# FE modelling of URM and PTM shear wall assemblies

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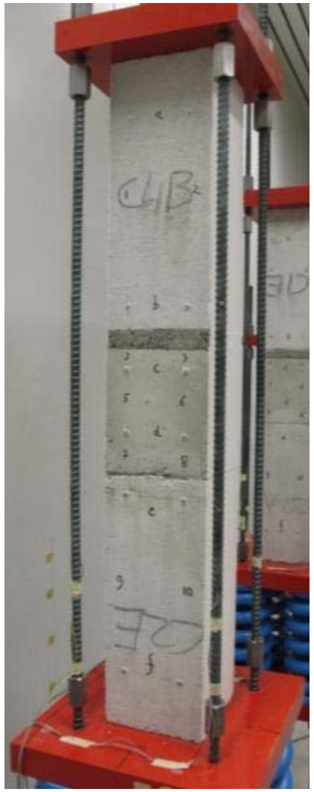
Where innovation starts

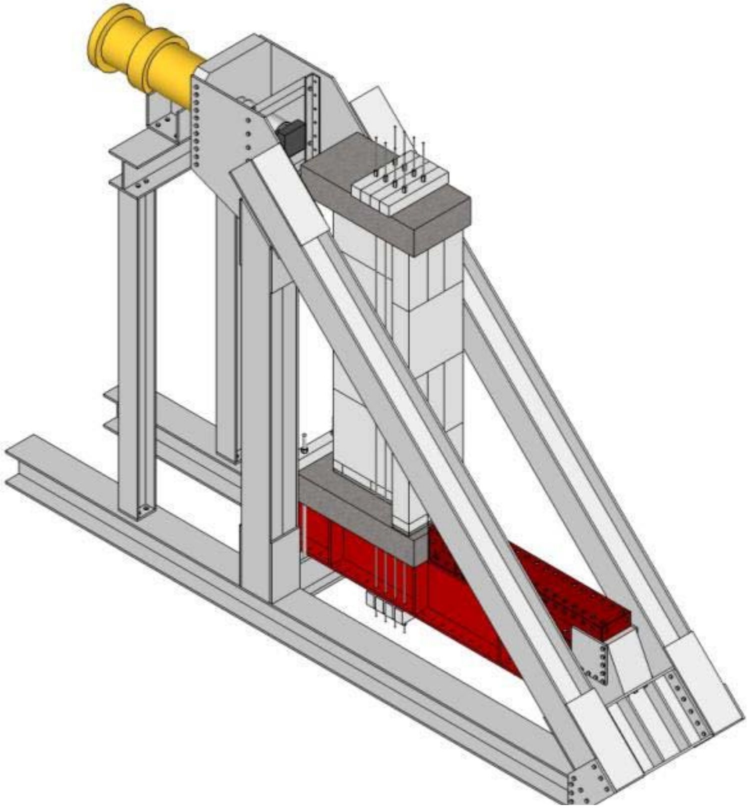
# / Introduction

## Post-tensioned shear walls of CASIEL-TLM masonry

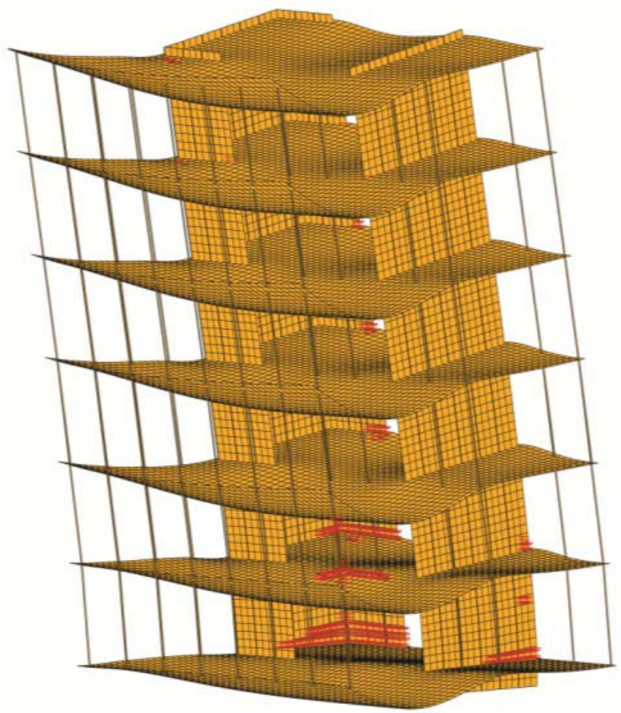
### Prestress loss



### PT shear wall behaviour



### PT shear wall assemblies



**Development of design rules and construction guidelines**

# / Introduction

## Assumptions

- Wind-loading
- Medium-rise buildings
- Shear walls cracked in ULS
- Post-tensioning = increase of axial load

## Why 3D simulations?

- Transverse walls / flanges
- Wall-floor interaction
- Horizontal load redistribution
- (In-plane out-of-plane interaction)



