HETEK

Control of Early Age Cracking in Concrete
Phase 8: Modelling of Support Conditions

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1997

Road Directorate Denmark Ministry of Transport

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Abstract	This report forms a part of the Danish Road Directorate's research programme called High Performance Concrete - The Contractor's Technology (abbreviated to HETEK). This report describes the modelling of support conditions in relation to stress calculations for early age concrete. Due to thermal strains and shrinkage during the hardening process of concrete, cracks can be formed. By means of stress calculations a method of construction not resulting in cracks can be chosen.	
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0. Preface

This project on control of early age cracking is part of the Danish Road Directorate's research programme, High Performance Concrete - The Contractor's Technology, [1] abbreviated to HETEK.

In this programme high performance concrete is defined as concrete with a service life in excess of 100 years in an aggressive environment.

The research programme includes investigations concerning the contractor's design of high performance concrete and execution of the concrete work with reference to the required service life of 100 years.

The total HETEK research programme is divided into segments/parts with the following topics:

- chloride penetration
- frost resistance
- control of early-age cracking
- compaction
- curing (evaporation protection)
- trial casting
- repair of defects.

The Danish Road Directorate invited tenders for this research programme which is mainly financed by the Danish Ministry for Commerce and Industry - The Commission of Research and Development Contracts.

The present report refers to the part of the HETEK project which deals with control of early age cracking.

For durability reasons reinforced structural members should be well protected against penetration of water, chloride etc. This means that cracks should be avoided or at least the crack-width limited. Formation of cracks can take place already during the hardening process. An evaluation of the risk of crack formation involves a stress analysis. In stress analysis of hardening concrete structures, the load consists of the differences in thermal strains that arise from the heat of hydration. The mechanical properties (including autogenous shrinkage) of the concrete also change during the hardening process. If a stress analysis shows high stresses compared to the tensile strength there is a high risk of crack formation.

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[1] In Danish: Højkvalitetsbeton - Entreprenørens Teknologi

The purpose of this project is to investigate these effects and to prepare a guideline regarding Control of Early Age Cracking.

The project was carried out by a consortium consisting of:

Danish Concrete Institute, represented by:

Højgaard & Schultz A/S
Monberg & Thorsen A/S
RAMBØLL
COWI

and

Danish Technological Institute, represented by the Concrete Centre

and

Technical University of Denmark, represented by the Department of Structural Engineering and Materials.

Two external consultants, professor Per Freiesleben Hansen and manager Jens Frandsen, are connected with the consortium.

1. Scope

In order to avoid durability problems in reinforced concrete structures it is intended to limit the formation of cracks during the hardening period. Cracks can of course be caused by external loads, settlements, etc., but there is also a risk of crack formation during the hardening process. The main cause of cracks in this period is thermal strains arising from the heat development of the concrete and shrinkage strains. Thermal strains have traditionally been limited by requiring the contractor to plan the concrete work so that large temperature differences between different parts of the structure do not arise. The strain arising from autogenous shrinkage cannot be affected by the contractor except through the choice of concrete mix design, but shrinkage arising from evaporation can be avoided by making an appropriate evaporation protection. If restrained, the thermal and shrinkage strains causes stresses in the concrete. The size and distribution of these stresses are affected by the structures support conditions. It is thus important to model the support conditions of the considered structure accurately.

2. Introduction

For accurate stress analyses of hardening concrete structures, the correct modelling of the support conditions is essential. The support conditions affects both the size and distribution of stresses.

It is complicated to model the actual support conditions of hardening concrete structures. However, in principle the modelling is similar to the modelling of the support conditions in an ordinary static analysis of any structure.

In order to model the support conditions accurately, the properties of the adjoining materials (e.g. soil, previously cast concrete and blinding layer) shall be modelled as well as the interaction between the considered structural part and the adjoining materials.

However, for practical applications of stress analyses, it is usually necessary to simplify the support conditions to reduce the complexity of the problem and the calculation time. The difficulty in simplifying the support conditions, is to make sure that the simple model results in a realistic and conservative estimate of the stresses with regard to the risk of cracking.

The present report outlines different methods of modelling the support conditions of hardening concrete structures, and describes some of the effects of different types of supports on the stress and deformation development. Furthermore, a number of guidelines are given for modelling of support conditions for practical applications.

In addition, a case study is presented in which the deformations of a real hardening concrete structure cast in situ have been measured.

2.1 Modelling of Support Conditions

The modelling of the support conditions of a concrete structure involves several important aspects such as:

- modelling of the properties of adjoining materials such as soil, previously cast concrete and blinding layer
- modelling of the geometry of adjoining structural parts or materials
- modelling of the interaction between the concrete and the adjoining materials

Modelling of Adjoining Materials

The modelling of previously cast concrete is usually simple as the concrete properties such as the modulus of elasticity and Poisson's ratio usually are well defined. In contrast, the modelling of the soil underneath the concrete structure is much more difficult as it depends on the composition of the soil, and materials such as rock, sand and clay have very different behaviour. Accurate material models for the soil are complicated and requires detailed knowledge about the material e.g. from in situ tests.

Modelling of the Geometry of Adjoining Materials

When modelling large concrete structures, the size of the structures may require simplification of the geometry in order to keep the duration of the temperature and stress calculation within acceptable limits.

If the Finite Element Method (FEM) is used for stress analysis, the necessary size of the adjoining materials can be estimated by modelling a part of the adjoining material and evaluate the part of the structure of concern which is stressed the most. By changing the size or the stiffness of the adjoining material/structure it is possible to find the size/stiffness where a change does not influence the stresses evaluated by more than 2-5%.

Example
A new wall section 30 cm wide, 10 meter long and 4 meter high is cast on top of a wall of a total height of 50 meters.

First the new wall is modelled on top of a 4 meter high wall section of old concrete. The maximum tensile stress is calculated to say 1.00 MPa.

Second the same new wall section is modelled on top of an 8 meter high old wall section. Assuming the maximum stress to be 1.10 MPa, a new calculation is required. Let's assume that an old concrete wall section with a height of 12 meters results in a maximum tensile stress of 1.12 Mpa then the influence is seen to decrease and the height to be used for detailed calculations can be assumed to be 12 meters out of the total of 50 meters.

Modelling of the Interaction Between the Concrete and Adjoining Materials

The strength of the bond between hardening and adjoining hardened concrete depends e.g. on the execution of the concrete work. However, if the concrete work is carried out according to good practice, i.e. the construction joint is made rough and wetted thoroughly before casting, the bond is usually very strong and it can be assumed that the hardening and hardened concrete are connected. The connection between hardening and hardened concrete has been verified in a full-scale laboratory test [Pedersen, 1997].

The interaction between a concrete structure and the soil underneath is very difficult to model accurately. Figure A1 in Appendix A shows four different deformation patterns and reaction distributions in the heating and cooling phase of a wall cast on a foundation. Two different wall lengths are considered.

Figure A1 shows that there may develop a gab between the concrete and the ground. Ideally, this gab should be included in the modelling of the support conditions as well as the friction between the concrete structure and the ground.

At present, it is not possible to determine the coefficient of friction between the concrete and the ground accurately by simple means, and the estimates that can be found in handbooks etc. vary widely. Accordingly, it is difficult to give safe and reasonable guidelines regarding friction for practical applications of stress analyses.

Modelling the traditional wall cast on top of a foundation slab placed on soil with a full 3 dimensional model will reveal deformations as shown in Figure A2 in Appendix A. The deformations are seen from an elevation of the wall. As the wall contracts due to the natural cooling and the slab resist this contraction, then the free end of the slab is forced up causing a mechanism lifting the slab from the soil. As this happens the self weight of the slab and the wall will act against this behaviour. Lifting the slab at the free end, will increase the pressure on the soil at the centre of the slab causing additional deformations in the soil. From a pragmatic point of view, slip will not occur as long as the lifting stress is less than the selfweight stresses on the soil.

3 dimensional calculations have revealed that the stresses in the bottom of the wall are not influenced significantly by the stiffness of the soil. However, the stiffness of the soil influences the stresses in the top of the wall. The stiffer soil the higher stresses in the top of the wall i.e. the same effect as the length of the wall. The longer the wall, the higher stresses in the top of the wall, while the stresses in the bottom of the wall is less influenced. The behaviour is confirmed by Figure A3 from [ACI Committee 207, 1980].

The effect on the structures is that having a fixed width and height of wall and slab will cause stresses in the bottom of the wall, where the highest stresses will be found, which will indicate whether cracks will be present or not. Short walls on soft soil may crack as well as long walls on stiff soil, but the cracks will not develop to the same height in a short wall as in a long wall i.e. the cracks will be shorter in a short wall than in a long wall.

2.2 Simplifications

The true modelling of the support conditions of concrete structures require a model including the ground underneath the concrete structure. However, for practical applications, the support conditions are usually simplified to avoid the modelling of the ground.

At present, the majority of the commercial computer programs for temperature and stress analysis of hardening concrete structures are based on the finite element method, and models the support conditions by prescribing either free of fixed displacement of the individual nodes in the x-, y- or z-direction. This principle can be used to model the support conditions of concrete structures.

Figure A4 in Appendix A shows examples of different types of support conditions in the plane and out of the plane modelled using the principle described above. By combining the in plane and out of plane supports, a large number of support conditions can be modelled.

The compensation plane method for two dimensional problems is an approximated method for calculating stresses in prismatic structures with an intermediate zone without shear deformations as described in [Pedersen, 1996].

The compensation plane method offers two choices (free or fixed) for each of the following deformation patterns:

- curvature around the x-axis, see Figure A4
- curvature around the y-axis, see Figure A4
- longitudinal deformation, see Figure A4

A structures ability to curve around the x-axis which has a significant effect of the size and distribution of stresses is affected by the length of the structure as shown in Figure A1 in Appendix A. If the length of the structure is small, the structure will curve around the x-axis. If the length is large, the middle part of the structure will not curve whereas curvature occur at the ends.

For practical applications of stress analyses using the compensation plane method, it would be beneficial to be able to determine whether the actual structure will curve around the x-axis or not. However, it is not possible, at present, to give precise guidelines to solve this problem. The stiffness of the subgrade and the length of the structure should be considered.

If the structure is cast on a very stiff subgrade, e.g. solid rock, no curvature will occur. If the structure is cast on subgrade of sand or clay, curvature may be possible.

Structures with a length to height ratio larger than approx. 3 to 4 can usually be considered as long structures with no or very limited curvature in the middle part, however, using the compensation plane method it is recommended to make two calculations for such structures (free and fixed curvature) to check that both support conditions lead to an acceptable risk of cracking. For short structures, with a length to height ratio smaller than approx. 2, free curvature can usually be assumed.

When carrying out 3 dimensional analyses, the actual length of the structure can be modelled and the problem related to long/short structures is irrelevant. However, the structures ability to curve must still be modelled, see Figure A2.

3. Consequences of the Support Conditions

The support conditions affect the stress distribution in hardening concrete structures significantly which means that measures for temperature control (e.g. cooling and heating) should be designed to the particular support conditions. In the following, some of the most important effects of the support conditions on the stress distribution are described and the consequences for the measures for temperature control are outlined.

Figure B1 in Appendix B shows the distribution of stresses in the longitudinal direction for a wall cast on a previously cast foundation at the end of the cooling period under the assumption of free curvature around the x-axis. Figure B2 shows the corresponding situation under the assumption of fixed curvature around the x-axis.

Figure B1 and B2 shows that the main effect of fixing the curvature around the x-axis is that high tensile stresses also develop in the top of the wall whereas free curvature only results in high tensile stresses in the bottom of the wall. This means that for structures with free curvature (short structures) cooling pipes should be located in the lower part of the wall whereas cooling pipes should be more evenly distributed in structures with fixed curvature (long structures).

A structures ability to expand and contract in the longitudinal direction has also essential influence on the strategy for temperature control. If a wall cast on a previously cast foundation is considered, and heating of the foundation is suggested as a means of preventing early-age cracking, it should be considered carefully whether the foundation is able to expand and contract in the longitudinal direction. If not, the heating of the foundation has no effect on the stress development in the wall.

4. Case Study

This Chapter presents the results of a case study measuring the deformations on a real concrete structure cast in situ.

4.1 Geometry and Casting Sequence

The dimensions of the tunnel considered are shown in Figure C1 in Appendix C. The tunnel was cast in two halves. In the present report only the casting of the first half is considered. The length is 18.15 m. The tunnel was founded directly on the ground with a 50 mm blinding layer.

The two foundations were cast several weeks prior to the simultaneous casting of the walls and the deck. For the walls and the deck, the duration of casting was 9 hours.

4.2 Concrete Properties

The following concrete properties were measured for the actual concrete:

- adiabatic heat development
- development of compressive and splitting tensile strength
- development of modulus of elasticity
- coefficient of thermal expansion
- creep and autogenous shrinkage.

The measuring programme corresponds to the one used in [Spange, 1996]. The test reports are owned by the contractor executing the concrete work.

4.3 Temperature Control

To prevent early-age cracking of the walls and the deck, 8 heating wires each with an effect of 133 kJ/mh were cast into each of the foundations. The heating was started 65 hours before casting was started and turned off 25 hours after casting was started. The exact location of the heating wires was not recorded.

The formwork on the outer surfaces was 19 mm plywood and the formwork on the inner surfaces was 22 mm timber. The free surface of the deck was covered with plastic foil.

For the outer and inner surfaces of the walls, the formwork was removed after 3 and 7 days respectively. The deck formwork was removed after 9 days.

4.4 Temperature Measurements

The temperature in the concrete was measured in 11 locations as shown in Figure C2. In addition, the air temperature was measured. The measured air temperature is shown in Appendix C Figure C3, and the measured temperature development in the concrete is shown in Figures C4, C6 and C8.

Figure C10 and C11 show the temperature differences measured between the average temperature of the wall and the foundation, and the deck and the wall respectively. The average temperatures in Figure C10 and C11 are calculated according the following principle:

$$T_{average} = 1/6 * T_{surface\,1} + 1/6 * T_{surface\,2} + 2/3 * T_{center}$$

Figure C10 shows that the development of the average temperature of the wall and the average temperature of the foundation in principle are similar. However, the temperature of the foundation is higher than the wall before peak temperature and lower than the wall after peak temperature.

4.5 Deformation Measurements

The deformations of the concrete wall were measured on the outer surface as the deformations between two measuring points with a distance of 200 mm. The deformations were measured with the DEMEC equipment which has a measuring accuracy of better than ±1📪10^{-5} strain. The deformations were measured in 30 locations of which 25 were located on the wall and 5 on the foundation as shown in Figure C12 and Table C1 in Appendix C.

The measuring points on the foundation were glued to the surface of the concrete close to the wall. The measuring points on the wall were glued to a Ø16 mm threaded steel bar placed in a cast-in insert, see Figure C13. In order to be able to measure the deformations while the forms were still on, Ø28 mm holes were drilled in the form to allow free movement of the threaded steel bar.

The measured deformations of the concrete are shown in Figure C14.
The figure shows that, as can be expected, the deformations increase toward the free top of the wall and toward the free ends of the casting section.

4.6 Crack Survey

After the concrete had cooled down to the ambient temperature, a crack survey was carried out and no cracks were observed.

4.7 Temperature and Stress Calculations

A temperature and two stress analyses have been carried out to evaluate the correspondence between the measured and calculated deformations. The calculations were carried out with the CIMS2D program based on the compensation plane method. To make the calculation of deformations as accurate as possible some of the input data to the temperature calculation were modified to obtain as good a correspondence between the measured and calculated temperature development as possible.

In Appendix C Figure C15 the model used for temperature and stress calculations is shown. In Figure C5, C7 and C9, the calculated temperature development is shown. The correspondence between the measured and calculated temperature development can be evaluated by comparing Figures C4 to C5, C6 to C7 and C8 to C9. The maximum deviation between measurement and calculation is approx. 2-5°C.

The calculated stress level in the wall and deck is shown in Appendix D Figure D1 to D5 under the assumption that curvature is fixed, and in Appendix E Figure E1 to E5 under the assumption that the structures curvature is free. The crack risk defined as the ratio of the main tensile stress to the tensile strength is below approx. 0.4 at all times for fixed curvature and below approx. 0.5 for free curvature, except at the upper surface of the deck where the risk of cracking is approx. 1 at 20 hours.

