# Tensile membrane action of thin, lightly reinforced concrete floor slabs under large deflection and at elevated temperatures

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# Project Objectives and Goals

- An in-depth investigation of BRE/Bailey simplified design method for composite floor slabs in fire. The project comprises:
  - Experimental studies at ambient and elevated temperatures.
  - Numerical modelling.
  - Further developments to the simple design method.

# Background to the Simplified Design Method

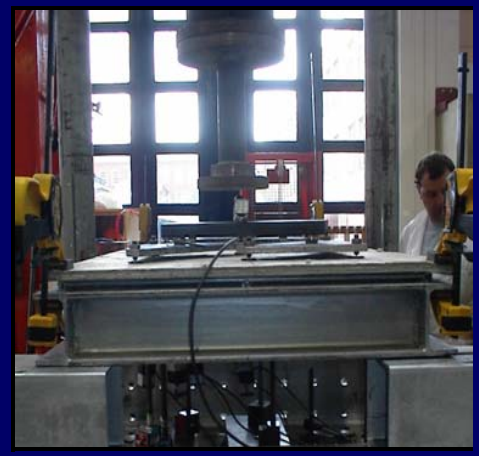
- The aim of the BRE method was to extend the existing codified methods, incorporating membrane action of the composite slab.
- Membrane action in concrete slabs creates in-plane forces that increase its load-carrying capacity above that predicted using normal yield-line theory.

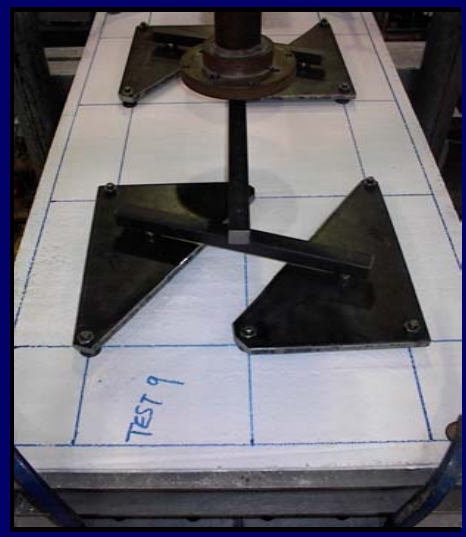
# Small Scale Experiments at Ambient Temperature

- Extensive experimental work was undertaken in first year of PhD to investigate:
  - The behaviour of isotropically and orthotropically reinforced concrete slabs.
  - The effect of smooth and deformed wire on the slab behaviour.
  - The behaviour of the slab with varying aspect ratio.
  - The assumptions made in the simplified method.

# Test Configuration and Instrumentation

- Two sizes of slabs were tested:
  - 1200x600x15 mm
  - 900x600x15 mm
- 12 point loading system
- Constant total area of reinforcement 0.3%
- Isotropic and orthotropic reinforcement