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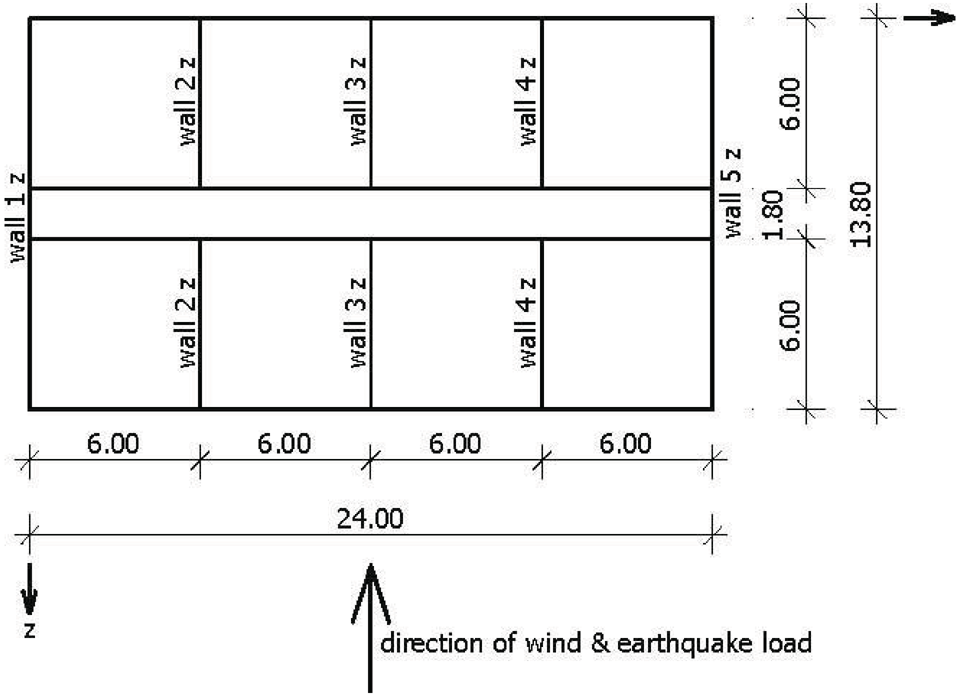
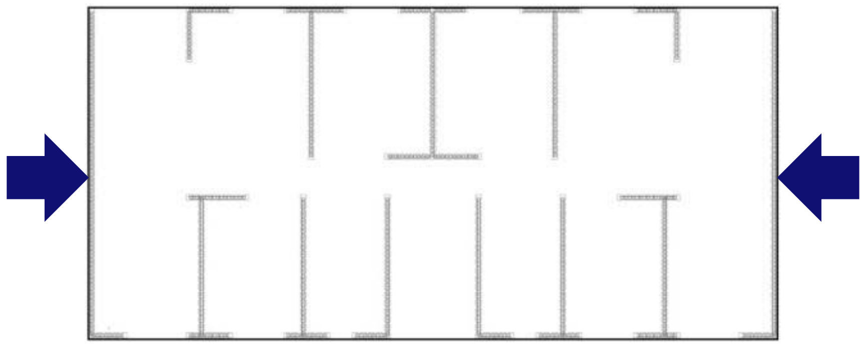
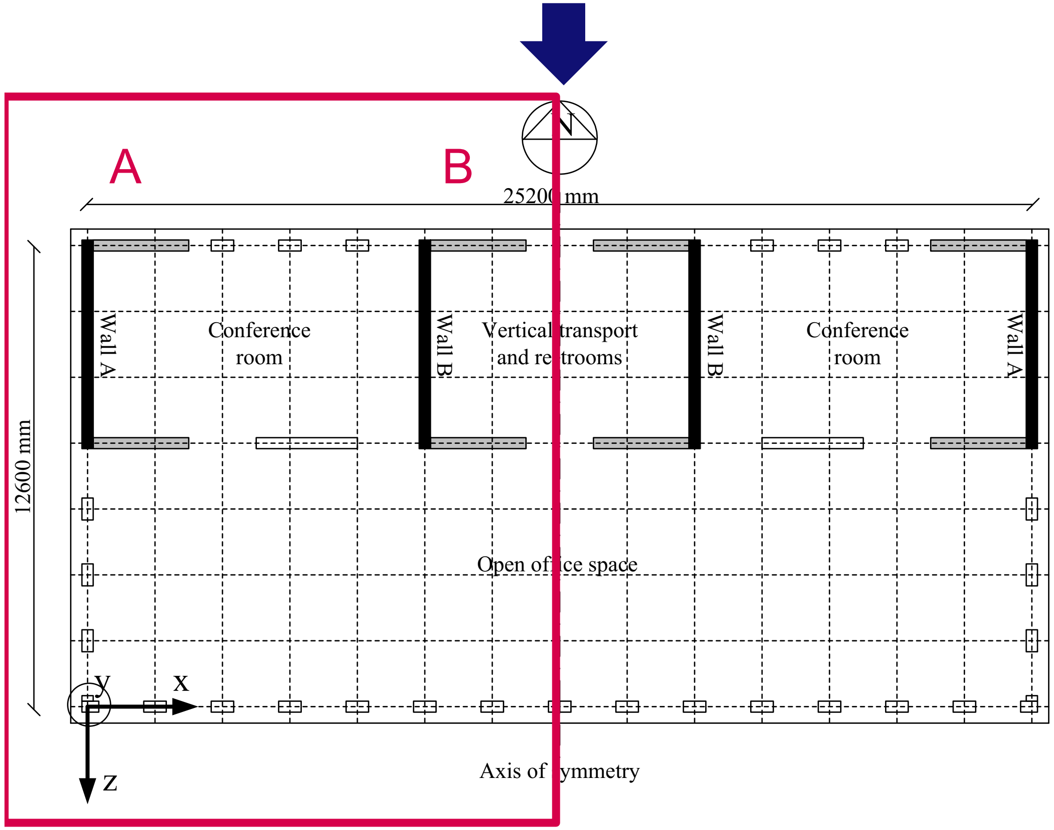
# / Literature

- Sing-Sang, P., Totoev, Y., & Page, A. W. (2009). "Wind and earthquake shear load in symmetrical loadbearing masonry buildings", *The Masonry Society Journal, Vol. 27, No 1, pp. 55-70* (left)
- Schermer, D. (2005). "ESECMaSE D3.2 Analysis of Apartment House", *ESECMaSE Report No. sce-24005005, TU München* (right)



