RETROFITTING

RETROFITTING OF EXISTING ROAD INFRASTRUCTURE STRUCTURES WITH ADVANCED CEMENTITIOUS MATERIALS (ACM'S)

MASTER THESIS CIVIL ENGINEERING (CIE5060-09)

HETTE PIETER WINK (4316258)

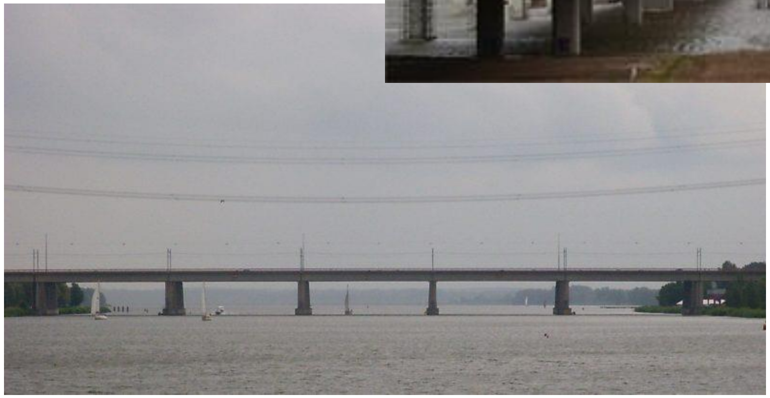
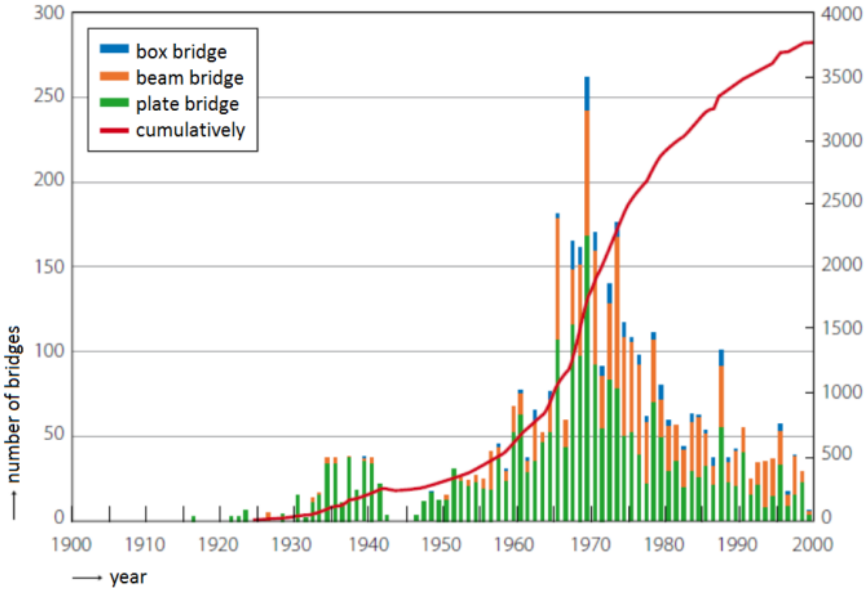
Contents

1. Introduction

Existing structures





1. Introduction

Challenges

- Structural
  - Increased traffic intensity
  - Increased traffic loads
  - Present concrete strength
- Durability
  - Exposure to de-icing salts
  - Less strict standards
  - Less knowledge about mix design
- Function
  - Changed function
  - New function

1. Introduction

Replace or retrofit?

- Demolish and replace
  - Large investments
  - Limited maintenance costs
  - Capital destruction?
- Retrofit
  - Extend life time
  - Limited costs
  - Postpone construction new structure

2. Results literature study

Retrofit solutions

- FRP lamellas
- External prestressing
- NSC overlay
- Cathodic protection
- Coatings

- ACM's

2. Results literature study

Material behaviour ACM's

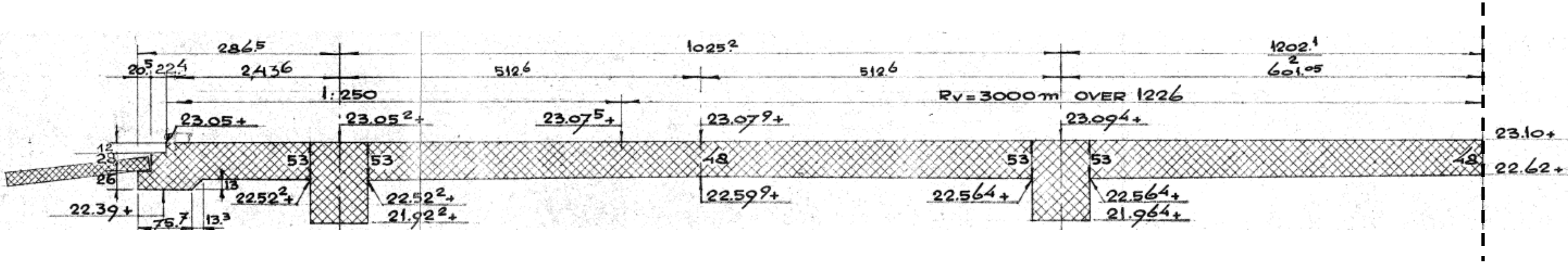
- **High Performance Concrete (HPC)**
  - Compressive strengths up to 105 N/mm^2
  - No tensile strength according to Eurocode
  - Dense matrix
- **Ultra-High Performance Fibre Reinforced Concrete (UHPFRC)**
  - High compressive strengths (up to 200 N/mm^2)
  - Extremely dense matrix
- **Strain-Hardening Cementitious Composite (SHCC)**
  - Negligible strengthening effect (equal to NSC)
  - High tensile strain capacity (up to 5.0%)
  - Crack control to fine widths

3. Case study

Viaduct highway A12 Ede-Bennekom

- Broader understanding of the potential problems

- Designed and built in 1941-1942
- Reinforced in-situ concrete plate bridge
- Cantilever 2.80 m – 10.00 m – 11.75 m – 10.00 m – cantilever 2.80 m
- Deck width 24.00 m
- Variable plate thickness 480 – 530 mm (near supports)



3. Case study

Potential problems/challenges

- Potential durability problems
  - Carbonation-initiated corrosion
  - Chloride-initiated corrosion

- Potential structural problems
  - Bending moment resistance
  - Shear force
  - Fatigue of the concrete under compression
  - Fatigue of the reinforcing steel
  - Crack width control

4. Retrofitting

Structural retrofitting

- Problems
  - Less severe problems
  - Shear strength problem part of asset management
    - Increased concrete strength
    - Advanced calculation methods
- Traditional retrofitting
  - FRP lamellas
  - External prestressing
  - NSC overlay
- Potential ACM layer
  - Limited potential ACM retrofitting