Figure F1 and F2 in Appendix F compares the measured and calculated deformations at the outer surface in line C, i.e. in the middle of the wall where the effect of the end zones is smallest, for respectively free and fixed curvature.

Comparing Figure F1 and F2 it can be concluded that there is little effect of the modelling of the structures ability to curve on the deformations in the concrete. This somewhat surprising conclusion may be the result of the heating of the foundations. The heating and cooling of the foundations almost follows the heating and cooling of the walls which means that the structure has very limited curvature. Instead the structure is just expanding and contracting in the longitudinal direction.

The planning and execution of temperature control during hardening was carried out by the contractor that carried out the concrete work. This means that the method of temperature control was not designed for the purpose of this investigation, namely to clarify the structures ability to curve.

Figure F1 and F2 also shows that the correspondence between measured and calculated deformations seems to decrease towards the top of the wall. This can be explained by an increasing effect of the shearing deformations at the end zones which has the largest effects at the top of the wall.

5. Summary

In practical applications of temperature and stress analyses of hardening concrete structures, the modelling of the support conditions is usually simplified.

One of the most important parameters in the modelling is the structures ability to curve around the horizontal axis in the cross-sections plane.

At present, it is not possible to give precise guidelines to determine whether free or fixed curvature will occur.

It is recommended that structures with a length to height ratio longer than approx. 3 to 4 are considered long and that two calculations are carried out (fixed and free curvature).

For short structures with a length to height ratio less than approx. 2, free curvature can be assumed.

The measured deformations in a real concrete structure on site indicates that the considered structure expands and contracts in the longitudinal direction, i.e. it is not fixed to the ground underneath.

6. Literature

ACI Committee 207, Cooling and insulating systems for mass concrete, Concrete International, Vol. 2, no. 5, 1980.

Pedersen, E.S. et al.: "HETEK - Control of Early Age Cracking in Concrete - State of the Art", Danish Road Directorate, Report no. 52, 1996.

Pedersen, E.J. and Spange, H.: "HETEK - Control of Early Age Cracking in Concrete - Phase 7: "Measured and Predicted Deformations in Hardened Concrete". Danish Road Directorate, Report. no. 106, 1997.

Spange, H. and Pedersen, E.S.: "HETEK - Control of Early Age Cracking in Concrete - Phase 1: Early Age Properties of Selected Concrete", Danish Road Directorate, Report no. 59, 1996.

APPENDIX A

Figure A1: Schematic deformation pattern and reaction distribution for a wall cast on a foundation in the heating and cooling phase.

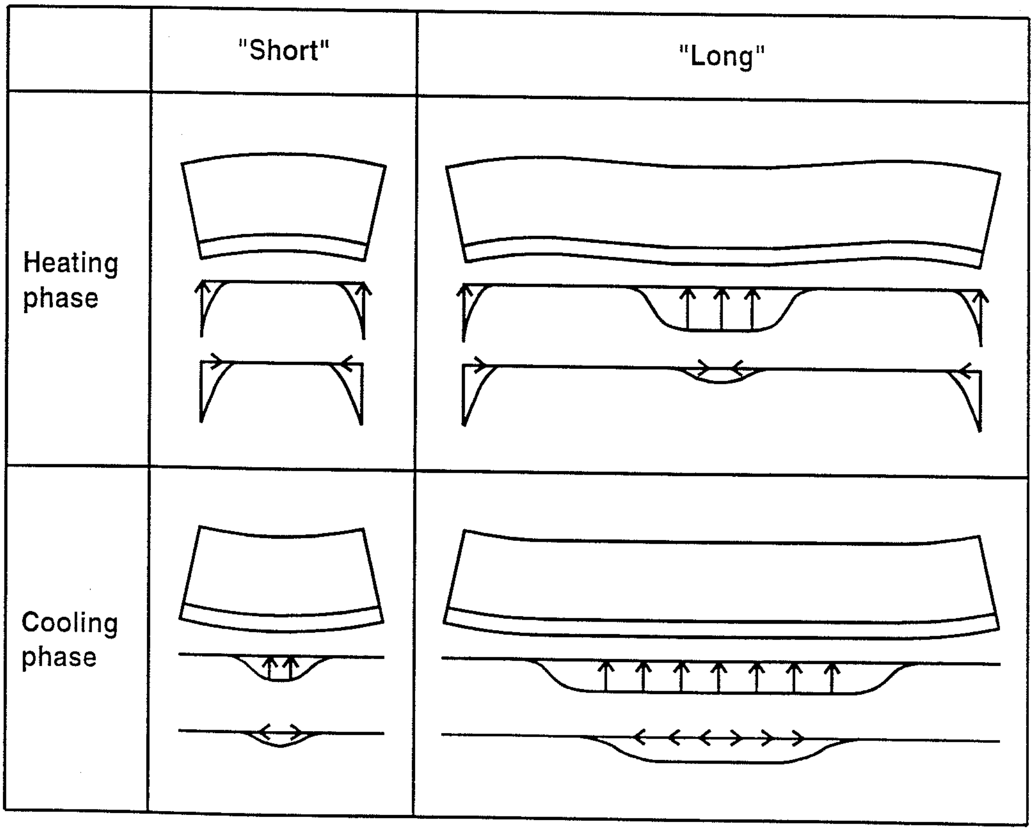


Figure A2: Deformation of wall due to contraction

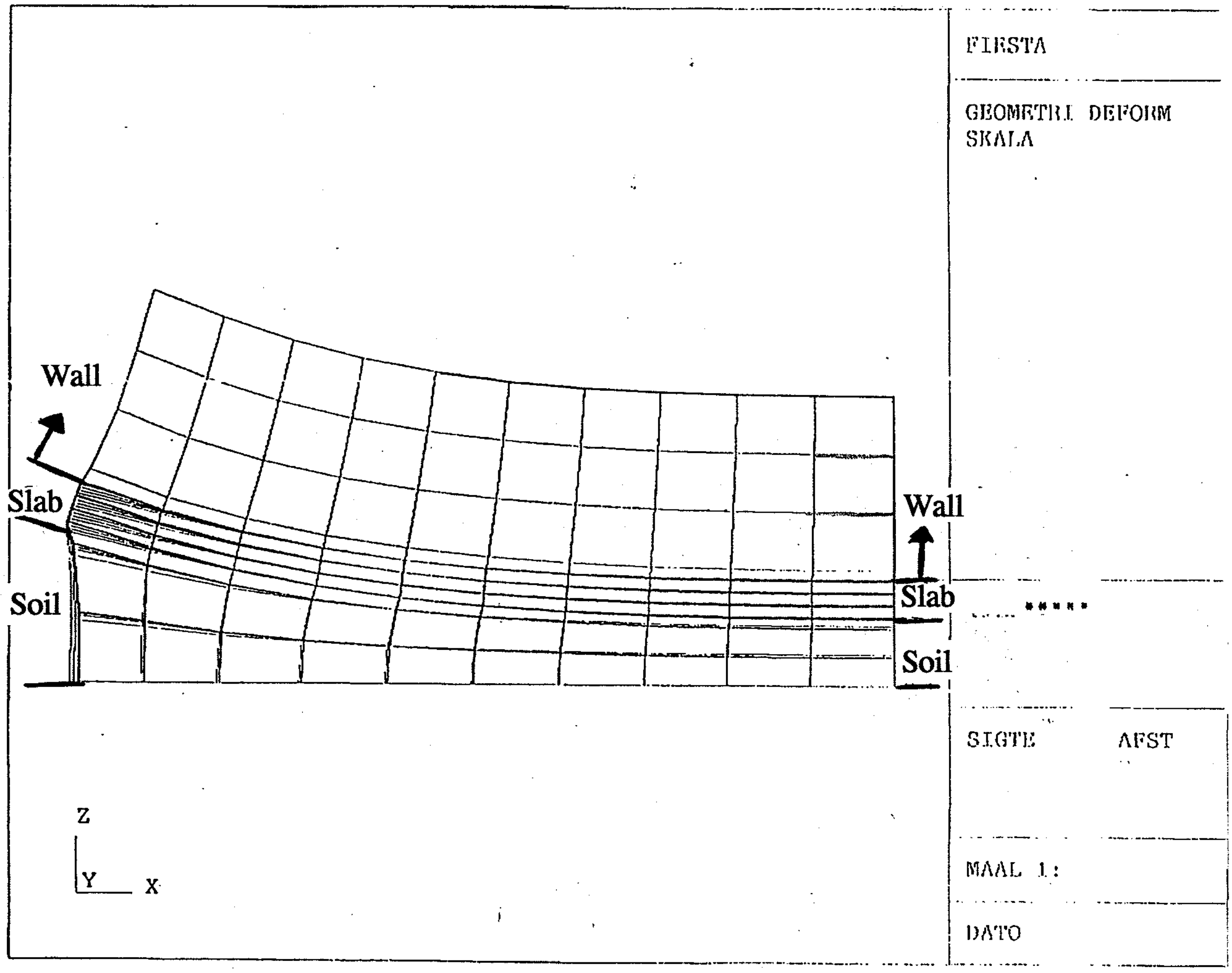


Figure A3: Restraint ratio K_R, as related to the lenght to height ratio

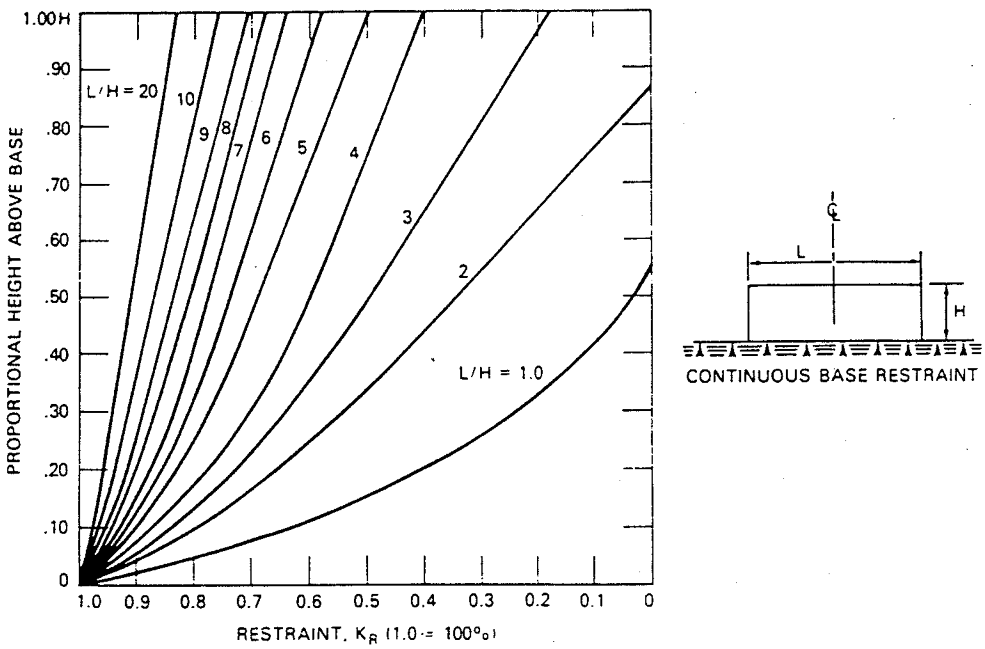
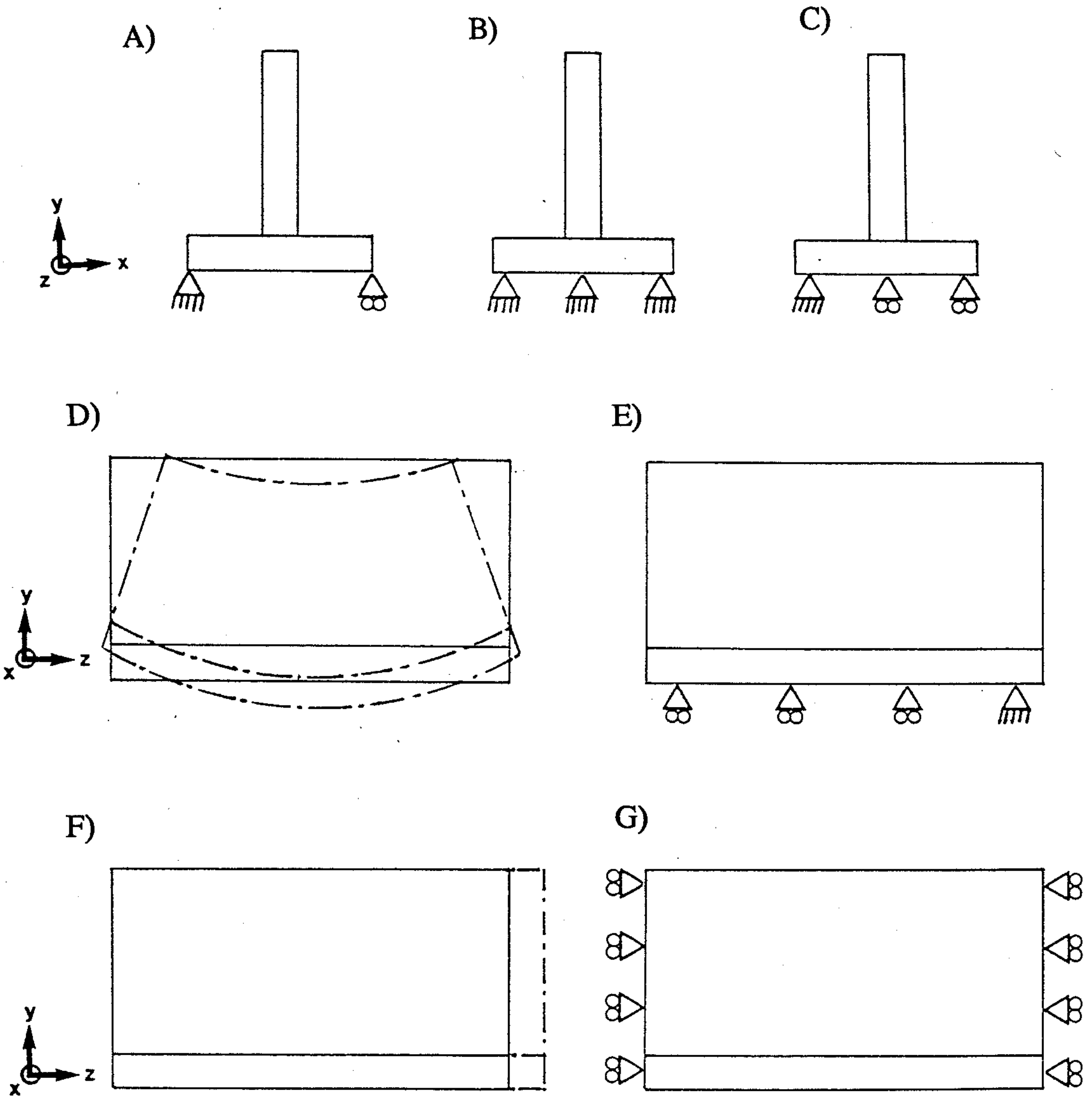


Figure A4: Support conditions - Examples
A to C: In plane support conditions
D to E: Out of plane support conditions (curvature)
F to G: Out of plane support conditions (longitudinal deformation)



APPENDIX B

Figure B1: Distribution of stress in the longitudinal direction for a wall cast on a previously cast foundation at the end of the cooling period. Free curvature around the x-axis.

