 6.4.

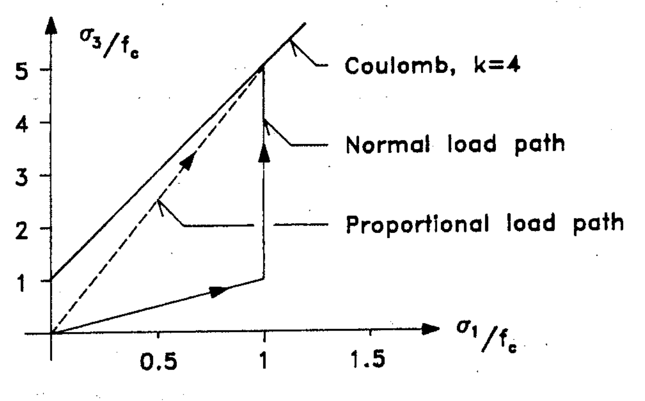


**Fig. 6.4:** Normal and proportional load paths.

Most researchers believe that there is little, or no, difference in the ultimate strength between tests utilizing the normal load path, as compared to tests utilizing the proportional load path. However, not much research has been undertaken in this area, so a definite conclusion is hard to make. A more thorough discussion of the subject can be found in [79.1] and [90.1].

In order to check the influence of the load path, a number of pilot tests were run. The results are shown in Fig. 6.5.

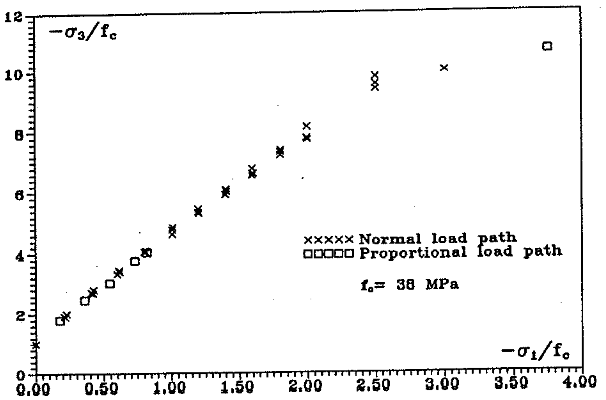


**Fig. 6.5:** Normal load path compared to proportional load path.

Although not enough tests were carried out to make a definite conclusion, it is obvious that these tests seem to confirm, that the ultimate triaxial strength of concrete is not very much dependant on, whether a normal load path, or a proportional load path is used.

However, there is one problem when using a proportional load path. The problem lies in the rather large scatter of the results that is normally experienced when testing proportionally. This because the proportional load path is intersecting the failure curve at a very small angle, as can be seen in Fig. 6.4. Small deviation in, for instance the confining pressure, or the uniaxial concrete strength, could therefore result in the test results being 'smeared out' along the failure curve. This scatter will be much less when using a normal load path, if for nothing else, simply because the confining pressure is constant.

As a result of this the normal load path has been used in all later tests in this investigation.

# Chapter 7

# Concluding remarks

In this report the complete test equipment, the calibration of the test equipment, and the procedures needed for testing a concrete cylinder under triaxial stresses, have been described. From the results obtained during the calibration and the pilot tests is it clear that using the above described techniques is it possible to induce a well defined triaxial stress field in the test specimen.

The test equipment has been used successfully in investigations of both the ultimate strength, and of the concrete strains of low, normal, and high strength concrete under triaxial stresses. The results obtained in these investigations are described together with the evolved failure criterion and constitutive model in the connected reports ([92.1] and [92.2]):

**A Failure Criterion for Normal and High Strength Concrete**

**A Constitutive Model for Normal and High Strength Concrete**

# References

[56.1] ***The laboratory use of bonded-wire electrical-resistance strain gauges at the Building Research Station.***
R.W. Cooke and A.E. Seddon, Magazine of Concrete Research, Vol. 8, No. 22, March 1956, pp. 31 - 38.

[60.1] ***Betongens trykfasthet - terning eller sylinder ?.***
H. Hansen, A. Kielland, K.E.C. Nielsen, and S. Thaulow, Nordisk Beton, 1960, 4, pp. 305 - 324.

[64.1] ***The Testing of Brittle Materials Under Uniform Uniaxial Compressive Stresses.***
K. Newman and L. Lahance, ASTM Proceedings, Vol. 64, 1964, pp. 1044 - 1067.

[74.1] ***Apparatus for testing concrete under multiaxial states of stress.***
J.B. Newman, Magazine of Concrete Research, Vol. 26, No. 89, December 1974, pp. 229 - 238.

[79.1] ***Effect of Stress Path on the Behavior of Concrete Under Triaxial Stress States.***
M.D. Kotsovos, Journal of the ACI, Februar 1979, pp. 213 - 223.

[81.1] ***Failure Criteria for Concrete.***
D.W. Hobbs, Manuscript to be published by Pitman Books Ltd in "Handbook of Structural Concrete", Manuscript dated September 1981.

[90.1] ***Preliminary State-of-the-art Report on Multiaxial Strength of Concrete.***
Kaare K. B. Dahl, Dept. of Struct. Engineering, Technical University of Denmark, Report R 262, 1990. Also published in 'Højkvalitetsbetoner i 90'erne', Report 5.1.

[92.1] *A Failure Criterion for Normal and High Strength Concrete.*
Kaare K. B. Dahl, Dept. of Struct. Engineering, Technical University of Denmark, Report R 286, 1992. Also published in 'Højkvalitetsbetoner i 90'erne', Report 5.6.

[92.1] *A Constitutive Model for Normal and High Strength Concrete.*
Kaare K. B. Dahl, Dept. of Struct. Engineering, Technical University of Denmark, Report R 287, 1992. Also published in 'Højkvalitetsbetoner i 90'erne', Report 5.7.