4. Retrofitting

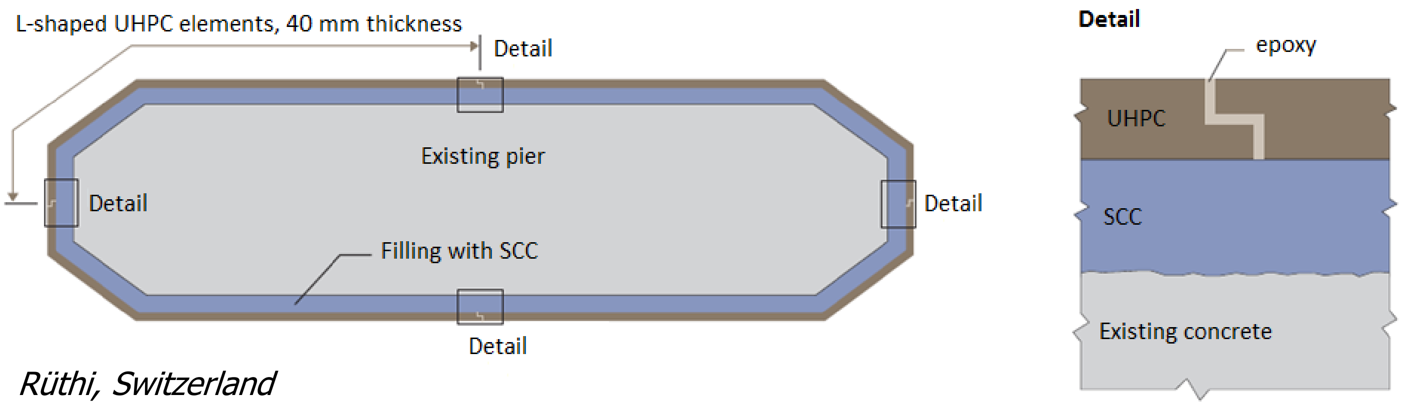
Durability retrofitting

- Problems
  - 50% chloride-induced reinforcement corrosion after 70 years
  - Expected increased chloride-initiated reinforcement corrosion
  - Also tidal zones of marine structures
- Traditional retrofitting
  - Cathodic protection
  - Ordinary concrete repairs
- Potential ACM layer
  - Dense matrix HPC and UHPFRC
  - Large tensile strain capacity SHCC

5. Durability retrofitting

Execution method

- Prefab
  - Controlled fabrication conditions
  - Fast execution and limited traffic hindrance
  - Glues, adhesives and/or anchorages behaviour
  - Connections between prefab parts
  - Durability of connections



Rüthi, Switzerland

5. Durability retrofitting

Execution method

- Cast in situ
  - Traffic hindrance
  - Time-dependent behaviour
  - Monolithic connection
  - Widely applied for concrete retrofitting

Why not in the Netherlands?

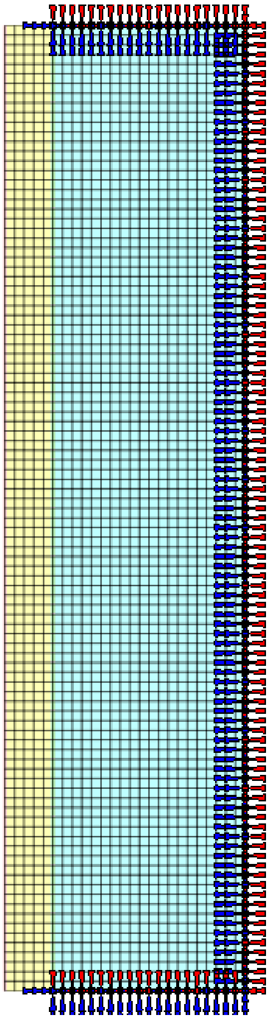
Killwangen, Switzerland

6. Numerical model durability retrofitting

Introduction

- Durability retrofitting
- Cast in situ ACM
- Vertical existing concrete surface

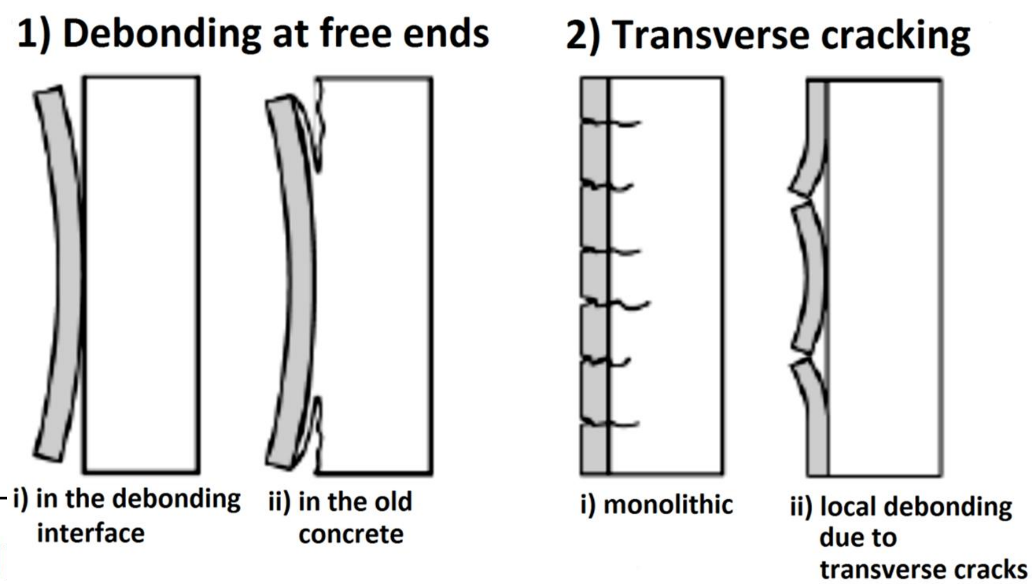
- FEM program DIANA of TNO Delft
- Two-dimensional
- Linear elements
- Mesh size of 10 mm

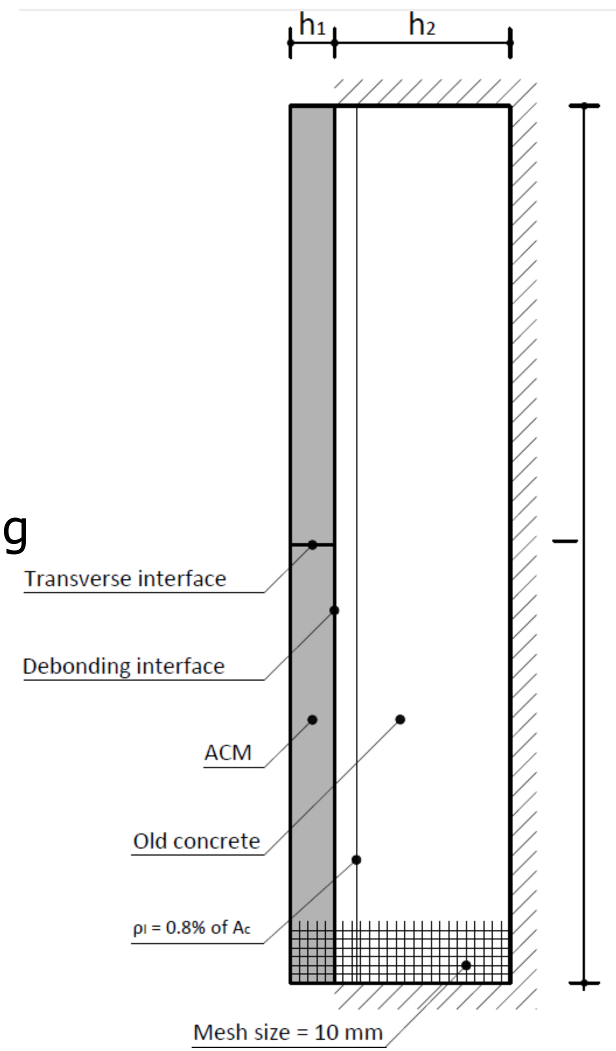


6. Numerical model durability retrofitting

Failure modes

- Debonding at the free ends
  - Debonding interface
  - Smeared cracking old concrete
- Transverse cracking
  - Smeared cracking ACM layer
  - Transverse ACM interface for local debonding

