Digital construction applications and tools for use in vocational training

DigiCon

Co-funded by the Erasmus+ Programme of the European Union

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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".

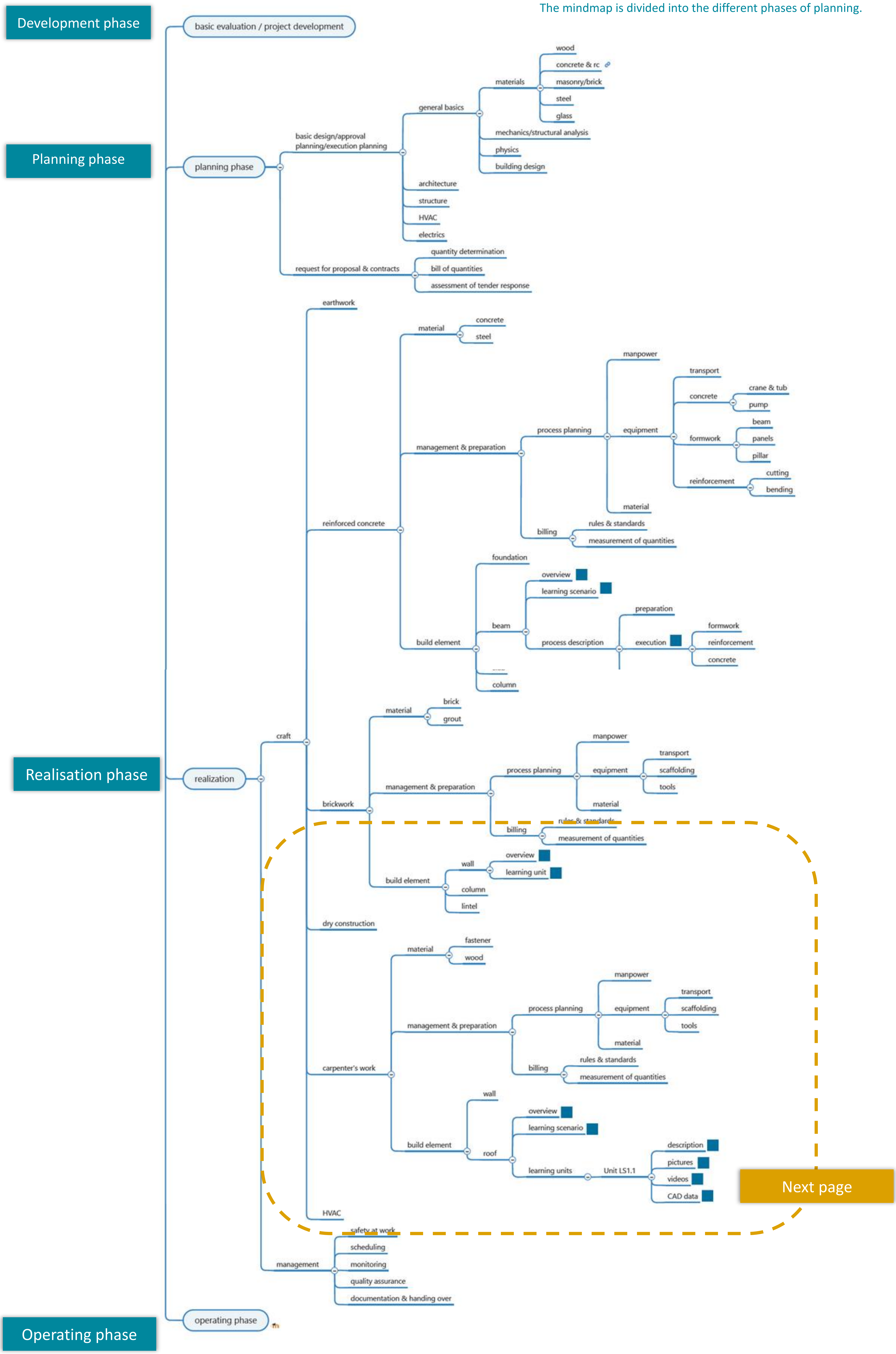
The actual objective, namely that various tasks in the construction process along the learning scenarios, based on the action scenarios, are practiced in a learning application, has no link with the term "digital construction file". For this reason, the term "digital construction file" will no longer 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.

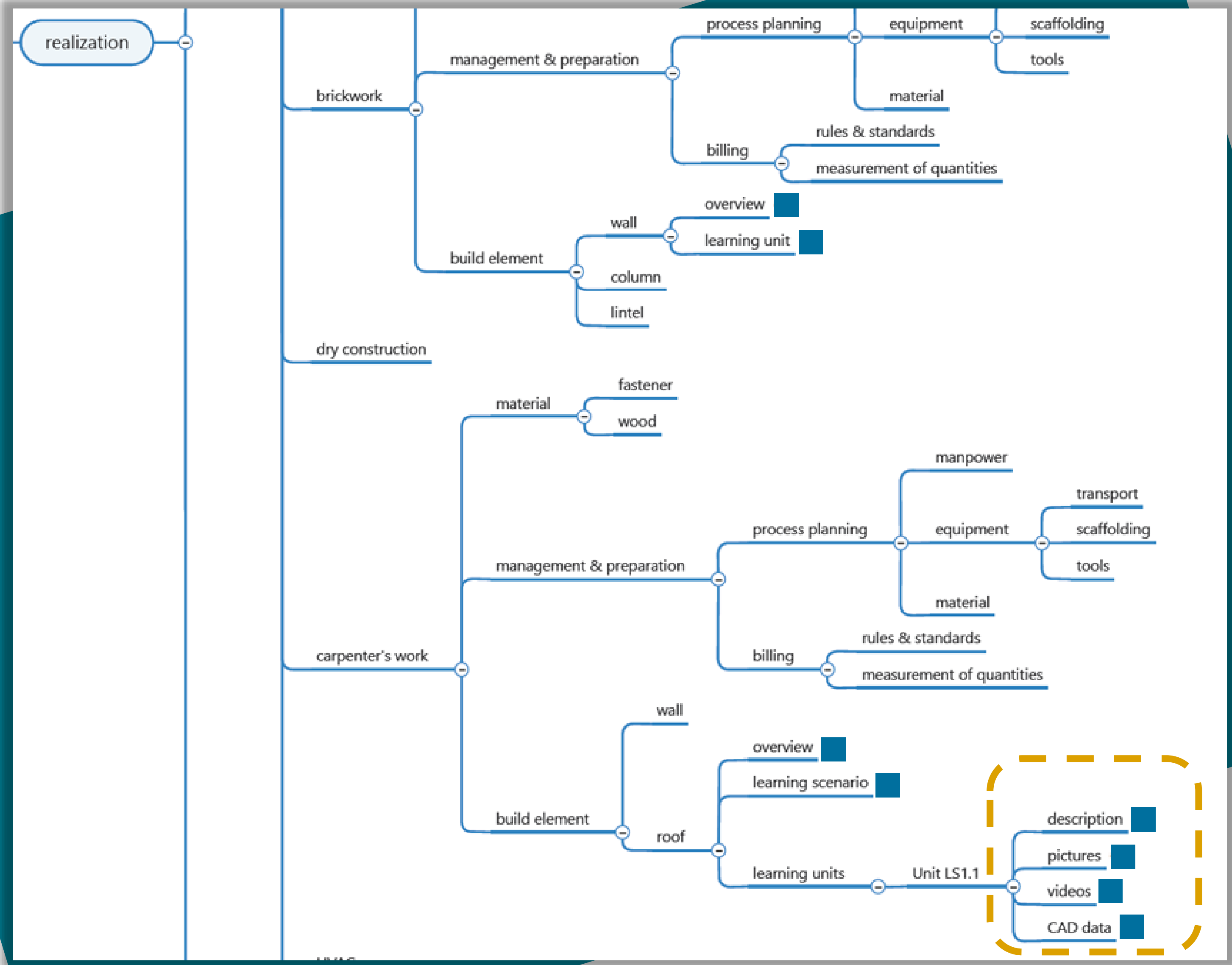
THE CREATED MINDMAP is the link between the action scenarios, the learning scenarios and manual for handling the learning materials and designing e-learning systems, and was developed instead of the "digital construction file".

The following screenshots shell give an overview about the constructed MINDMAP. It can be reached by the following LINK:

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.





By clicking on the blue boxes, you can access the learning content.

