BGZ

Digital construction applications and tools for use in vocational training

DigiCon

Co-funded by the
Erasmus+ Programme
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1. INTRODUCTION

One part of the project DigiCon was to adapt and develop new applications that were used in the training of construction professionals (p. e. a series of iOS- and Android-based workflow apps for digital data acquisition, logging, real-time collection and access, such as DALUX, dROFUS, 123erfasst).

Therefore, the project team conducted a survey to identify available applications and analysed those in terms of usability for the VET level. Application options, conditions for use for educational purposes and adaptation needs were identified and described.

The following applications

were newly developed for the use in the learning scenarios:

Learning application digital construction file:

This tool was used to practise the various tasks in the construction process along the learning scenarios and intended to map all functionalities of a construction file and provide the data required for working with the learning scenarios. The performance parameters (data scope, functional scope, display, etc.) were specified more precisely in the development process depending on the action scenarios and the learning scenarios.

Learning videos and AR applications:

They support the visualisation of concrete work steps in complex processes. Where applications are too expensive or impracticable for use in teaching, simulations can be used to apply innovative technologies in practice. The simulations for such applications were documented in a video and then used in learning scenarios. The AR applications edited an interactive component: in simulated sequences the trainees operated devices, read and interpreted data and then carried out actions.

The development of these formats was done in close communication with the VET partners to ensure an exact fit. Test were run for the applications with teachers and trainees. The lessons learned from programming or production and test runs were collected, documented and reflected back to the development work.

2. LEARNING APPLICATIONS

2.1 DIGITAL CONSTRUCTION FILE / MINDMAP

There is no uniform definition for the term DIGITAL CONSTRUCTION FILE. In practice, the term is used for systems that aim to document project-relevant information. In the simplest case, these are pure document management systems in which, for example, daily construction reports, obstruction notices, drawings or even defect tracking are managed. In order to be competitive as a provider of such systems and also to make processes lean as a result of the trend, there are, among other things, portals that also support work with building models and their inspection. Such a system is distributed by the company DALUX. In line with the project's objective, the DALUX system was used in the learning scenario "Creating a roof truss".

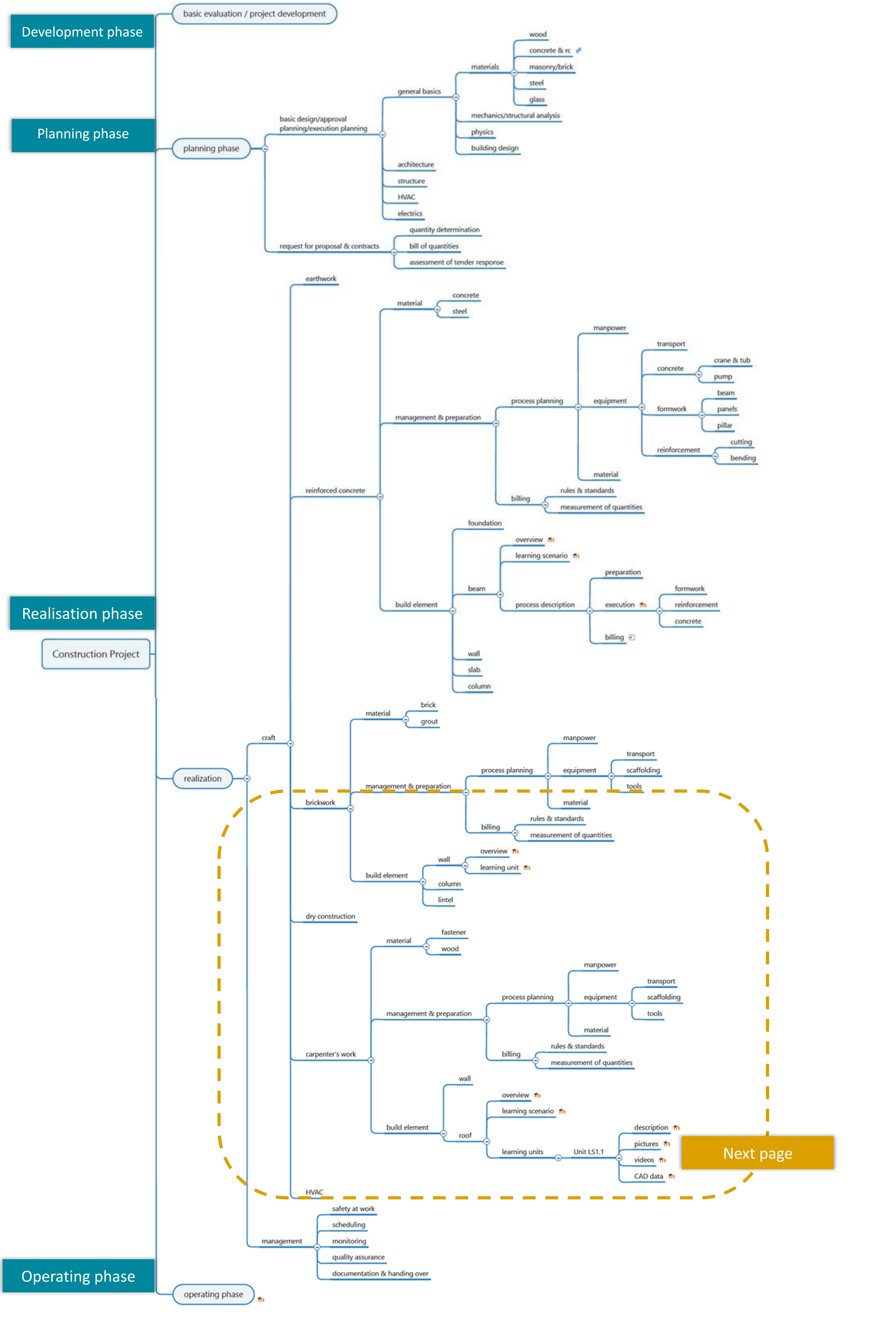
The actual objective, namely that various tasks in the construction process along the learning scenarios, based on the action scenarios, are practiced in a learning application, has no link with the term "digital construction file". For this reason, the term "digital construction file" will no longer be used in the following. In the context of the project, a learning application is understood as a platform in which pupils, students and teachers can access learning units and materials through process-oriented navigation. The learning application is structured in such a way that students can independently find learning units and materials in order to promote self-study.

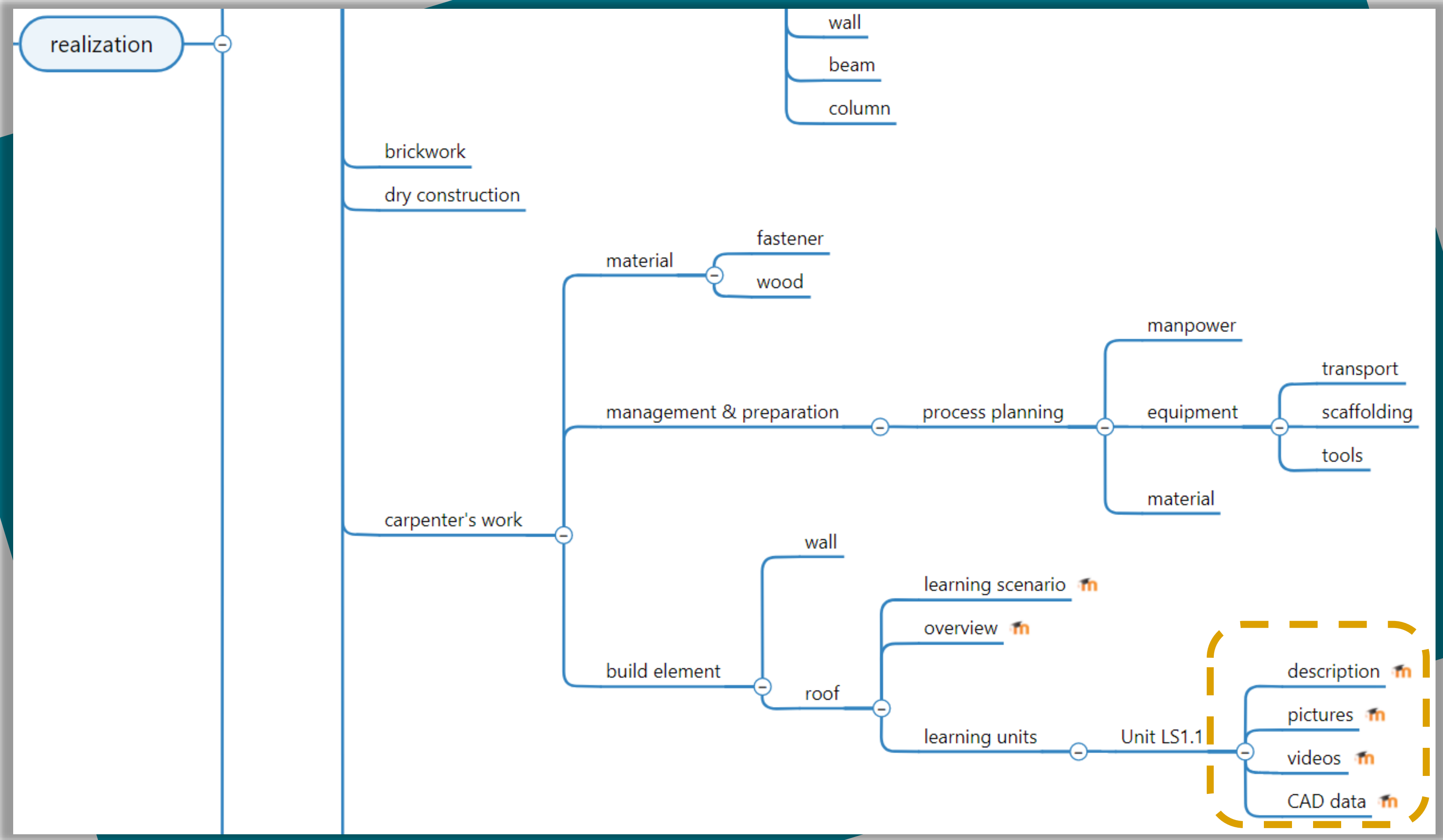
THE CREATED MINDMAP is the link between the action scenarios, the learning scenarios and manual for handling the learning materials and designing e-learning systems (IO1+IO2 and IO4), and was developed instead of the "digital construction file".

The following screenshots shell give an overview about the constructed Mindmap, as it cannot reached by a link. It is only available via the Moodle platform, that is used by the HTW Berlin.

1. Structure of the Mindmap

Users access the respective learning content via the mindmap using hyperlinks.
The mindmap is divided into the different phases of planning.



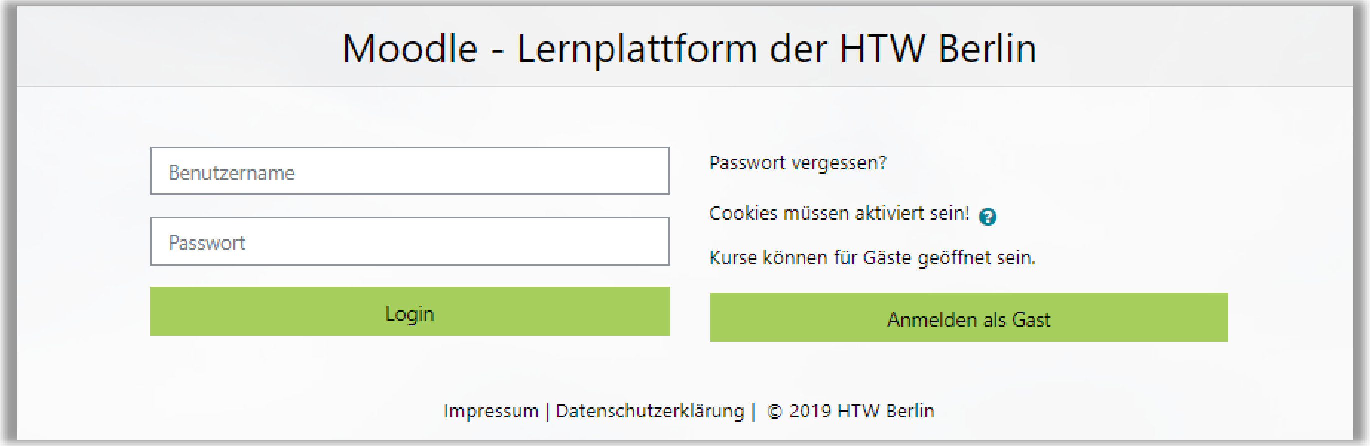


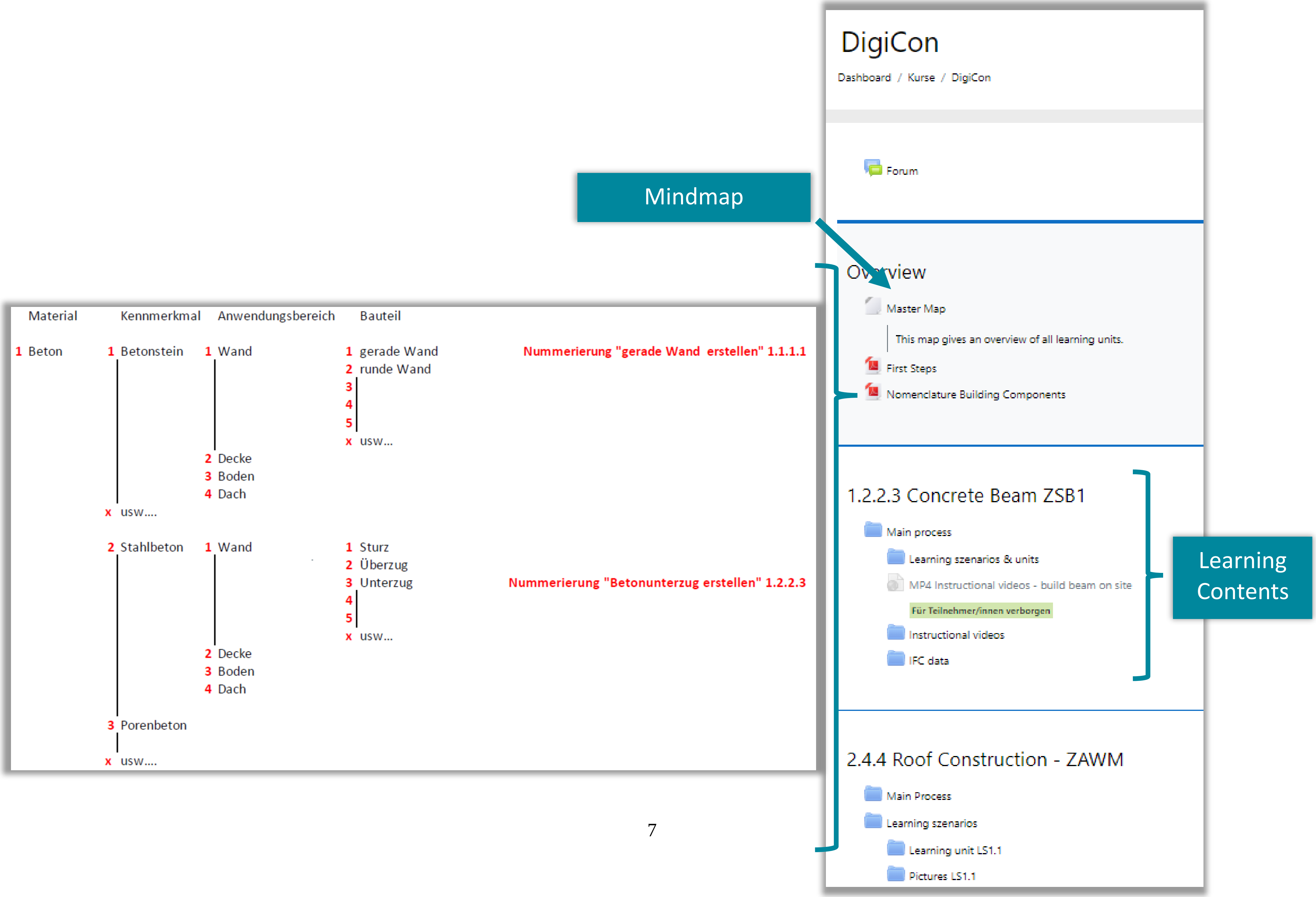
Here are the corresponding links that lead to the learning content

2. Structure and learning contents of Moodle Platform

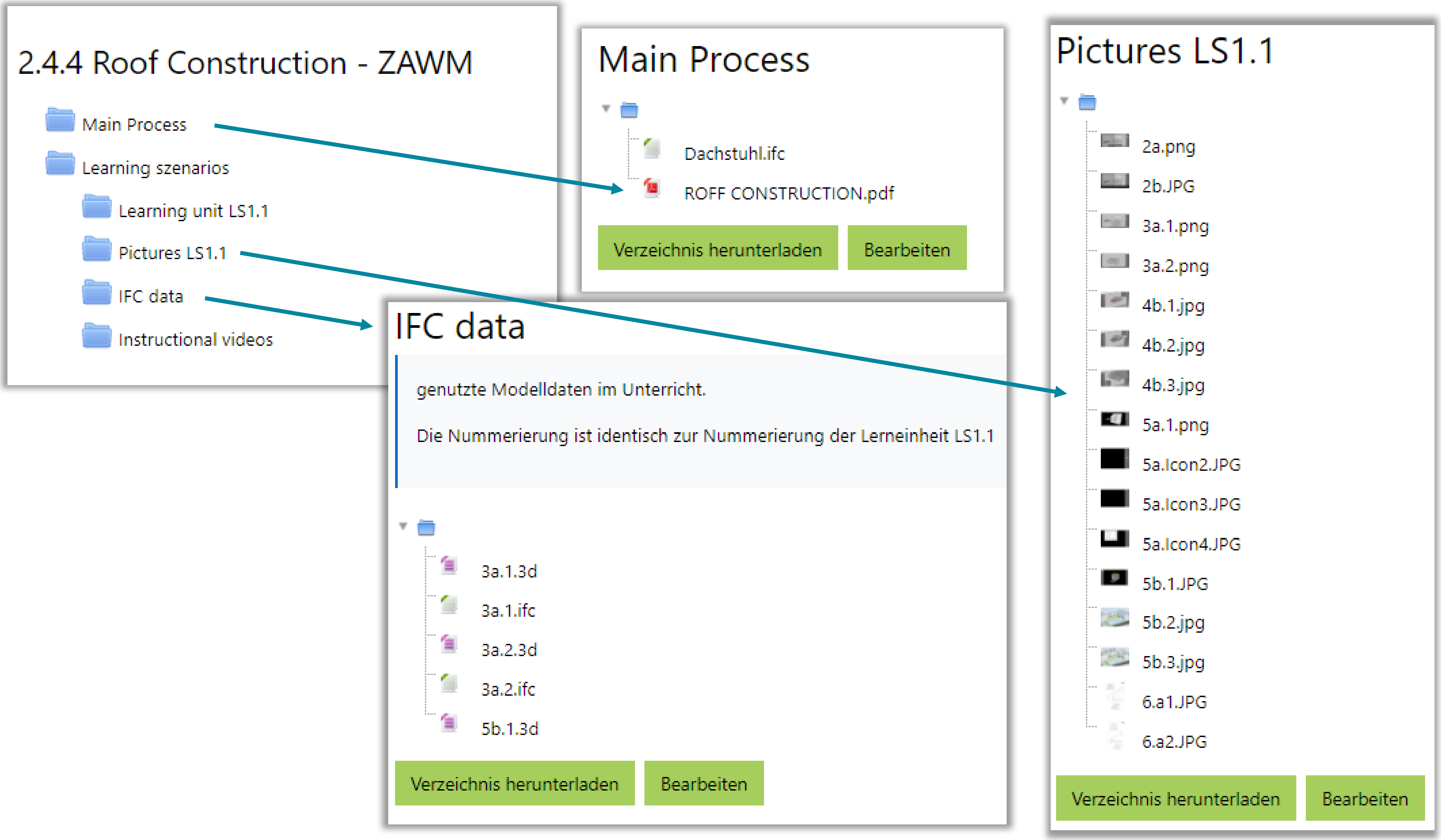
The action/learning scenarios and learning contents are made available in a digital learning environment. The Moodle platform is used because it is international and can be used on all common operating systems (PC, Apple, Android). It is also inexpensive to operate.

The Moodle system of the HTW Berlin is used in the DigiCon project.



