# MC2010 Shear Provisions and Recent Developments in Shear Research

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Maastricht
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*fib* symposium 2017
*High tech concrete:* Where technology and engineering meet!

# Presentation outline

- Main past contributions of *fib* Working party 2.2.1: Shear in beams
- MC2010 shear provisions
- Shear research at the University of Liège
- Future activities of Working party 2.2.1: Shear in beams

# Working party 2.2.1: Shear in beams

Part of Task group 2.2: Ultimate limit state models, together with:

- Party 2.2.2: Shear in members with steel fibres
- Party 2.2.3: Punching and shear slabs
- Party 2.2.4: Strut and tie modelling

# Members of working party 2.2.1: Shear in beams

Convener:

Bayrak - University of Texas at Austin

Members:

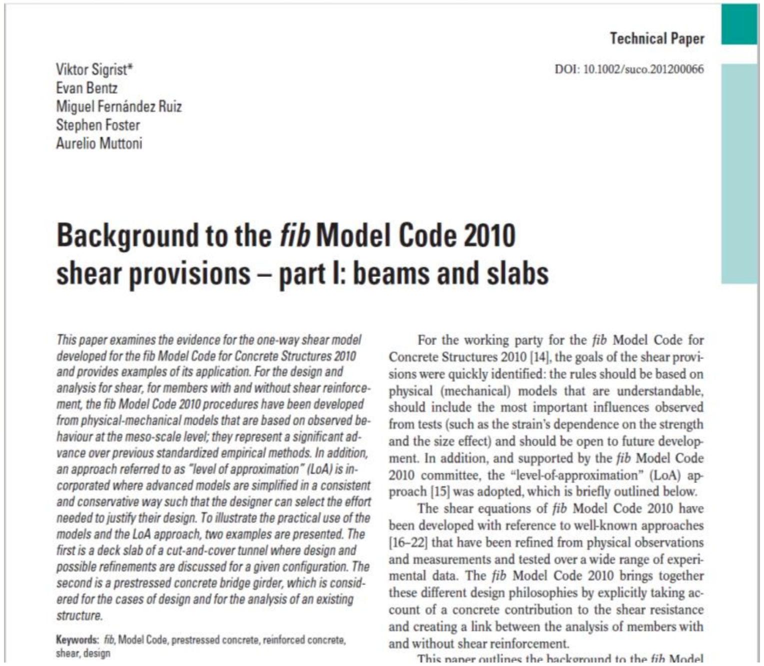
Bentz - University of Toronto
Belletti - Univ. degli Studi di Parma
Cladera - University of Balearic Islands
Fernández Ruiz - EPF Lausanne
Hegger - RWTH Aachen
Hong - Seoul National University
Huber - TU Wien
Kaufmann - ETH Zürich
Kuchma - Tufts University
Muttoni - EPF Lausanne
Sagaseta - University of Surrey
Sigrist - Hochschule Luzern
Uzel - Yeditepe University

Corresponding members:

Foster - UNSW Australia
Vollum - Imperial College London
Walraven - Delft University of Technology

# Main past contributions

- 2010-2012: Work on Model Code 2010 (MC2010)
- 2013-2014: Publications outlining the background of MC2010



Technical Paper

Viktor Sigrist*
Evan Bentz
Miguel Fernández Ruiz
Stephen Foster
Aurelio Muttoni

DOI: 10.1002/suco.201200066

## Background to the *fib* Model Code 2010 shear provisions – part I: beams and slabs

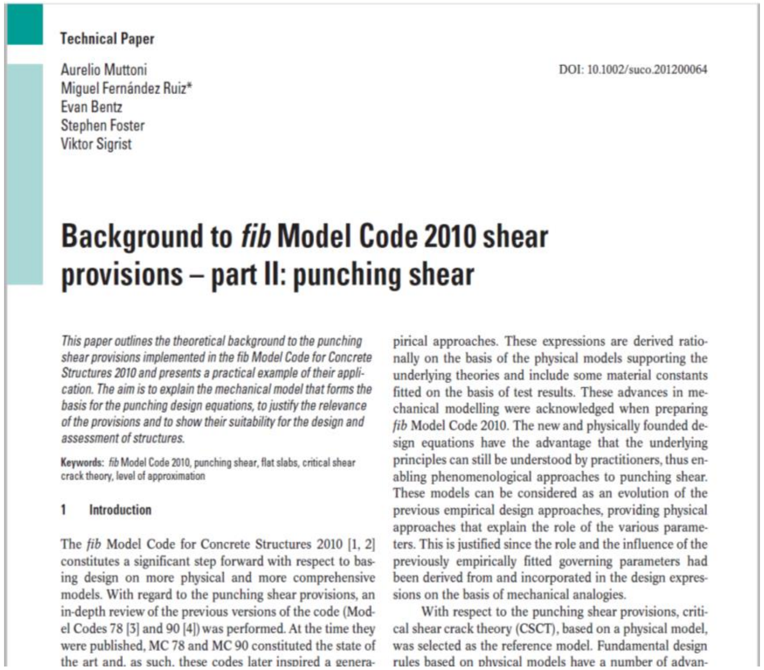
*This paper examines the evidence for the one-way shear model developed for the fib Model Code for Concrete Structures 2010 and provides examples of its application. For the design and analysis for shear, for members with and without shear reinforcement, the fib Model Code 2010 procedures have been developed from physical-mechanical models that are based on observed behaviour at the meso-scale level; they represent a significant advance over previous standardized empirical methods. In addition, an approach referred to as "level of approximation" (LoA) is incorporated where advanced models are simplified in a consistent and conservative way such that the designer can select the effort needed to justify their design. To illustrate the practical use of the models and the LoA approach, two examples are presented. The first is a deck slab of a cut-and-cover tunnel where design and possible refinements are discussed for a given configuration. The second is a prestressed concrete bridge girder, which is considered for the cases of design and for the analysis of an existing structure.*

**Keywords:** *fib*, Model Code, prestressed concrete, reinforced concrete, shear, design

For the working party for the *fib* Model Code for Concrete Structures 2010 [14], the goals of the shear provisions were quickly identified: the rules should be based on physical (mechanical) models that are understandable, should include the most important influences observed from tests (such as the strain's dependence on the strength and the size effect) and should be open to future development. In addition, and supported by the *fib* Model Code 2010 committee, the "level-of-approximation" (LoA) approach [15] was adopted, which is briefly outlined below.

The shear equations of *fib* Model Code 2010 have been developed with reference to well-known approaches [16–22] that have been refined from physical observations and measurements and tested over a wide range of experimental data. The *fib* Model Code 2010 brings together these different design philosophies by explicitly taking account of a concrete contribution to the shear resistance and creating a link between the analysis of members with and without shear reinforcement.