STRUCTURE AND LEARNING CONTENTS THROUGH OPEN ONLINE ACCESS

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

Due to access restrictions at the HTW Moodle, the content of the material is made public under the following link and has open access:

STRG + CLICK → Digicon Start (bfw-bb.de)

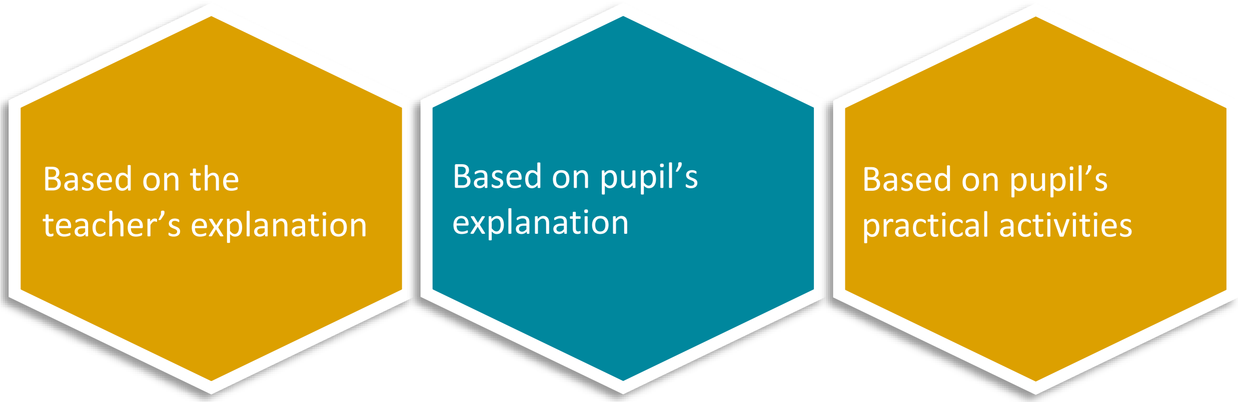
Users can then integrate the mindmap and all developed learning content into their own learning environments!

3. LEARNING VIDEOS AND AR APPLICATIONS

The following pages show the developed learning videos and AR applications. It shows the *Numerical experiment as a teaching aid in vocational training on building structures (2.1)* as well as *videos on learning scenarios (2.2)*.

These support the visualisation of specific work steps in complex processes. Where applications are too expensive or impractical for use in teaching, simulations can be used. The simulations for such applications were documented in the form of videos and can be used in the learning scenarios.
With the AR applications, there is an additional interactive component - in simulated processes, the trainees can operate devices, read and interpret data on the basis of which specific actions can be carried out. These formats were developed in close communication with the VET partners to ensure the accuracy of fit. The applications were tested in test runs with teachers and Apprentices tested and positively evaluated.

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].

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[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.

3.1 Learning Videos on Learning Scenarios

DigiCon aimed to increase the quality of training in the use of digital tools in construction. The project administration has consulted with other technical schools and employers on the objectives and results, paying attention to their needs in the creation of videos.

This mainly relates to the skills of a future employee. Both lesson plans and the accompanying instructional videos were tested and evaluated twice with the learners.

The videos are also part of the created mindmap and illustrate the EXECUTION of the PLANNING PHASE.

They represent the following learning steps:

1. Formwork preparation and assembly
2. Preparation of reinforcement
3. Installation of reinforcement
4. Laying and compacting of concrete mix
5. Dismantling of the formwork
6. Final acceptance of the beam made

The learning videos on the learning scenarios (1-6)

can be reached via THE FOLLOWING LINK:

STRG + CLICK

https://bfw-bb.de/digicon/02_videod.html?usp=sharing

3.2 Videos on a numerical experiment as a teaching aid in vocational training on building structures

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.

3.2.1 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

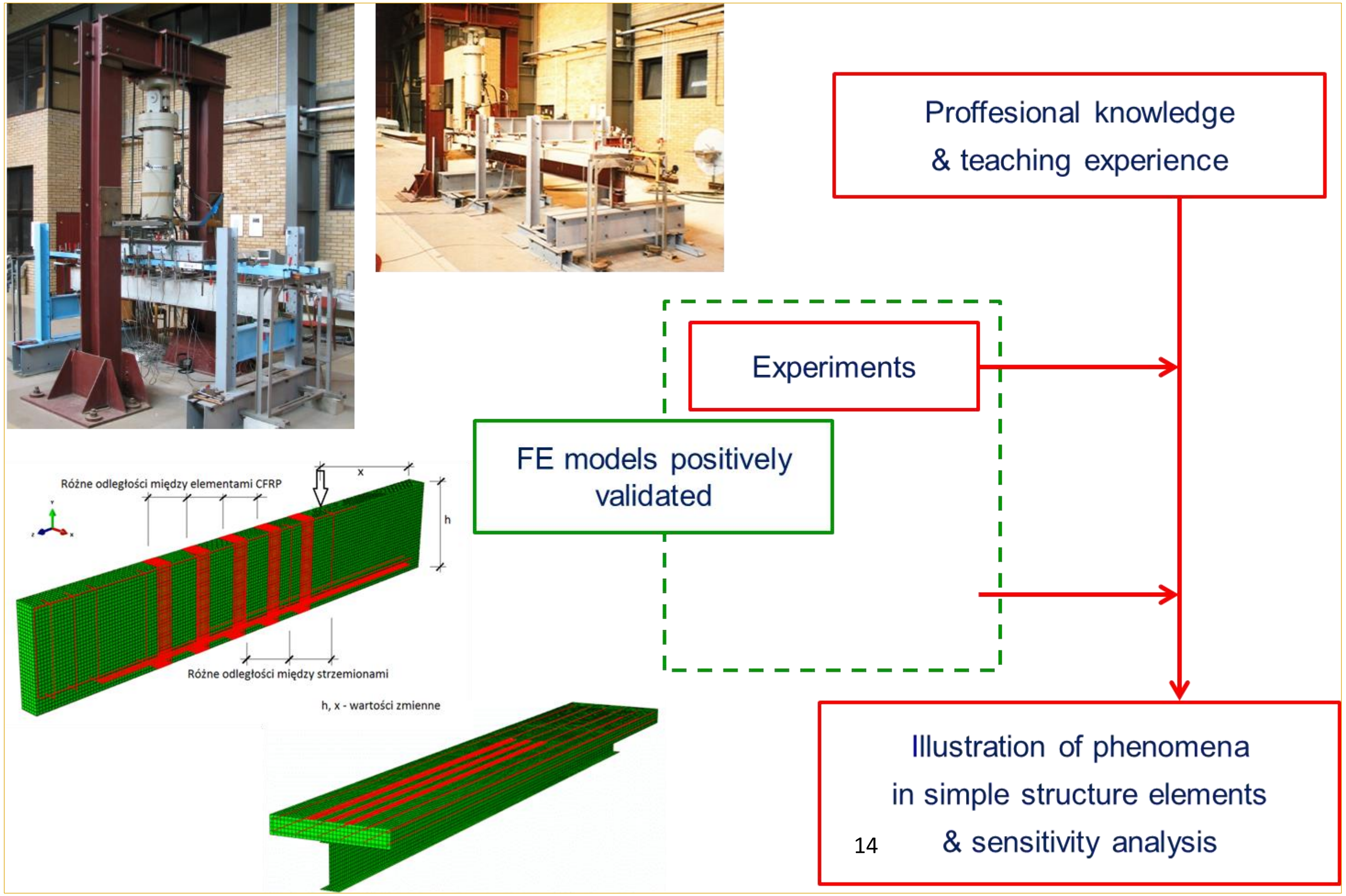
The preparation of an advanced numerical model, which should be the basis for the numerical experiment, requires advanced knowledge of solid mechanics and the use of specialised software.

For this reason, it is not possible for the student 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.

