ENQUADRAMENTO LEGAL E NORMATIVO DA CONSTRUÇÃO EM TERRA

TÉRMICA ESTRUTURAS

3ª Mesa Redonda – Porto (11.nov.2018)

Melhoria do comportamento sísmico de construções de taipa

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INTRODUCTION

INTRODUCTION

Earth construction?

- ❑ raw earth is the main building material
- ❑ usually associated with vernacular architecture, meaning that many building techniques exist


Adobe masonry


Rammed earth


Cob

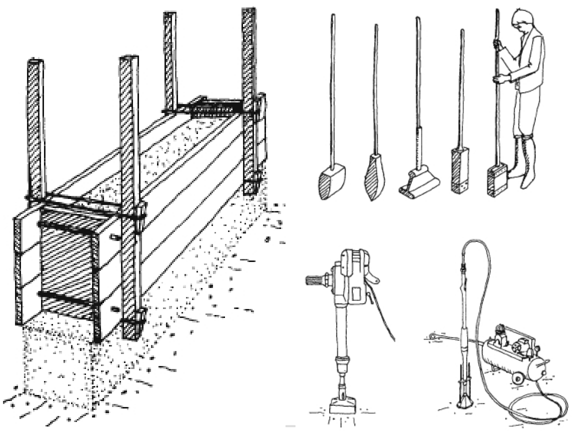

Wattle-and-daub

INTRODUCTION

- What is **rammed earth**?

  It has many names: *"taipa", "tapial", "pise de terre", "terra cruda", "stampflehm"*

- It consists in **compacting moistened soil** inside a formwork to build **walls**



INTRODUCTION

- Some relevant features of **earthen constructions**:
  - very **low embodied energy** & almost no waste production
  - good thermal and acoustic performances & good fire resistance
  - relatively **low cost material**
  - about **20% of the world's population** lives in a house built with earth
  - about **10% of the World heritage sites** were built with earth

- But it presents some problems:
  - high self-weight
  - low mechanical properties
  - poor connections between structural elements
  - requires regular maintenance

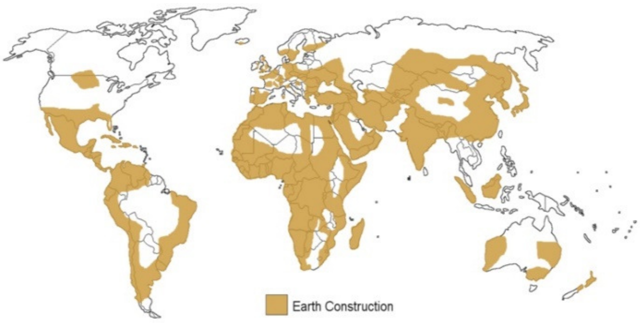
Gravity loads: OK

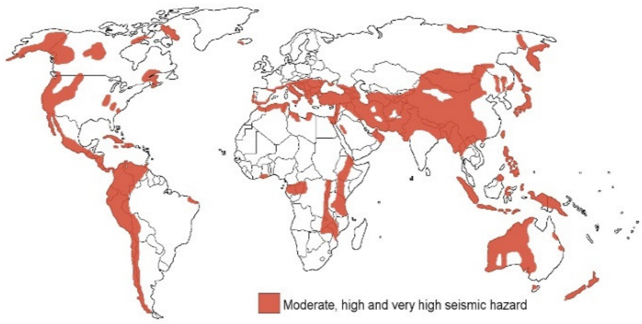
Earthquakes: ??

high seismic vulnerability

INTRODUCTION

- Earthen construction and seismic hazard…

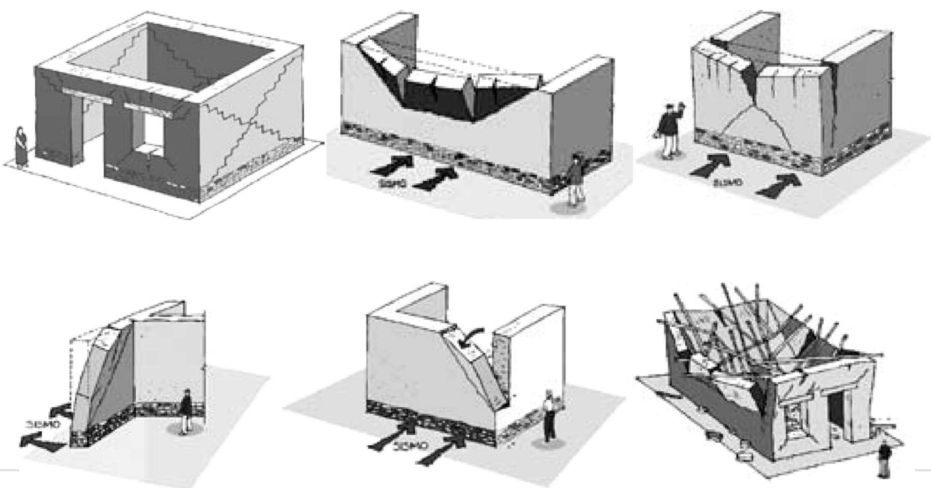




INTRODUCTION

- Effects of earthquakes on earthen constructions…

severe in-plan and out-of-plane **failure modes**



INTRODUCTION

- Traditional strengthening options (local seismic culture):
  - Butresses

  - Steel ties

INTRODUCTION

- Innovative strengthening options:
  - Grout injection with compatible materials