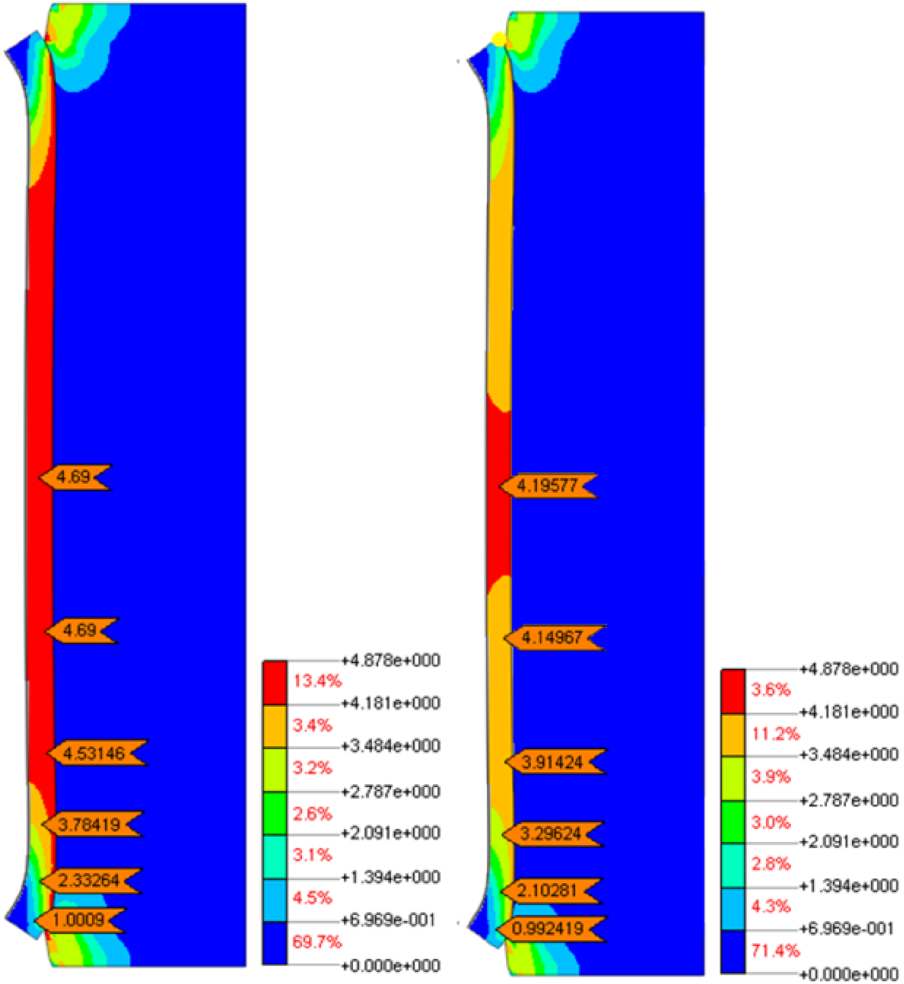




6. Numerical model durability retrofitting

Time-dependent behaviour ACM layer

- Time dependency
  - Based on maturity load
- Shrinkage
  - Restrained by old concrete
  - Direct time-dependent shrinkage strain input
- Creep behaviour
  - Stress relaxation effect
  - Maxwell Chain Model
  - Based on direct input of creep compliance – time function

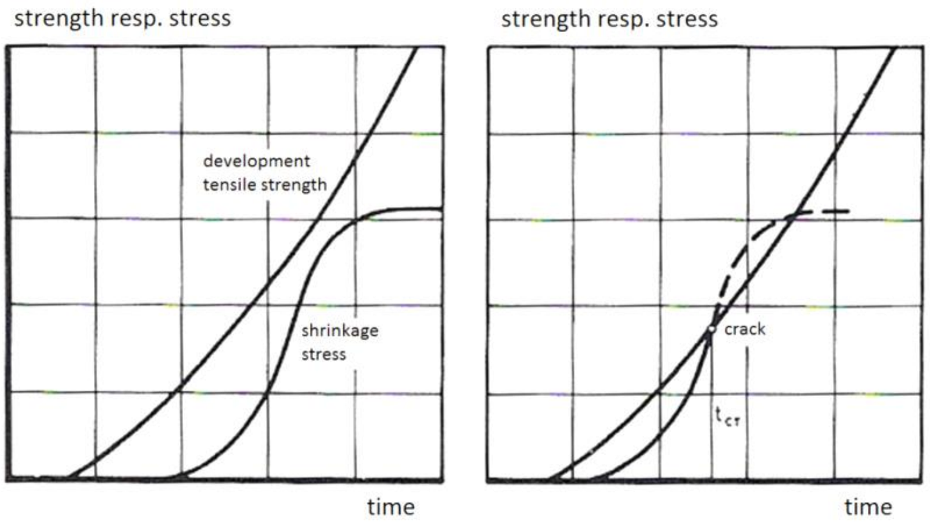


Tensile stresses [N/mm^2] shrinkage (left) and shrinkage and creep behaviour (right)

6. Numerical model durability retrofitting

Time-dependent behaviour ACM layer

- Mechanical properties development
  - On-going hydration
  - Direct time-dependent input



- Temperature development
  - Not included
  - Limited influence on stresses
  - Not in combination with time dependency

6. Numerical model durability retrofitting

Parameter analysis

INPUT

Material data

- C35/45
- HPC
- UHPFRC
- SHCC

Time dependent behaviour of HPC, UHPFRC and SHCC

- Mechanical properties
- Shrinkage
- Creep behaviour
- Debonding interface behaviour
- Transverse interface behaviour

PARAMETERS

Material of ACM layer

- HPC
- UHPFRC
- SHCC

Dimensions

- Thickness old layer
- Thickness new layer
- Length of the layers

Material parameters

- Shrinkage
- Creep behaviour
- Debonding interface tensile strength
- Debonding interface fracture energy