3.2.2 Numerical experiment description

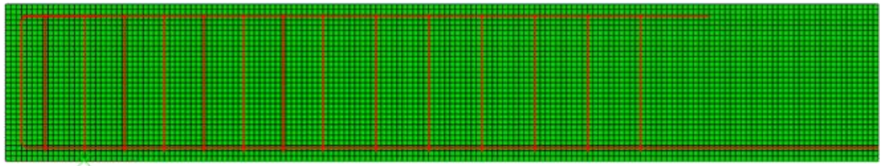
Validation of the numerical analysis of reinforced concrete beams



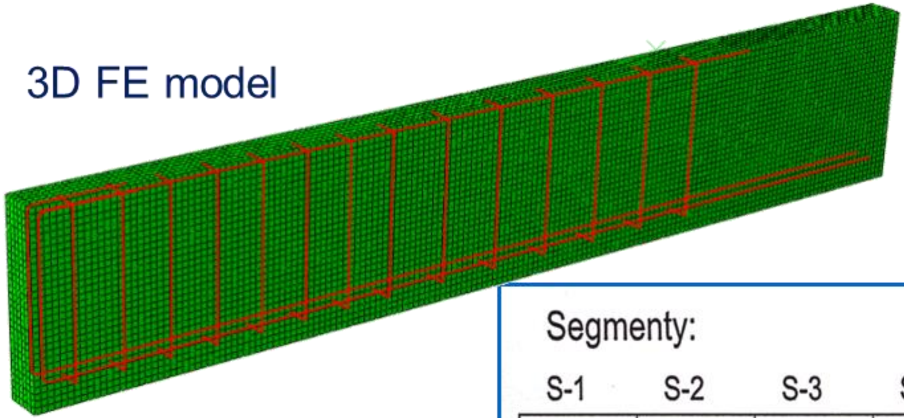
Reinforced Concrete beam

Numerical models created on the basis of data from laboratory tests:

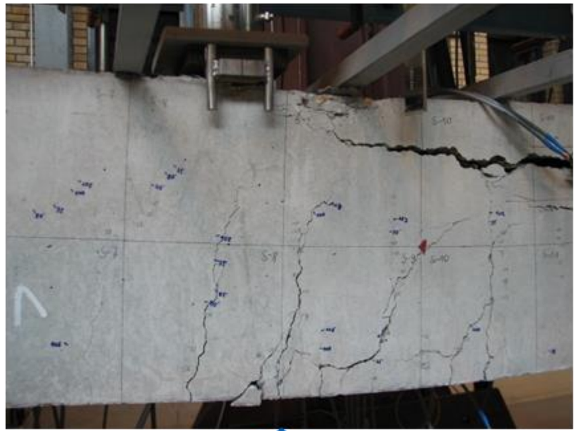
2D FE model

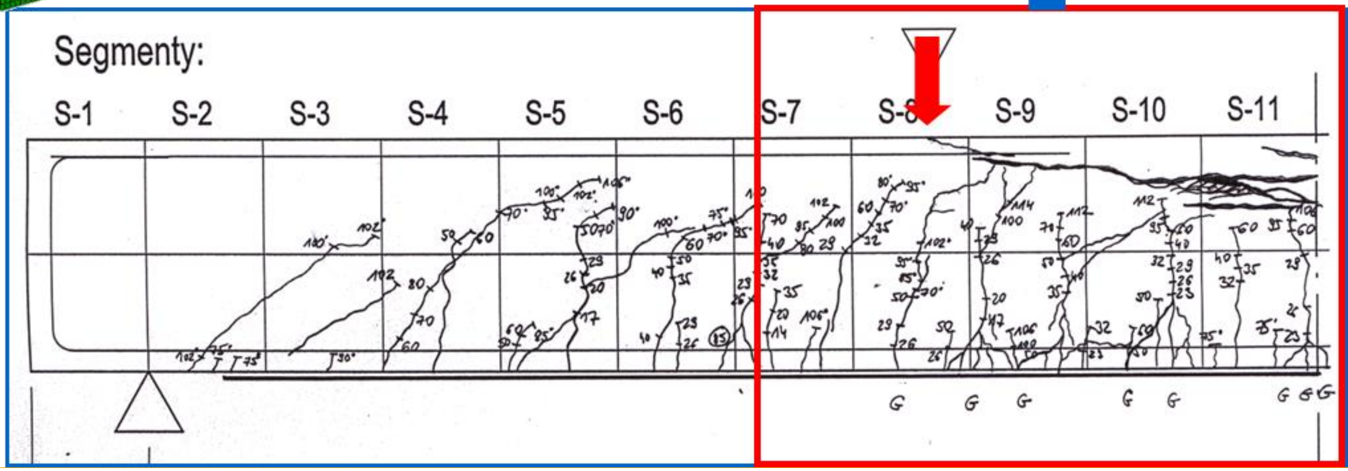


3D FE model



Data for **model verification** obtained from laboratory tests:

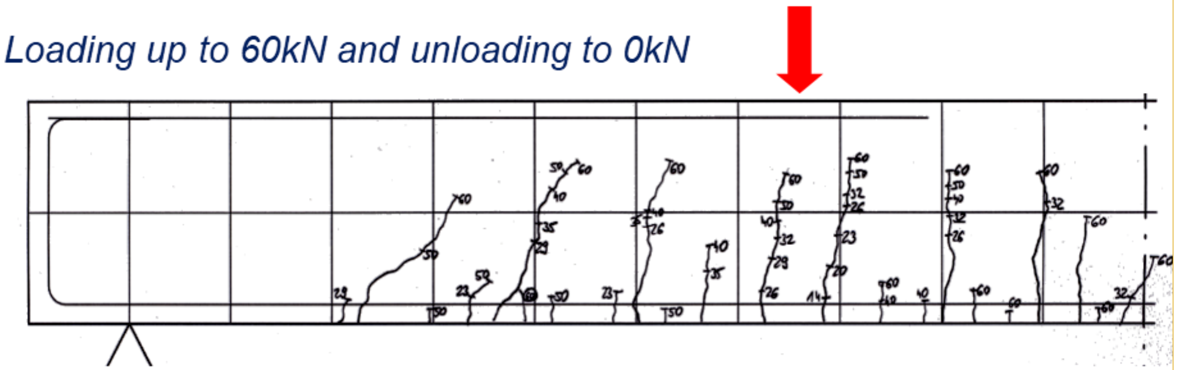




Reinforced Concrete beam

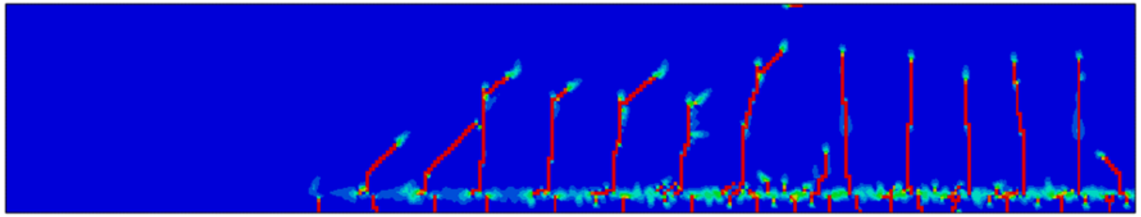
REAL experiment

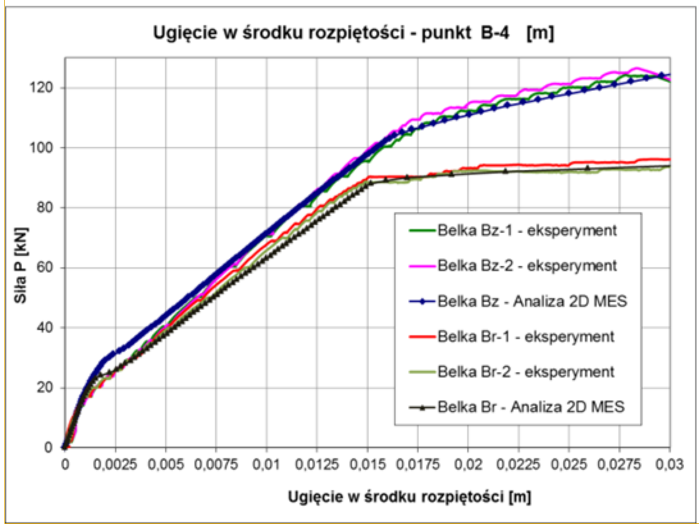
Loading up to 60kN and unloading to 0kN



NUMERICAL experiment

Layout of cracks in FEM analysis





Qualitative and quantitative verification

Motivation for the numerical experiment

Didactic purpose

Presentation on the basis of the created models, how the structural elements (RC beams) behave in the function of various variables

Scope of observation

Phenomenon:

- the layout of cracks
- the mechanism of the destruction of an element

Value:

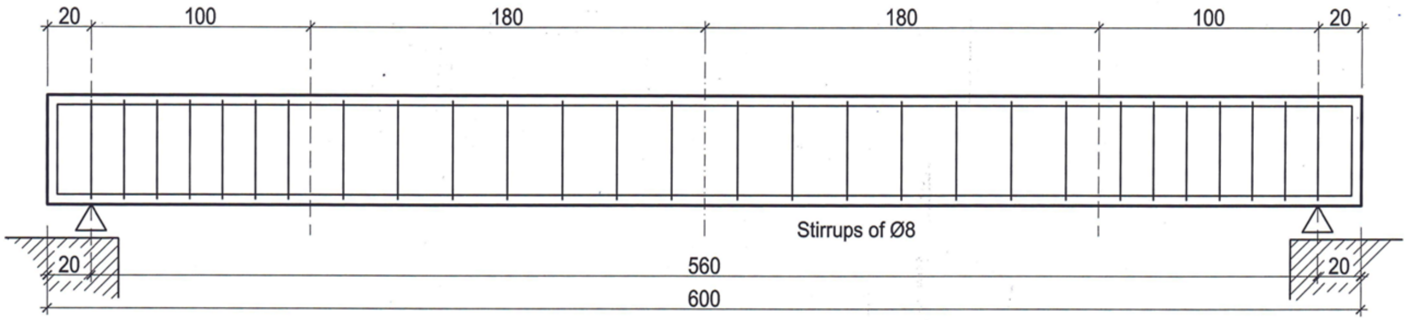
- cracking bending moment
- failure bending moment
- stresses

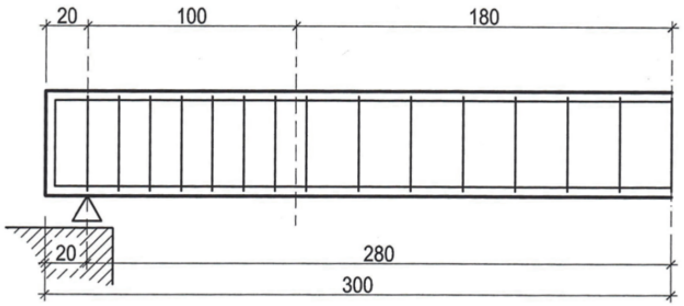
Representation of the phenomenon

- maps of deformation
- maps of stresses
- graphs
- etc.

Scope of the numerical experiment

Reinforcement beam – details



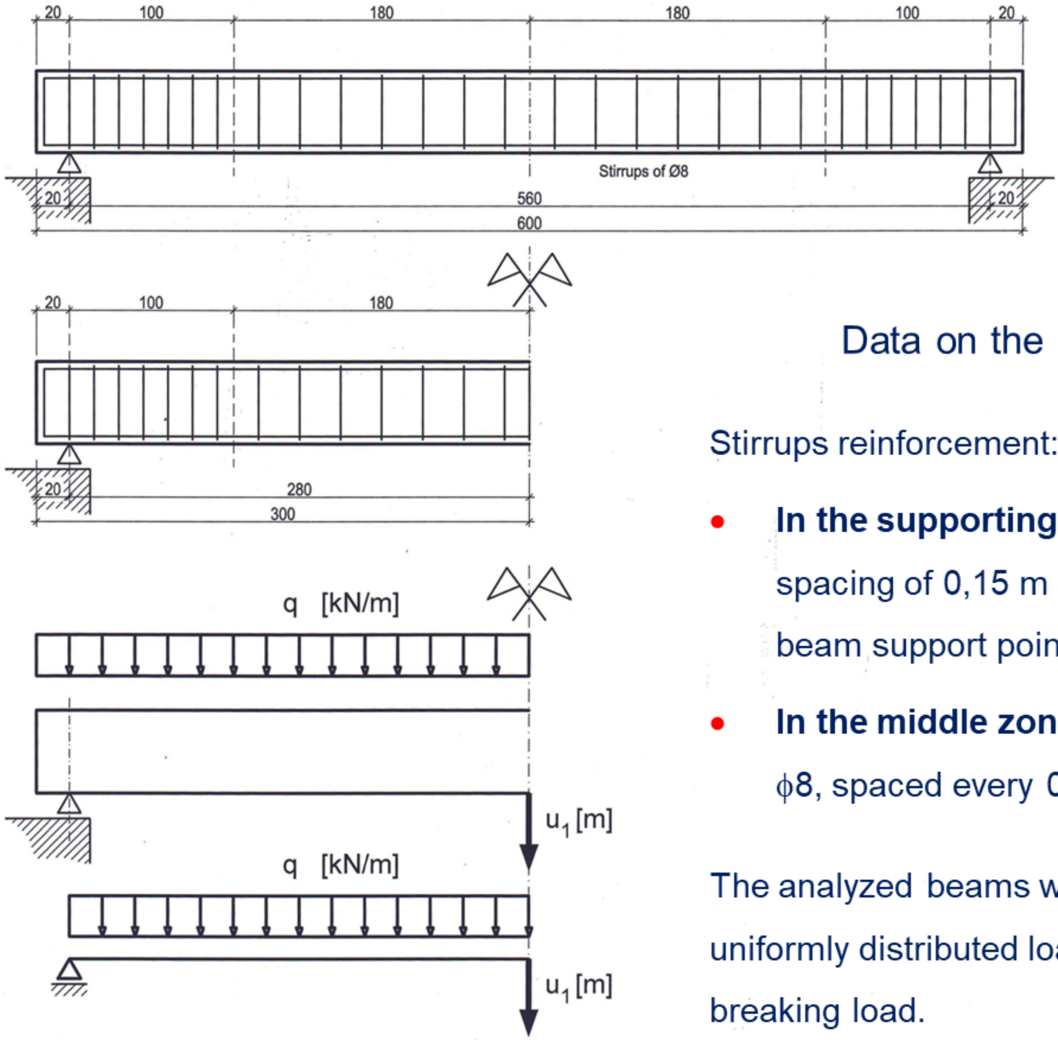


Data on the RC beam:

- 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



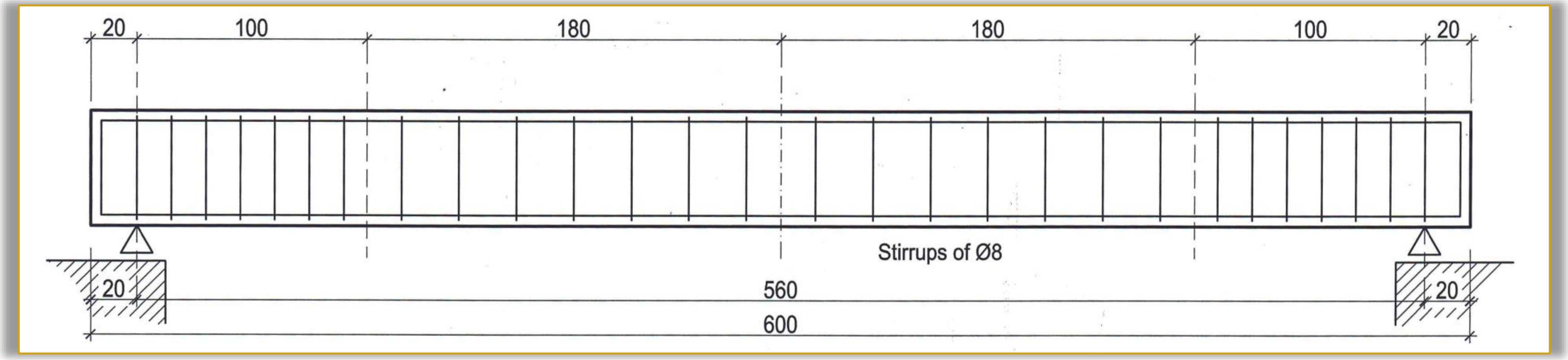
Data on the RC beam:

Stirrups reinforcement:

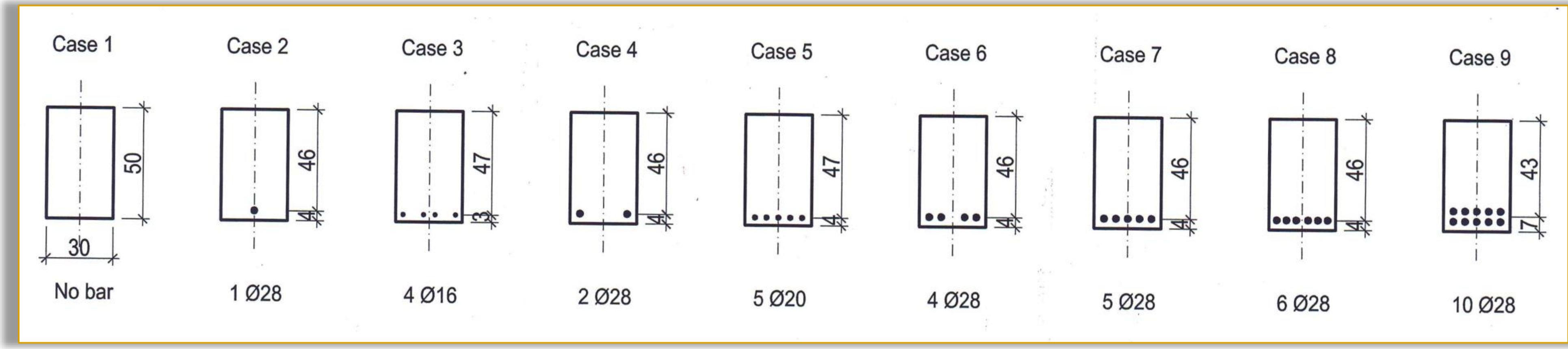
- **In the supporting zones** - 2-bar stirrups from bars ϕ8 at a spacing of 0,15 m (at a section of 1,0 m from the theoretical beam support point)
- **In the middle zone of the beam** - 2-bar stirrups from bars ϕ8, spaced every 0,25 m (on the 3,6 m section)

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

Layout of analysed RC beam

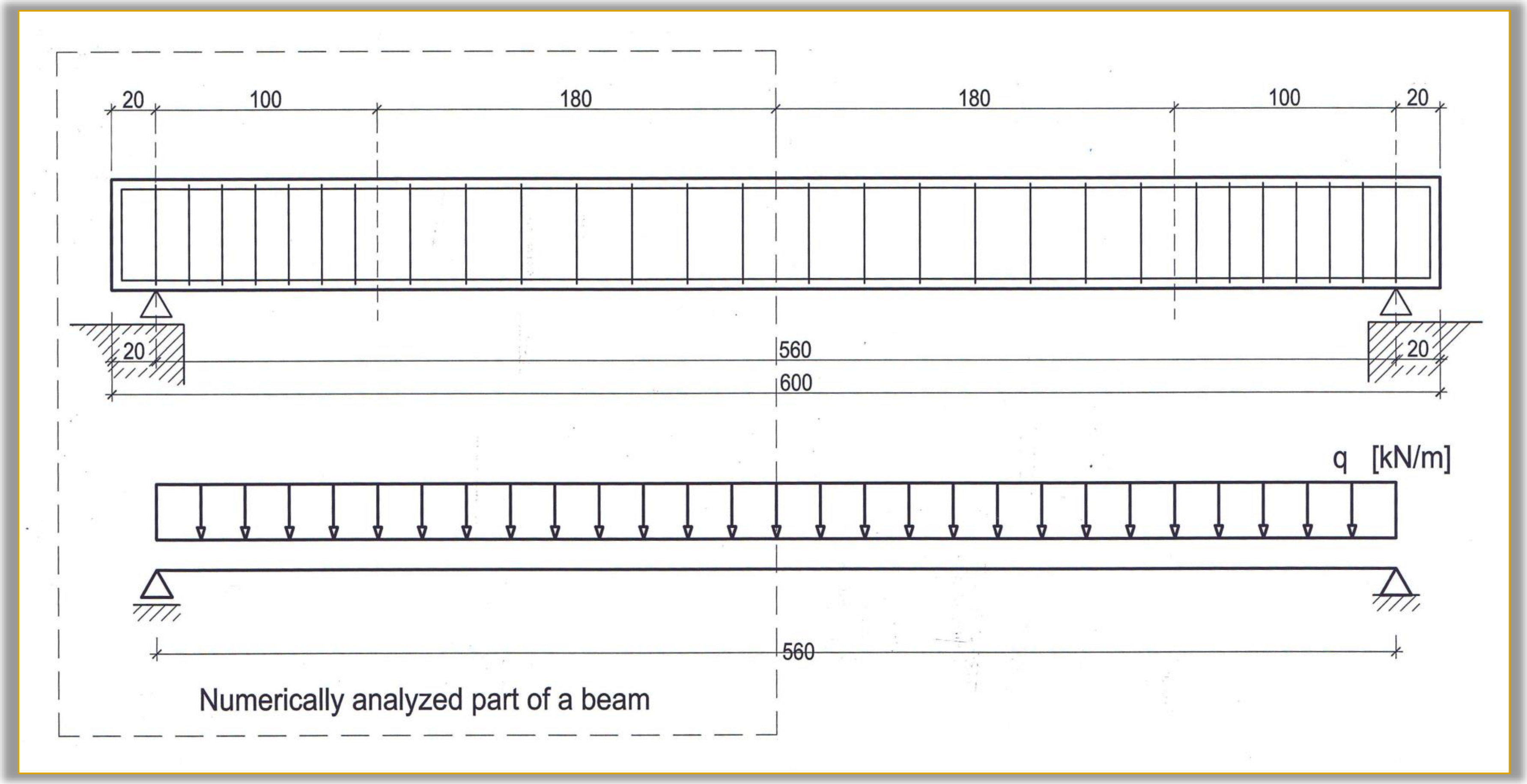


Different sets of analysed beams with **different reinforcement ratios:**



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

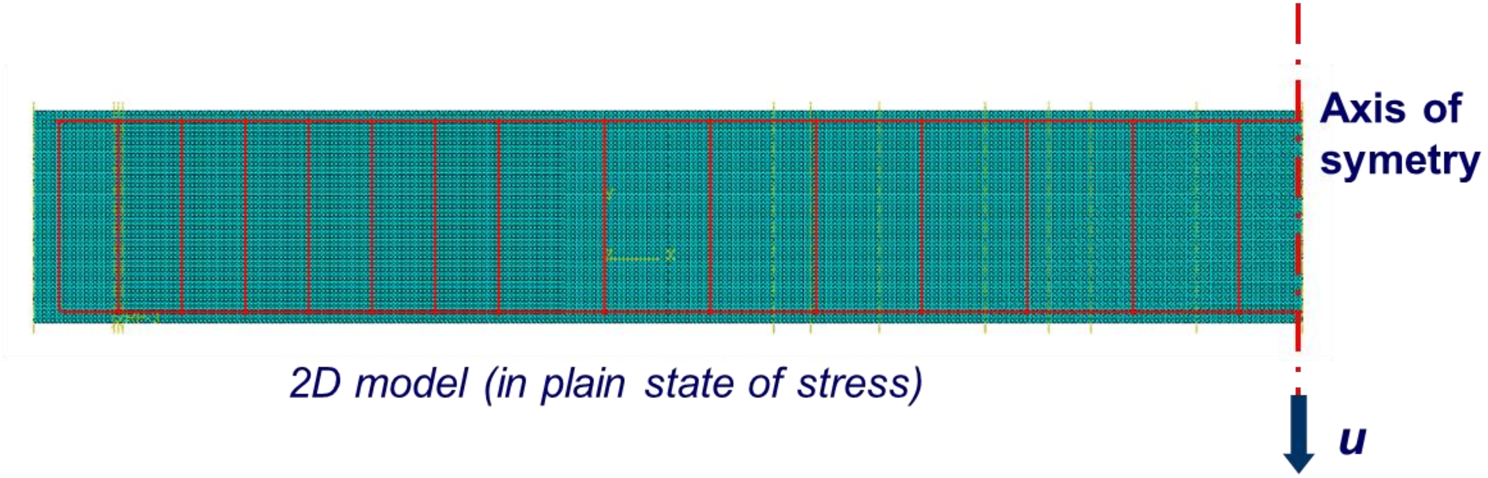


GOAL - analysis of only half of the beam will allow to reduce the time-consuming performance of numerical calculations held on the whole numerical model