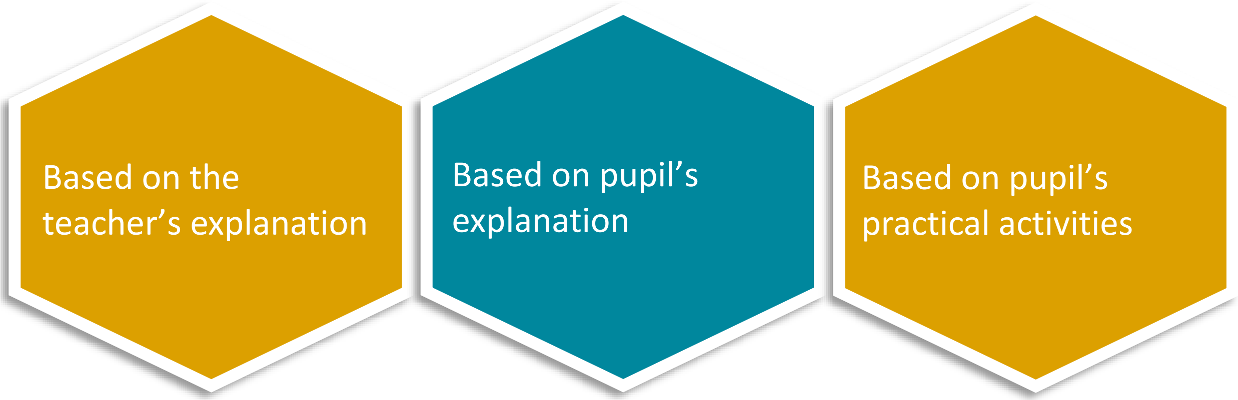

Mindmap
Material
Kennmerkmal
Anwendungsbereich
Bauteil
1 Beton
1 Betonstein
1 Wand
1 gerade Wand
2 runde Wand
3
4
5
x usw...
Nummerierung "gerade Wand erstellen" 1.1.1.1
2 Decke
3 Boden
4 Dach
x usw....
2 Stahlbeton
1 Wand
1 Sturz
2 Überzug
3 Unterzug
4
5
x usw...
Nummerierung "Betonunterzug erstellen" 1.2.2.3
2 Decke
3 Boden
4 Dach
3 Porenbeton
x usw....
DigiCon
Dashboard / Kurse / DigiCon
Forum
Overview
Master Map
This map gives an overview of all learning units.
First Steps
Nomenclature Building Components
1.2.2.3 Concrete Beam ZSB1
Main process
Learning szenarios & units
MP4 Instructional videos - build beam on site
Für Teilnehmer/innen verborgen
Instructional videos
IFC data
Learning Contents
2.4.4 Roof Construction - ZAWM
Main Process
Learning szenarios
Learning unit LS1.1
Pictures LS1.1

3. Examples for Learning Contents



2.2 LEARNING VIDEOS AND AR APPLICATIONS

Three groups of methods can be distinguished in the vocational training related to the construction site works:



Nowadays, various means are used in the didactic process. Audio-visual means, using auditory-visual stimuli, are particularly effective. This group includes films, which enable the transmission and reception of information across a wide range of human perceptual abilities. Films of this kind have a scientific and didactic character in that, during the teaching process, a lot of selected information is conveyed to the pupils. A teaching method in which pupils are presented with learning videos is referred to as the video method. This method consists of presenting pupils with a learning video, the content of which consists of selected activities related to specific construction works. The main advantage of this method is that certain sequences of activities can be repeated several times. The learning video, in its content, must be adapted to the specific curriculum. The construction of such a video should take into account that it is part of a specific educational process and part of a lesson[1,2].

[1] Leja L. (red.). 1970. Film skuteczną pomocą dydaktyczną. PWN, Warszawa

[2] May M. A., Lumsdaine A.A. 1958. Learning from films. Yale Univeristy Press, New Haven.

As part of the DigiCon grant, the following lesson activities were developed using learning videos:

a) The fabrication of a precast reinforced concrete beam,
b) The creation of a 3D computer model of a roof truss for manufacturing purposes,
c) The comparative test of simply supported reinforced concrete beams of variable reinforcement arrangement under uniformly distributed loading.

The series a) is based on the data acquired in the factory of precast concrete members, the series b) is based on the live shooting of a computer screen and the series c) is a simulation based on the numerical analysis results.

With regard to the fabrication of a precast reinforced concrete beam, the following steps were presented using the videos:

- Formwork preparation and assembly
- Preparation of reinforcement
- Installation of reinforcement
- Laying and compacting of concrete mix
- Dismantling of the formwork
- Final acceptance of the beam

With regard to the creation of a 3D computer model of a roof truss for manufacturing purposes, the following steps were presented using the videos:

- Creating the model of the roof truss in the vicinity of the chimney
- Creating the model of the roof trusses in the vicinity of the roof bay

With regard to the bending of a simply supported reinforced concrete beam under uniformly distributed loading, the following phenomena were presented using the videos:

Differences between concrete and reinforced concrete member behaviour	Influence of the degree of reinforcement on concrete crack pattern	Member failure mechanism due to yielding of reinforcing bars

The series a) and b) were included in learning scenarios given in IO2. The series c) is submitted as a database of pictures and videos for individual or guided exploration, accompanied by example presentations that may be applied during lesson on the behaviour of structural members in bending.

2.2.1 Numerical experiment as a teaching aid in vocational training on building structures

Introduction

The increasing access to software capable of advanced analysis of the behaviour of building structures and the increasing abilities of this software prompted an attempt to implement numerical experiments in the education process of university students of construction.
The benefits of this form of education are multifaceted. Apart from the primary one of supporting the cognitive value of education, the most important additional ones are:

- for the student - acquiring the ability to interpret the graphical information offered by advanced structural analysis software
- for the school/university - improving the attractiveness of education by extending it to include interactive experiences

In contrast to the traditional one, the numerical experiment gives much more scope for variation in the parameters of the analysed phenomenon and comparison of variants. This is an additional cognitive value that facilitates understanding of the nature of phenomena.

Conditions for a numerical experiment appropriate as teaching aid

The prerequisites for the preparation of a correct numerical experiment are:

a) software capable of reproducing:

- the actual geometry of the tested member,
- non-linear material behaviour (e.g. plasticisation, fracture) of the member,
- the interaction of member components (for example: reinforcing steel and concrete),
- the transfer of loads to a finite area of a structural element

b) skilled personnel responsible for the creation of computational models enabling the correct representation of the phenomena analysed

c) a reference (real) experiment and a numerical experiment mapping it (on the basis of "a" and "b"), in order to

- verify the correctness of the modelling technique used (including the computational model),
- obtaining an image of the real phenomena in the numerical analysis software environment

d) database of numerical results for a range of sets of experiment parameters which may be controlled by teacher/student for comparison purposes,

e) a guide to the content of the database together with explanation how the results of the numerical experiment reflect the real phenomena (based on “c”)

Numerical representation of phenomena present in building structures

The purpose of the numerical experiment is to present mainly qualitative, not quantitative, phenomena. For this reason, the knowledge of phenomena in real structures and how they can be reflected in numerical models is essential.

The basic materials used in building structures are steel and concrete. The most common structures are steel, reinforced concrete and prestressed concrete. The behaviour of these materials under loading is related to strain and indicated by the phenomena such as:

- yielding of steel – structural steel (in steel structures), reinforcing bars (in reinforced concrete structures) or prestressing tendons (in prestressed concrete structures),
- cracking of concrete in tension zones (in reinforced and prestressed concrete structures),
- crushing of concrete in compressed zones (in reinforced and prestressed concrete structures)

whereby the failure mechanism may be accompanied by one or more phenomena.

In numerical models that reflect the actual member geometry, the above phenomena can be tracked by means of strain maps and stress maps within in the structural materials. In this case, the deformations or stresses with values within a certain range correspond to a single colour. Extensive areas of equal colour indicate mild changes. The narrower the areas, the more intense the change (greater gradient). In this way, it is possible to identify:

a) stress concentrations – local stress extremes with a large gradient in the vicinity,

b) steel plastification – stresses close to yield or strains greater than those corresponding to plasticisation,

c) concrete cracking – local strain extremes with a value greater than the limit deformation corresponding to cracking

d) crushing of concrete – local deformation extremum with a value greater than the limit deformation corresponding to crushing,

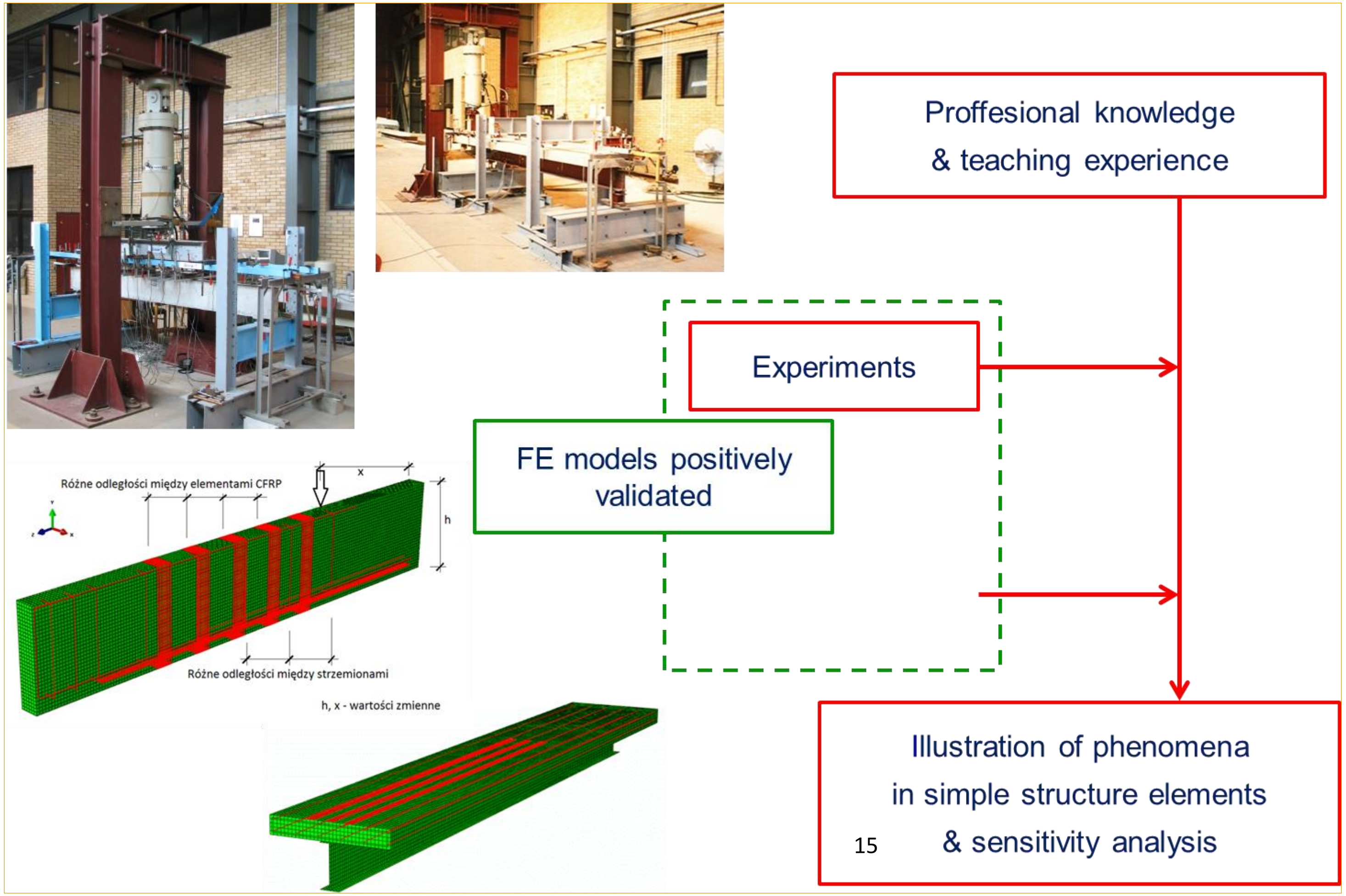
e) location of the so-called neutral axis of the section – at the boundary between the colours referring to small values of deformation (or stress) of the opposite sign.

Interactivity of numerical experiment

The preparation of an advanced numerical model, which should be the basis for the numerical experiment, requires advanced knowledge of solid mechanics and the use of specialised software. For this reason, it is not possible for the student/student to work directly with the computer programme. The solution envisaged is to prepare a number of variants of the experiment in advance with their graphical documentation (video) and the possibility of pairwise comparisons to illustrate the phenomena.

2.2.2 Numerical experiment description

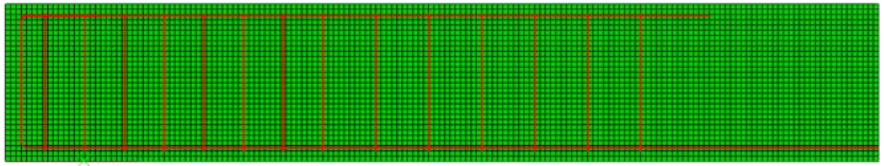
Validation of the numerical analysis of reinforced concrete beams



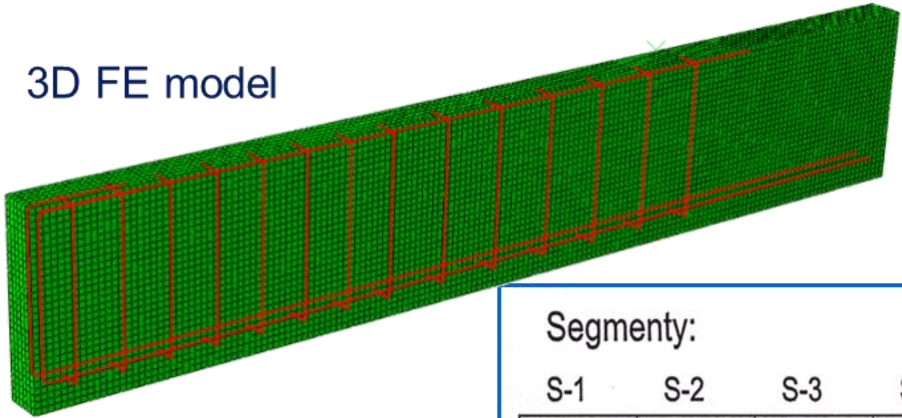
Reinforced Concrete beam

<u>Numerical models</u> created on the basis of data from laboratory tests:

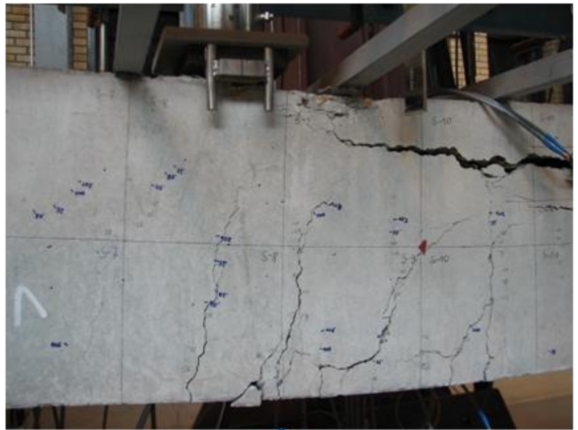
2D FE model

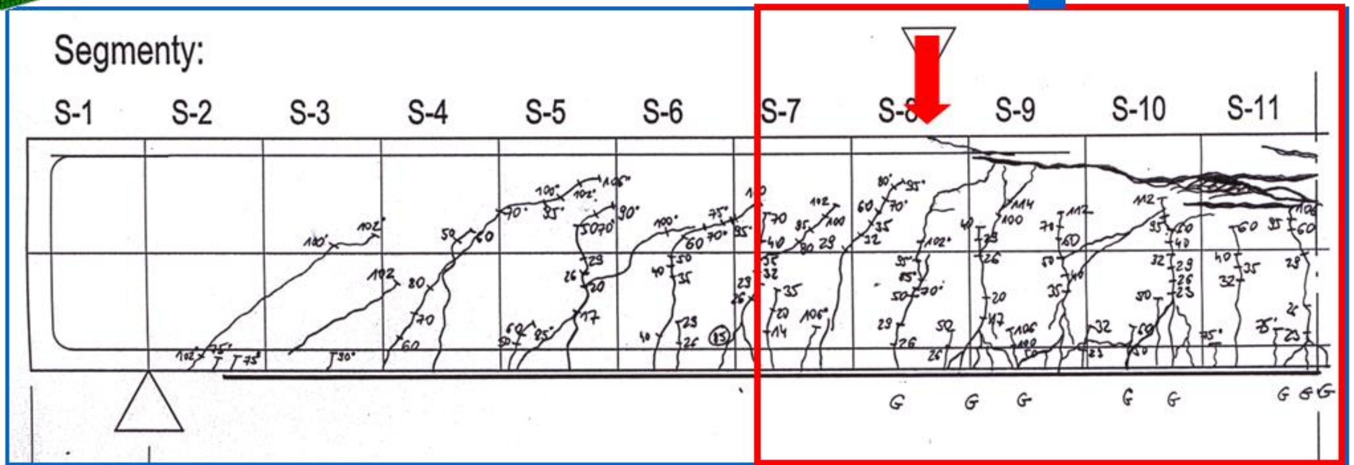


3D FE model



Data for **<u>model verification</u>** obtained from laboratory tests:

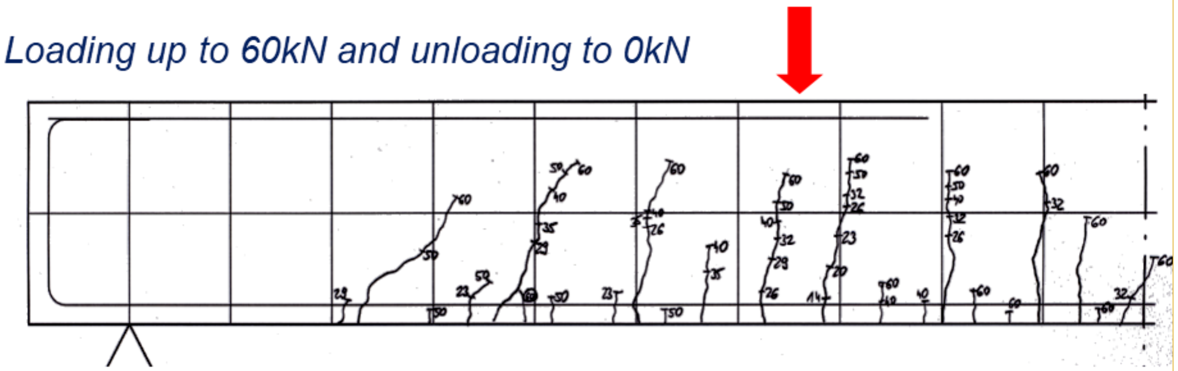




Reinforced Concrete beam

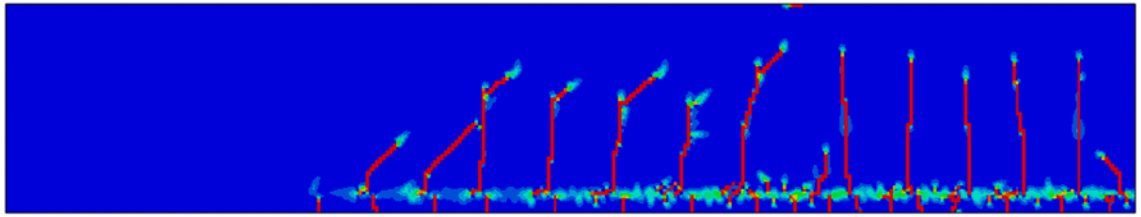
REAL experiment

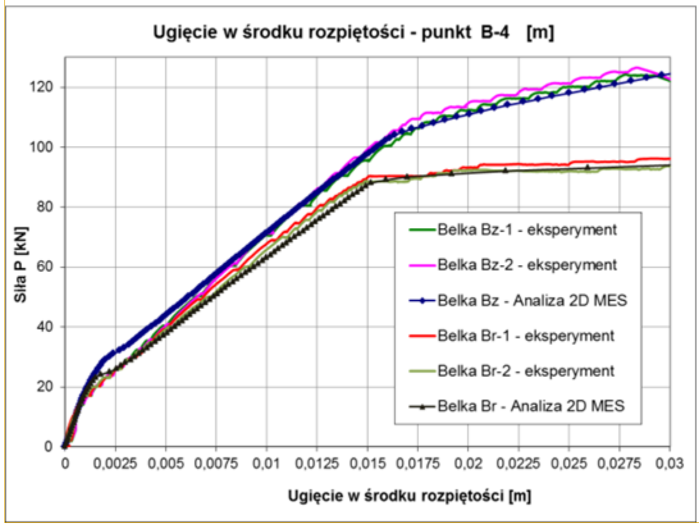
Loading up to 60kN and unloading to 0kN



NUMERICAL experiment

Layout of cracks in FEM analysis





Qualitative and quantitative verification

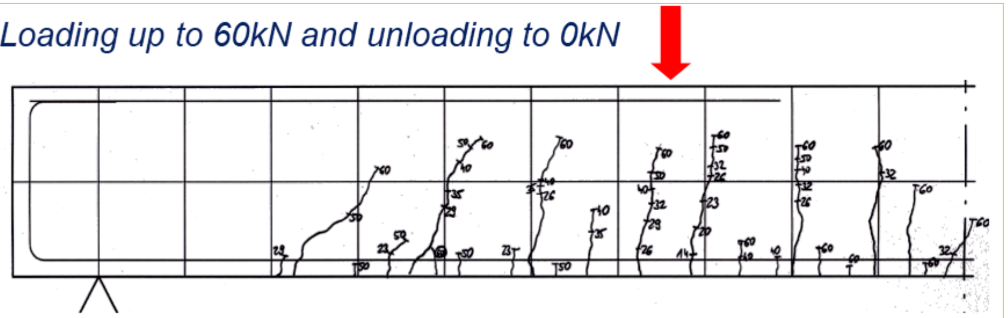
RC beam strenghtened using CFRP materials

Analyses of different cases of:

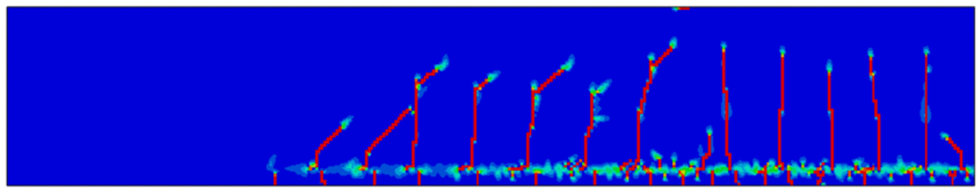
- reinforcement ratio
- loading
- dimensions of beams
- strengths of used materials
- different …
- etc.