  - Reinforced plasters

MATERIALS & INTERACTION

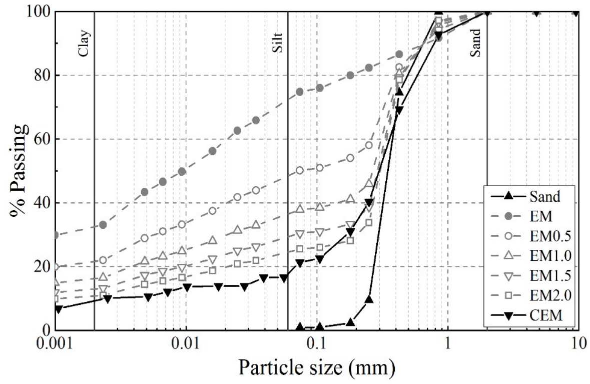
MORTAR

- Physical and mechanical **compatibility with the substrate** is a key issue
- 9 different mortar compositions were studied

Mortar	Category	OPC (%wt.)	Hydraulic Lime (%wt.)	Earth (%wt.)	Sand (%wt.)	W/S	
EM	EM	-	-	100	-	0.32	unstabilized earth mortar
EM0.5	EM	-	-	67	33	0.24	
EM1.0	EM	-	-	50	50	0.21	
EM1.5	EM	-	-	40	60	0.19	
EM2.0	EM	-	-	33	67	017	
S10EM2.0	SEM	-	10	30	60	0.20	stabilized earth mortar
S20EM2.0	SEM	-	18	27	55	0.21	
CEM	CEM	-	-	-	100	0.16	commercial earth mortar
CHM	CHM	9	4	-	87	0.17	cement mortar

MORTAR

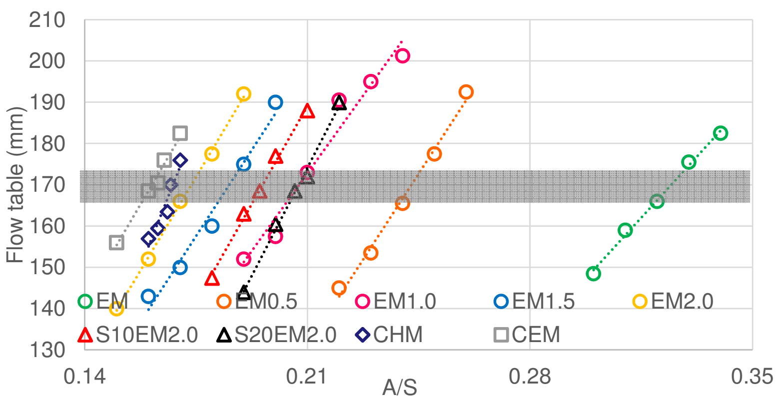
- Mortar parameters under study:
  - particle size distribution



❖ sieved soil and a fine sand with **max. particle size of 2 mm**

MORTAR

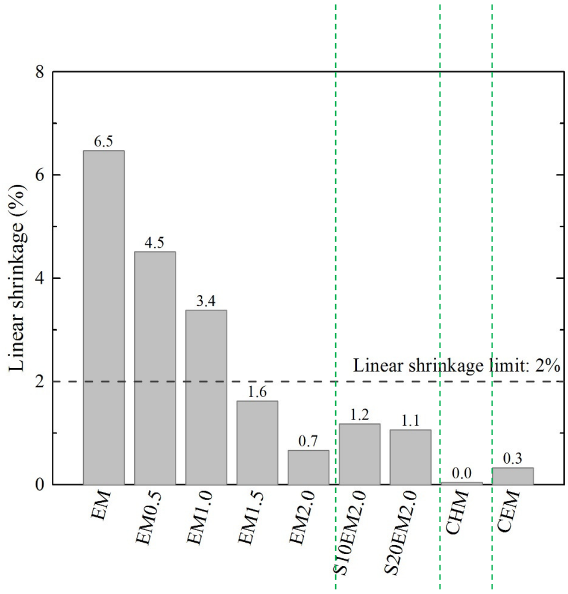
- Mortars parameters under study:
  - workability



❖ water/solids ratio defined for a flow table value of about 170 mm

MORTAR

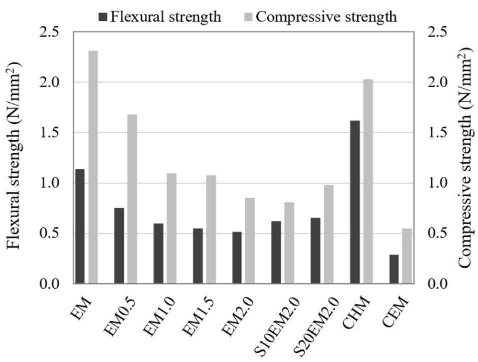
- Mortars parameters under study:
  - linear shrinkage (Alcock test)



- **high shrinkage** as a consequence of **high clay content**
- addition of hydraulic lime results in additional shrinkage

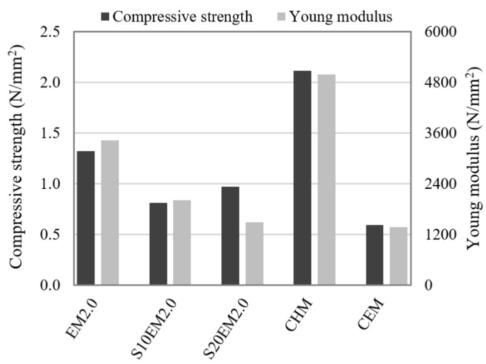
MORTAR

- Mortars parameters under study:
  - **mechanical properties** (flexural & compressive strength, Young's modulus)



prisms ←

cylinders →



- **strength decreases** as the **clay content decreases**
- use of hydraulic lime results in a small strength increase
- **cement mortar much stiffer** than the substrate