# / Building layout and test scheme

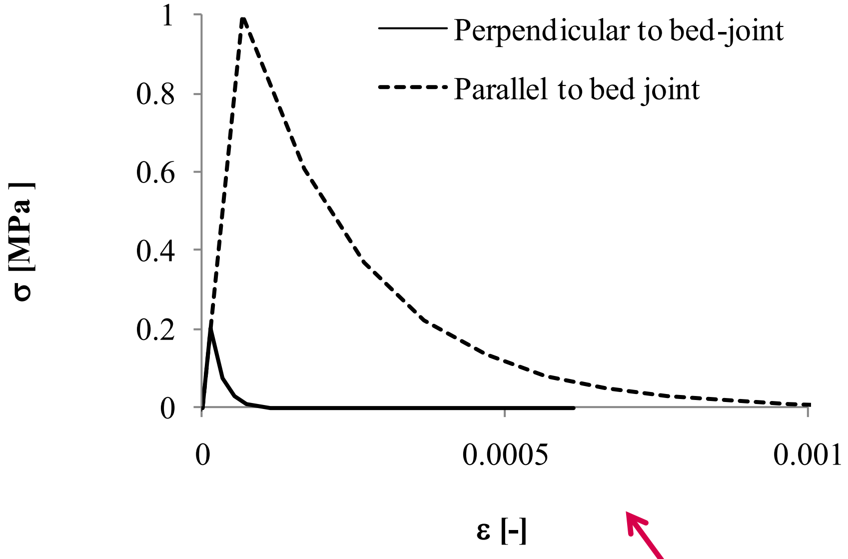


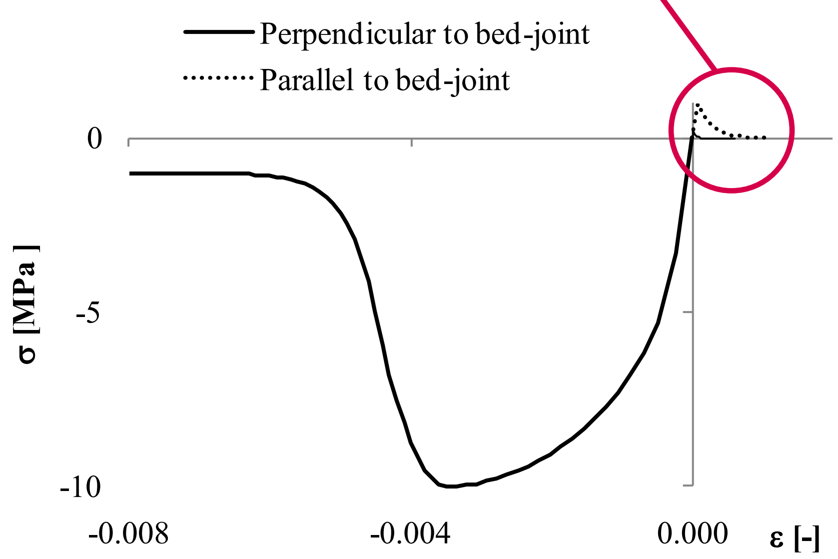

| Wall B → Wall A ↓ | IU | LU | CU | IP | LP | CP |
|---|---|---|---|---|---|---|
| IU | 2 | | | | | |
| LU | 2 | 2 | | | | |
| CU | 1 | | 1 | 2 | | 2 |
| IP | | | | 2 | | |
| LP | | | | 2 | 2 | |
| CP | 2 | | 2 | 1 | | 1 |

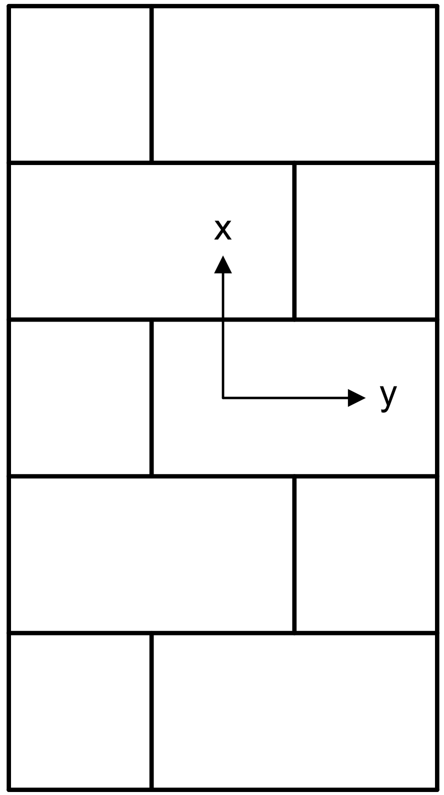
# / FE modelling

- **DIANA 9.4.2 + Intel Visual Fortran Pro 11.1.051 + MS Visual Studio Pro 2008 SP1**
- **Smeared orthotropic material model by Paulo Lourenço (http://www.civil.uminho.pt/masonry)**
- **4-node curved shell elements (Q20SH)**
- **Indirect displacement control (**ARCLEN UPDATE REGULA**)**
- **Convergence based on energy norm**
  **(**ENERGY CONTIN TOLCON=1E-4**)**

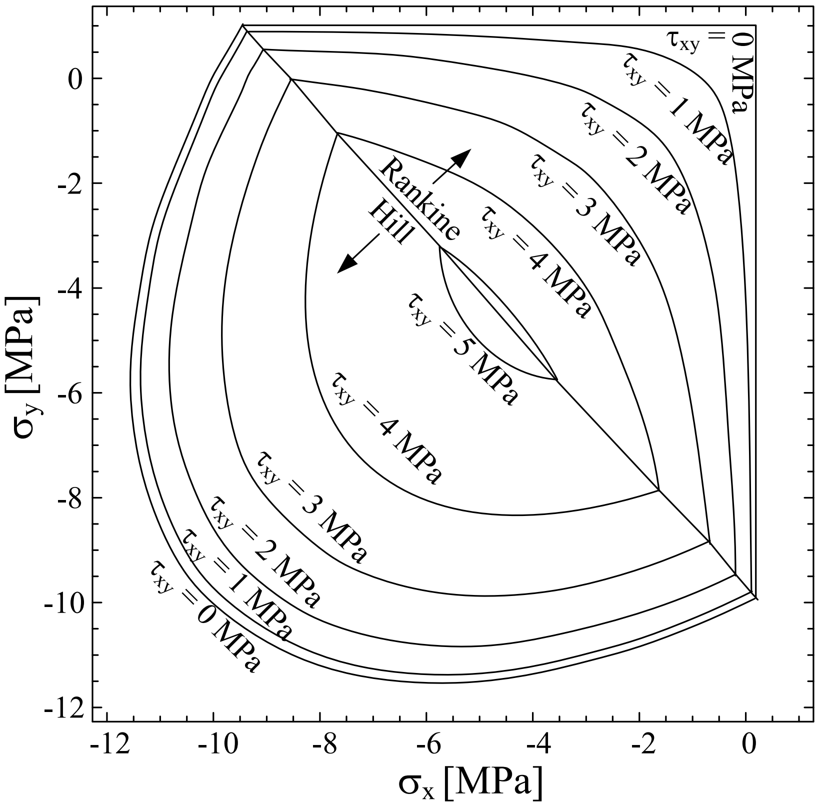
# / FE modelling: masonry material model