OUTPUT

Debonding interface

- Debonding length
- Relative displacement
- Time of initiation

Cracking old concrete

- Crack width
- Time of initiation

Cracking ACM

- Crack width
- Time of initiation

Transverse interface

- Debonding length
- Relative displacement
- Time of initiation

6. Numerical model durability retrofitting

Parameter variation for each ACM

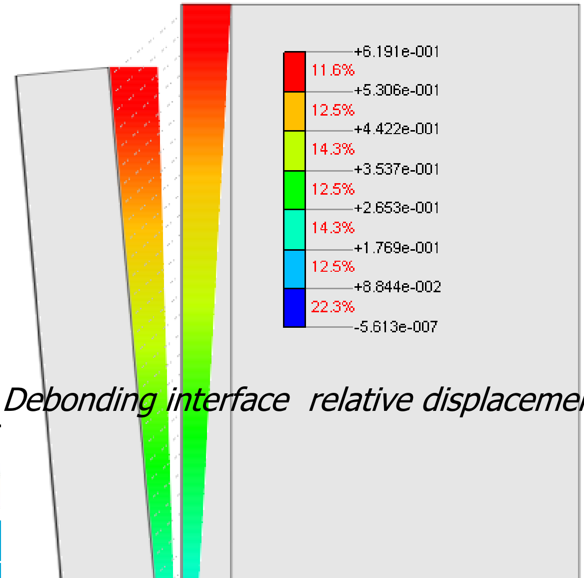
- Only minimum and maximum values
- Influence of parameters on structural behaviour

PARAMETERS							
Thickness new layer	Thickness old layer	Length layers	Shrinkage	Creep compliance	Debonding interface tensile strength	Debonding interface fracture energy	
h_1	h_2	l	ε_{shr}	C_{compl}	$f_{t;deb.int.}$	$G_{F;deb.int.}$	
[mm]	[mm]	[mm]	[µm/m]	[µm/m/MPa]	[N/mm^2]	[N/mm]	
10	100	500	250	25	1.0	0.000	
50	200	1000	ACM	ACM	ACM	0.036	*Default values*
100	400	4000	1500	750	5.0	0.072	

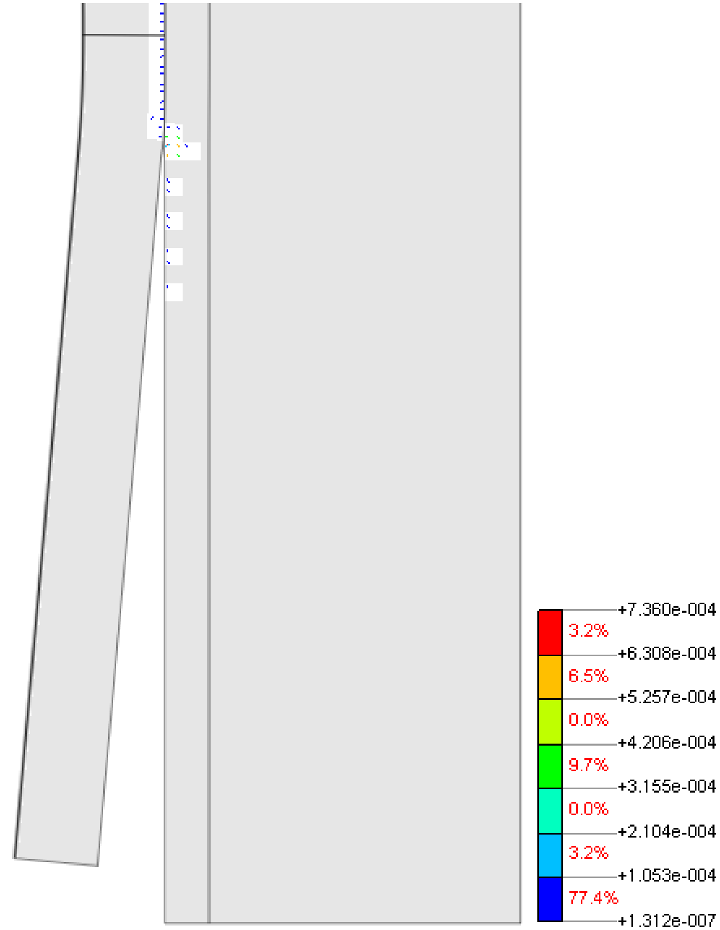
6. Numerical model durability retrofitting

SHCC numerical model – minimum debonding interface fracture energy

- Debonding behaviour
  - 440 mm debonding length
  - 0.619 mm relative displacement
  - 0.010 mm crack width old concrete
- Transverse cracking
  - 0.002 mm crack width SHCC
  - No relative displacement



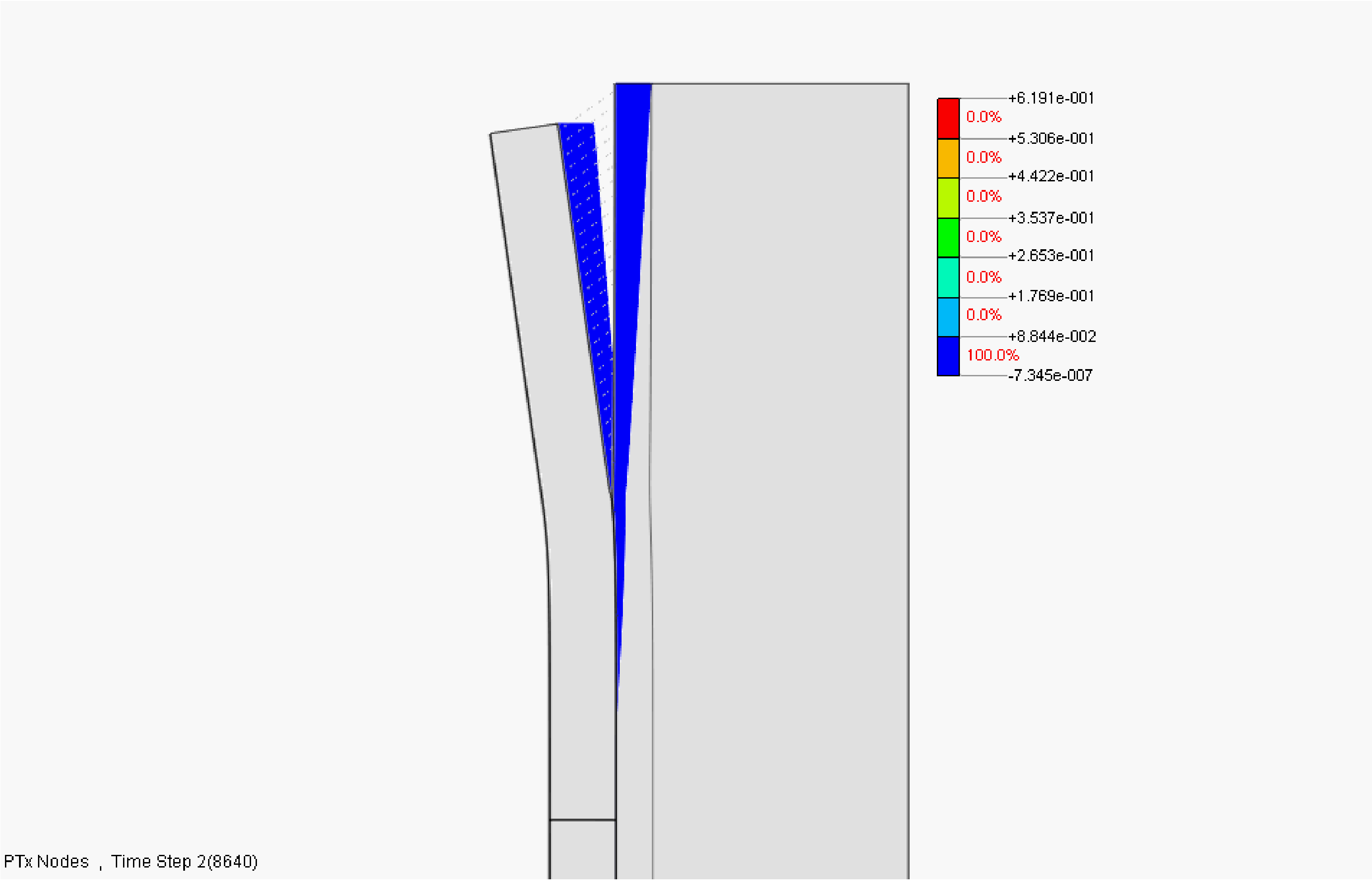
Debonding interface relative displacement [mm] at 56 days