# Casting of the Slabs

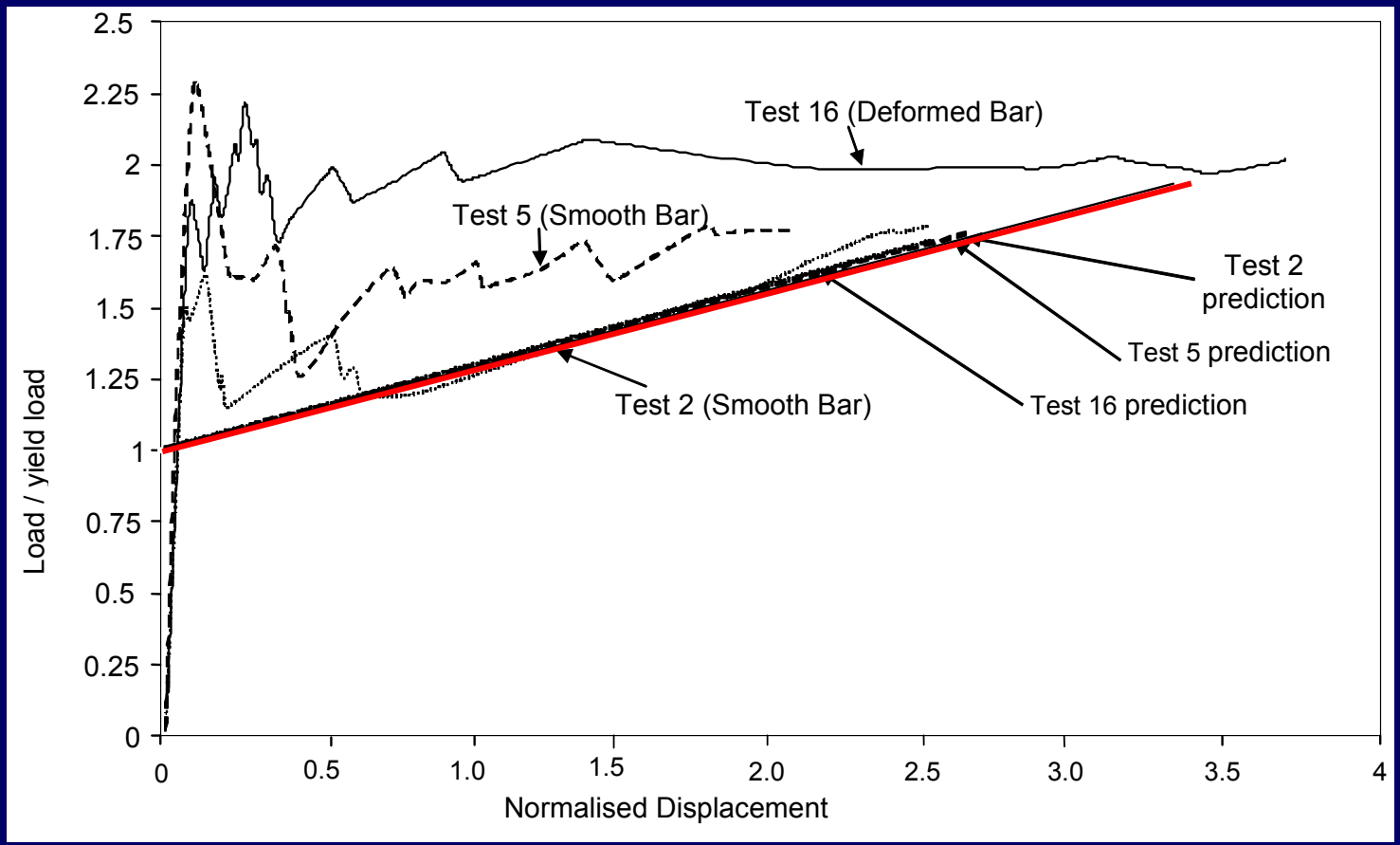
Reinforcement
placed at half depth

Casting the slab

Finished slab

# Test Results

## Isotropic Slabs of Aspect Ratio 2.09

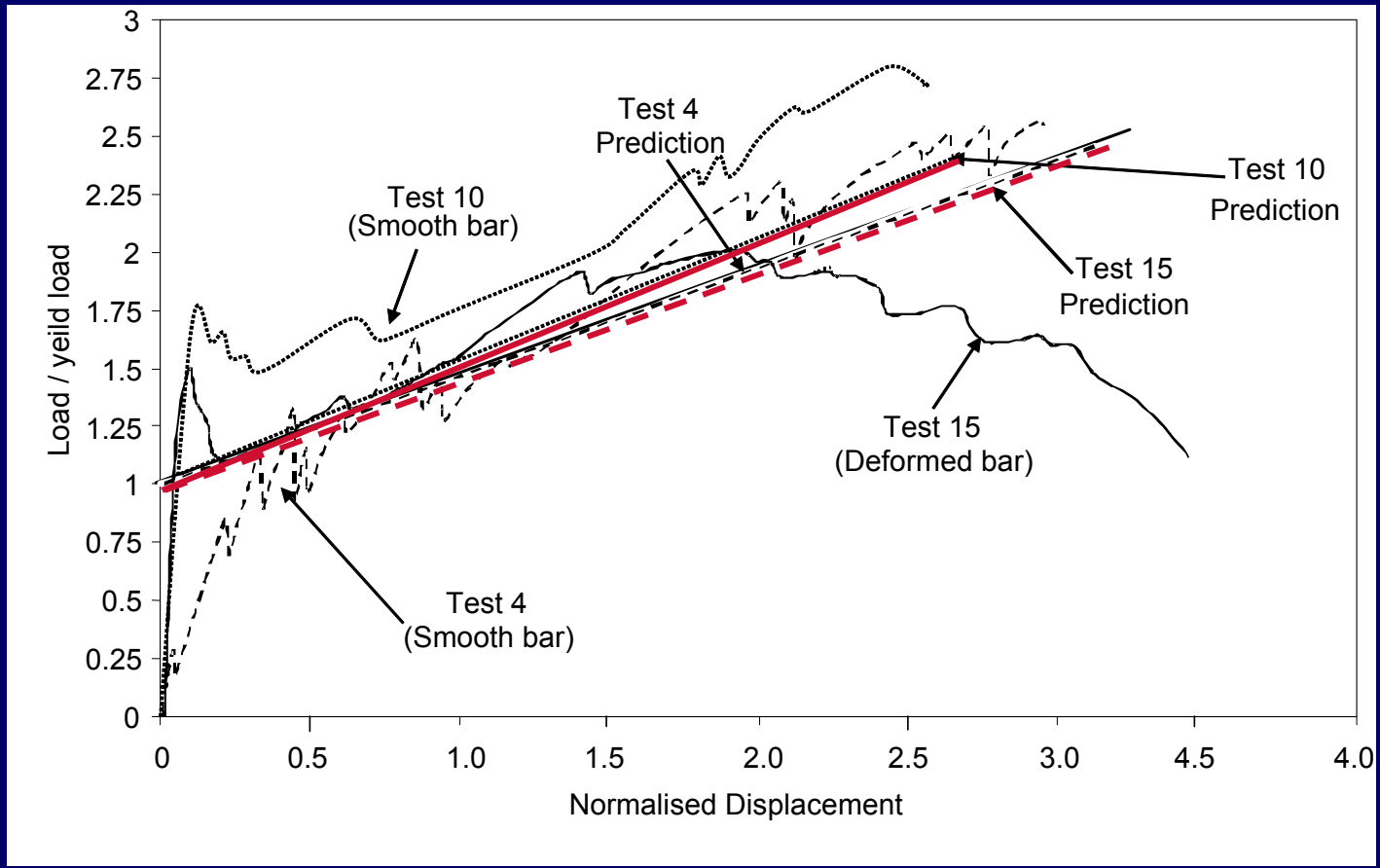


# Isotropic Slabs of Aspect Ratio 2.09

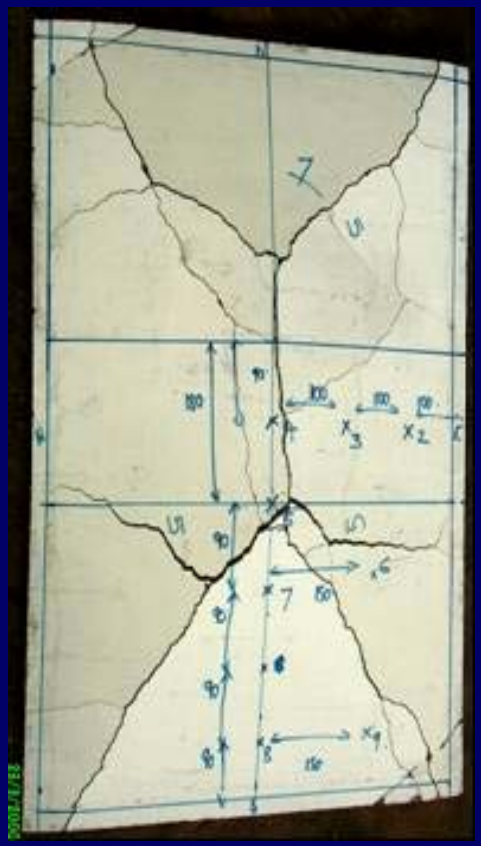
Test 5: Bottom surface

Test 16: Bottom surface

# Isotropic Slabs of Aspect Ratio 1.55



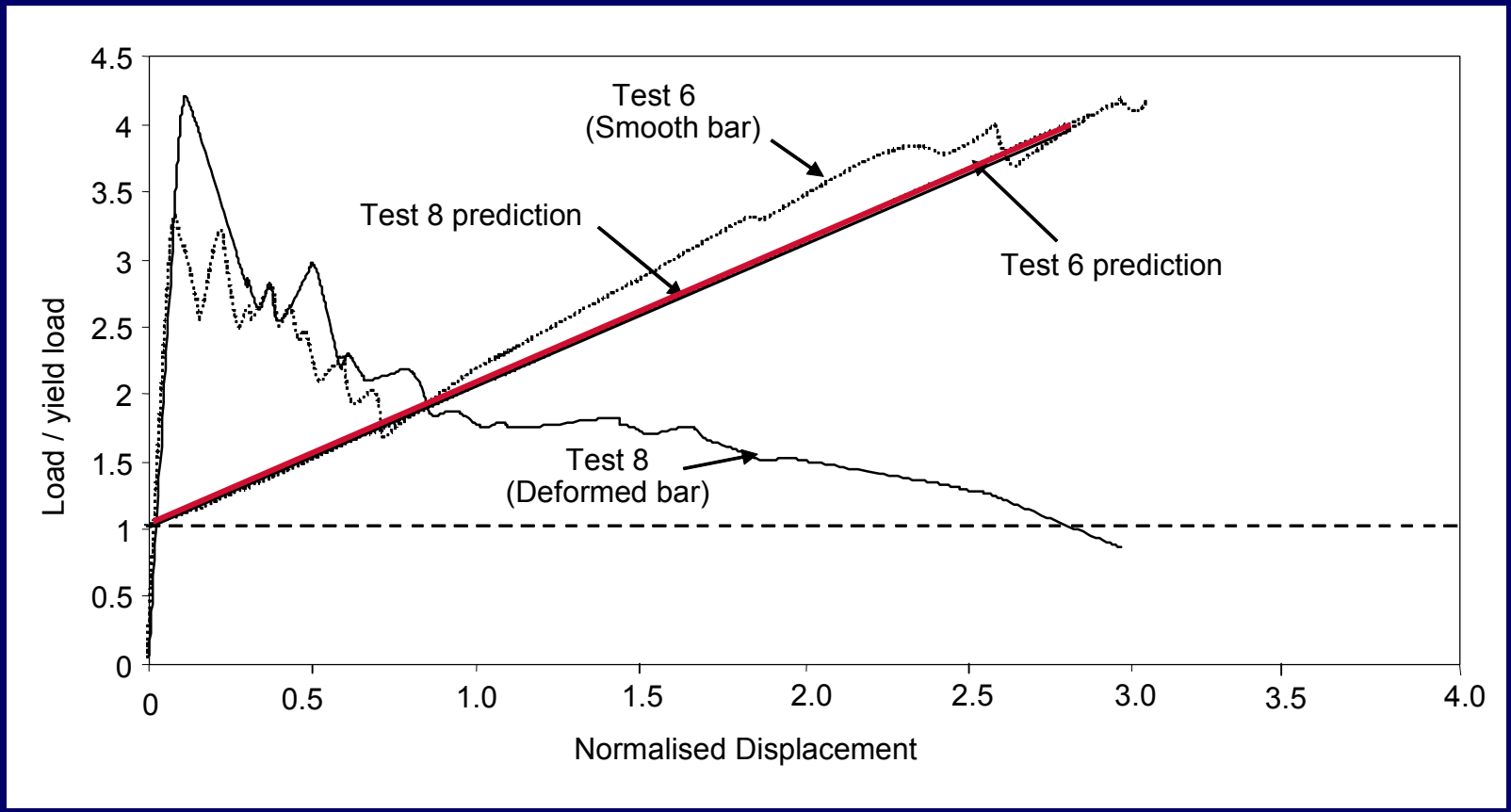
# Isotropic Slabs of Aspect Ratio 1.55



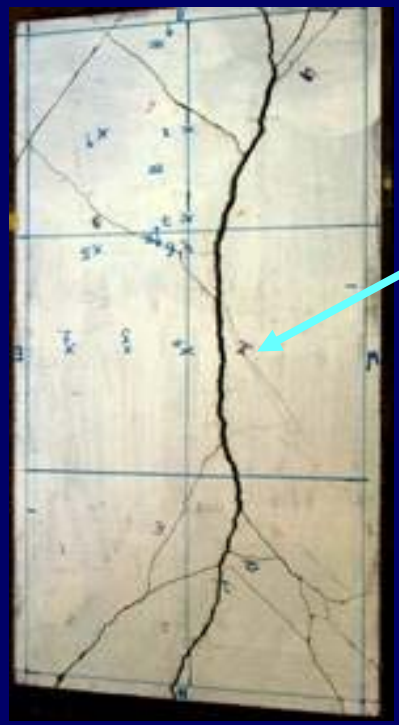
Test 10: Bottom surface

Test 15: Bottom surface

# Orthotropic slabs (*μ=0.2)* of aspect ratio of 2.09



# Orthotropic slabs ($\mu$=0.2) of aspect ratio of 2.09



No development of tension crack across short span

Test 6: Bottom surface

Test 8: Bottom surface

# Key Findings at Ambient Temperature

- The load-carrying capacity of the slabs was far greater than the design capacity using the well-known yield-line theory.
- Design method compares well with the experimental results for the slabs reinforced with smooth wire.
- Deformed wire causes high initial peak but more rapid decline.

# High Temperature Tests

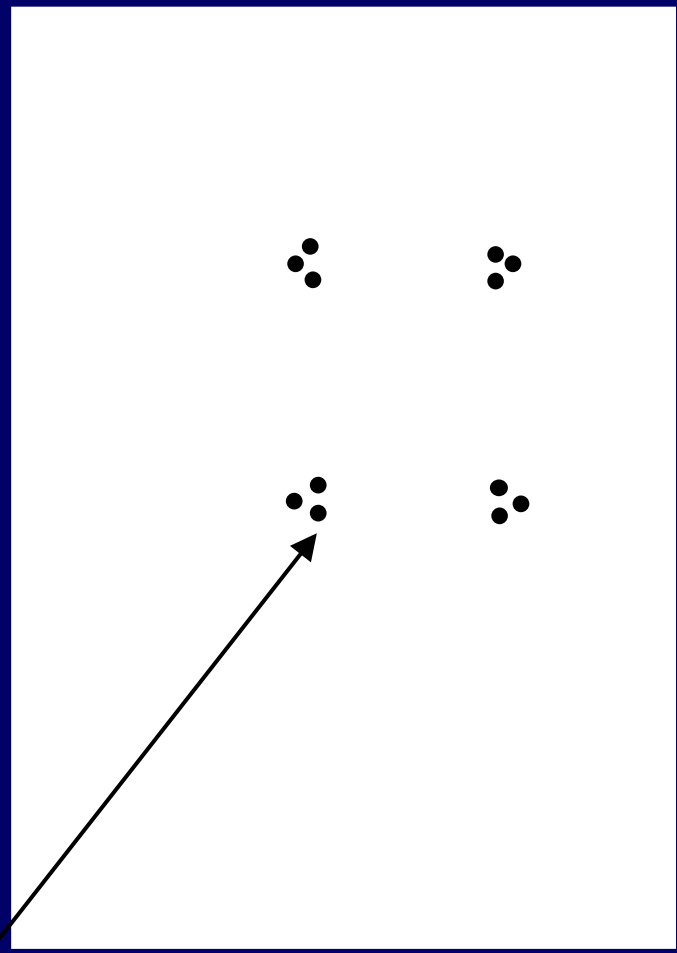
- The objectives of the next set of experiments:
  - Investigate the behaviour of the concrete floor slabs at elevated temperatures.
  - Attempt to understand the effect of heating and bond on the structural response.
  - Investigate the influence of thermal bowing on the load-carrying capacity of the slab.
  - Further developments to the simple design method.

