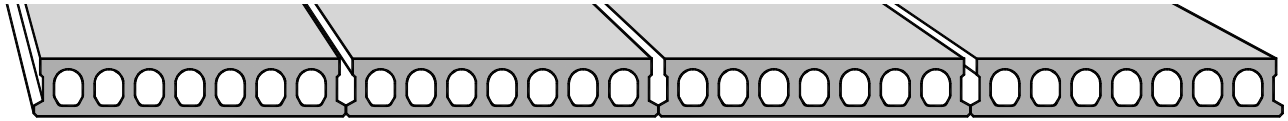
SSCS 2017
Numerical Modeling
Strategies for Sustainable Concrete Structures

NUMERICAL STUDY ON LOAD DISTRIBUTION IN HC FLOORS



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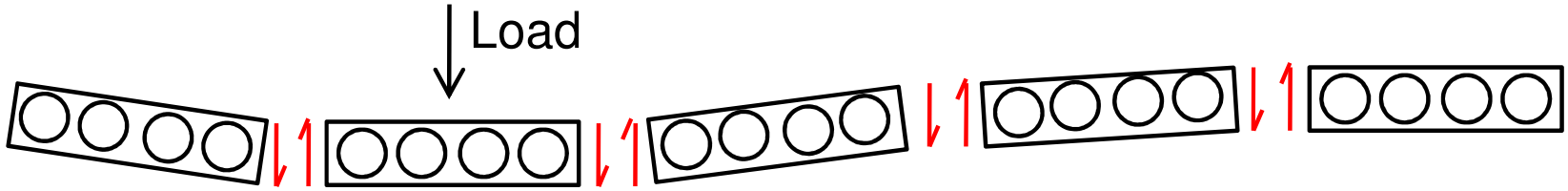
LOAD DISTRIBUTION IN HC FLOORS

REQUIREMENTS OF HC FLOORS →

- Vertical load bearing capacity
- Transverse load distribution → *longitudinal joints*



MAIN EFFECTS DUE TO CONCENTRATED LOADS:

- additional shear stresses due to torsion
- transverse bending moments → two-way slab behavior of the floor

↓

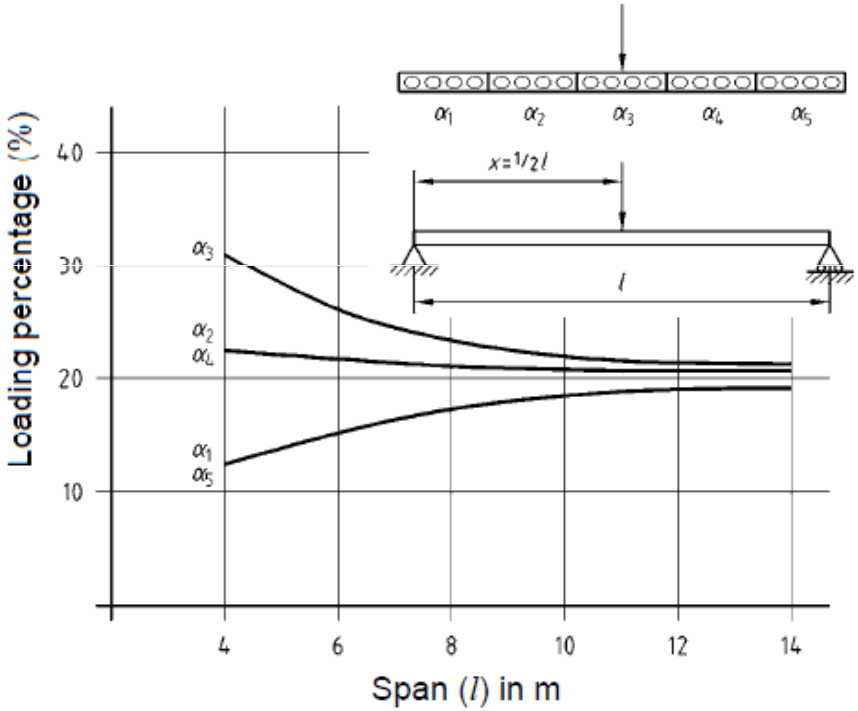
Transverse distribution of shear forces and of bending and torsional moments:

- SIMPLIFIED CURVES (DESIGN STANDARDS)
- NUMERICAL APPROACHES

SIMPLIFIED CURVES (UNI EN 1168)

Main simplified assumptions:

- Theory of elasticity
- Simply supported floor
- Five 1200mm wide units
- Line or point loads applied in the centre or along the edge of the floor



➢ Not clear if they are referred to:

- ***bending moment distribution*** at midspan
- ***shear force distribution*** at supports

MAY BE VERY DIFFERENT FROM EACH OTHERS

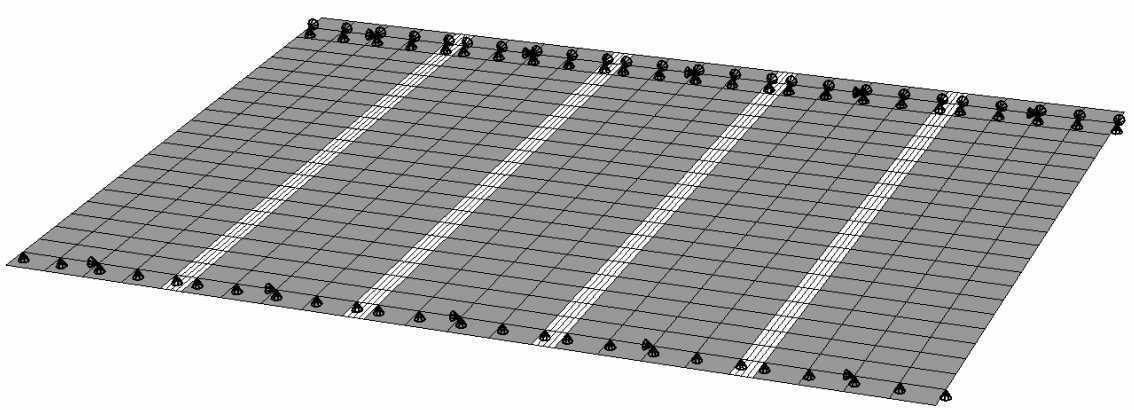
➢ Not dependent on the ***ratio EI/GJ$_t$*** of the HC cross section

➡ **NUMERICAL APPROACHES required**

SIMPLIFIED LINEAR ELASTIC FE MODELS

Definition of the case studies and adopted FE mesh

- Simply supported floor
- Five units, 1200mm wide and 300mm thick
- Variable net spans (4 - 14m)



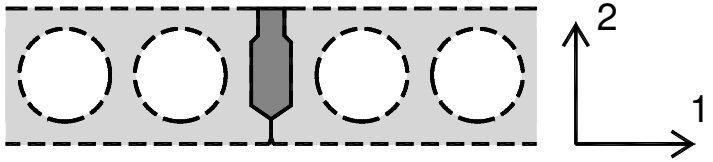
- Floor FE mesh, with ***four-node, one-layered shell elements*:**

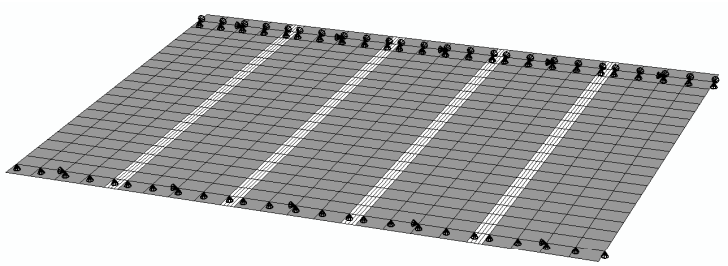
  - ***presence of webs neglected***
  - *same bending stiffness* as the real units in the main direction
  - *overestimation of torsional stiffness*

→ $EI/GJ_t = 0.73$ (effective value ***1.06***)