Crack pattern strain [-] at 56 days

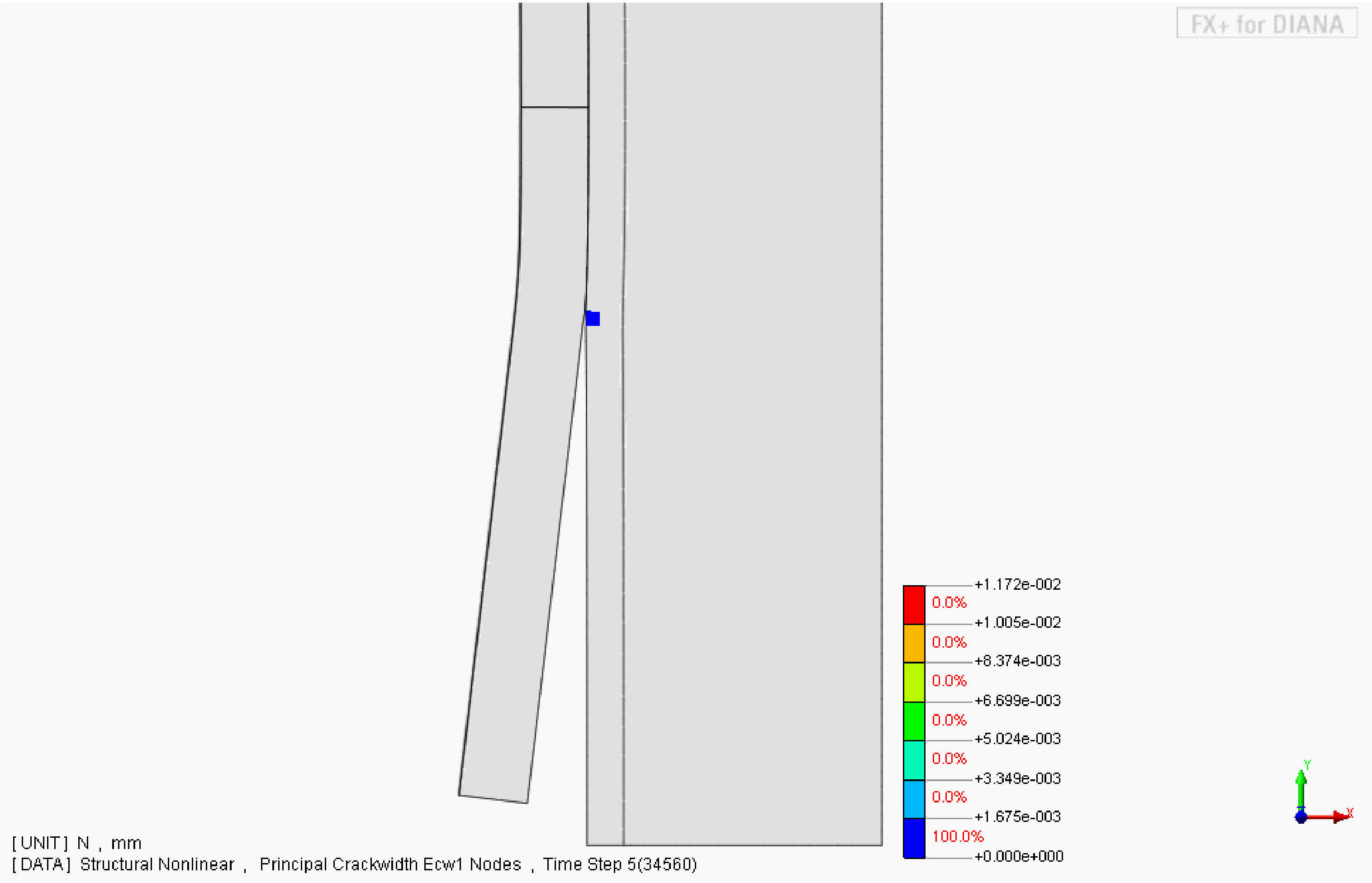
6. Numerical model durability retrofitting

SHCC numerical model – minimum debonding interface fracture energy



6. Numerical model durability retrofitting

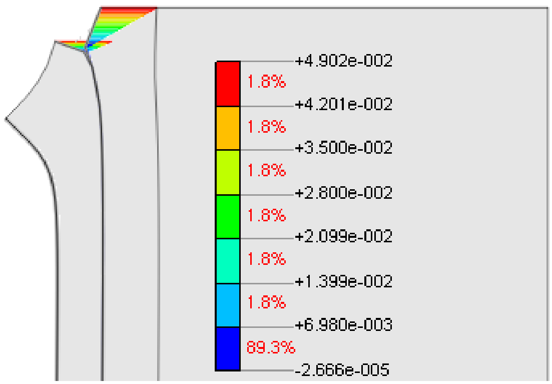
SHCC numerical model – minimum debonding interface fracture energy



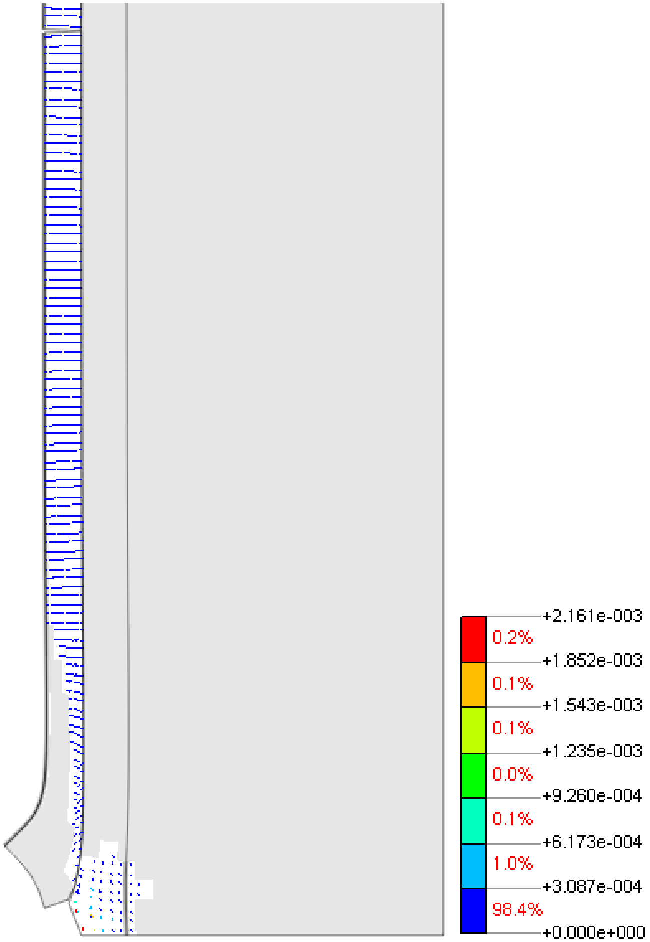
6. Numerical model durability retrofitting