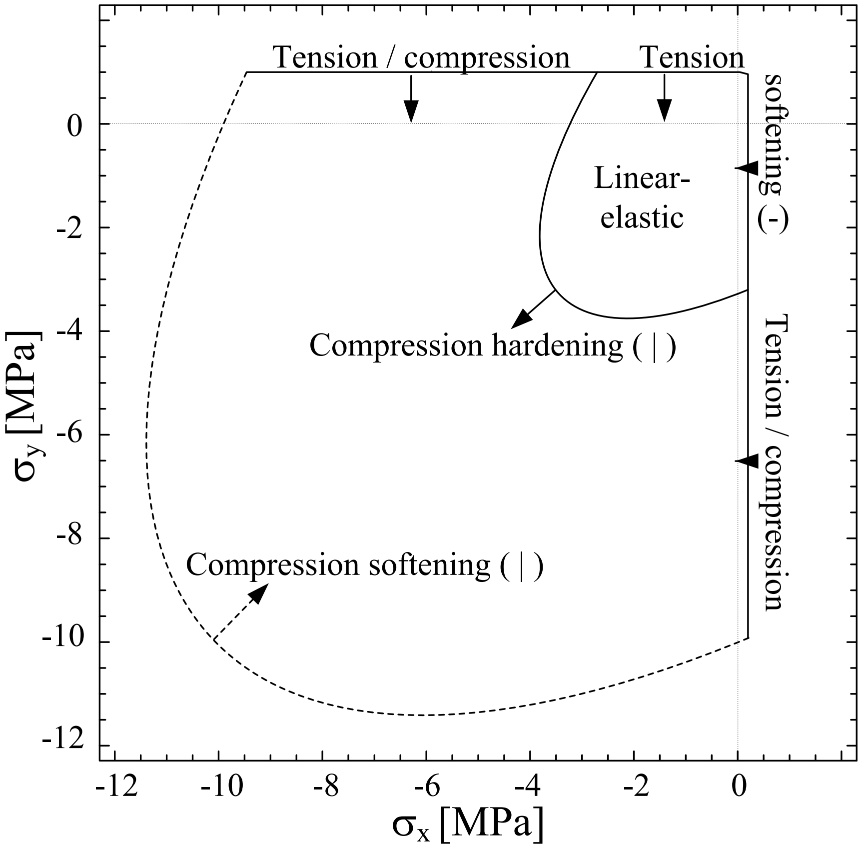


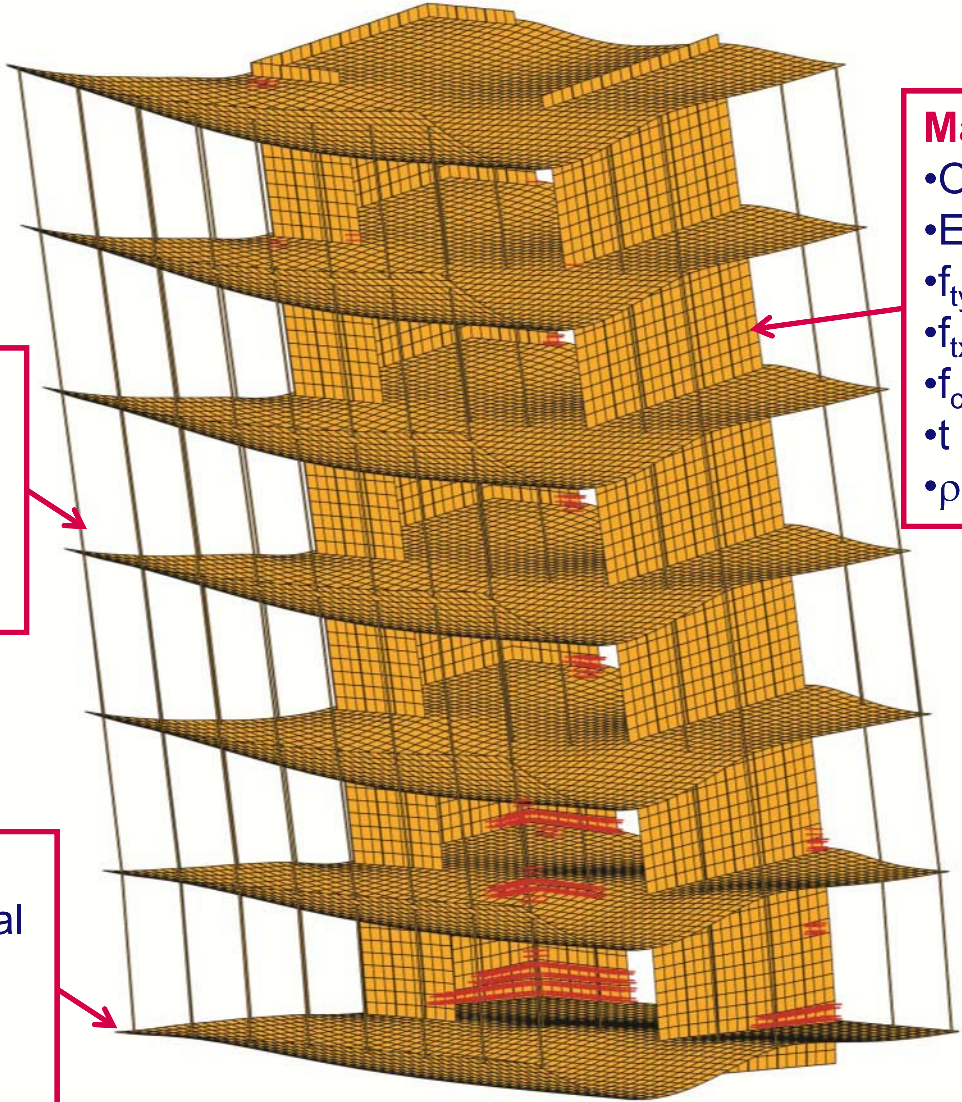



# / FE modelling: masonry material model



# / FE modelling: deformed mesh



**Masonry columns**
- Linear-elastic material
- E = 15.0 GPa
- A = 600 x 214 $mm^2$
- $\rho$ = 2200 $kg/m^3$

**Masonry shear walls**
- Orthotropic Rankine-Hill
- E = 15.0 GPa
- $f_{ty}$ = 1.0 MPa
- $f_{tx}$ = 0.2 MPa
- $f_c$ = 10.0 MPa
- t = 300 mm
- $\rho$ = 2200 $kg/m^3$

**Concrete floors**
- Linear-elastic material
- E = 30.0 GPa
- t = 260 mm
- $\rho$ = 2400 $kg/m^3$



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# / FE modelling: DIANA details

## Preprocessing

- **Type commands in MS Excel, export as** **.prn*
- **In iDiana: read the commands with** *@*.prn*
- **Include: UTILITY WRITE DIANA** **.dat*
- **Material parameters in** *usrmat.dat*

```
USRMAT
USRVAL    0.2 1.696E-3 1.0 8.48E-2 1.0 1.0 10. 3.82 10. 3.82
          -1.0 3.0 2.833E-3 424.3 15.E3 15.E3
USRSTA    0.0 0.0 0.0
USRIND    0
```