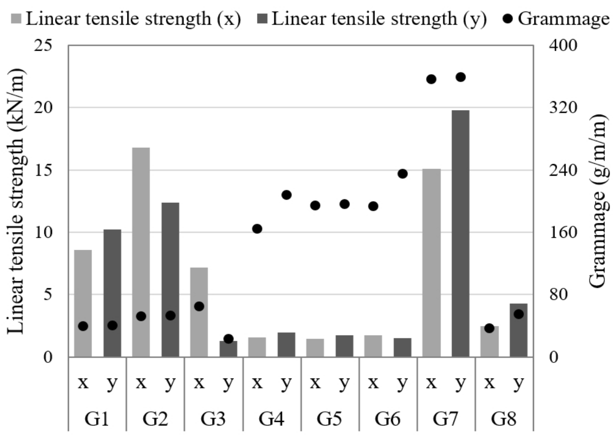
MESH

- ❑ Low-cost and low-performance meshes are to be used
- ❑ 8 low-cost meshes were selected from 2 local suppliers
  - ➢ mesh aperture ranging from 4 to 21 mm
  - ➢ cost ranging from 0.63 to 2.80 Euro/m²
- ❑ Materials used:
  - ➢ glass meshes
  - ➢ plastic meshes
  - ➢ metallic mesh
  - ➢ nylon mesh

Mesh	Material	Colour	Mesh aperture (mm)	Cost (€/m²)
G1	Glass fibre	White	4 x 5	0.85
G2	Glass fibre	White	8 x 9	0.85
G3	Glass fibre	White	6 x 4	1.05
G4	Plastic	White	8 x 21	1.90
G5	Plastic	White	7 x 8	2.80
G6	Plastic	Green	11 x 12	1.90
G7	Galvanized steel	Metallic	13 x 13	2.73
G8	Nylon	Black	16 x 21	0.63

MESH

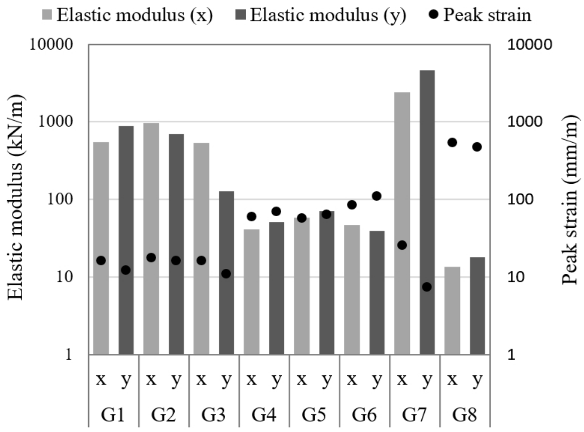
- ❑ **Direct tensile tests** in both directions (dry mesh)

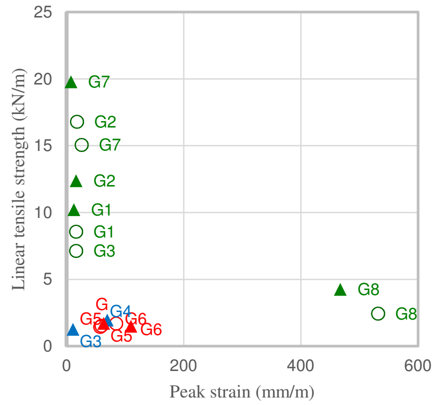


- ❖ G7 (metallic) is the strongest mesh, followed by G2 (glass fibre)
- ❖ plastic and nylon meshes are very weak
- ❖ tensile strength depends of the direction

MESH

❑ **Young's modulus** and peak strain in both directions (dry mesh)





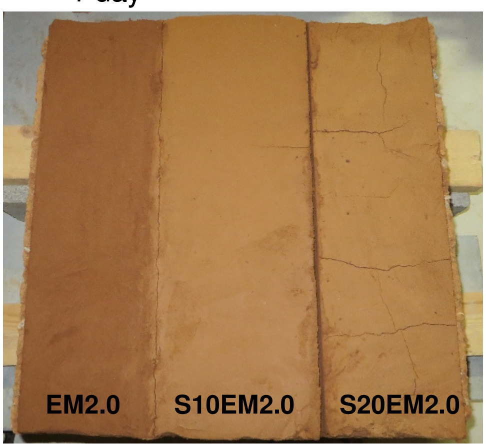
❖ G7 (metallic) is the stiffest mesh, followed by glass fibre meshes

❖ plastic (≈ 7%) and nylon (≈ 50%) meshes show very high peak strains

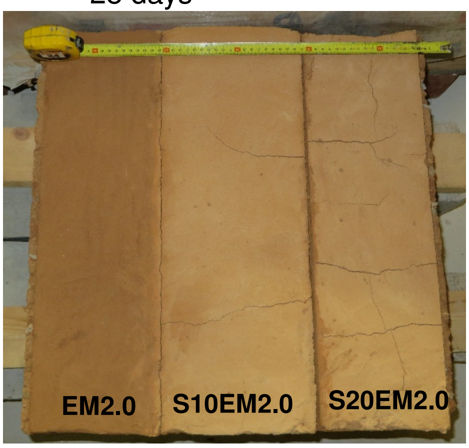
SUBSTRATE & MORTAR

❑ Pull-off tests (without any mesh)