SHCC numerical model – maximum debonding interface fracture energy

- Debonding behaviour
  - 20 mm debonding length
  - 0.049 mm relative displacement
  - 0.028 mm crack width old concrete
- Transverse cracking
  - 0.002 mm crack width SHCC
  - 0.005 mm relative displacement



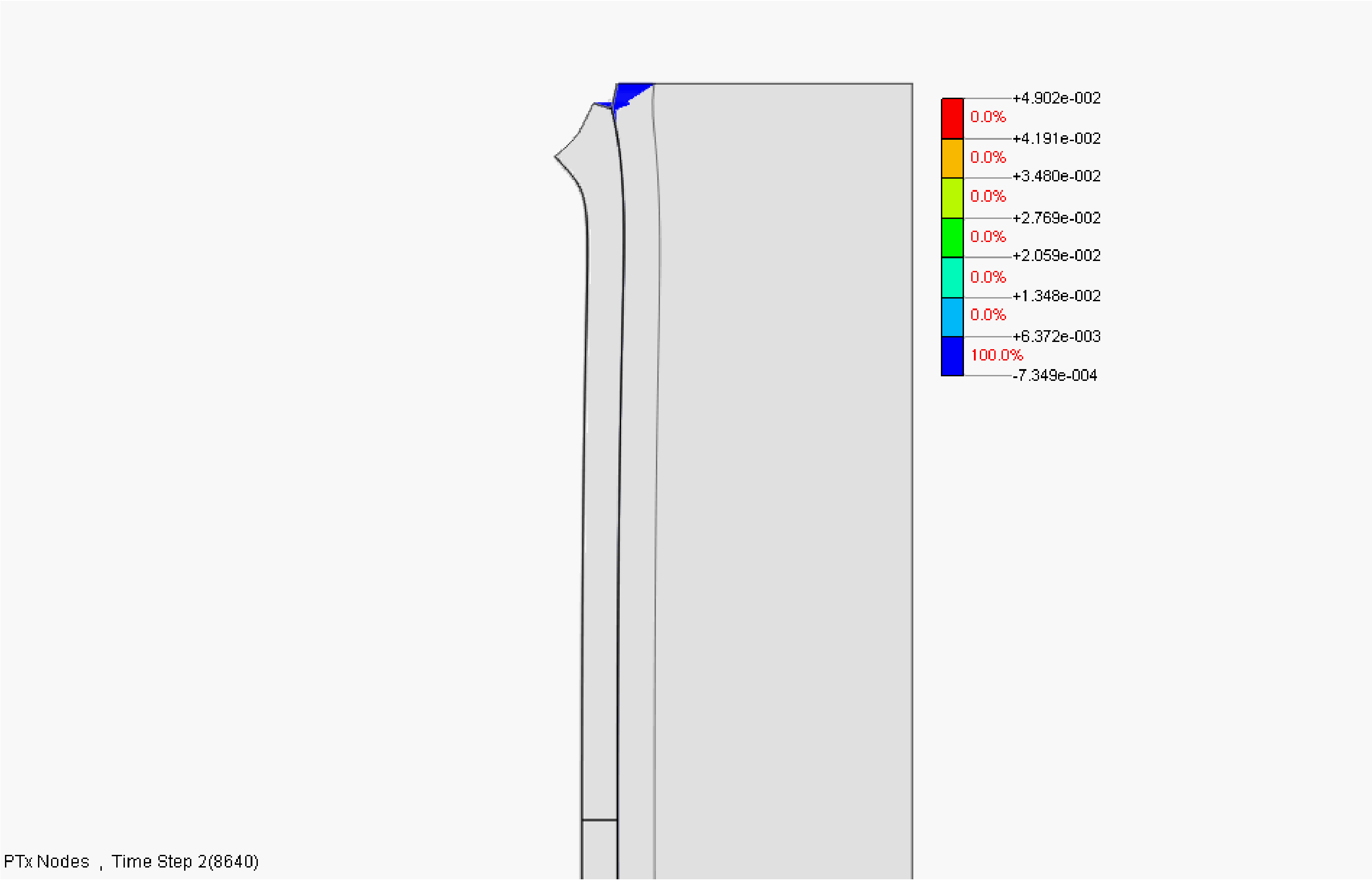
Debonding interface relative displacement [mm] at 56 days