# Appendix 1

# TRIAX program, source listing

This appendix is a source listing of the data logging and control program TRIAX. The program is written in the ASYST language, and is further described in chapter 2.3.

```
echo off
\ +-------------------------------------------------------------+
\ I  Program :   TRIAX    -   Triaxial test, Datalogging and    I
\ I                           test control.                      I
\ I  Author  :   Kaare K. B. Dahl                                I
\ I  Date    :   14 / 12 - 1990                                  I
\ I                                                              I
\ I  Standarts :                                                 I
\ I     Authors words are written in capital letters, and in the I
\ I     form <nn_nnn>, NOT the ASYST standart <nn.nnn>           I
\ I                                                              I
\ +-------------------------------------------------------------+

\ --------------- setup til datalogger
integer dim[ 150 ] array bcddat            \ vektor recieve datalogger
9 gpib.device datalogger
bcddat []gpib.buffer                       \ define bcddat as recieving buffer

\ --------------- Windows
 0   0   0  79  window header_scr          \ legend line
 2   1  11  78  window scan_scr            \ window for scan data
13   1  13  79  window status_scr          \ status area
22   0  25  79  window ftaster_scr         \ ruler for functionkeys
15   1  20  13  window actual_sigma_scr    \ window for sigma1 and sigma2

 0   0  17  79  window menu_scr            \ window for mainmenu
17   0  23  79  window menu_err_scr        \ mainmenu error screen
 vuport loadpath_display                   \ grafics area for load path

\ --------------- variable
integer  scalar  first_channel
         scalar  last_channel
         scalar  number_channels
         scalar  posx
         scalar  posy
         scalar  number_point
         scalar  scan_counter
         scalar  black
         scalar  blue
         scalar  green
         scalar  red
         scalar  white
         scalar  bright_red
         scalar  bright_blue
         scalar  intens_white
         scalar  no_of_felt
         scalar  top_row
         scalar  antal_bro
         scalar  antal_oil
         scalar  antal_force
         scalar  bro_channel
         scalar  force_channel
         scalar  oil_channel
         scalar  flyt_channel
         scalar  yes
         scalar  no
         scalar  is_current_on
         scalar  is_screen_off
         scalar  is_printer_off
         scalar  stop_timescan
         scalar  tmp_var2
         scalar  no_of_days
         scalar  previous_time

real     scalar  sigma1
         scalar  this_force
         scalar  old_force
         scalar  oil_pressure
         scalar  delta_sigma2
```

```
         scalar  max_delta_sigma2
         scalar  data_speed
         scalar  max_allow_oil
         scalar  cylinder_areal
         scalar  tmp_val
         scalar  load_speed
         scalar  max_oil_level
         scalar  time_oil_up
         scalar  path_sigma2
         scalar  old_delta_sigma2
         scalar  old_flyt
         scalar  delta_flyt

dp.real  scalar  start_time
         scalar  elapsed_time
         scalar  next_time
         scalar  test_time
         scalar  test_start_time
         scalar  old_time
         scalar  time_between_scans

real     dim[ 20 , 3 ] array channel_array

token    color_palette
token    maal_val               \ measured values from the last scan
token    bytes
token     byte123                \ unpacked total bcddat, only from 1.-last
channel
token    ref_val                \ referance scan measured values
token    unpacked_bcddat        \ unpacked total bcddata

15 string filename
50 string command
80 string overskrift_string
 1 string koert_opsaet
 1 string drive_name
12 string file_name_min
 3 string first_channel_str
 3 string last_channel_str
 4 string load_speed_str
 5 string max_oil_level_str
 3 string max_oil_str
 8 string current_off
 8 string current_on

load.overlay c:\asyst\runtime.aov
\ ---------------------------------------------------------------------------
\ ANSWER.POW  17.9.86.  GM
\
\ REVISED: 22.8.90 :    "LEFT changed to "LEFT_STRING so that it will return
\                       an empty string if cursor position is 1.  /KBD
\ ---------------------------------------------------------------------------
INTEGER
   SCALAR IA
   SCALAR MAXIA
   SCALAR LINSERT                               \ 1 if insert on else 0

1 string empty_string

?VIDEO.ATTRIBUTE
  7 VIDEO.ATTRIBUTE
  0 77  0 79 WINDOW {INSERT.MARK}
VIDEO.ATTRIBUTE
```

```
: "left_string
    dup 0 = if
      empty_string
      drop
    else
      "left
    then
;

: FORWSP ?REL.COL 1 + 80 MODULO ?REL.ROW GOTO.XY ;

: "TYPE.STRING  \ Stack: n1 n2, types string from n1 with n2 additional spaces
    "LEN SWAP - 1 + DUP 0 > IF
      "DUP "RIGHT ?REL.COL ?REL.ROW "TYPE ROT SPACES GOTO.XY
    ELSE DROP ?REL.COL ?REL.ROW ROT SPACES GOTO.XY THEN
;

: "REMOVE.CHARACTER
    DUP 0 > IF DUP "LEN <= IF
    DUP 1 - "DUP "LEFT_STRING "SWAP DUP "LEN < IF
      "LEN SWAP - "RIGHT "CAT ELSE "DROP DROP THEN
    ELSE DROP THEN ELSE DROP THEN
;

: "APPEND.CHARACTER              \ String on symbol stack, and on # stack:
    "LEN - DUP 0 >= IF           \ ascii character value to be inserted
    DUP 0 > IF "  " "CAT         \ and place to insert
    DUP 1 > IF 1 DO "  " "CAT LOOP ELSE DROP THEN
    ELSE DROP THEN ASCII" "CAT
    ELSE 2 *DROP THEN
;

: "INSERT.CHARACTER              \ String on symbol stack, and on # stack:
    DUP 0 > IF                   \ ascii character value to be inserted
      1 - DUP "LEN < IF          \ and place to insert
        DUP "DUP "LEFT_STRING SWAP ASCII" "CAT "SWAP   \ If LINSERT = 0
                                                     \ then overwrite
        "LEN SWAP - LINSERT 0 = IF 1 - THEN         \ else insert character
        DUP 0 > IF "RIGHT "CAT ELSE DROP "DROP THEN
      ELSE "APPEND.CHARACTER THEN
    ELSE 2 *DROP THEN
;

: EXIT.ANSWER
    4 UNROLL -TRAILING GOTO.XY
    VIDEO.ATTRIBUTE
    MAXIA "LEN - 1 "TYPE.STRING
    {INSERT.MARK} 3 SPACES PREVIOUS.WINDOW
;

: "TYPE.INSERT         \ Type if insert on or off in upper right corner
   {INSERT.MARK}
   LINSERT 1 = IF ." INS" ELSE ." OVW" THEN
   PREVIOUS.WINDOW
;

: "ANSWER
    MAXIA := 1 IA := ?VIDEO.ATTRIBUTE ?REL.COL ?REL.ROW
\   ?VIDEO.ATTRIBUTE 32 < IF 96 ELSE 7 THEN VIDEO.ATTRIBUTE \ FOR OLIVETTI
     4 VIDEO.ATTRIBUTE
   MAXIA "LEN - 1 "TYPE.STRING "TYPE.INSERT
    BEGIN
      PCKEY IF
        DUP CASE
          F1 OF DROP IA MAXIA <= IF IA 1 + IA := FORWSP THEN ENDOF \ One char
          F3 OF DROP MAXIA IA :=                        \ Move to end
                  OVER MAXIA + 1 - OVER GOTO.XY ENDOF    \  of string
          F4 OF DROP "DROP "NULL OVER OVER GOTO.XY       \ Clear string
                  1 IA := MAXIA 1 "TYPE.STRING ENDOF
```

```
          71 OF EXIT.ANSWER EXIT ENDOF                        \ HOME
          72 OF EXIT.ANSWER EXIT ENDOF                        \ UP-ARROW
          73 OF EXIT.ANSWER EXIT ENDOF                        \ PG UP
          75 OF IA 1 <= IF EXIT.ANSWER EXIT THEN              \ LEFT-ARRAOW
                DROP IA 1 - IA := 8 EMIT ENDOF
          77 OF IA MAXIA > IF EXIT.ANSWER EXIT THEN           \ RIGHT-ARROW
                DROP IA 1 + IA := FORWSP ENDOF
          79 OF EXIT.ANSWER EXIT ENDOF                        \ END
          80 OF EXIT.ANSWER EXIT ENDOF                        \ DOWN-ARROW
          81 OF EXIT.ANSWER EXIT ENDOF                        \ PG DN
          82 OF DROP 1 LINSERT - LINSERT := "TYPE.INSERT ENDOF    \ INS
          83 OF DROP IA "REMOVE.CHARACTER 1 IA "TYPE.STRING ENDOF \ DEL
        ENDCASE
      ELSE
        DUP CASE
           8 OF IA 1 > IF EMIT                                  \ Back space
                 IA 1 - DUP IA := "REMOVE.CHARACTER 1 IA "TYPE.STRING
               ELSE DROP THEN ENDOF
           9 OF DROP IA MAXIA >= IF                             \ Tabulator
                 1 IA := OVER OVER GOTO.XY   \ Move to other end of string
               ELSE MAXIA IA := OVER MAXIA + 1 - OVER GOTO.XY THEN ENDOF
            DUP 32 >= IF                \ Insert character into string
              "LEN MAXIA <= IA MAXIA <= AND IF
                "LEN MAXIA < LINSERT 0 = OR IF
                  IA "INSERT.CHARACTER 0 IA "TYPE.STRING IA 1 + IA := FORWSP
                ELSE DROP THEN
              ELSE DROP THEN
            ELSE DROP EXIT.ANSWER EXIT THEN
        ENDCASE
      THEN
    AGAIN
;

 banner: HEADLINE
   cr cr
   ."          "
   inverse.on
   ." +-------------------------------------------------------+" cr
   inverse.off
   ."          "
   inverse.on
   ." I                                                       I" cr
   inverse.off
   ."          "
   inverse.on
   ." I       TTTTTTTT   RRRR     IIII     AAAA     X       X   I" cr
   inverse.off
   ."          "
   inverse.on
   ." I          TT       RR    RR   II      A      A     XX   XX   I" cr
   inverse.off
   ."          "
   inverse.on
   ." I          TT       RRRRRR     II    AAAAAAAA       XX        I" cr
   inverse.off
   ."          "
   inverse.on
   ." I          TT       RR  R      II    AA      AA     XX   XX   I" cr
   inverse.off
   ."          "
   inverse.on
   ." I          TT       RR    RR  IIII   AA      AA   X       X   I" cr
   inverse.off
   ."          "
   inverse.on
   ." I                                                       I" cr
   inverse.off
   ."          "
   inverse.on
```

```
 ." I                                                       I" cr
 inverse.off
 ."                   "
 inverse.on
 ." I         Dataacquisition and control system           I" cr
 inverse.off
 ."                   "
 inverse.on
 ." I                                                       I" cr
 inverse.off
 ."                   "
 inverse.on
 ." I          Version 2.0 - 14. december 1990             I" cr
 inverse.off
 ."                   "
 inverse.on
 ." I                                                       I" cr
 inverse.off
 ."                   "
 inverse.on
 ." +-------------------------------------------------------+" cr
 inverse.off
 cr cr cr cr cr cr cr
;banner

: SET_COLORS
   color.on
   0  black :=
   1  blue  :=
   2  green :=
   4  red   :=
   7  white :=
   11 bright_blue  :=
   12 bright_red   :=
   15 intens_white :=
;

: SET_COLOR_PALETTE
   def.palette    becomes> color_palette
   blue           color_palette [ 1 ] :=                \ background color
   color_palette  graphics.palette
;

: SET_DEF_VARS
"TRIAX - triaxial dataacquisition and testrig control system - v. 2.0 /KBData"
   overskrift_string ":=
  3 max_delta_sigma2 :=
;

: BELL 500 300 tune
;

: BELL2
  300 900 tune
  400 800 tune
;

: NUMBER_CHK
   #input
   not
      if bell posx posy goto.xy 4 spaces
              posx posy goto.xy myself
      else
              posx posy goto.xy 4 spaces
      then
;
```

```
: WRITE
   80 "len - 2 / swap goto.xy "type
;

: WRT
   posy :=
   80 "len dup posx := - 2 7 dup posx + posx :=
   posy goto.xy "type
   NUMBER_CHK
;

: STATUS_MESSAGE
   status_scr