1 day



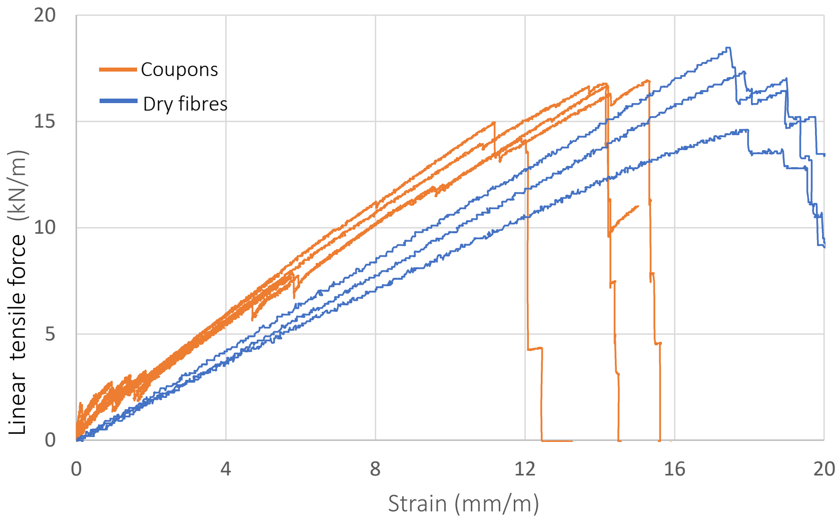
28 days



❖ Similar pull-off forces (about 65 kPa, with differences around 10%)

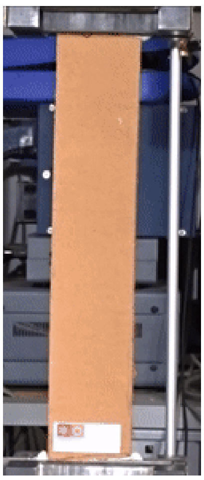
MESH & MORTAR

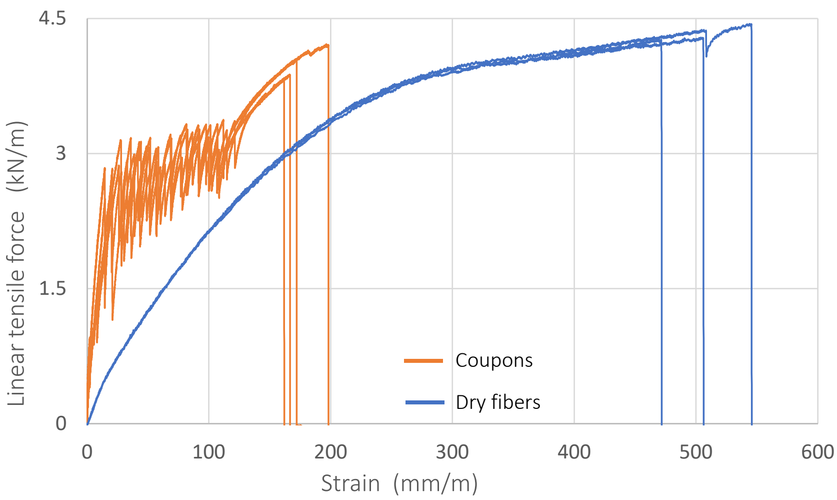
- Direct tensile tests on coupons (glass fibre mesh G2, X direction & EM2.0)



MESH & MORTAR

- Direct tensile tests on coupons (nylon mesh G8, Y direction & EM2.0)





STRUCTURAL PERFORMANCE (LAB)

DIAGONAL COMPRESSION TESTING

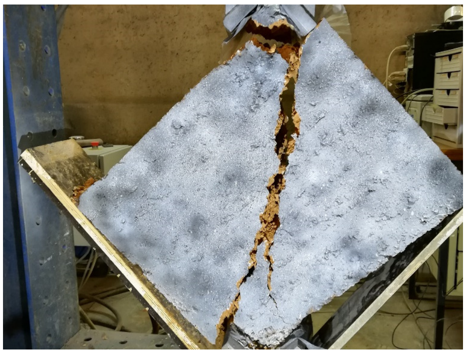
- Testing of rammed earth wallets, plain and strengthened with glass and nylon meshes

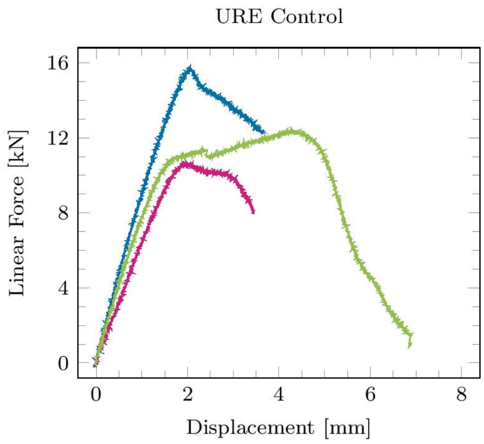


DIAGONAL COMPRESSION TESTING

Unreinforced wallets

- ❑ Main shear crack crossing the layers
- ❑ Friction bewteen the 2 halves

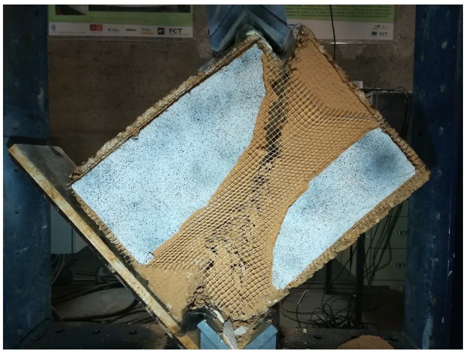


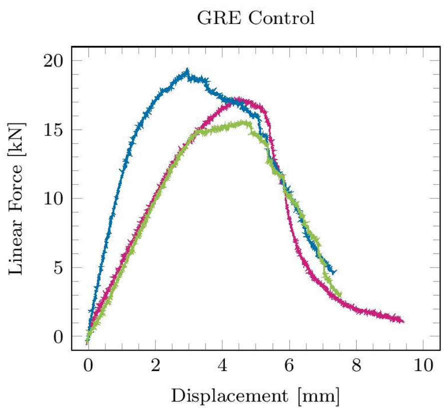


DIAGONAL COMPRESSION TESTING

Wallets reinforced with glass mesh

- ❑ Detachment of the plaster around the main shear crack
- ❑ Minor increase in strength; enhanced displacement ductility