This paper outlines the background to the *fib* Model



Technical Paper

Aurelio Muttoni
Miguel Fernández Ruiz*
Evan Bentz
Stephen Foster
Viktor Sigrist

DOI: 10.1002/suco.201200064

## Background to *fib* Model Code 2010 shear provisions – part II: punching shear

*This paper outlines the theoretical background to the punching shear provisions implemented in the fib Model Code for Concrete Structures 2010 and presents a practical example of their application. The aim is to explain the mechanical model that forms the basis for the punching design equations, to justify the relevance of the provisions and to show their suitability for the design and assessment of structures.*

**Keywords:** *fib* Model Code 2010, punching shear, flat slabs, critical shear crack theory, level of approximation

### 1 Introduction

The *fib* Model Code for Concrete Structures 2010 [1, 2] constitutes a significant step forward with respect to basing design on more physical and more comprehensive models. With regard to the punching shear provisions, an in-depth review of the previous versions of the code (Model Codes 78 [3] and 90 [4]) was performed. At the time they were published, MC 78 and MC 90 constituted the state of the art and, as such, these codes later inspired a genera-

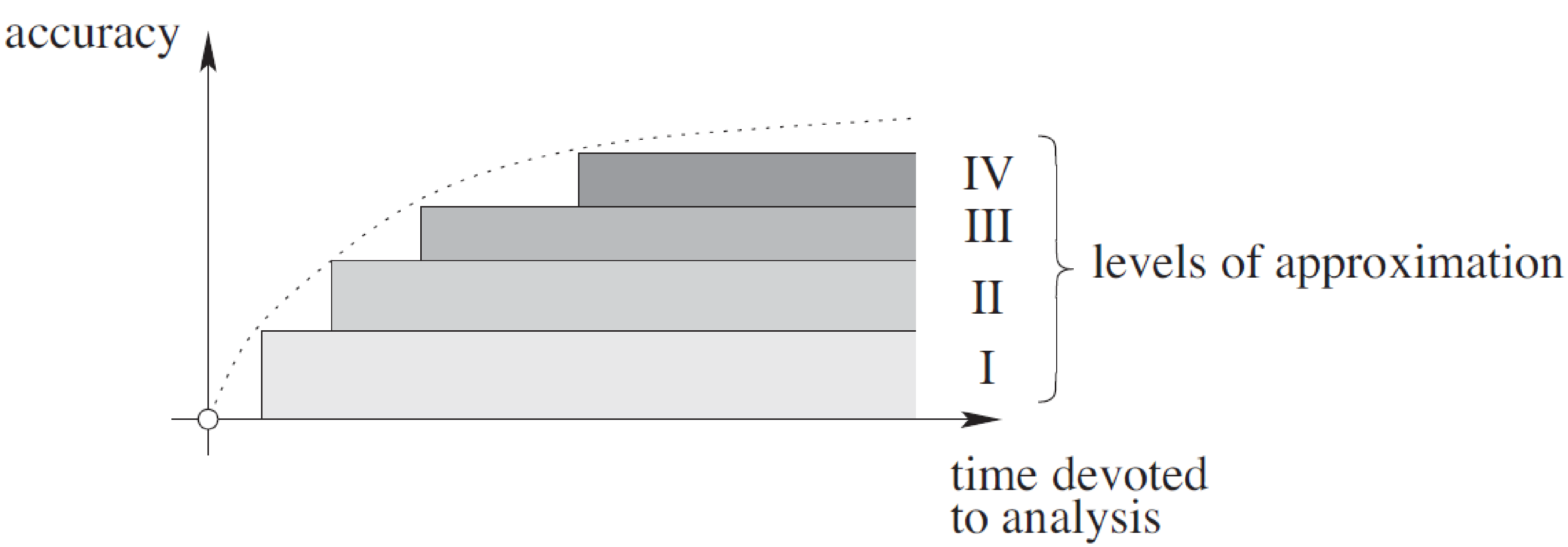
pirical approaches. These expressions are derived rationally on the basis of the physical models supporting the underlying theories and include some material constants fitted on the basis of test results. These advances in mechanical modelling were acknowledged when preparing *fib* Model Code 2010. The new and physically founded design equations have the advantage that the underlying principles can still be understood by practitioners, thus enabling phenomenological approaches to punching shear. These models can be considered as an evolution of the previous empirical design approaches, providing physical approaches that explain the role of the various parameters. This is justified since the role and the influence of the previously empirically fitted governing parameters had been derived from and incorporated in the design expressions on the basis of mechanical analogies.

With respect to the punching shear provisions, critical shear crack theory (CSCT), based on a physical model, was selected as the reference model. Fundamental design rules based on physical models have a number of advan-

- 2015: meetings at *fib* Copenhagen and ACI Denver

# Shear provisions in MC2010

# Levels of approximation (LoA)




Muttoni (2003)

# Levels of approximation (LoA)

- Members w/o shear reinforcement:

  Level I: fast design, conservative

  Level II: maximum accuracy, more complex

  Level III: Finite Element Analysis

Simplified Modified Compression Field Theory (Levels I–II)

(Bentz et al., 2006)

- Members with shear reinforcement:

  Level I: fast design, conservative

  Level II: fast design, conservative

  Level III: maximum accuracy, more complex

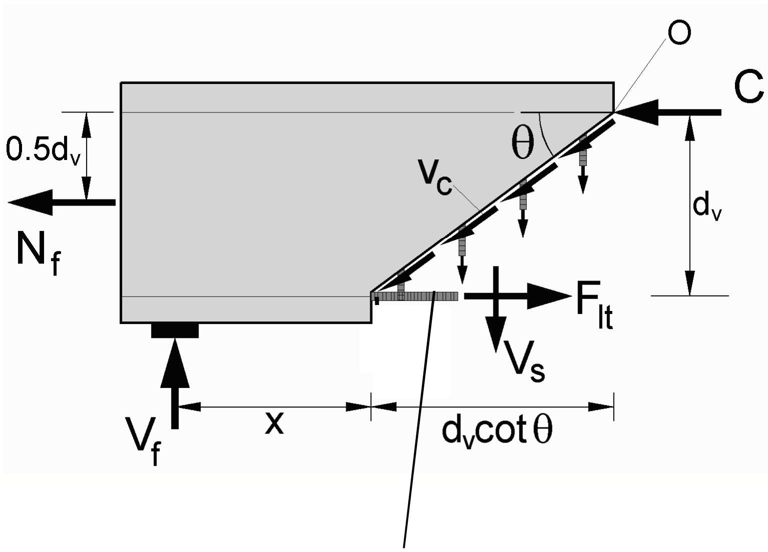
  Level IV: Finite Element Analysis

Simplified MCFT + general stress field approach (Levels I–III)

(Bentz et al. 2006, Muttoni et al. 1997, Sigrist 2011)