CALCULATION RESULTS

Documentation sheet

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Ref. nr.: 12345
Initials :

Project: demo1afr
Id. nr. : ME-AA0102

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Time: 04:42

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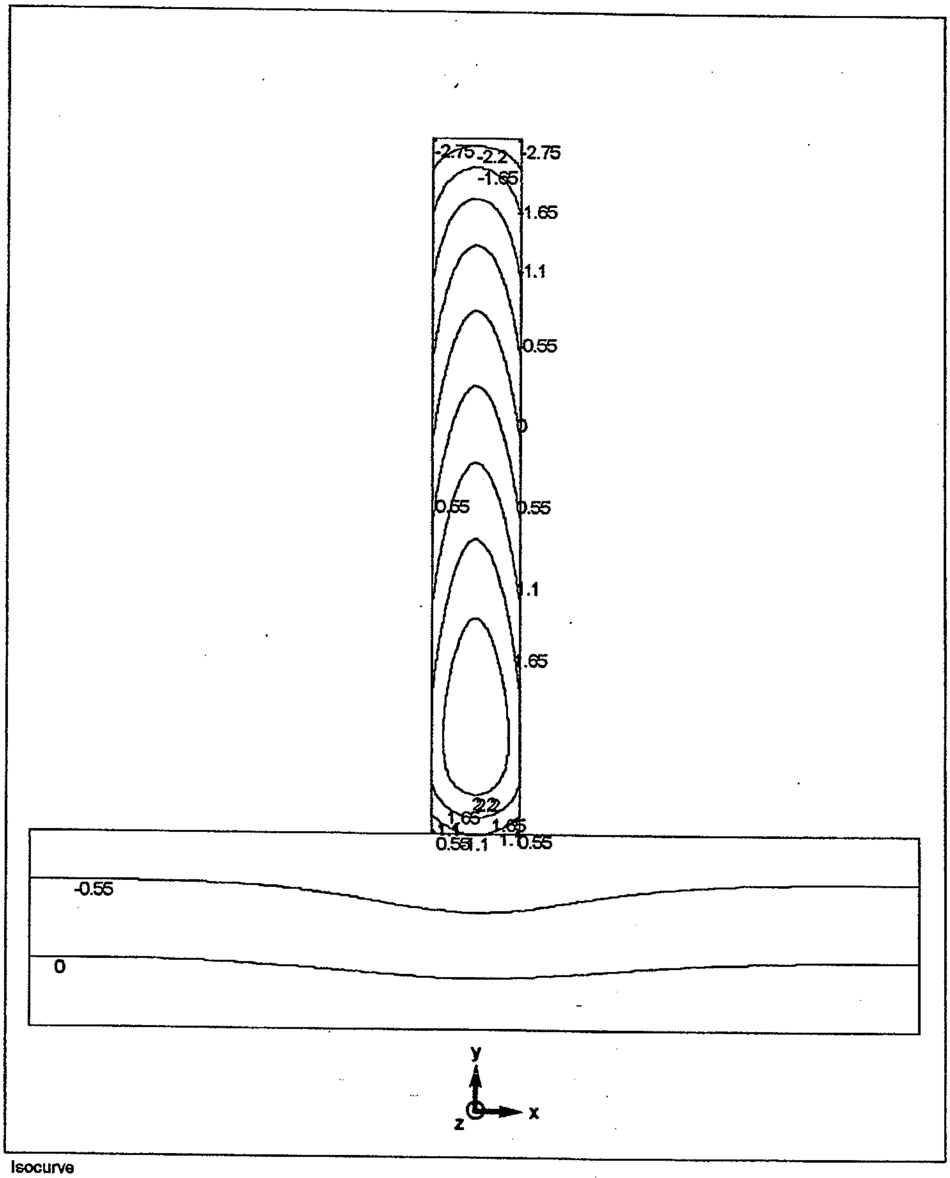

DATA:	
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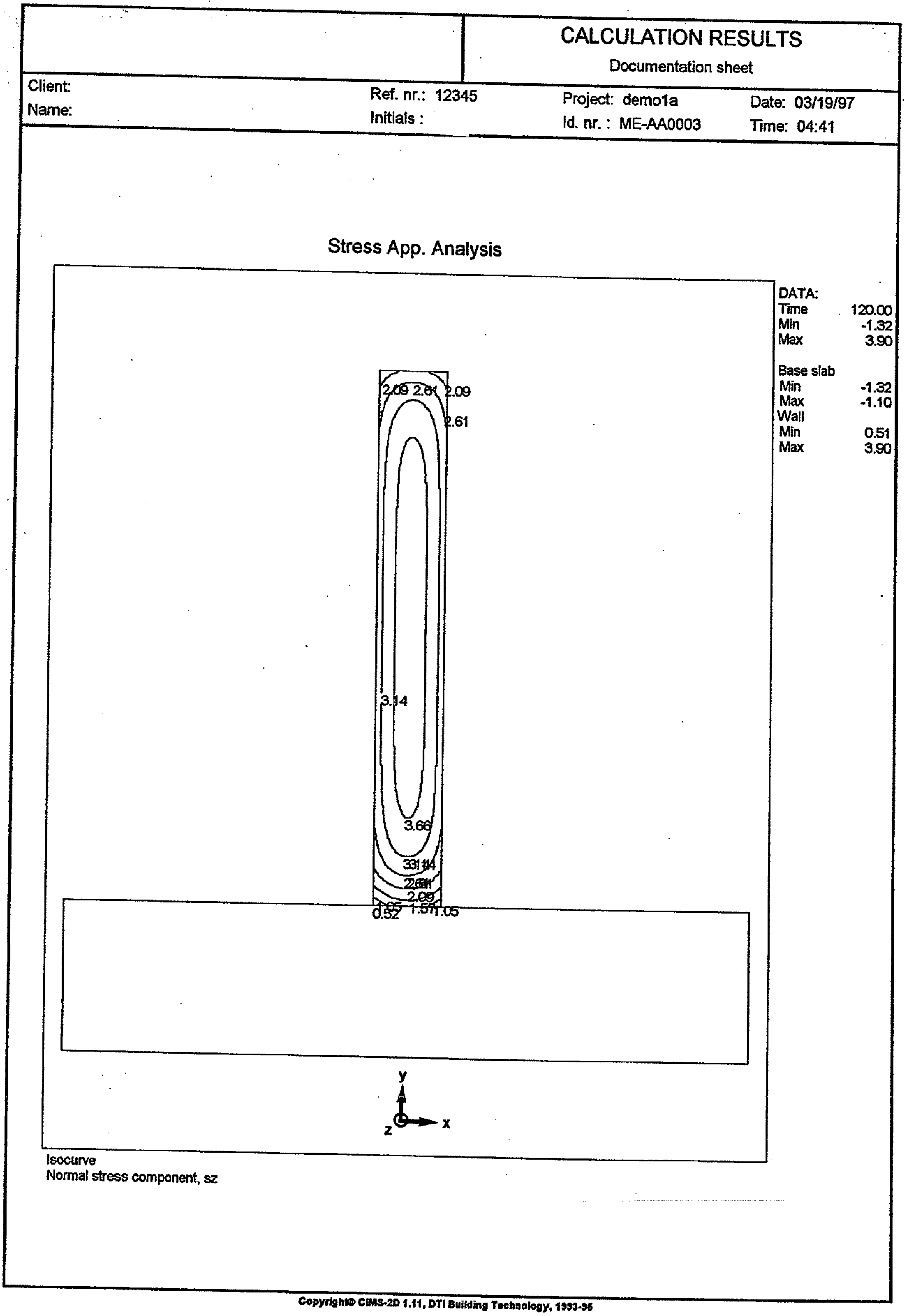
Min	-2.78
Max	2.71
Base slab	
Min	-1.11
Max	0.49
Wall	
Min	-2.78
Max	2.71

Isocurve
Normal stress component, sz

Figure B2: Distribution of stress in the longitudinal direction for a wall cast on a previously cast foundation at the end of the cooling period. Fixed curvature around the x-axis.



CALCULATION RESULTS
Documentation sheet

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Ref. nr.: 12345
Initials :
Project: demo1a
Id. nr. : ME-AA0003
Date: 03/19/97
Time: 04:41

Stress App. Analysis

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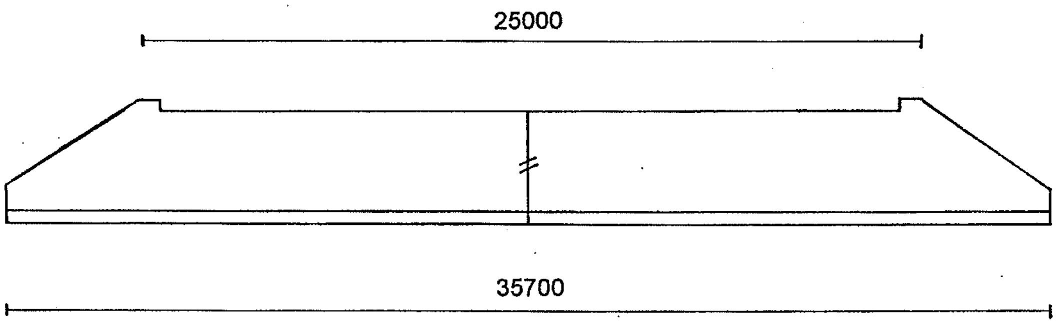
Max	3.90
Base slab	
Min	-1.32
Max	-1.10
Wall	
Min	0.51
Max	3.90

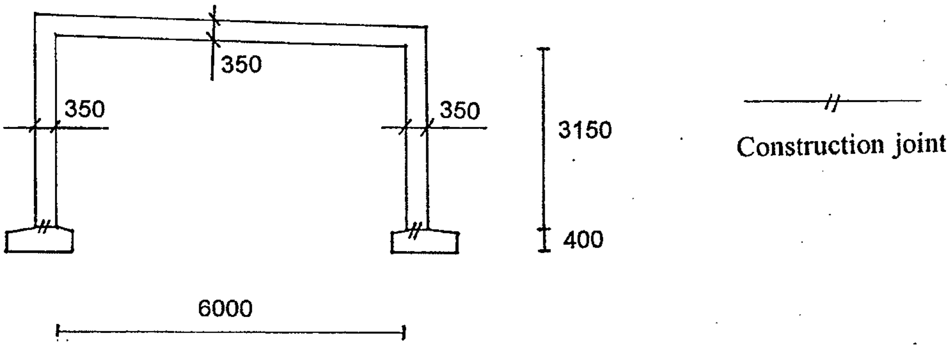
Isocurve
Normal stress component, sz

APPENDIX C

Figure C1: Dimensions of tunnel in millimetres



Side view



Cross-section

Figure C2: Location of thermocouples. Thermocouples 1,3,4,6,7 and 9 were placed 10 mm from the surface. Thermocouple 12 was placed 360 mm below the foundation.