# Test Set-Up

Heating box is placed underneath the support frame

12 point loading system

# Thermocouples



**12 thermocouples:**
**4 surface, 4 reinforcement**
**4 underside of slab**

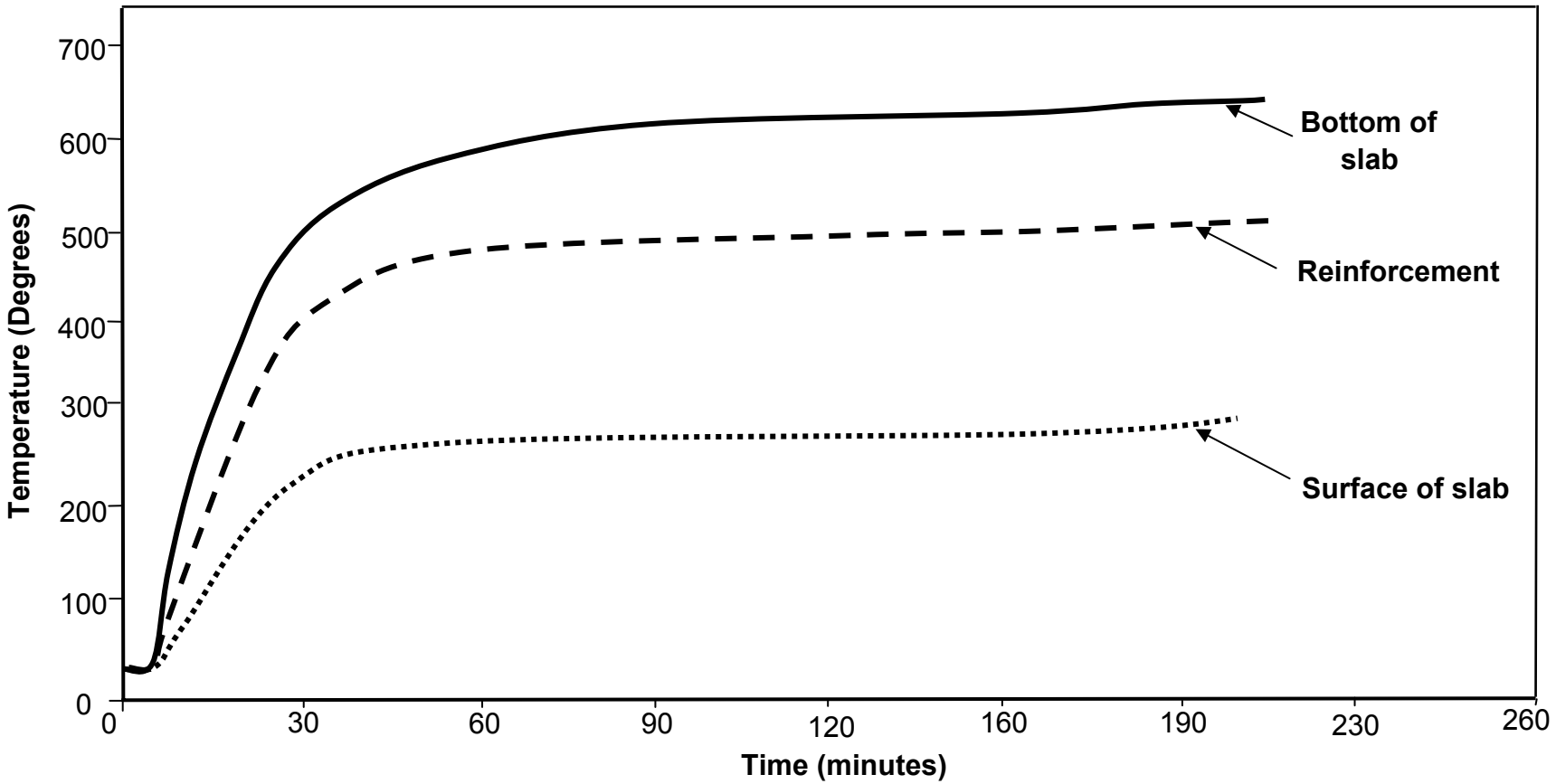
# Schedule of High-Temperature Tests

- 32 slabs to be tested.
- The following parameters to be investigated:
  - Aspect ratio of the slab.
  - Effect of reinforcement bond strength.
  - Effect of increasing the reinforcement percentage.
  - Effective depth of the slab.

# Tests Completed

- 16 High-Temperature tests completed:
  - 9 tests with smooth bars
  - 7 tests with deformed bars
  - Slab depths of 15 and 22 mm
  - Reinforcement 0.1%, 0.2%, 0.3% and 0.5%
  - Aspect ratio 1.55 only

# Results

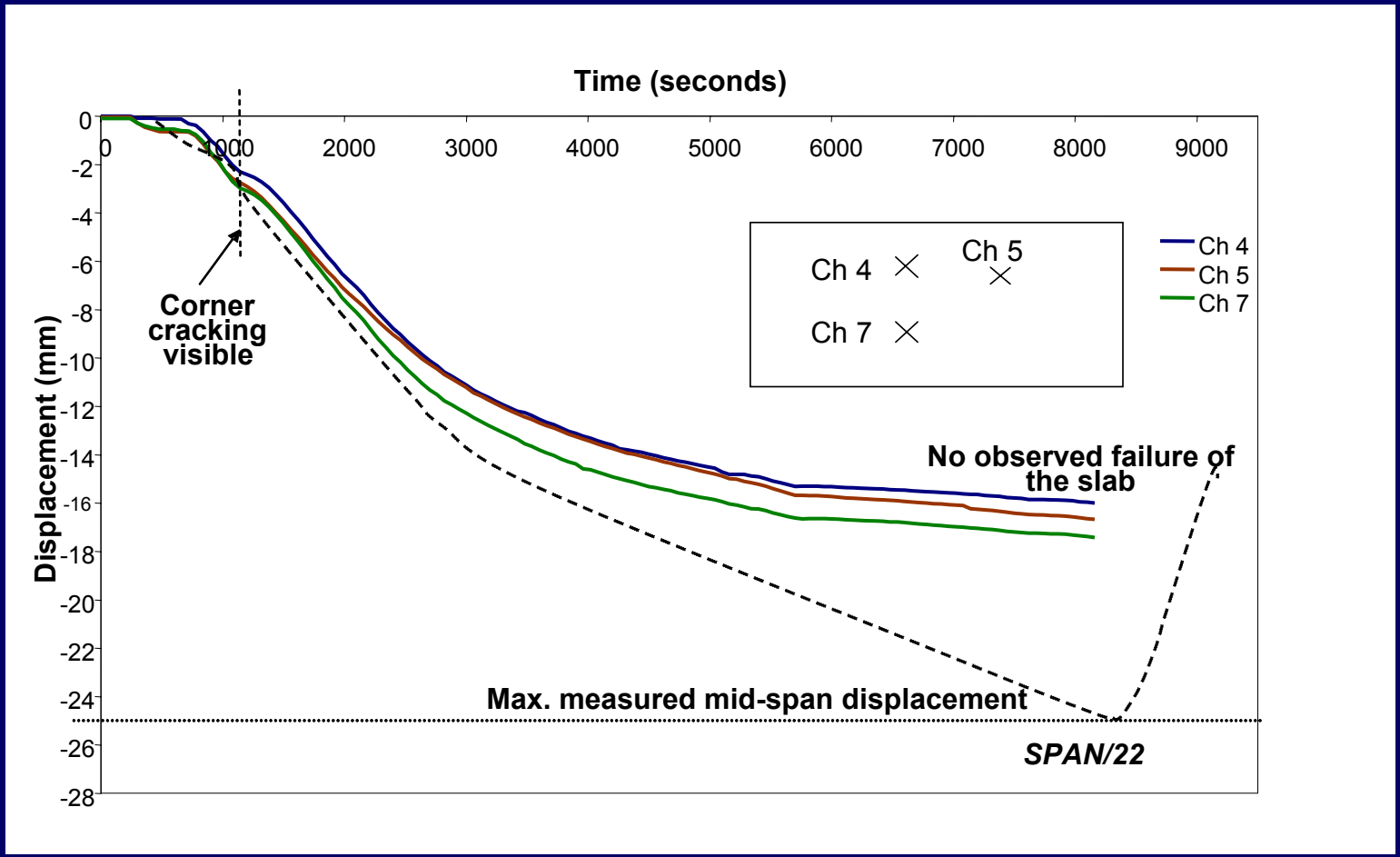



**Temperature profiles through the depth of the slab**

# Test 1

- Slab size 850x550mm reinforced with smooth wire.
  - Reinforcement 0.3%
  - Yield Line load *($W_u$)* of 1.81 kN/m$^2$
  - Imposed load *(Q)* of 2.95 kN/m$^2$
  - $$\frac{Q}{W_u} = 1.63$$