# / FE modelling: DIANA details

## Command file (*.dcf) and analysis

```
*FILOS
INITIA
*INPUT
*FORTRAN
TAKE "usrmat.f"
*NONLIN
TYPE PHYSIC
:execute block for self-weight and post-tensioning load
:execute block for horizontal (wind-)load
OUTPUT STATUS USER
*END
```

Analysis (multiple in *.bat file)

diana –m analysis1 analysis1.dat  analysis1.dcf analysis1.ff
del analysis1.ff
diana –m analysis2 analysis2.dat analysis2.dcf analysis2.ff
del analysis2.ff



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# / FE modelling: DIANA details

## Postprocessing

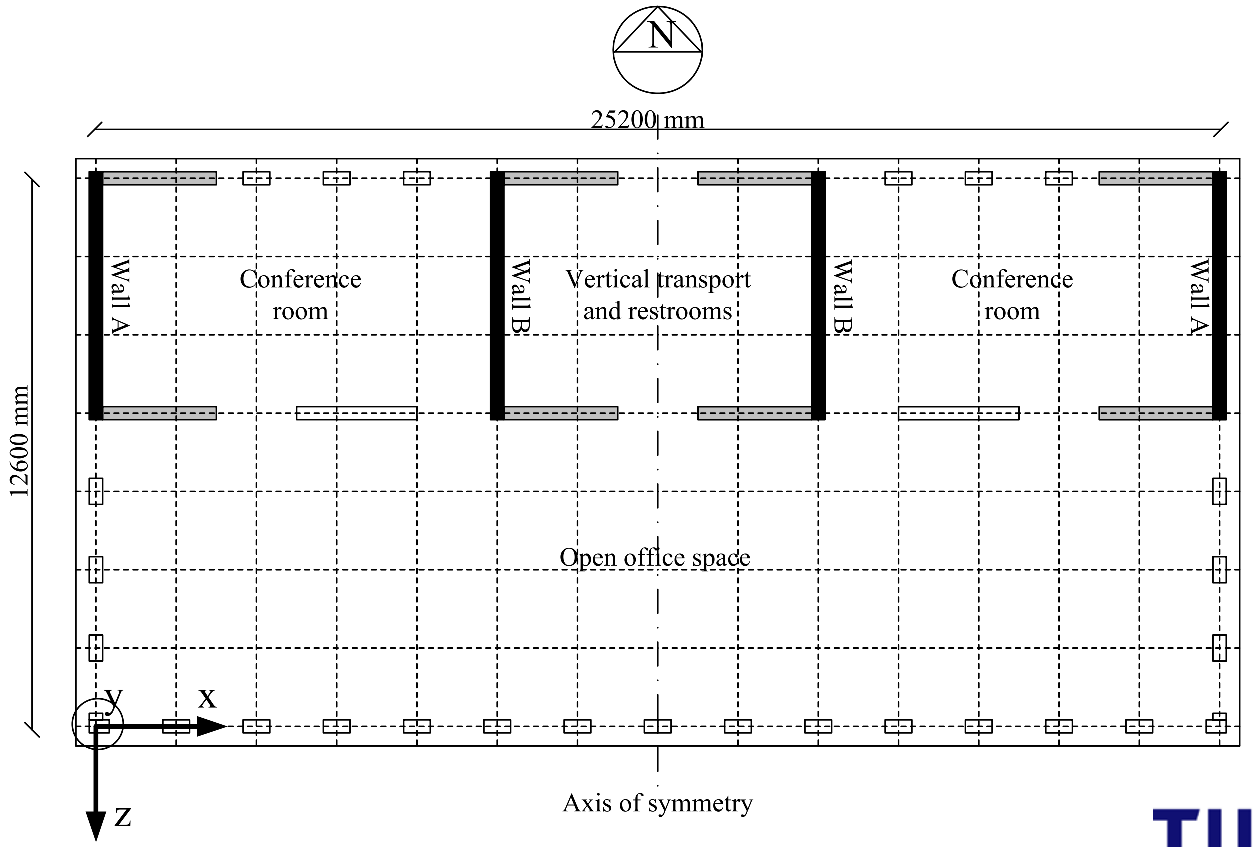
- **User state variables in USSR: usrsta(3) corresponds to RESULTS GAUSSIAN EL.ITEMS ITEM03 etc**
- **PRESENT OPTIONS SYMBOL ‘- RANGE EQUAL 1 (display “-” symbol for tension regime of yield surface)**
- **Write postprocessing commands in *.fvc, for example**

```
RESULTS LOADCASE LC2
RESULTS NODAL TDTX...G TDTZ
UTILITY TABULATE PRINTFILE OPEN loaddisp.dat
PRESENT OPTIONS SIGNIF 6
PRESENT GRAPH NODE 13860
UTILITY TABULATE PRINTFILE CLOSE
```