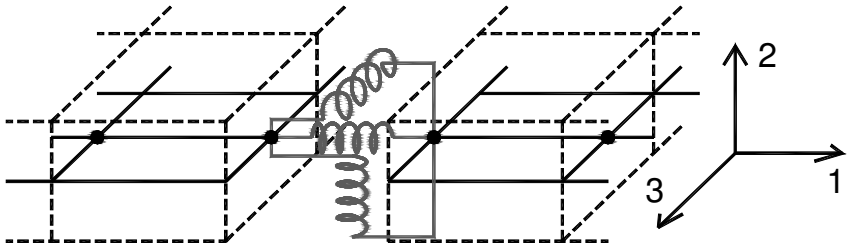
SIMPLIFIED LINEAR ELASTIC FE MODELS

Joint modelling



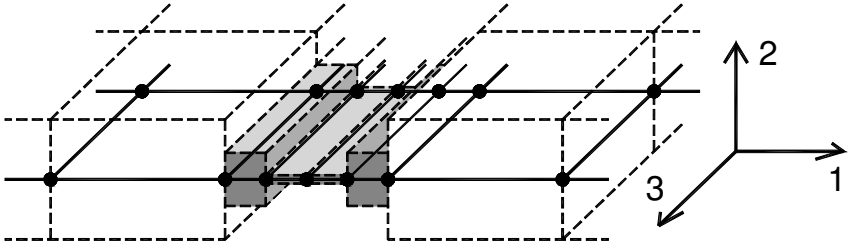


Two adopted approaches:



"Model S1": ***spring elements*** connected to shell elements modelling the units

Spring stiffness/Shell thickness evaluated so to simulate an ***hinge behaviour***

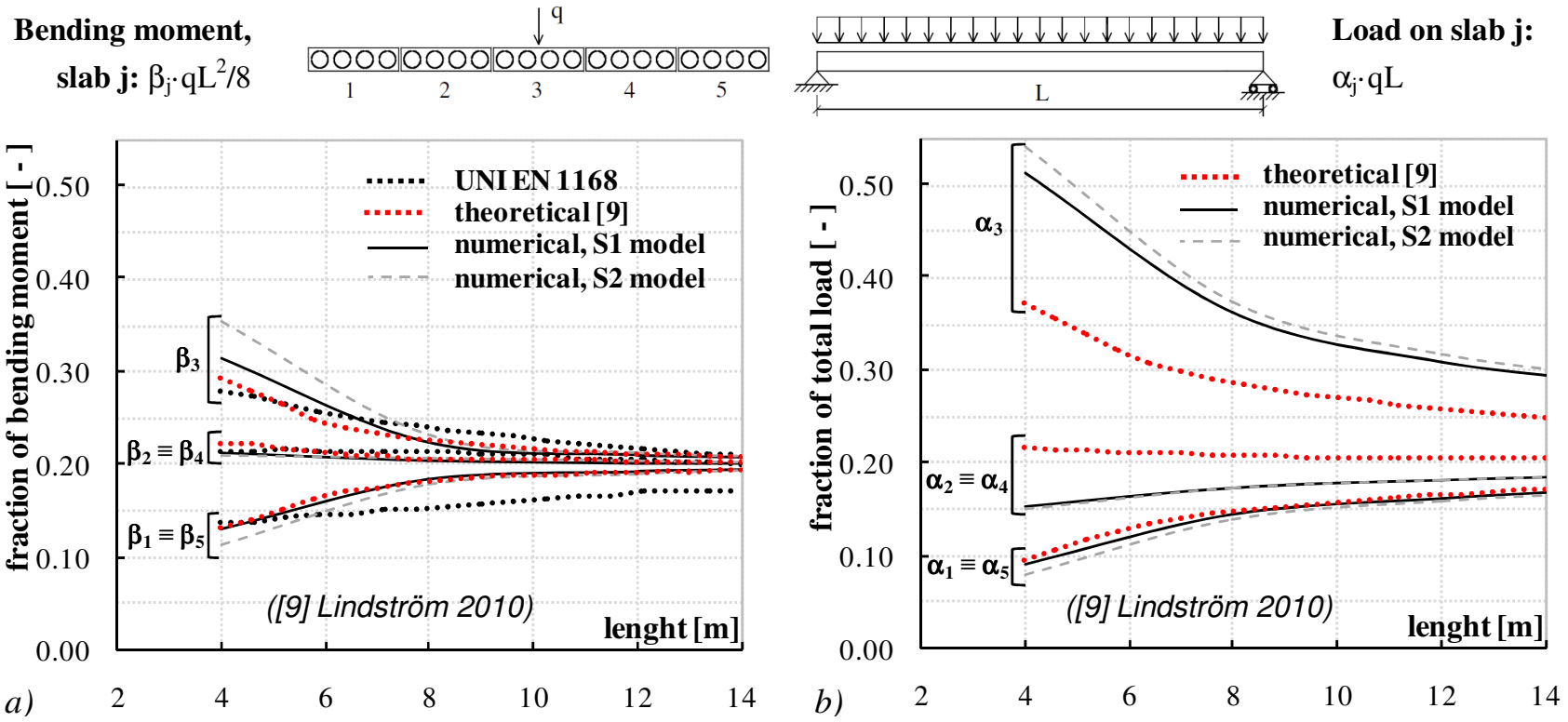


"Model S2": ***horizontal shell elements*** with variable thickness, connected to shell elements modelling the units