# Test 1




## Vertical Displacement

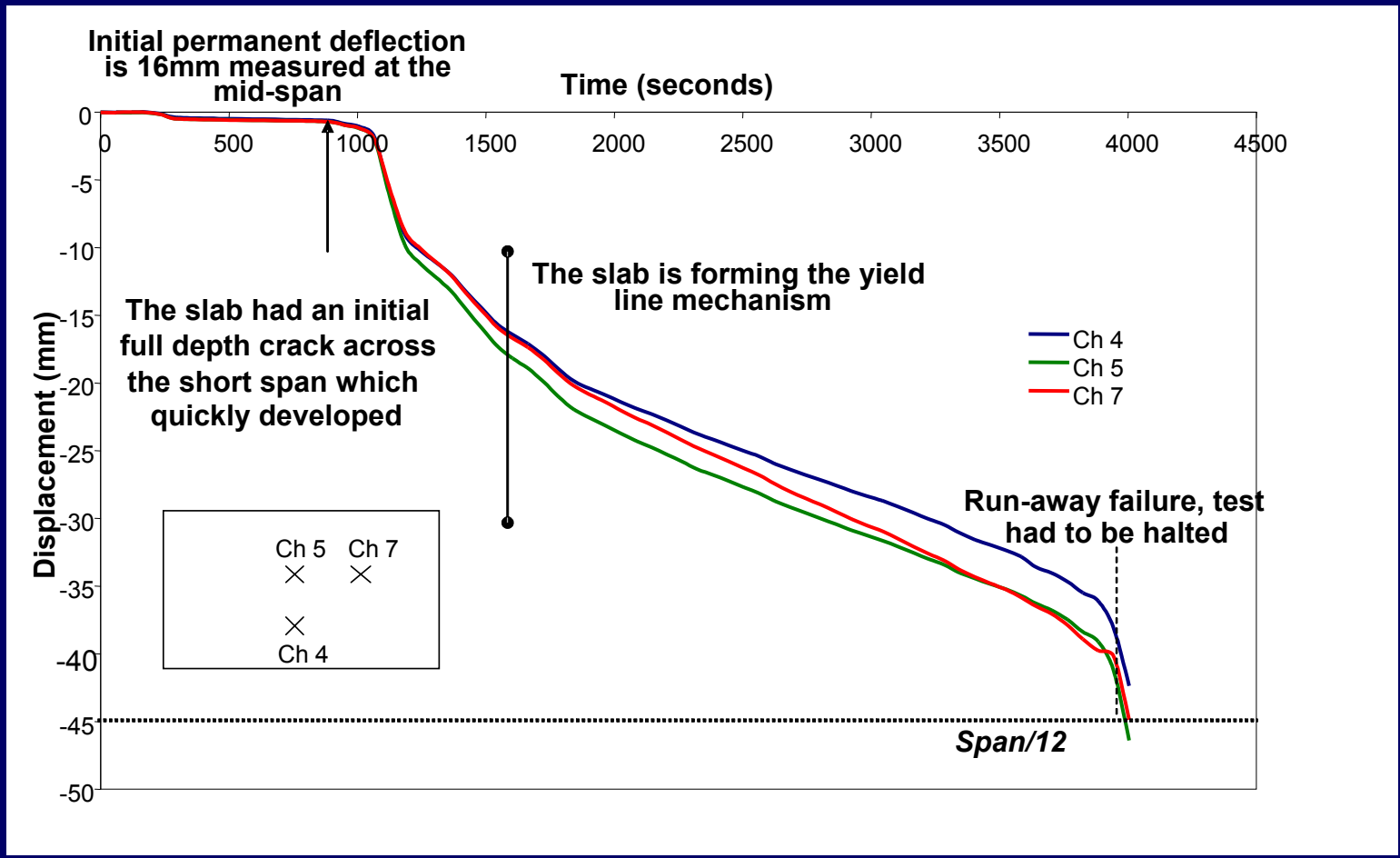
# Test 1

Crack formed across the short span

# Test 2

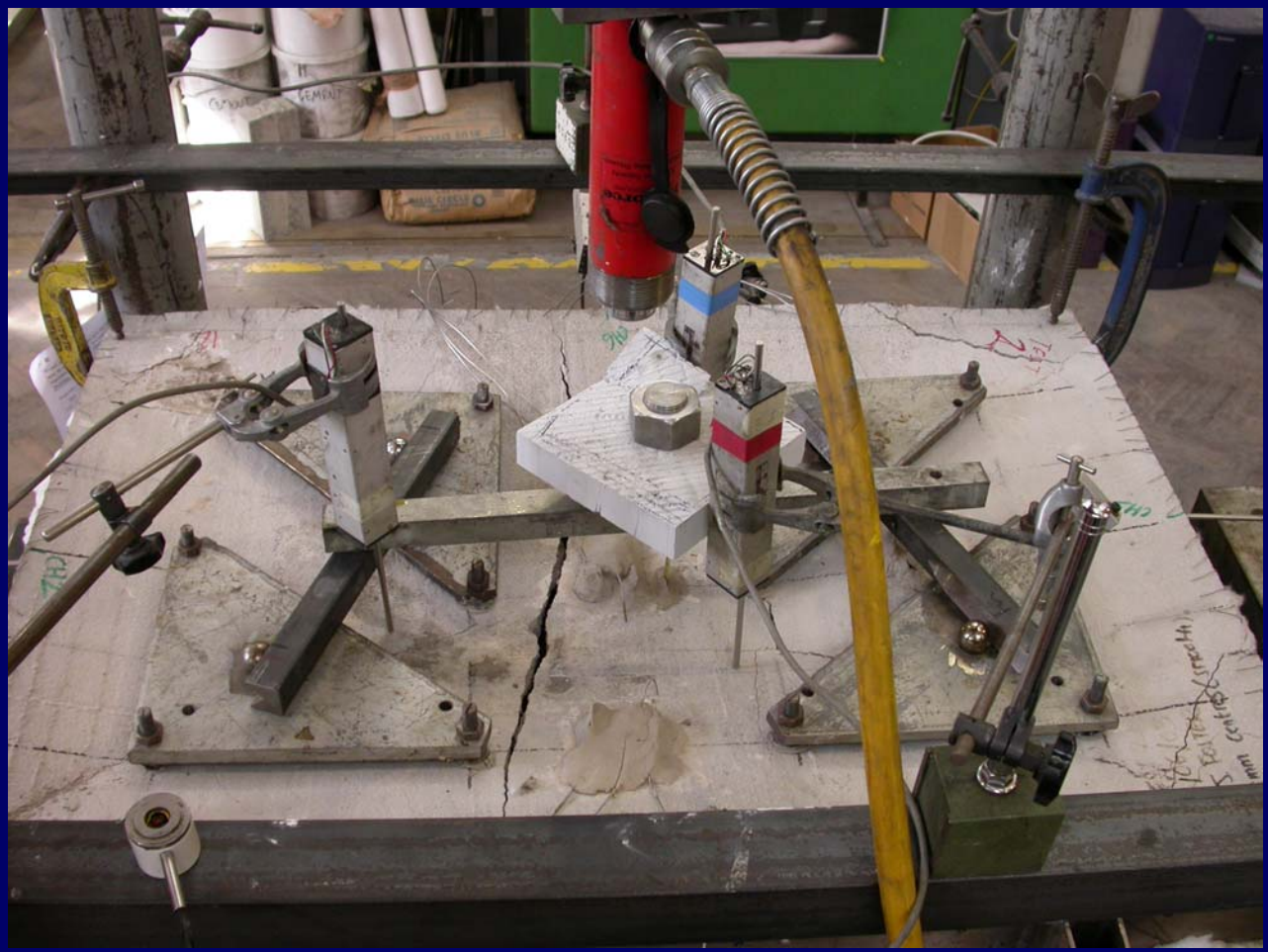
- Slab size 850x550mm reinforced with smooth wire.
  - Reinforcement 0.3%
  - Yield Line load *(Wu)* of 1.81 kN/m$^2$
  - Imposed Load *(Q)* of 4.60 kN/m$^2$
  - $\frac{Q}{W_u} = 2.5$