# Basic shear resistance equations

$$V_{Rd} = V_{Rd,c} + V_{Rd,s} \geq V_{Ed}$$



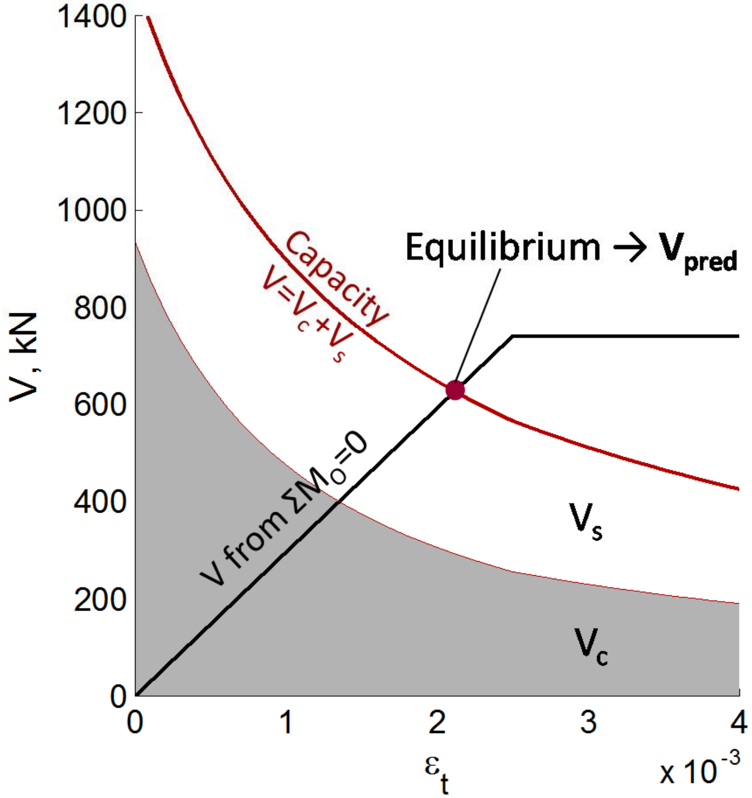

Strain $\boldsymbol{\varepsilon_t}$

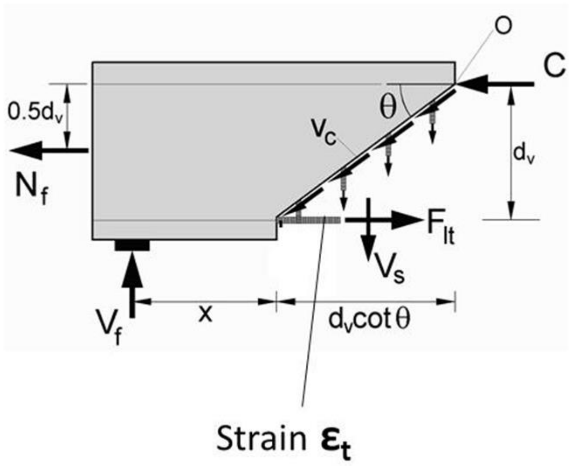
$$V_{Rd,c} = k_v \frac{\sqrt{f_{ck}}}{\gamma_c} b_w z$$

$$V_{Rd,s} = \frac{A_{sw}}{s_w} z f_{ywd} \cot\theta$$

LoA Level III: $k_v$ and θ depend on $\boldsymbol{\varepsilon_t}$ → strain effect

# Strain effect in shear – LoA III




Beam properties:

400/1200 mm section

$\rho_l$ = 1%

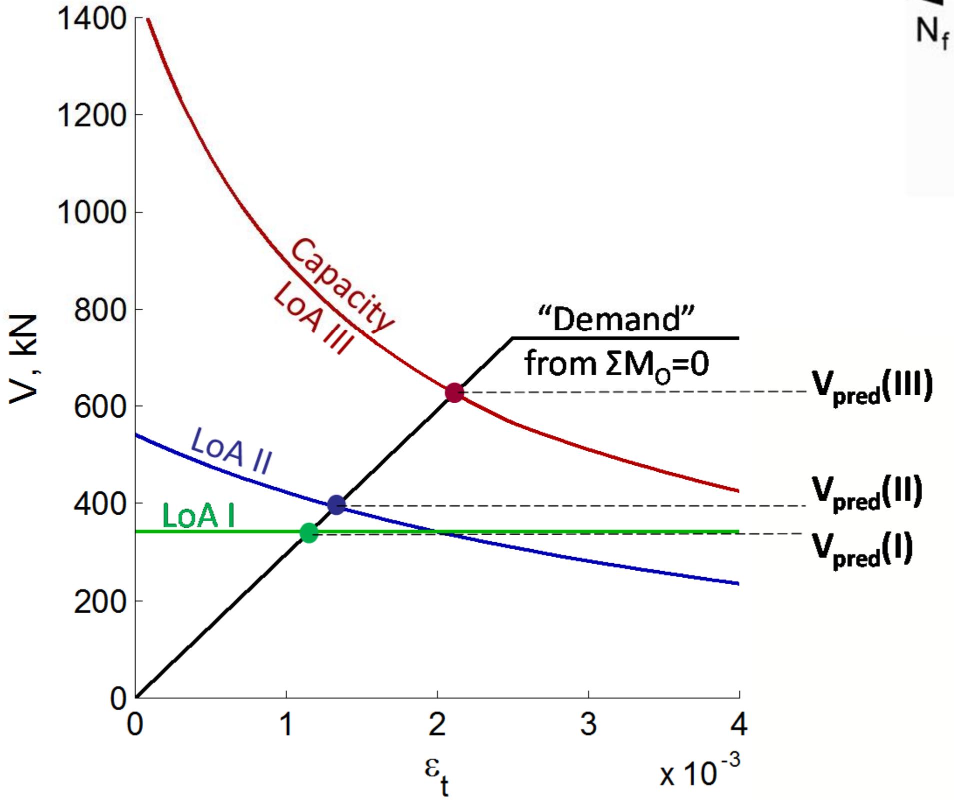
$\rho_v$ = 0.1%

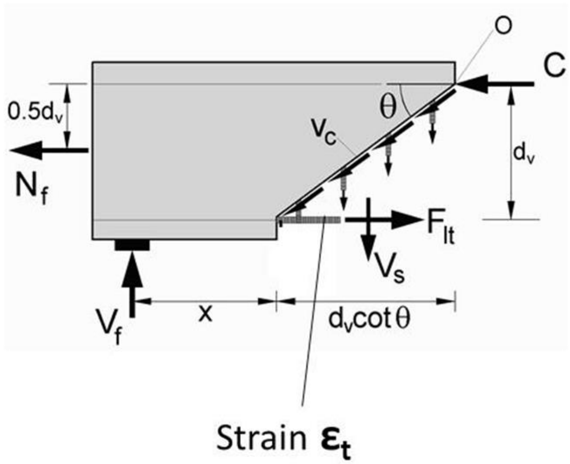
$f_y$ = 500 MPa

$f_c$ = 35 MPa

shear-span-to-depth ratio = 2.9

# Strain effect in shear – LoA I-III




Beam properties:

400/1200 mm section

$\rho_l$ = 1%

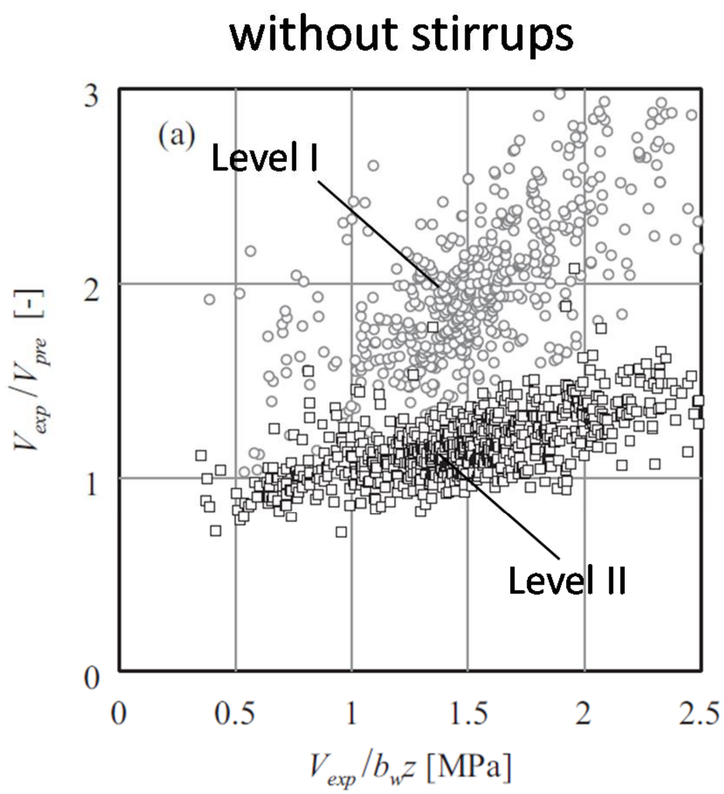
$\rho_v$ = 0.1%

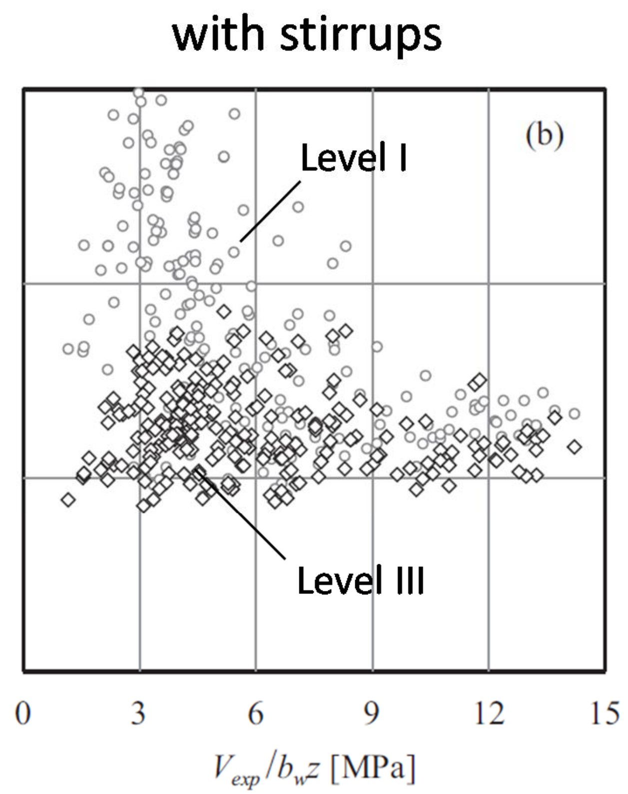
$f_y$ = 500 MPa

$f_c$ = 35 MPa

shear-span-to-depth ratio = 2.9

# MC2010 shear strength predictions




| | Avg | COV |
|---|---|---|
| Level I | 1.98 | 18.1% |
| Level II | 1.15 | 10.6% |

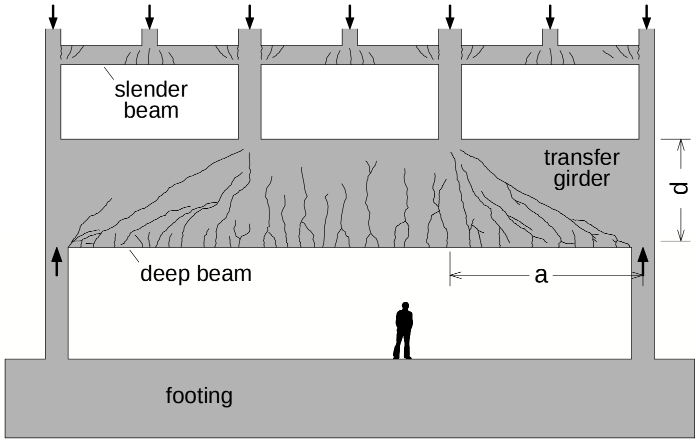
| | Avg | COV |
|---|---|---|
| Level I | 1.49 | 21.0% |
| Level III | 1.20 | 13.0% |

Sigrist et al. (2013)

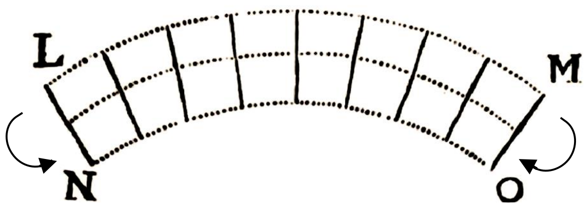
# Shear research at the University of Liège

*Boyan Mihaylov, University of Liège*

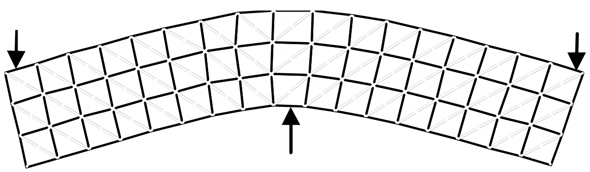
# Deep beams



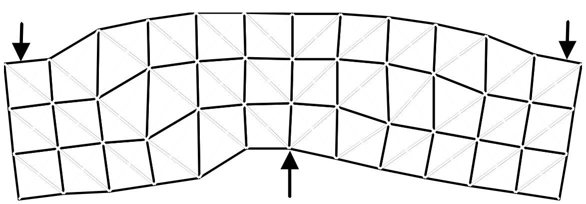

Slender and deep
beams in a building




Plane sections remain plane
*Robert Hooke 1678*



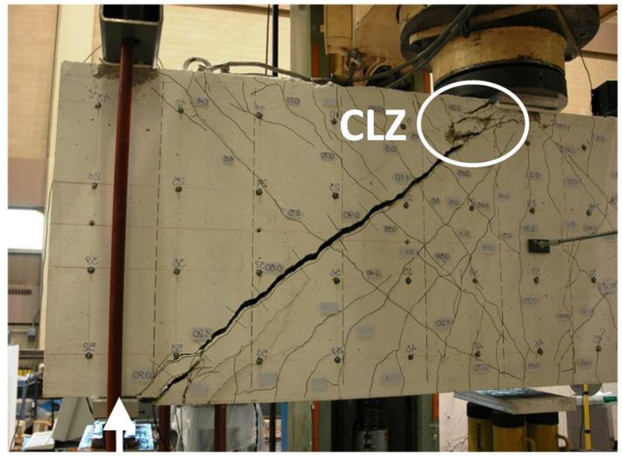
Measured deformations × 300 of
cracked "slender" beam



