# ANKARM
# Numerical simulation of anchor plate capacity considering concrete structure reinforcement

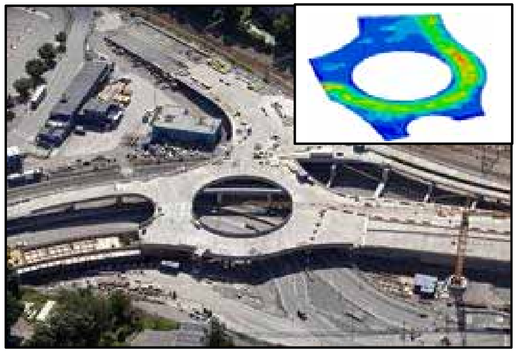
Energiforsk - Seminar
Stockholm, 2015-11-03


- Albin Larsson
M.Sc. Civ. Engineer

Company Profile

## SCANSCOT TECHNOLOGY

- Head office in Lund (Sweden) and subsidiary in Lyon (France)
- Established in 1992
- Experts in numerical simulation
- Offers Engineering Services and Simulation Software Products
- Long experience within the nuclear power industry



# Company Profile

## SCANSCOT TECHNOLOGY - AREAS OF EXPERTISE

STRUCTURAL DESIGN

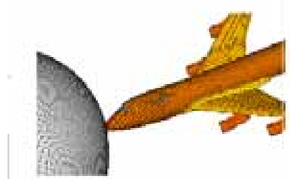
- Analysis and design
- Analysis models (e.g. finite element models)
- Advanced analyses and simulations

EXTREME LOADING EVENTS

- Earthquake, impact, explosion, airplane crash:
  Structural capacity, vibrations and response spectra
- Elevated pressure & temperature, flooding

REQUIREMENTS

- Codes & Standards / Guidelines for structural design
- Structural Design Specifications



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# ANKARM PROJECT

# Agenda

CONTENTS

# Introduction

**PURPOSE**

Investigate how numerical simulations best can be used considering the effect of reinforcement on anchor capacities.

Comparison with:

- Physical tests from other projects
- Design code capacities

**TWO PARTICIPANT TEAMS**

- Scanscot Technology: Albin Larsson, Johan Kölfors, Robert Persson
- Inspecta Nuclear: Peter Segle, Alexander Wulff, Jessica Strömbro

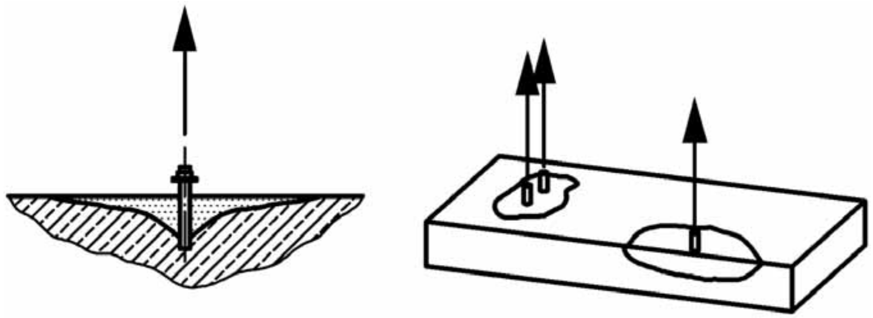
**FINANCED BY**

The Swedish Radiation Safety Authority (SSM)

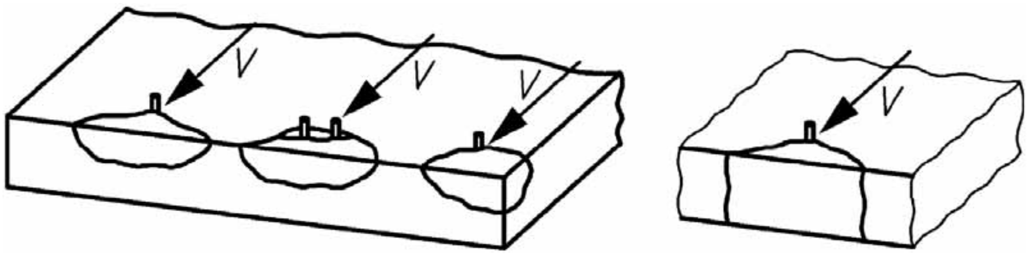
# Introduction

**INVESTIGATED FAILURE MODES:**

- Concrete cone failure (Inspecta team)



- Concrete edge failure (Scanscot Technology team)