   1 0 goto.xy
   "                                                                " "type
   1 0 goto.xy
   " Status..> "  "swap  "cat   "type
;

: STOP_ACQUIS
   normal.display
   menu_err_scr
   " Your datafile: "  filename  "cat  "  has been closed"  "cat  4  WRITE
   " N" koert_opsaet ":=
;

: ERROR_IN_CHOICE
   menu_err_scr screen.clear
   BELL
   " Incorrect entry !!!  try again"
   17 WRITE
;

: ME_TALKER
   unlisten untalk
   me talker datalogger listener
;

: DATALOGGER_TALKER
   unlisten untalk
   me listener datalogger talker
;


: MAKE_DATLOG_COMMAND
   " SD0VT4VR5AC" first_channel "." "CAT
   " VD5VF2VS2VN" "CAT number_channels "." "CAT
   " AE1AF" "CAT first_channel "." "CAT
   " AL" "CAT last_channel "." "CAT " VT3VS" "CAT
   32 "COMPRESS
   COMMAND ":=
   " DO4,0SD0" current_off ":=
   " DC4,0SD0" current_on  ":=
;

: BIN_DEC_CONVERTION
   byte123 sub[ 1 , number_channels , 3 ] bytes xsect[ 1 , ! ] :=
   byte123 sub[ 2 , number_channels , 3 ] bytes xsect[ 2 , ! ] :=
   byte123 sub[ 3 , number_channels , 3 ] bytes xsect[ 3 , ! ] :=
   bytes xsect[ 1 , ! ] 16 modulo bytes xsect[ 4 , ! ] :=
   bytes xsect[ 1 , ! ] bytes xsect[ 4 , ! ] - 16 / bytes xsect[ 1 , ! ] :=
   bytes xsect[ 1 , ! ] 2 modulo bytes xsect[ 10 , ! ] :=
   bytes xsect[ 1 , ! ] bytes xsect[ 10 , ! ] - 2 / bytes xsect[ 1 , ! ] :=
   bytes xsect[ 1 , ! ] 2 modulo bytes xsect[ 9 , ! ] :=
   bytes xsect[ 1 , ! ] bytes xsect[ 9 , ! ] - 2 / bytes xsect[ 1 , ! ] :=
   bytes xsect[ 1 , ! ] 4 modulo bytes xsect[ 11 , ! ] :=
   bytes xsect[ 2 , ! ] 16 modulo bytes xsect[ 6 , ! ] :=
   bytes xsect[ 2 , ! ] bytes xsect[ 6 , ! ] - 16 / bytes xsect[ 5 , ! ] :=
   bytes xsect[ 3 , ! ] 16 modulo bytes xsect[ 8 , ! ] :=
```

```
    bytes xsect[ 3 , ! ] bytes xsect[ 7 , ! ] - 16 / bytes xsect[ 7 , ! ] :=
    bytes xsect[ 4 , ! ] 0.1 * bytes xsect[ 5 , ! ] 0.01 * +
    bytes xsect[ 6 , ! ] 0.001 * + bytes xsect[ 7 , ! ] 0.0001 * +
    bytes xsect[ 8 , ! ] 0.00001 * + maal_val :=
    maal_val bytes xsect[ 10 , ! ] + 1 bytes xsect[ 9 , ! ] 2 * - *
    bytes xsect[ 11 , ! ] 1 - 10 ln * exp * maal_val :=
;

: ANALOG_TO_PHYSICAL

    number_channels 1 + 1 do

       channel_array [ i , 2 ]
       case 2 of                              \ pressure transducer
             maal_val [ 1 , i ]  200  *  maal_val [ 1 , bro_channel ]  /
             channel_array [ i , 3 ]  /  maal_val [ 1 , i ]  :=
          endof
          3 of                                \ Force signal
             maal_val [ 1 , i ]  1000  *  channel_array [ i , 3 ]  *
             maal_val [ 1 , i ]  :=
          endof
\
\          straingauge measurements are calculated in SUBTRACT_REFERANCE
\
          5 of                                \ deformation transducer
             maal_val [ 1 , i ] maal_val [ 1 , bro_channel ] /
             channel_array [ i , 3 ] * maal_val [ 1 , i ] :=
          endof
       endcase
    loop
;

: PUT_ZEROES_AND_VREF_IN_REF_VAL
    number_channels 1 + 1 do
       channel_array [ i , 2 ]
       case 0 of   0  ref_val [ 1 , i ] := endof
            4 of   ref_val [ 1 , i ]  ref_val [ 1 , bro_channel ]  /
                   ref_val [ 1 , i ]     := endof
            6 of   0  ref_val [ 1 , i ] := endof
            7 of   0  ref_val [ 1 , i ] := endof
            8 of   0  ref_val [ 1 , i ] := endof
            9 of   0  ref_val [ 1 , i ] := endof
       endcase
    loop
;

: SUBTRACT_REFERANCE
    number_channels 1 + 1 do
       channel_array [ i , 2 ] tmp_var2 :=
       tmp_var2 2 =  tmp_var2 3 =  tmp_var2 5 =  or or  if
          maal_val [ 1 , i ]  ref_val [ 1 , i ] - maal_val [ 1 , i ] :=
       else
          tmp_var2 4 = if
             maal_val [ 1 , i ] maal_val [ 1 , bro_channel ] /
             ref_val [ 1 , i ] - tmp_val :=
             tmp_val 4 *  tmp_val 2 * 1 + channel_array [ i , 3 ] * /
             maal_val [ 1 , i ] :=
          then
       then
    loop

\
\ Subtract the dynamic friction from the force signal
\
   maal_val [ 1 , force_channel ] maal_val [ 1 , oil_channel ] 28.174 *
   maal_val [ 1 , oil_channel ] maal_val [ 1 , oil_channel ] * 0.075 * -
   1490.44 + - maal_val [ 1 , force_channel ] :=
;
```

```
: FIND_AND_SET_FORMAT
    abs tmp_val :=
    tmp_val 0.999999 <= if
       9 6 fix.format
    else
       tmp_val 9.99999 <= if
          9 5 fix.format
       else
          tmp_val 99.9999 <= if
             9 4 fix.format
          else
             tmp_val 999.999 <= if
                9 3 fix.format
             else
                tmp_val 9999.99 <= if
                   9 2 fix.format
                else
                   tmp_val 99999.9 <= if
                      9 1 fix.format
                   else
                      -1 0 fix.format
                   then
                then
             then
          then
       then
    then
;

: PUT_DATA_IN_FILE
    out>file.cont console.off
    9 1 fix.format elapsed_time "." "type
    number_channels 1 + 1 do
       channel_array [ i , 2 ] 0 > if
          maal_val [ 1 , i ] dup  FIND_AND_SET_FORMAT . 3 spaces
       then
    loop
    cr
    console

    onerr:
       console
       BELL  "  Error  when  writing  data  to  file  -  strike  any  key."
STATUS_MESSAGE
       pckey drop "drop
;

: SHOW_DATA_ON_SCREEN
    actual_sigma_scr
    5 0 fix.format
    8 4 goto.xy scan_counter "." "type
    scan_scr
    7 2 fix.format
    is_screen_off no = if
      " Scan#: " scan_counter "." "cat "  at " "cat "time "cat "  - " "cat
      "date "cat "  elapsed time (s): " "cat elapsed_time "." "cat "type cr
      number_channels 1 + 1 do
         channel_array [ i , 2 ] 0 > if