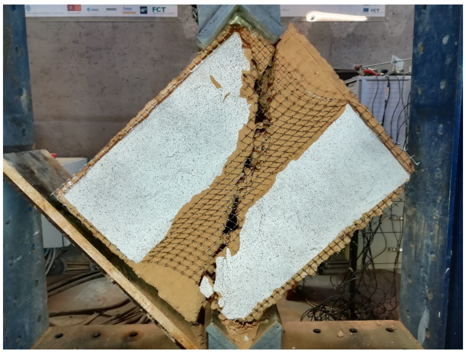


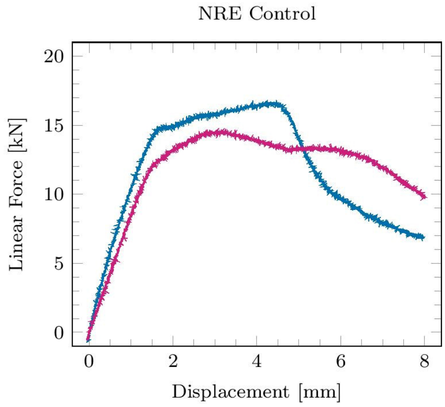


DIAGONAL COMPRESSION TESTING

Wallets reinforced with nylon mesh

- Detachment of the plaster around the main shear crack
- Light increase in strength; enhanced displacement ductility

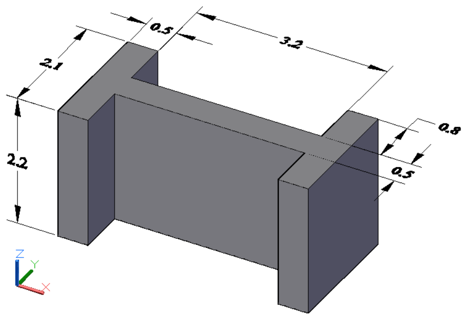


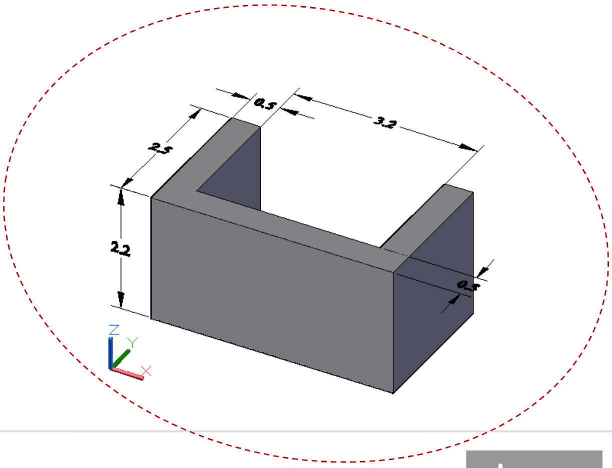


STRUCTURAL PERFORMANCE (MODEL)

MODELLING OF SEISMIC BEHAVIOUR

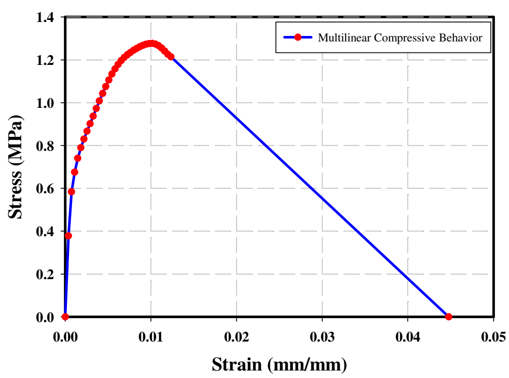
- Geometry based on in-situ surveys and dimensions of the shaking table
- Seismic performance of rammed earth components considering unstrengthened vs. TRM-strengthening option

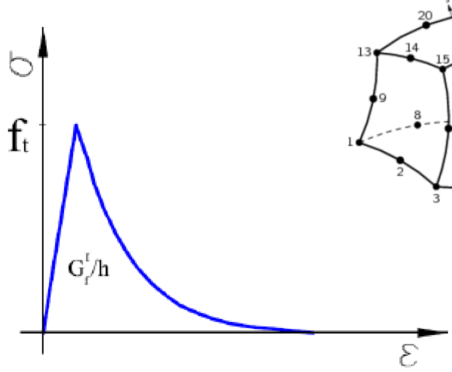


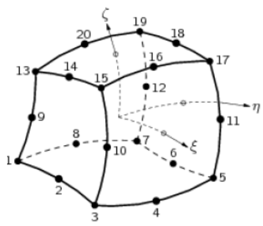


Material Properties and Modeling (unstrengthened model)

- Total strain rotating crack model
- Multilinear behaviour for compression & exponential softening for tension
- 20-nodes solid elements