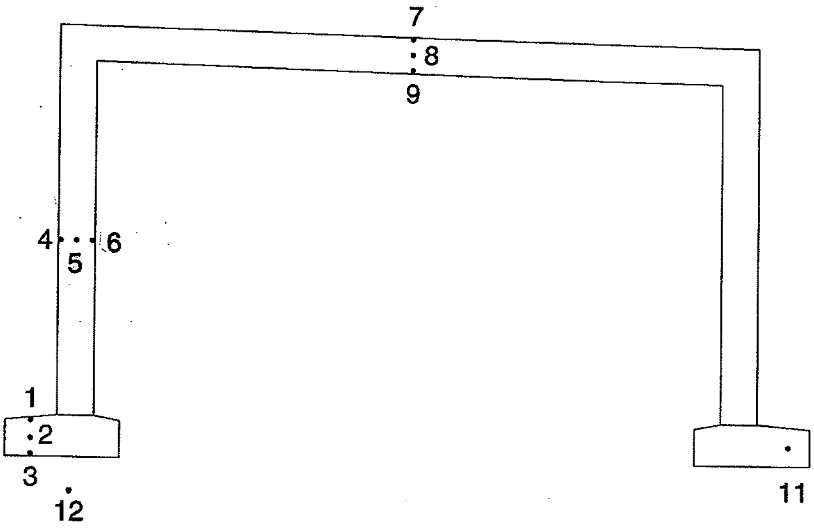


Figure C3 Measured ambient temperature development

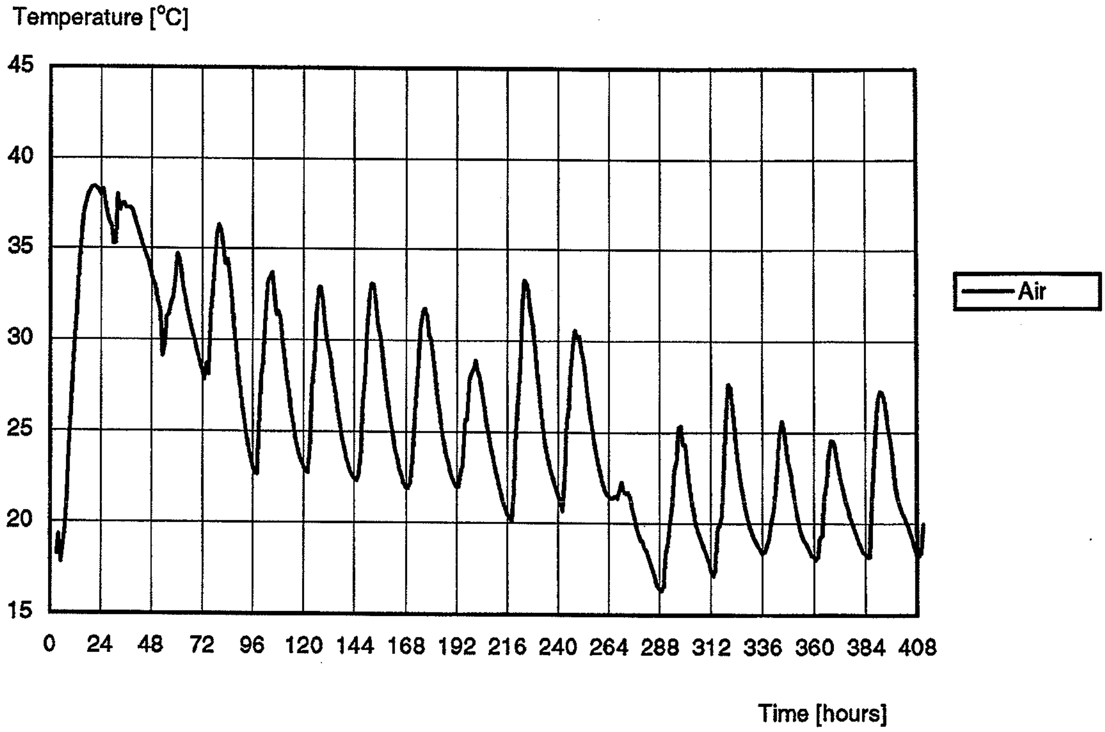


Figure C4: Measured temperature development in the foundation, location 1 to 3

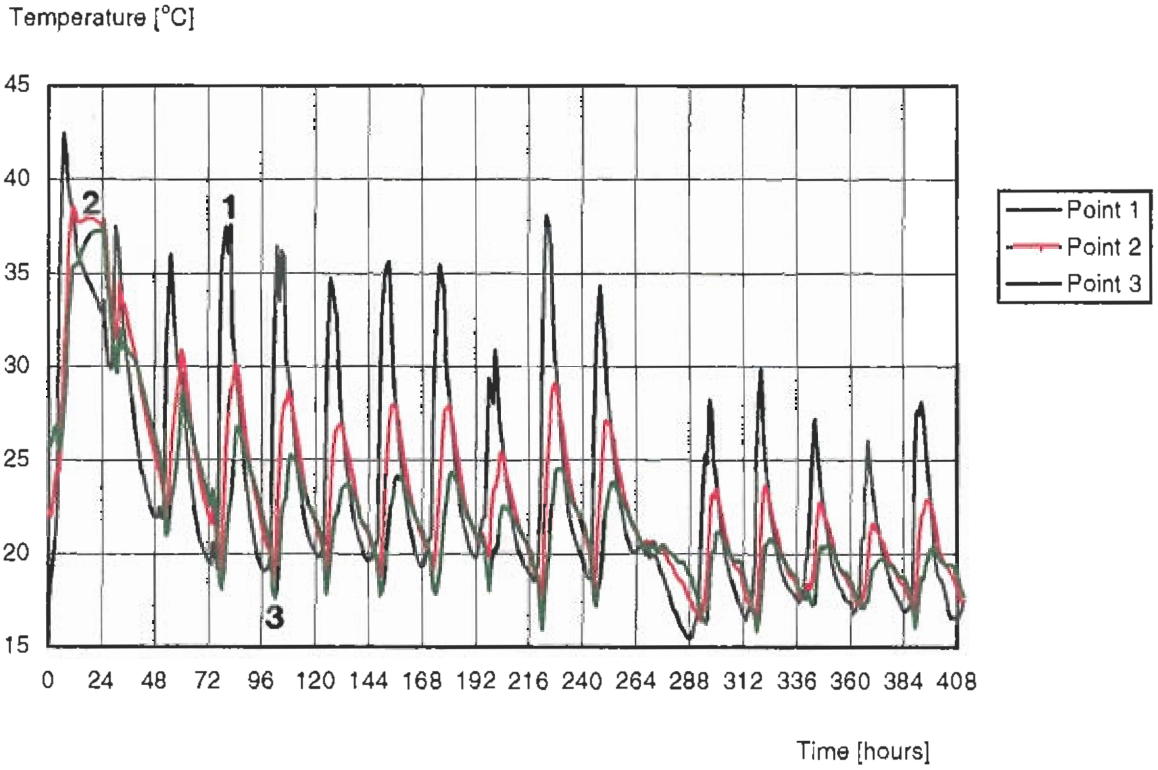


Figure C5: Calculated temperature development in the foundation, location 1 to 3

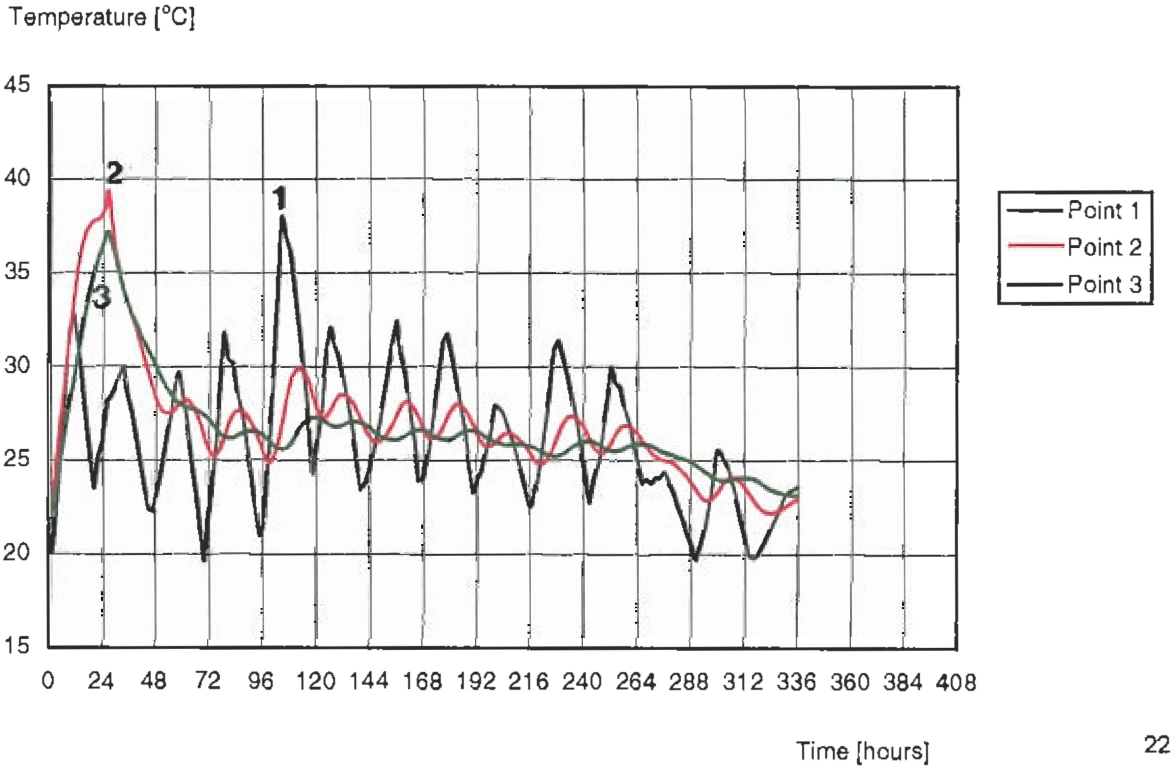


Figure C6: Measured temperature development in the wall, location 4 to 6

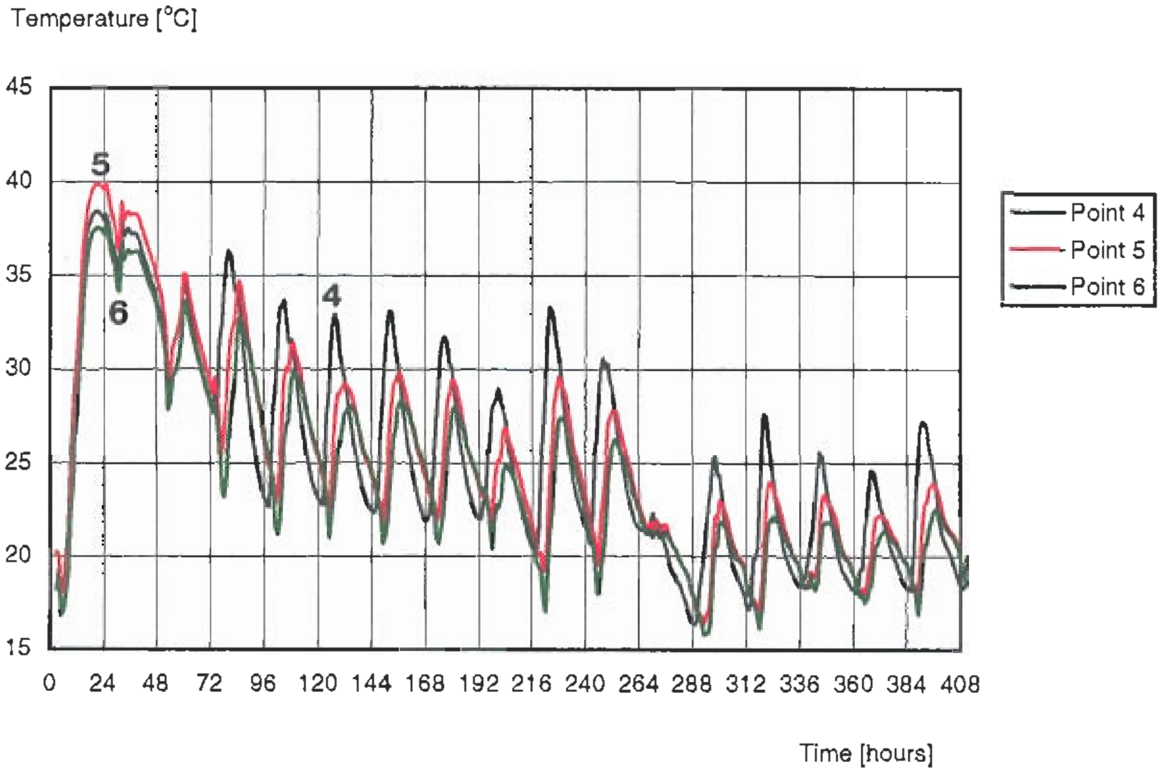


Figure C7: Calculated temperature development in the wall, location 4 to 6

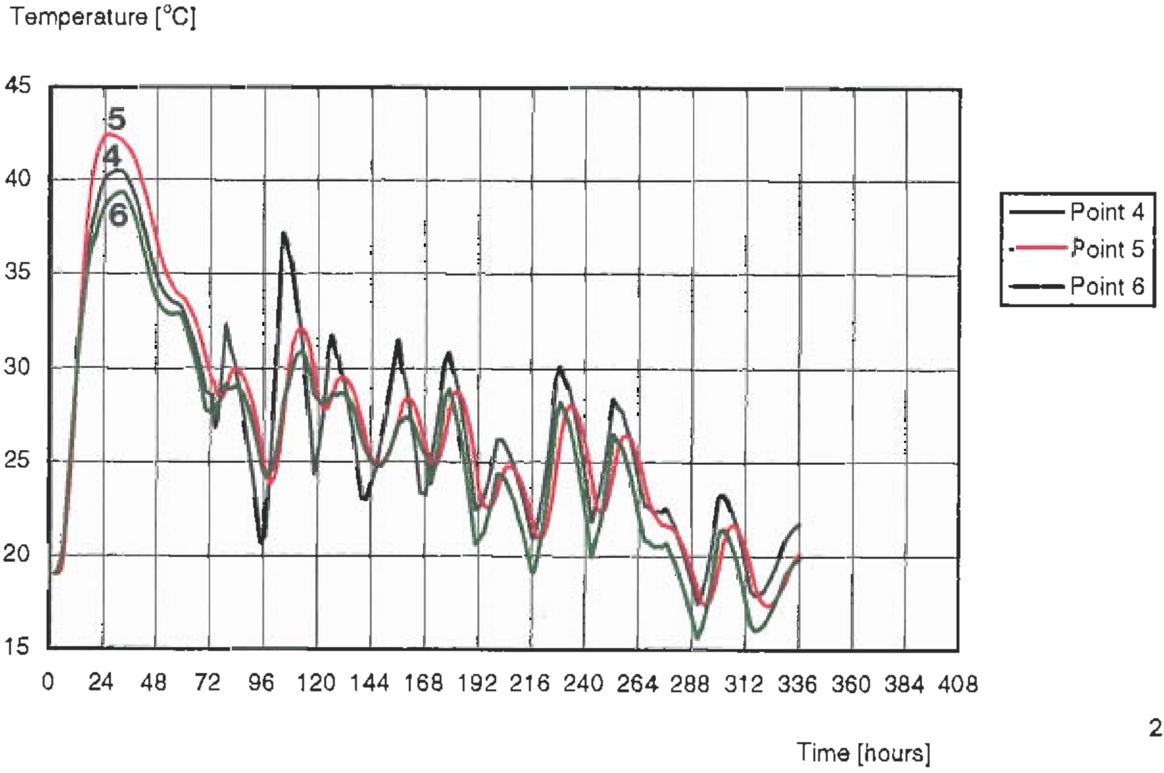


Figure C8: Measured temperature development in the deck, location 7 to 9

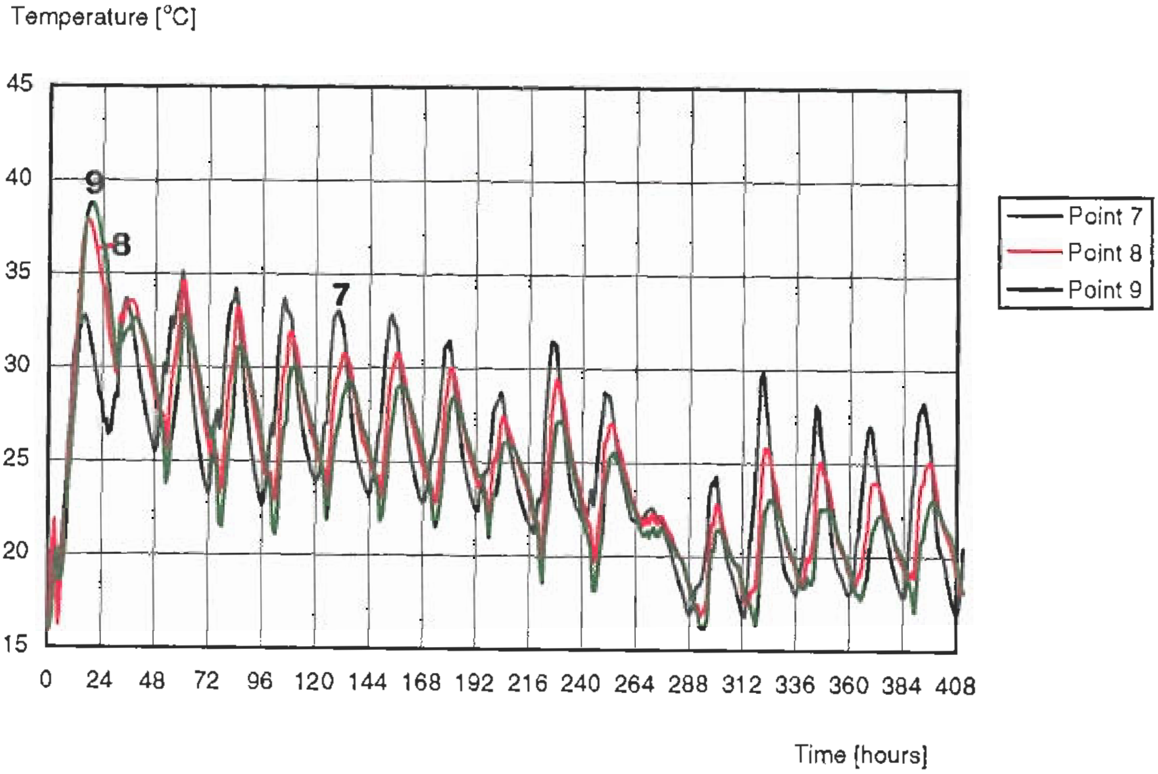


Figure C9: Calculated temperature development in the deck, location 7 to 9

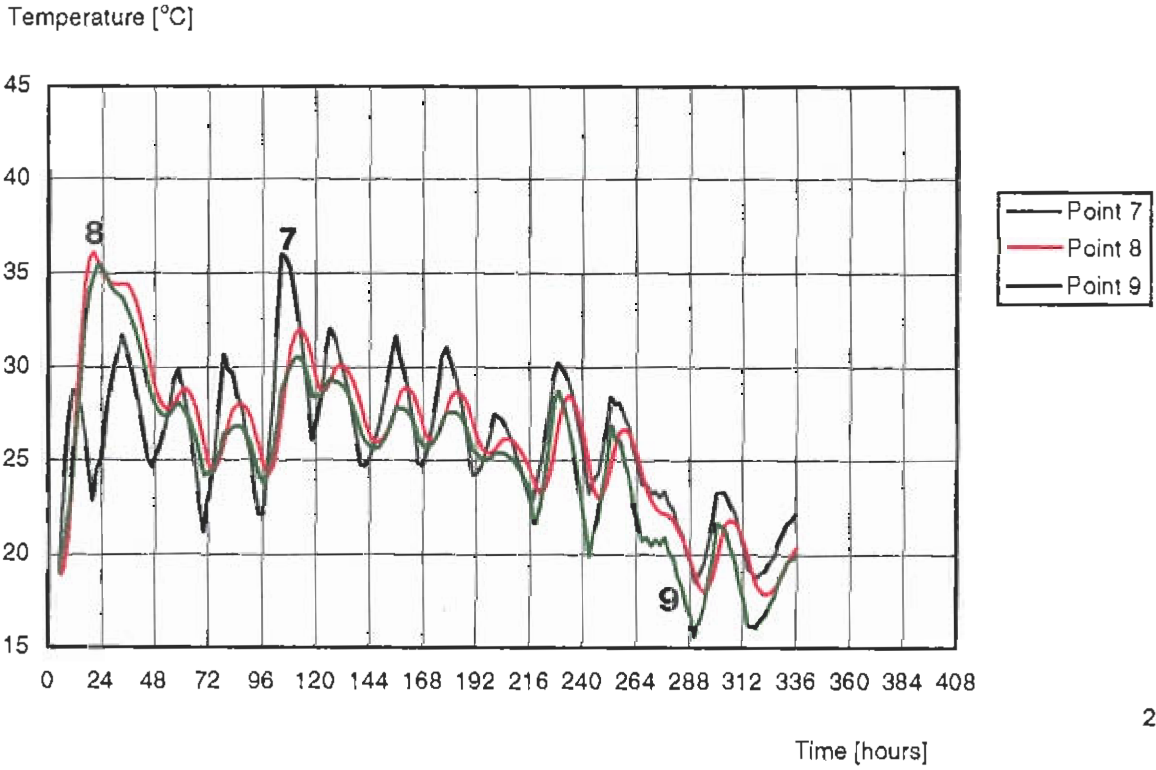


Figure C10: Calculated average temperature development for foundation and wall based on temperature measurements