SIMPLIFIED FE MODELS: NUMERICAL RESULTS

line load on panel 3

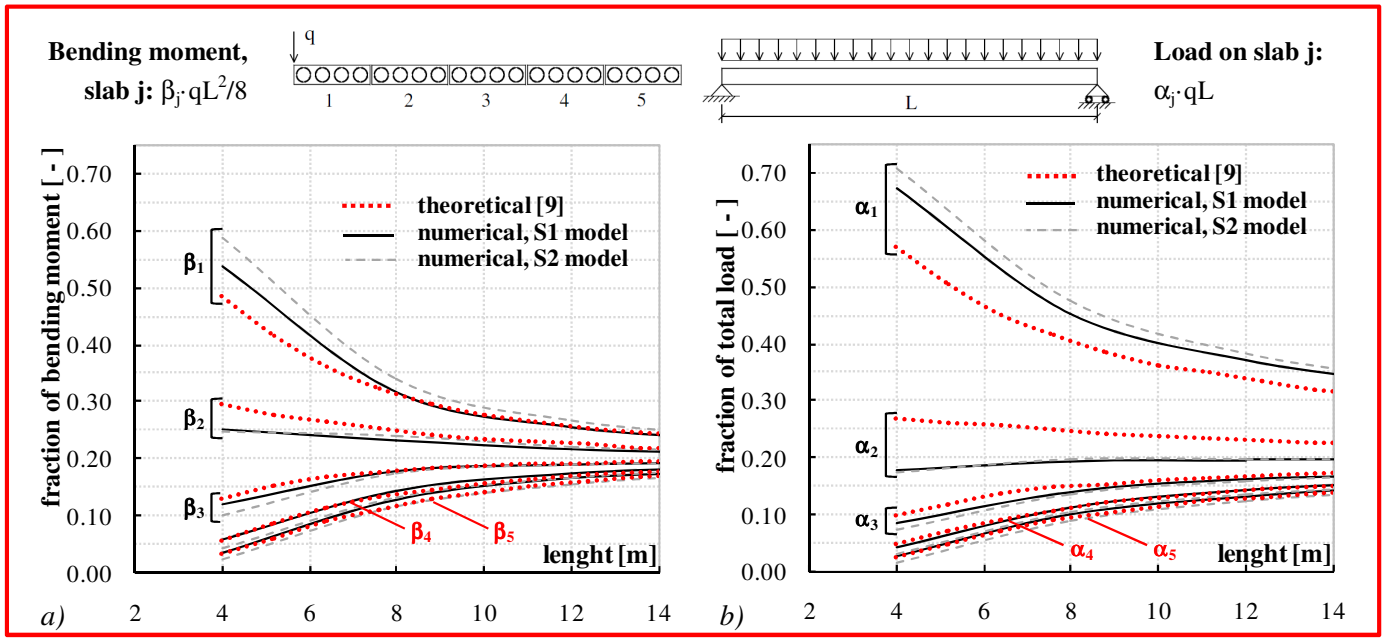
EI/GJ$_t$ = 0.73

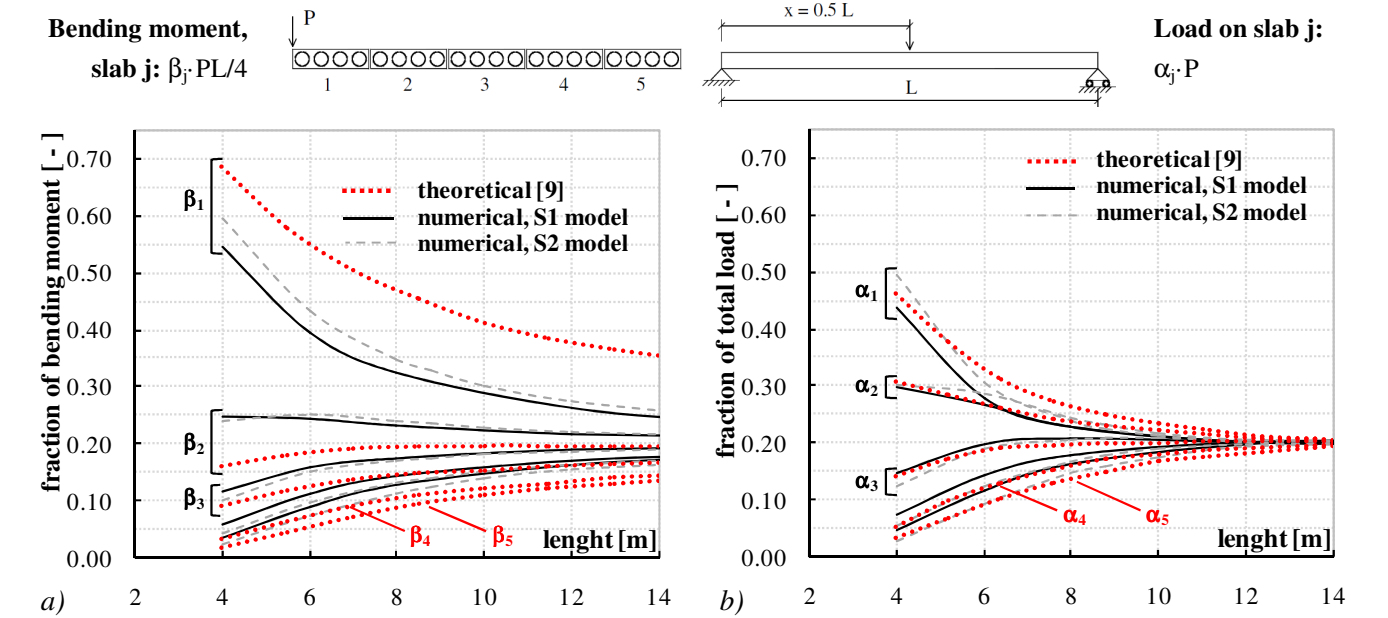


bending moment at midspan ***total load at support***

- *Shear* at support ***less distributed*** with respect to *bending effects*.
- Similar numerical curves (S1, S2).
  Better agreement with theoretical provisions in terms of bending effects.

SIMPLIFIED FE MODELS: NUMERICAL RESULTS





bending moment at midspan **total load at support**

EI/GJ$_t$ = 0.73

line load on panel 1

*Shear effects **less distributed** than bending ones.*

point load on panel 1

*Bending effects **less distributed** than shear ones.*

([9] Lindström 2010)

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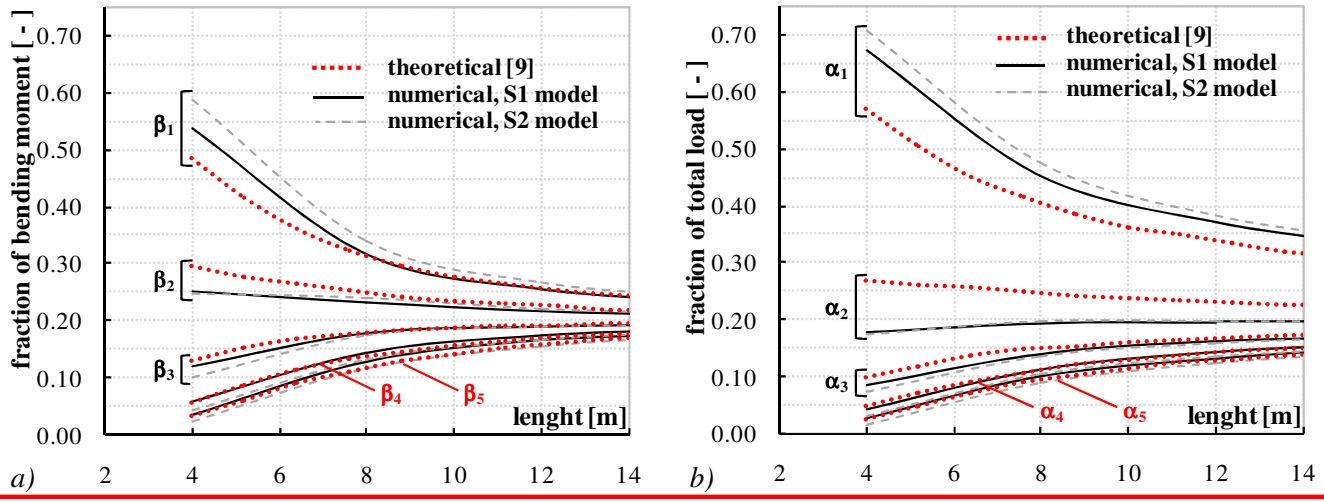
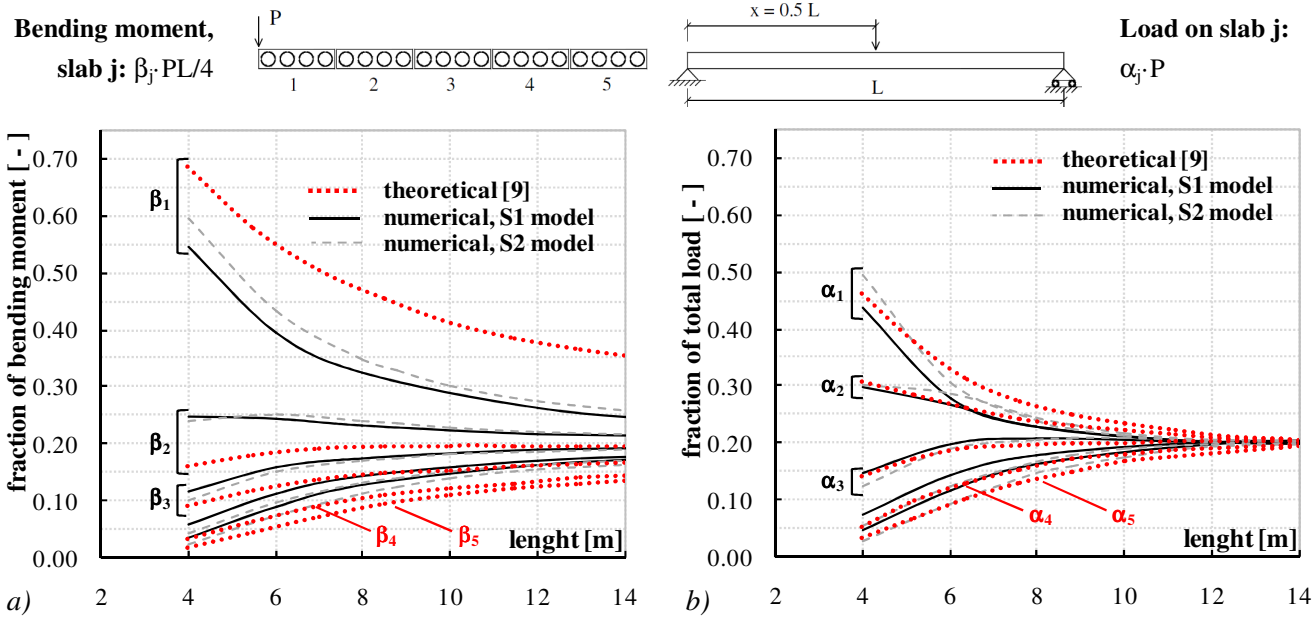
"Numerical study on load distribution in HC floors"

SIMPLIFIED FE MODELS: NUMERICAL RESULTS

Bending moment, slab j: $\beta_j \cdot qL^2/8$ — **Load on slab j:** $\alpha_j \cdot qL$