            2 spaces
            channel_array [ i , 1 ] tmp_var2 :=
            2 0 fix.format  inverse.on  tmp_var2 . inverse.off
            maal_val [ 1 , i ] dup  FIND_AND_SET_FORMAT .
            ?col 70 > if cr then
         then
      loop
      cr
    then
;
```

```
: WRITE_DATA_ON_PRINTER
   no is_printer_off = if
      out>printer
      console.off
     " Scan#: " scan_counter "." "cat "  at " "cat "time "cat "  - " "cat
      "date "cat "  ************************" "cat "type cr
      number_channels 1 + 1 do
         channel_array [ i , 2 ] 0 > if
            maal_val [ 1 , i ] dup  FIND_AND_SET_FORMAT .
            ?col 70 > if cr then
         then
      loop
      cr
      console
   then

   onerr:
      console
      BELL " Printer not online - strike any key to retry operation."
      STATUS_MESSAGE
;

: CALC_AND_PLOT_SIGMA
    maal_val [ 1 , oil_channel ] oil_pressure :=
    maal_val [ 1 , force_channel ] cylinder_areal / oil_pressure + sigma1 :=
    test_time  time_oil_up  < if
       oil_pressure test_time load_speed * - delta_sigma2 :=
       loadpath_display
       bright_blue color
       old_time 0 position test_time 0 draw.to
       bright_red color
       max_delta_sigma2 2 * delta_sigma2 > if
          old_time old_delta_sigma2 position test_time delta_sigma2 draw.to
       else
          BELL
       then
       test_time old_time :=
       delta_sigma2 old_delta_sigma2 :=
    else
       oil_pressure max_oil_level - delta_sigma2 :=
    then

    maal_val [ 1 , force_channel ] old_force < if
       bell2
    then
    maal_val [ 1 , force_channel ] old_force :=

    maal_val [ 1 , flyt_channel ] old_flyt - delta_flyt :=
    maal_val [ 1 , flyt_channel ] old_flyt :=

    actual_sigma_scr
    5 1 fix.format
    1 1 goto.xy sigma1 .
    8 1 goto.xy oil_pressure .
    1 4 goto.xy delta_sigma2 .
    5 4 fix.format
    8 5 goto.xy delta_flyt .

    onerr:
       BELL  " Error in plotting - try again."  STATUS_MESSAGE
;

: MAKE_TOKENS_RESET_VARS
   1 number_channels over over swap
   real    dim[ ? , ? ] unnamed.array []ramp swap
   real    dim[ ? , ? ] unnamed.array 0 * becomes> maal_val
   integer dim[ 11 , number_channels ]  unnamed.array becomes> bytes
   integer dim[ number_channels 3 * ] unnamed.array becomes> byte123
   maal_val becomes> ref_val 0.0 ref_val :=
```

```
   1 number_point :=
   0 scan_counter :=
   1 yes :=
   0 no  :=
   no  is_screen_off :=
   yes is_printer_off :=
   100 100 * pi * 4 / cylinder_areal :=
   0 test_start_time :=
   0 old_force :=
;

: FUNCTION_KEY_TEMPLATE
   4  0 goto.xy ." F1"   3 1 goto.xy ." SCAN"    2 2 goto.xy ." 1>FILE"
   11 0 goto.xy ." F2"  10 1 goto.xy ." SCAN"   10 2 goto.xy ." 1>CRC"
   19 0 goto.xy ." F3"  18 1 goto.xy ." TIME"   17 2 goto.xy ." X>FILE"
   27 0 goto.xy ." F4"  26 1 goto.xy ." REF."   26 2 goto.xy ." SCAN"
   34 0 goto.xy ." F5"  33 1 goto.xy ." STOP"   33 2 goto.xy ." DATA"
   41 0 goto.xy ." F6"  39 1 goto.xy ." CONTIN" 39 2 goto.xy ." PRINT"
   49 0 goto.xy ." F7"  47 1 goto.xy ." SCREEN" 47 2 goto.xy ."  OFF"
   56 0 goto.xy ." F8"  55 1 goto.xy ." START"  55 2 goto.xy ." TEST"
   66 0 goto.xy ." F9"  65 1 goto.xy ." SCAN"   65 2 goto.xy ." FAST"
   73 0 goto.xy ." F10" 73 1 goto.xy ."  "      72 2 goto.xy ."  "
;

: SETUP_GRAPHICS
   normal.coords
   horizontal axis.on  grid.off  linear  0  1  label.points
              no.labels  label.scale.off
   vertical   axis.on  grid.off  linear  0  1  label.points
              -1.2  0.0  2  label.format  label.scale.off

   max_oil_level  load_speed  /  time_oil_up :=

   0.05  0.100   axis.orig
   0.92  0.8     axis.size
   0.05  0.5     axis.point
   10.   6.      axis.divisions
   0.025  0.025  tick.size
   0.5    0.5    tick.just

   0.0  time_oil_up  horizontal axis.fit.off world.set
   -3.  3.           vertical   axis.fit.off world.set
   xy.axis.plot

   world.coords
   blue color
   0.01 0.01 0.01 0.01 dashed
   0. 0 max_delta_sigma2 - position
   time_oil_up 0 max_delta_sigma2 - draw.to
   0.01 0.01 0.01 0.01 dashed
   0. max_delta_sigma2 3 / max_delta_sigma2 - position
   time_oil_up  max_delta_sigma2 3 / max_delta_sigma2 - draw.to
   0.01 0.01 0.01 0.01 dashed
   0. max_delta_sigma2 3 / 2 * max_delta_sigma2 - position
   time_oil_up  max_delta_sigma2 3 / 2 * max_delta_sigma2 - draw.to
   0.01 0.01 0.01 0.01 dashed
   0. max_delta_sigma2 3 /  position
   time_oil_up  max_delta_sigma2 3 /  draw.to
   0.01 0.01 0.01 0.01 dashed
   0. max_delta_sigma2 3 / 2 * position
   time_oil_up  max_delta_sigma2 3 / 2 *  draw.to
   0.01 0.01 0.01 0.01 dashed
   0. max_delta_sigma2 position
   time_oil_up  max_delta_sigma2  draw.to
   time_oil_up  0 max_delta_sigma2 -  draw.to
   solid
```

```
     normal.coords
     0.27 0.05 position " Hydrostatic part of load path" label
     red color
     0.75 0.85 position " Too much oil" label
     0.75 0.15 position " Too little oil" label
     0.10 0.95 position filename label
     bright_red color
     world.coords  0. 0. position  cursor.off
 ;

 : SET_DATAACQ_GRAF_SCREEN
     graphics.display
     text.cursor.off
     16 graphics.display.mode
     SET_COLOR_PALETTE

     header_scr         bright_red    foreground screen.clear
     scan_scr           bright_blue   foreground screen.clear {border}
     status_scr         intens_white  foreground screen.clear
     ftaster_scr        bright_blue   foreground screen.clear
     actual_sigma_scr   green         foreground screen.clear {border}

     loadpath_display
     0.20 0.1325 vuport.orig    0.90 0.2825 vuport.size    vuport.clear
     green  vuport.color  vuport.clear