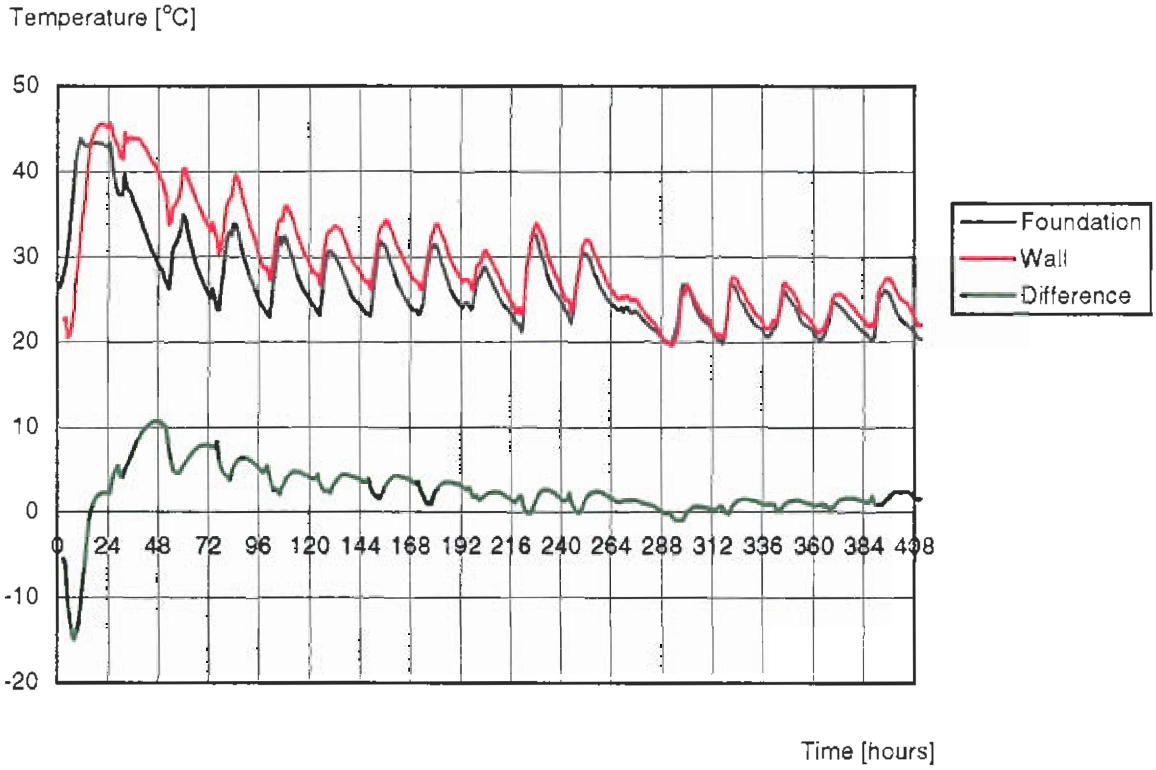


Figure C11: Calculated average temperature development for deck and wall based on temperature measurements

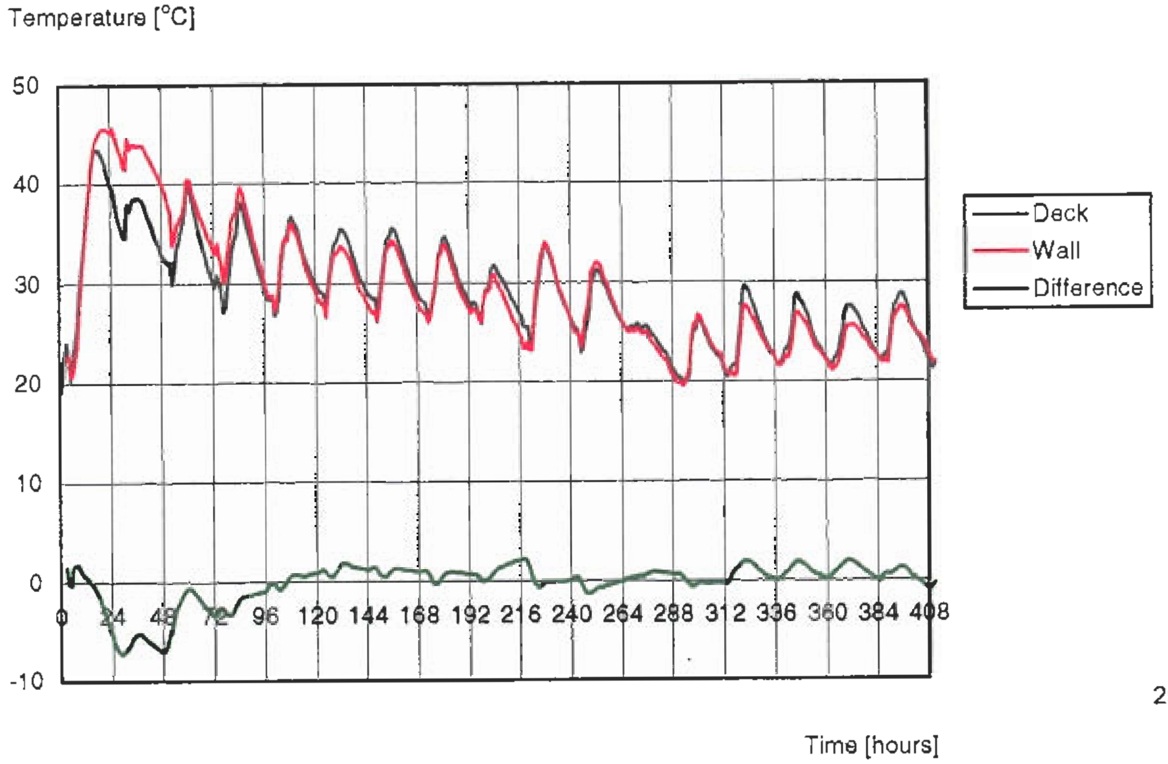


Figure C12: Location of measuring points on the outer concrete surface of the wall and foundation

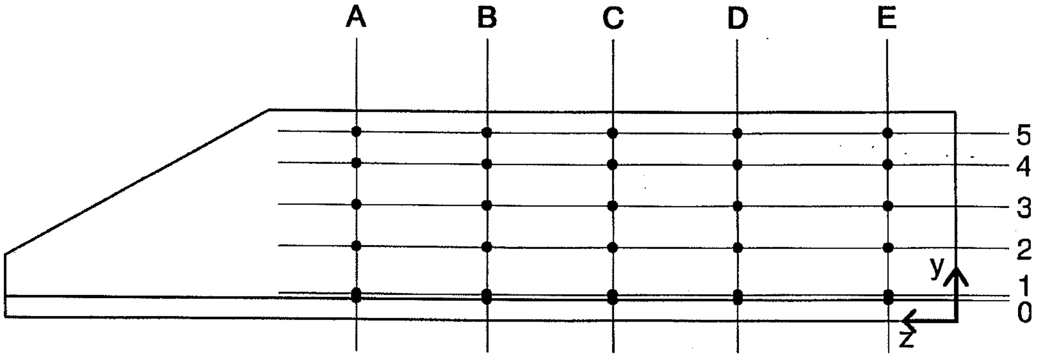


Table C1: Co-ordinates in centimetres for measuring points, see Figure C12

		A	B	C	D	E
5	z y	1151 316	909 313	658 312	419 313	128 313
4	z y	1151 256	908 253	658 253	427 251	128 253
3	z y	1153 175	909 174	672 173	409 173	128 175
2	z y	1149 93	909 95	670 95	427 95	128 95
1	z y	1148 12	914 10	672 10	421 9	130 20
0	z y	1143 0	892 0	647 0	411 0	160 0

Figure C13:
Sketch of the system used for placement of the measuring points on the wall.
a) During casting, the insert is fixed by a threaded steel bar and a nut. The threaded steel bar is placed in the center of the hole in the form by means of a piece of pipe. Shortly after setting of the concrete, the nut is loosened and the piece of pipe removed. The threaded steel bar is fixed by glue.
b) After setting, the deformations can also be measured after formwork removal.

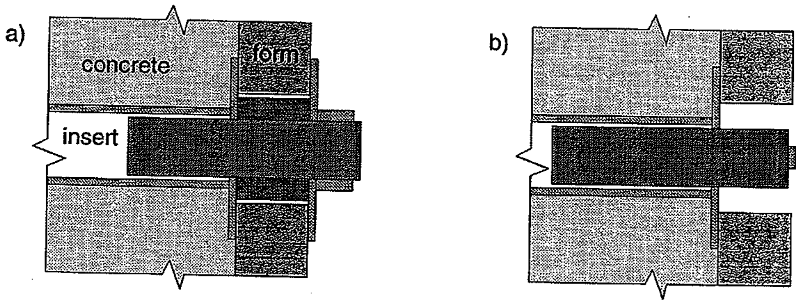
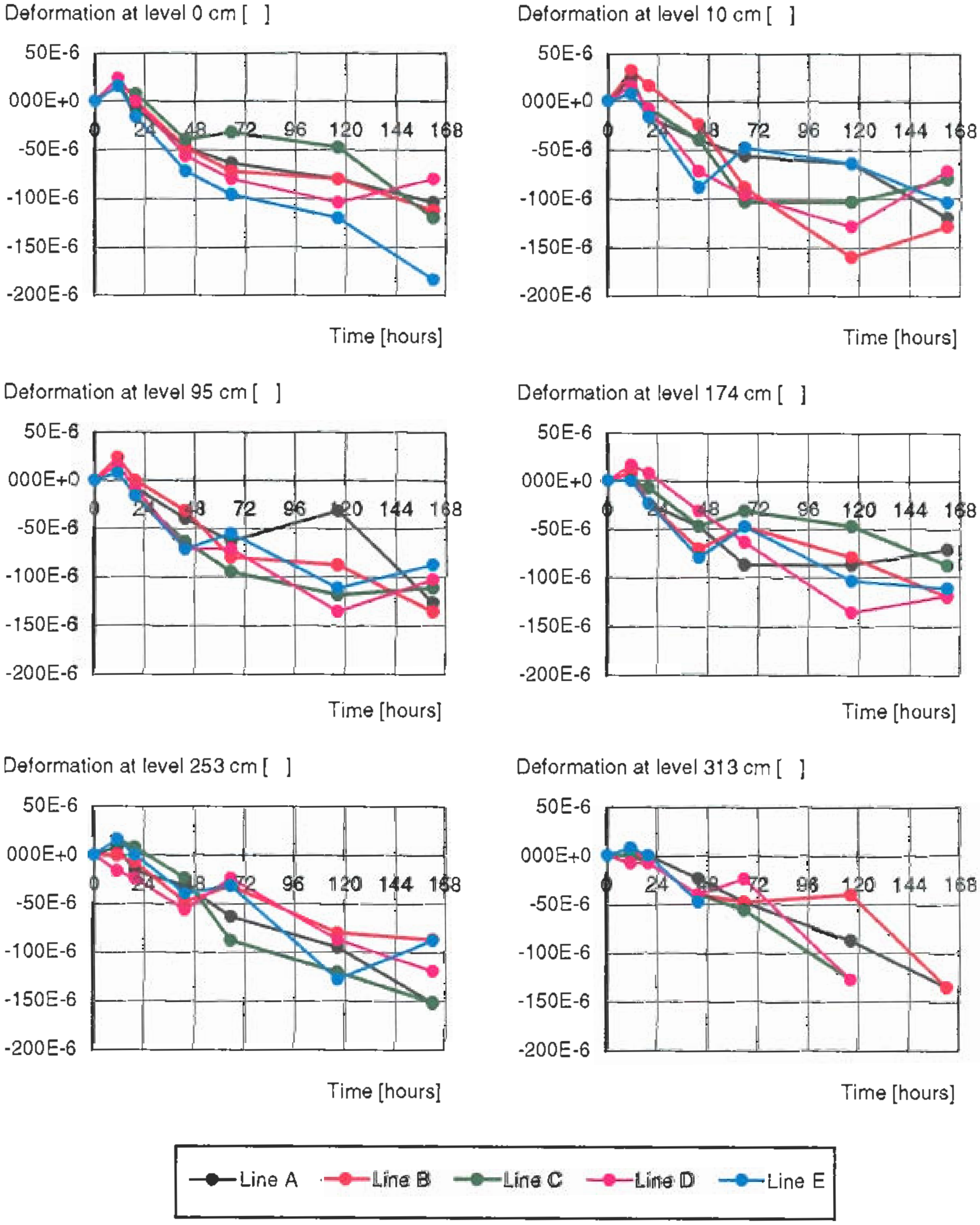


Figure C14: Time development of the measured deformations in the 30 locations



Deformation at level 0 cm [ ]

Deformation at level 10 cm [ ]

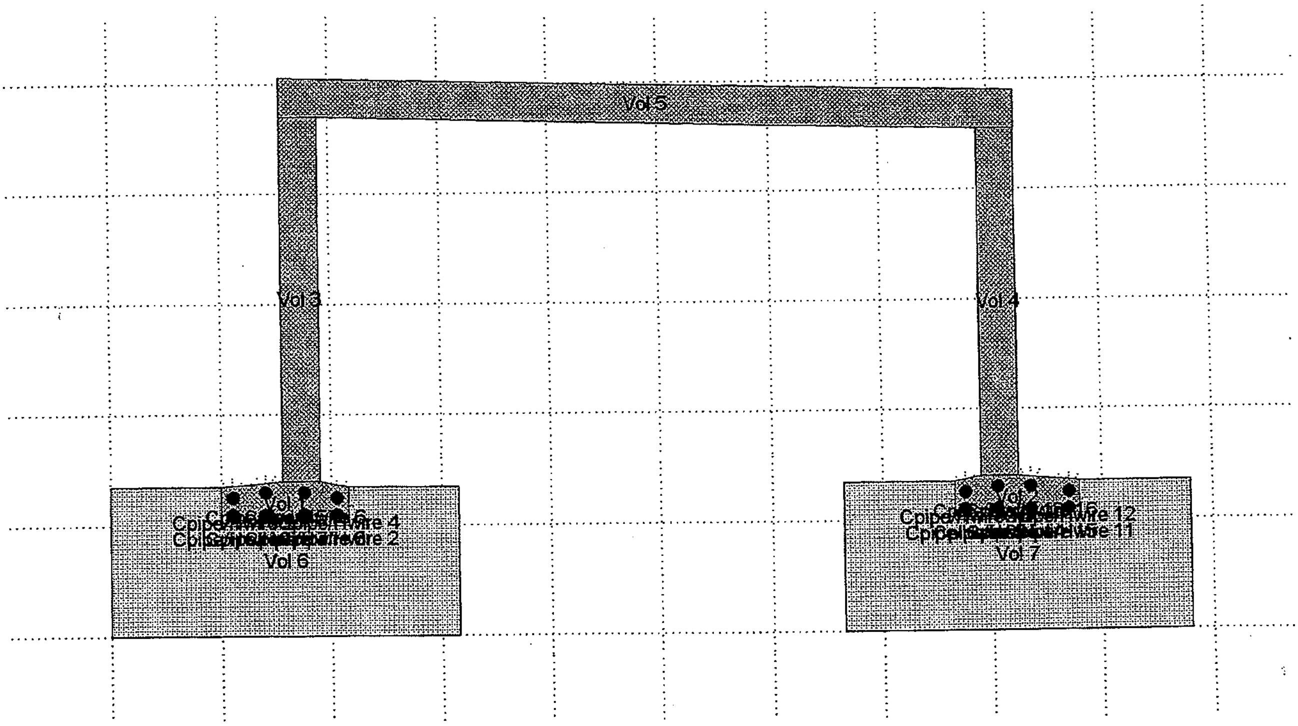
Deformation at level 95 cm [ ]

Deformation at level 174 cm [ ]

Deformation at level 253 cm [ ]

Deformation at level 313 cm [ ]