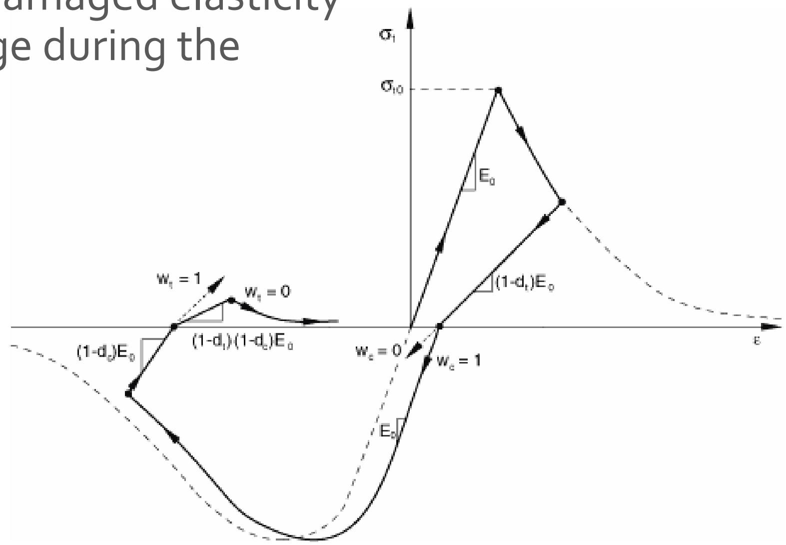


# Introduction

**CONSTITUTIVE CONCRETE MATERIAL MODEL**

CONCRETE DAMAGED PLASTICITY (CDP) IN ABAQUS

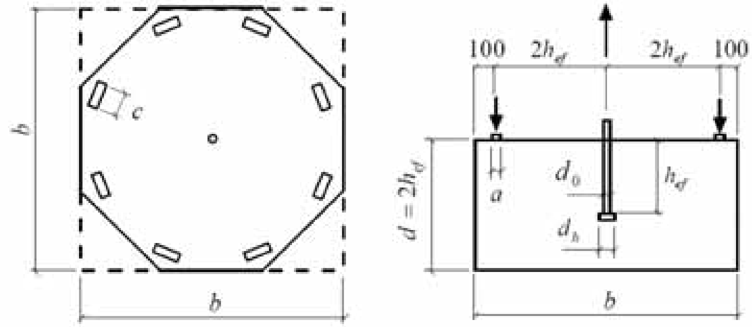
- Isotropic damaged elasticity in combination with isotropic tensile and compressive plasticity
- Combination of non-associated multi-hardening plasticity and scalar (isotropic) damaged elasticity describes the irreversible damage during the fracturing process



# CONCRETE CONE FAILURE

# Tension tests

## SINGLE ANCHOR IN NON-REINFORCED CONCRETE



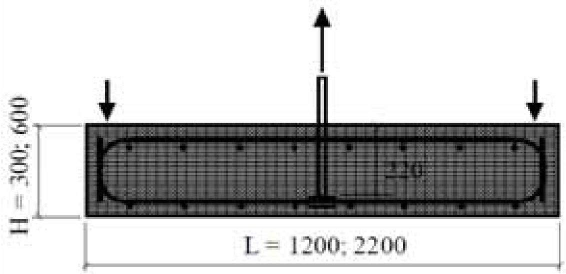

| Size | Anchor | | | Specimen | | Support | |
|---|---|---|---|---|---|---|---|
| | $h_{ef}$ | $d_0$ | $d_h$ | b | d | a | c |
| Small | 50 | 8 | 12.7 | 400 | 100 | 10 | 40 |
| Medium | 150 | 24 | 32.9 | 800 | 300 | 30 | 100 |
| Large | 450 | 72 | 88.5 | 2000 | 900 | 100 | 180 |

$f_{cm,cube} = 31.3$ MPa

**Eligehausen R, Bouska P, Cervenka V, Pukl R, 1992.** Size effect of the concrete cone failure load of anchor bolts. In: Bazant, Z.P. (Editor), Fracture Mechanics of Concrete Structures, pp. 517-525, Elsevier Applied Science, London, New York.

# Tension tests

## SINGLE ANCHOR IN REINFORCED CONCRETE




$f_{cm.cyl}$ = 25 MPa

| No. | *L* [m] | *H* [m] | Top rein-forcement | Pre-crack [mm] |
|---|---|---|---|---|
| 1 | 1.2 | 0.3 | - | 0 |
| 2 | 1.2 | 0.3 | ø12cc300 | 0 |
| 3 | 1.2 | 0.3 | ø16cc150 | 0 |
| 4 | 1.2 | 0.3 | ø16cc100 | 0 |
| 5 | 1.2 | 0.6 | ø12cc300 | 0 |
| 6 | 2.2 | 0.3 | ø12cc400 | 0 |
| 7 | 2.2 | 0.3 | ø12cc150 | 0 |
| 8 | 2.2 | 0.6 | ø12cc150 | 0 |
| 9 | 1.2 | 0.3 | - | 0.5 |
| 10 | 1.2 | 0.3 | ø12cc300 | 0.5 |
| 11 | 1.2 | 0.3 | ø16cc150 | 0.5 |
| 12 | 1.2 | 0.3 | ø16cc100 | 0.5 |
| 13 | 2.2 | 0.3 | ø12cc500 | 0.5 |

**Nilsson M, Elfgren L, 2009.** Fastenings (Anchor Bolts) in Concrete Structures – Effect of Surface Reinforcement on. Nordic Symposium on Nuclear Technology, 25-26 November 2009, Stockholm.