# Test 2



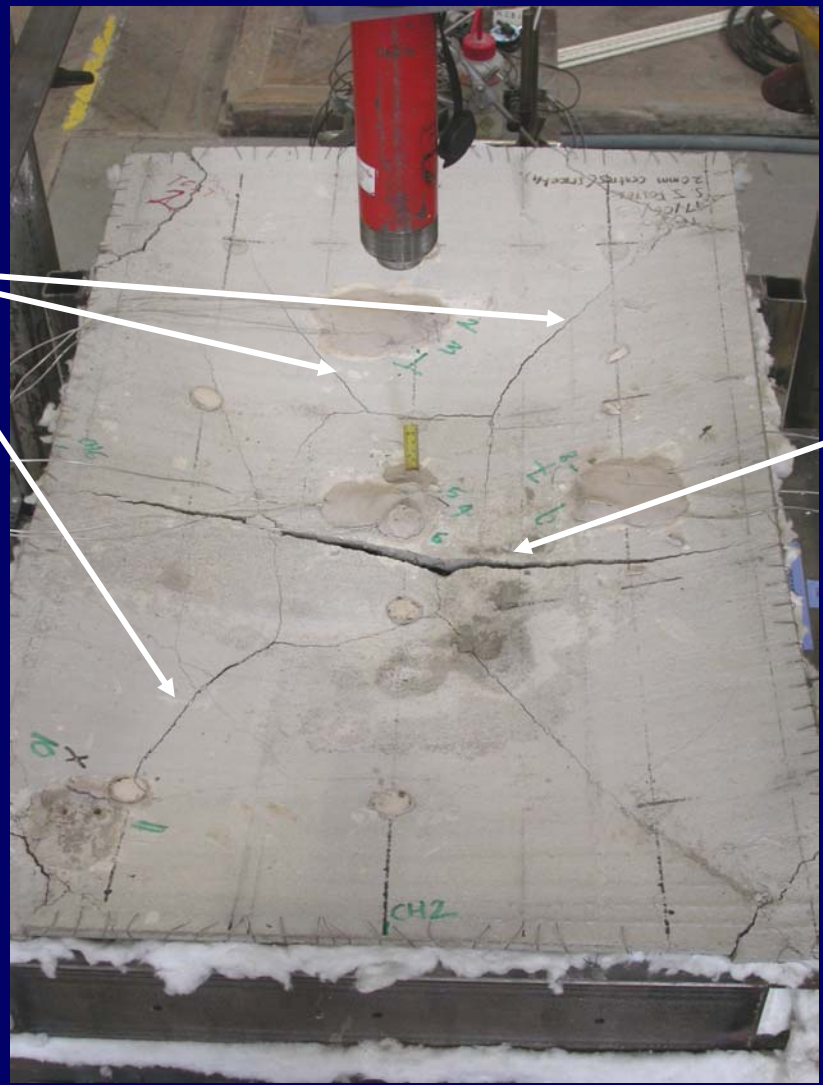

## Vertical Displacements

# Test 2

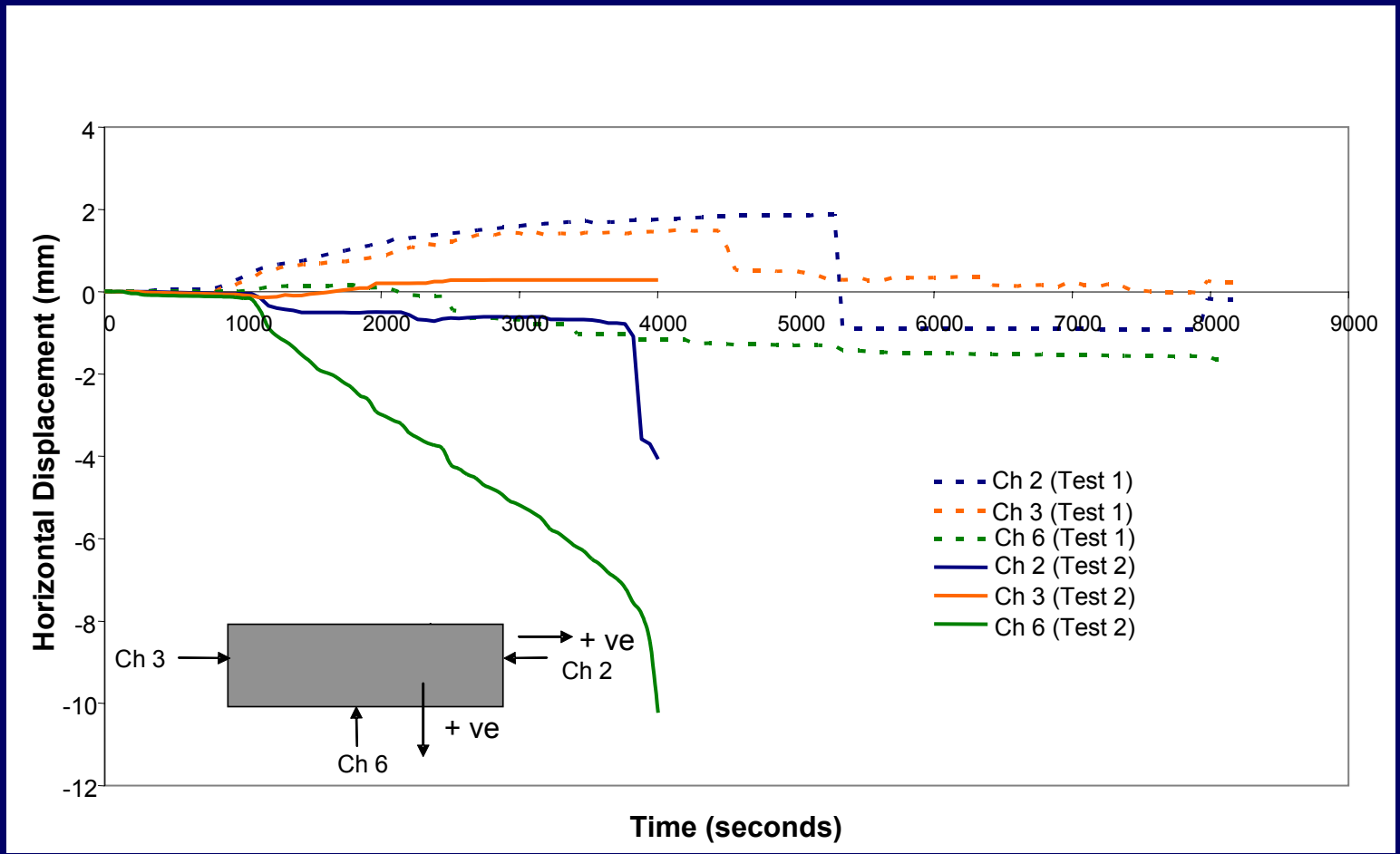


View of slab at end of test

# Test 2

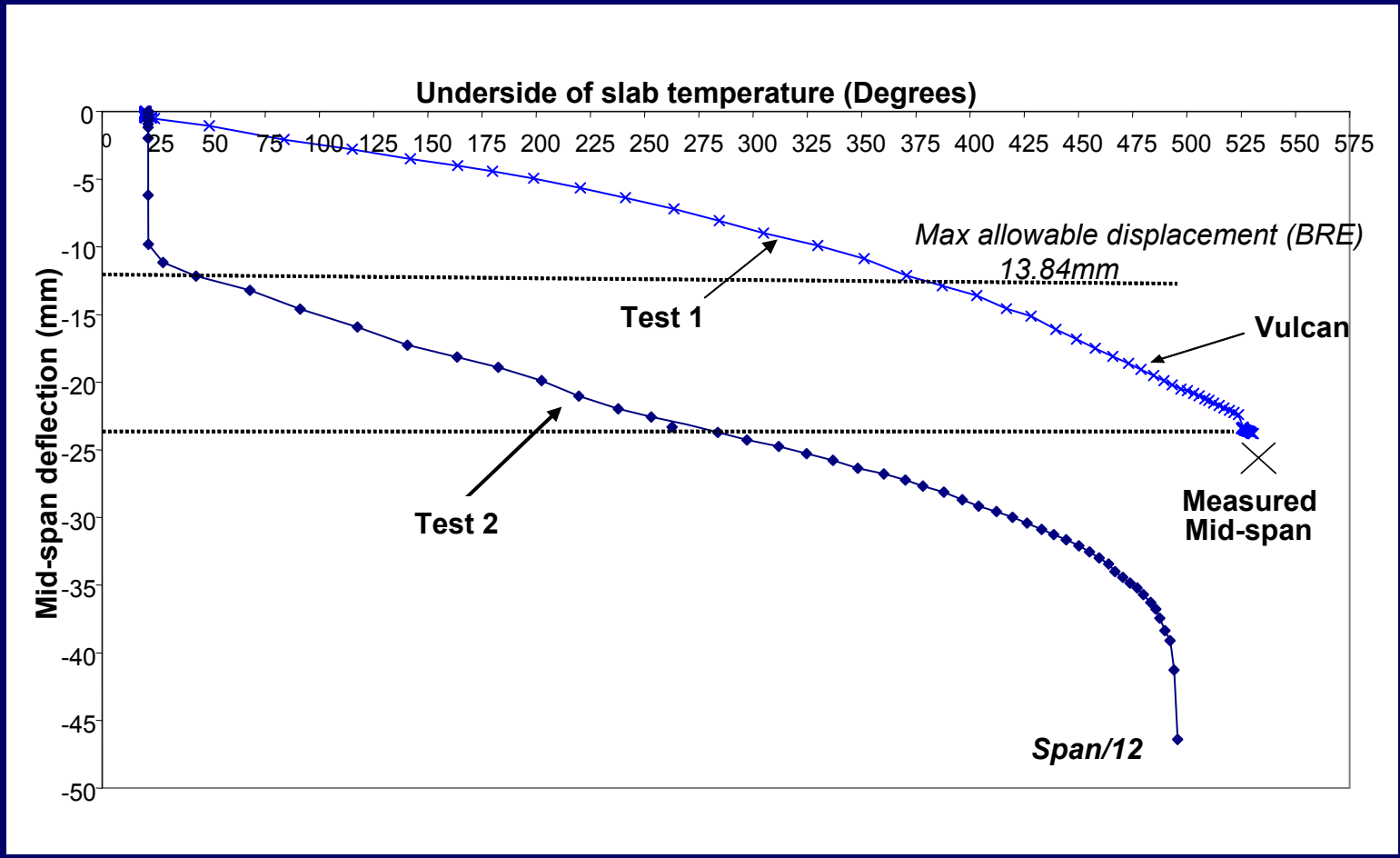


# Horizontal Displacements




## Comparison between Test 1 and 2

# Vertical Displacement

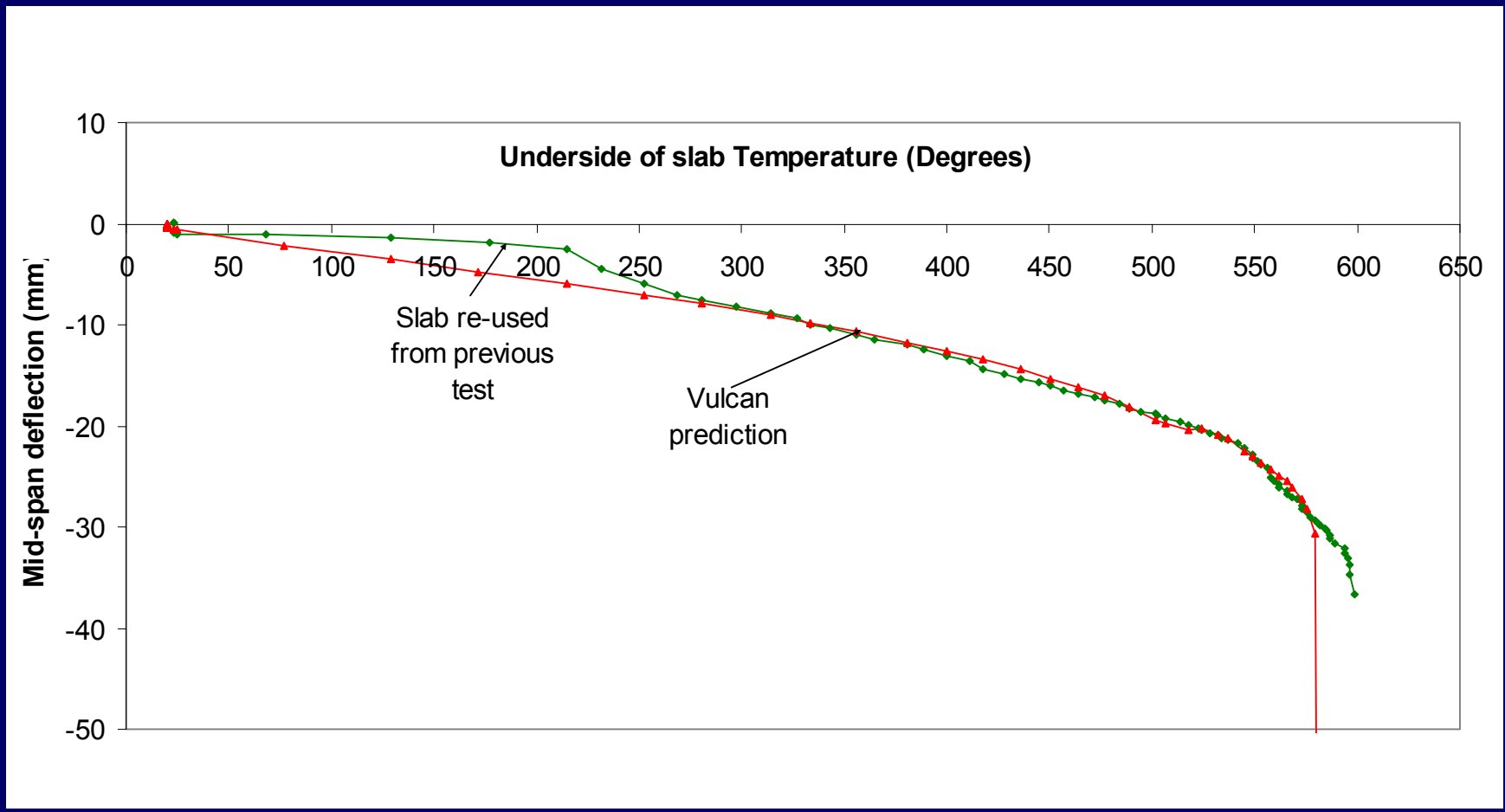



## Comparison between Test 1 and 2

# Test 3

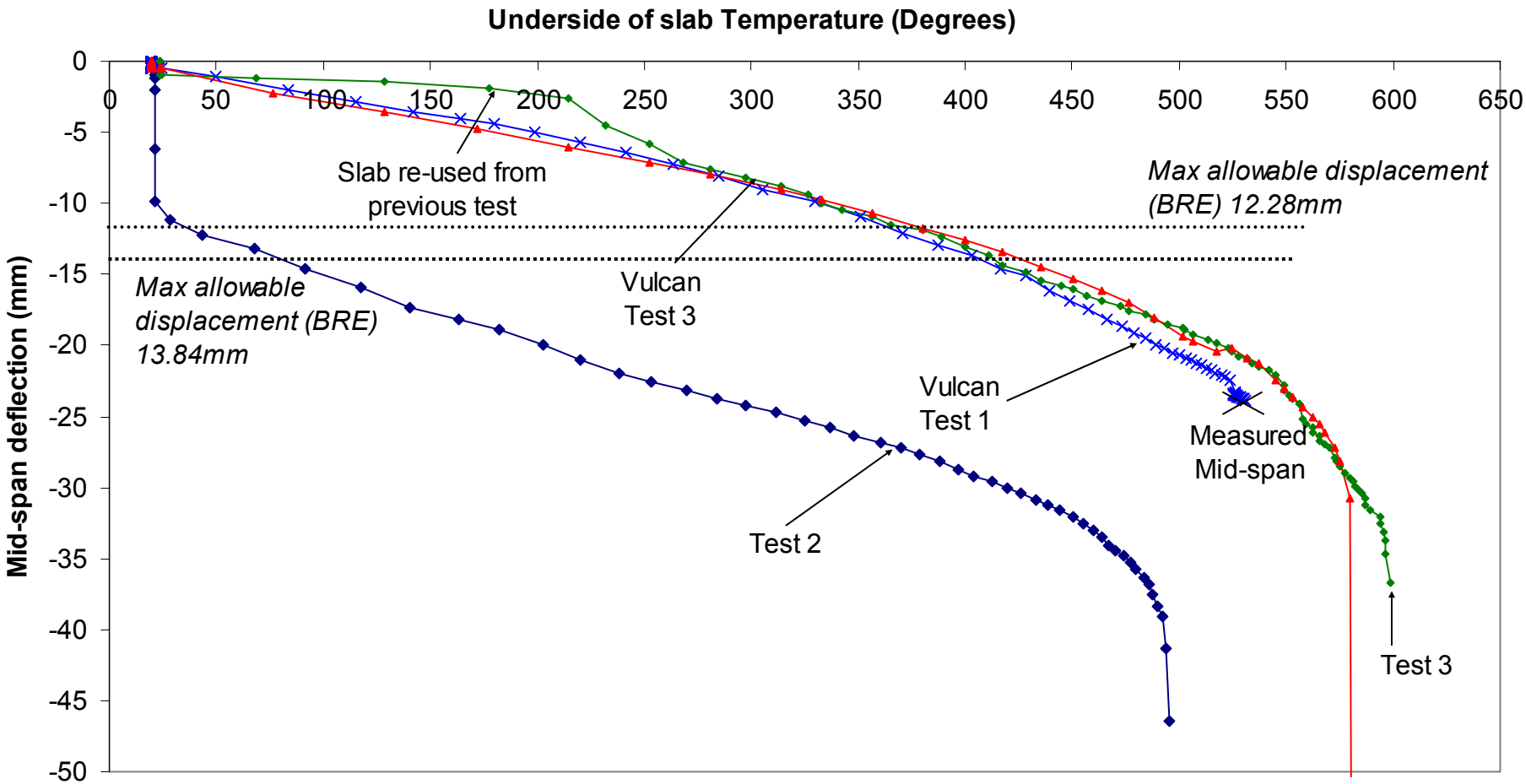
- Slab size 850x550mm reinforced with smooth wire.
  - Reinforcement 0.3%
  - Yield Line load *(Wu)* of 1.95 kN/m$^2$
  - Imposed Load *(Q)* of 4.66 kN/m$^2$