Stage 1

Loading up to 60kN and unloading to 0kN

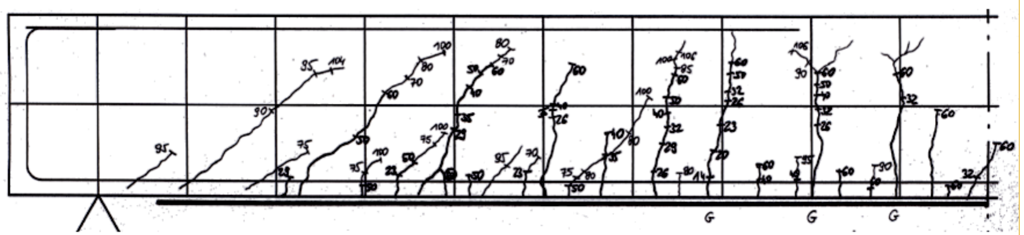


Layout of cracks in FEM analysis

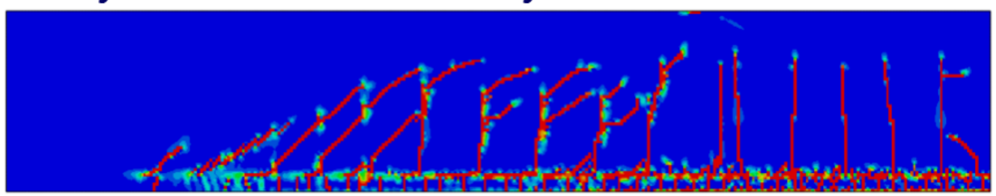


Stage 2

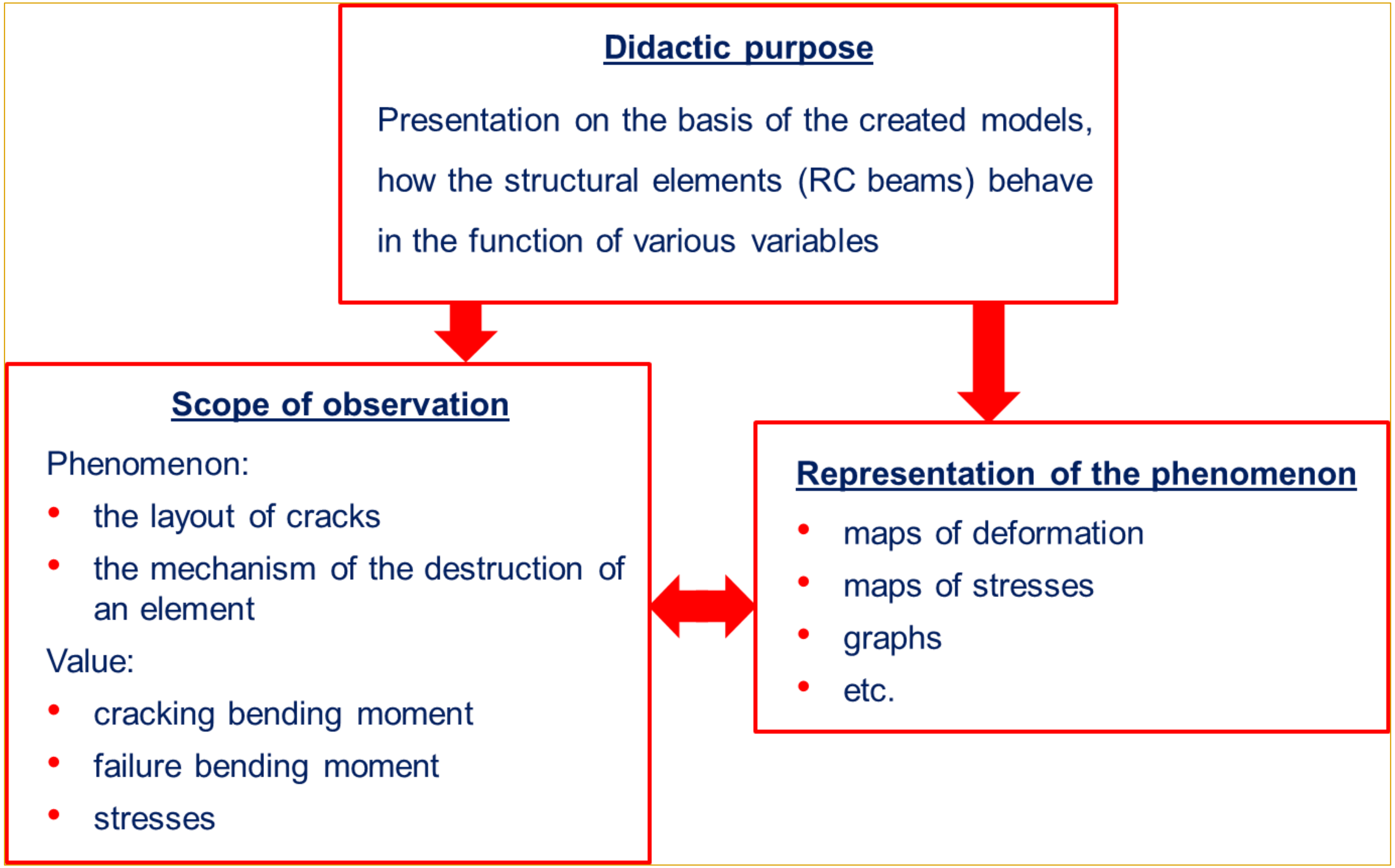
After CFRP strenghtening – before failure P=120kN



Layout of cracks in FEM analysis

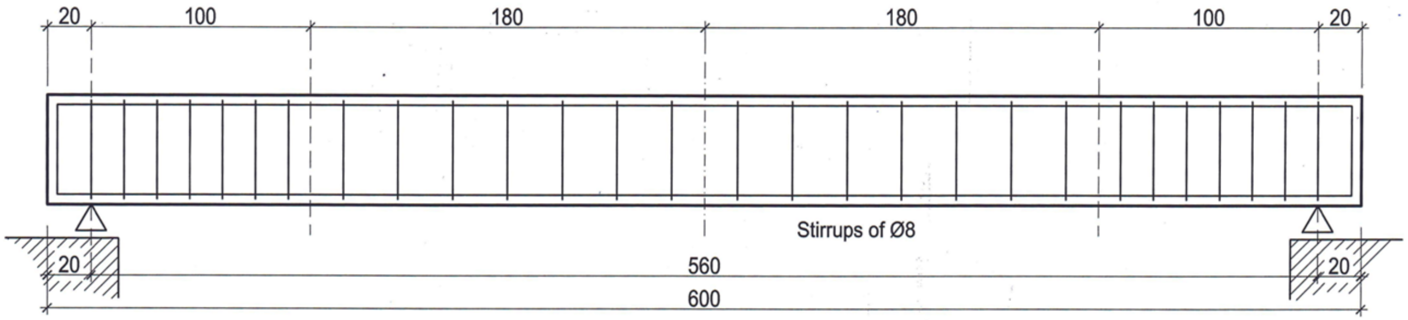


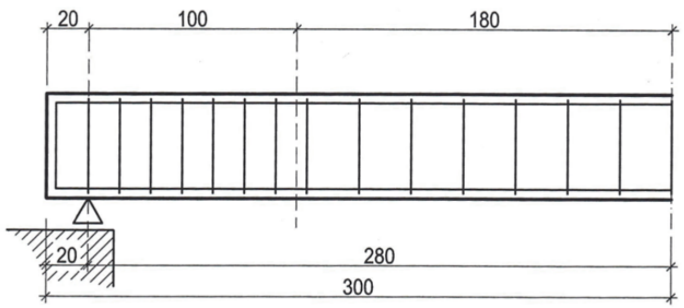
Motivation for the numerical experiment



Scope of the numerical experiment

Reinforcement beam – details





Data on the RC beam:

- Cross section dimensions: 0,30 x 0,5 m
- Total beam length: 6,0 m
- Theoretical beam length: 5,6 m
- Concrete: class C50/60

  f_{ck} = 50 MPa

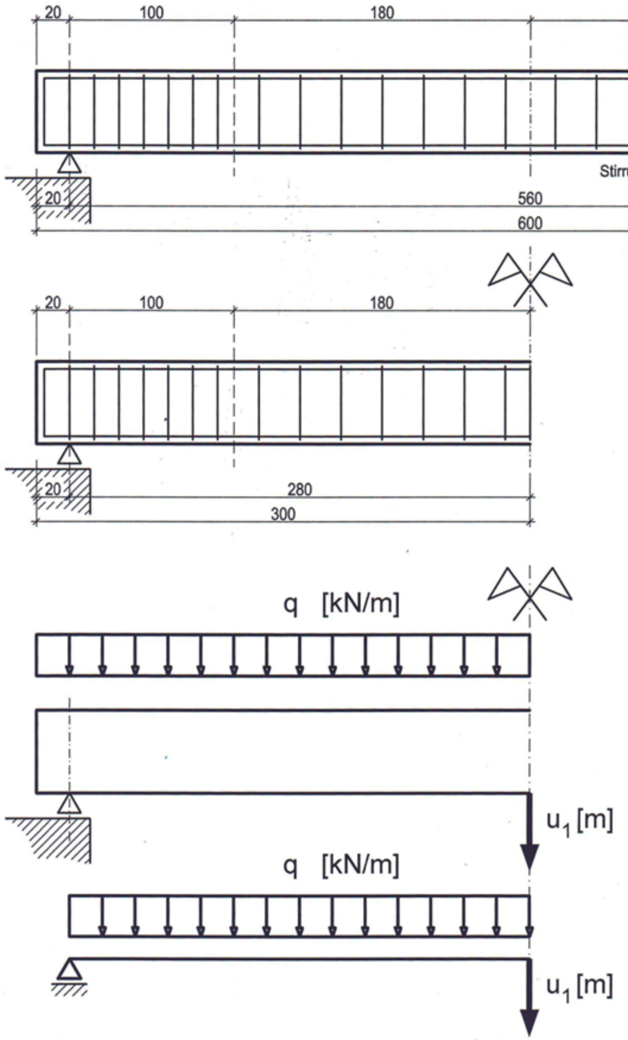
  E_c = 37 GPa
- Reinforcing steel: steel type B500SP

  f_{yk} = 500 MPa

  E_a = 210 GPa

Beams with different numbers and diameters of reinforcing bars will be analyzed ...

Reinforcement beam - details



Data on the RC beam:

Stirrups reinforcement:

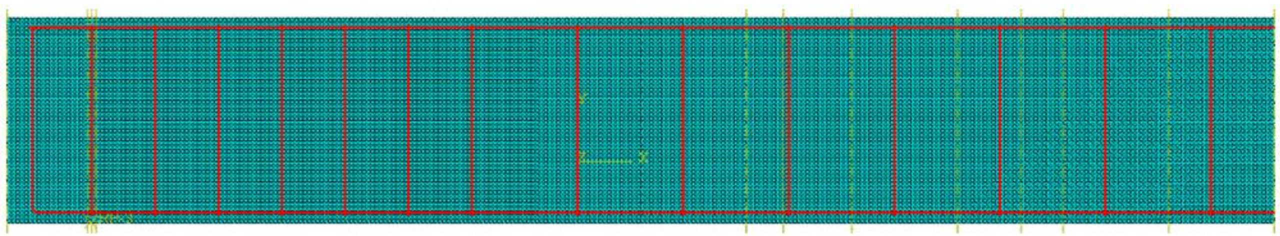
- **In the supporting zones** - 2-bar stirrups from bars ϕ8 at a spacing of 0,15 m (at a section of 1,0 m from the theoretical beam support point)
- **In the middle zone of the beam** - 2-bar stirrups from bars ϕ8, spaced every 0,25 m (on the 3,6 m section)

The analyzed beams will in each case be loaded with a uniformly distributed load with a value close to the calculated breaking load.

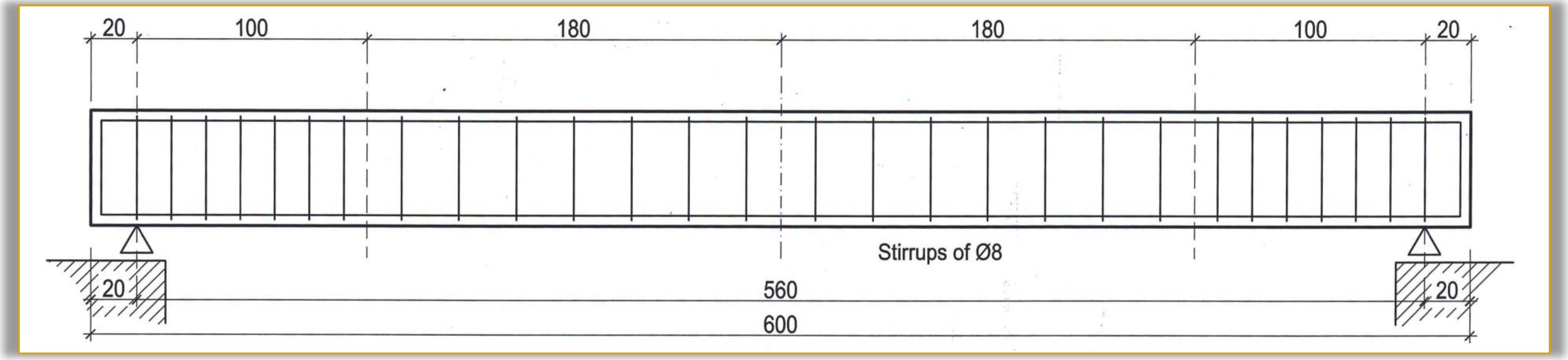
RC beam with different reinforcement ratio

FEM analyses of different cases of reinforcement ratio:

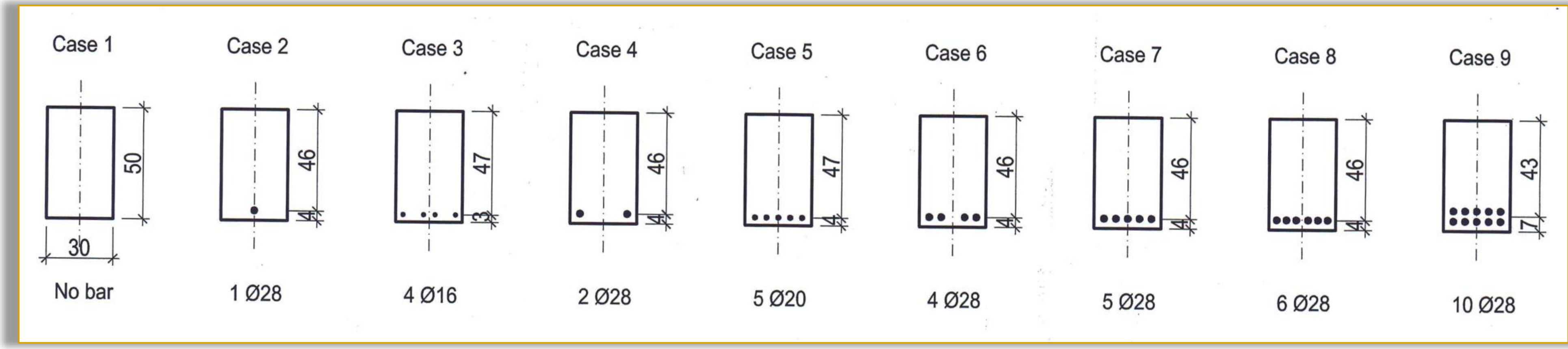
Type of analysis	Reinforcement bars	Reinforcement ratio [%]
2D analyses – different reinforcement ratios	Lack of reinforcement bar	0
	1 ϕ28	0,41
	4 ϕ16	0,54
	2 ϕ28	0,82
	5 ϕ20	1,0
	4 ϕ28	1,6
	5 ϕ28	2,1
	6 ϕ28	2,5
	10 ϕ28	4,1



Layout of analysed RC beam

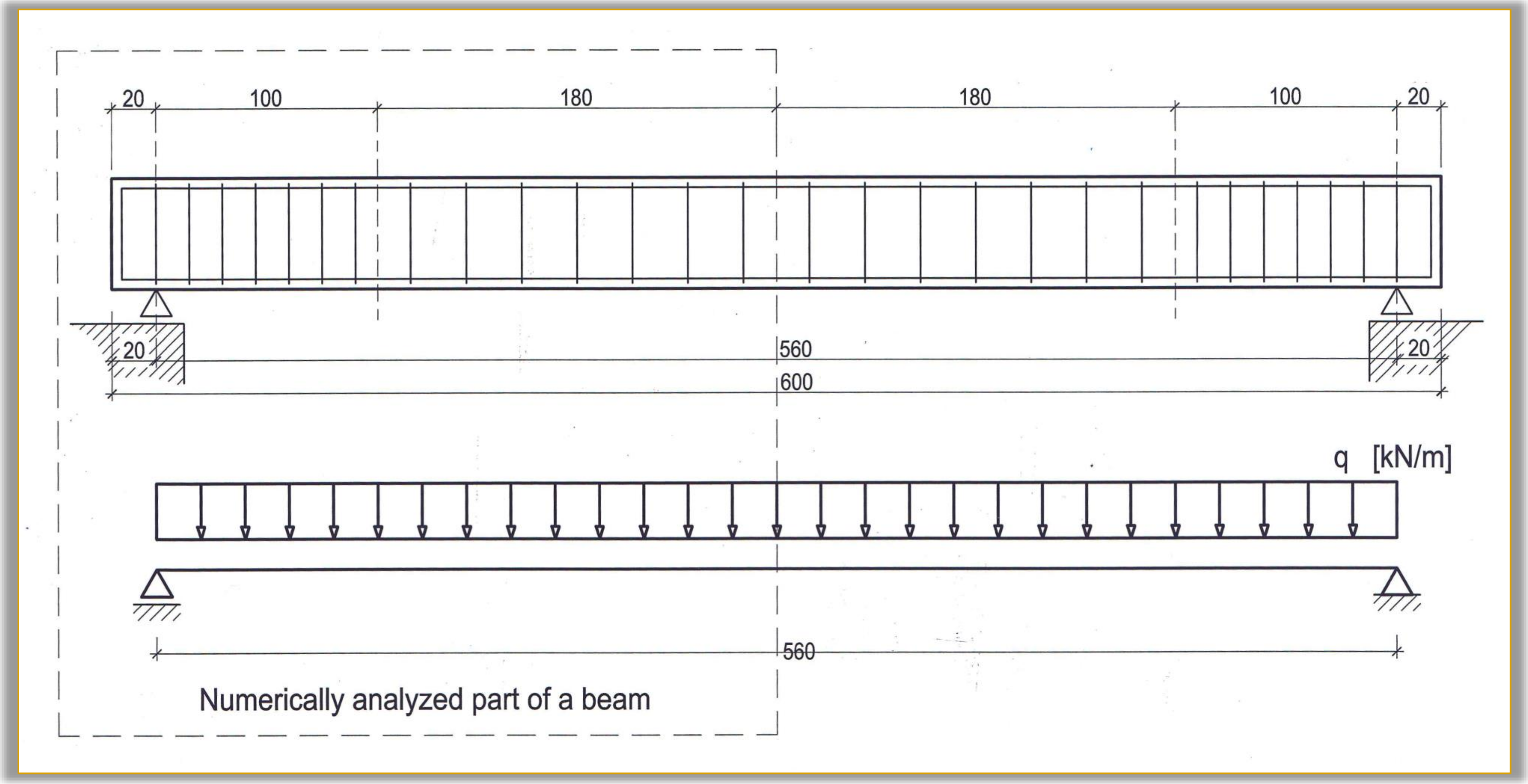


Different sets of analysed beams with **different reinforcement ratios:**



0% < 0,41% < 0,54% < 0,82% < 1,0% < 1,6% < 2,1% < 2,5% < 4,1%

Reinforcement beam – simplification of the numerical 2D model

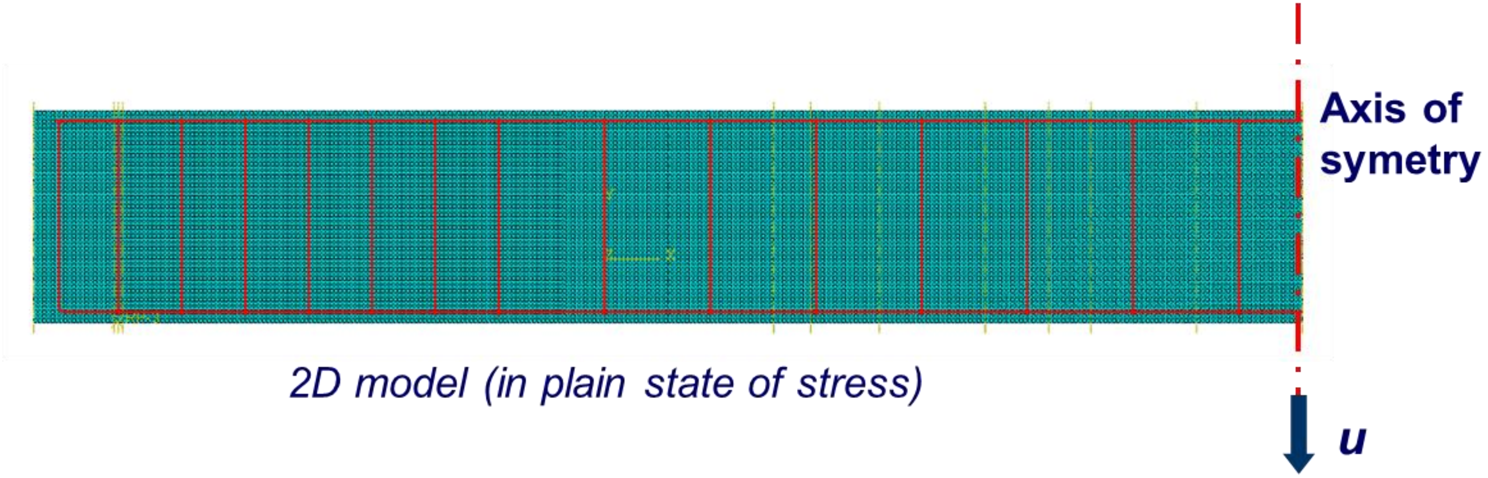


GOAL - analysis of only half of the beam will allow to reduce the time-consuming performance of numerical calculations held on the whole numerical model