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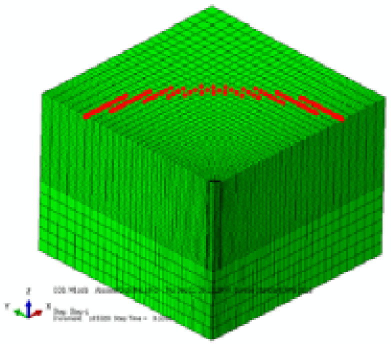
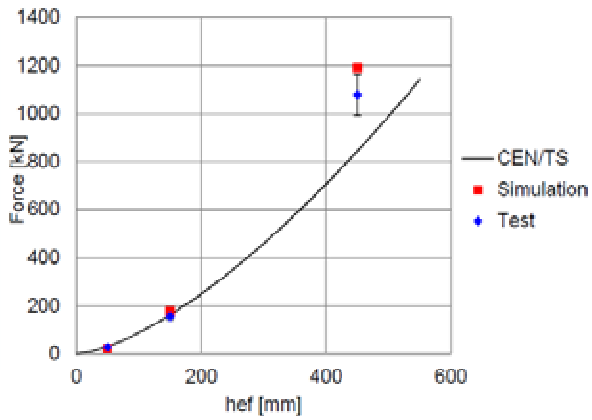
Numerical simulation of tension tests

## ANALYSIS RESULTS – NON-REINFORCED CONCRETE

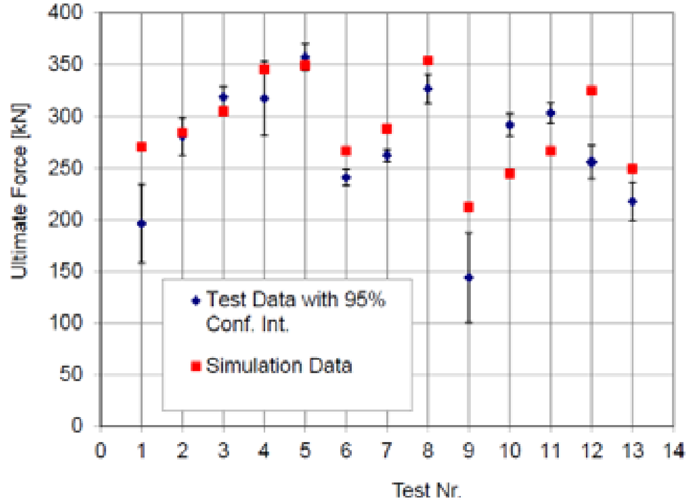





Failure load prediction based on CEN/TS: $N_u = 1.33 \cdot 11.9 \cdot \sqrt{f_{cm,cube}} \cdot h_{ef}^{1.5}$

Numerical simulation of tension tests

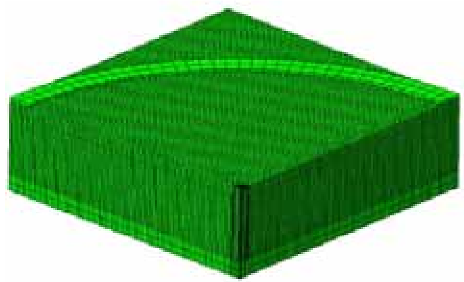
## ANALYSIS RESULTS – REINFORCED CONCRETE




| No. | $L$ [m] | $H$ [m] | Top rein-forcement | Pre-crack [mm] |
|---|---|---|---|---|
| 1 | 1.2 | 0.3 | - | 0 |
| 2 | 1.2 | 0.3 | ø12cc300 | 0 |
| 3 | 1.2 | 0.3 | ø16cc150 | 0 |
| 4 | 1.2 | 0.3 | ø16cc100 | 0 |
| 5 | 1.2 | 0.6 | ø12cc300 | 0 |
| 6 | 2.2 | 0.3 | ø12cc400 | 0 |
| 7 | 2.2 | 0.3 | ø12cc150 | 0 |
| 8 | 2.2 | 0.6 | ø12cc150 | 0 |
| 9 | 1.2 | 0.3 | - | 0.5 |
| 10 | 1.2 | 0.3 | ø12cc300 | 0.5 |
| 11 | 1.2 | 0.3 | ø16cc150 | 0.5 |
| 12 | 1.2 | 0.3 | ø16cc100 | 0.5 |
| 13 | 2.2 | 0.3 | ø12cc500 | 0.5 |

Failure load prediction based on CEN/TS: $N_u = 296$ kN (no pre-crack)

$N_u = 212$ kN (pre-cracked)