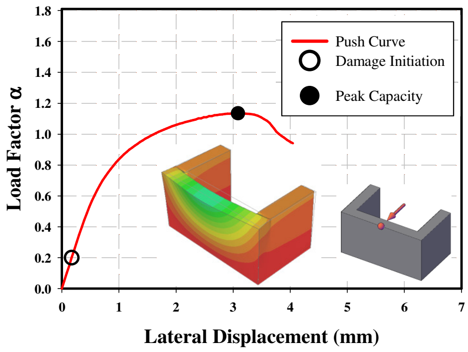


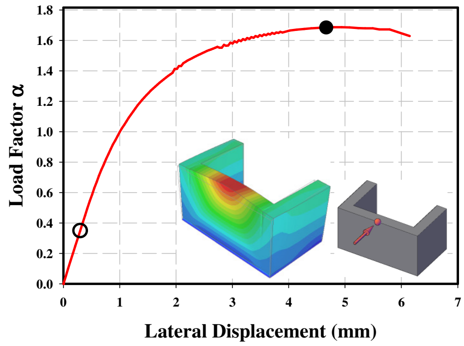




Pushover Analysis (unstrengthened model)

- ❑ Pushing in negative direction is crucial (damage initiation, peak capacity and post-peak behavior)
- ❑ Failure is due to detachment of web from wing walls and bending the mid-section of the web

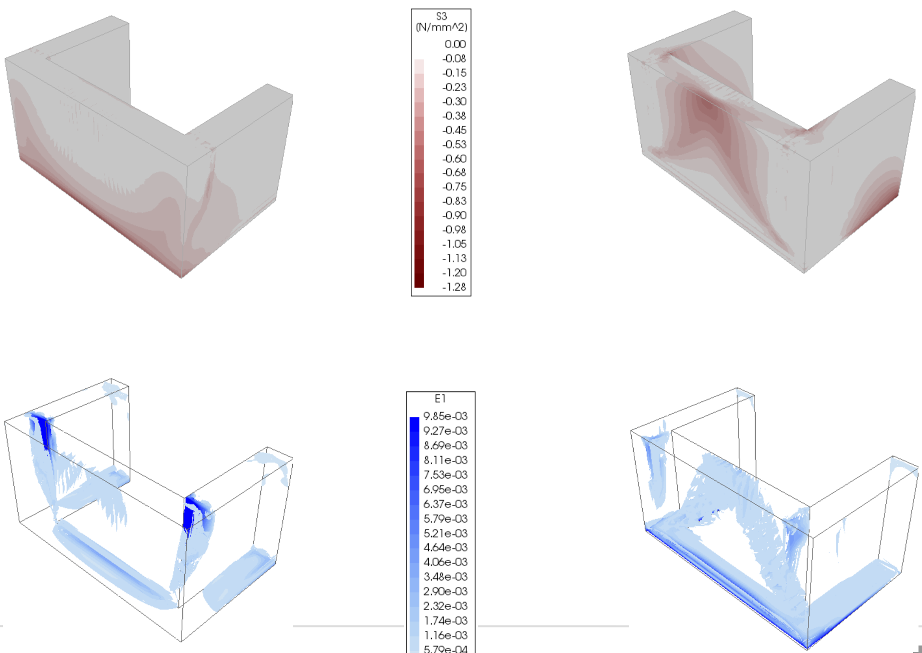




Pushover Analysis (unstrengthened model)

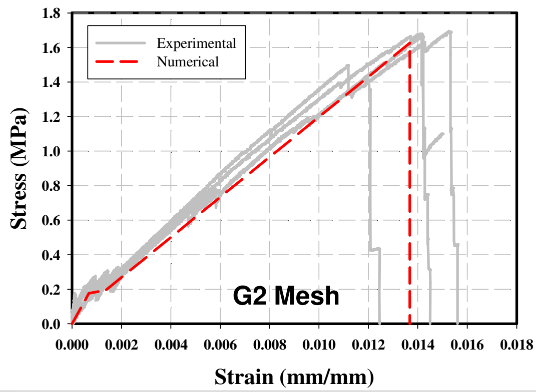
- Y Push

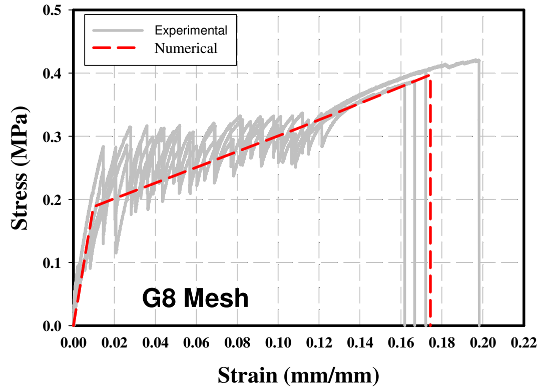
+ Y Push



Material Properties and Modeling (strengthened models)

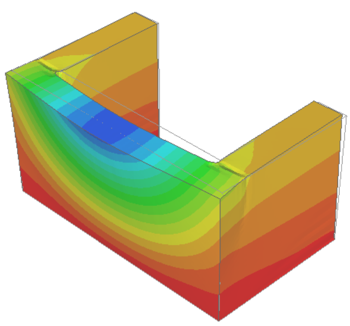
- ❑ Modelling of the strengthening system as a composite material (*is there experimental evidence???*)
- ❑ Simplifying hypothesis due to lack of data