     blue   axis.color
     blue   label.color
     blue   cursor.color
     red    color
     outline

     SETUP_GRAPHICS

     header_scr   overskrift_string  1  WRITE
     status_scr
     " System initialized. Activate scanning by function-keys"  STATUS_MESSAGE
     ftaster_scr  FUNCTION_KEY_TEMPLATE
     actual_sigma_scr
     text.cursor.off
     0.   0.   goto.xy   " sigma1" "type
     7.   0.   goto.xy   " sigma3" "type
     0.   3.   goto.xy   " dsigm3" "type
     8.   3.   goto.xy   " scan#"  "type
     6    1    fix.format
 ;

 : SET_SCREEN2_UP
    9 7 fix.format
    " Channel#   Type                         Channel constant" 5 1 goto.xy "type
    1 top_row :=
    " TYPE: 0-unused, 1-bridge, 2-pressure, 3-force, 4-gauge, 5-deformation"
    5 22 goto.xy "type
    number_channels 1 + 1 do
       1 i top_row + goto.xy i first_channel + 1 - "." "type
      16 i top_row + goto.xy " 0" "type
      19 i top_row + goto.xy " <not in use>" "type
      45 i top_row + goto.xy 0.0 "." "type
    loop
 ;
 : ENTER_DATA_FOR_CHANNELS

    {def} screen.clear
    SET_SCREEN2_UP
    1 no_of_felt :=
    0 antal_bro  :=
    999 bro_channel :=
```

```
0 channel_array :=
channel_array sub[ 1 , 20 ; 1 , 1 , 0 ] []ramp
first_channel channel_array sub[ 1 , 20 ; 1 , 1 , 0 ] + 1 -
channel_array sub[ 1 , 20 ; 1 , 1 , 0 ] :=

begin
 stack.clear
 channel_array [ no_of_felt , 2 ]
 case 0 of " 0" endof
      1 of " 1" endof
      2 of " 2" endof
      3 of " 3" endof
      4 of " 4" endof
      5 of " 5" endof
      6 of " 6" endof
      7 of " 7" endof
      8 of " 8" endof
      9 of " 9" endof
 endcase

 16 no_of_felt top_row + goto.xy 1  "answer 0 "number if
                 dup  channel_array [ no_of_felt , 2 ] :=

   case 1 of 19 top_row no_of_felt + goto.xy " <bridge excitation>  " "type
             no_of_felt bro_channel :=
            endof
        2 of 19 top_row no_of_felt + goto.xy " <pressure transducer>" "type
             45 no_of_felt top_row + goto.xy 9
             channel_array [ no_of_felt , 3 ] "." "answer 0 "number
             channel_array [ no_of_felt , 3 ] :=
             no_of_felt oil_channel :=
            endof
        3 of 19 top_row no_of_felt + goto.xy " <vert. force transd.>" "type
             45 no_of_felt top_row + goto.xy 9
             channel_array [ no_of_felt , 3 ] "." "answer 0 "number
             channel_array [ no_of_felt , 3 ] :=
             no_of_felt force_channel :=
            endof
        4 of 19 top_row no_of_felt + goto.xy " <strain gauge>       " "type
             45 no_of_felt top_row + goto.xy 9
             channel_array [ no_of_felt , 3 ] "." "answer 0 "number
             channel_array [ no_of_felt , 3 ] :=
            endof
        5 of 19 top_row no_of_felt + goto.xy " <deformation transd.>" "type
             45 no_of_felt top_row + goto.xy 9
             channel_array [ no_of_felt , 3 ] "." "answer 0 "number
             channel_array [ no_of_felt , 3 ] :=
             no_of_felt flyt_channel :=
            endof
        0 of
             19 no_of_felt top_row + goto.xy " <not in use>        " "type
             45 no_of_felt top_row + goto.xy 0.0 "." "type
            endof
        0 " wrong channel-type" 24 WRITE BELL "drop
   endcase

   case  0 of    no_of_felt no_of_felt      :=  endof
        13 of    no_of_felt 1 + no_of_felt  :=  endof
        71 of    1 no_of_felt               :=  endof
        72 of    no_of_felt 1 - no_of_felt  :=  endof
        73 of    1 no_of_felt               :=  endof
        75 of    no_of_felt 1 - no_of_felt  :=  endof
        77 of    no_of_felt 1 + no_of_felt  :=  endof
        79 of    number_channels no_of_felt :=  endof
        80 of    no_of_felt 1 + no_of_felt  :=  endof
        81 of    number_channels no_of_felt :=  endof
    endcase
     1 24 goto.xy 78 spaces
```

```
        else
           " non-numeric character entered - try again" 24 WRITE BELL
        then
        0 no_of_felt = 1 number_channels + no_of_felt = or if
           0 antal_bro   :=
           0 antal_force :=
           0 antal_oil   :=
           number_channels 1 + 1 do
              channel_array [ i , 2 ] 1 = if antal_bro   1 + antal_bro   := then
              channel_array [ i , 2 ] 2 = if antal_oil   1 + antal_oil   := then
              channel_array [ i , 2 ] 3 = if antal_force 1 + antal_force := then
           loop
           antal_bro 1 > antal_bro 1 < or if
             1 24 goto.xy 78 spaces
   " Error: too many or no channel(s) for bridge excitation entered - try again."
             2 24 goto.xy "type BELL
             1 no_of_felt :=
           then
           antal_oil 1 > antal_oil 1 < or if
             1 24 goto.xy 78 spaces
     " Error: too many or no channel(s) for oil transducer entered - try again."
             2 24 goto.xy "type BELL
             1 no_of_felt :=
           then
           antal_force 1 > antal_force 1 < or if
             1 24 goto.xy 78 spaces
  "Error: too many or no channel(s) for vert. force trans. entered - try again."
             2 24 goto.xy "type BELL
             1 no_of_felt :=
           then
        then
      0 no_of_felt = 1 number_channels + no_of_felt = or
      until
;

: SET_SCREEN1_UP
   menu_scr screen.clear

   " Enter disk drive for the datafile ........> " 10  3 goto.xy "type
   " Enter datafile name (max 15 char).........> " 10  4 goto.xy "type
   " Enter first channel to scan ..............> " 10  6 goto.xy "type
   " Enter last channel to scan ...............> " 10  7 goto.xy "type
   " Enter load speed (MPa/s) .................> " 10  9 goto.xy "type