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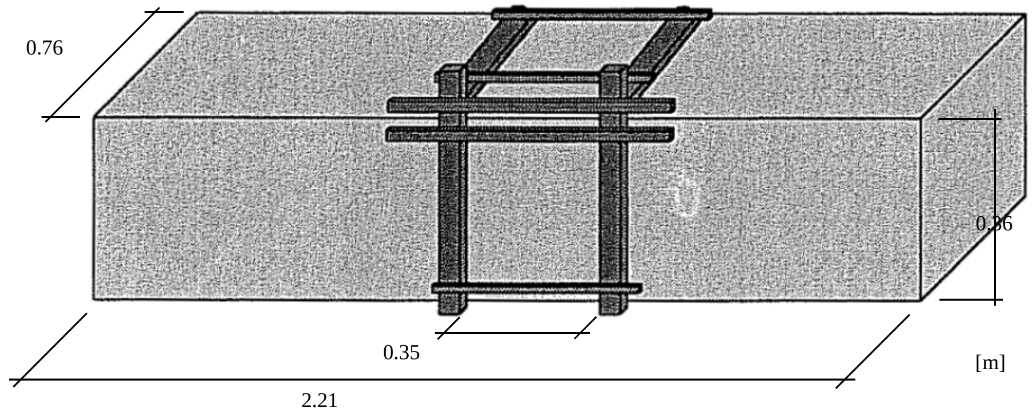
# CONCRETE EDGE FAILURE

# Shear tests of single anchor studs

## NON-REINFORCED CONCRETE LAB TESTS

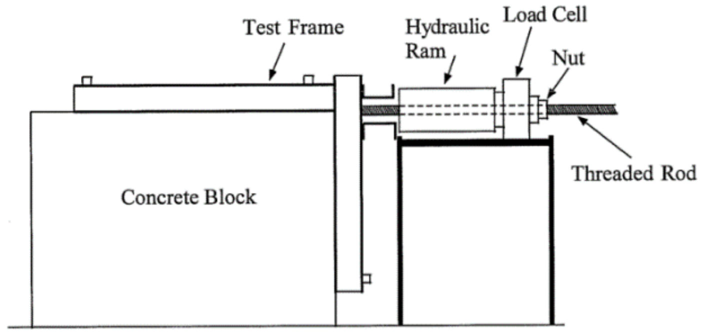
- Research project at the university of Texas under sponsorship of the U.S. Nuclear Regulatory Commission, 2001 [Hallowell Gross et al. 2001]
- Concrete cylinder compressive strength 32.4 MPa



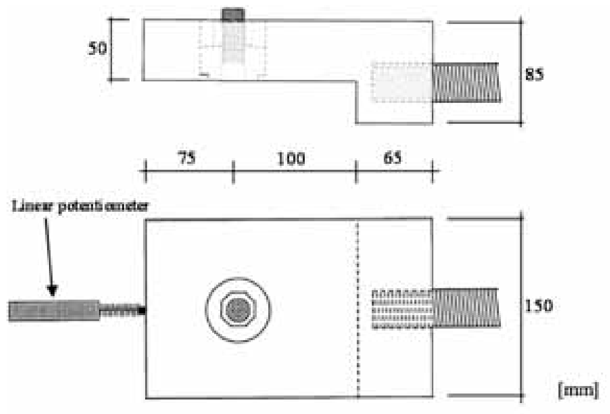
# Shear tests of single anchor studs

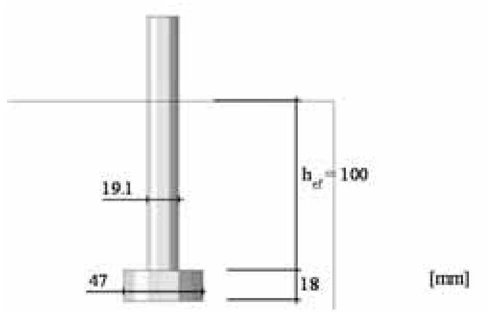
**TEST RIG**

Side view:



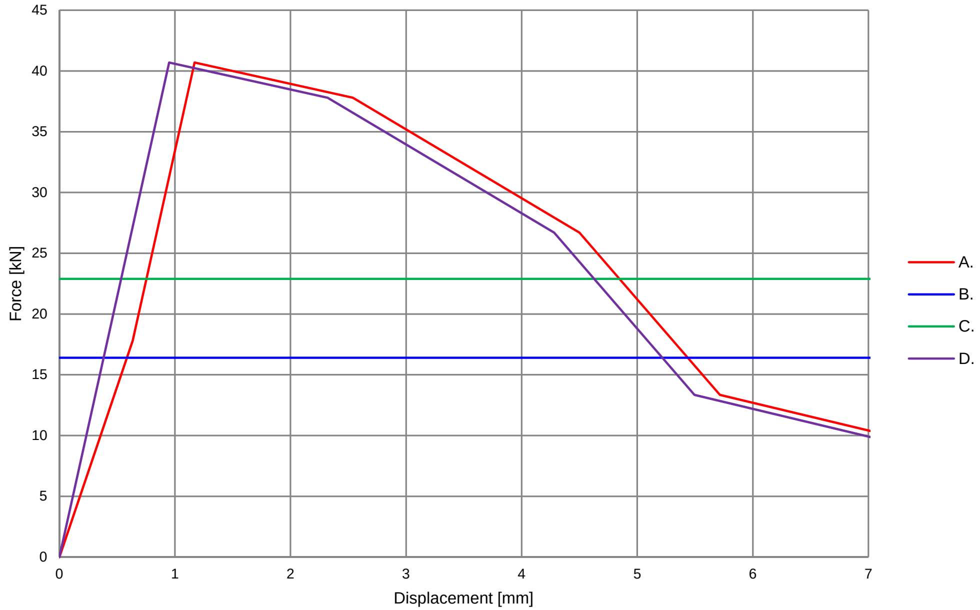

Anchor steel plate and bolt:



# Shear tests of single anchor studs

## TEST RESULTS – A COMPARISON WITH CEN/TS 1992-4-2




A. Physical test [Hallowell Gross et al. 2001]

B. Characteristic capacity of single anchor bolt according to [CEN/TS 1992-4-2 2009]

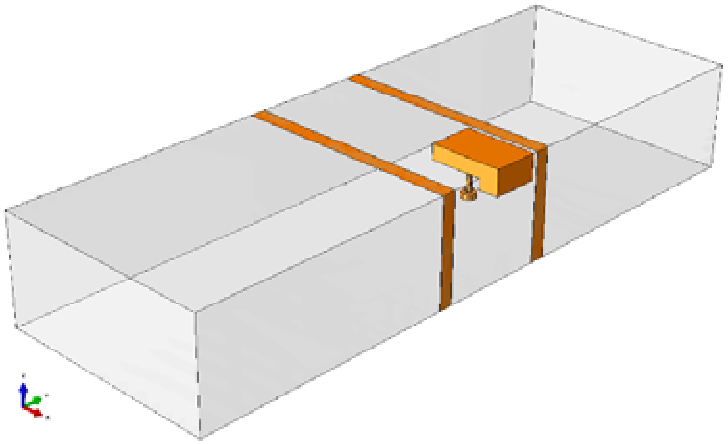
C. Predicted mean capacity of single anchor bolt based on [CEN/TS 1992-4-2 2009]

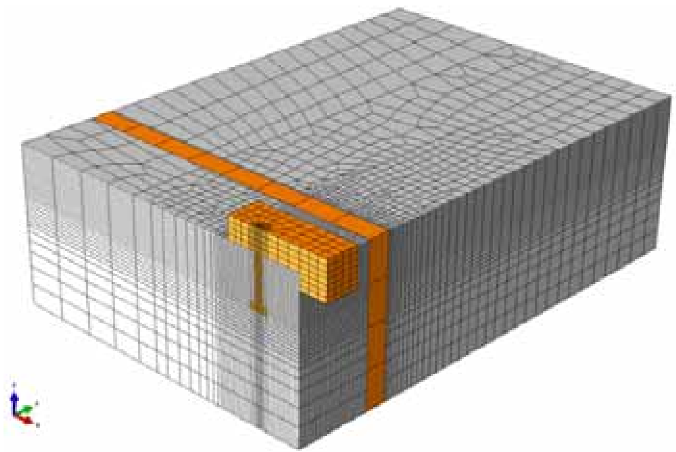
D. Modified force – displacement relation of physical test

# Numerical simulation of shear tests

## ANALYSIS

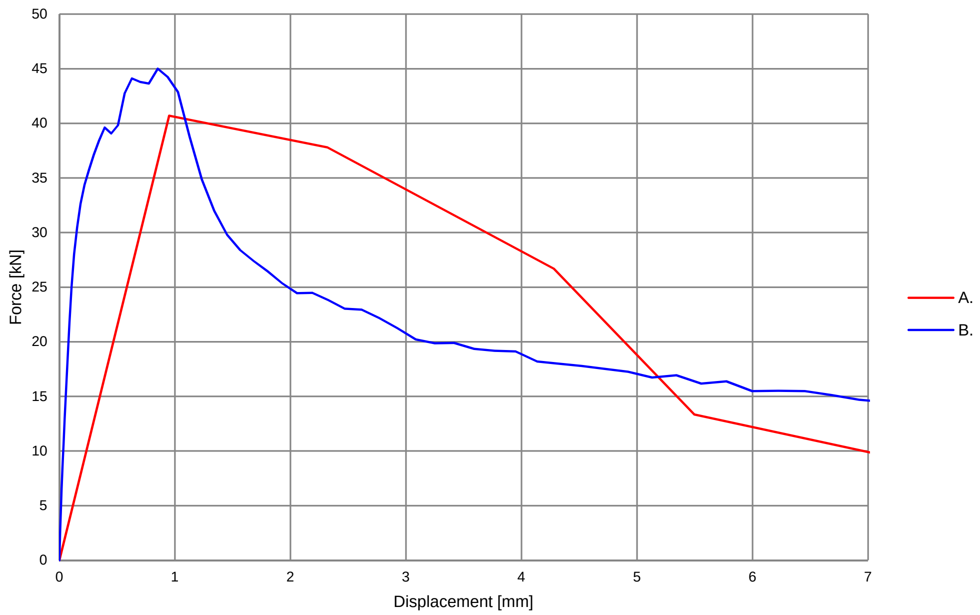
- ABAQUS/Explicit version 6.10
- Quasi static analyses
- ~7 mm element size in dense meshed region
- Displacement rate 30 mm/s
- Frictionless contact formulation between steel and concrete