Bending moment, slab j: $\beta_j \cdot PL/4$ — **Load on slab j:** $\alpha_j \cdot P$



bending moment at midspan **total load at support**

$EI/GJ_t = 0.73$

line load on panel 1

*Shear effects **less distributed** than bending ones.*

point load on panel 1

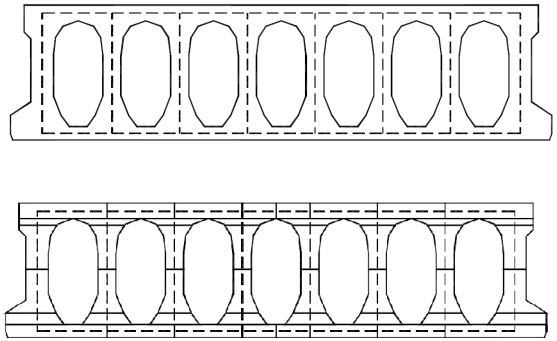
*Bending effects **less distributed** than shear ones.*

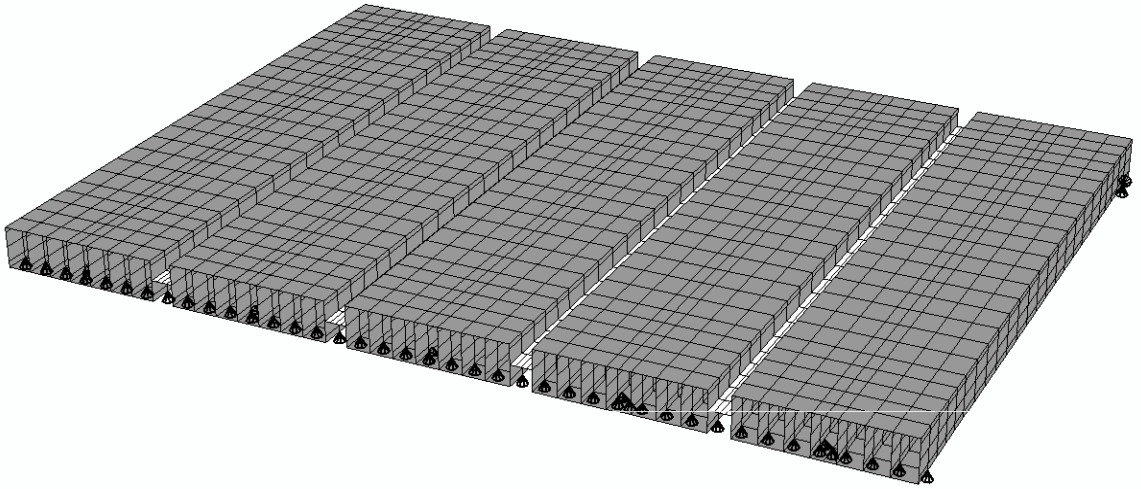
([9] Lindström 2010)

MORE COMPLEX FE MODELS

Simplified models not able to represent the effective behaviour of HC floors

For a correct description of shear and torsion transferring mechanisms it is necessary to ***model each web*** *with solid or shell elements*



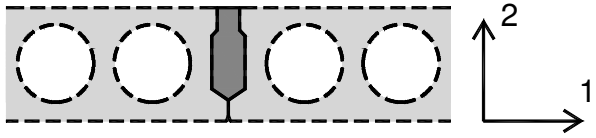


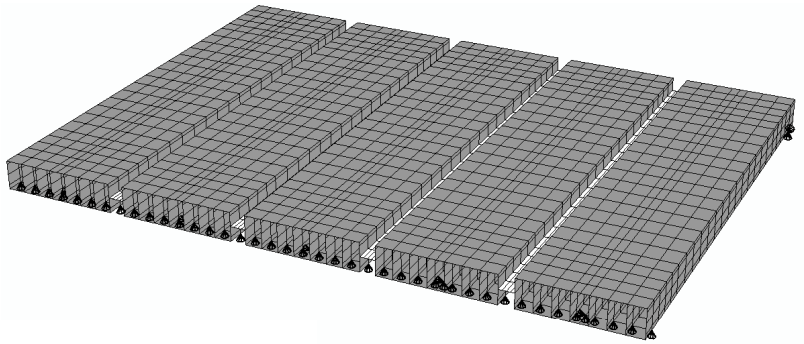
$EI/GJ_t = 1.06$ (effective value)

FE mesh, with four-node, one-layered shell elements representing the *middle plane of the webs and of the bottom and top slabs* for *HC units*

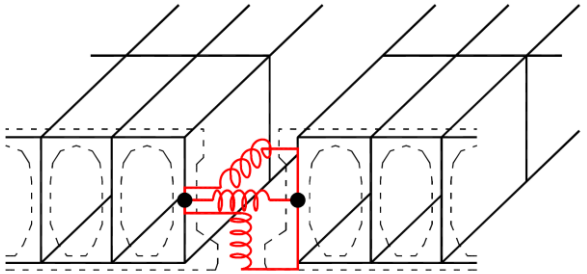
MORE COMPLEX FE MODELS

Joint modelling



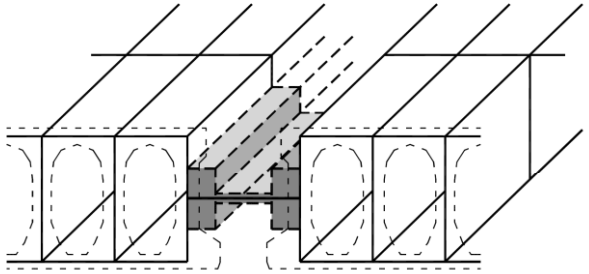


"Model C1": ***spring elements*** connected to shell elements nodes, in the external webs of the units



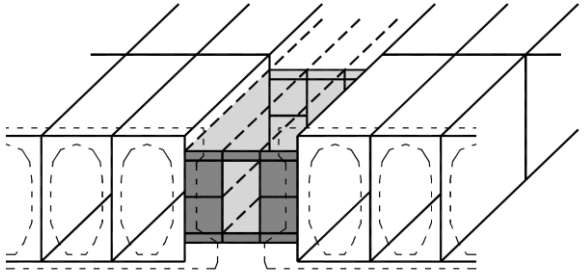
same as ***"Model S1"***

"Model C2": ***horizontal shell elements*** connected to shell element nodes, in the external webs of the units



same as ***"Model S2"***

"Model C3": ***vertical shell elements*** connected to shell element nodes, in the external webs of the units



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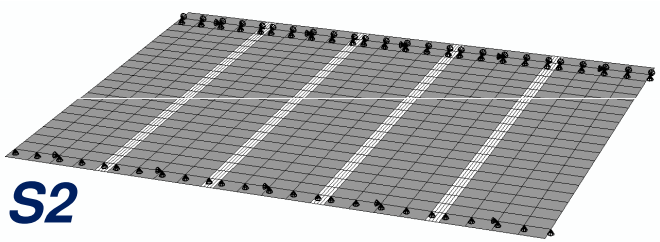
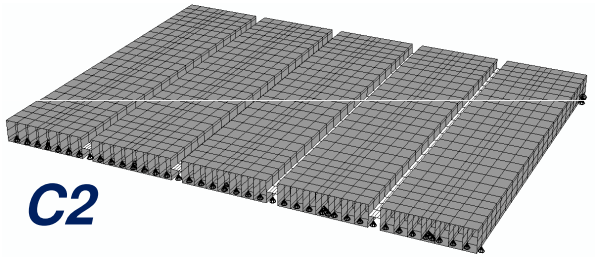
COMPARISONS BETWEEN SIMPLIFIED AND COMPLEX MODELS

- *Same* modelling technique for *joints* but *different* schematization for *units*

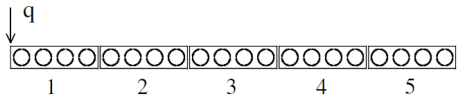
e.g.:

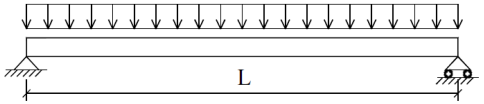




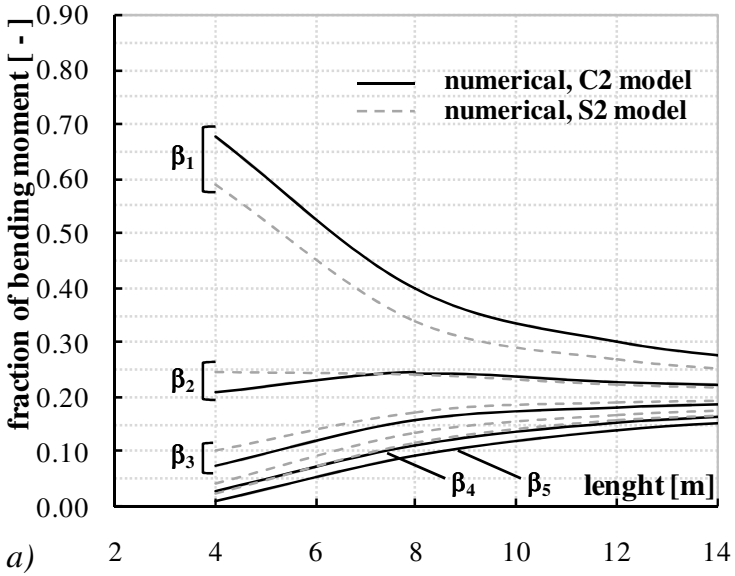
line load on panel 1

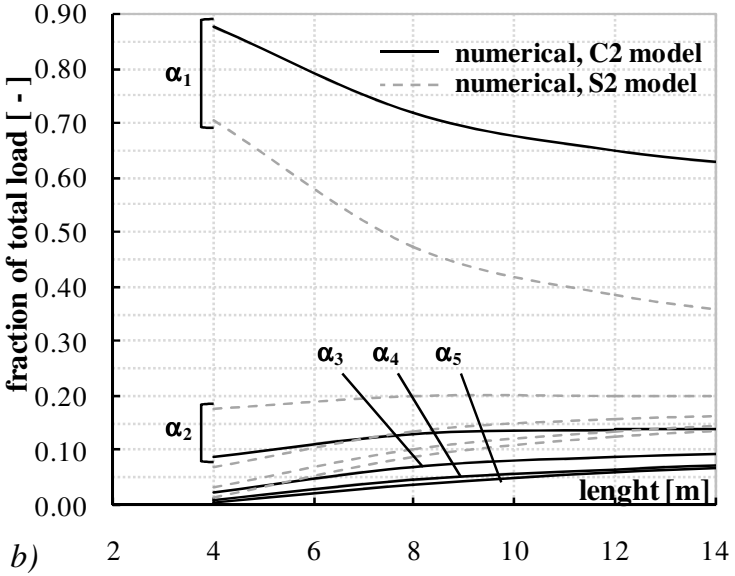
Bending moment, slab j: $\beta_j \cdot qL^2/8$





Load on slab j: $\alpha_j \cdot qL$





When considering the *real floor geometry*

greater concentration of loading effects

bending moment at midspan

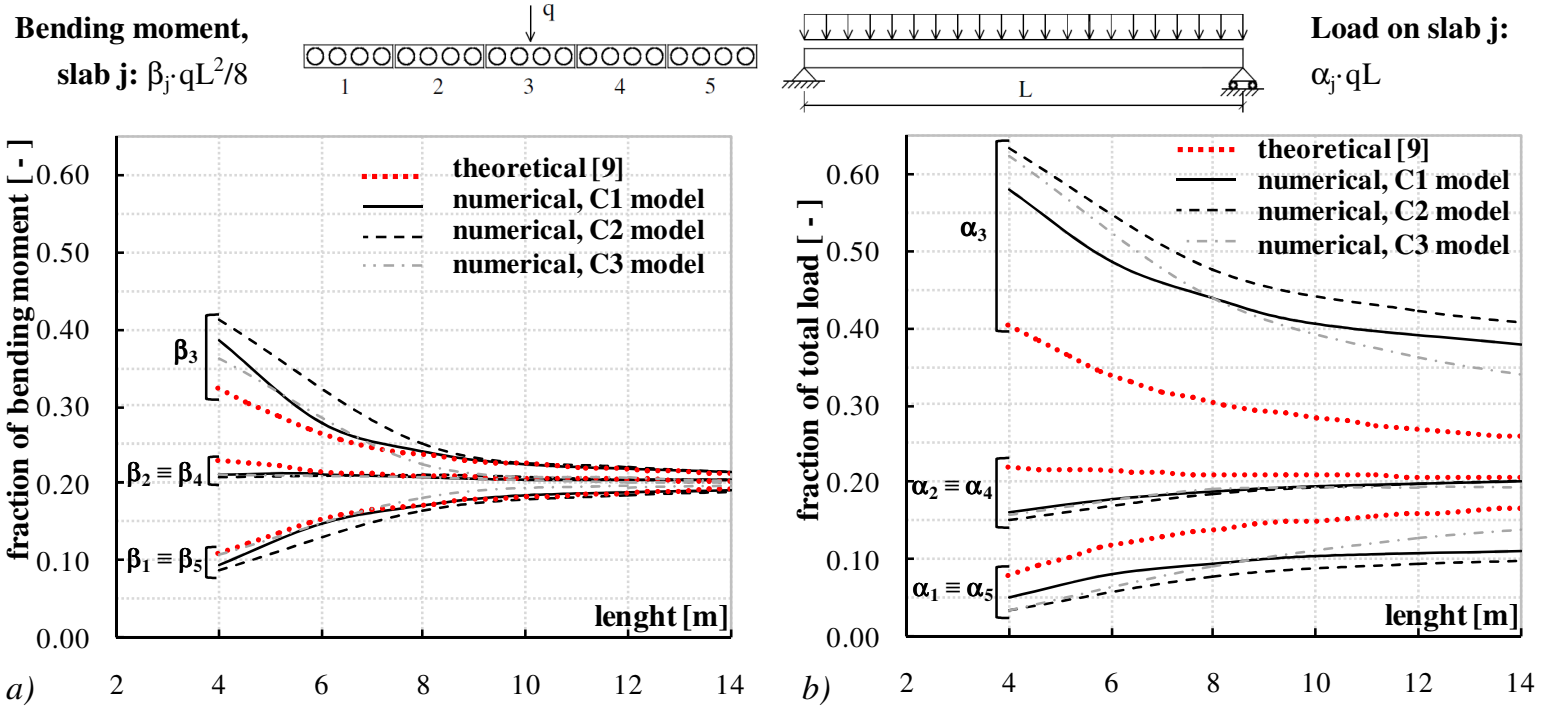
total load at support

COMPARISONS AMONG COMPLEX MODELS

- *Same* modelling technique for *units* but *different* schematization for *joints*

line load on panel 3

EI/GJ$_t$ = 1.06



bending moment at midspan ***total load at support***

([9] Lindström 2010)

- Models C1, C2, C3 predict the *different behaviour in shear and bending*
- *Overestimation* of load effects *with respect to theoretical solutions*

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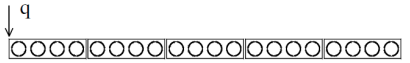
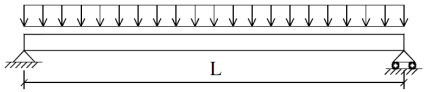
COMPARISONS AMONG COMPLEX MODELS