Crack pattern strain [-] at 56 days

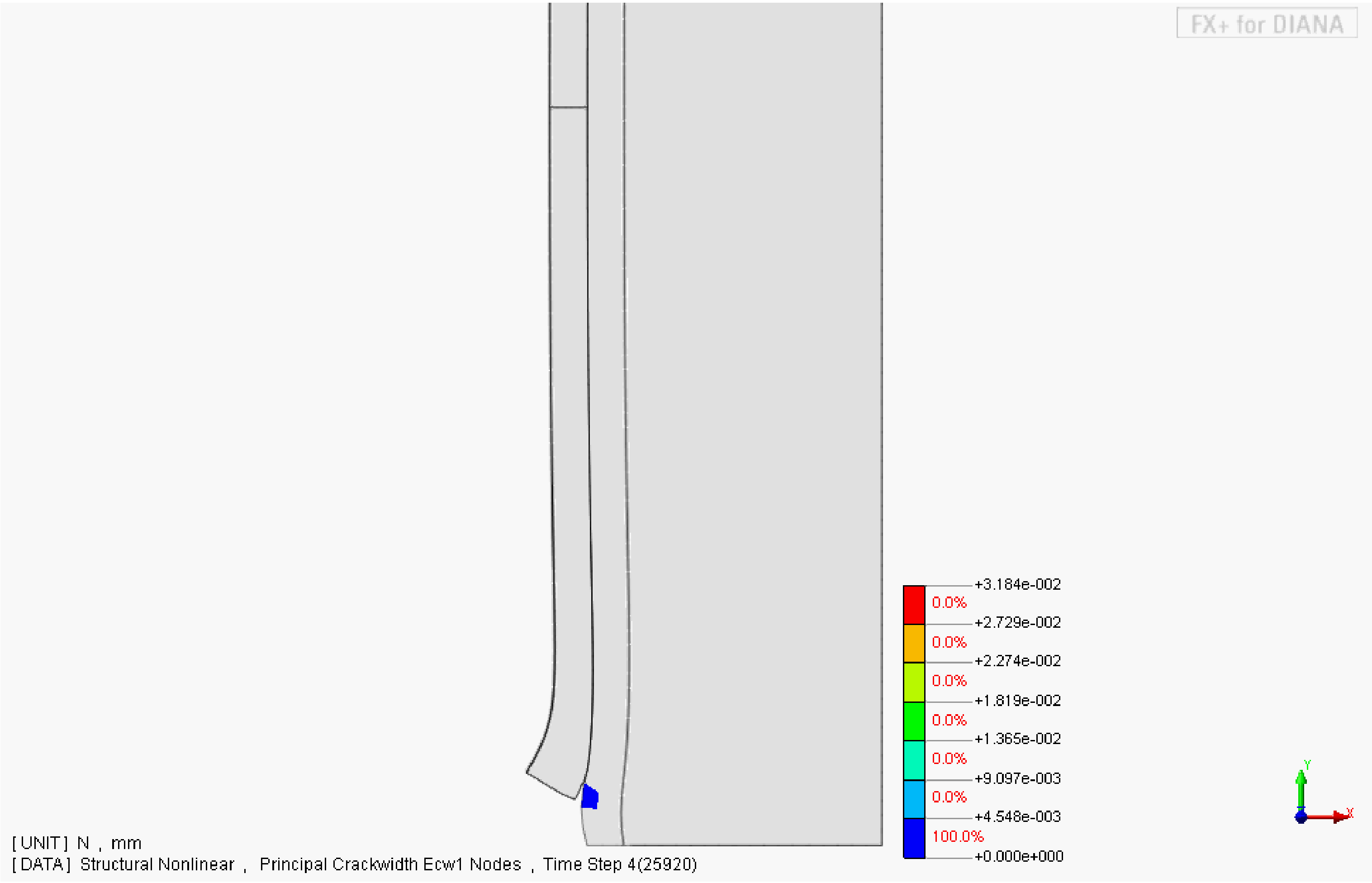
6. Numerical model durability retrofitting

SHCC numerical model – maximum debonding interface fracture energy



6. Numerical model durability retrofitting

SHCC numerical model – maximum debonding interface fracture energy



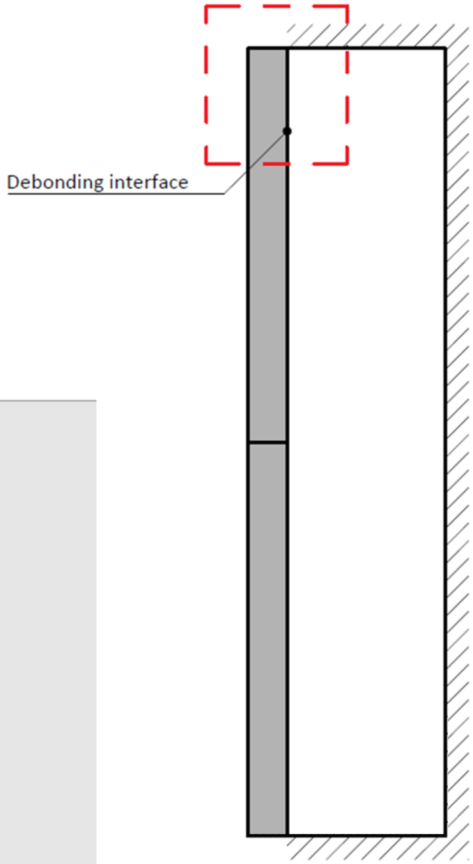
6. Numerical model durability retrofitting

Summary parameter analysis results

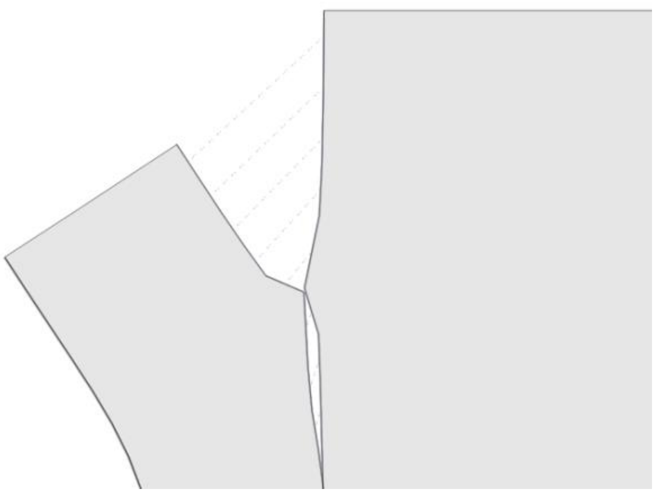
Parameter	Influence increased value of parameter on cracking behaviour	Caused by:
Thickness new layer	Increased debonding and transverse cracking behaviour	Increased shrinkage deformation in thickness direction
Thickness old layer	Limited	High degree of restraint in general
Length layers	Limited	Increased total number of transverse cracks *Longitudinal ACM cracking for maximum length*
Shrinkage	Increased debonding and transverse cracking behaviour	Increased shrinkage deformation
Creep compliance	Decreased debonding and transverse cracking behaviour	Increased stress relaxation
Interface tensile strength	Decreased debonding behaviour	Increased tensile strength of the interface
Interface fracture energy	Decreased debonding behaviour	More energy needed to open the interface
Parameter	**Cracking behaviour**	**Caused by:**
ACM's	Small debonding UHPFRC Small transverse crack widths SHCC	Slow increase UHPFRC shrinkage strain Large tensile strain capacity

6. Numerical model durability retrofitting

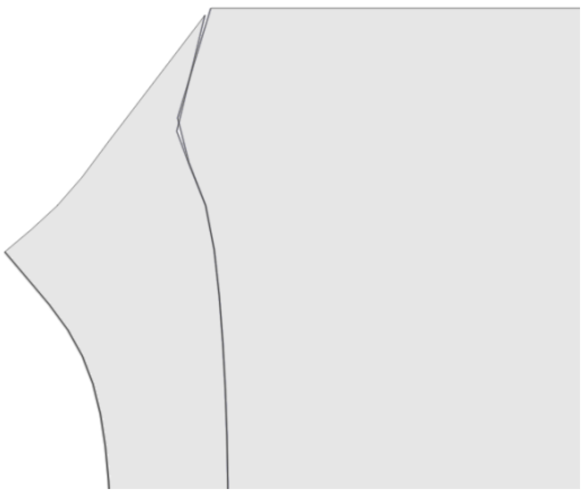
Numerical model: debonding interface



- Locking of a debonding interface element node
  - Underestimation debonding behaviour
  - Large convergence tolerance