# Numerical simulation of shear tests

## ANALYSIS RESULTS



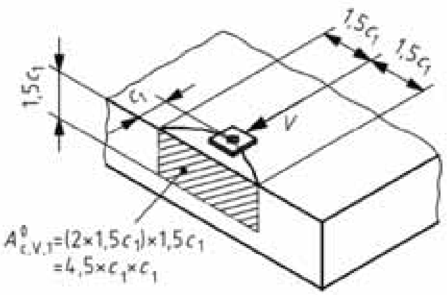

A. Modified force – displacement relation of physical test

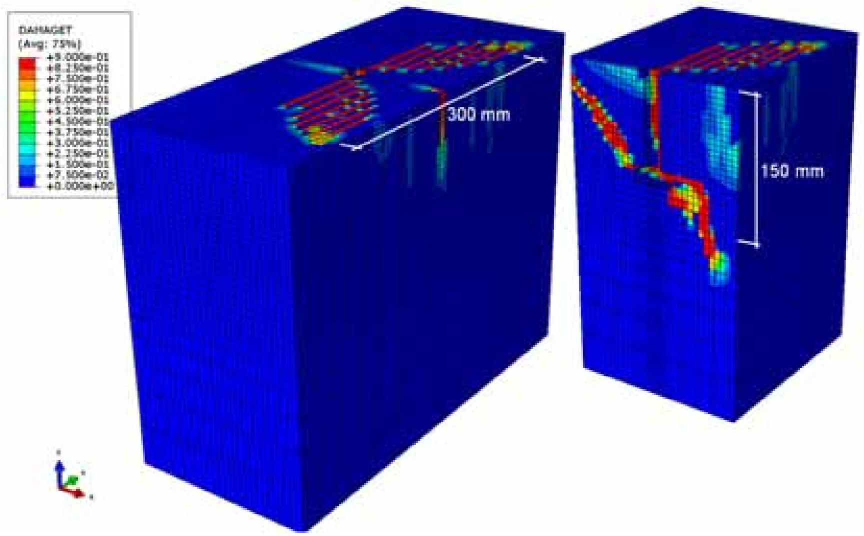
B. Numerical simulation results

Numerical simulation of shear tests

## ANALYSIS RESULTS – FRACTURE SURFACE

A comparison with CEN/TS 1992-4-2



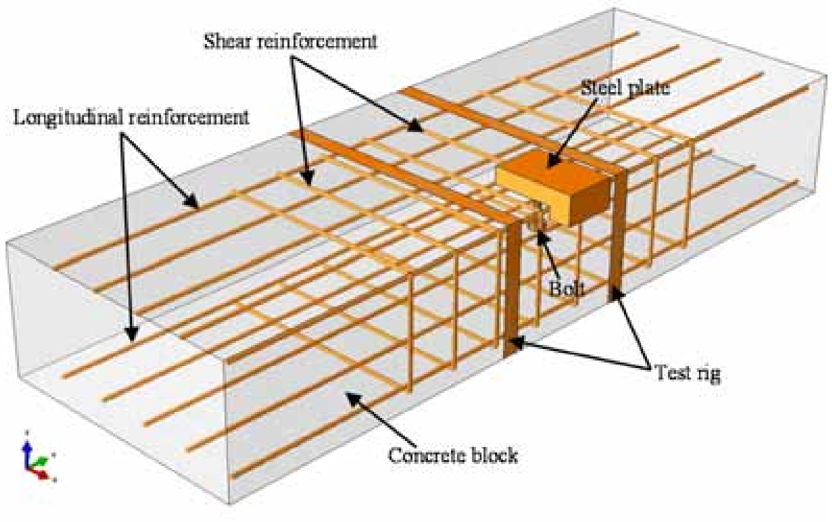



Distance $c_1$ = 100 mm

Ideal breakout surface:
Width = 1.5·100·2 = 300 mm
Height = 150 mm

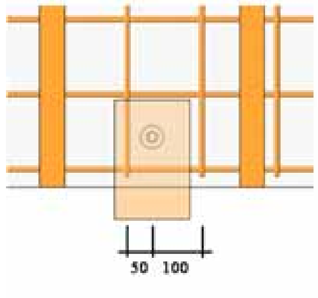
Numerical simulation of shear tests

## ANALYSIS – REINFORCEMENT SETUPS

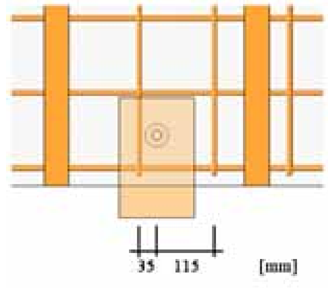



| Part | Elements |
|---|---|
| Concrete block | Solids (C3D8R & C3D6R) |
| Bolt and steel plate | Solid bricks (C3D8R) |
| Test rig | Rigid (R3D4) |
| Reinforcement | Beam (B31) |