Measured deformations × 40 of
cracked "deep" beam

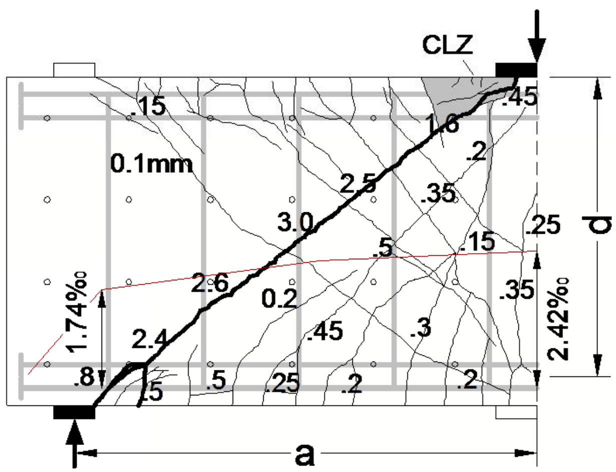
# Shear failure of deep beams

Deep beam after shear failure

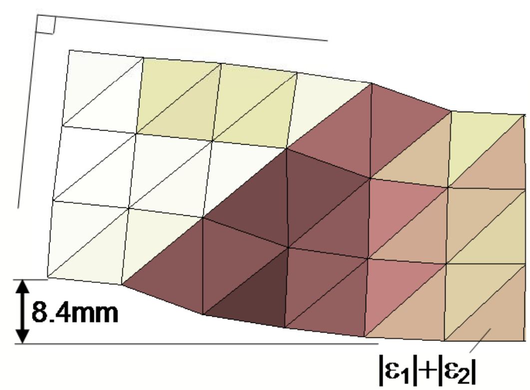



d=1095 mm
a/d=1.55
$\rho_l$= 0.70%
$\rho_v$= 0.10%
$f_c'$= 33.5 MPa

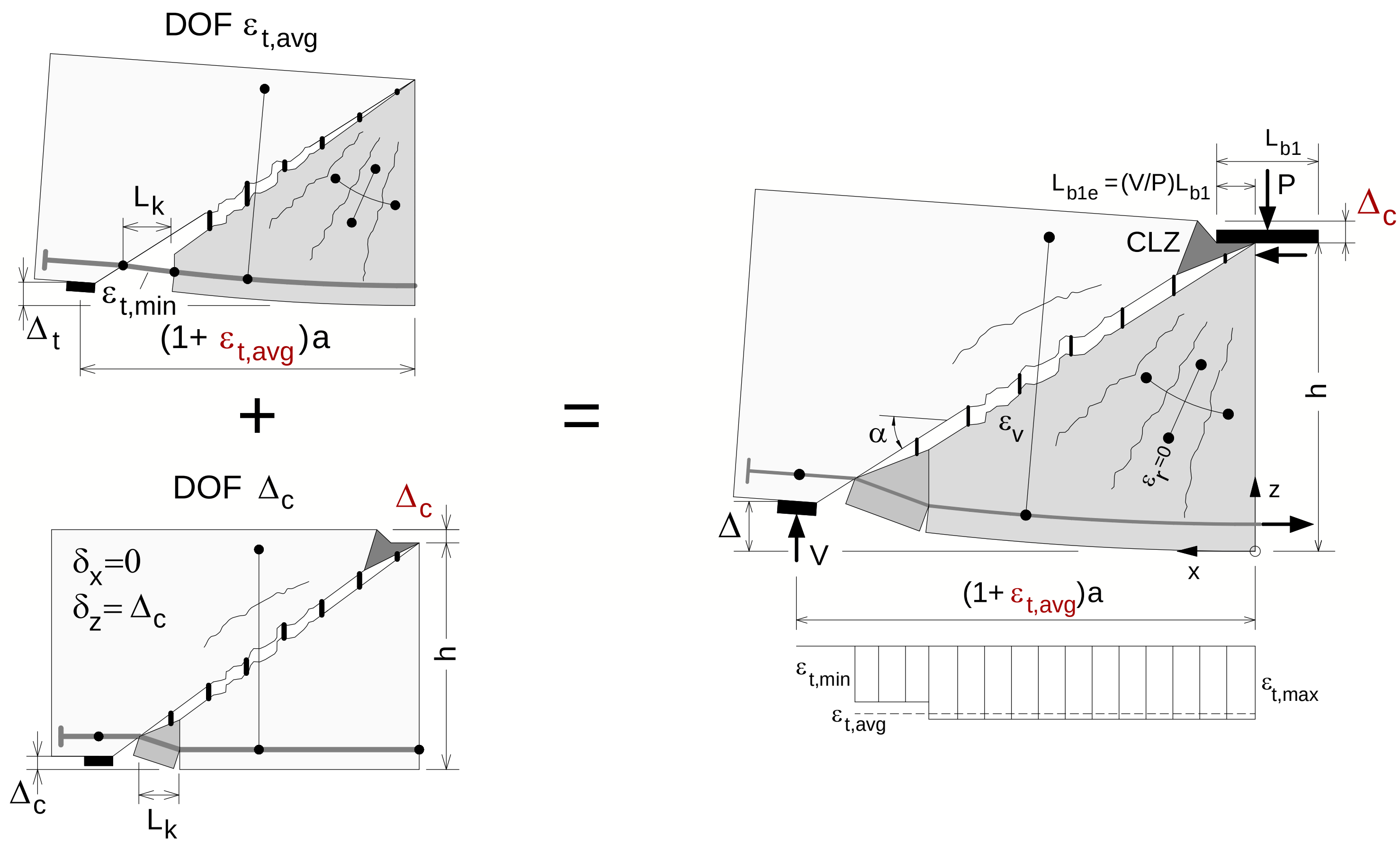
Crack widths at failure




Deformations at failure × 30

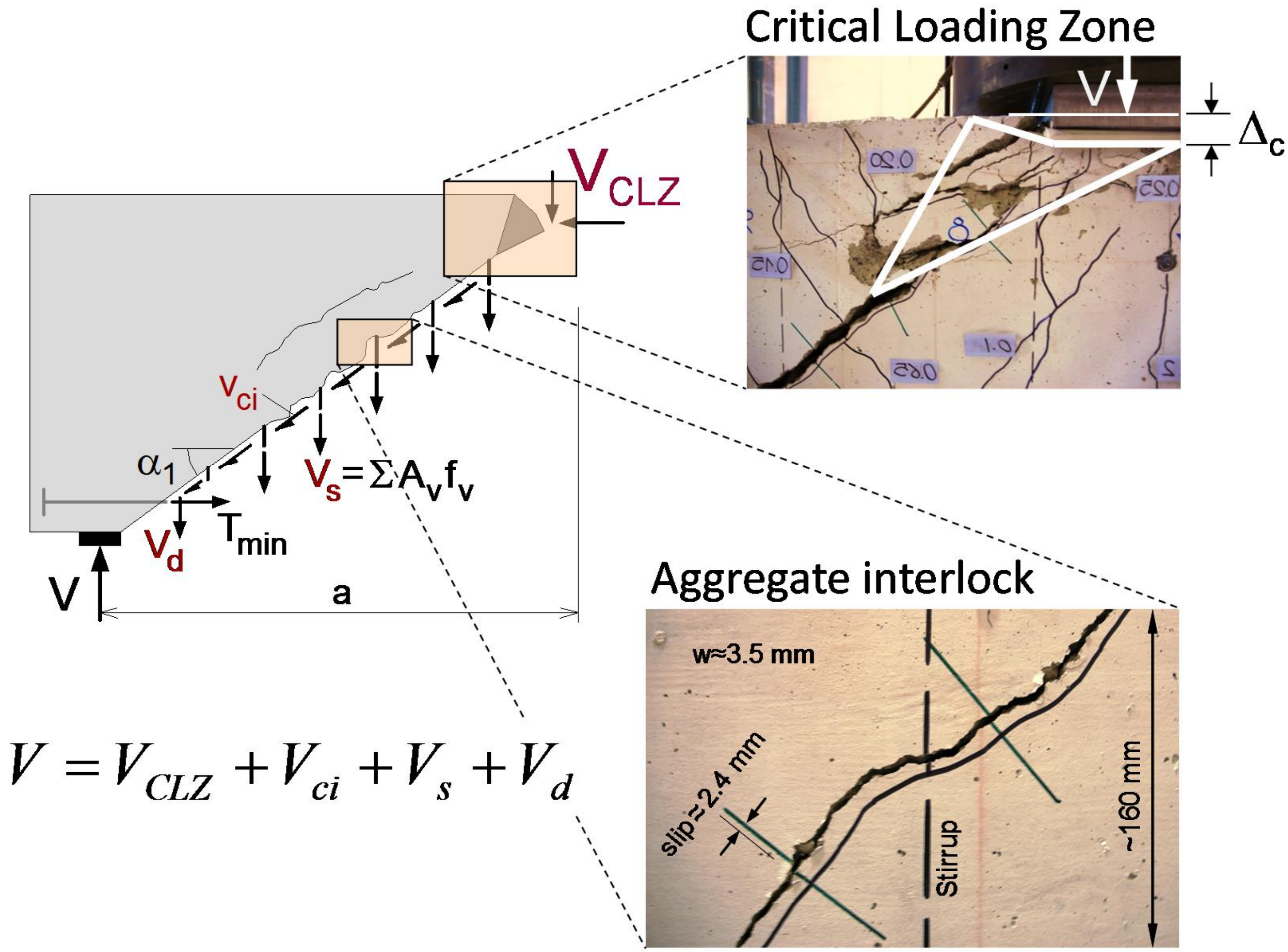


# Two-parameter kinematic theory (2PKT) for deep beams



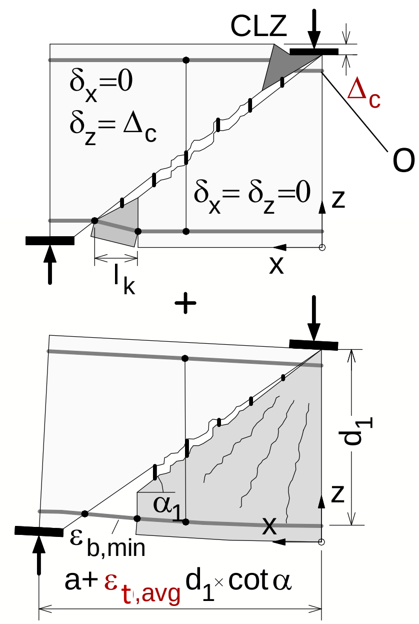