Figure C15: Model used for temperature and stress calculation



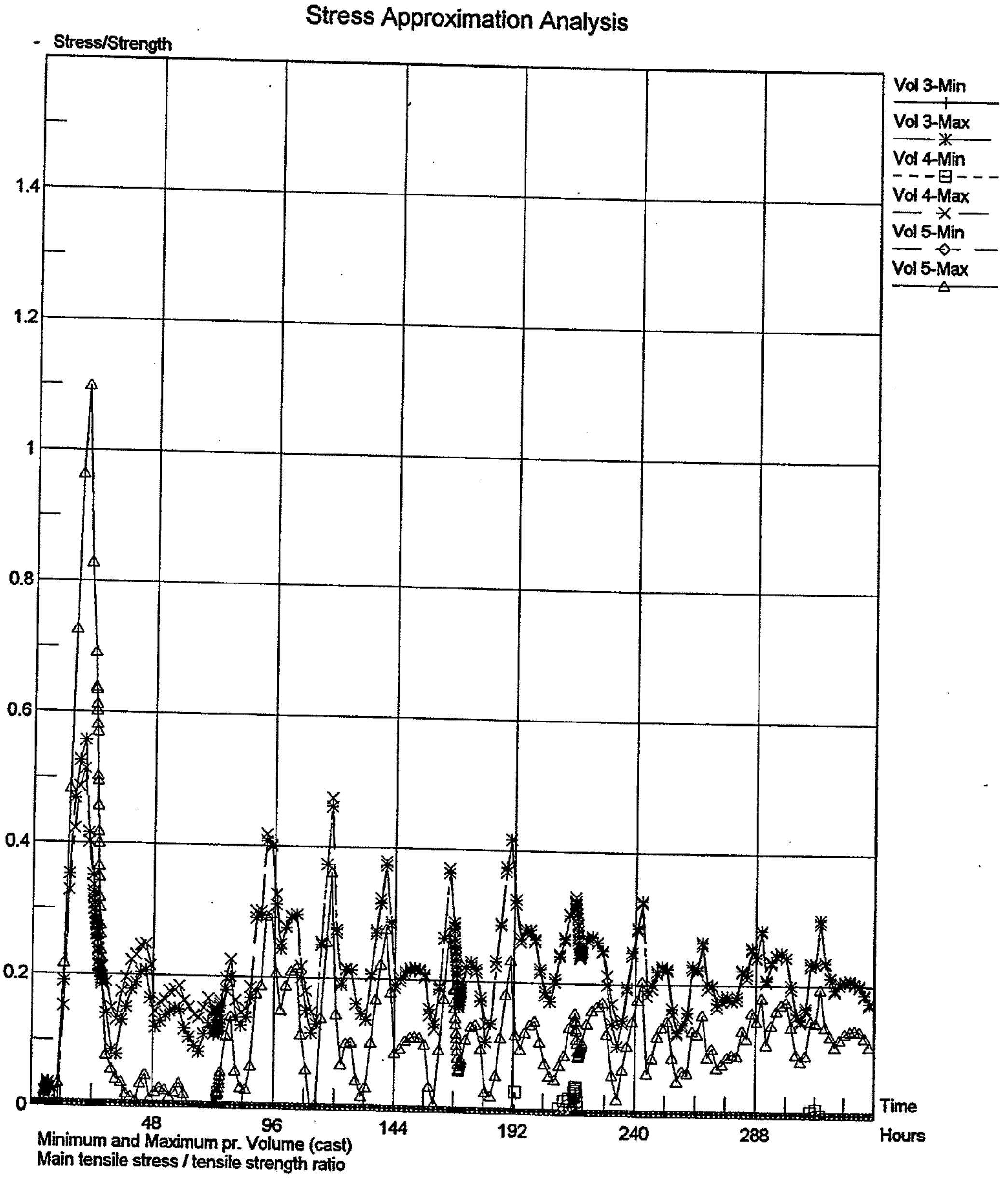
APPENDIX D

Figure D1: Maximum and minimum crack risk for the two walls (vol. 3 and 4) and the deck (vol. 5)

CALCULATION RESULTS

Documentation sheet

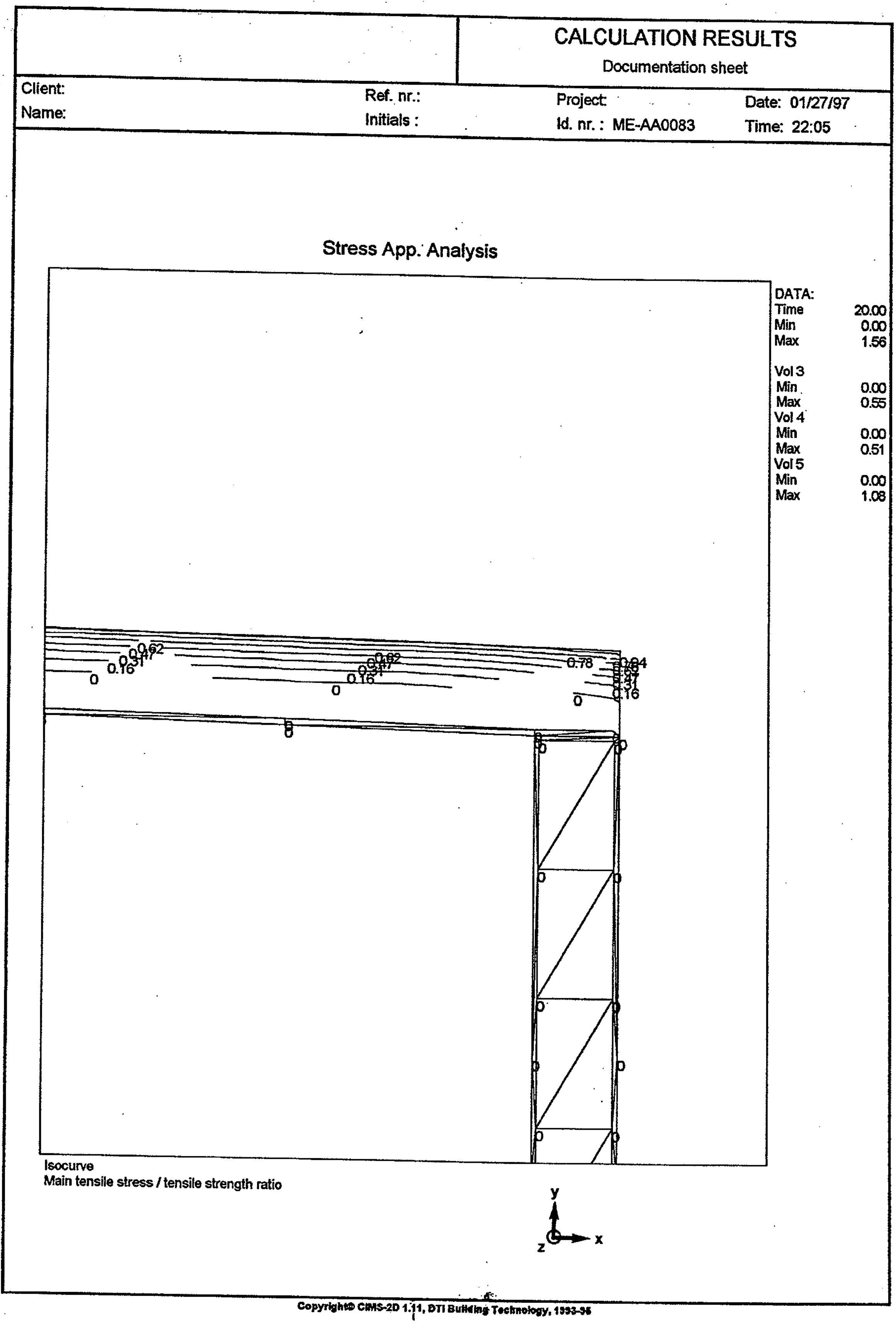
Client:
Name:
Ref. nr.:
Initials :
Project:
Id. nr. : ME-AA0083
Date: 01/27/97
Time: 21:33



Stress Approximation Analysis

Minimum and Maximum pr. Volume (cast)
Main tensile stress / tensile strength ratio

Figure D2: Iso-curve for crack risk upper right corner (t = 20 hours)



CALCULATION RESULTS

Documentation sheet

Client:
Name:

Ref. nr.:
Initials :

Project:
Id. nr. : ME-AA0083

Date: 01/27/97
Time: 22:05

Stress App. Analysis

DATA:	
Time	20.00
Min	0.00
Max	1.56
Vol 3	
Min	0.00
Max	0.55
Vol 4	
Min	0.00
Max	0.51
Vol 5	
Min	0.00
Max	1.08

Isocurve
Main tensile stress / tensile strength ratio

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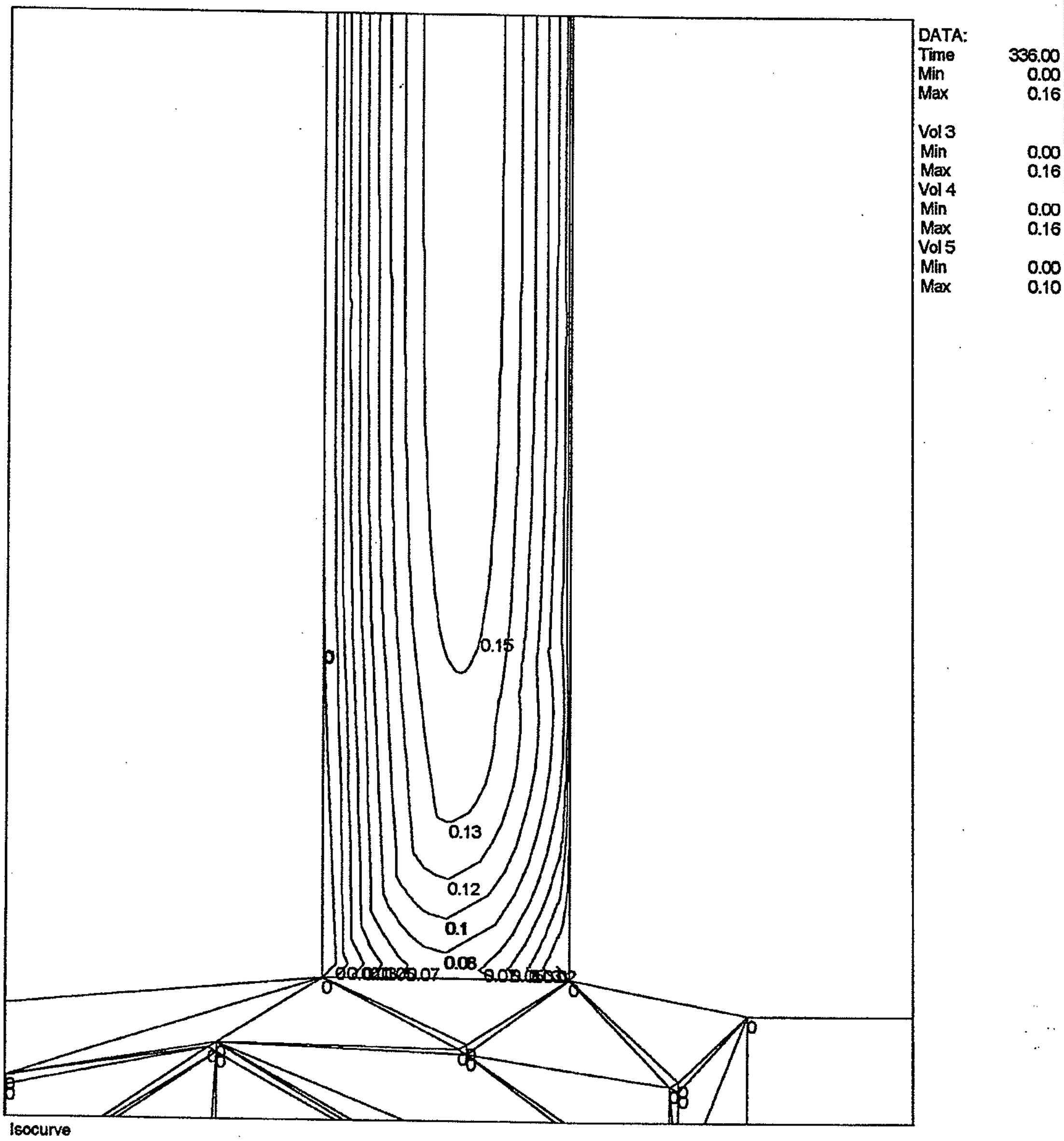
Figure D3: Iso-curve for crack risk lower part of wall (t=336 hours)

CALCULATION RESULTS

Documentation sheet

Client:	Ref. nr.:	Project:	Date: 01/27/97
Name:	Initials :	Id. nr. : ME-AA0083	Time: 22:08

Stress App. Analysis



Isocurve
Main tensile stress / tensile strength ratio

Figure D4: Stress in the longitudinal direction in the wall, point 4 to 6

CALCULATION RESULTS

Documentation sheet

Client:
Name:
Ref. nr.:
Initials :
Project:
Id. nr. : ME-AA0083
Date: 01/27/97
Time: 22:13