Reinforcement beam – FEM analysis of 2D model

Assumptions of FEM analyses in general:

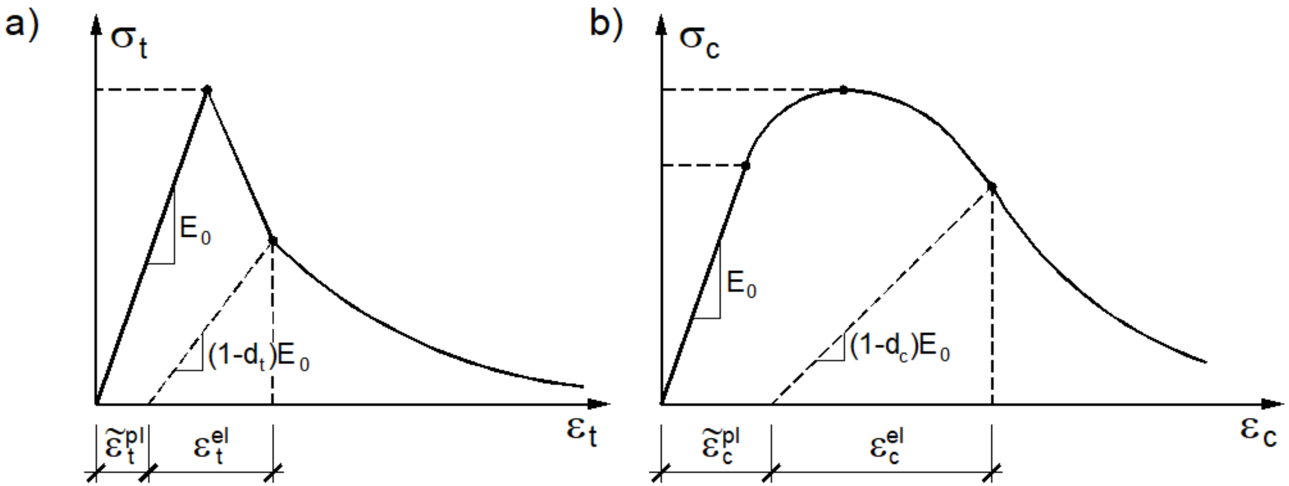
- Numerical models were prepared and analysed by Abaqus/Standard code
- The analyses have been performed on 2D models (in a plane state of stress)
- In 2D model the symmetry of the beams was taken into account. Hence the model of half was made with the appropriate displacement constraints imposed on the appropriate axis of symmetry



2D model (in plain state of stress)

CONCRETE:

- **<u>Concrete Damage Plasticy model</u>** was used to describe behaviour of concrete



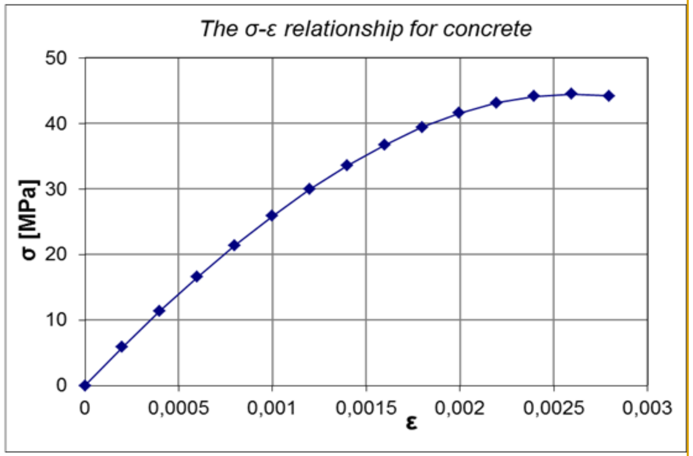
The σ–ε curves for concrete:

a) for uniaxial tension,

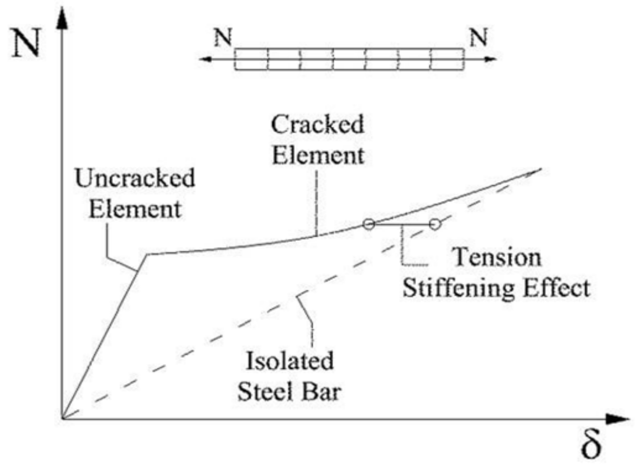
b) for uniaxial compression

CONCRETE:

- The σ–ε curve for **concrete under compression** was based on laboratory tests



- Reinforced concrete can work in tensile zones even after the cracks occur ('tension stiffening' effect)
- A proper value of fracture energy was used to represent the behaviour of **concrete in tension**

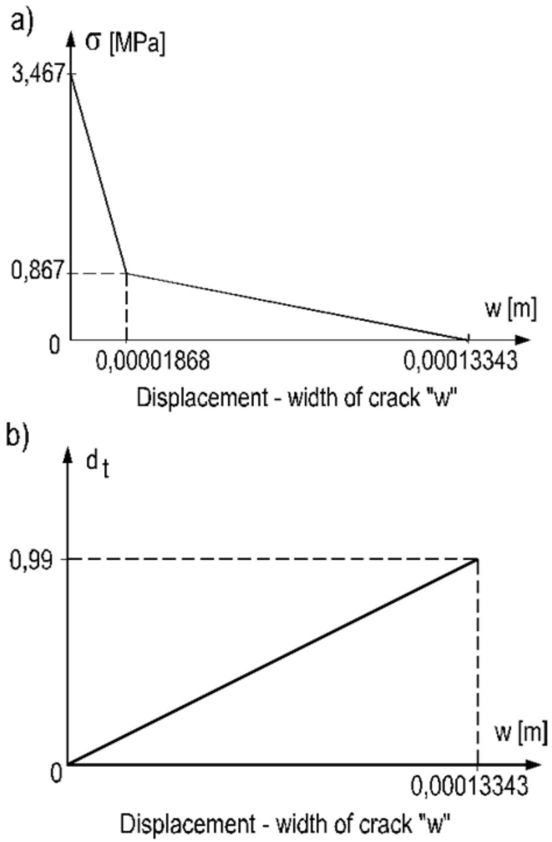


The ‚tension stiffening' approach in concrete of tensioned members

Reinforcement beam – FEM analysis of 2D model

CONCRETE:

- The strain-softening behavior of **concrete in tension** was given as the stress-displacement relationship (σ-w)
- In the analysis **the elastic degradation of concrete after cracking** is defined by means of the tensile damage parameter d_t. A linear relationship of d_t-w (damage parameter - width of crack) was accepted.



a) the σ-w relationship as functions of cracks width

b) distribution of damage parameter d_t as functions of cracks width

The damage variables d_t can take values from zero, representing the undamaged material, to one, which represents total loss of strength.

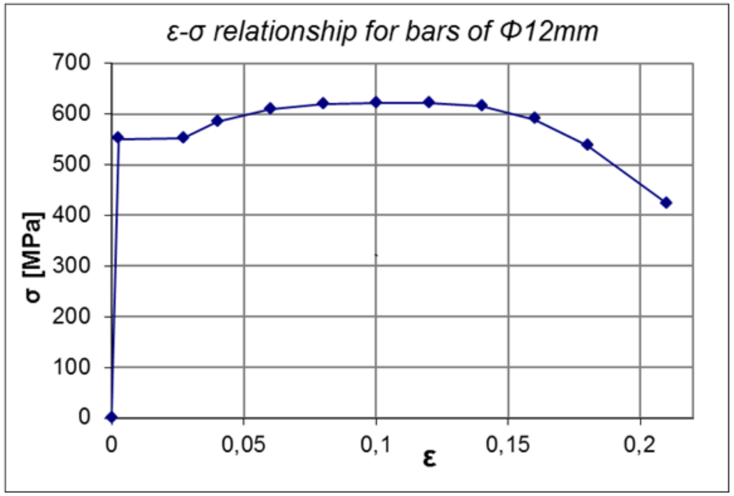
Beginning of the crack formation: ***$d_t = 0$***

Crack development

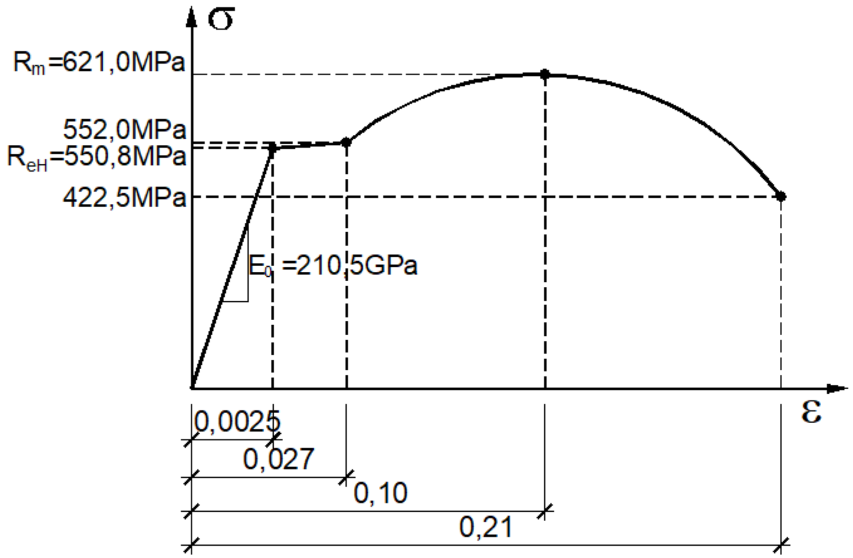
Crack with the maximum width: ***$d_t = 1$***

STEEL:

- Steel of rebars was assumed as a linear elastic-plastic material with isotropic hardening
- The σ–ε curve for steel was based on laboratory tests
- In the FEM model reinforcement bars were embedded into concrete host elements

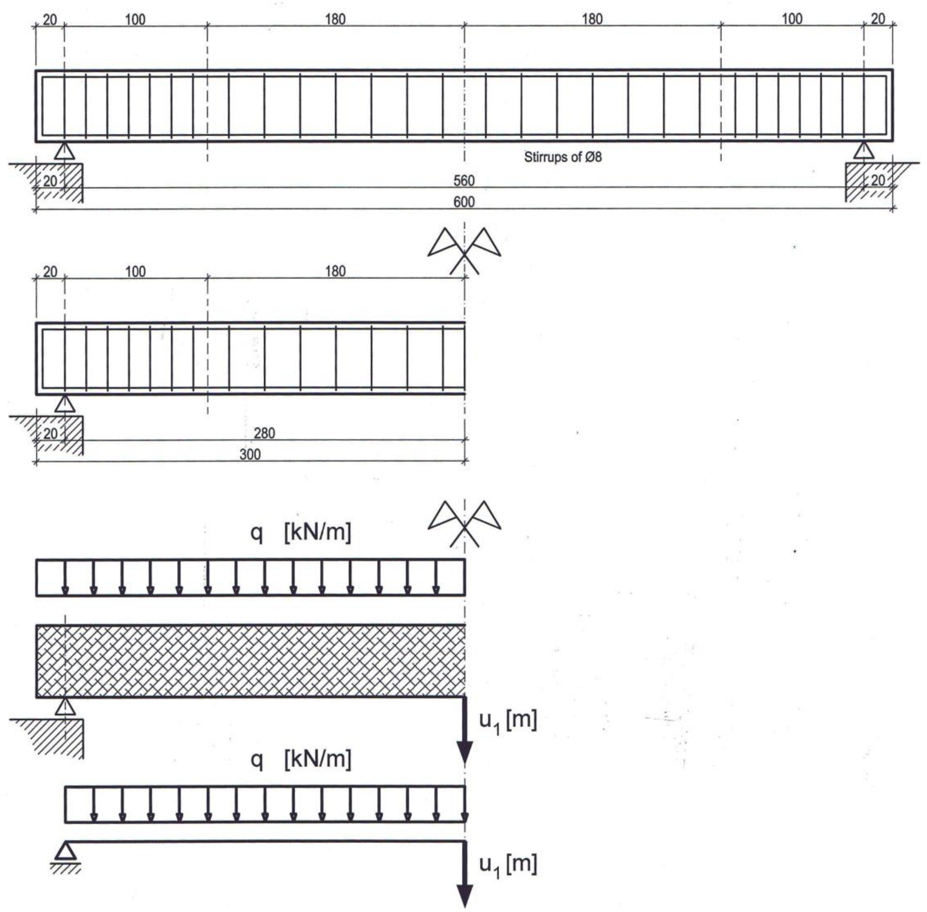


The σ-ε relationship for steel of rebars determined in the laboratory tests



Schematic diagram determining the characteristic points of the σ-ε relationship for steel of rebars

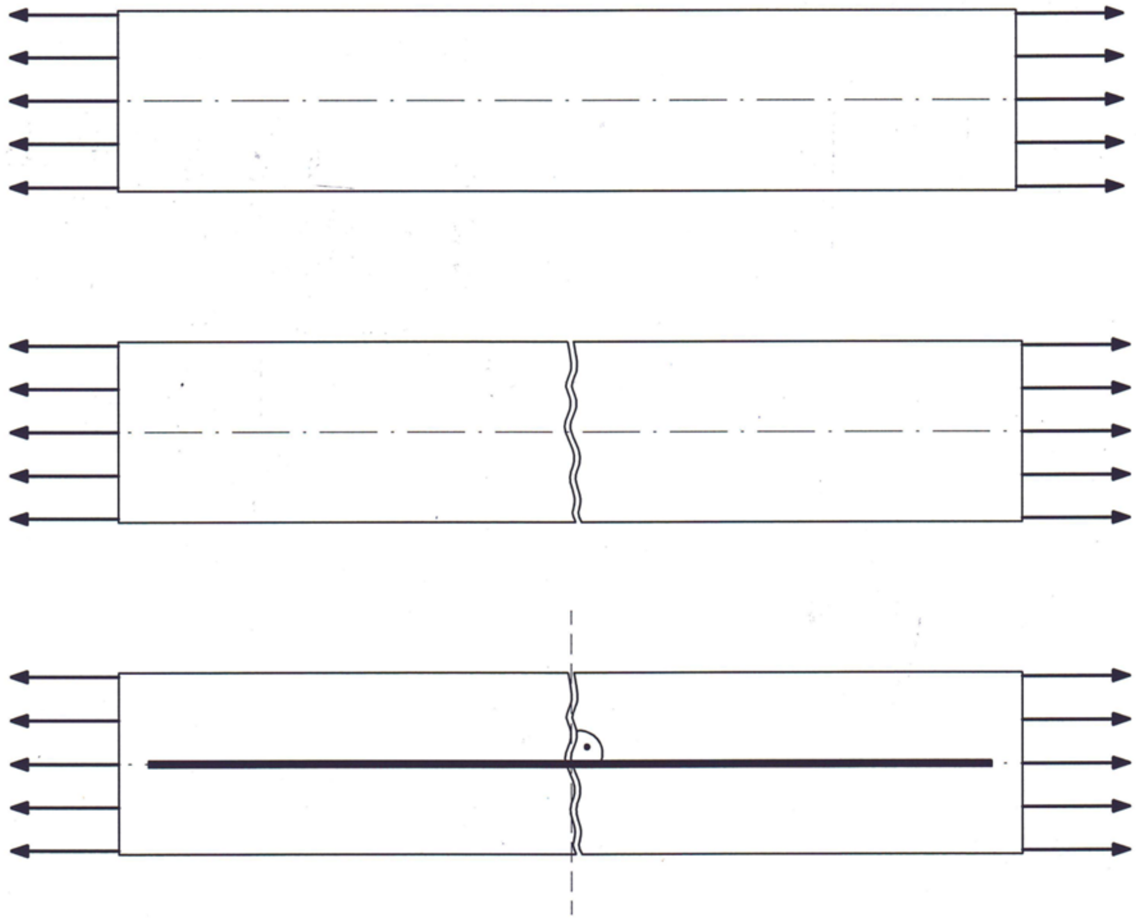
Beam load – FEM analysis of 2D model



Load:

Distributed load is applied to the top edge of beam models

The idea of using reinforcing bars in a concrete concrete beam



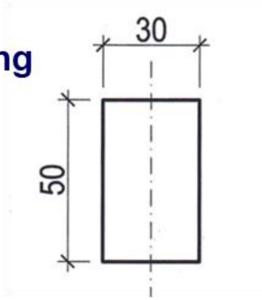
Direction of main tensile stresses

In isotropic materials, the direction of cracks are perpendicular to the direction of main tensile stresses

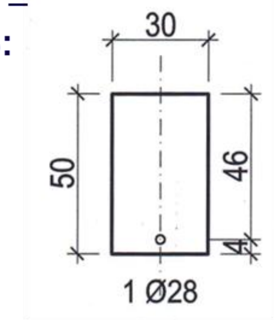
Cracks tensile direction

Analysed beams

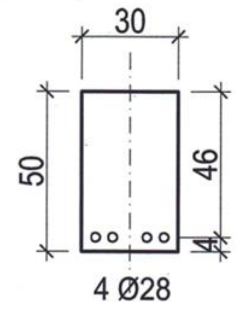
Concrete beam – with **no reinforcing bars:**



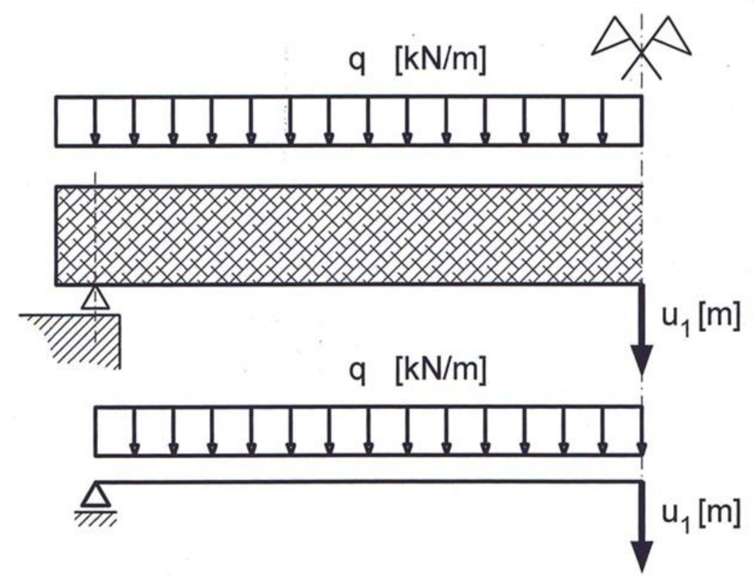
RC beam – with **1ϕ28:**



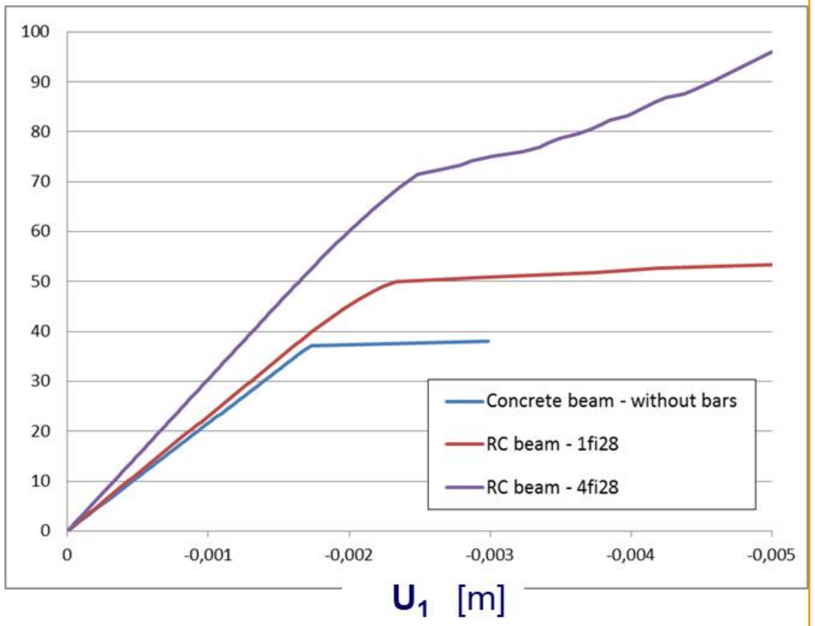
RC beam – with **4ϕ28:**



Part of beam with load and measuring point:

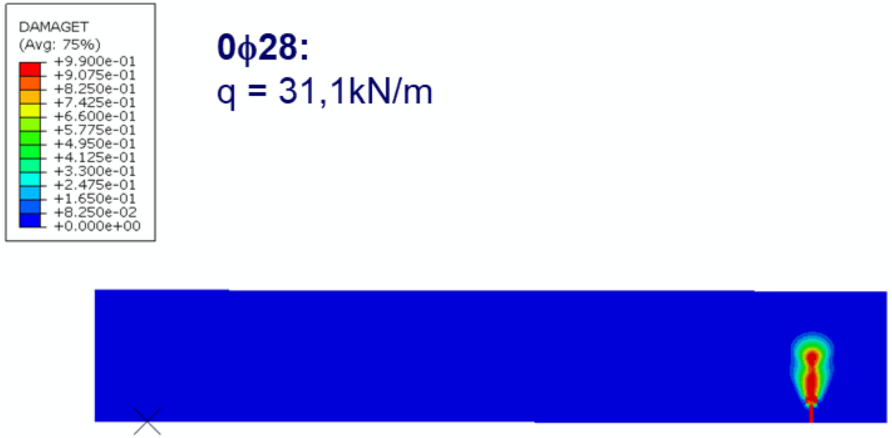


Deflection in the middle-span point of beams:

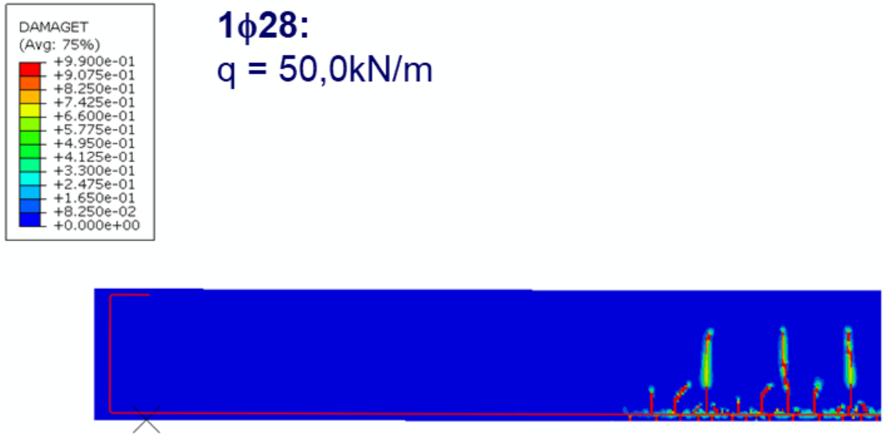


Analysed beams – analysis of DAMAGE_T parametr

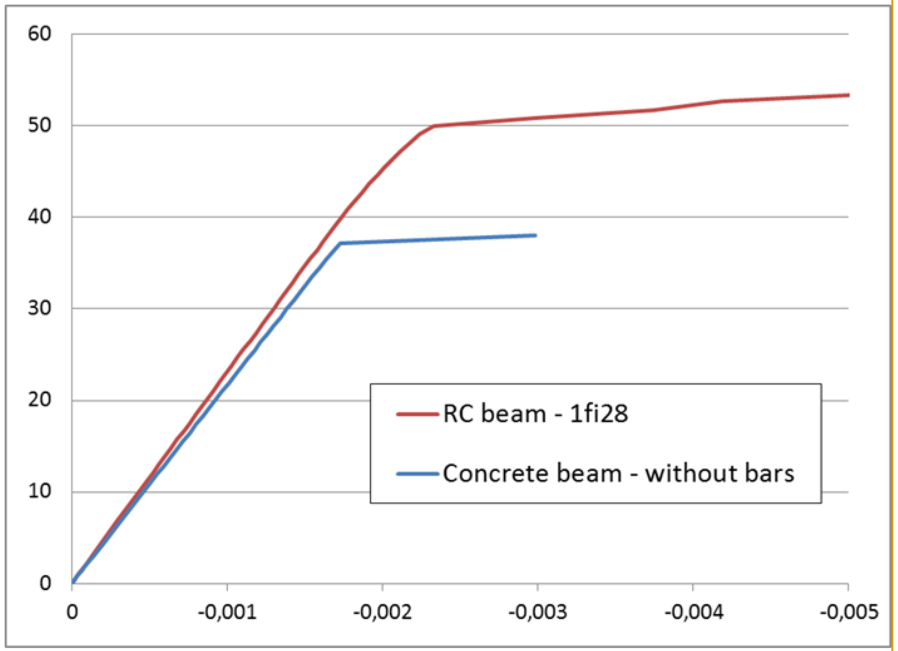
0ϕ28:
q = 31,1kN/m



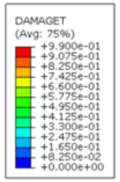
1ϕ28:
q = 50,0kN/m



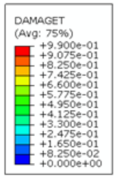
Deflection in the middle-span point of beam:



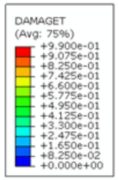
Analysed beams – analysis of DAMAGE_T parameter



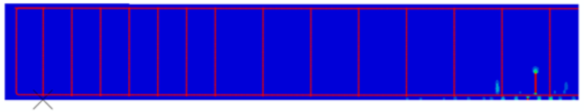
0ϕ28:
q = 31,1kN/m



1ϕ28:
q = 50,0kN/m

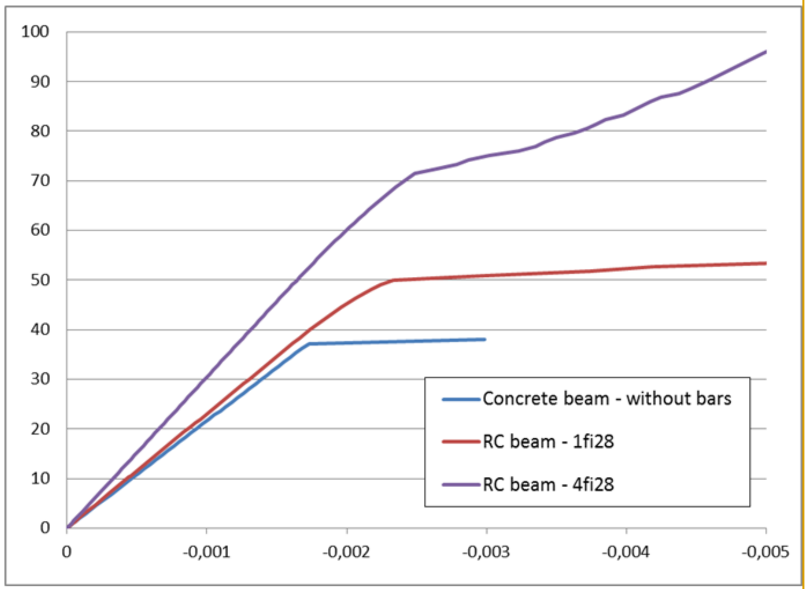


4ϕ28 + shear stirrups:
q = 70,0kN/m

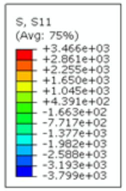


The beginning of the initiation of the first cracks:

Deflection in the middle-span point of beams:



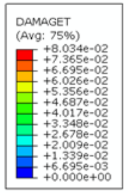
Analysed beams – analysis of beam with no bars

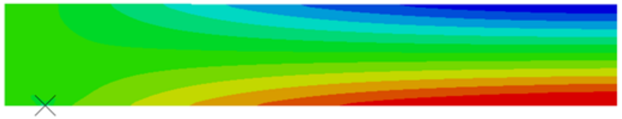


0ϕ28:

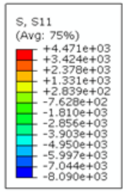
q = 30,0kN/m (just before the first crack appears)

- Stress S11
- DamageT parameter





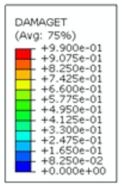
The beginning of the initiation of the first cracks:

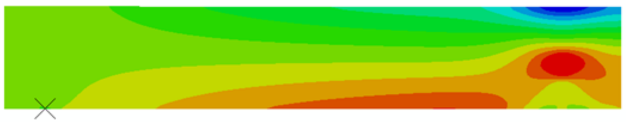


0ϕ28:

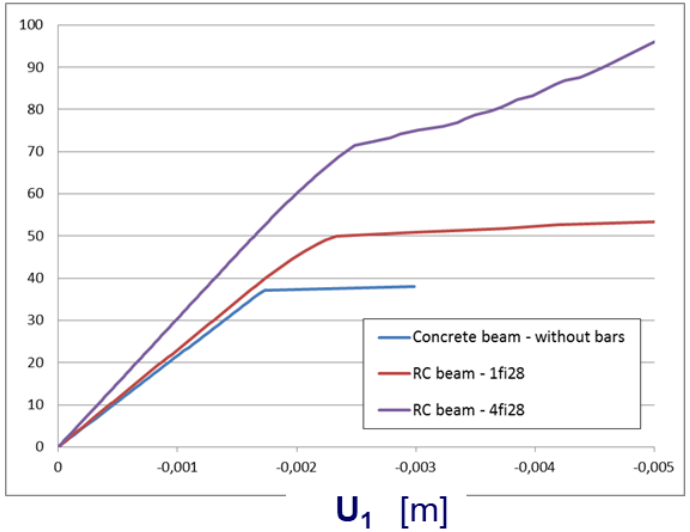
q = 31,5kN/m

- Stress S11
- DamageT parameter

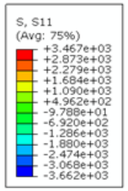




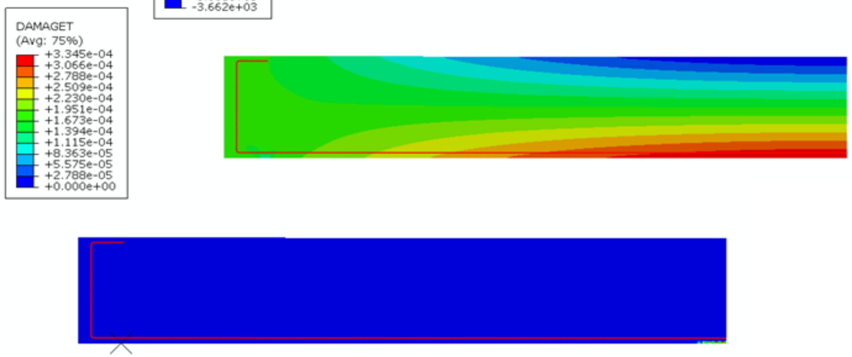
Deflection in the middle-span point of beams:

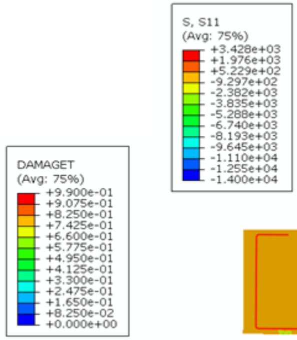


Analysed beams – analysis of beam with 1ϕ28

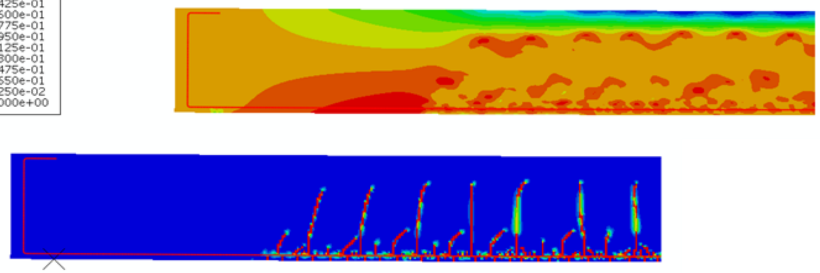


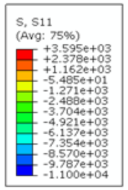
1ϕ28:
q = 30,0kN/m
- Stress S11
- DamageT parameter



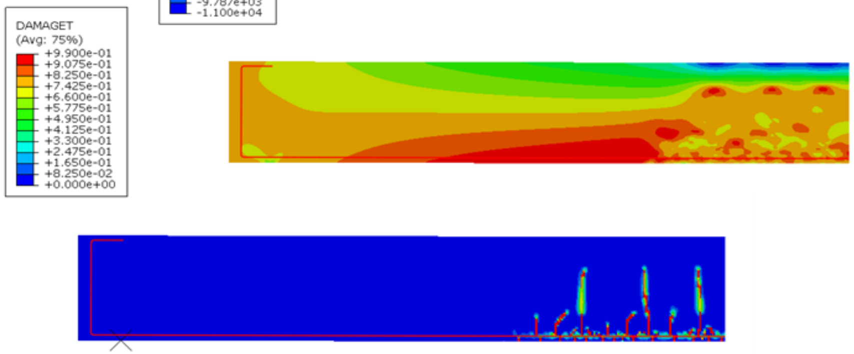


1ϕ28:
q = 70,0kN/m
- Stress S11
- DamageT parameter

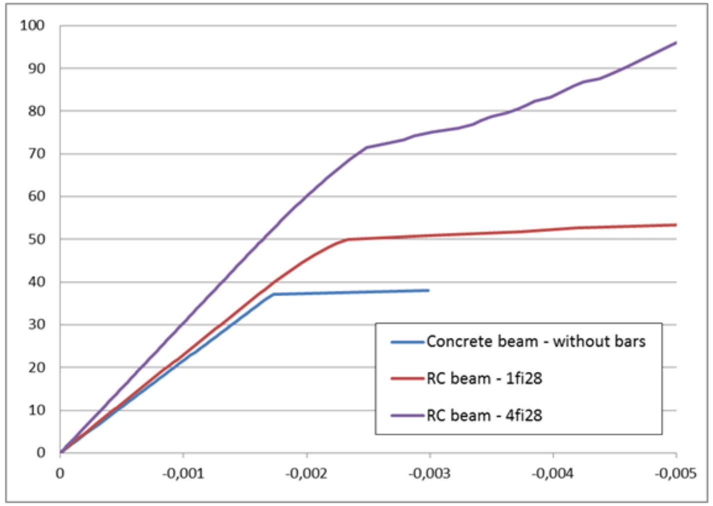




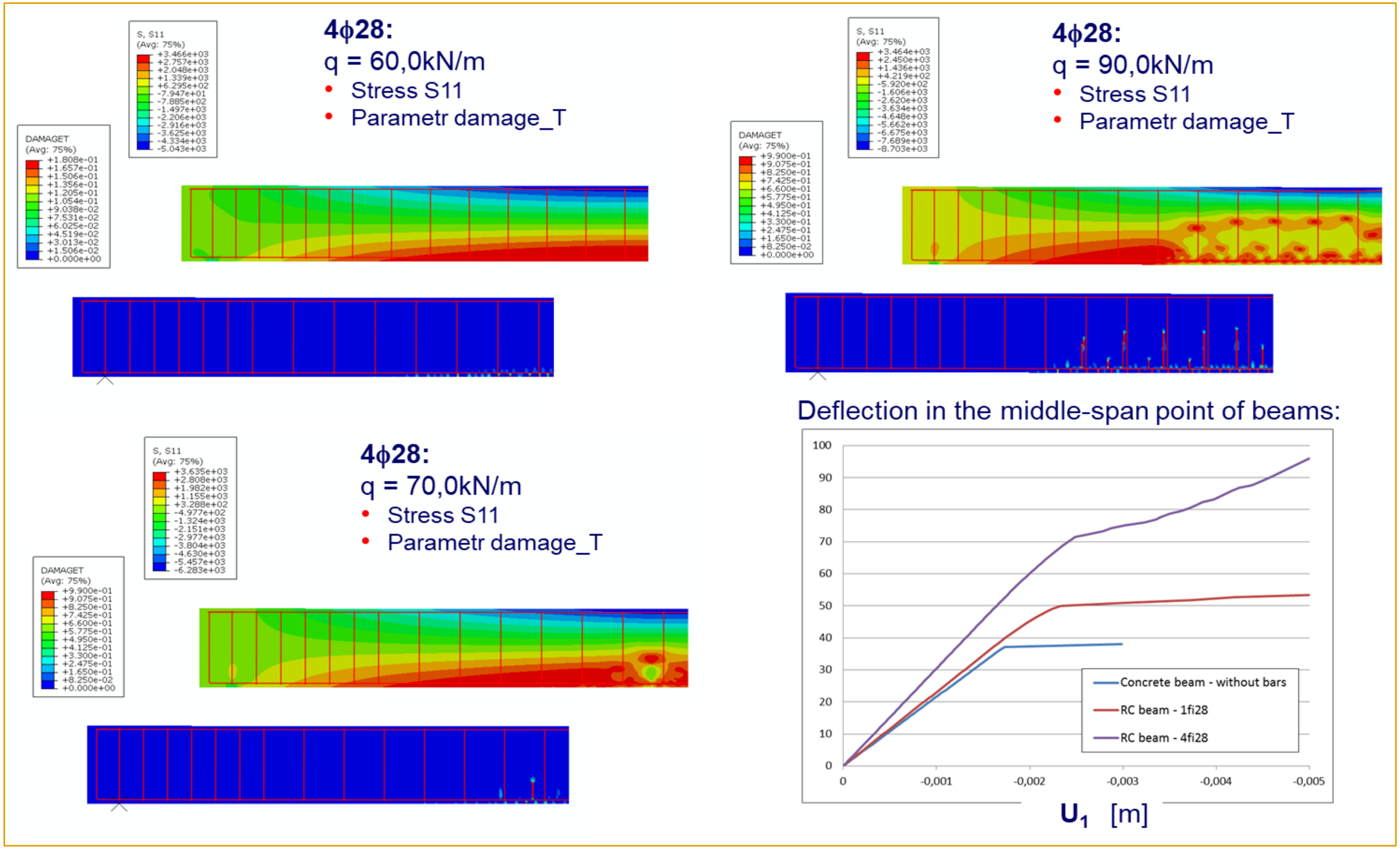
1ϕ28:
q = 50,0kN/m
- Stress S11
- DamageT parameter



Deflection in the middle-span point of beams:



Analysed beams – analysis of beam with 4ϕ28

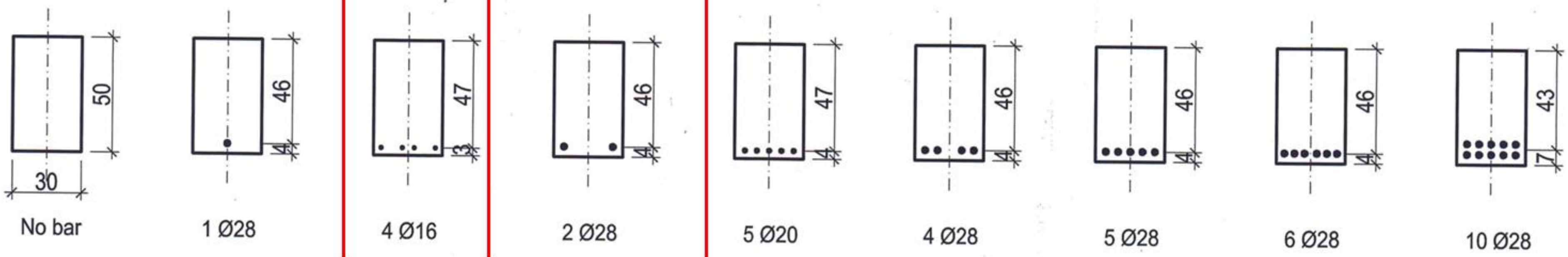


Influence of the reinforcement ratio on the reinforced beam behaviour

Analysed beams – analysis of beams with different reinforcement ratios

The analysis will concern:

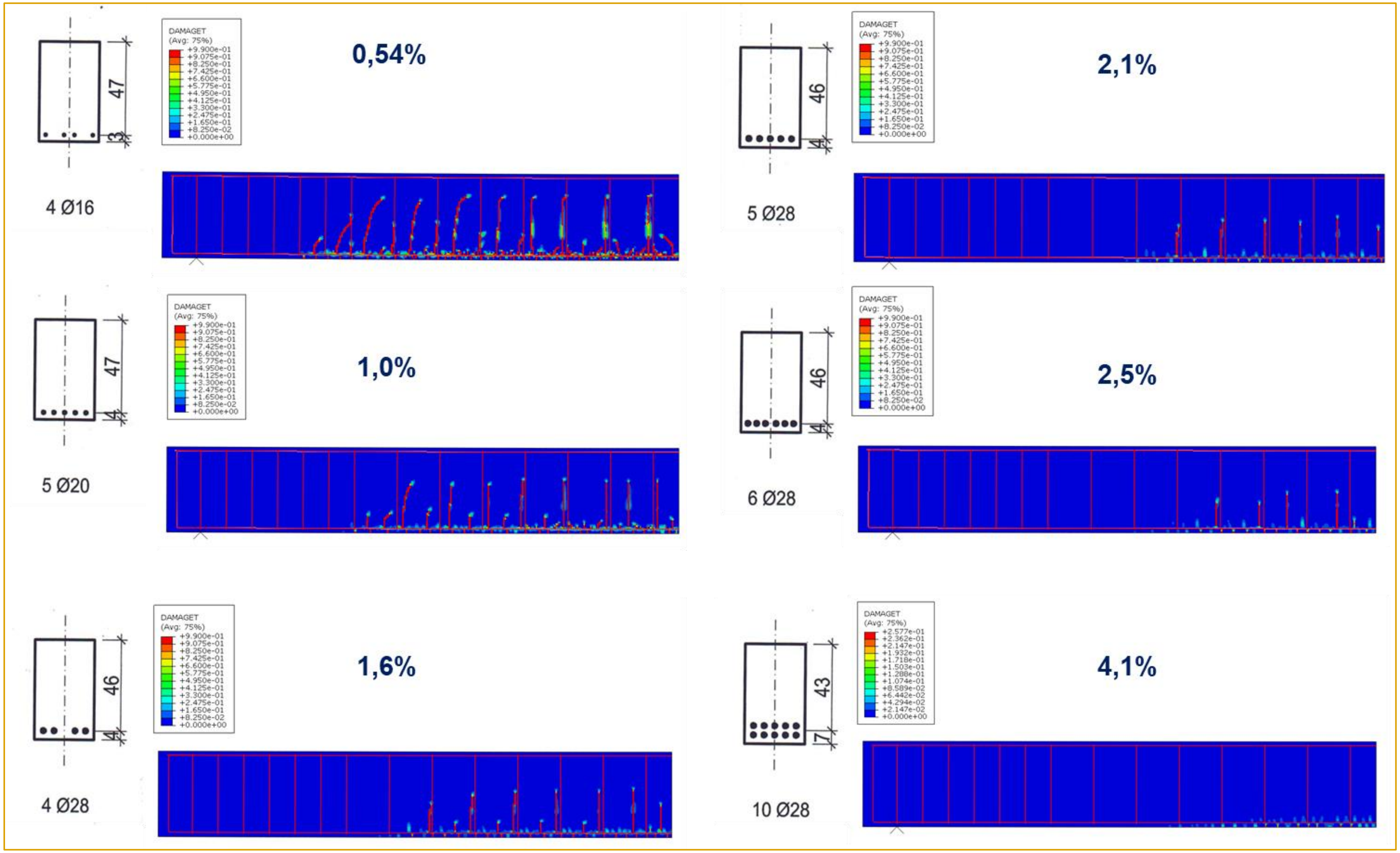
- beams with different reinforcement ratios:



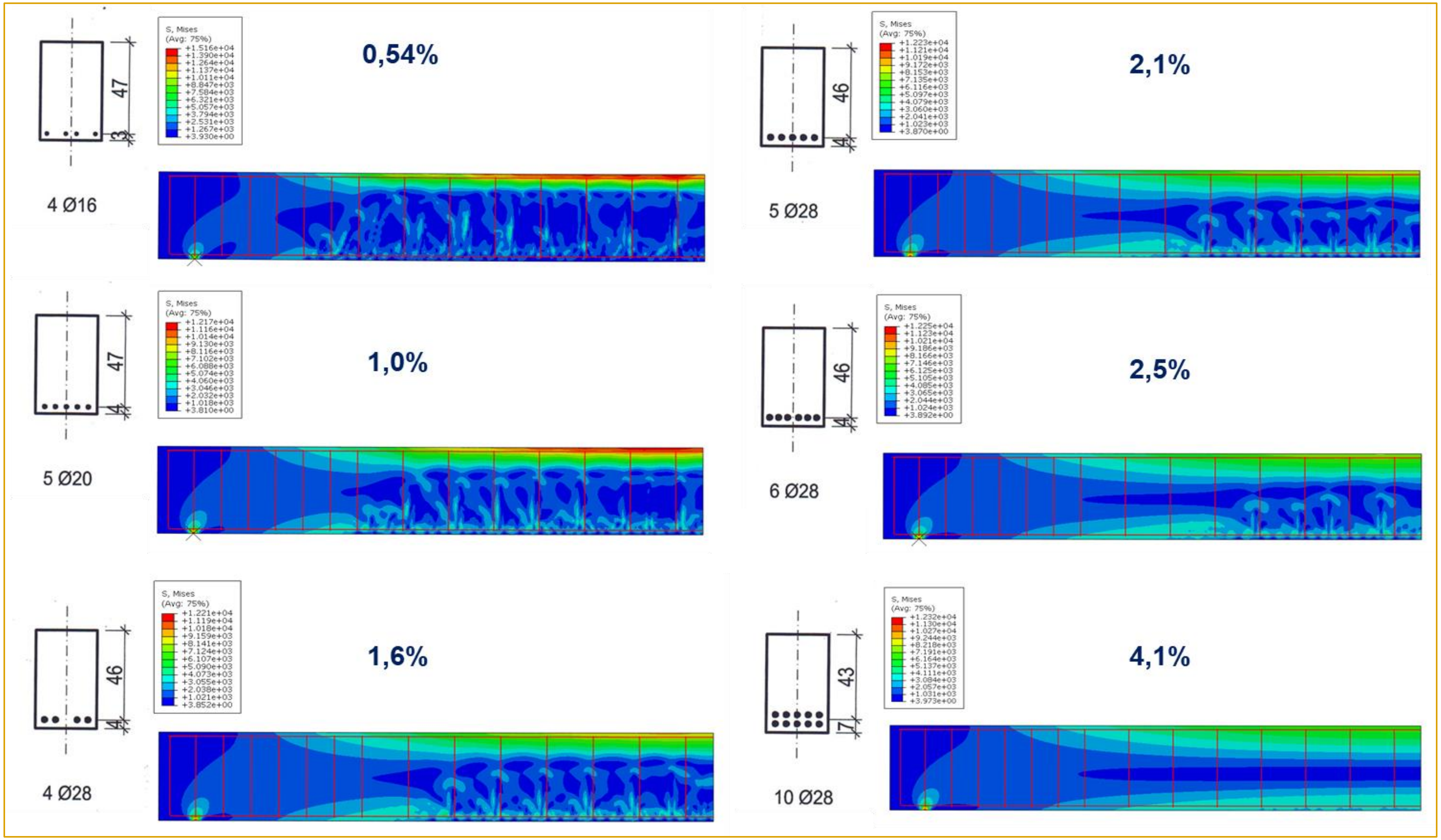
0% < 0,41% < 0,54% < 0,82% < 1,0% < 1,6% < 2,1% < 2,5% < 4,1%

- comparisson of results maps for the load level of q=100kN/m will be presented:
  - Maps of d_t parameter
  - Maps of Misses stresses
  - Maps of S11 stresses

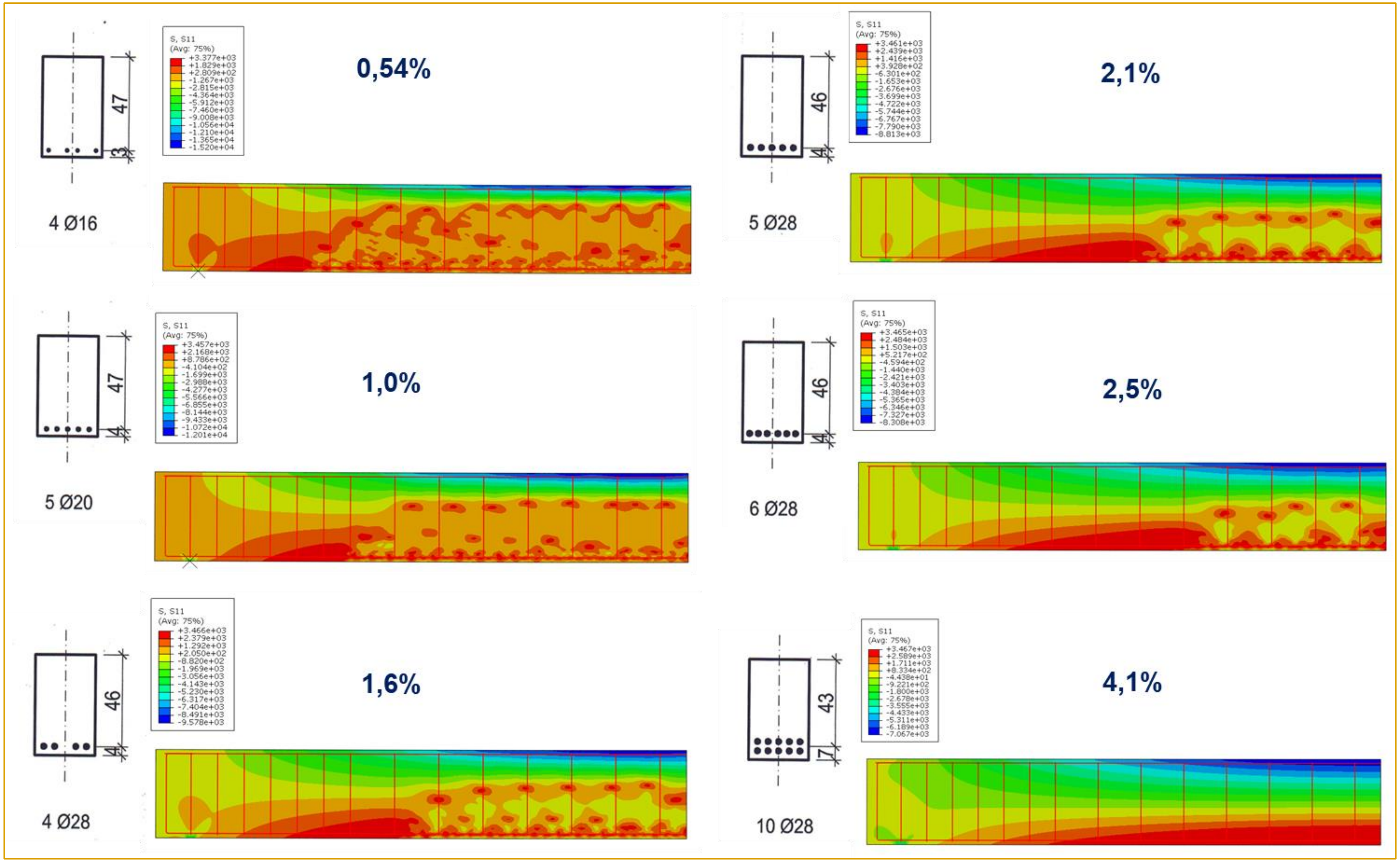
Analysis of dt parameter – LOAD q=100kN/m



Analysis of MISES stresses – LOAD q=100kN/m



Analysis of S11 stresses – LOAD q=100kN/m



2.2.3 Experiment results database

GUIDE – INTRODUCTION

The following videos include assorted results for numerical experiments concerning the simply supported beams under increasing uniformly distributed load (Fig. 1). The beams have different reinforcement layouts that are reflected in the names of the videos.

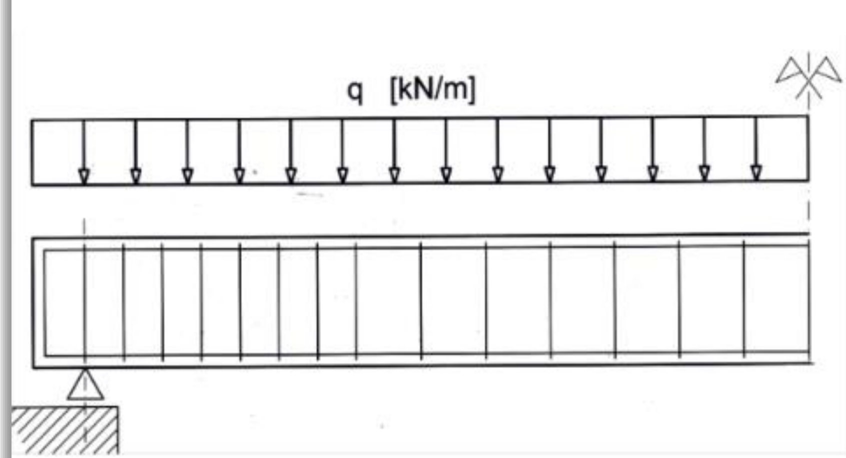


Fig. 1. General layout of the numerical experiment

GUIDE – LEARNING VIDEO NAMES

The video names are according to the following pattern:
{number-of-bars}fi{bar-diameter}-{model-type}, as follows:

0fi0-2D –	concrete beam (no reinforcement), plane stress model
1fi28-2D –	RC beam reinforced with 1 ∅28 bar, plane stress model
2fi28-2D –	RC beam reinforced with 2 ∅28 bars, plane stress model
4fi16-2D –	RC beam reinforced with 4 ∅16 bars, plane stress model
4fi28-2D –	RC beam reinforced with 4 ∅28 bars, plane stress model
5fi20-2D –	RC beam reinforced with 5 ∅20 bars, plane stress model
5fi28-2D –	RC beam reinforced with 5 ∅28 bars, plane stress model
6fi28-2D –	RC beam reinforced with 6 ∅28 bars, plane stress model
10fi28-2D –	RC beam reinforced with 10 ∅28 bars, plane stress model

Explanation for the naming of the videos:

- Name-DAMAGET – a group of figures (as separate tiff files) showing crack development (the concrete cracking state for various load magnitudes given in kN in the file names)
- Name-MISES – a group of figures (as separate tiff files) showing equivalent (Mises) stress development in concrete (the equivalent stress state for various load magnitudes given in kN in file names),
- Name-S11 – two groups of figures (as separate tiff files) showing development of normal stress in concrete ("for_beam) and reinforcement ("for_bars") – the normal stress state for various load magnitudes given in kN in file names,

Explanation for the content of the videos:

- Name-DAMAGET– a film showing the concrete cracking development
- Name-MISES_for_bars – a film showing the equivalent stress development in reinforcement
- Name-MISES_for_beam – a film showing the equivalent stress development in concrete
- Name-S11_for_bars– a film showing the normal stress development in reinforcement
- Name-S11_for_beam– a film showing the normal stress development in concrete

GUIDE – FIGURES AND LEARNING VIDEOS

Figures and films show the elevation (side view) of the half of the beams – up to the symmetry plane in the middle of the beam span.
For the figures showing stress (strain) distribution the sign and the magnitude are marked by colour – Fig. 2.
For the figures showing concrete cracking the damage is marked by colour. Red means material discontinuity (crack) – Fig. 3.

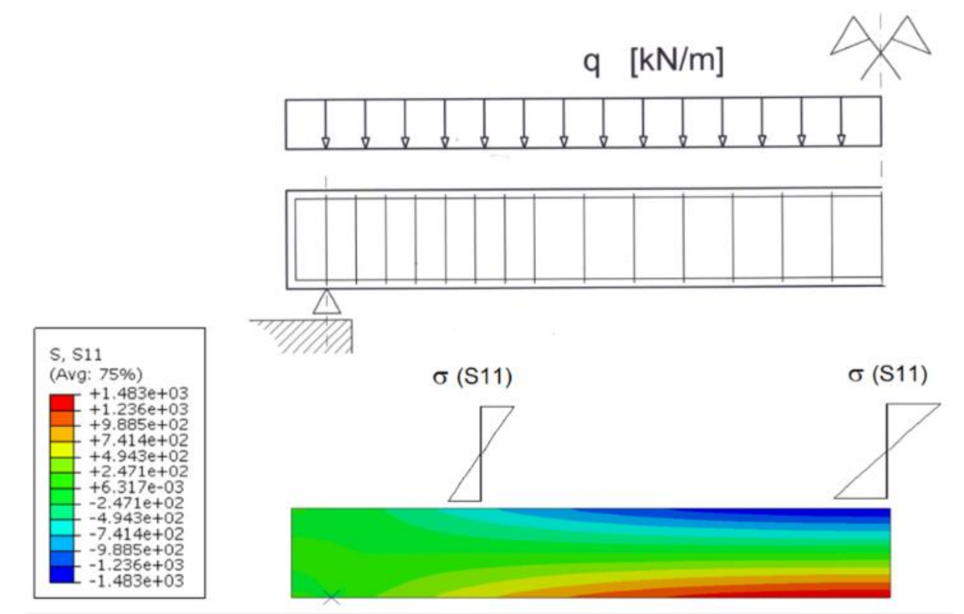


Fig. 2. Strain (stress) mapping

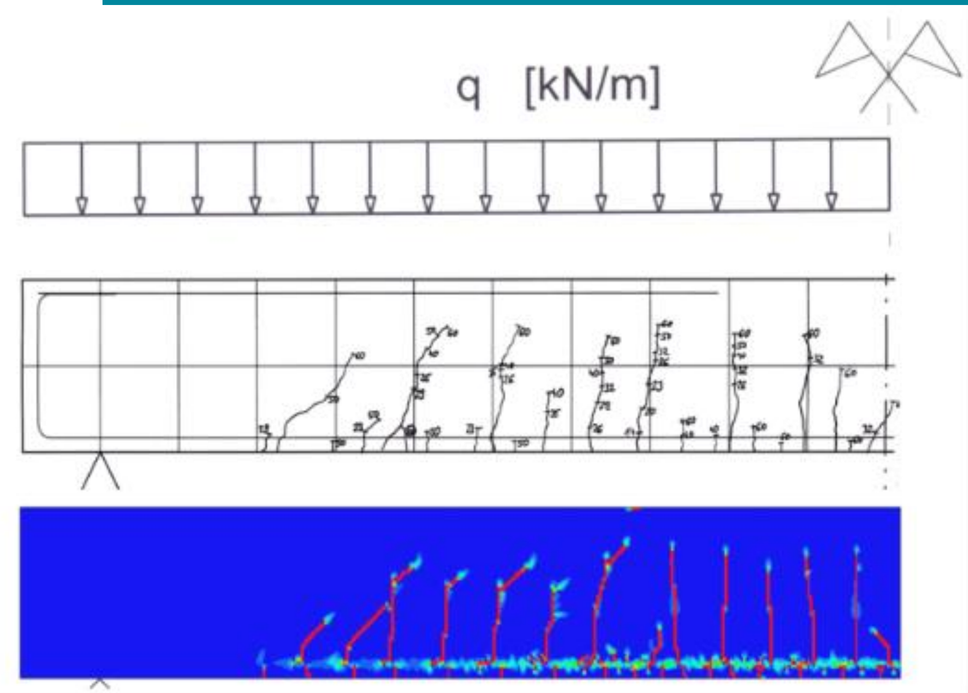


Fig. 3. Concrete crack mapping

LEARNING VIDEOS

The links to the learning videos can be activated by strg+clicking on the underlined title:

1.Learning videos for **0fi0-2D**

- <u>0fi0 2D DAMAGET</u>
- <u>0fi0 2D MISES for beam</u>
- <u>0fi0 2D S11 for beam</u>

2.Learning videos for **1fi28-2D**

- <u>1fi28 2D DAMAGET</u>
- <u>1fi28 2D MISES for bars</u>
- <u>1fi28 2D MISES for beam</u>
- <u>1fi28 2D S11 for bars</u>
- <u>1fi28 2D S11 for bars vs2</u>
- <u>1fi28 2D S11 for beam</u>

3.Learning videos for **2fi28 2D**

- <u>2fi28 2D DAMAGET</u>
- <u>2fi28 2D MISES for bars</u>
- <u>2fi28 2D MISES for beam</u>
- <u>2fi28 2D S11 for bars</u>
- <u>2fi28 2D S11 for bars</u> vs2
- <u>2fi28 2D S11 for beam</u>

4.Learning videos for **4fi16 2D**

[4fi16 2D DAMAGET]

[4fi16 2D MISES for bars]

[4fi16 2D MISES for beam]

[4fi16 2D S11 for bars]

[4fi16 2D S11 for bars]

[4fi16 2D S11 for beam]

5.Learning videos for **4fi28 2D**

[4fi28 2D DAMAGET]

[4fi28 2D MISES for bars]

[4fi28 2D MISES for beam]

[4fi28 2D S11 for bars]

[4fi28 2D S11 for bars] vs

[4fi28 2D S11 for beam]

6.Learning videos for **5fi20 2D**

[5fi20 2D DAMAGET]

[5fi20 2D MISES for bars]

[5fi20 2D MISES for beam]

[5fi20 2D S11 for bars]

[5fi20 2D S11 for bars vs2]

[5fi20 2D S11 for beam]

7.Learning videos for **5fi28 2D**

- 5fi28 2D DAMAGET
- 5fi28 2D MISES for bars
- 5fi28 2D MISES for beam
- 5fi28 2D S11 for bars
- 5fi28 2D S11 for bars vs 2
- 5fi28 2D S11 for beam

8.Learning videos for **6fi28 2D**

- 6fi28 2D DAMAGET
- 6fi28 2D MISES for bars
- 6fi28 2D MISES for beam
- 6fi28 2D S11 for bars
- 6fi28 2D S11 for bars v2
- 6fi28 2D S11 for beam

9.Learning videos for **10fi28 2D**

- 10fi28 2D DAMAGET
- 10fi28 2D MISES for bars
- 10fi28 2D MISES for beam
- 10fi28 2D S11 for bars
- 10fi28 2D S11 for bars v2
- 10fi28 2D S11 for beam

2.2.4 Application in vocational training

INTRODUCTORY INFORMATION

Digital construction applications and tools for use in vocational training

Numerical experiment as an aid in teaching on the reinforced concrete (RC) beam behaviour