Mihaylov, Bentz & Collins (2013)

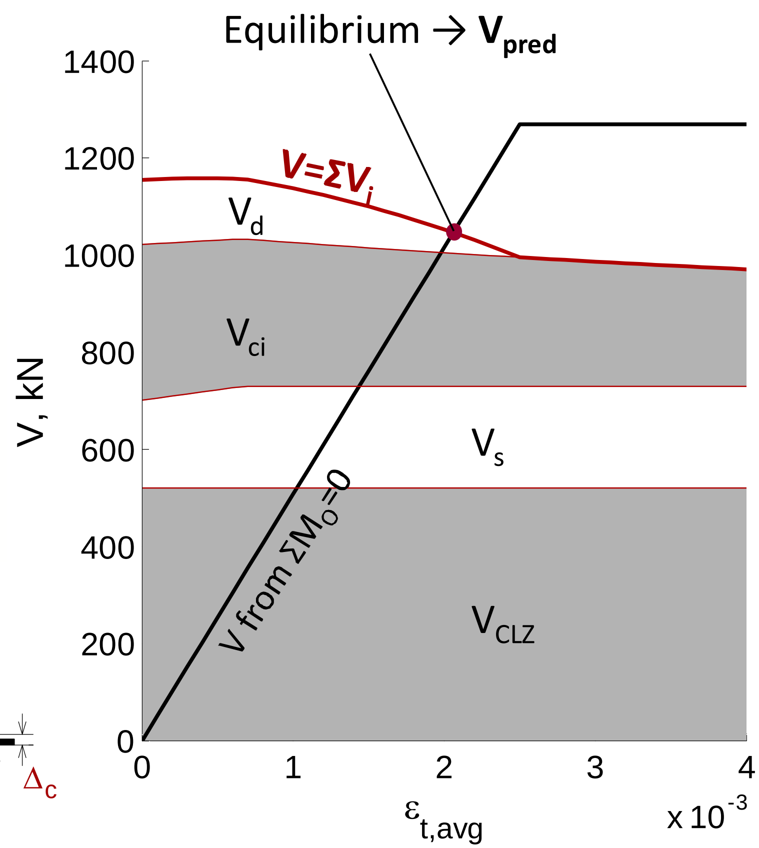
# Components of shear resistance in deep beams

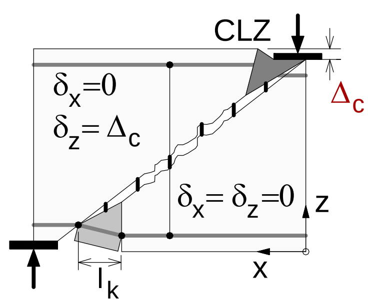



$$V = V_{CLZ} + V_{ci} + V_s + V_d$$

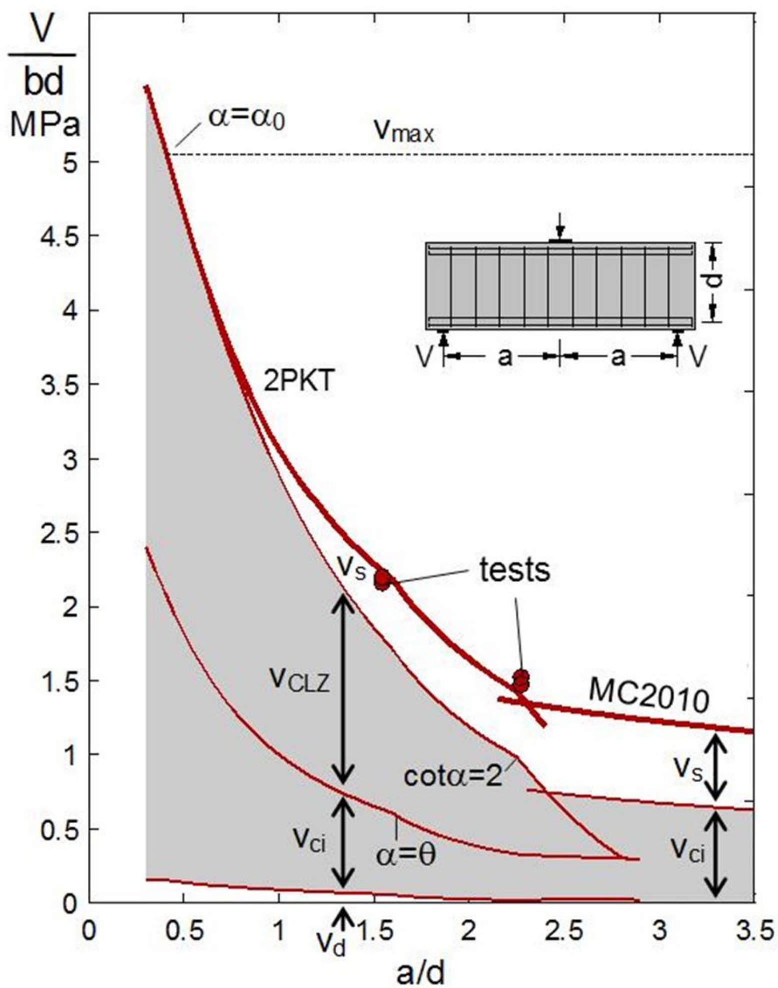
# Strain effect in deep beams



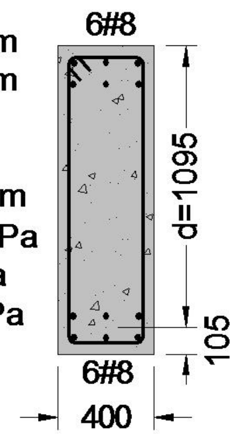



# Transition from deep to slender beams



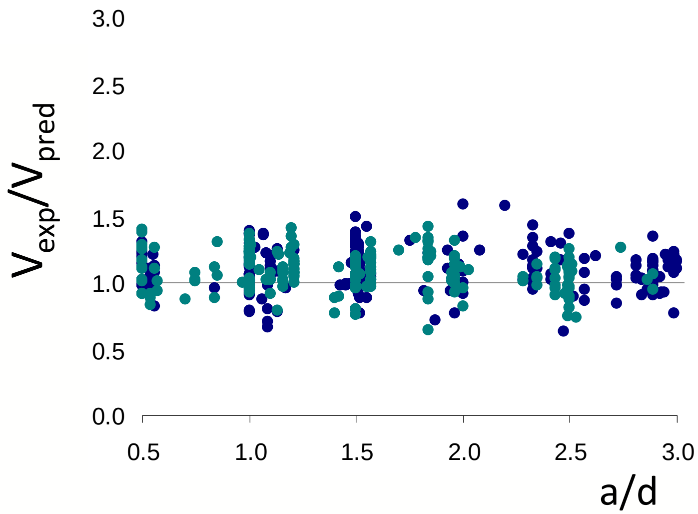

$L_{b1}$=300mm
$L_{b2}$=150mm
V/P=0.5
Stirrups
#3@350mm
$\rho_v f_{yv}$=0.5MPa
$f_y$=652MPa
$f_c'$=33.5MPa
$a_g$=20mm