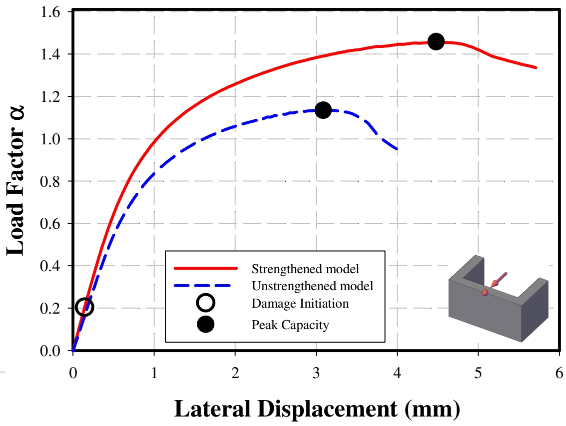




Pushover Analysis (strengthened model; glass; -Y)

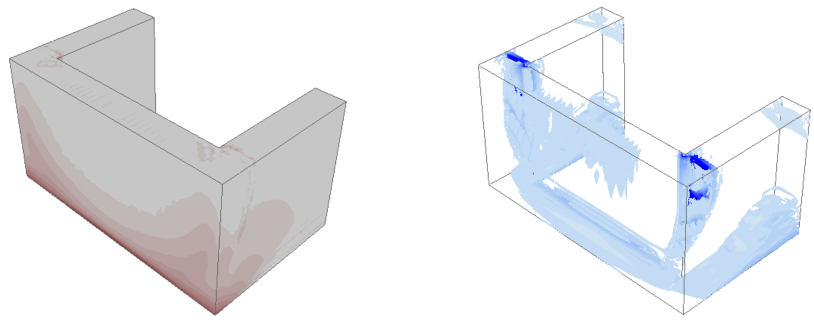
- ❑ Stiffness is slightly increased
- ❑ 45% and 28% increase in displacement and load capacities
- ❑ Damage at early stages (as before)
- ❑ Failure still due to detachment of the web from wing walls and mid-section bending of the web





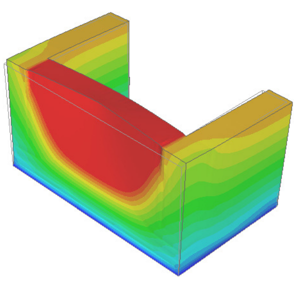
Pushover Analysis (strengthened model; glass; -Y)

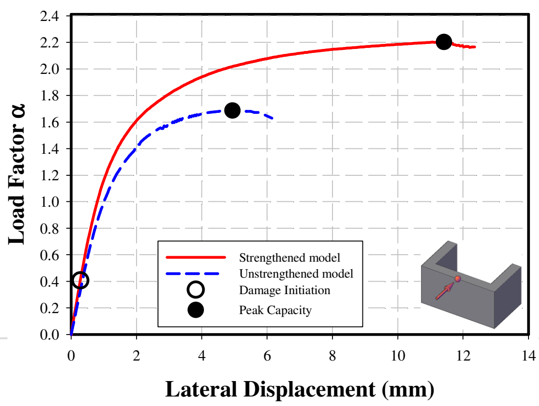
- ❑ Detachment of the web from wing walls is prevented in the strengthened model at a lateral load equal to the peak capacity of the unstrengthened model
- ❑ Larger mid-section of the web tends to bend at the peak capacity of the strengthened model



Pushover Analysis (strengthened model; glass; +Y)

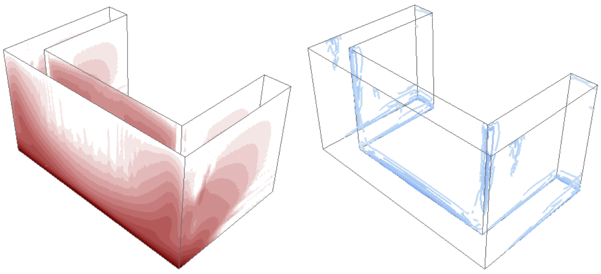
- ❑ Pushing in +Y is less crucial for the out-of-plane behaviour
- ❑ 130% and 30% increase in displacement and load capacity is observed
- ❑ Damage initiation point at low loads
- ❑ Failure due to shear sliding of the web's connection with wing walls and mid-section bending of the web



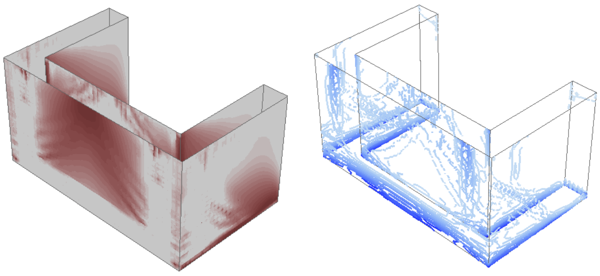


Pushover Analysis (strengthened model; glass)

- ❑ Efficient strengthening should contribute in regions that are likely to fail
- ❑ Strengthening fails at the web-wing walls connections and at the mid-section of the web



Push -Y

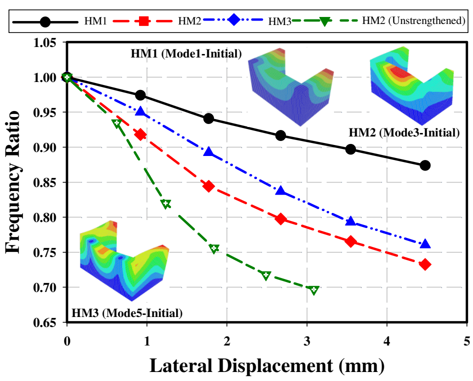


Push +Y

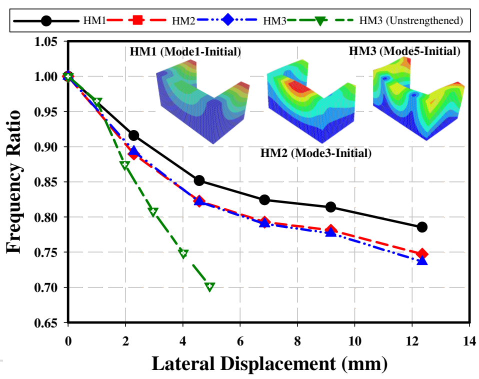
Damage Effects on Dynamic Properties (strengthened models)