- **In iDIANA: FEMVIEW analysis, @*.fvc**

# / Results: linear-elastic analysis

| | Wind load [%] | | Vertical load [%] | | | Vertical stress [MPa] | |
|---|---|---|---|---|---|---|---|
| | Wall A | Wall B | Wall A | Wall B | Columns | Wall A | Wall B |
| C-C | 49.2 | 50.8 | 29.0 | 32.6 | 38.4 | 1.28 | 1.45 |
| C-I | 60.7 | 39.3 | 30.1 | 19.7 | 50.2 | 1.28 | 1.68 |





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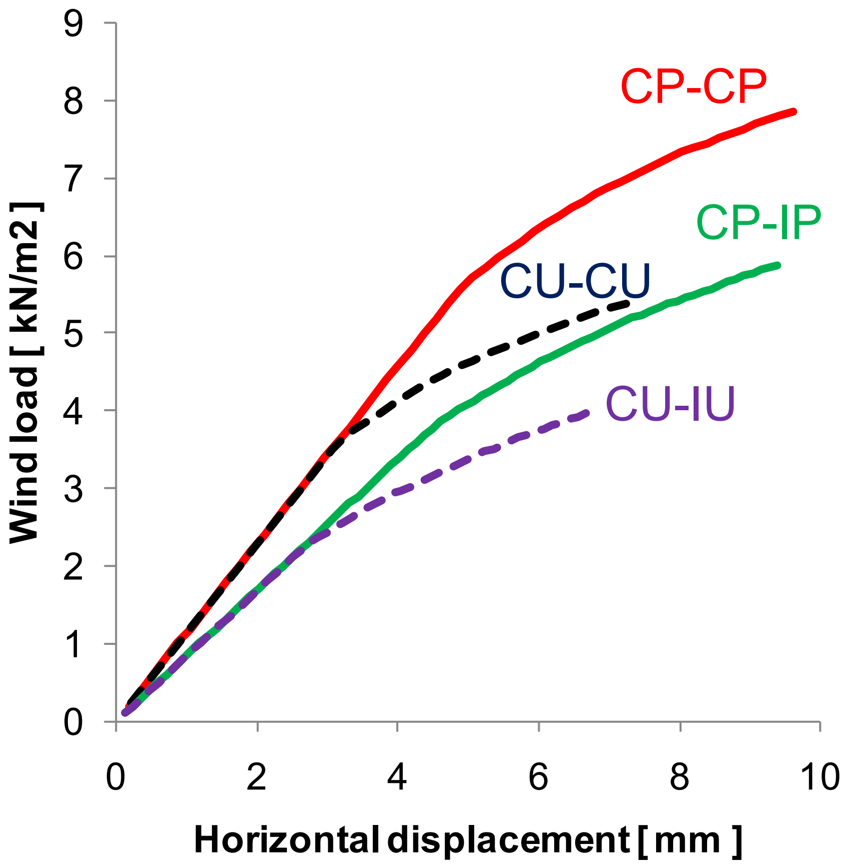
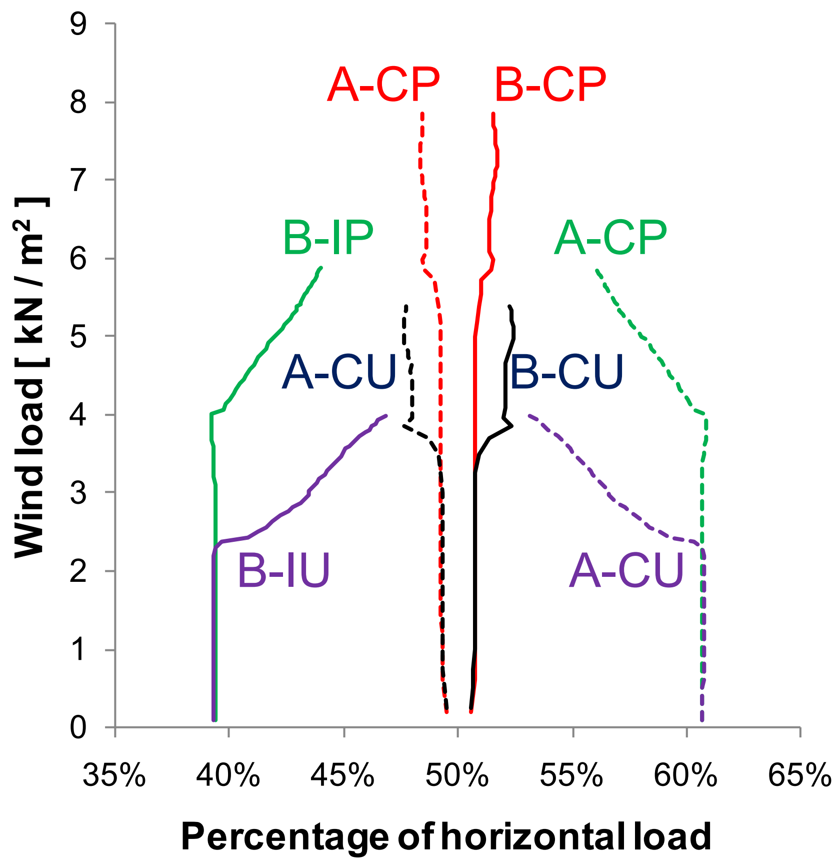
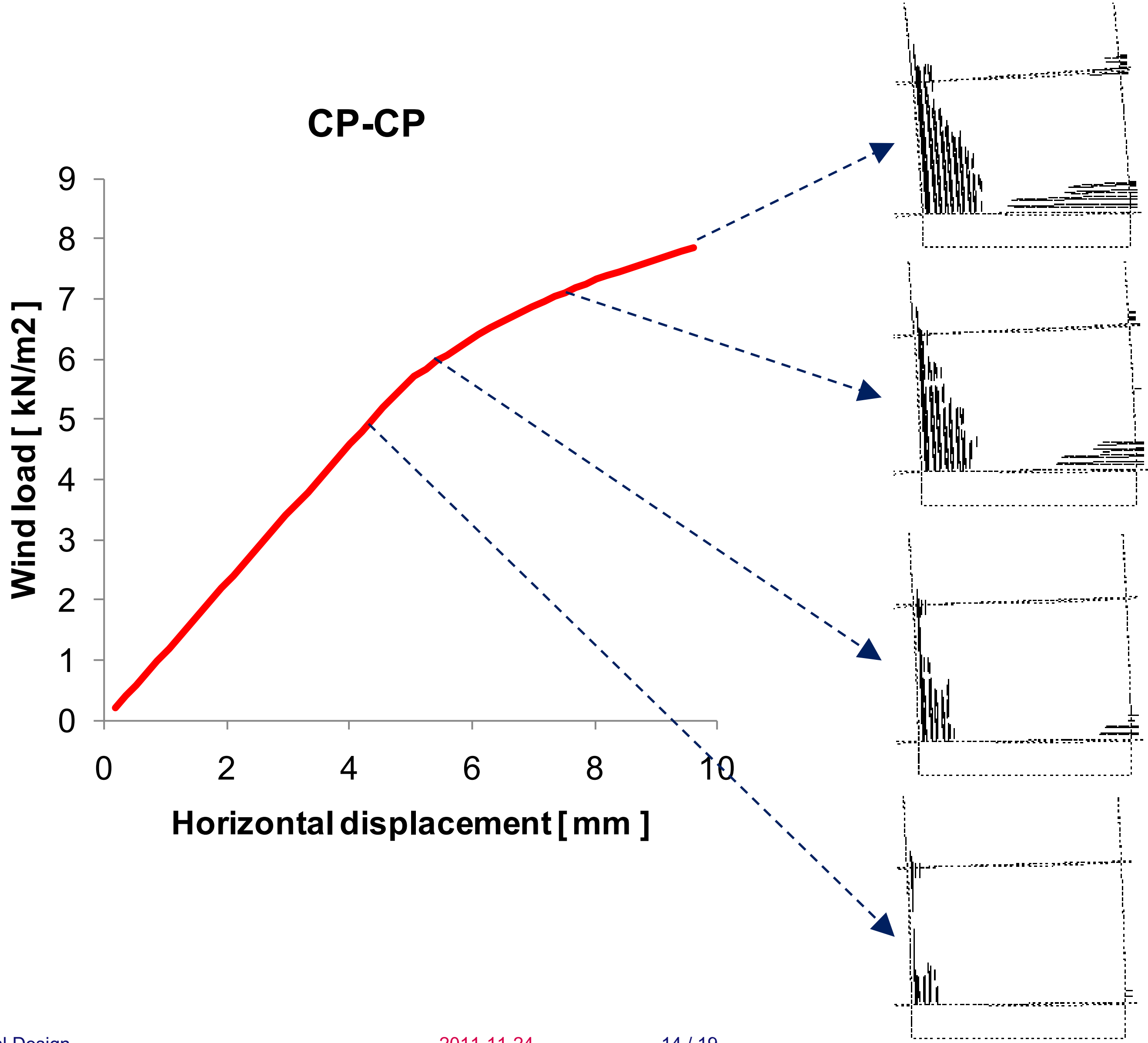
# / Results: load-displacement & redistribution