  - $$\frac{Q}{W_u} = 2.4$$

# Test 3



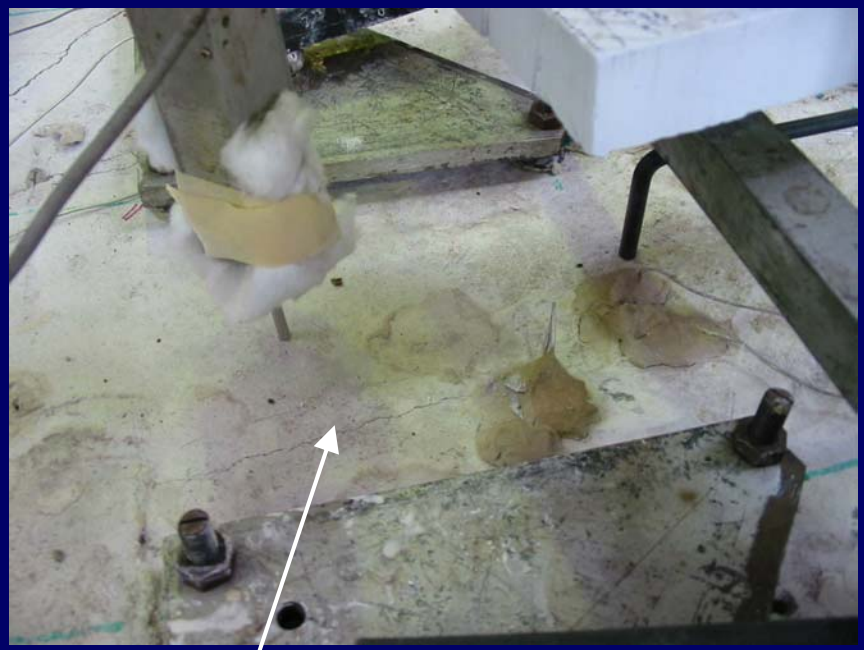

## Vertical Displacements

# Vertical Displacement



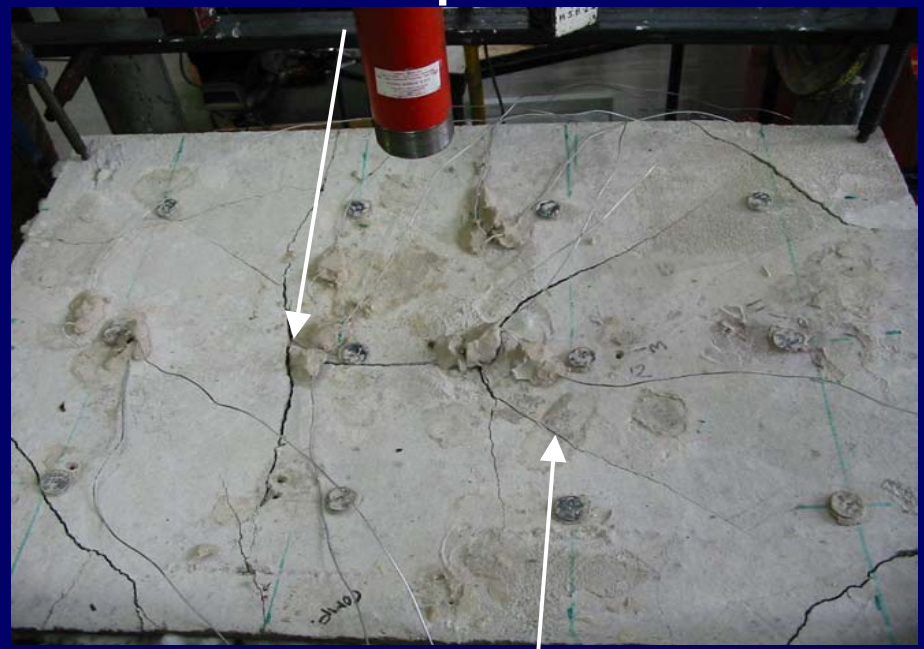

## Comparison of Tests 1, 2 and 3 with Vulcan

# Test 3



Crack across short span progressing

Second crack across short span



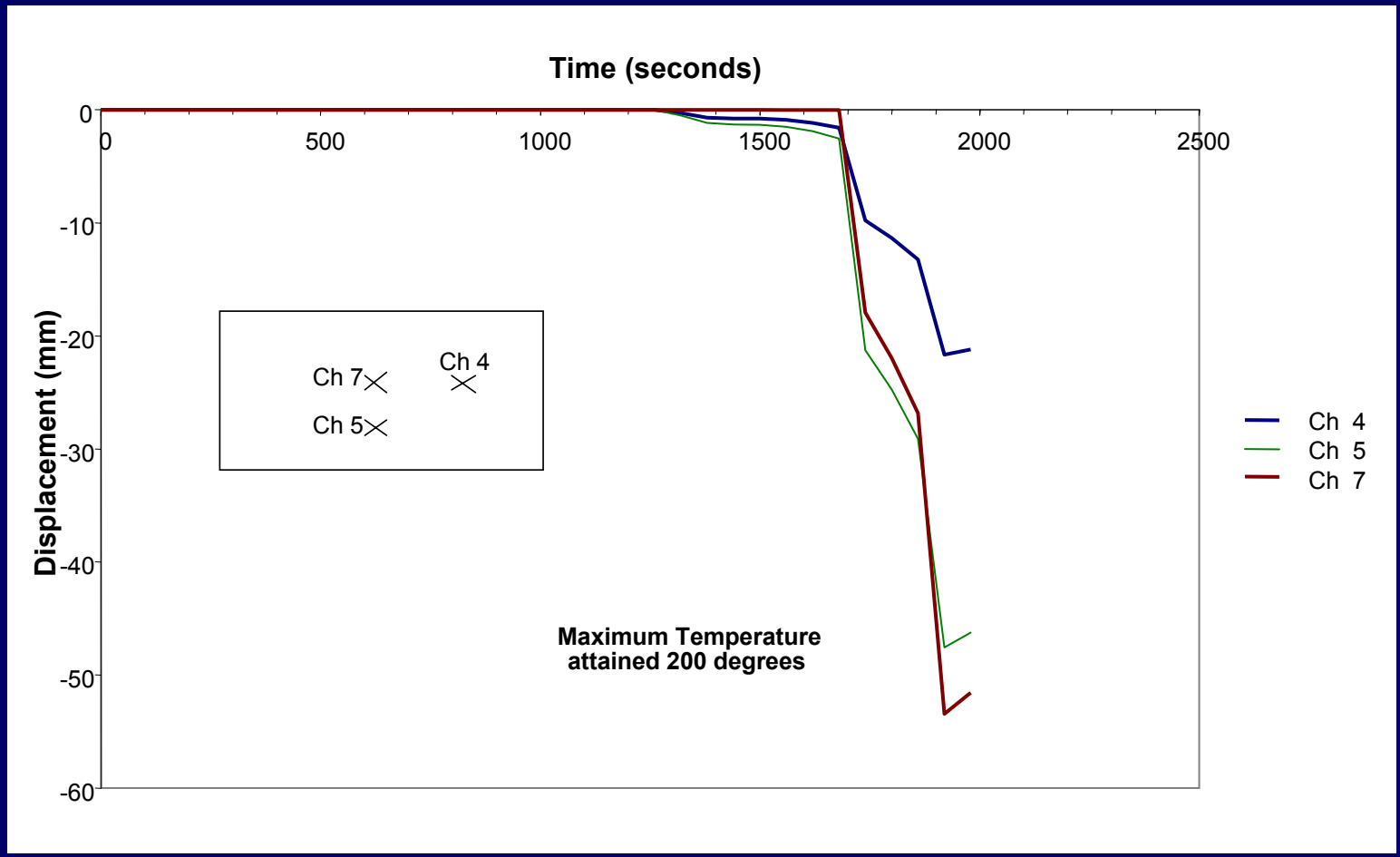
Yield line cracks

# Test 4

- Slab size 850x550mm reinforced with deformed wire.
  - Reinforcement 0.3%
  - Yield Line load *(Wu)* of 1.58 kN/m$^2$
  - Imposed Load *(Q)* of 4.73 kN/m$^2$
  - $$\frac{Q}{W_u} = 2.99$$