- ❑ Maximum drop in the out-of-plane model (*lower than before*):
  - ➢ 22% in -Y direction
  - ➢ 19% in +Y direction
- ❑ Catastrophic drops are prevented

- Y Push

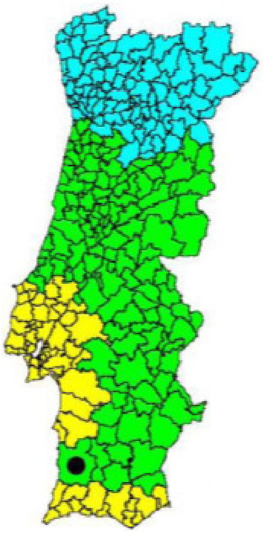


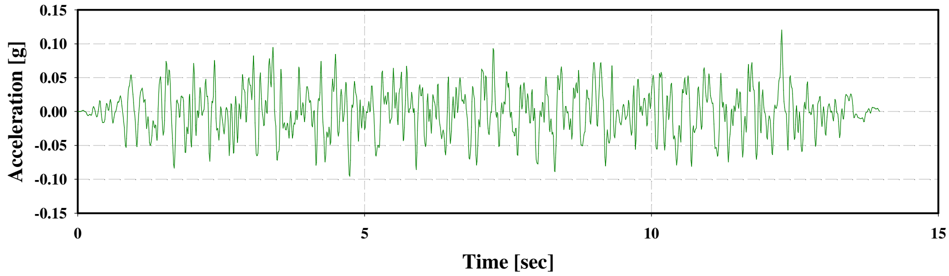
+ Y Push

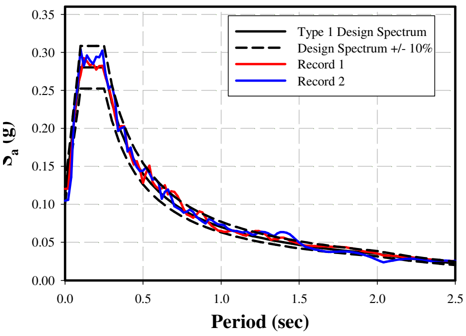


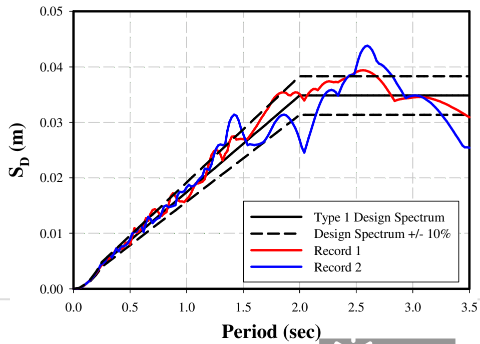
Next Steps: nonlinear time-history analysis

- Generation of code-compatible near-field ground motion records

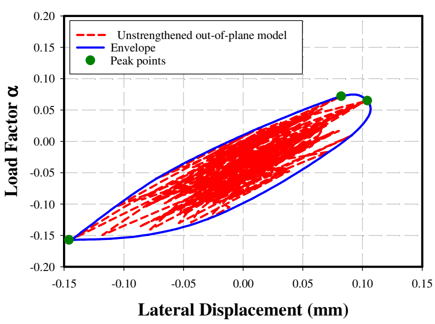


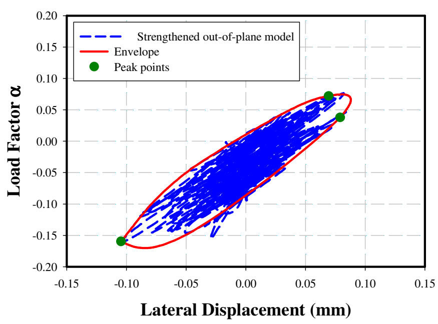


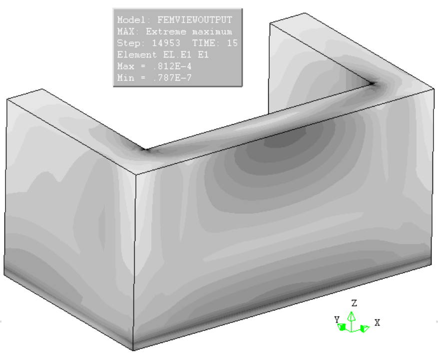


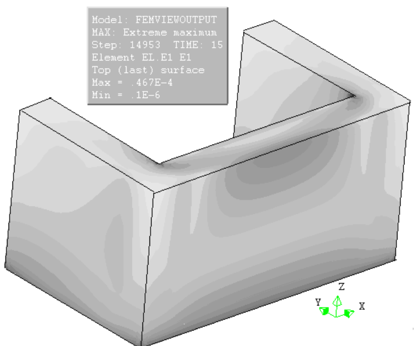


Next Steps: nonlinear time-history analysis









Next Steps: shaking table tests

Next Steps: shaking table tests

CONCLUSIONS

- Studying rammed earth (weak material) behaviour is **extraordinarily difficult**…
- **Geothecnics + Materials + Structures** subjects come together
- Particularly for rammed earth, material compatibility is an **ISSUE**
- Need to understand the interaction between materials: global behaviour requires the understanding of the local interaction
- **Low cost materials** properly associated can make the difference

Thank you!

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