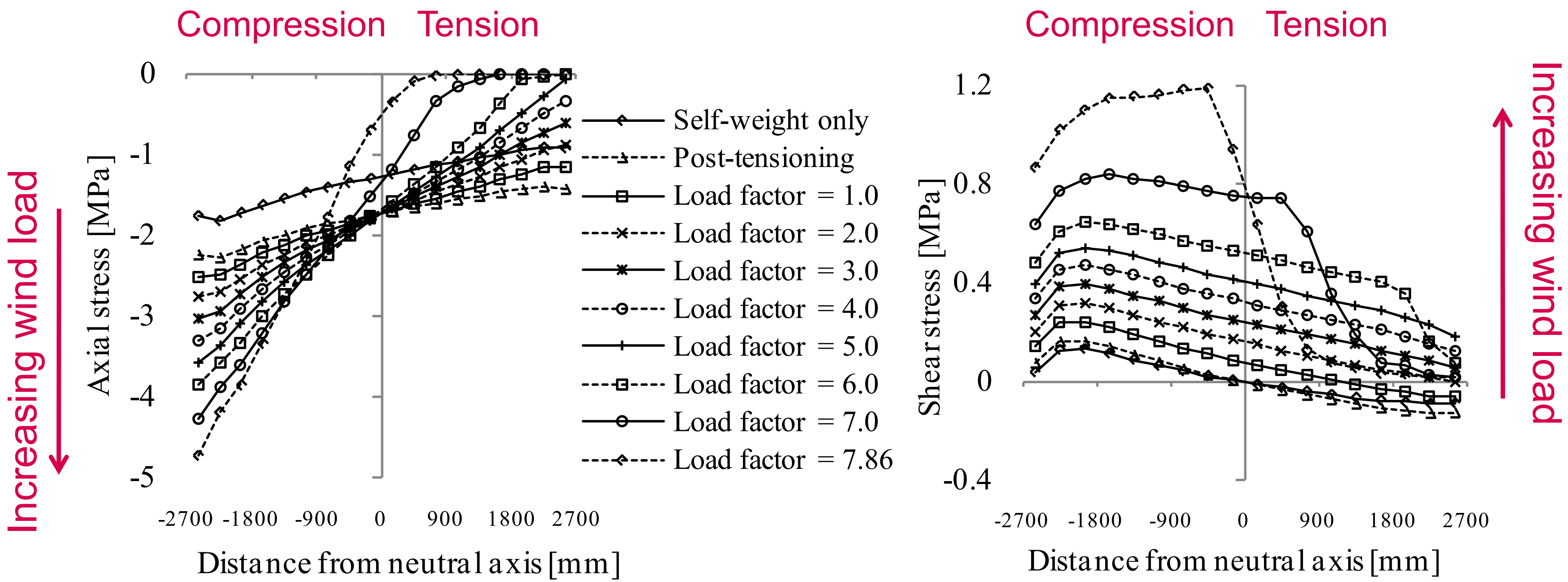


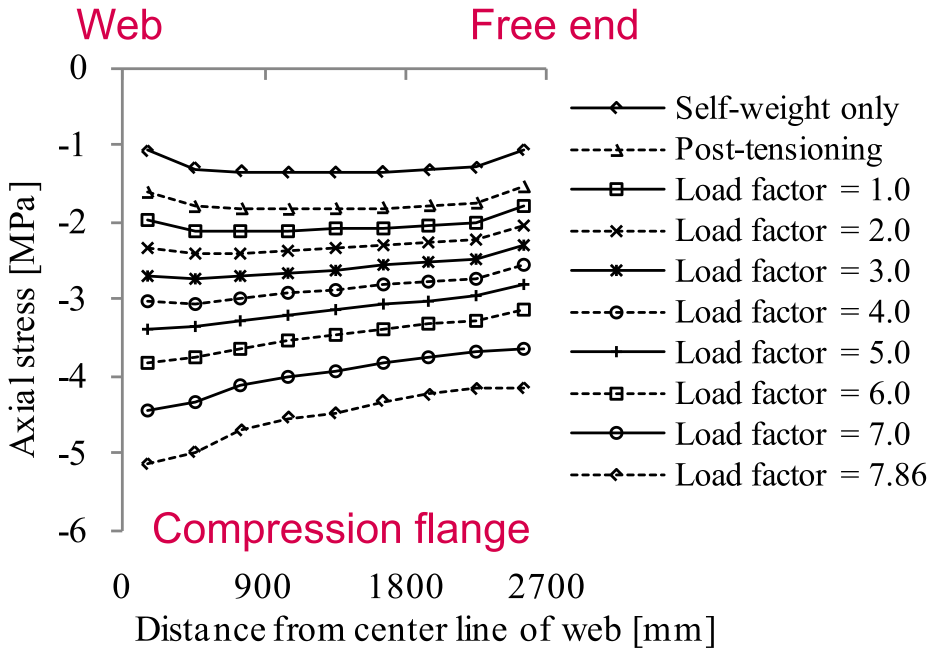
# / Results: cracking & plasticity

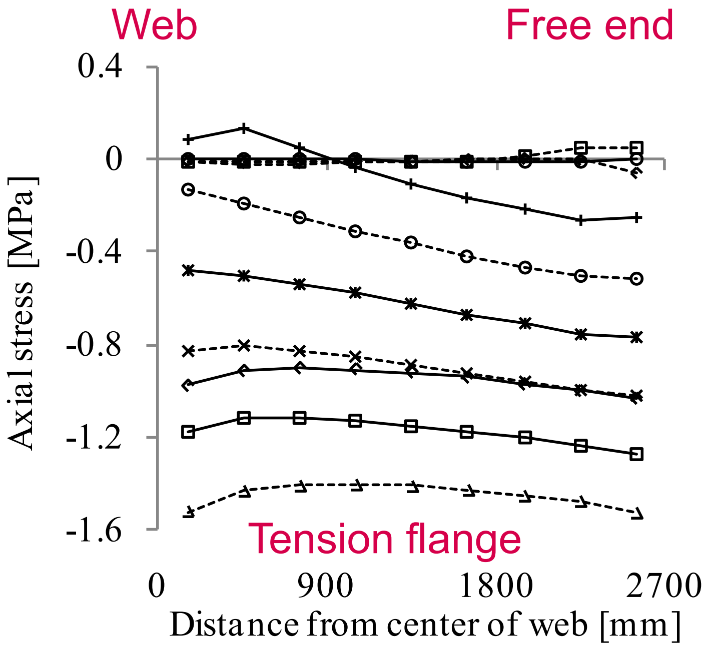


# / Results: stresses along web of C-wall



# / Results: axial stress along flanges of C-wall



# / Discussion

- **3D FE simulations are useful**
- **Complex and time-consuming**
- **Convergence difficulties**
- **Not all factors can be investigated (i.e. element type, mesh size, number of integration points, load step procedure, convergence criteria, adopted stress-strain diagram in USSR)**

# / Conclusions

- Post-tensioning increases capacity
- Contribution of flanges increases capacity
- ULS was not reached
- Flexure and overturning
- Cantilevered shear walls
- Significant redistribution for unequal shear walls

# / Further research

- Additional single element tests and benchmarks
- Simulations of tested I- and T-walls to calibrate model
- Linear-elastic load distribution based on presented model
- Simplified FE model of two coupled shear walls without floors and façade columns
- Use truss elements for post-tensioning tendons to include activation of prestress
- Compare results of FE model and simplified FE model


## Acknowledgements

- The financial support of VNK

9th AUSTRALASIAN MASONRY CONFERENCE

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DSI

# Suggestions

and/or

# questions?

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