1. General concept of presenting numerical experiment data in vocational training

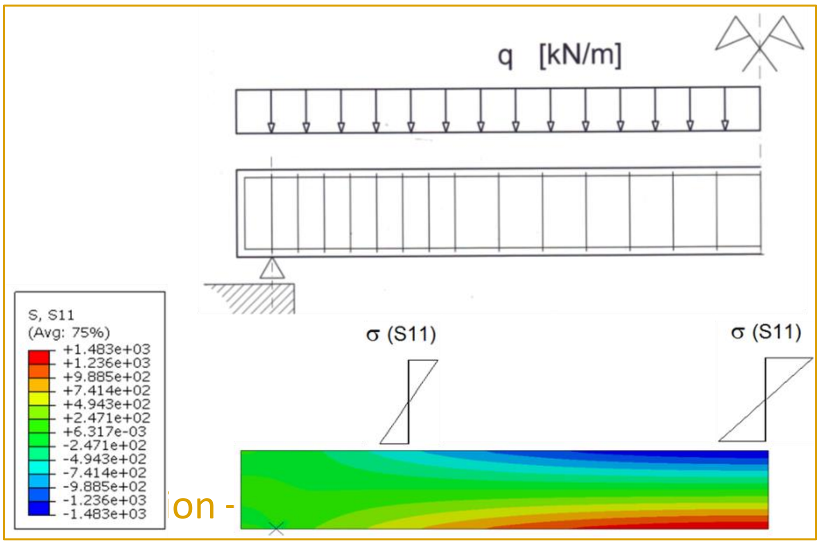
- introduction on how to interpret numerical experiment results
- explanation on physical phenomenon
- graphics (pictures, films) based on numerical experiments completed
- summary / conclusions

2. Phenomena that may be explained with an aid of the numerical experiment completed

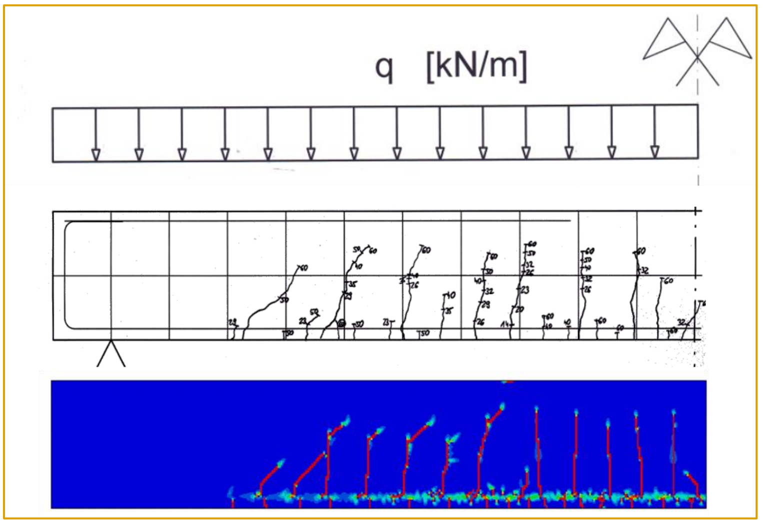
- behaviour of concrete and reinforced concrete (RC) beams in bending
- failure of an RC beam in bending due to steel yielding
- degree of reinforcement impact on load bearing capacity in bending
- main reinforcement diameter impact on concrete cracking in bending

Introduction stress (strain) maps

The sign and the magnitude are marked by colour:



The damage is marked by colour:



3. Behaviour of concrete and reinforced concrete (RC) beams in bending

The aim is:

- to show the behaviour and failure mechanism of a concrete beam without reinforcement as a consequence of concrete properties
- to show the change of the behaviour and failure mechanism after introduction of reinforcing bars

Numerical experiment-based support:

- maps of stress and strain of both types of beams for comparable load magnitudes
- M-u curves (bending moment – deflection) at L/2
- shows failure mechanism of both types of beams

4. Behaviour of concrete and reinforced concrete (RC) beams

- strain / normal stress distribution in a beam in bending
- concrete s-e characteristics
- characteristics of the concrete beam
- normal stress / cracking – maps – the concrete beam
- normal stress / cracking – variations – the concrete beam
- characteristics of steel (compared to characteristics of concrete)
- characteristics of the RC beam

- normal stress / cracking – maps – the RC beam
- normal stress / cracking – variations – the RC beam
- comparison of M-u curves (bending moment – deflection) at L/2 for both beams
- summary / conclusions

5. Failure of an RC beam in bending due to steel yielding

The aim:

- to show the mechanism associated with yielding of reinforcing steel in tension in the midspan

Numerical experiment-based support:

- maps of stress and strain for both types of failure mechanism
- films on both types' failure mechanism

6. Failure of an RC beam in bending

- changes in the distribution of internal forces in the cross-section of an RC beam corresponding to both failure mechanisms
- characteristics of the RC beams
- strain / normal stress maps of the beam collapsing due to concrete failure for several load levels
- strain / normal stress maps of the beam collapsing due to steel failure for several load levels
- comparison of strain / normal stress maps for both RC beams (both types of failure mechanism) at failure
- comparison of M-u curves at L/2 illustrating the nature of failure – a diagrams with descriptions referring to maps
- summary / conclusions

7. Degree of reinforcement impact on RC beam behaviour in bending

The aim is:

- to show the change of the neutral axis location
- to show the change of the load bearing capacity
- Numerical experiment-based support:
- maps of strain / normal stress for different degrees of reinforcement
- films on failure for the representative beams

8. Degree of reinforcement impact on RC beam behaviour

- change of neutral axis location in a RC beam in bending
- distribution of internal forces in the cross-section of a reinforced concrete flexural beam in the state corresponding to the exhaustion of the steel resistance
- characteristics of the RC beams
- stress maps of the beams for several load levels (indicating different locations of the neutral axis and different levels of breaking load)
- synchronous films of experiments - stress distributions
- comparison of M-u curves for specimens
- summary / conclusions

8. Main reinforcement diameter impact on cracking of concrete of RC beam in bending

The aim is:

- to show the change of concrete cracking pattern

Numerical experiment-based support:

- maps of strain / normal stress for different reinforcement diameters
- films on cracking of the representative beams

9. Main reinforcement diameter impact on cracking of concrete of RC beam in bending

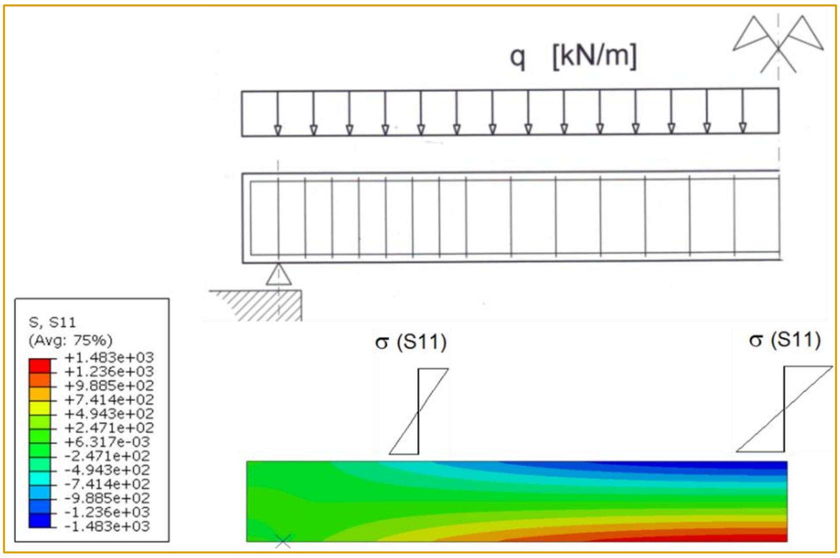
- deformability of tensile concrete in the vicinity of the reinforcing bar
- characteristics of the RC beams
- strain maps for the tested beams for several load levels (showing different cracks pattern)
- synchronous films of experiments - strain distributions
- comparison of max. crack width as a function of M for the tested beams (a diagram with descriptions referring to figures)
- summary/conclusions

BEHAVIOUR OF CONCRETE AND RC BEAM IN BENDING

Digital construction applications and tools for use in vocational training
Example 1 of application of numerical experiment:
Behaviour of concrete and reinforced concrete (RC) beams in bending

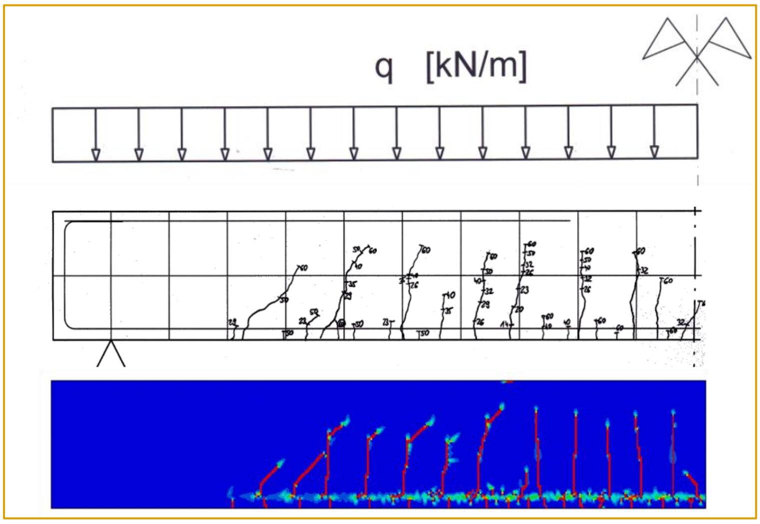
Introduction stress (strain) maps

The sign and the magnitude are marked by colour



Introduction – cracking maps

The damage is marked by colour



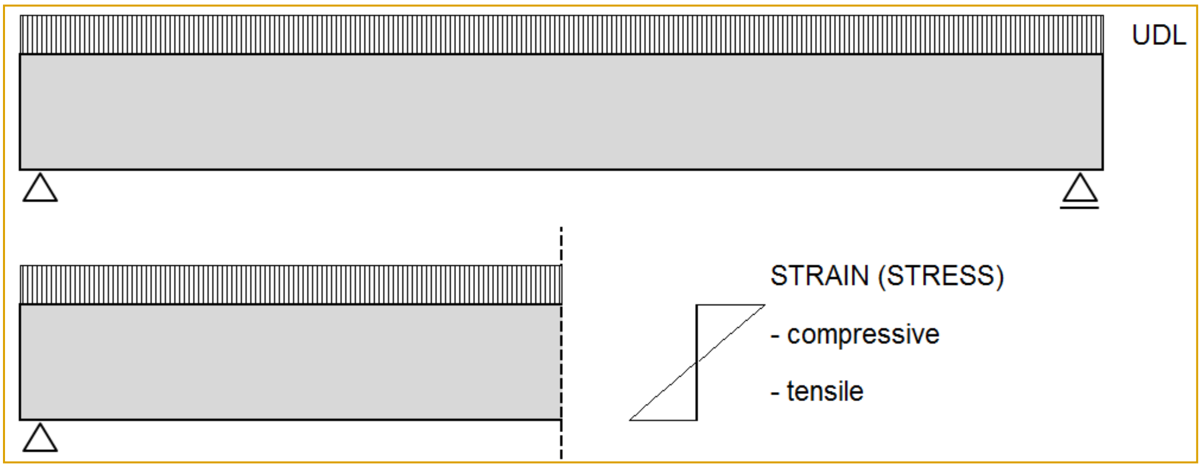
The aim is:

- to show the behaviour and failure mechanism of a concrete beam without reinforcement as a consequence of concrete properties
- to show the change of the behaviour and failure mechanism after introduction of reinforcing bars

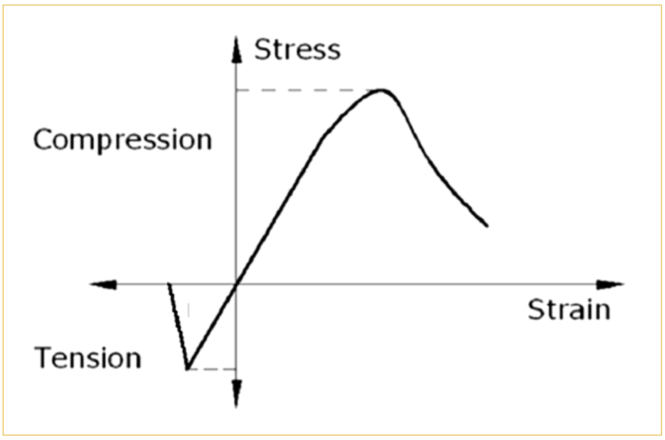
Numerical experiment-based support:

- maps of stress and strain of both types of beams for comparable load magnitudes
- M-u curves (bending moment – deflection) at L/2
- films on failure mechanism of both types of beams

Strain / normal stress distribution in a beam in bending



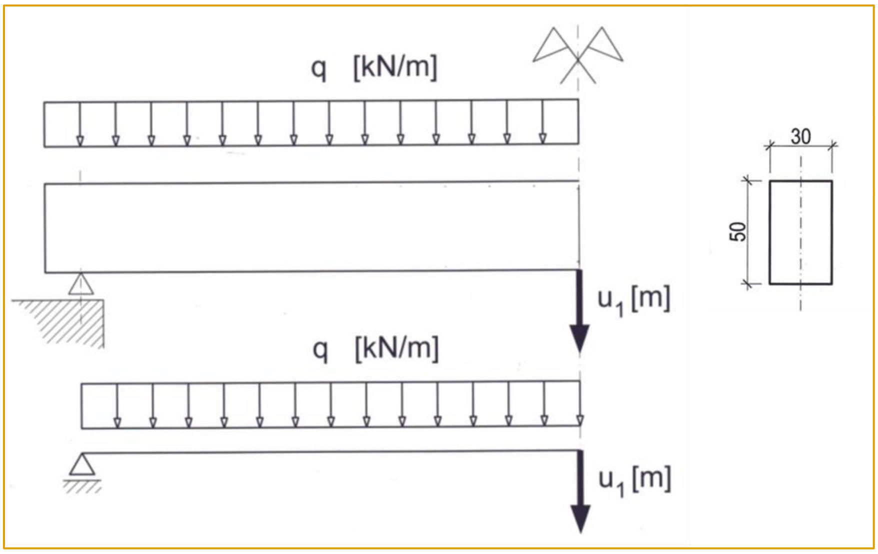
Concrete s-e characteristics



The concrete strength in tension is about 10 times smaller than the concrete strength in compression.

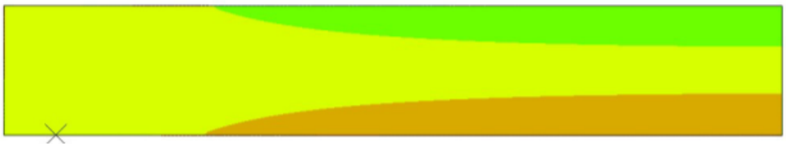
Characteristics of the concrete beam

L_t=6.0 m
C50/60, f_{ck}=50 MPa, E_c=37 GPa



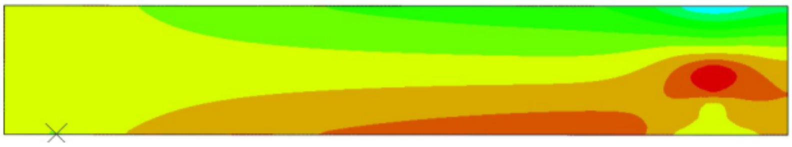
Normal stress / cracking – maps – the concrete beam

Elastic range: Stress



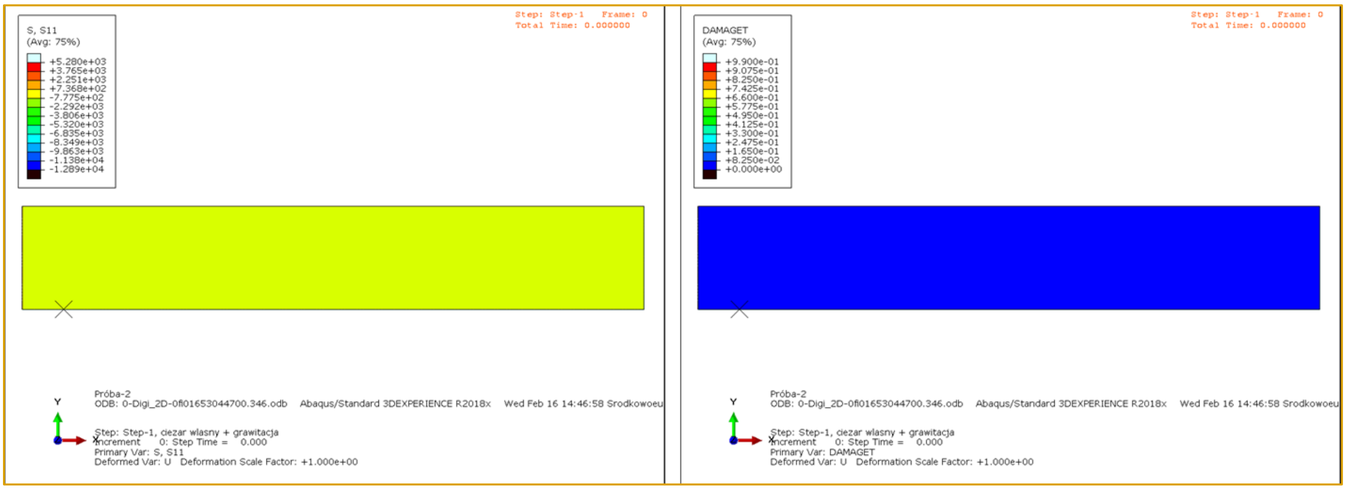
Cracks

Failure: Stress

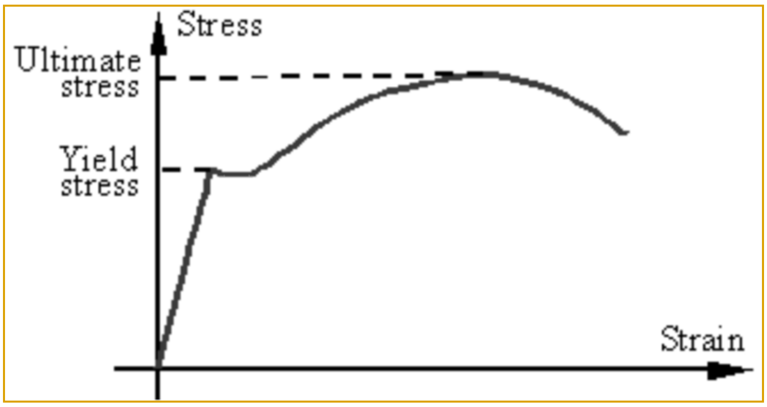


Cracks

Normal stress / cracking – variations – the concrete beam



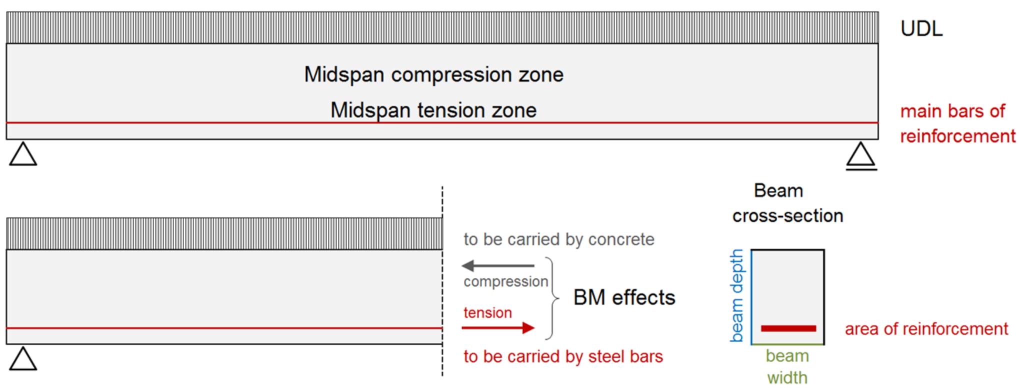
Characteristics of steel (compared to characteristics of concrete)



The yield stress and the ultimate stress values for steel do not depend on the stress sign

The RC beam behaviour in bending

The RC beam behaviour in bending



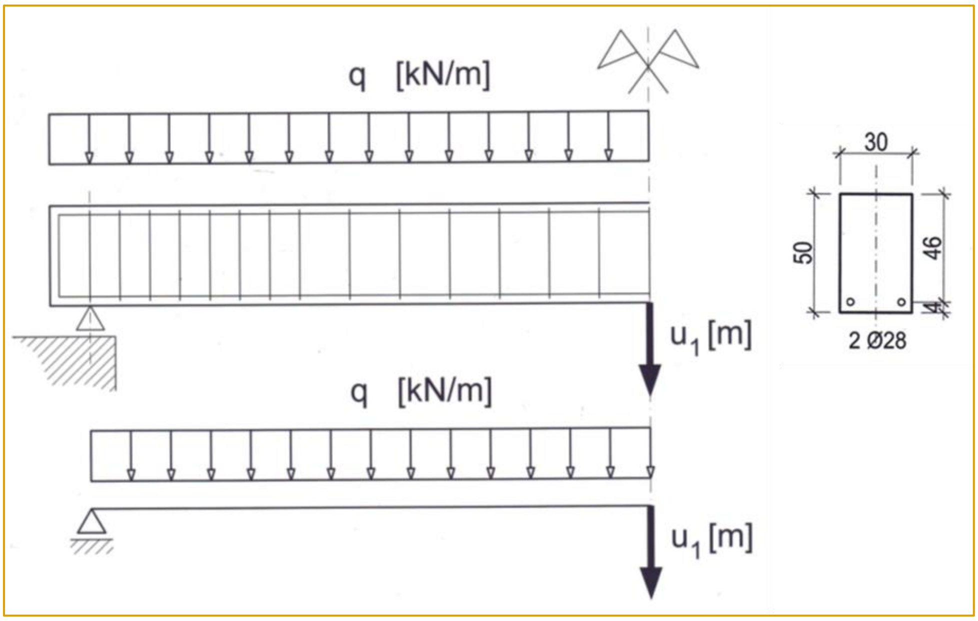
Load carrying capacity factors:

- strength of concrete
- beam cross-sectional dimensions
- strength of steel
- number of steel bars

Characteristics of the RC beam

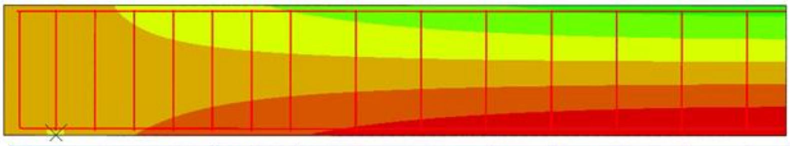
L_t=6.0 m

C50/60, f_{ck}=50 MPa, E_c=37 GPa / B500SP, f_{yk}=500 MPa, E_a=210 GPa

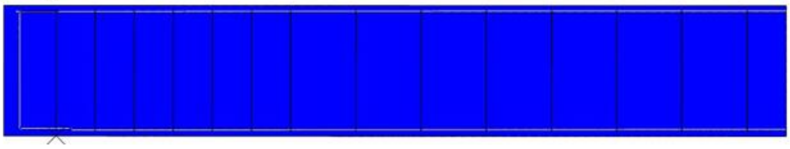


Normal stress / cracking – maps – the RC beam

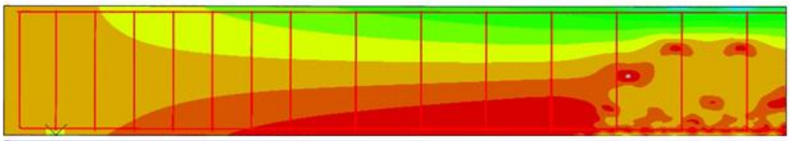
Elastic range: Stress



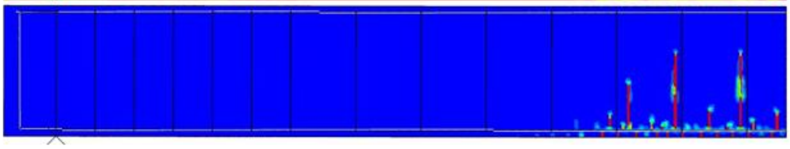
Cracks



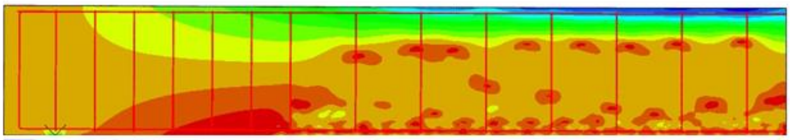
Cracked: Stress



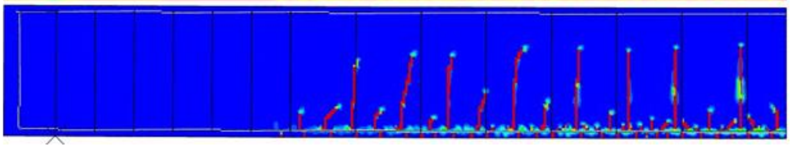
Cracks



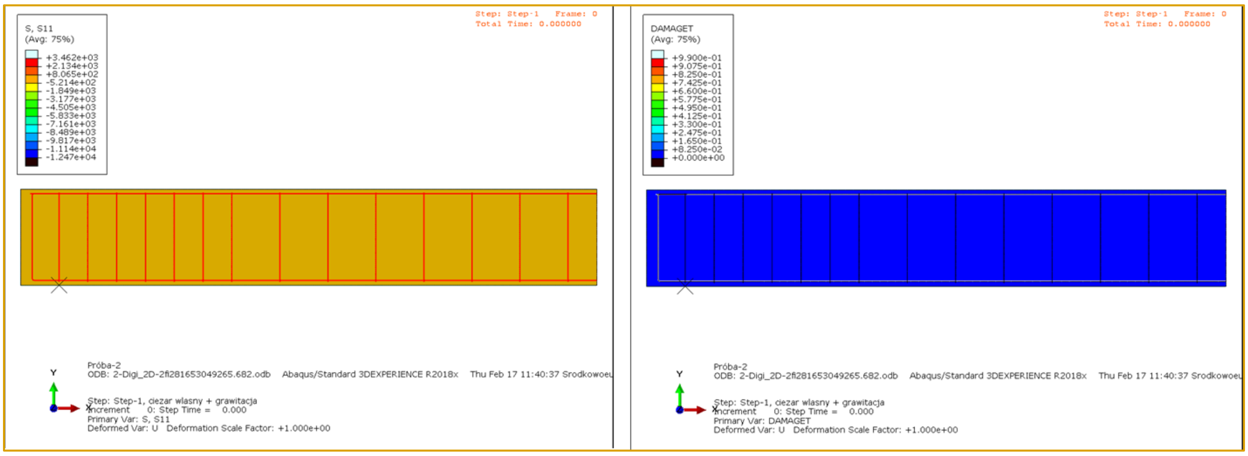
Failure: Stress



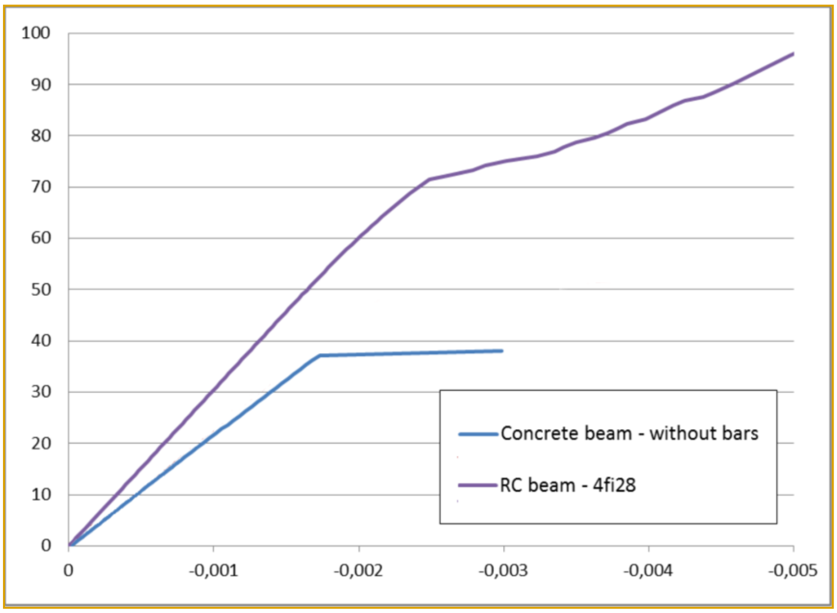
Cracks



Normal stress / cracking – variations – the RC beam



Comparison of M-u curves (bending moment – deflection) at L/2 for both beams



Summary / conclusions

- A beam made of concrete without reinforcement is inefficient – concrete weakness in tension significantly limits its bearing capacity.
- In the case of the concrete beam cracking usually equals failure.
- Reinforcement „replaces" concrete where it is in tension and improves beam behaviour (stiffness and bearing capacity) in bending.
- In the case of the reinforced concrete (RC) beam cracking is usually a consequence of the way it carries loads.
- Concrete cracks endanger structural durability if they are too wide (corrosion of steel bars and concrete)

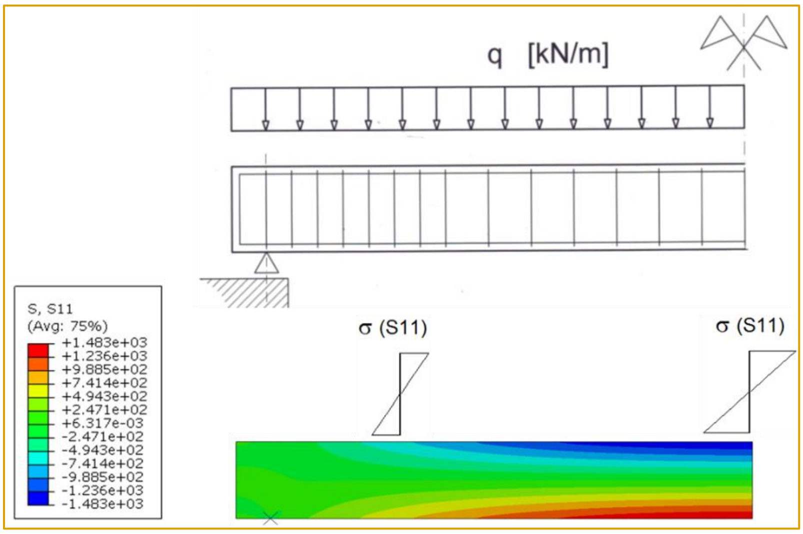
Digital construction applications and tools for use in vocational training

Example 2 of application of numerical experiment:

Failure of an RC beam in bending due to yielding of steel

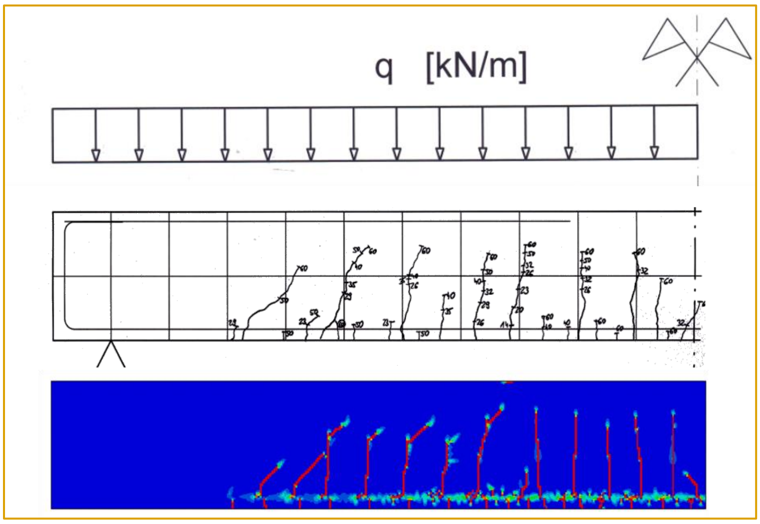
Introduction stress (strain) maps

The sign and the magnitude are marked by colour



Introduction – cracking maps

The damage is marked by colour



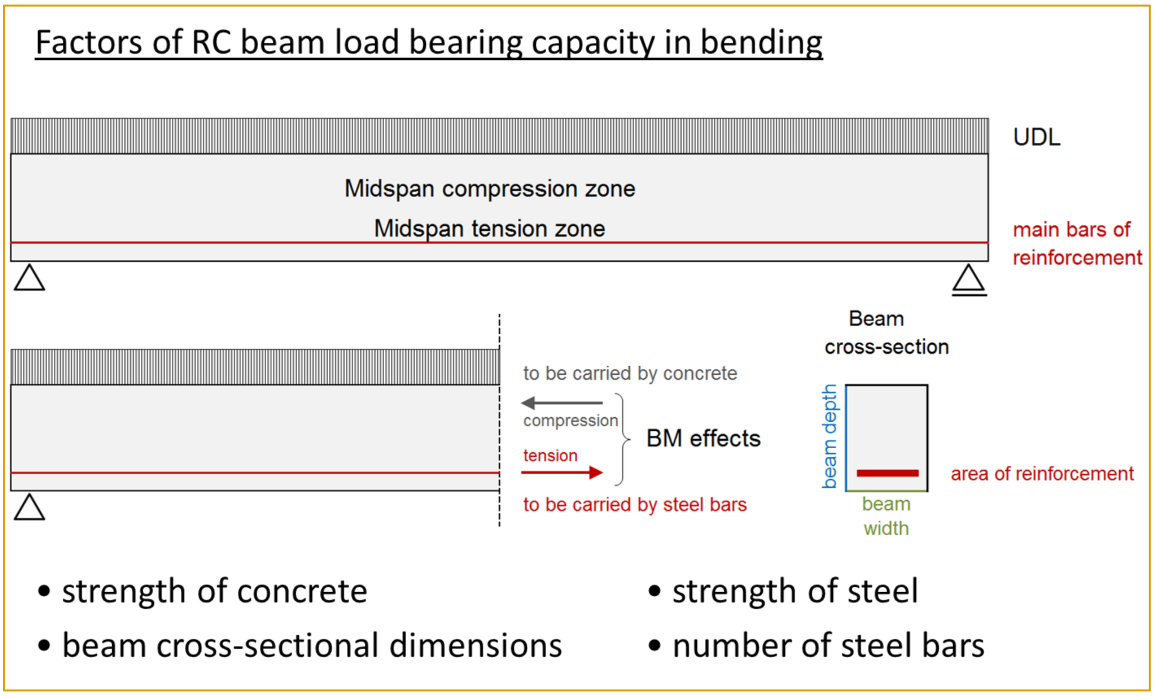
The aim:

- to show the mechanism associated with yielding of reinforcing steel in tension in the midspan

Numerical experiment-based support:

- maps of stress and strain for both types of failure mechanism
- films on both types' failure mechanism

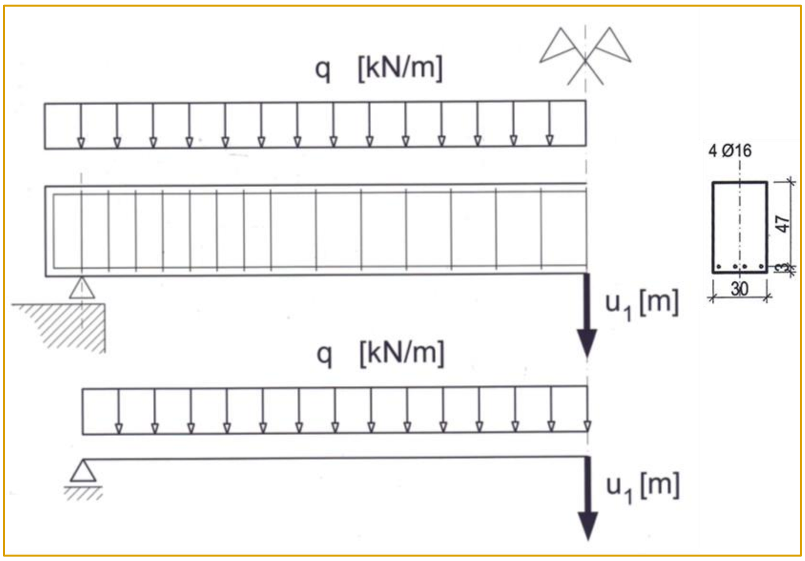
Factors of RC beam load bearing capacity in bending



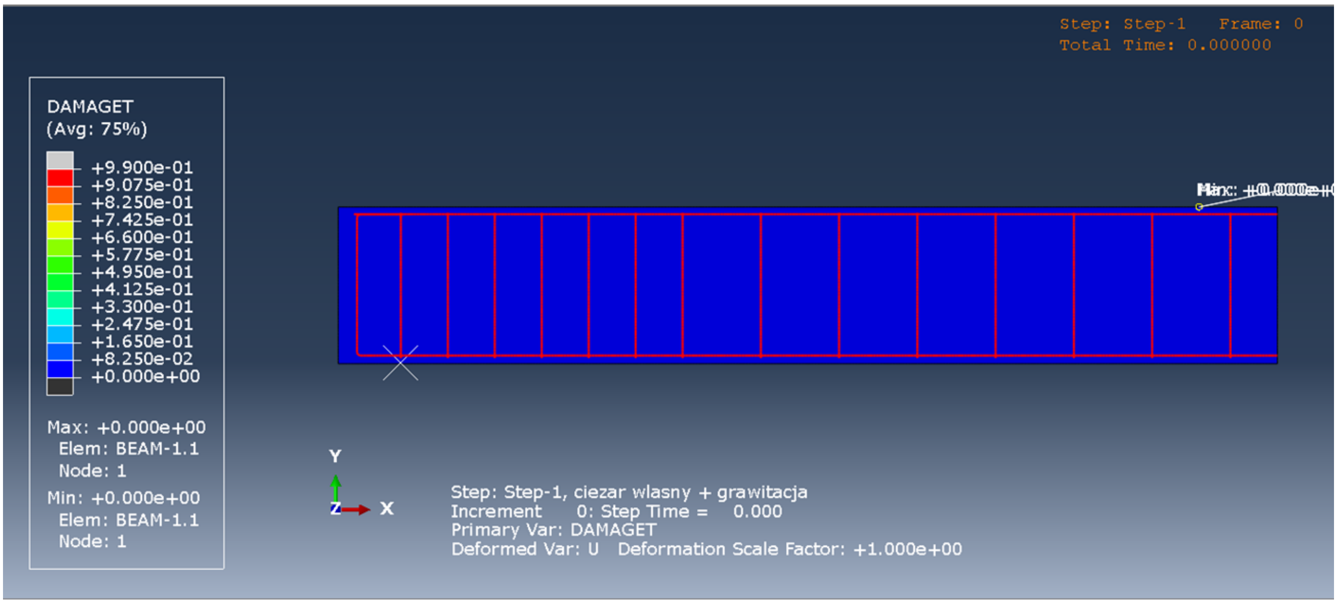
Characteristics of the RC beams analysed

Lt=6.0 m

C50/60, fck=50 MPa, Ec=37 GPa / B500SP, fyk=500 MPa, Ea=210 GPa

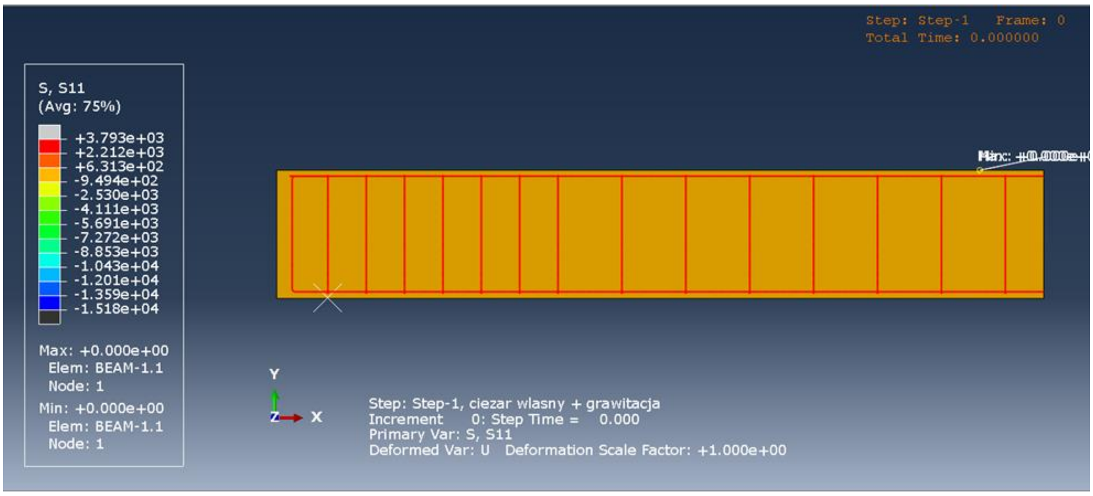


Crack pattern in failure due to yielding of steel bars

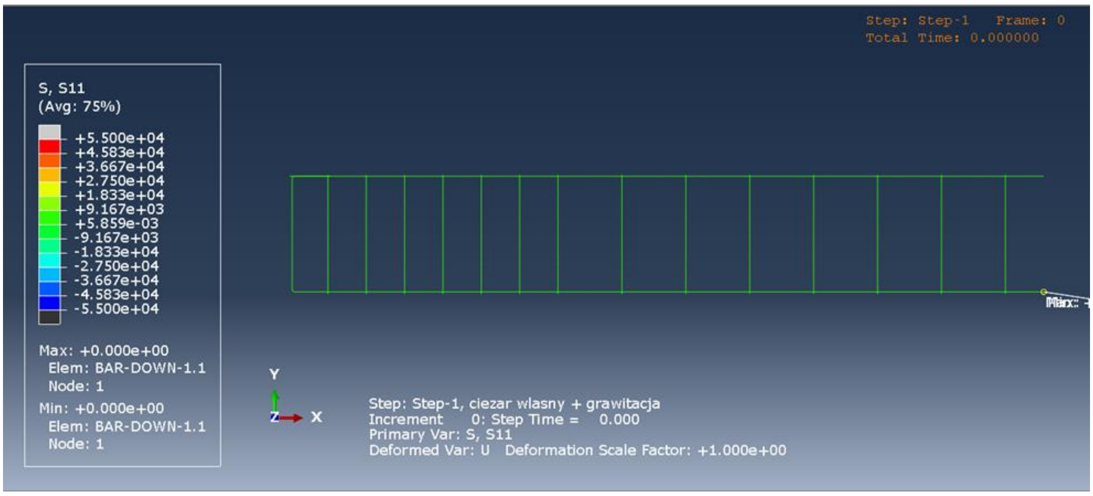


Normal stress [kPa] in:

Concrete



Steel bars (4 ⌀16)



Summary / conclusions

- A simply supported RC beam may fail in the midspan due to excessive bending moment.
- The failure may be caused due to insufficient load bearing capacity of steel bars in tension.
- The insufficient load bearing capacity of steel bars in the tension zone may be caused by:
  – insufficient steel strength or
  – insufficient number of steel bars
- The failure due to insufficient load bearing capacity of steel bars in the tension is the desired failure mechanism in design practice.

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