   " Enter maximum oilpressure in test (MPa)...> " 10 10 goto.xy "type
   " Enter maximum allowable oilpressure (MPa).> " 10 12 goto.xy "type

   " C"         "dup  drive_name        ":=  54  3 goto.xy "type
   " TRIAX.DAT" "dup  file_name_min     ":=  54  4 goto.xy "type
   " 0  "       "dup  first_channel_str ":=  54  6 goto.xy "type
   " 3  "       "dup  last_channel_str  ":=  54  7 goto.xy "type
   " 0.3 "      "dup  load_speed_str    ":=  54  9 goto.xy "type
   " 1    "     "dup  max_oil_level_str ":=  54 10 goto.xy "type
   " 140"       "dup  max_oil_str       ":=  54 12 goto.xy "type

  1 no_of_felt  :=
;

: GET_MENU_PARAMETERS
   SET_SCREEN1_UP
   begin
      no_of_felt
      case  1 of  54  3 goto.xy  1 drive_name          "answer
                  drive_name        ":=  endof
            2 of  54  4 goto.xy 12 file_name_min       "answer
                  file_name_min     ":=  endof
            3 of  54  6 goto.xy  3 first_channel_str   "answer
                  first_channel_str ":=  endof
            4 of  54  7 goto.xy  3 last_channel_str    "answer
                  last_channel_str  ":=  endof
```

```
            5 of  54  9 goto.xy  4 load_speed_str    "answer
                  load_speed_str    ":=  endof
            6 of  54 10 goto.xy  5 max_oil_level_str "answer
                  max_oil_level_str ":=  endof
            7 of  54 12 goto.xy  3 max_oil_str       "answer
                  max_oil_str       ":=  endof
      endcase
      case 13 of   no_of_felt 1 + no_of_felt :=  endof
           71 of   1 no_of_felt :=               endof
           72 of   no_of_felt 1 - no_of_felt :=  endof
           73 of   1 no_of_felt :=               endof
           75 of   no_of_felt 1 - no_of_felt :=  endof
           77 of   no_of_felt 1 + no_of_felt :=  endof
           79 of   7 no_of_felt :=               endof
           80 of   no_of_felt 1 + no_of_felt :=  endof
           81 of   7 no_of_felt :=               endof
      endcase
      no_of_felt dup  0 = 8 = or
   until

   drive_name " :" "cat file_name_min "cat filename ":=
   first_channel_str  0  "number  first_channel     :=
   last_channel_str   0  "number  last_channel      :=  and
   load_speed_str     0  "number  load_speed        :=  and
   max_oil_level_str  0  "number  max_oil_level     :=  and
   max_oil_str        0  "number  max_allow_oil     :=  and  if
      last_channel first_channel - 1 + number_channels :=
      number_channels 20 > if
         " ERROR: no more than 20 channels are supported in this version."
         21 WRITE  BELL  myself
      then
      MAKE_DATLOG_COMMAND
      MAKE_TOKENS_RESET_VARS
      ENTER_DATA_FOR_CHANNELS
      screen.clear
      " Y" koert_opsaet ":=
   else
      " ERROR: non-numerical data entered somewhere - try again."
      21 WRITE  BELL myself
   then

   onerr:
      BELL  " Incorrect reply or other error, retry whole operation."
      STATUS_MESSAGE
;

: END_PROGRAM
   -1 4 fix.format  menu_err_scr  screen.clear
   " Do you really want to terminate the program (Y/N) .....> "
   4 WRITE key dup 121 = 89 = or
   if
      bye
   else
      screen.clear
   then
;

: WRITE_SETUP_TO_FILE
    filename defer> out>file console.off
    rel.time start_time :=
    " Starting logging of data at: " "type .time "  - " "type .date cr cr
    1 tmp_var2 :=
    "     col: " tmp_var2 "." "cat " : elapsed time since start of test."
    "cat "type cr
    number_channels 1 + 1 do
       channel_array [ i , 2 ]
       -1 0 fix.format
       0 > if
          tmp_var2 1 + tmp_var2 :=
```

```
            "    col: "  tmp_var2  "." "cat
            channel_array [ I , 2 ]  dup
            case 1 of " : Bridge excitation (V)                " endof
                 2 of " : Oil pressure (MPa)                   " endof
                 3 of " : Vertical force (N)                   " endof
                 4 of " : Strain_gauge (microstrain)           " endof
                 5 of " : Deformation transducer (microstrain) " endof
            endcase
            "cat
            1 > if
               10 6 fix.format
               " trans.const.: " "cat channel_array [ i , 3 ] "." "cat
            then
            "type cr
         then
      loop
      cr cr
      console

      onerr:
         BELL " Error when writing to file - stop and start again"
         STATUS_MESSAGE
;

: SCAN
   send.interface.clear ME_TALKER
   command talk  " VS" talk  DATALOGGER_TALKER  buffer.listen
   bcddat unpack becomes> unpacked_bcddat
   unpacked_bcddat sub[ first_channel , number_channels 3 * ] becomes> byte123
   previous_time rel.time >  if
      no_of_days 1 + no_of_days :=
   then
   rel.time start_time - 1000 / 86400 no_of_days * + dup elapsed_time :=
   previous_time :=
   elapsed_time test_start_time - test_time :=
   BIN_DEC_CONVERTION
;

: OPEN_CLOSE_CURRENT
   yes is_current_on = if
      oil_pressure max_allow_oil > if
         send.interface.clear ME_TALKER current_off talk
         no is_current_on :=
      else
         send.interface.clear ME_TALKER current_on  talk
      then
   else
      oil_pressure max_allow_oil <= if
         send.interface.clear ME_TALKER current_on talk
         yes is_current_on :=
      then
   then
;

: CONTROL_SCAN
   WRITE_SETUP_TO_FILE
   send.interface.clear  device.clear  remote.enable.on
   send.interface.clear ME_TALKER current_on talk
   yes is_current_on :=

   begin
    ?key if
     pckey  ?drop
     case 59 of                \ F1 - scan once, and put in file
          1 scan_counter + scan_counter :=
          SCAN ANALOG_TO_PHYSICAL SUBTRACT_REFERANCE