Shear reinforcement with 25 mm eccentricity

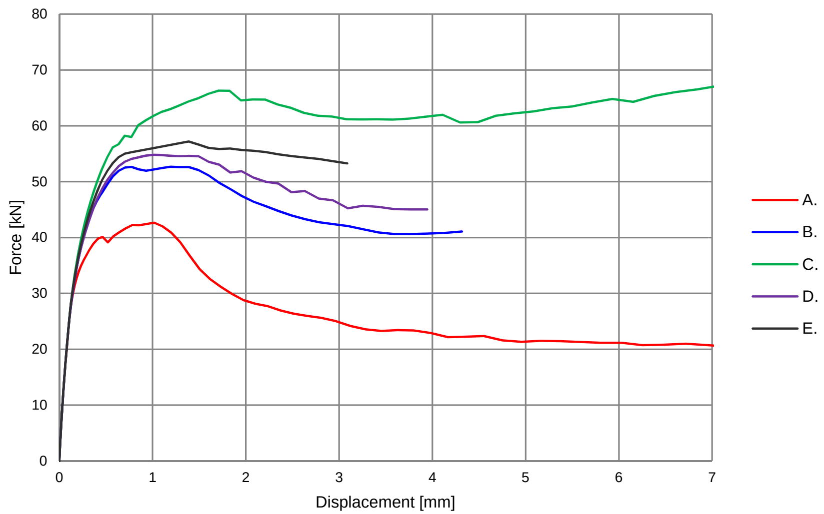



Shear reinforcement with 40 mm eccentricity



# Numerical simulation of shear tests

## ANALYSIS RESULTS – REINFORCEMENT SETUPS




| Setup | Failure load [kN] | Corresponding shear reinforcement stresses [MPa] |
|---|---|---|
| A | 42.6 | - |
| B | 52.6 | 66.3; 66.3 |
| C | 66.3 | 15.9; 138.8; 141.5; 15.9 |
| D | 54.8 | 123.8; 49.5 |
| E | 57.2 | 184.0; 23.9 |

A. Longitudinal reinforcement Φ12cc150 mm

B. Longitudinal reinforcement Φ12cc150 mm + shear reinforcement Φ12cc150 mm

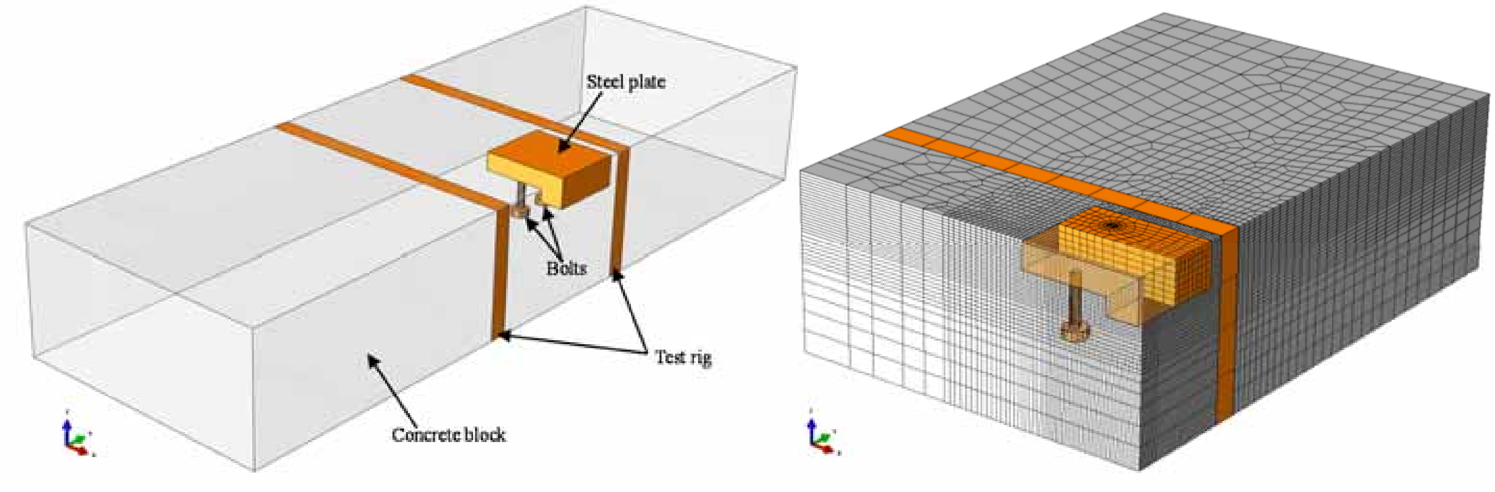
C. Longitudinal reinforcement Φ12cc150 mm + shear reinforcement Φ12cc100 mm