# Shear strength predictions for deep beams

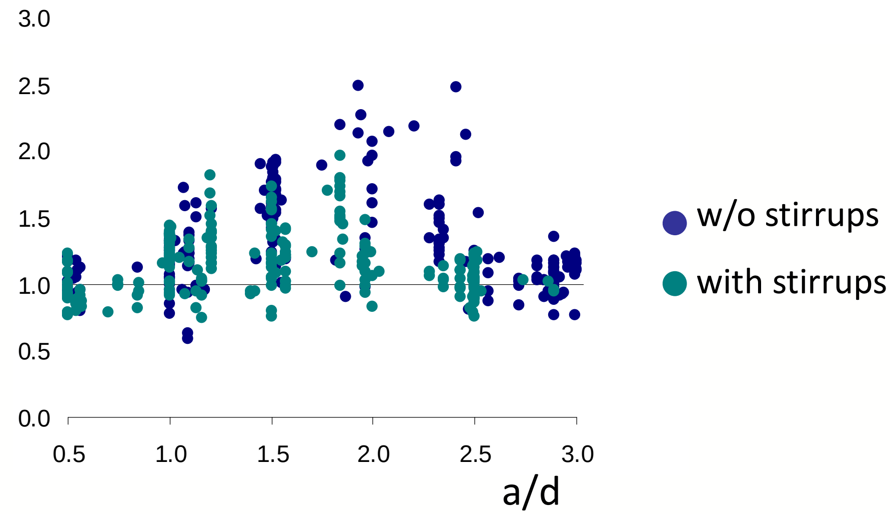
**2PKT** + MC2010

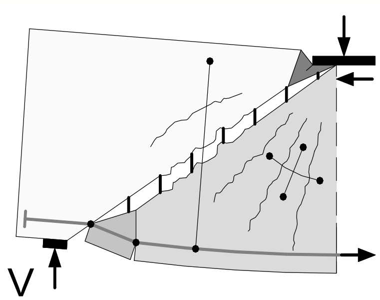
Avg.=1.10  COV=13.7%

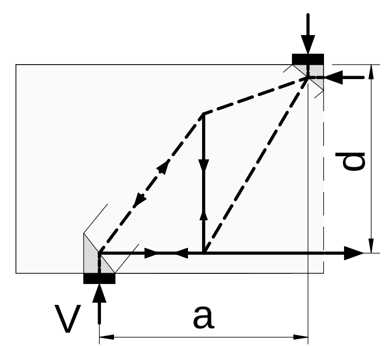



AASHTO **strut-and-tie**

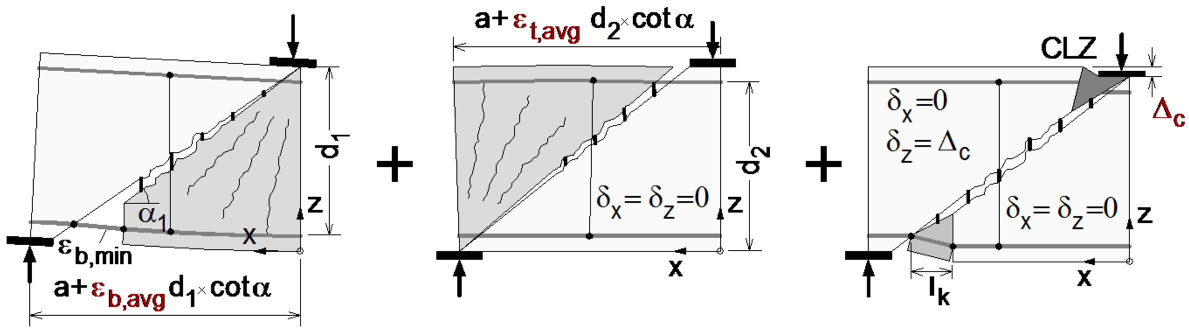
Avg.=1.25  COV=24.6%

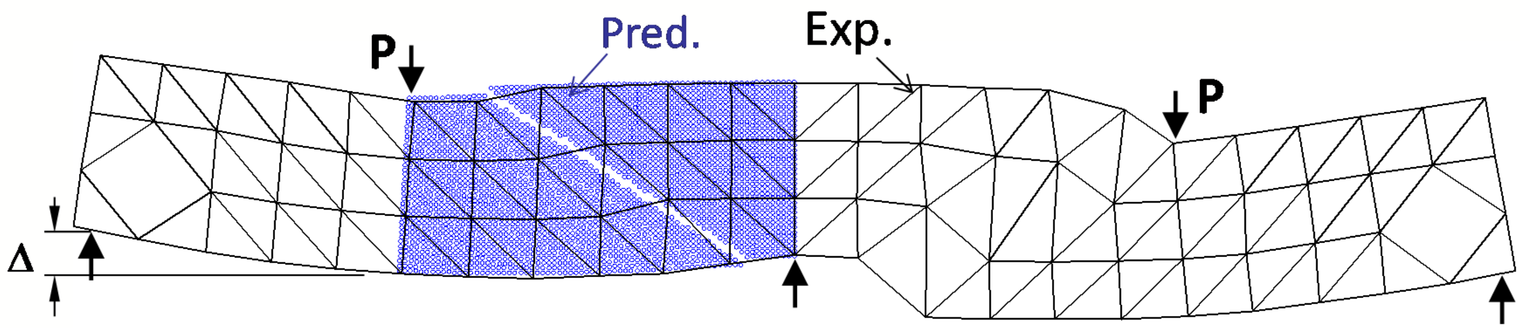


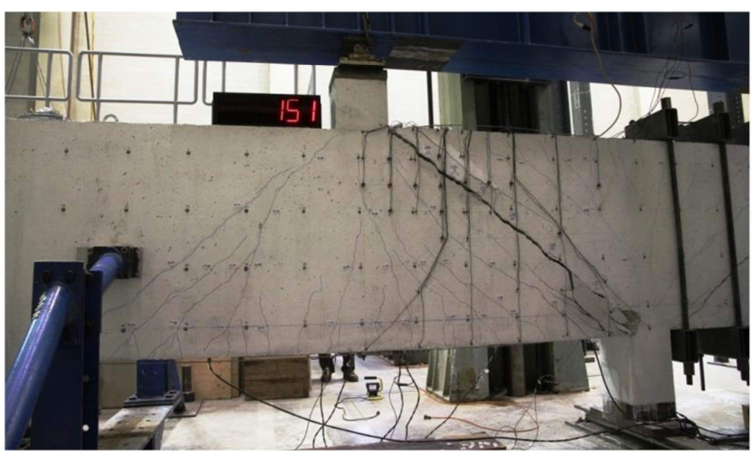



# Kinematic theory for continuous deep beams



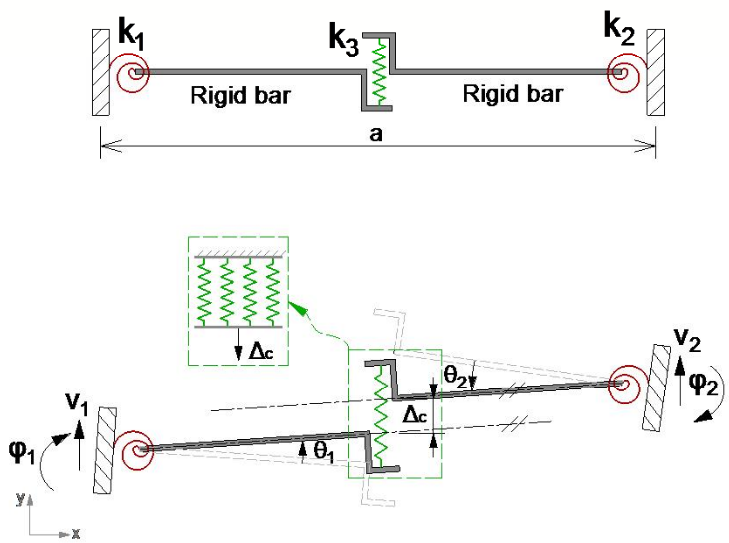



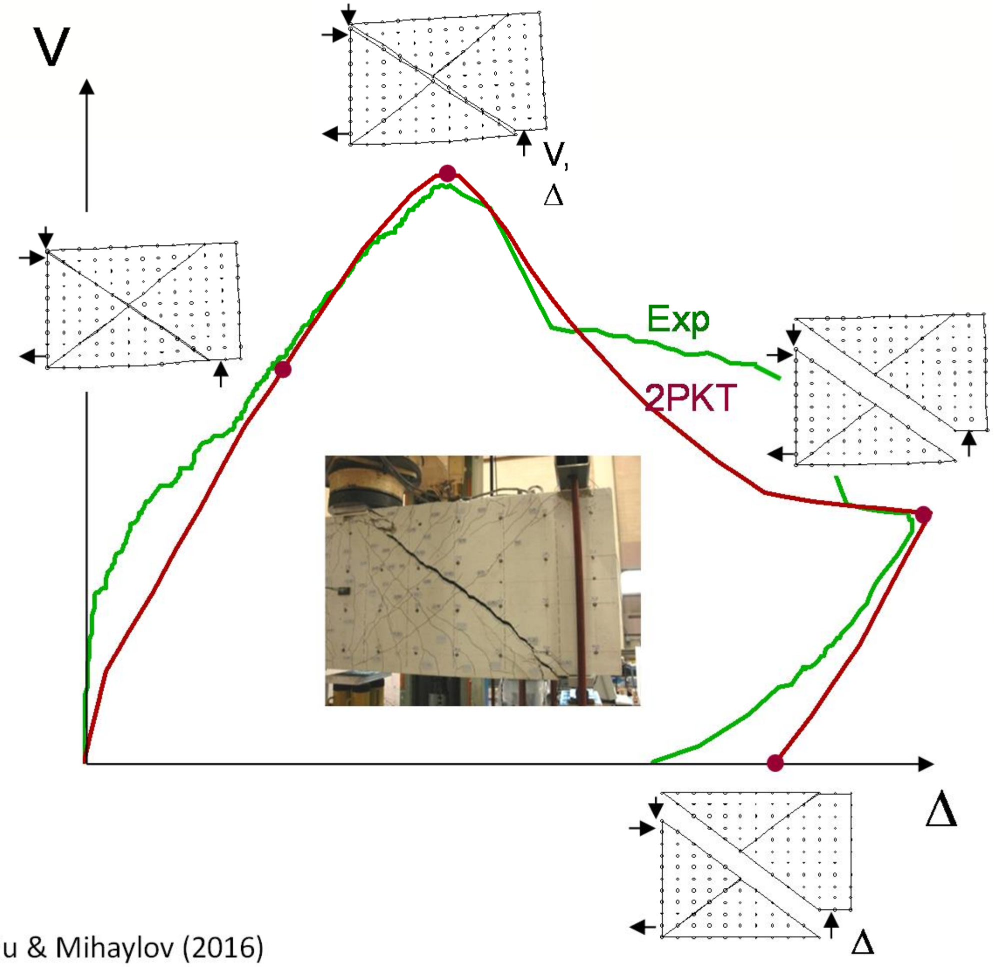



Mihaylov, Hunt, Bentz & Collins (2015)

# Kinematic theory for complete non-linear analysis of deep beams

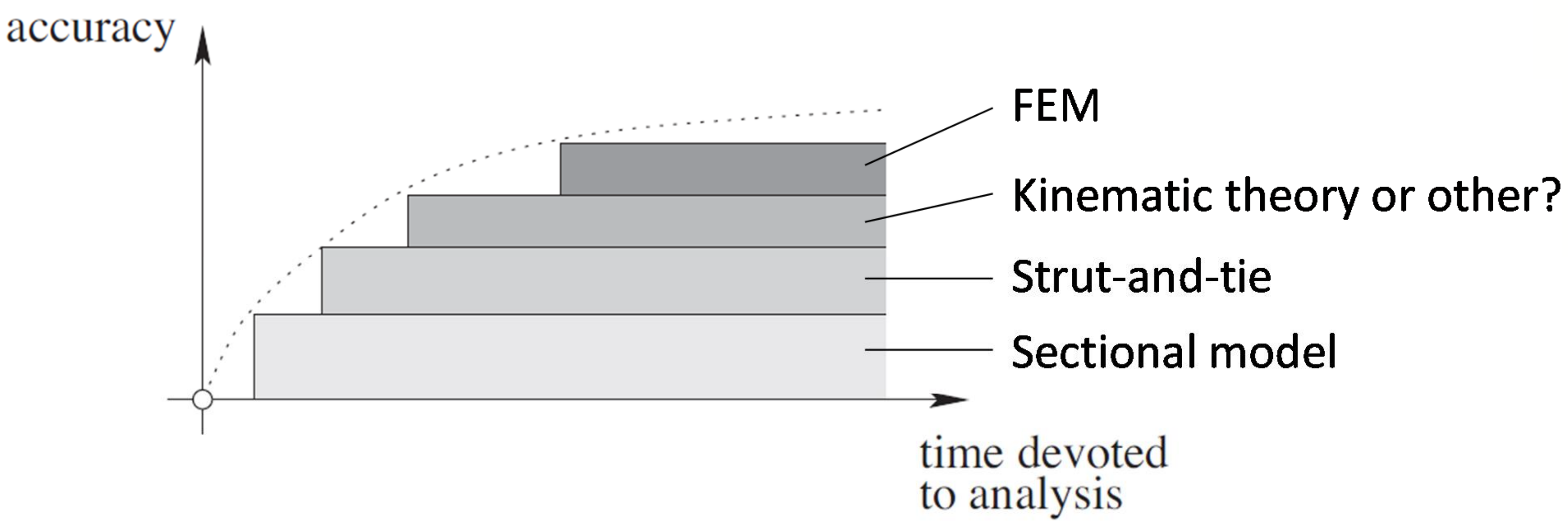
Macro element for shear spans of deep beams




Liu & Mihaylov (2016)

# Levels of approximation (LoA) for deep beams?




adapted from Muttoni (2003)

# Future Activities of work party 2.2.1: Shear in beams

2016: Workshop in Switzerland (to be confirmed) with the following objectives:

- In-depth discussion with invited speakers on shear design and analysis
- Papers used to prepare an *fib* bulletin (physical basis and experimental validation)
- Define future research topics and activities

Thank you for your attention!

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