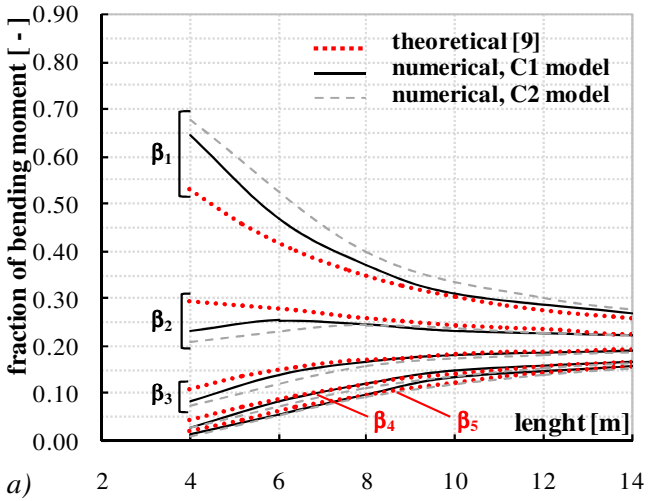
line load on panel 1

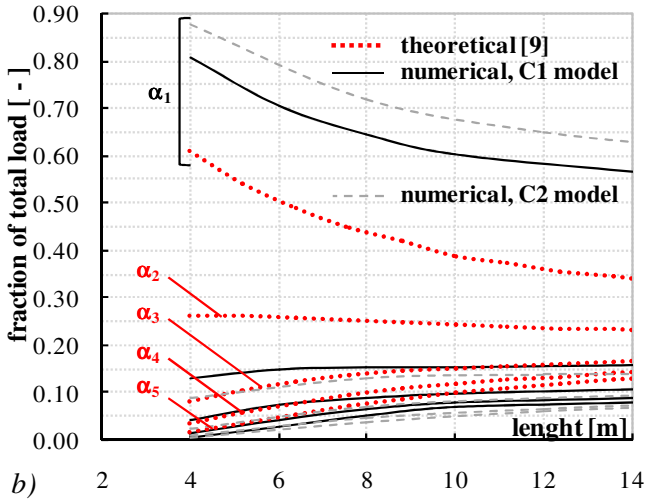
Bending moment, slab j: $\beta_j \cdot qL^2/8$

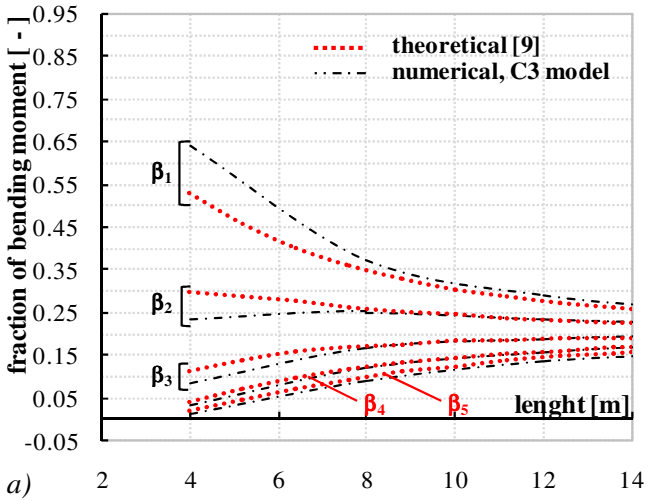


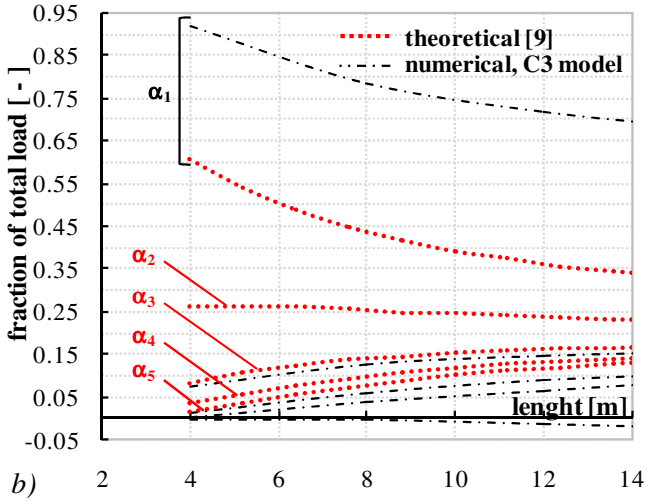


Load on slab j: $\alpha_j \cdot qL$









bending moment at midspan ***total load at support***

$EI/GJ_t = 1.06$

- Different behaviour in shear and bending
- *Overestimation* of load effects with respect to theoretical solutions

especially for *shear distribution*

([9] Lindström 2010)

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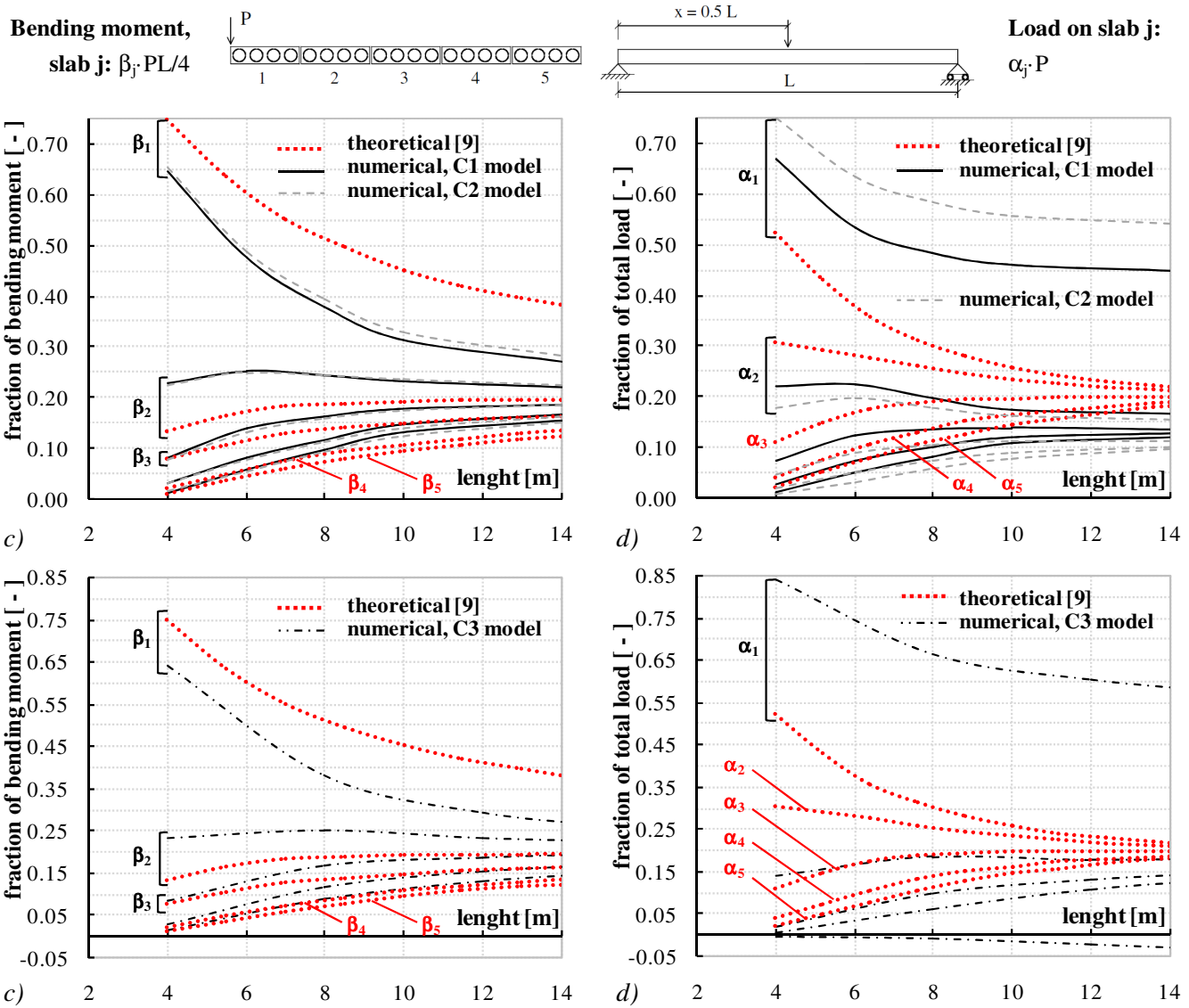
COMPARISONS AMONG COMPLEX MODELS

point load on panel 1



bending moment at midspan ***total load at support***

EI/GJ$_t$ = 1.06

- Different behaviour in shear and bending
- *Overestimation* of total load with respect to theoretical solutions
- *Greater load effects redistribution in bending with respect to shear*, differently from theoretical solutions

([9] Lindström 2010)

FE MODEL VALIDATION – COMPARISONS WITH EXPERIMENTAL RESULTS

Simulation of a *full-scale test on a HC floor* (Suikka et al., VTT, 1991) through the ***complex models***