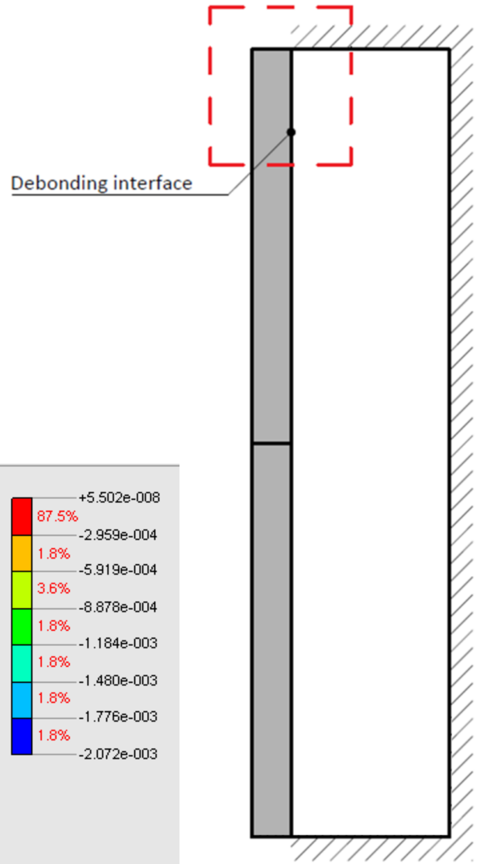
Debonding interface local locking



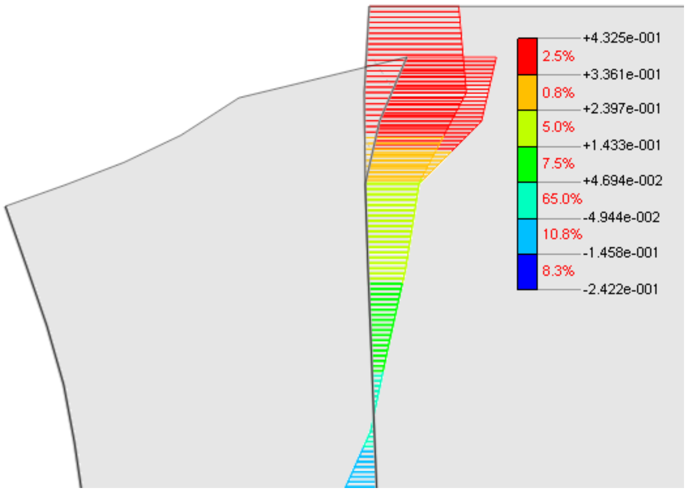
Debonding interface end locking

6. Numerical model durability retrofitting

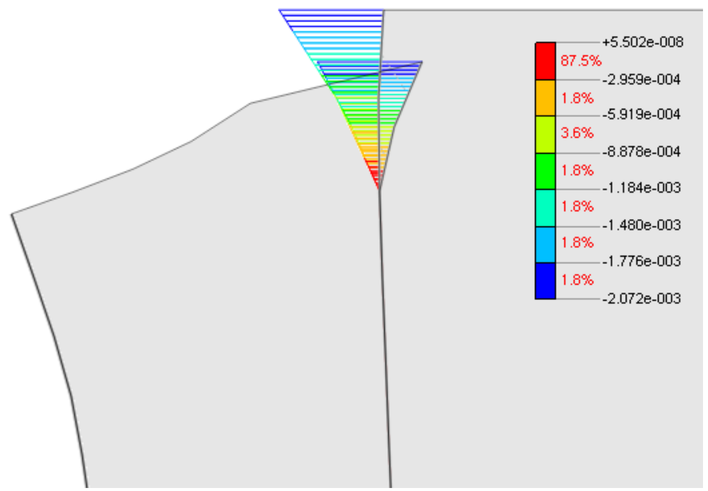
Numerical model: debonding interface



- Penetration of ACM layer in old concrete
  - Interface tensile stresses
  - Negative relative displacement
  - Underestimation of debonding behaviour



Debonding interface tensile stresses [N/mm²]

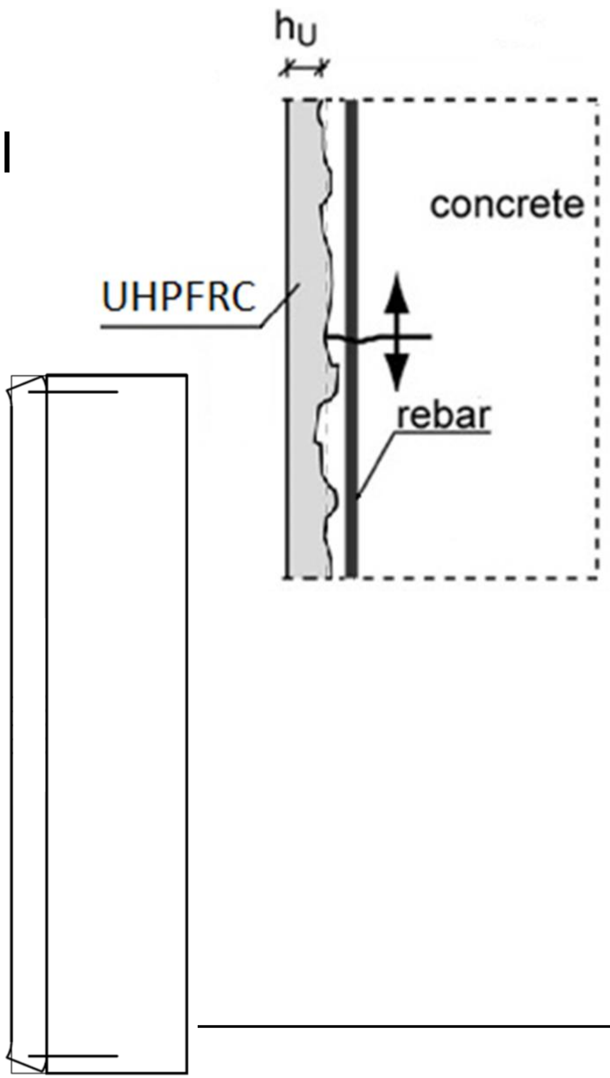


Debonding interface negative relative displacement [mm]

7. Durability retrofitting in practice

- Based on the results of the numerical model

- 50 mm thickness new layer possible
- UHPFRC
  - Less severe debonding behaviour
  - 10 mm thickness for durability reasons
- Precautionary measure
  - Debonding at free ends
  - Underestimated due to locking/penetration



8. Conclusion

Conclusions

- Potential of ACM retrofitting
  - Durability retrofitting
    - Reinforcement corrosion
    - Material properties ACM's
  - Cast in situ ACM overlay
- Numerical model
  - Debonding cracking behaviour
  - Transverse cracking behaviour
  - Mechanical properties
  - Shrinkage
  - Creep
- Structural behaviour influenced by:
  - Thickness new ACM layer
  - Shrinkage
  - Creep behaviour
  - Debonding interface properties
  - ACM
- Durability retrofitting in practice:
  - 50 mm new layer thickness
  - UHPFRC
  - Precautionary measure
    - Debonding at the free ends

8. Conclusion

Recommendations

- Material data
    - Experimental program
    - Specific mixture

- Numerical model
    - Causes of behaviour of the debonding interface
    - Possibility of smaller time steps and convergence tolerance
    - Multiple transverse ACM interfaces instead of smeared cracking ACM
    - Detailed analysis to measures

Thank you very much for your attention.
Are there any questions ?