# Test 4

# Test 4



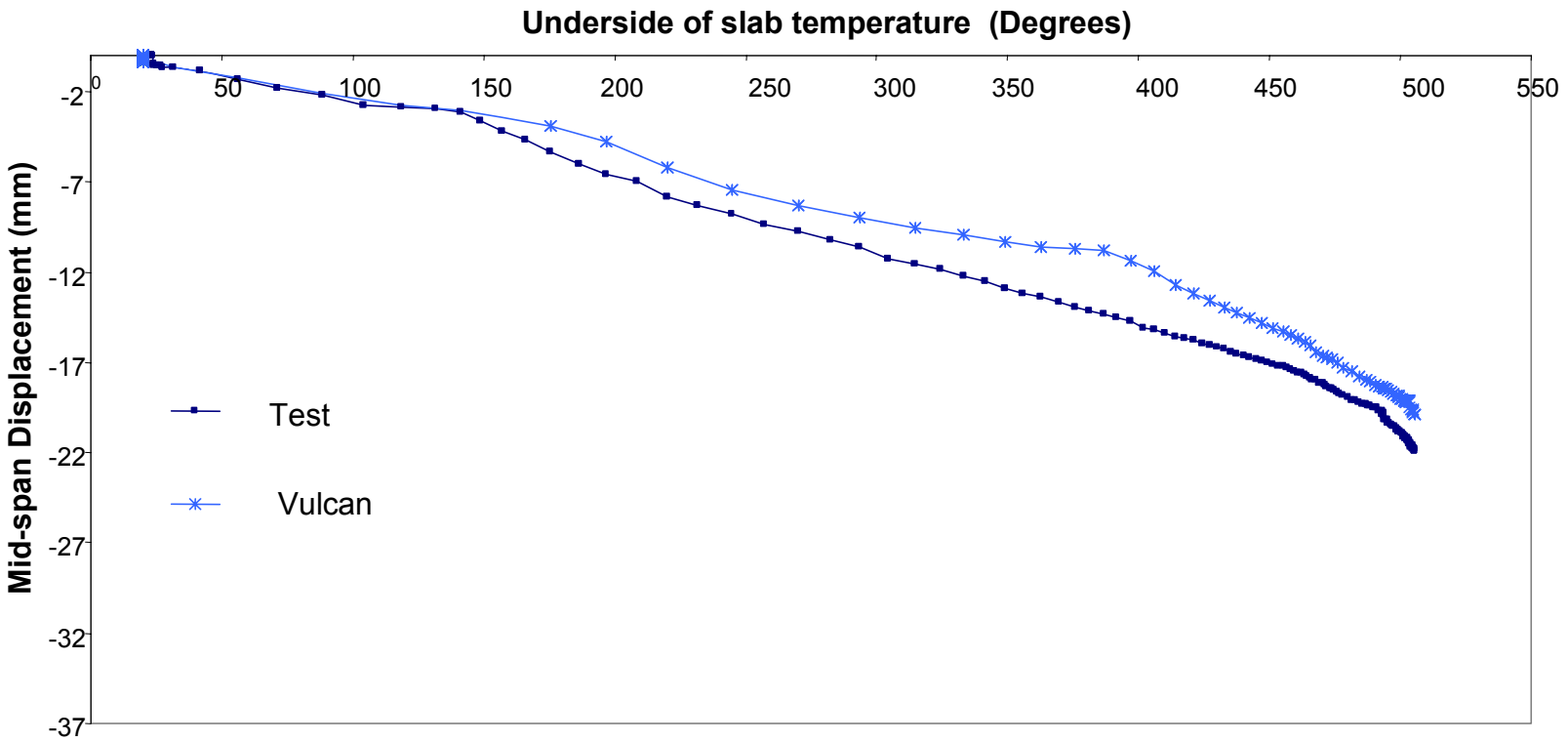

## Vertical Displacement

# Test 5

- Slab size 850x550mm reinforced with smooth wire.
  - Reinforcement 0.1%
  - Yield Line load *($W_u$)* of 0.73 kN/m$^2$
  - Imposed Load *(Q)* of 2.67 kN/m$^2$