Geometry of the specimen:

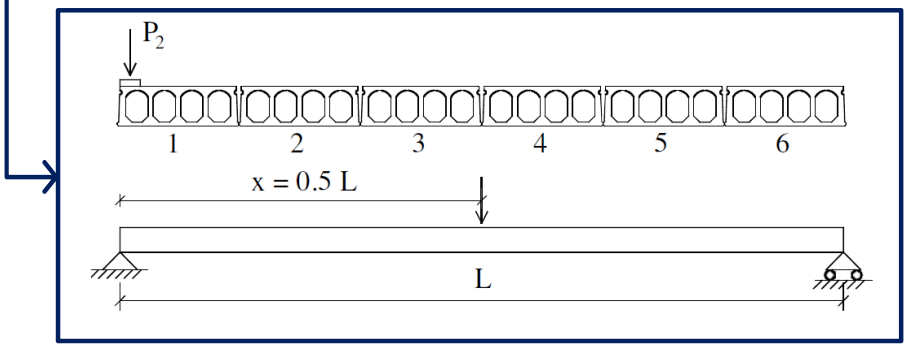
- Six 400 mm thick panels
- Simply supported floor (net span = 12.1 m)

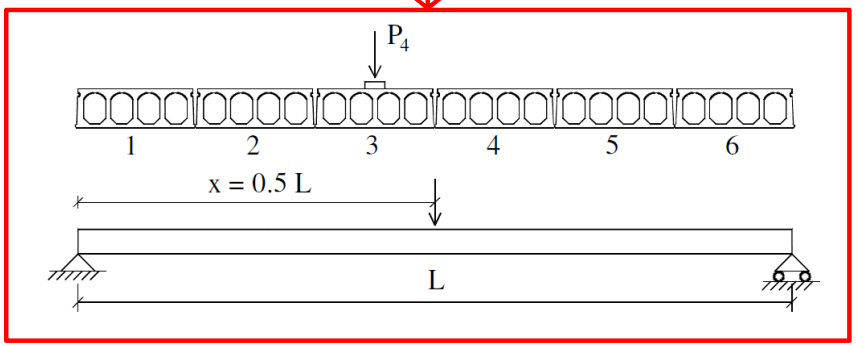
Loading arrangement:

Point load positions:

- P1 → *floor edge*, L/6 from one support
- P2 → *floor edge*, midspan
- P3 → *centre of panel 3*, L/6 from one support
- P4 → *centre of panel 3*, midspan

4 loading cases (***service loads***)





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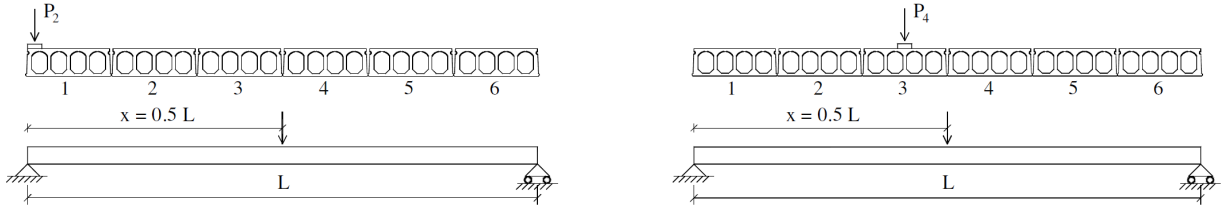

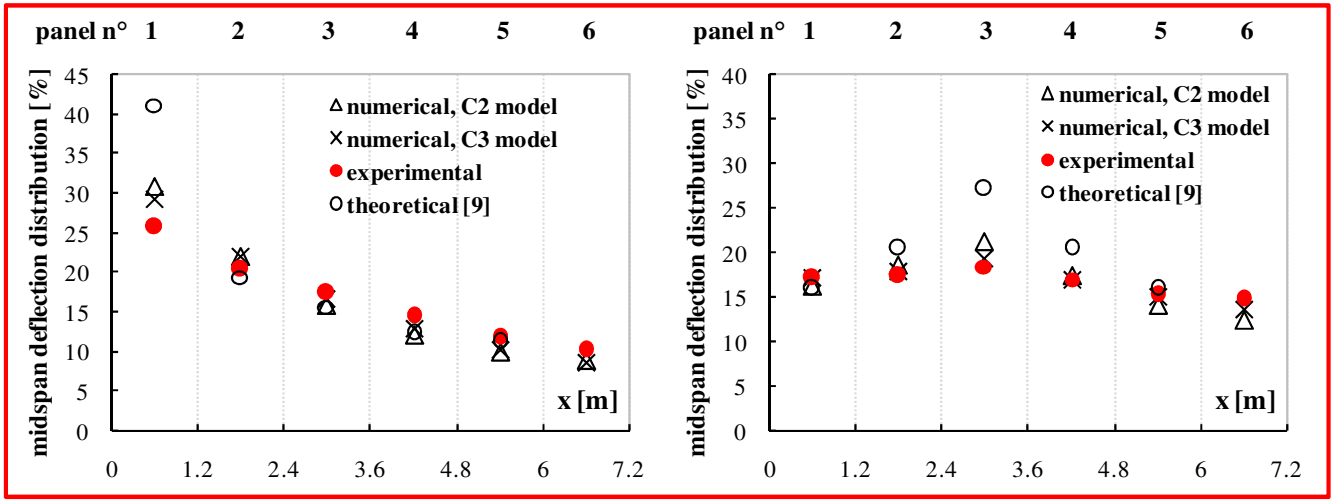

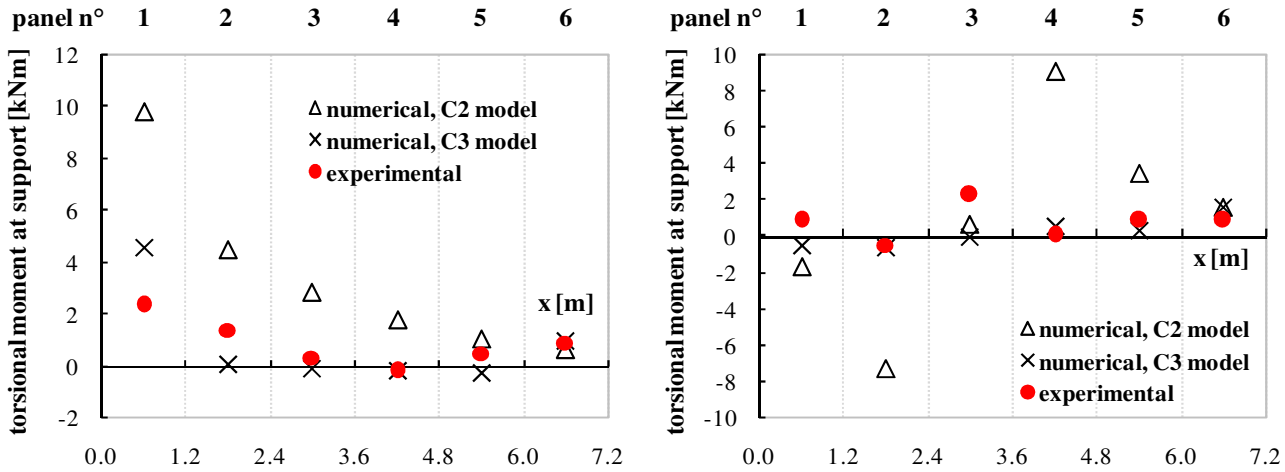

([9] Lindström 2010)

Flexural behaviour

Numerical values of ***midspan deflections*** are:

- *similar to experimental ones*
- *not influenced by joint modelling* technique

Theoretical provisions (for 5 units) suggest a ***lower redistribution***

Torsional behaviour

Numerical values of ***torsional moments*** are *affected by joint modelling*

model C3 better fits experimental data

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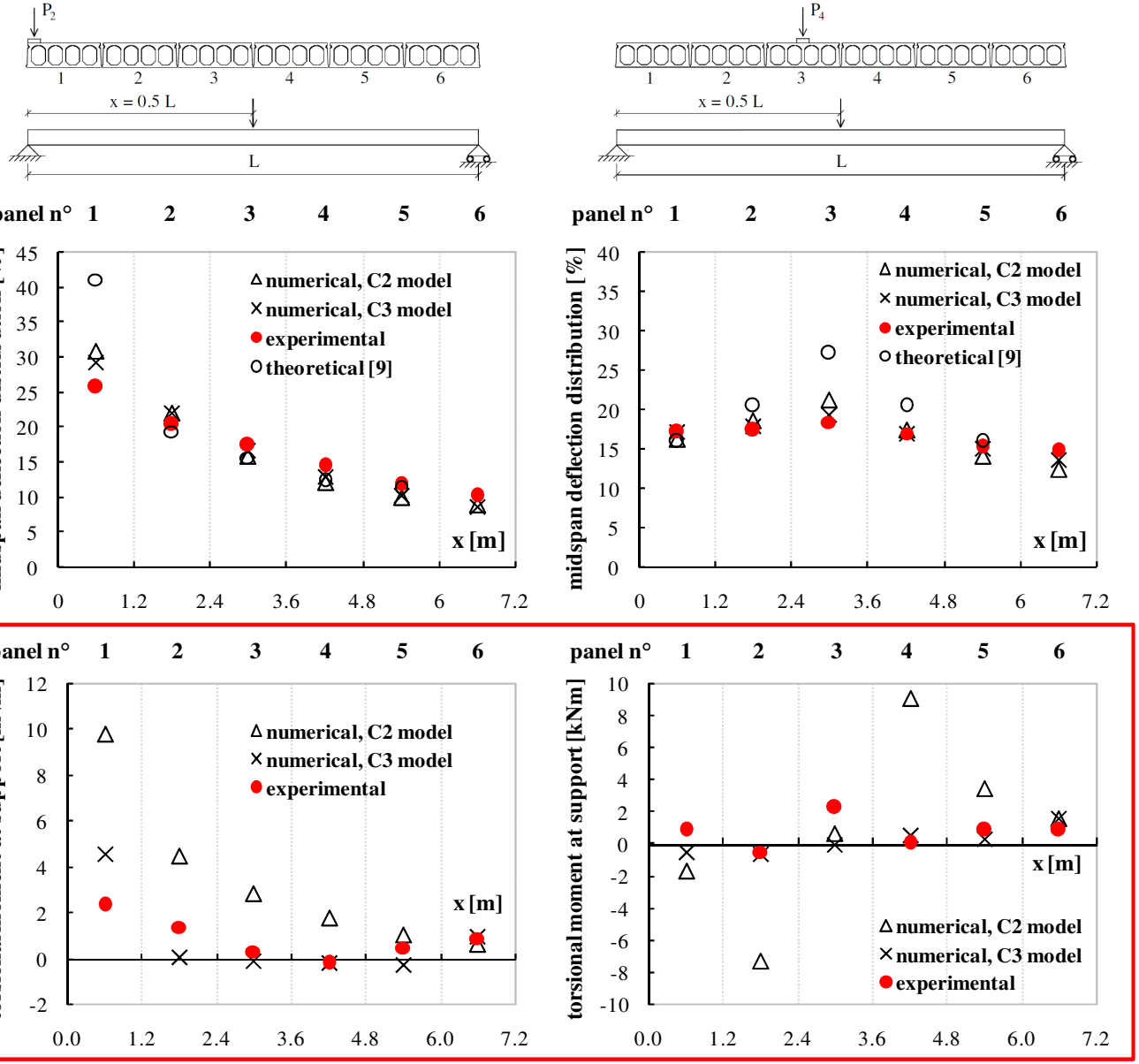
FE MODEL VALIDATION – COMPARISONS WITH EXPERIMENTAL RESULTS



([9] Lindström 2010)

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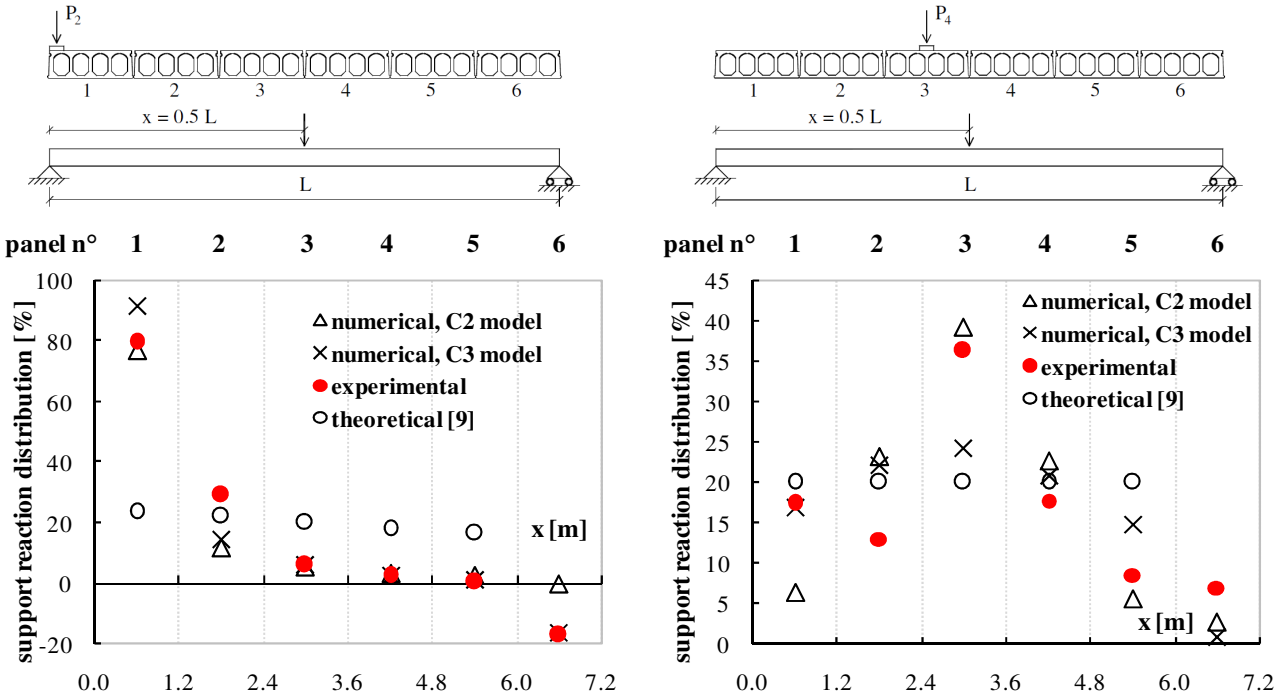

([9] Lindström 2010)

Shear behaviour

Numerical values of ***support reactions*** are *affected by joint modelling*

Theoretical provisions (for 5 units) suggest a ***greater redistribution***

➢ ***Load case P2***: similar response of models C2 and C3, *close to experimental data in the central part of the floor*.

➢ ***Load case P4***: trend of models C2 and C3 consistent with theoretical provisions even if it seems not to be confirmed by experimental data.
Higher concentration of loading effects for model C2 with respect to model C3.

CONCLUSIONS

• FE procedures represent a useful tool for analyzing the distribution of loading effects in HC floors. *Different modelling techniques have been applied both for panels and for longitudinal joints*, with an increasing degree of complexity.

• When a ***simplified approach*** is used ***for panel discretization***, the global behaviour is *very close to theoretical one* both in flexure and in shear, independently of joint modelling.

• When a ***schematization more close to effective panel geometry*** is adopted, a *larger gap* between numerical and theoretical provisions can be observed (especially for *shear distribution*), since FE models suggest a minor redistribution of load effects among panels. This trend seems to be confirmed also by experimental data, which are quite correctly predicted by complex approaches.

• In this last case, *joint modelling exerts a major influence* on structural response.

FURTHER DEVELOPMENTS

Further developments will be relative to the extension of this model to ***nonlinear FE analysis***, able to describe global HC floor behaviour up to failure

ACKNOWLEDGEMENTS

This research work is part of a larger study funded by the ASSAP Association (Prestressed HC floor Producers Association).

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The Authors would also like to thank Dr Tony Crane at IPHA, as well as Dr Olli Korander and Dr Erkki Kaivola at Consolis Technology Oy (Finland), for having provided the technical reports containing the experimental data.