D. Longitudinal reinforcement Φ12cc150 mm + 25 mm ecc. shear reinforcement Φ12cc150 mm

E. Longitudinal reinforcement Φ12cc150 mm + 40 mm ecc. shear reinforcement Φ12cc150 mm

# Numerical simulation of shear tests

## ANALYSIS – GROUP OF ANCHORS




| Part | Elements |
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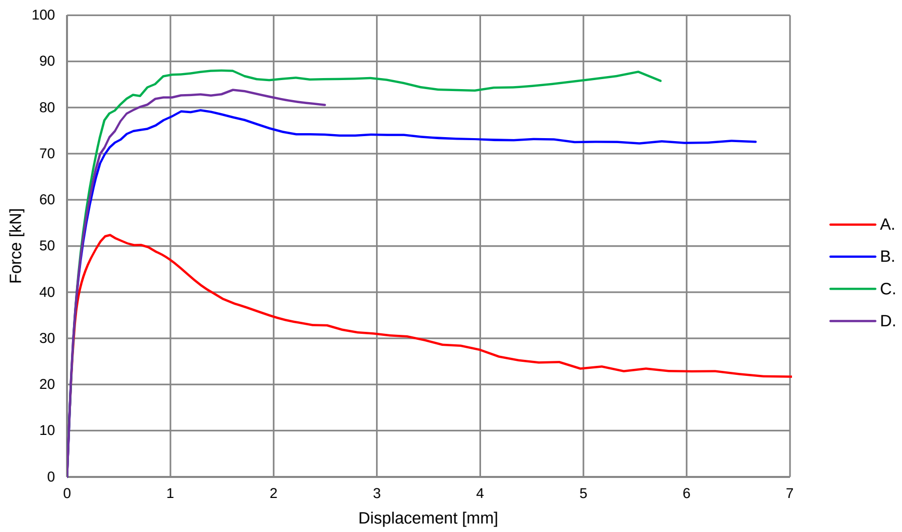
| Concrete block | Solids (C3D8R & C3D6R) |
| Bolt and steel plate | Solid bricks (C3D8R) |
| Test rig | Rigid (R3D4) |

Numerical simulation of shear tests

## ANALYSIS RESULTS – GROUP OF ANCHORS




| Setup | Failure load [kN] | Corresponding shear reinforcement stresses [MPa] |
|---|---|---|
| A | 52.4 | - |
| B | 79.4 | 47.4; 307.9; 46.7 |
| C | 87.9 | 9.8; 112.0; 222.3; 112.7; 10.0 |
| D | 83.8 | 58.4; 303.4; 19.4 |

A. Longitudinal reinforcement Φ12cc150 mm

B. Longitudinal reinforcement Φ12cc150 mm + shear reinforcement Φ12cc150 mm

C. Longitudinal reinforcement Φ12cc150 mm + shear reinforcement Φ12cc100 mm

D. Longitudinal reinforcement Φ12cc150 mm + 25 mm ecc. shear reinforcement Φ12cc150 mm

# CONCLUSIONS & FURTHER STUDIES

# Conclusions

## CONCLUSIONS OF THIS R&D PROJECT

- Studied failure modes can be simulated with confidence using finite element analyses
- Simulations show good agreement with results from physical tests
- The CDP constitutive model in Abaqus is found to work well for the simulation of the failure modes studied
- Mean concrete cylinder strength values seems to be most appropriate for simulation of physical responses
- Reinforcement makes the failure more ductile
- Global stiffness of the concrete structure is not considered by design codes when designing anchors. If the concrete structure is flexible, this might result in an overestimation of the concrete cone capacity
- Simulated concrete cone failure loads for anchors in non-cracked reinforced concrete show better agreement with physical tests than that of anchors in pre-cracked reinforced concrete
- Reinforcement in the direction of the applied load leads to a distinct increase of the concrete edge failure capacity

# Further work / Ongoing work

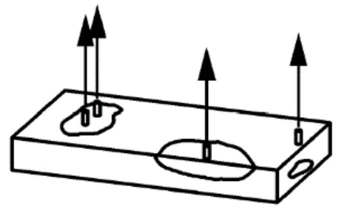
**ANKARM II, 2015-2017**

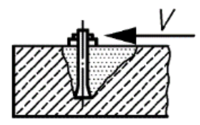
Ongoing project 2015-2017

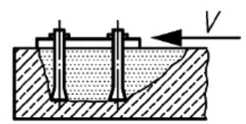
Additional numerical simulations:

- Eccentrically loaded anchor plates (tension)
- Concrete pryout failure (shear)
- Concrete blowout failure (tension)
- Combined tension and shear loaded anchor plates

Special interest in effect of reinforcement content and its configurations on the anchor plate capacities





Thank you for your attention

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