Reinforcement beam – FEM analysis of 2D model

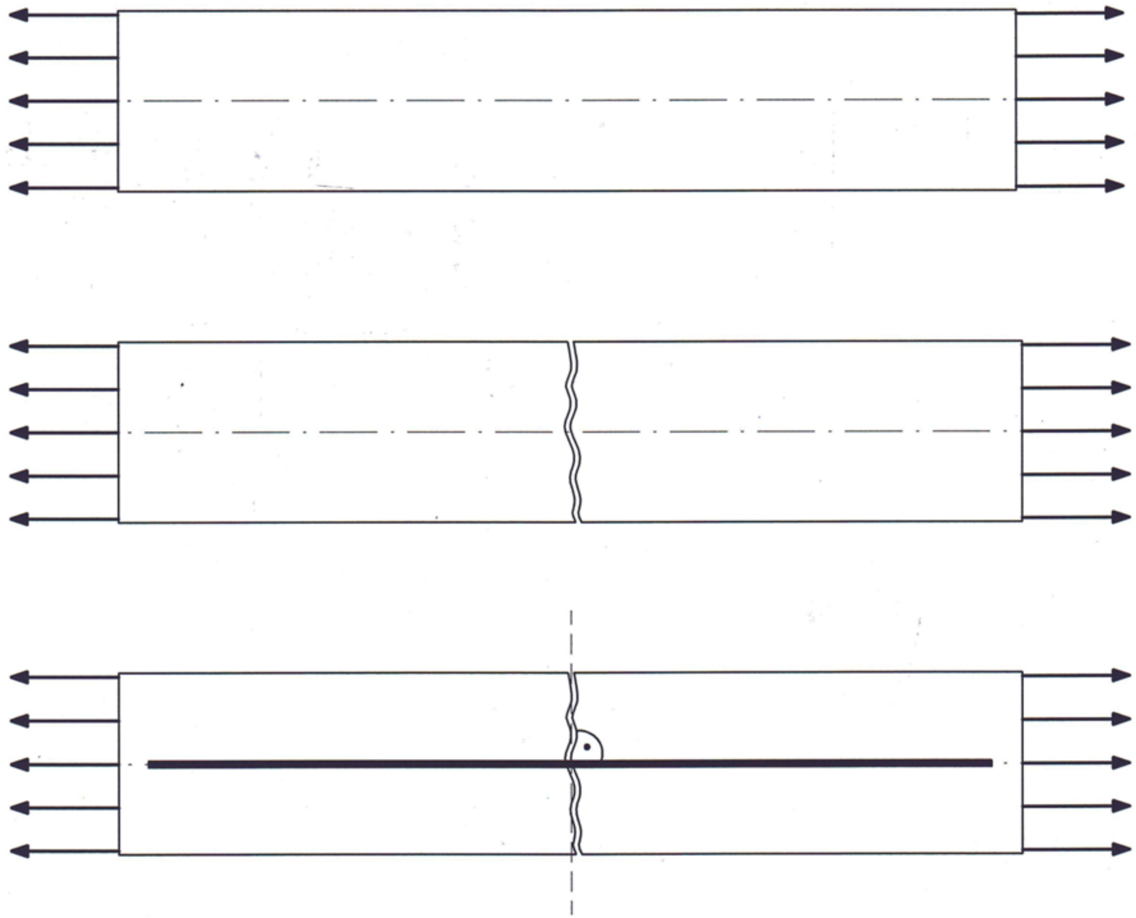
Assumptions of FEM analyses in general:

- 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)

The idea of using reinforcing bars in a concrete concrete beam



Direction of main tensile stresses

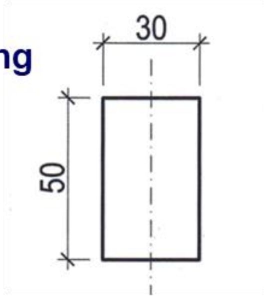
is applied to the top edge of

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

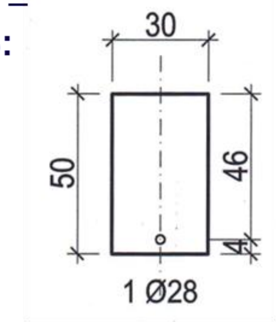
Cracks tensile direction

Analysed beams

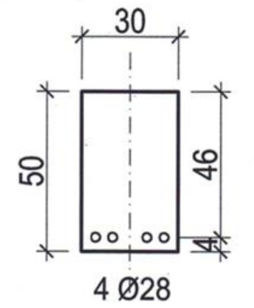
Concrete beam – with **no reinforcing bars:**



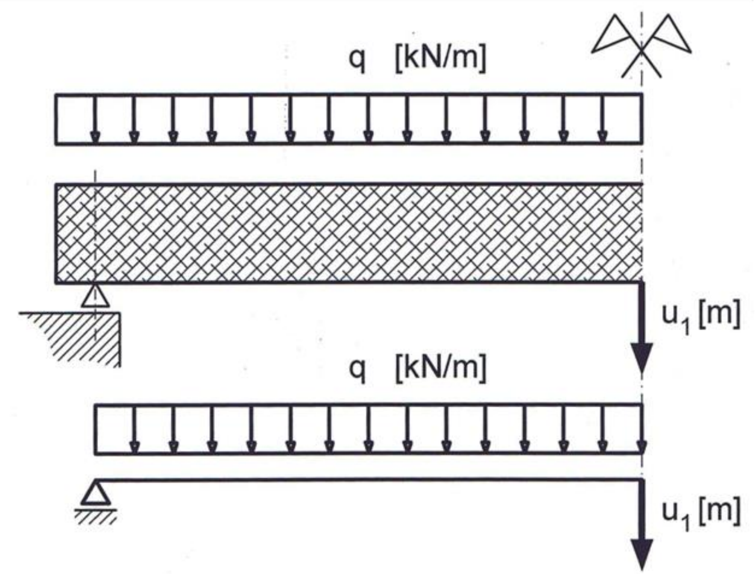
RC beam – with **1ϕ28:**



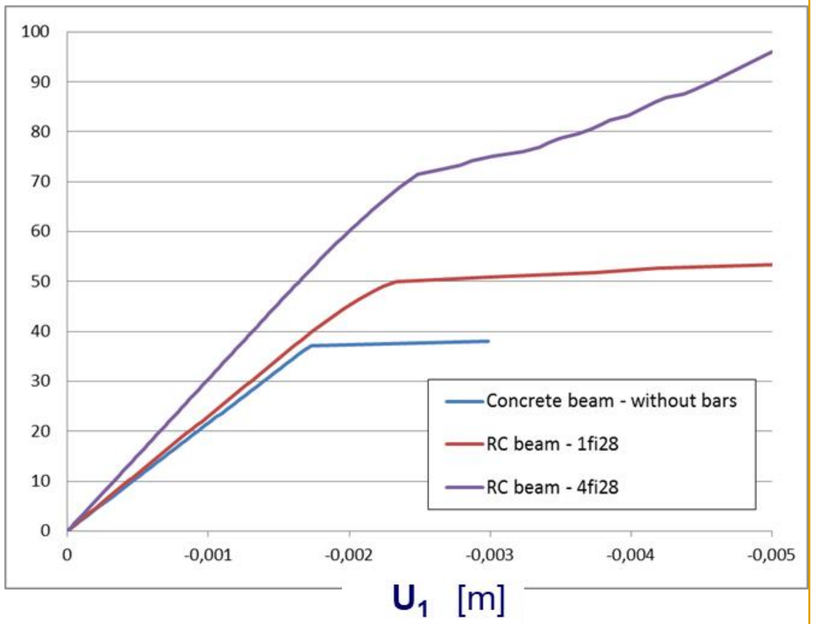
RC beam – with **4ϕ28:**



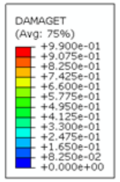
Part of beam with load and measuring point:



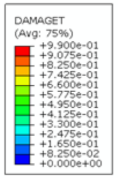
Deflection in the middle-span point of beams:



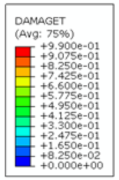
Analysed beams – analysis of DAMAGE_T parameter



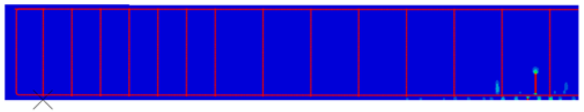
0ϕ28:
q = 31,1kN/m



1ϕ28:
q = 50,0kN/m

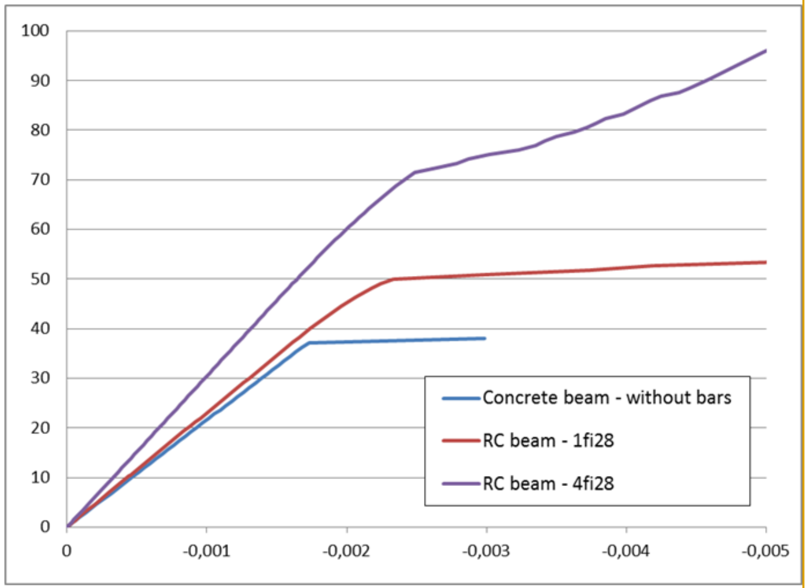


4ϕ28 + shear stirrups:
q = 70,0kN/m



The beginning of the initiation of the first cracks:

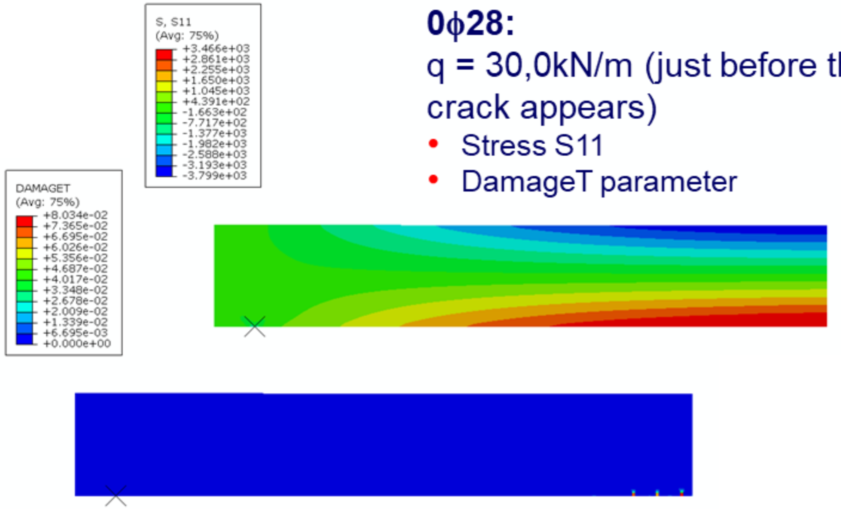
Deflection in the middle-span point of beams:



Analysed beams – analysis of beam with no bars

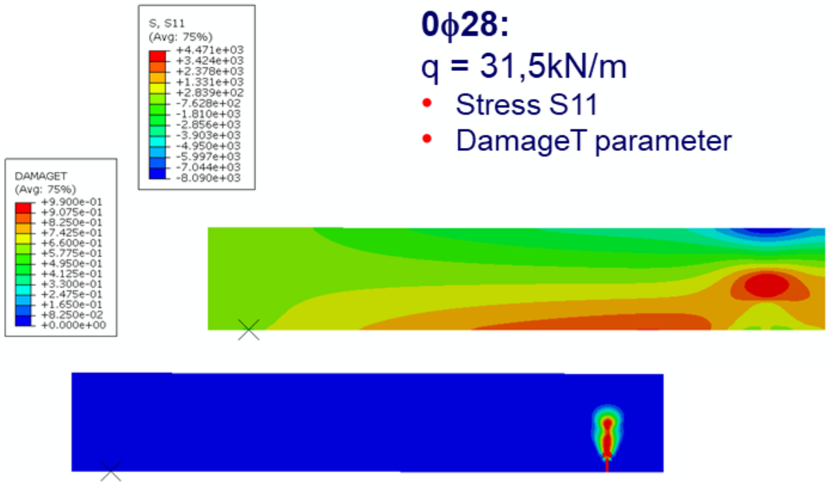
0ϕ28:
q = 30,0kN/m (just before the first crack appears)

- Stress S11
- DamageT parameter



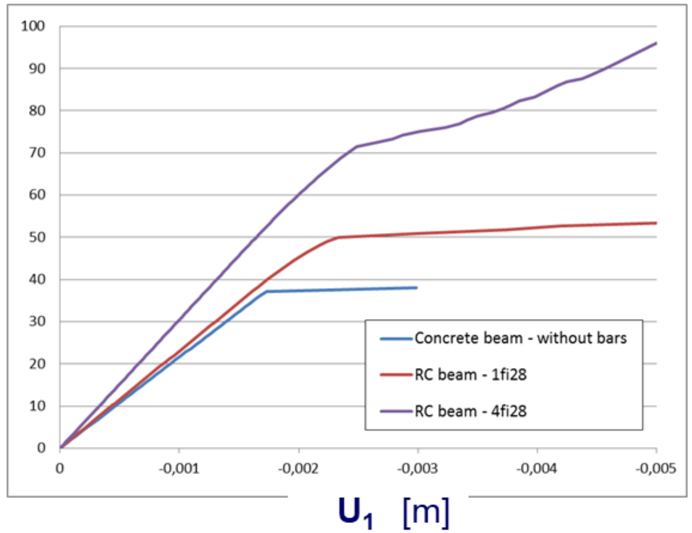
0ϕ28:
q = 31,5kN/m

- Stress S11
- DamageT parameter



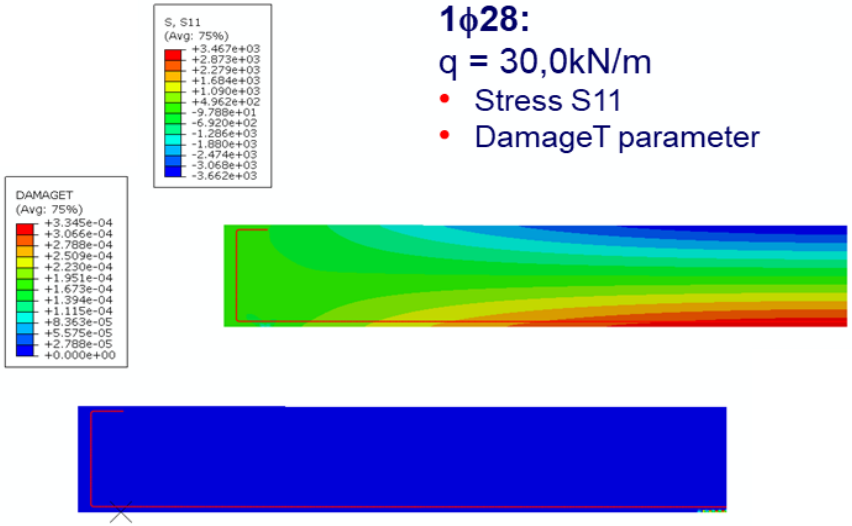
The beginning of the initiation of the first cracks:

Deflection in the middle-span point of beams:

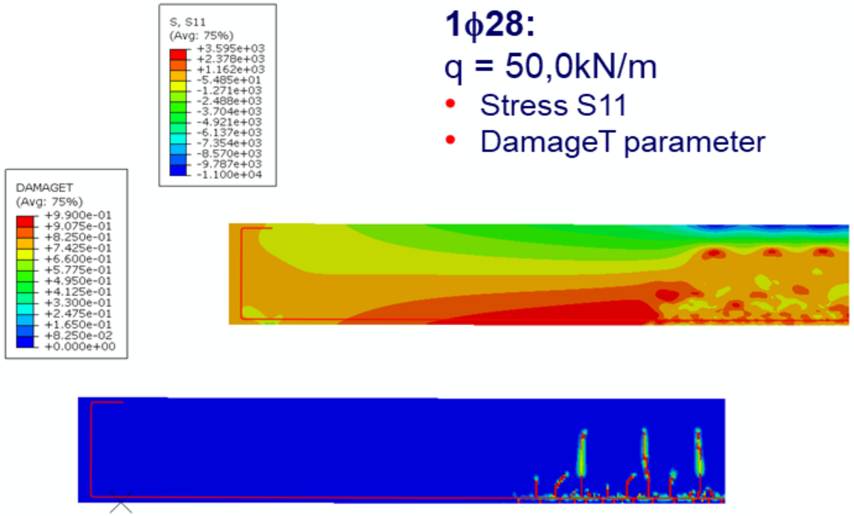


Analysed beams – analysis of beam with 1ϕ28

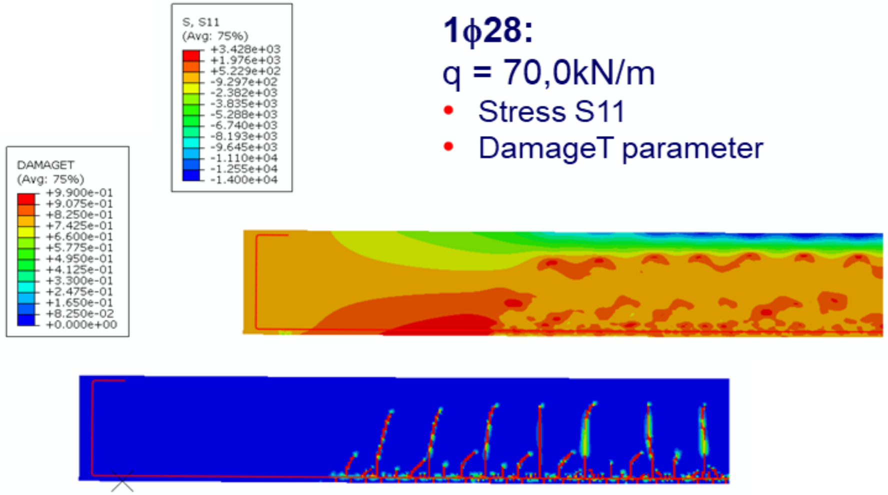
1ϕ28:
q = 30,0kN/m
- Stress S11
- DamageT parameter



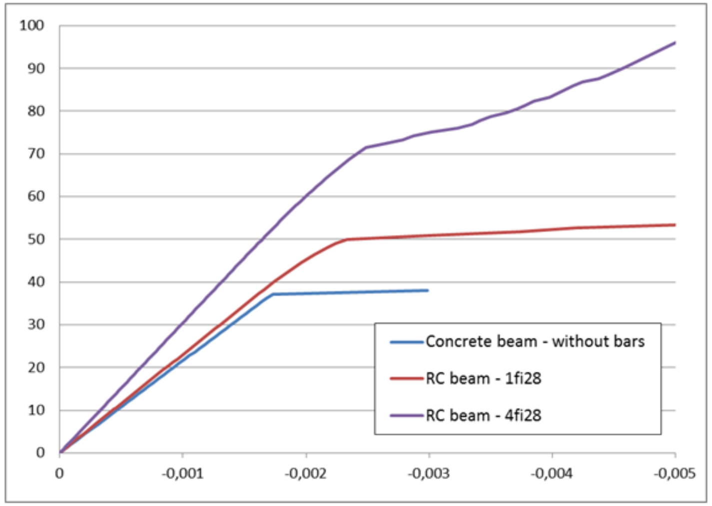
1ϕ28:
q = 50,0kN/m
- Stress S11
- DamageT parameter



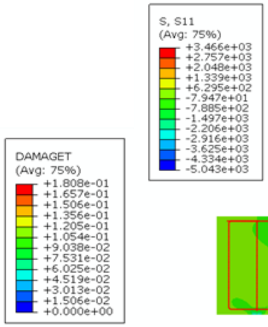
1ϕ28:
q = 70,0kN/m
- Stress S11
- DamageT parameter



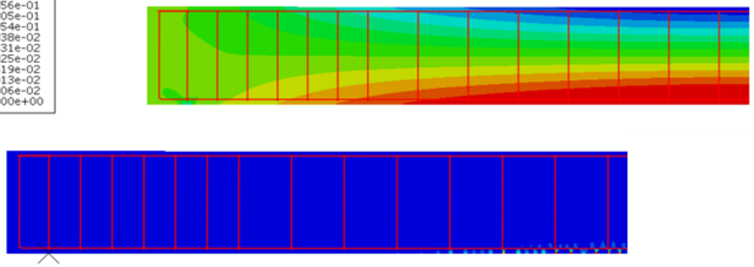
Deflection in the middle-span point of beams:

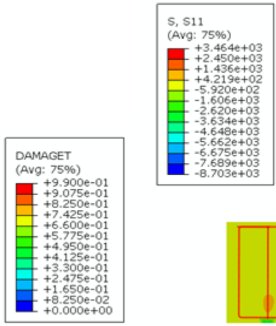


Analysed beams – analysis of beam with 4ϕ28

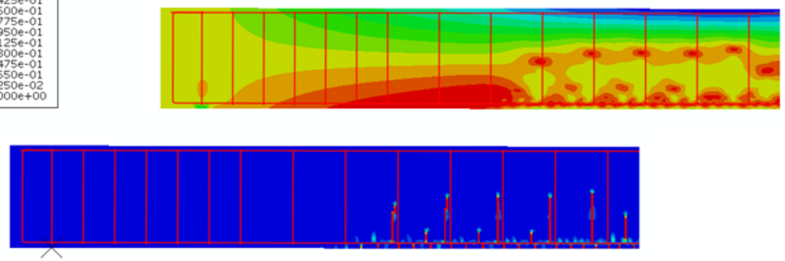


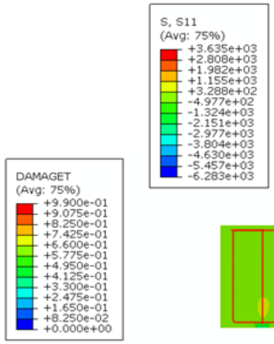
4ϕ28:
q = 60,0kN/m
- Stress S11
- Parametr damage_T



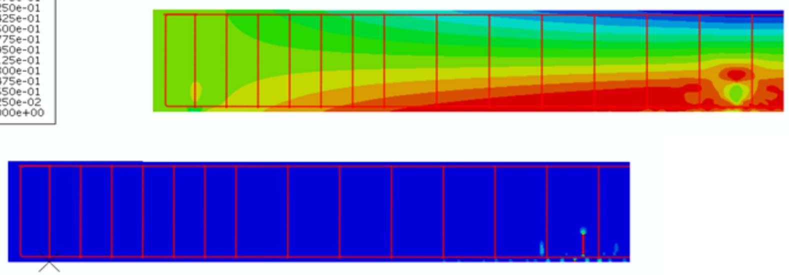


4ϕ28:
q = 90,0kN/m
- Stress S11
- Parametr damage_T

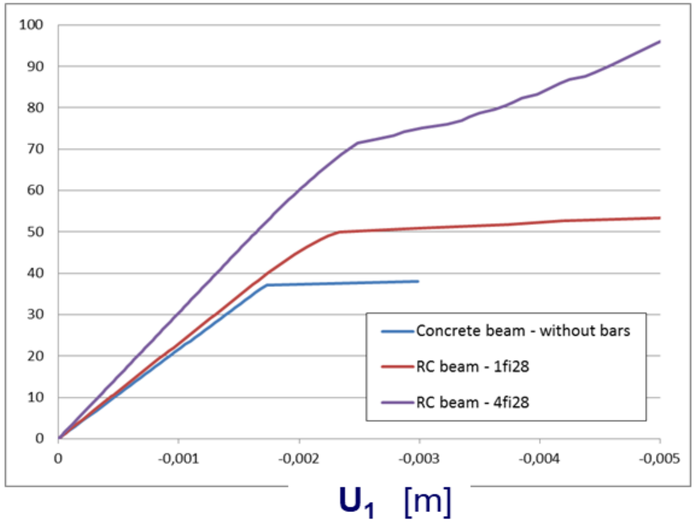




4ϕ28:
q = 70,0kN/m
- Stress S11
- Parametr damage_T



Deflection in the middle-span point of beams:



3.2.3 Learning Videos Numerical Experiment

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

The videos are part of the created mindmap and illustrate the **EXECUTION** of the **PLANNING PHASE.**

They are to be used in conjunction with the above instructions, graphics and the guide. They serve as a **VISUALISATION IN CLASS**.

The videos presented are:

01. Mises for beam
02. Damaget
03. For beam

04. Damaget
05. Mises for bars
06. Mises for beam
07. for bars v2
08. for beam

The learning videos (01-08) can be reached via the following link.

The shown **GUIDE** is giving an introduction into the numerical experiment and an explanation on the names of the videos:

STRG + CLICK

https://bfw-bb.de/digicon/02_videod.html?usp=sharing

The videos shown are only a small selection of the videos developed. A total of 51 videos on stress behaviour were created, which can be viewed online
under the following link:

www.zawm.be

www.bfw-bb.de

www.htw-berlin.de

www.put.poznan.pl

Publisher & Project coordination

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