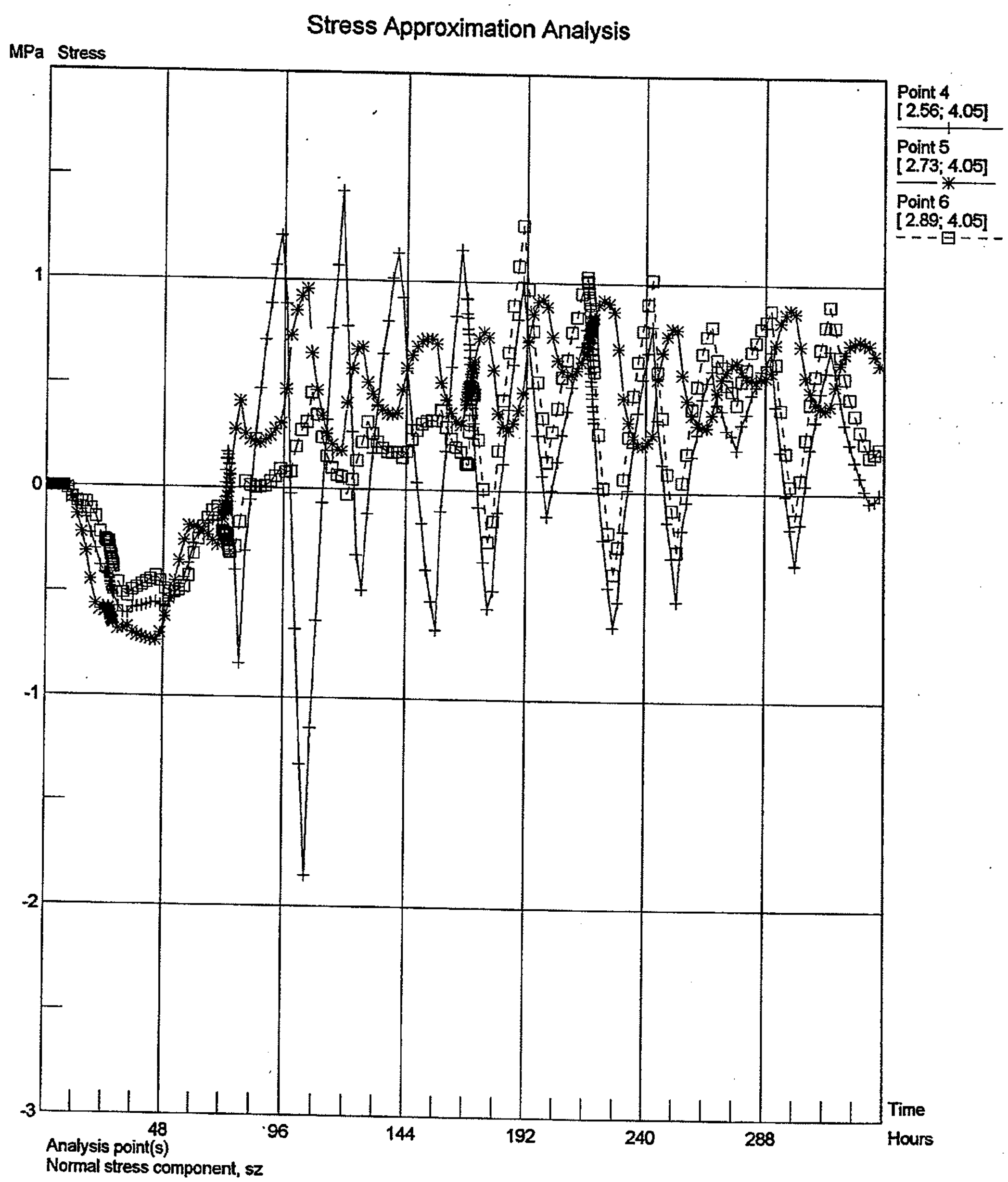
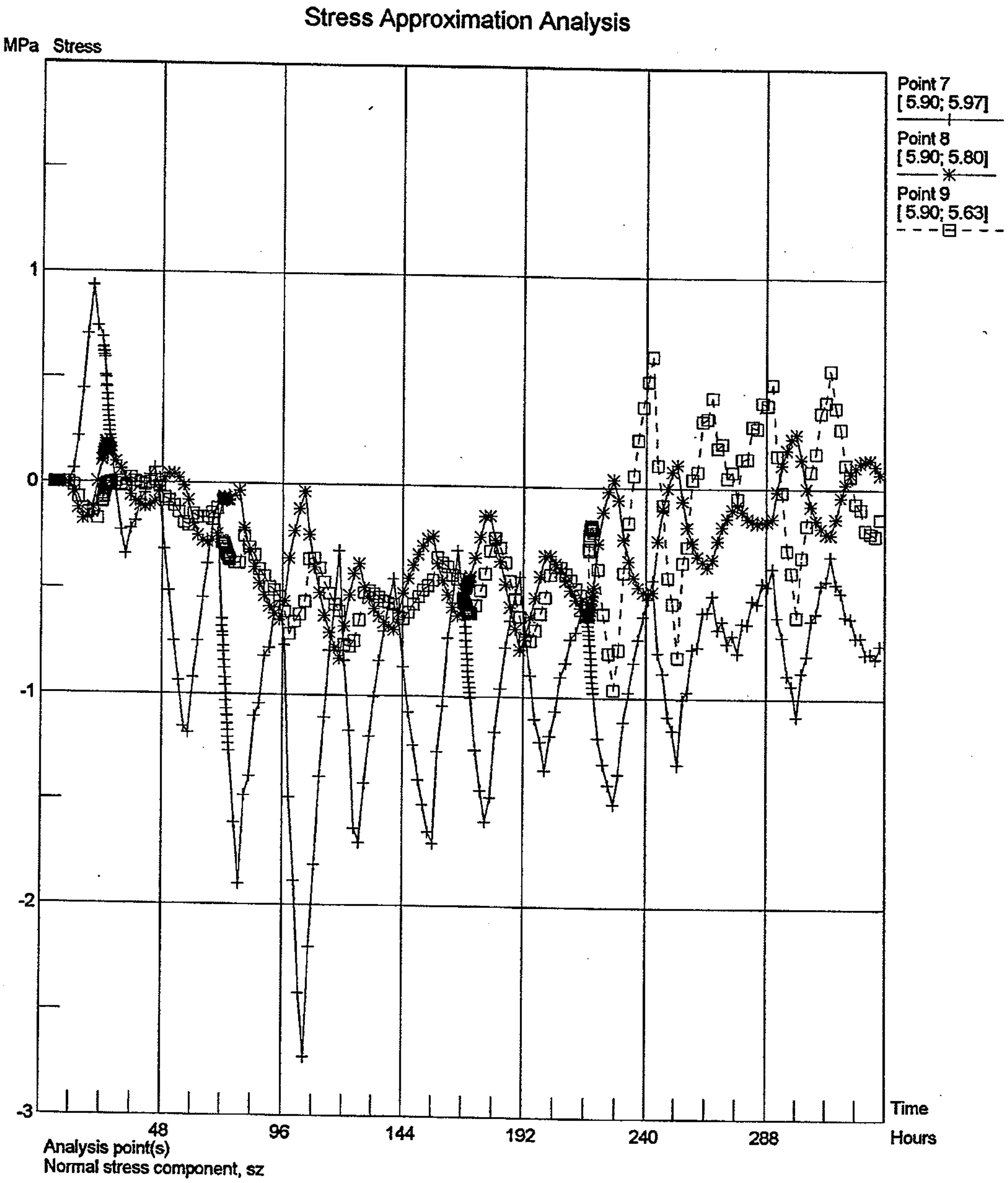


Figure D5: Stress in the longitudinal direction in the deck, point 7 to 9

CALCULATION RESULTS

Documentation sheet

Client:	Ref. nr.:	Project:	Date: 01/27/97
Name:	Initials :	Id. nr. : ME-AA0083	Time: 22:10



APPENDIX E

Figure E1: Maximum and minimum crack risk for the two walls (vol. 3 and 4) and the deck (vol. 5)

CALCULATION RESULTS

Documentation sheet

Client:	Ref. nr.:	Project:	Date: 01/27/97
Name:	Initials :	Id. nr. : ME-AA0084	Time: 22:16

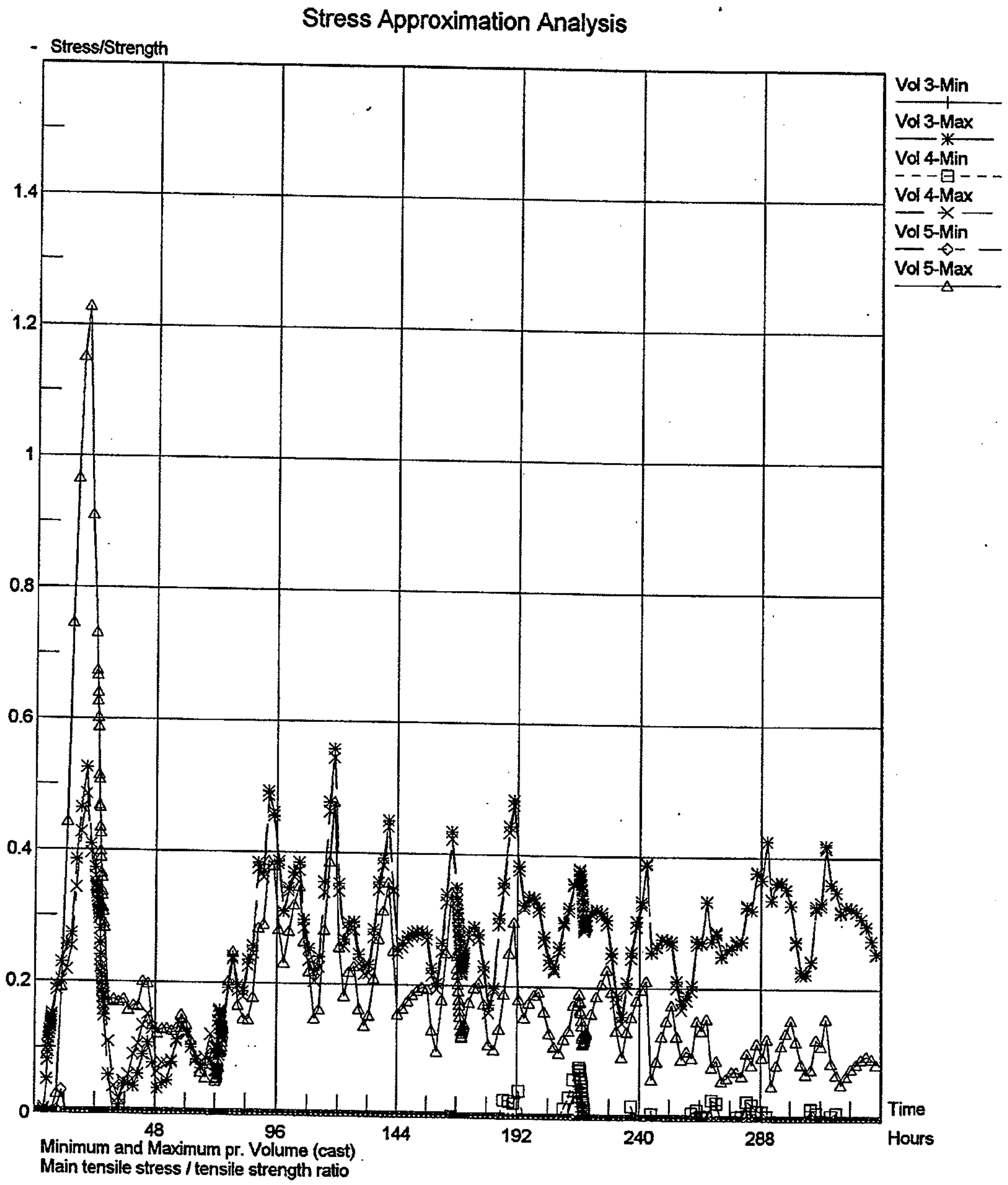


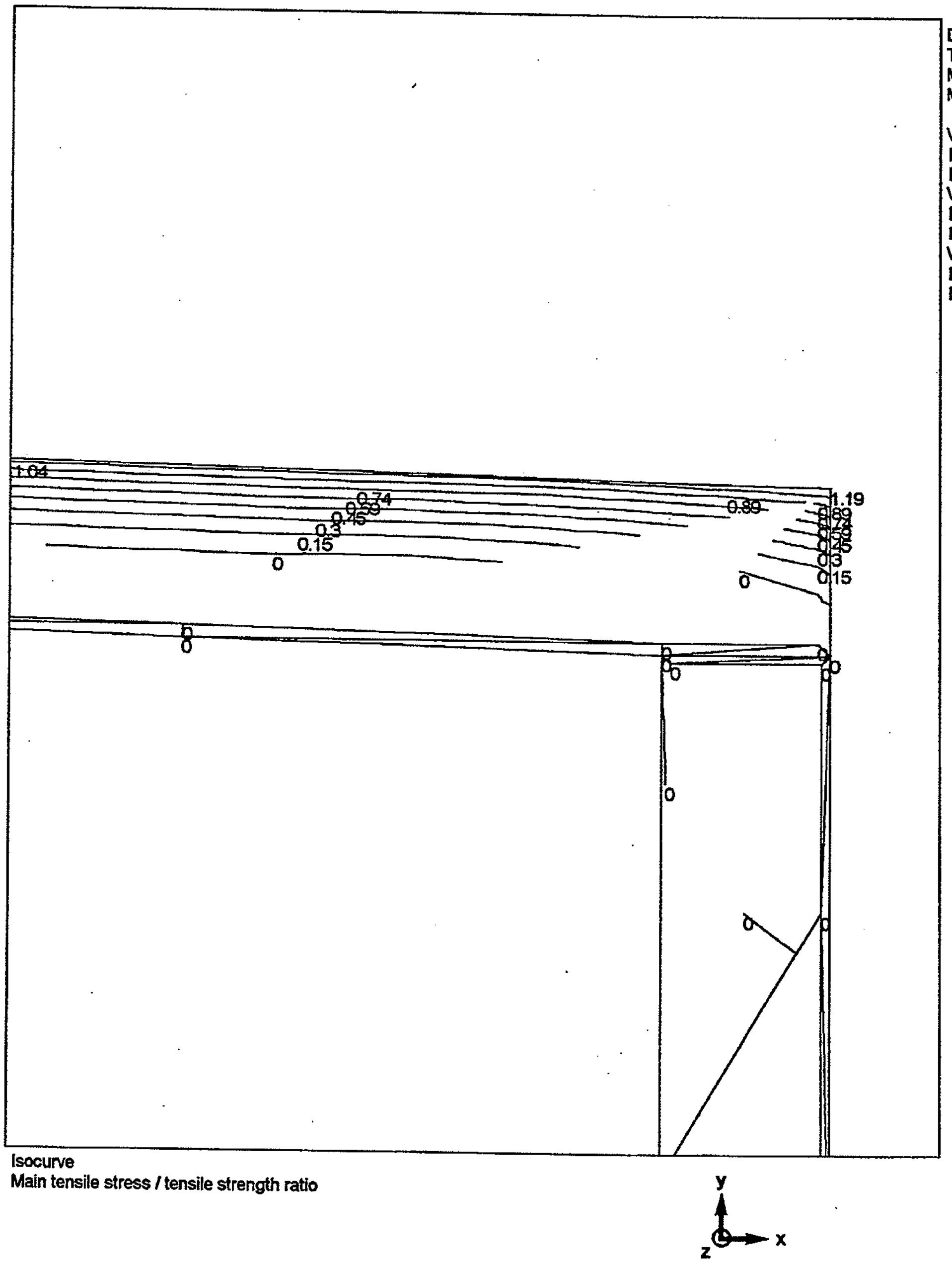
Figure E2: Iso-curve for crack risk upper right corner (t=20 hours)

CALCULATION RESULTS

Documentation sheet

Client:	Ref. nr.:	Project:	Date: 01/27/97
Name:	Initials :	Id. nr. : ME-AA0084	Time: 22:21

Stress App. Analysis



DATA:	
Time	20.00
Min	0.00
Max	1.49
Vol 3	
Min	0.00
Max	0.52
Vol 4	
Min	0.00
Max	0.48
Vol 5	
Min	0.00
Max	1.22

Isocurve
Main tensile stress / tensile strength ratio

Figure E3: Iso-curve for crack risk lower part of wall (t=336 hours)

CALCULATION RESULTS

Documentation sheet

Client:	Ref. nr.:	Project:	Date: 01/27/97
Name:	Initials :	Id. nr. : ME-AA0084	Time: 22:19

Stress App. Analysis

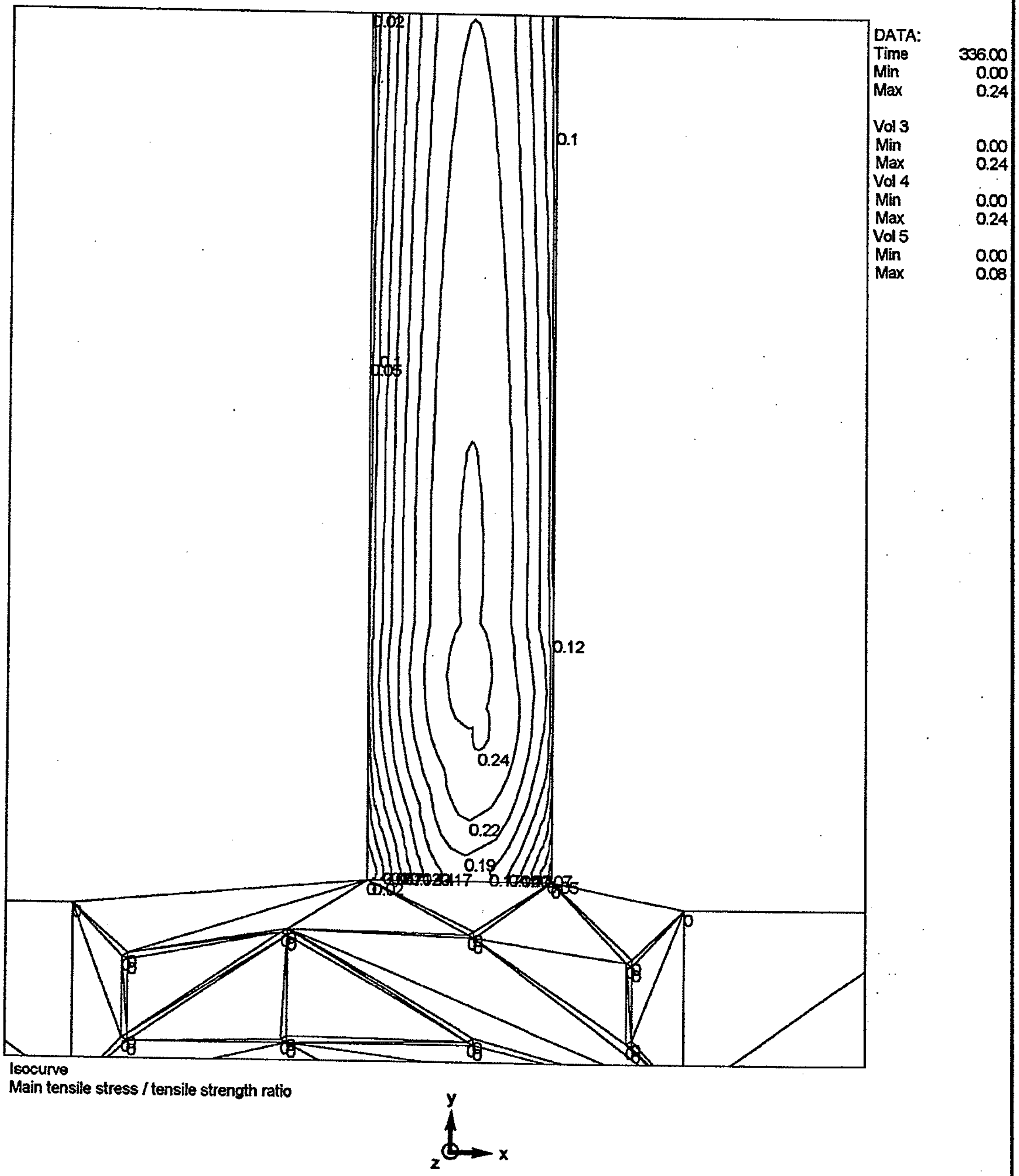


Figure E4: Stress in the longitudinal direction in the wall, point 4 to 6

CALCULATION RESULTS

Documentation sheet

Client:	Ref. nr.:	Project:	Date: 01/27/97
Name:	Initials :	Id. nr. : ME-AA0084	Time: 22:23