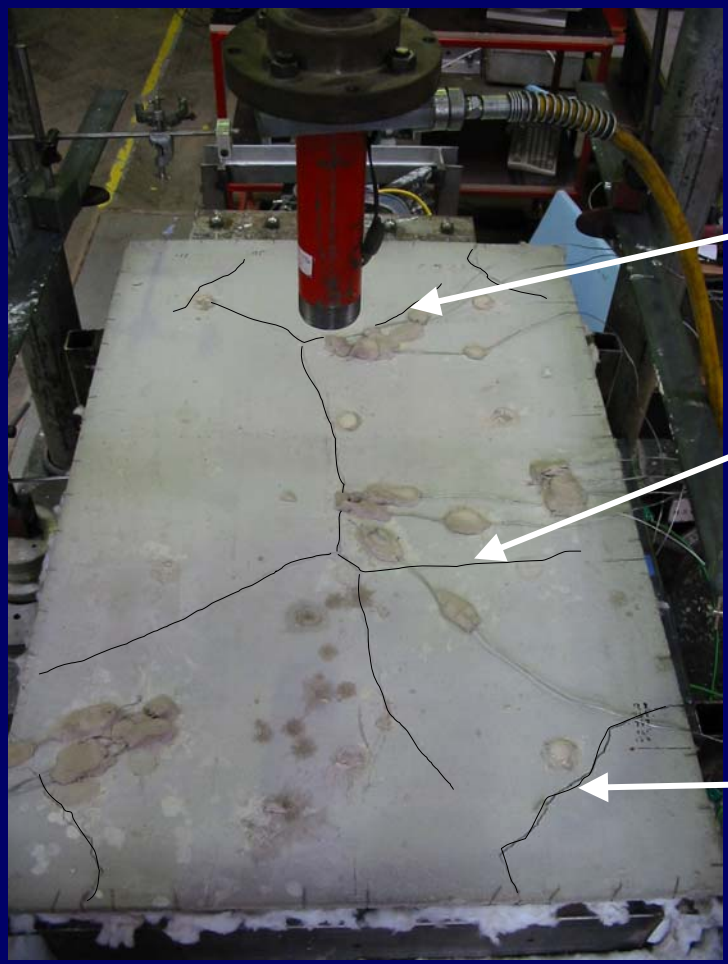
$$\frac{Q}{W_u} = 3.66$$

# Test 5




## Vertical Displacements

# Test 5

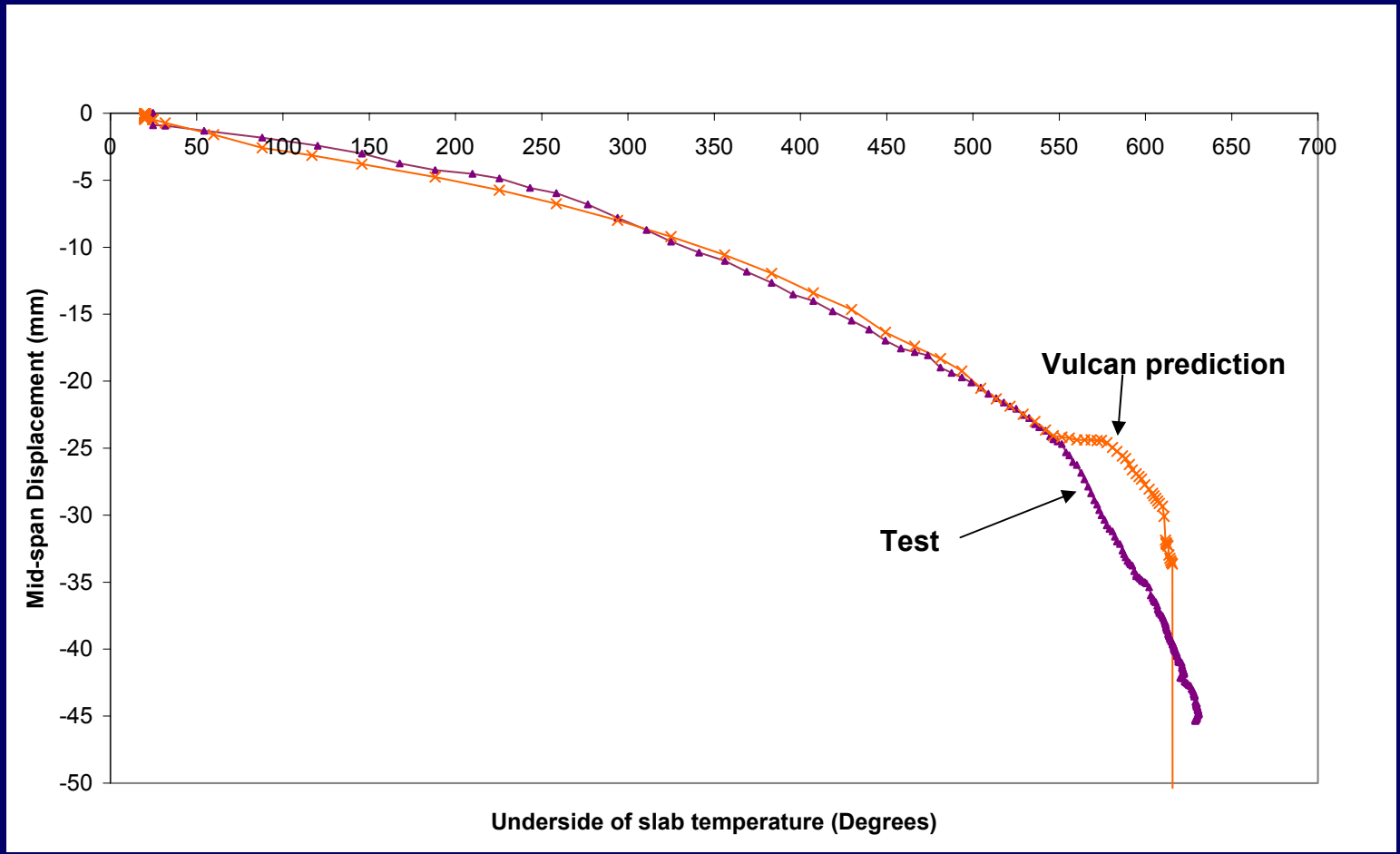



View of top of slab

# Test 6

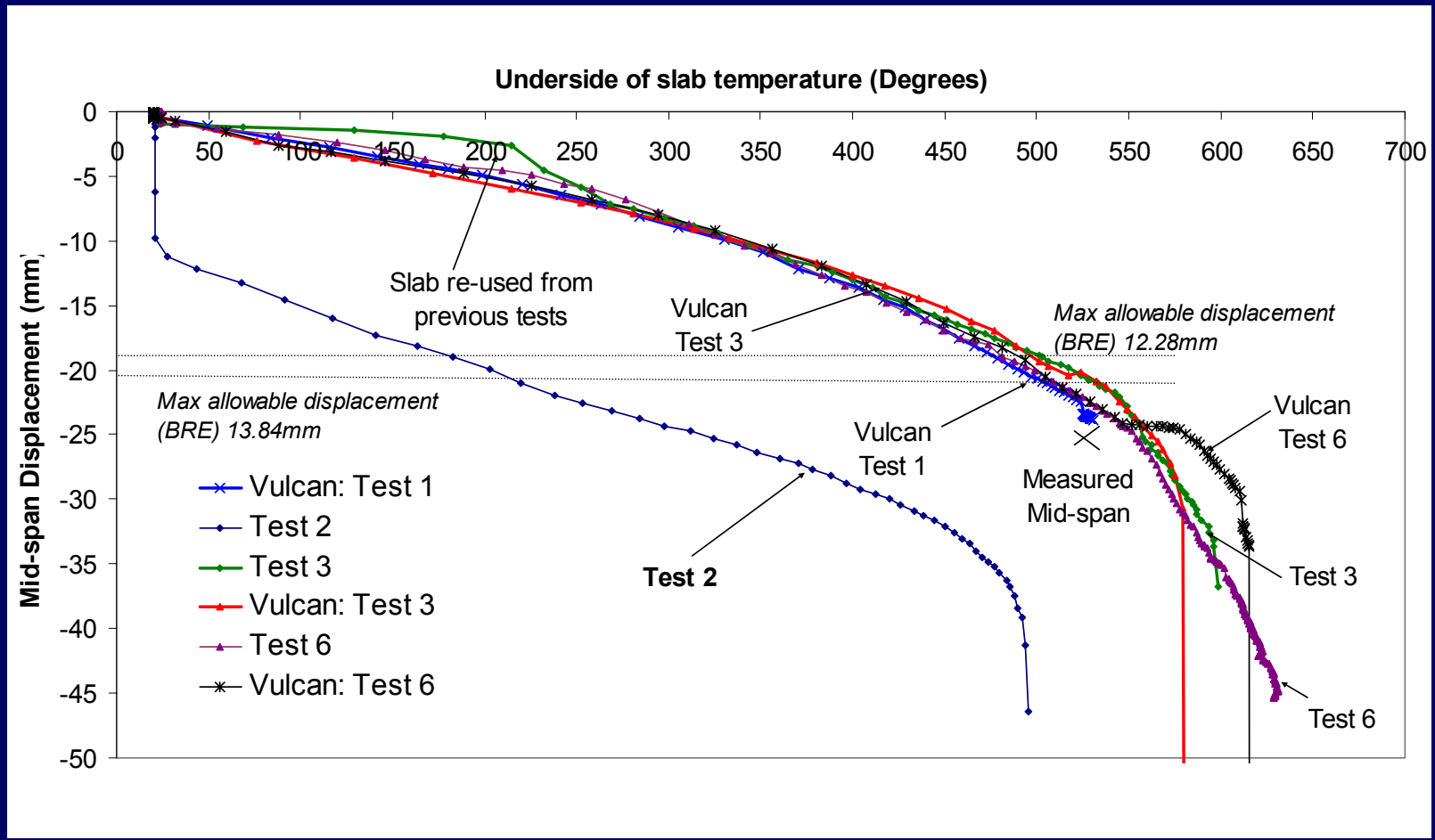
- Slab size 850x550mm reinforced with deformed wire.
  - Reinforcement 0.3%
  - Yield Line load *($W_u$)* of 2.11 kN/m$^2$
  - Imposed Load *(Q)* of 3.30 kN/m$^2$
  - $$\frac{Q}{W_u} = 1.56$$

# Test 6



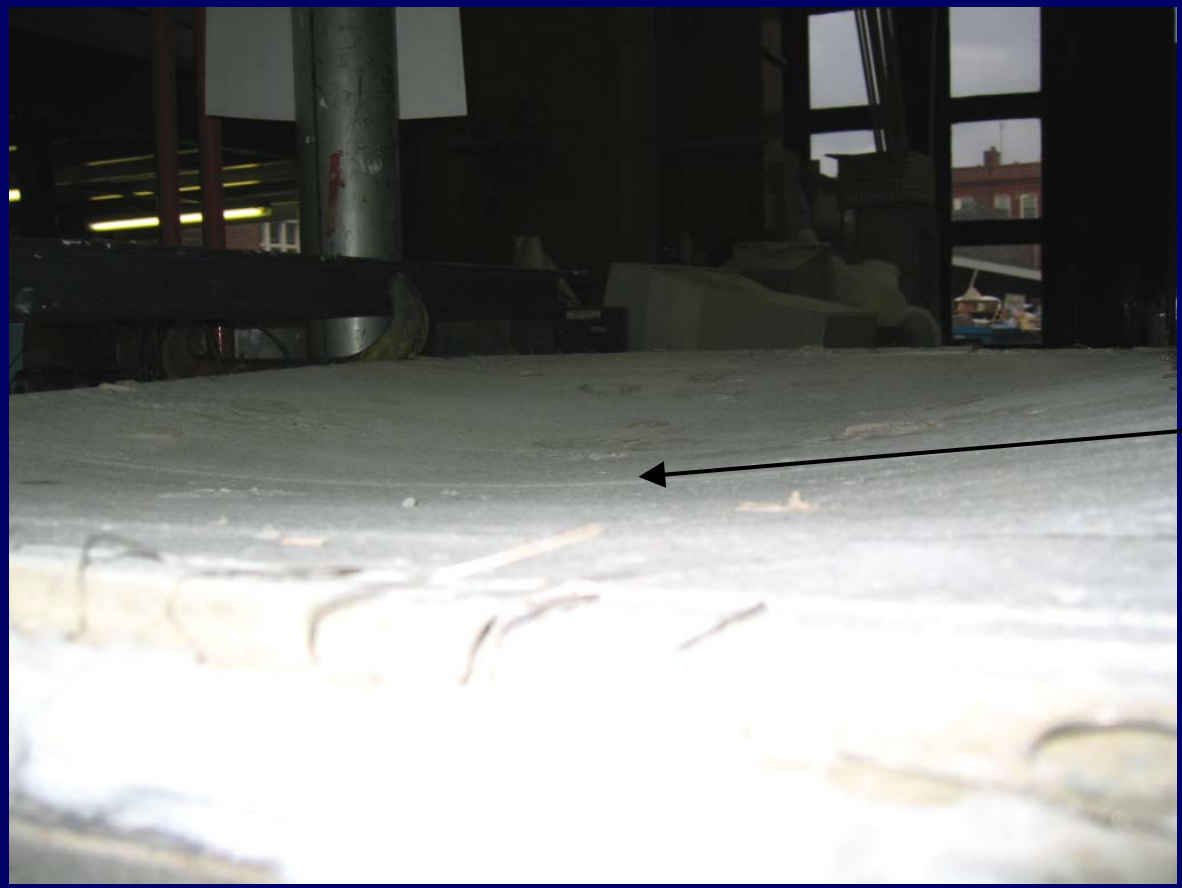

## Vertical Displacements

# Vertical Displacement




## Comparison of Tests 1,2,3 and 6 with Vulcan

# Test 6

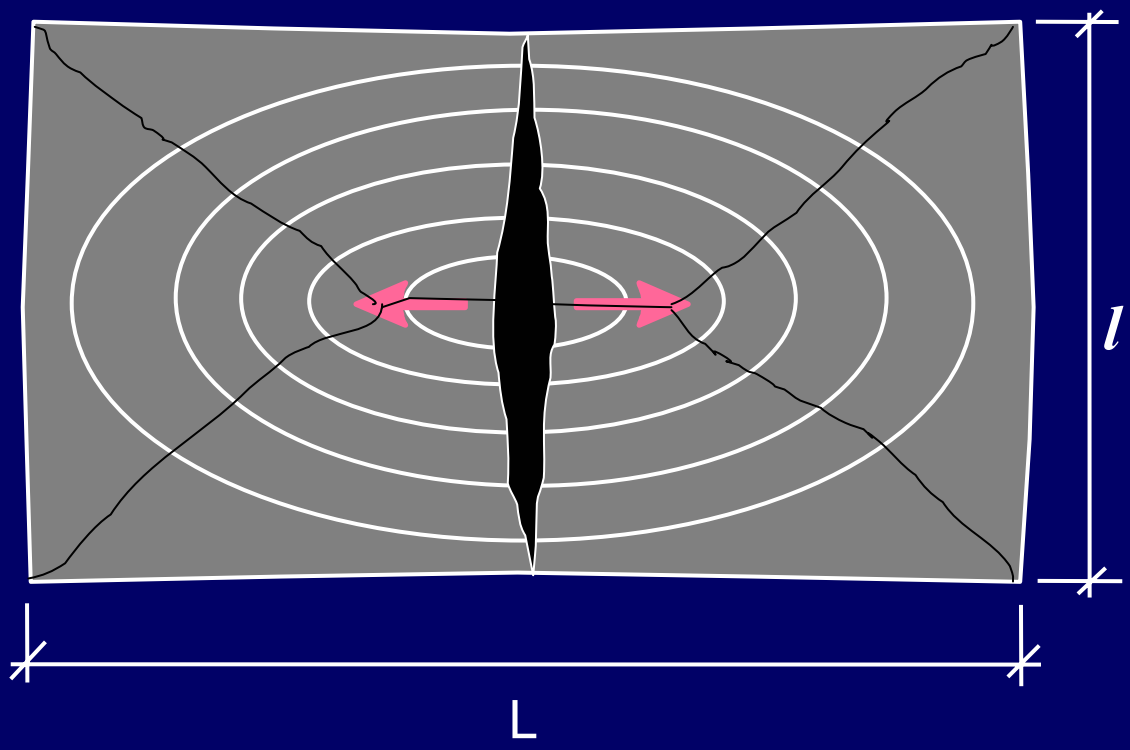


Profile of slab after test

# Test 6

View of the underside of slab

# Observed mode of failure from model tests



# Key Findings at High Temperature

- From the six tests shown, the mechanism of failure is different from that at ambient temperature.
- The slabs reinforced with deformed wire behave differently from smooth wire.
- The experimental results compare well with Vulcan.
- Numerical studies to follow.

# Summary

- The experimental results from the small scale tests at ambient temperature compare well with the simplified design method.
- Observations from high temperature tests have shown that the mechanism of failure differs from that assumed in the simplified design method.
- Numerical studies have been carried out using Vulcan and these compare well with experimental results.