          SHOW_DATA_ON_SCREEN
          PUT_DATA_IN_FILE
          " Data have been stored in file."  STATUS_MESSAGE
```

```
      WRITE_DATA_ON_PRINTER  CALC_AND_PLOT_SIGMA
      OPEN_CLOSE_CURRENT
   endof
   60 of                          \ F2 - scan once, only to screen
      SCAN
      ANALOG_TO_PHYSICAL  SUBTRACT_REFERANCE
      SHOW_DATA_ON_SCREEN
      " None of the above data are stored in file."
      STATUS_MESSAGE
   endof                          \ F3 - scan with a given timeinterval
   61 of
      " Enter time in sec. between scans: "
      STATUS_MESSAGE  NUMBER_CHK  1000 * time_between_scans :=
      -1 0 fix.format
      " press any key to stop " time_between_scans 1000 / "." "cat
      " second scans" "cat STATUS_MESSAGE
      no stop_timescan :=
      rel.time time_between_scans + next_time :=
      begin
         next_time 864E5 > if
            begin
               rel.time 500 msec.delay rel.time >=
            until
            next_time 864E5 - next_time :=
         then
         rel.time next_time >= if
            1 scan_counter + scan_counter :=
            SCAN  ANALOG_TO_PHYSICAL  SUBTRACT_REFERANCE
            SHOW_DATA_ON_SCREEN  PUT_DATA_IN_FILE
            WRITE_DATA_ON_PRINTER
            CALC_AND_PLOT_SIGMA
            OPEN_CLOSE_CURRENT
            rel.time time_between_scans + next_time :=
         then
         ?key if
            pckey drop ?drop yes stop_timescan :=
            " Timed scanning stopped." STATUS_MESSAGE
         then
         stop_timescan yes =
      until
   endof
   62 of                          \ F4 - reference scan
      SCAN  ANALOG_TO_PHYSICAL  SHOW_DATA_ON_SCREEN
      maal_val becomes> ref_val
      PUT_ZEROES_AND_VREF_IN_REF_VAL
      " Reference scan has been made - this scan NOT stored."
      STATUS_MESSAGE
   endof
   63 of                         \ F5 - stop logging, and return to menu
      BELL
      " Do you really want to stop data-acquisition (Y/N)"
      STATUS_MESSAGE
      key  dup  121  =  89  =  or
      if
         normal.display
         out>file.close
         text.cursor.on   exit
      else
         " Returning to data-acquisition"  STATUS_MESSAGE
      then
   endof
   64 of                         \ F6 - continuesly logging on printer
      " Continous printing of scanned data on printer (Y/N):"
      STATUS_MESSAGE
      key  dup  121  =  89  =  or
      if
         " Scanned data will be printed (except when using F2-key)"
         STATUS_MESSAGE
         no is_printer_off :=
```

```
               else
                  " Data will no longer be printed"
                  STATUS_MESSAGE
                  yes is_printer_off :=
               then
            endof
            65 of                      \ F7 - disconnect screen
               yes is_screen_off = if
                  no is_screen_off :=
                  status_scr 69 0 goto.xy "           " "type
               else
                  yes is_screen_off :=
                  status_scr 69 0 goto.xy " Screen off" "type
               then
            endof
            66 of                      \ F8 - start timing of the test

               rel.time start_time - 1000 / test_start_time :=
               0 old_time :=
               0 old_delta_sigma2 :=
               " Test-timing have been started."
               STATUS_MESSAGE
            endof
            67 of                      \ F9 - scan as fast as possible
              " Contineous scanning started - strike any key to stop"
              STATUS_MESSAGE
              no stop_timescan :=
              begin
                 1 scan_counter + scan_counter :=
                 SCAN  ANALOG_TO_PHYSICAL  SUBTRACT_REFERANCE
                 SHOW_DATA_ON_SCREEN
                 PUT_DATA_IN_FILE
                 WRITE_DATA_ON_PRINTER
                 CALC_AND_PLOT_SIGMA
                 OPEN_CLOSE_CURRENT
                 ?key if
                    pckey drop ?drop yes stop_timescan :=
                    " Contineous scanning stopped." STATUS_MESSAGE
                 then
                 stop_timescan yes =
             until
          endof
          BELL
        endcase
      then
     again
;

: MENU_TEXT
   menu_scr
   bright_red foreground
   overskrift_string
   1 WRITE
   bright_blue foreground
   " Main menu for triaxial test control package."
   5  WRITE
   " 1:  Declare parameters for dataacquisition ......"
   9  WRITE
   " 2:  Start measurements .........................."
   10 WRITE
   " 9:  Exit program ................................"
   13 WRITE
;
```

```
: MENU
    stack.clear  MENU_TEXT
    menu_scr  " Choose item please ......> "
    17 wrt
    menu_err_scr screen.clear
    case 1 of  GET_MENU_PARAMETERS myself
           endof
         2 of  koert_opsaet  " Y" "= if
                  SET_DATAACQ_GRAF_SCREEN
                  CONTROL_SCAN
                  STOP_ACQUIS
               else
                  menu_err_scr
                  BELL
                  " Parameters for the test have not been set - do that first"
                  4 WRITE
               then
               myself
           endof
         9 of  END_PROGRAM  myself
           endof
         ERROR_IN_CHOICE myself
    endcase
;

: MAIN
    normal.display
    SET_COLORS
    SET_DEF_VARS
    {def}  screen.clear
    menu_err_scr blue background  bright_blue foreground  screen.clear
    menu_scr     blue background  bright_blue foreground  screen.clear
    MENU
;

\*************************************EOF**************************************

 install MAIN in turnkey
 make.turnkey c:triax
 install nop in turnkey
```