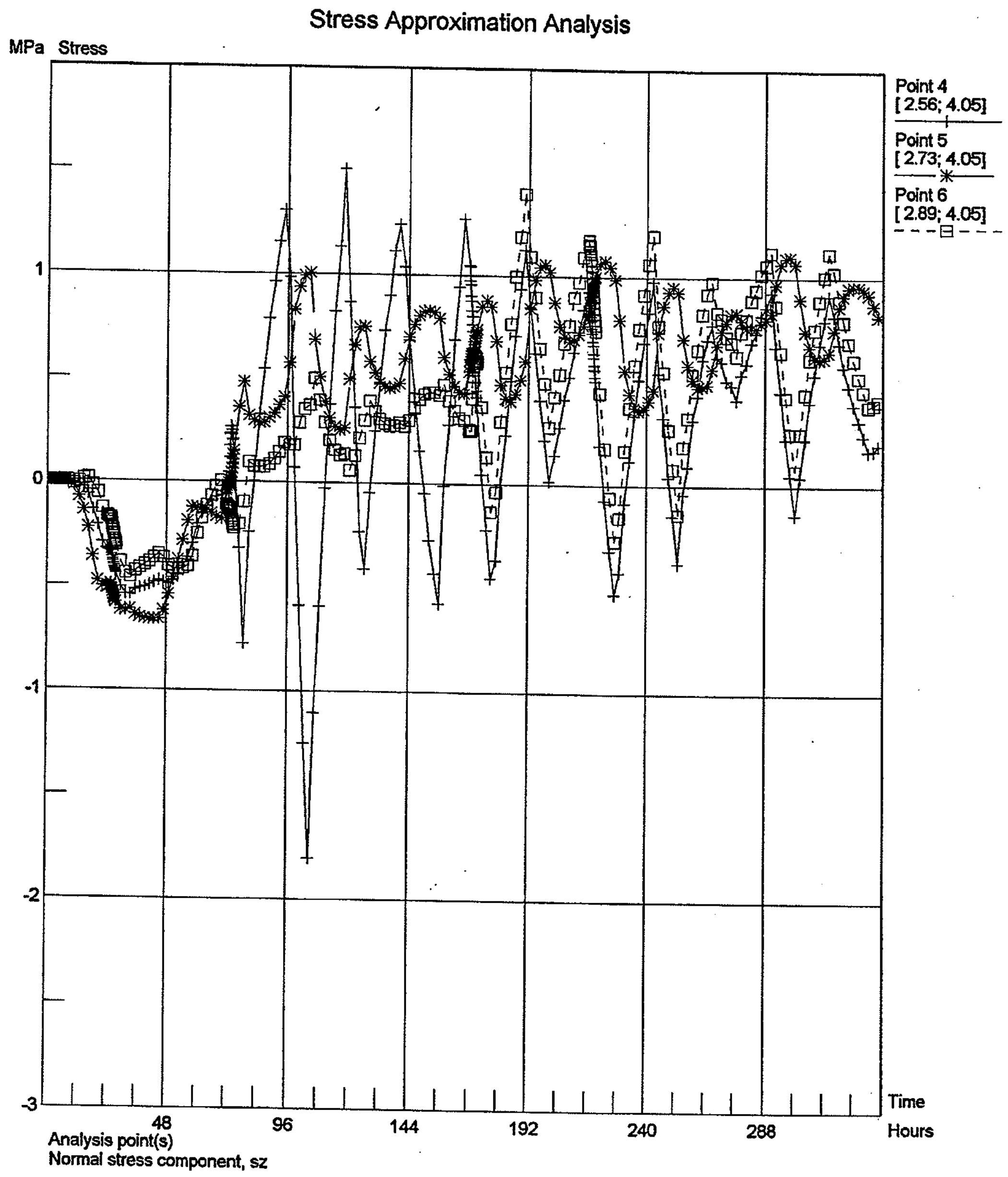


Figure E5: Stress in the longitudinal direction in the deck, point 7 to 9

CALCULATION RESULTS

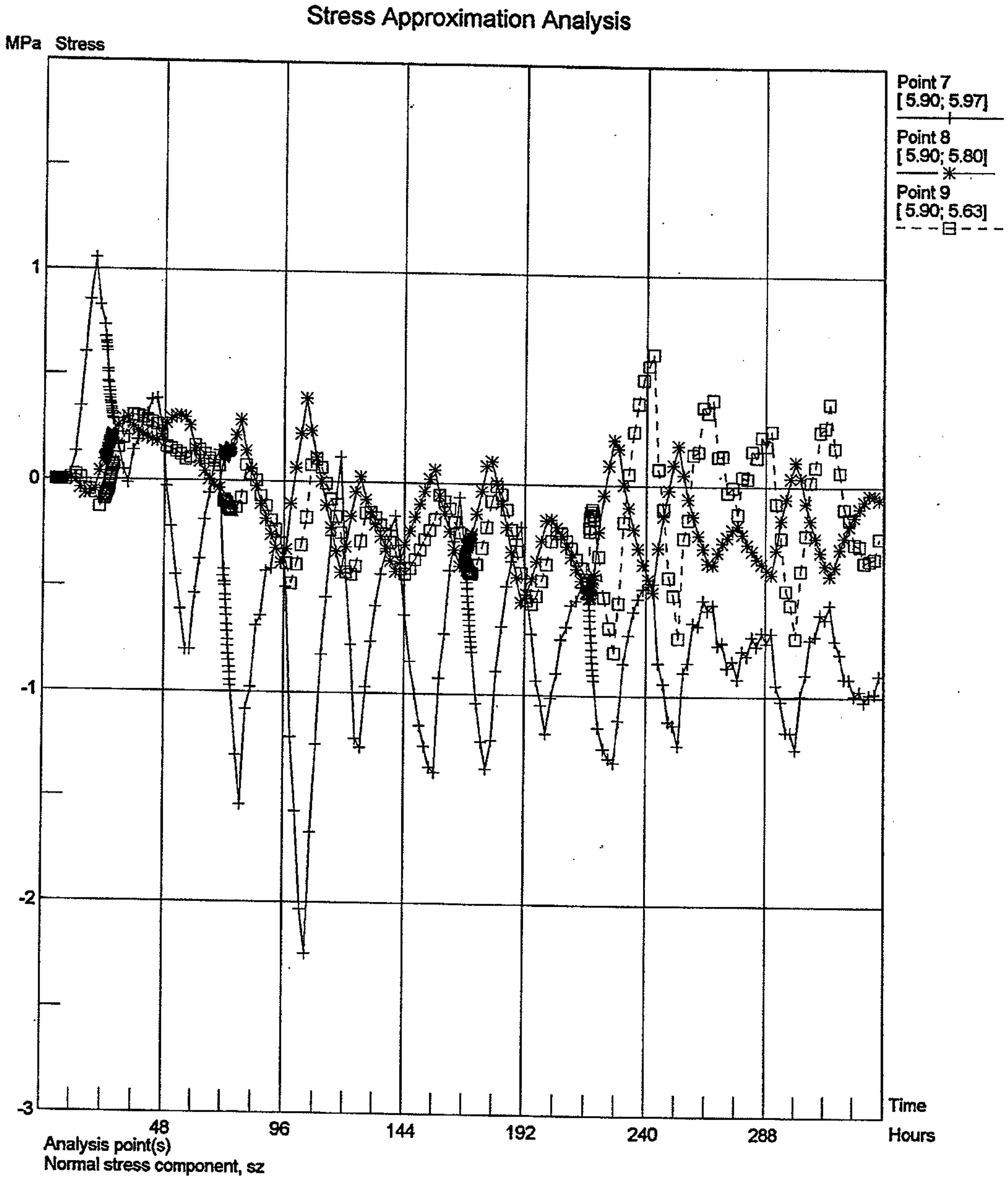
Documentation sheet

Client:
Name:

Ref. nr.:
Initials :

Project:
Id. nr. : ME-AA0084

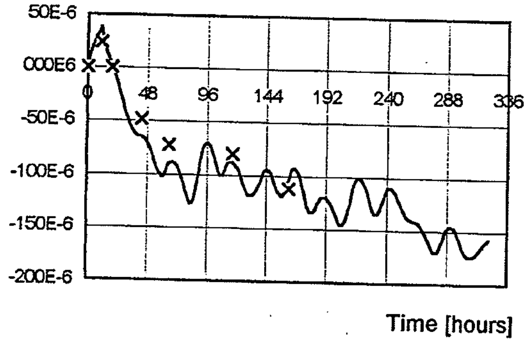
Date: 01/27/97
Time: 22:25



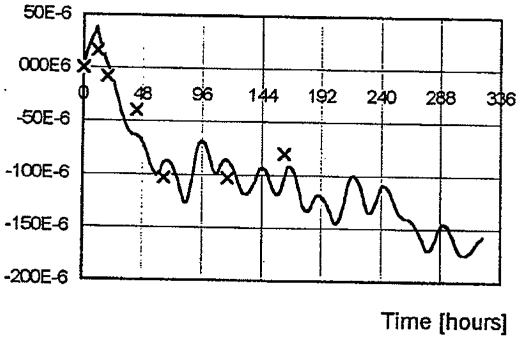
APPENDIX F

Figure F1: Correspondence between measured and calculated deformations at the outer surface in line C for free curvature

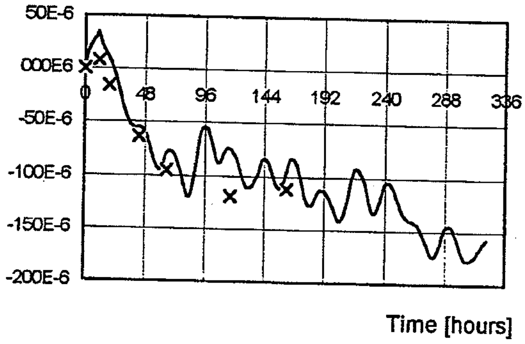
Deformation at level 0 cm [ ]



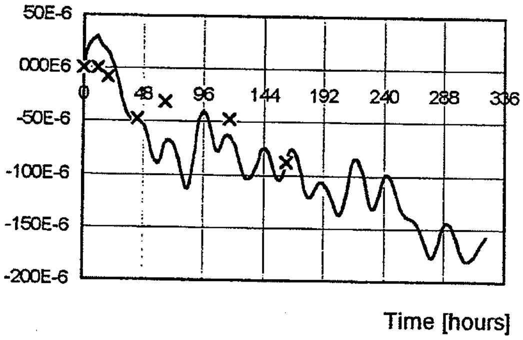
Deformation at level 10 cm [ ]



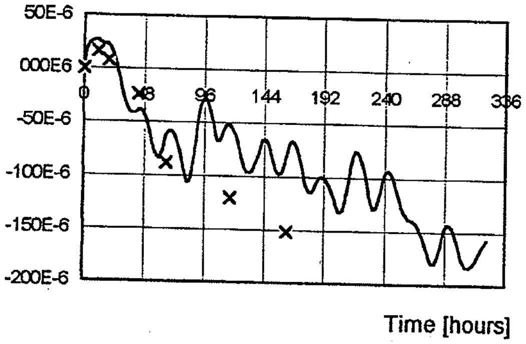
Deformation at level 95 cm [ ]



Deformation at level 173 cm [ ]



Deformation at level 253 cm [ ]



Deformation at level 312 cm [ ]

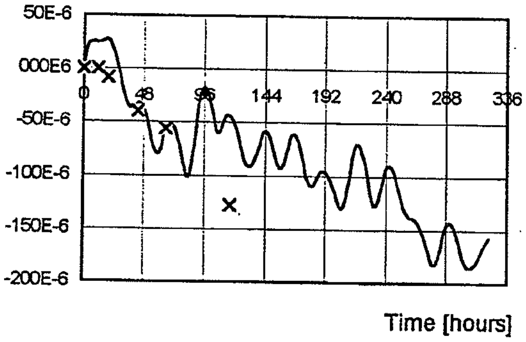
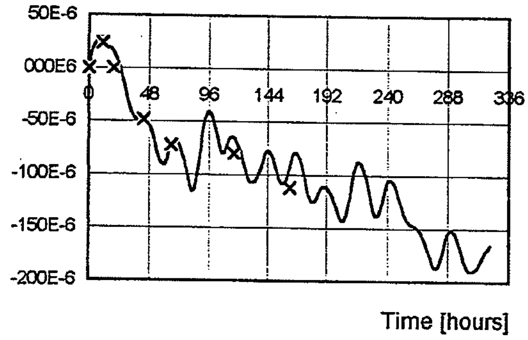
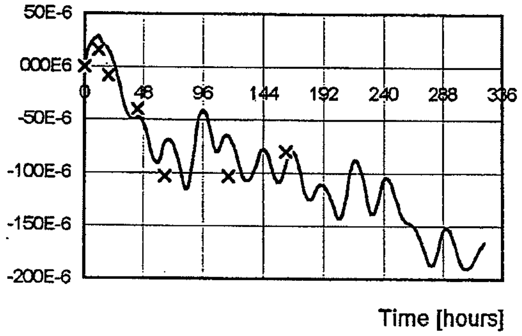


Figure F2: Correspondence between measured and calculated deformations at the outer surface in line C for fixed curvature

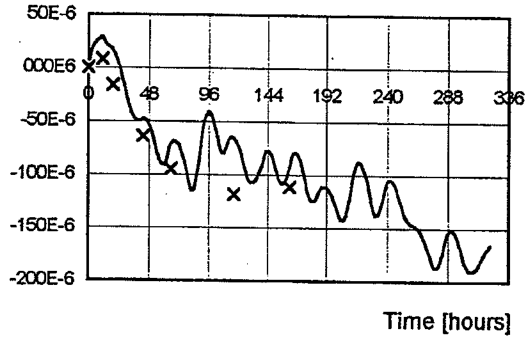
Deformation at level 0 cm [ ]



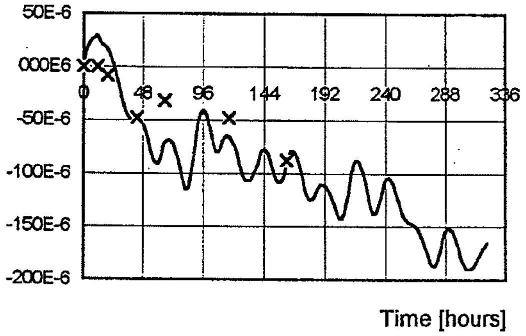
Deformation at level 10 cm [ ]



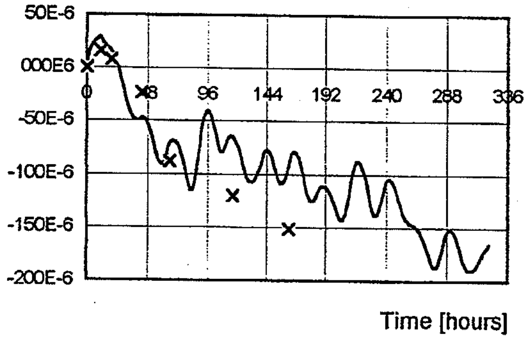
Deformation at level 95 cm [ ]



Deformation at level 173 cm [ ]



Deformation at level 253 cm [ ]



Deformation at level 312 cm [ ]