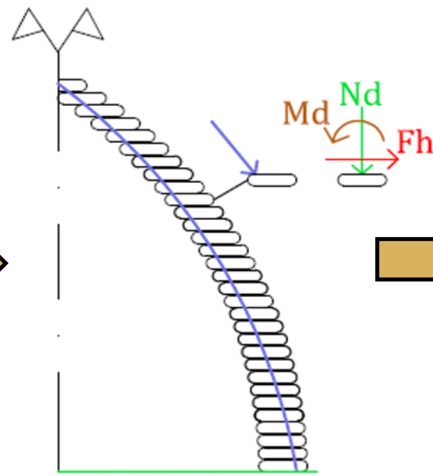
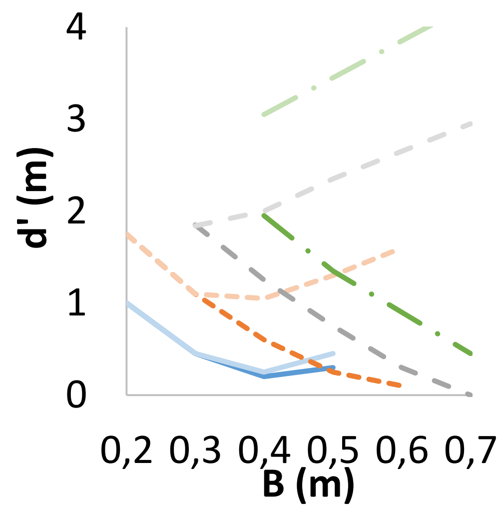
Comprehensive design method for earthbag domes





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WHY?

- Emergency shelters
  - Wars
  - Hazardous natural events

Shelters

Safe

Cheap

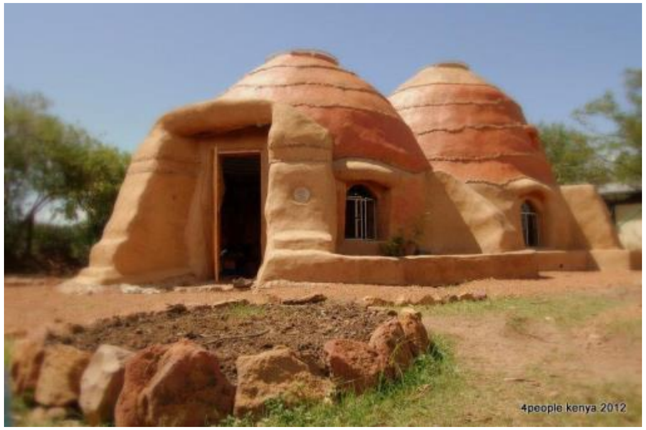
Fast & Easy

EARTHBAG

- Earth
  - Abundant material
  - Available in the enviroment
  - Compression stress
  - Isulating thermal

- Bag
  - Cheap
  - Traction stress
  - Formwork
  - Degradable

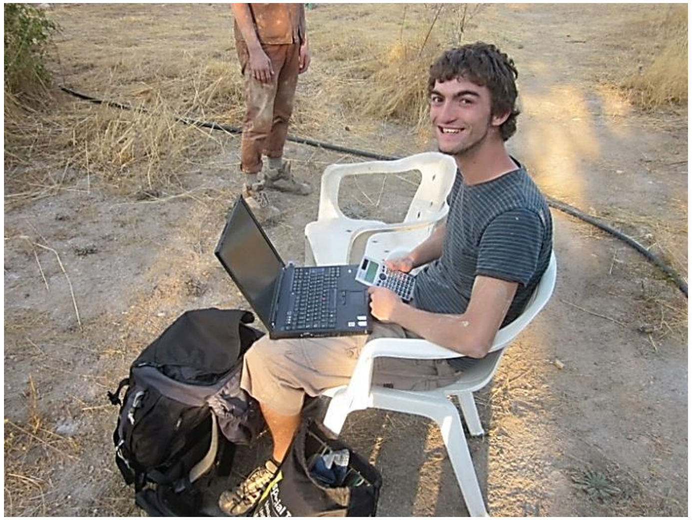
EARTHBAG DOMES



INEFICIENT DOME DESIGN

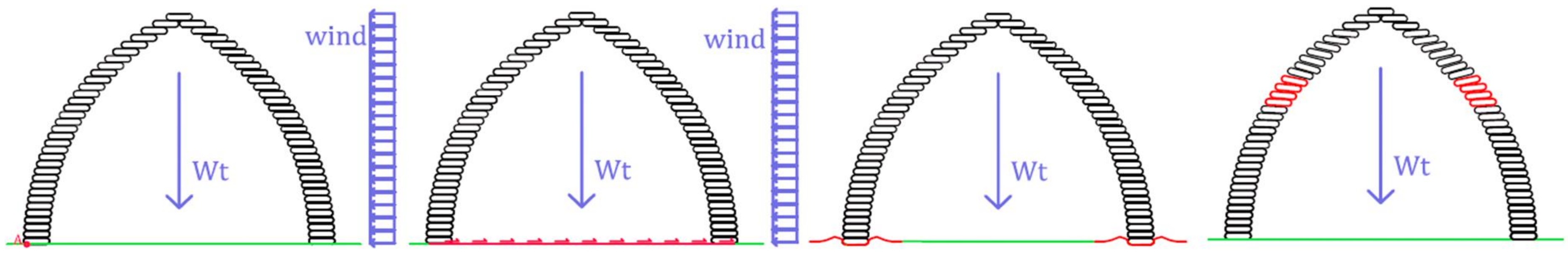
- Empiric, semi-empiric rules
  - Oversize
  - Understimation

  (wasting material and time resources)
- Lack of theoretical models
- Need for regularization codes



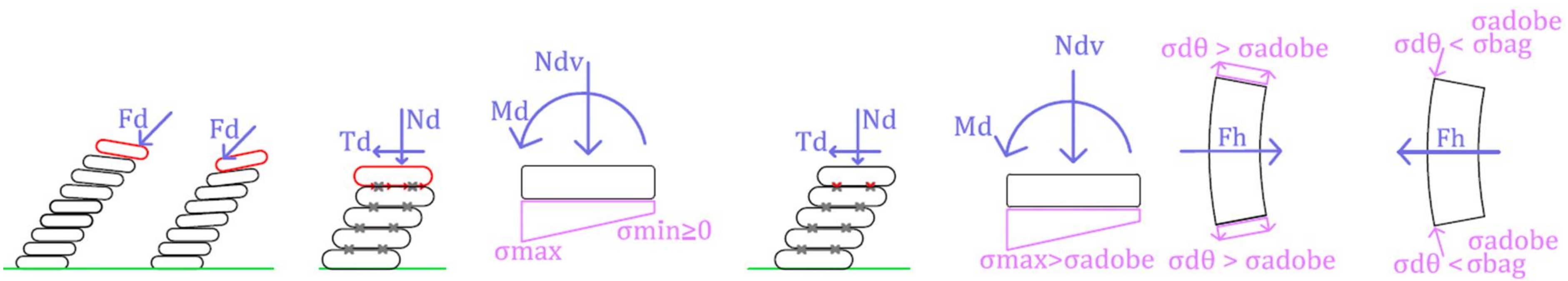
DOME METHOD(1)

- Global failures mechanisms



Roll-Over | Slipping | Collapse | Buckling

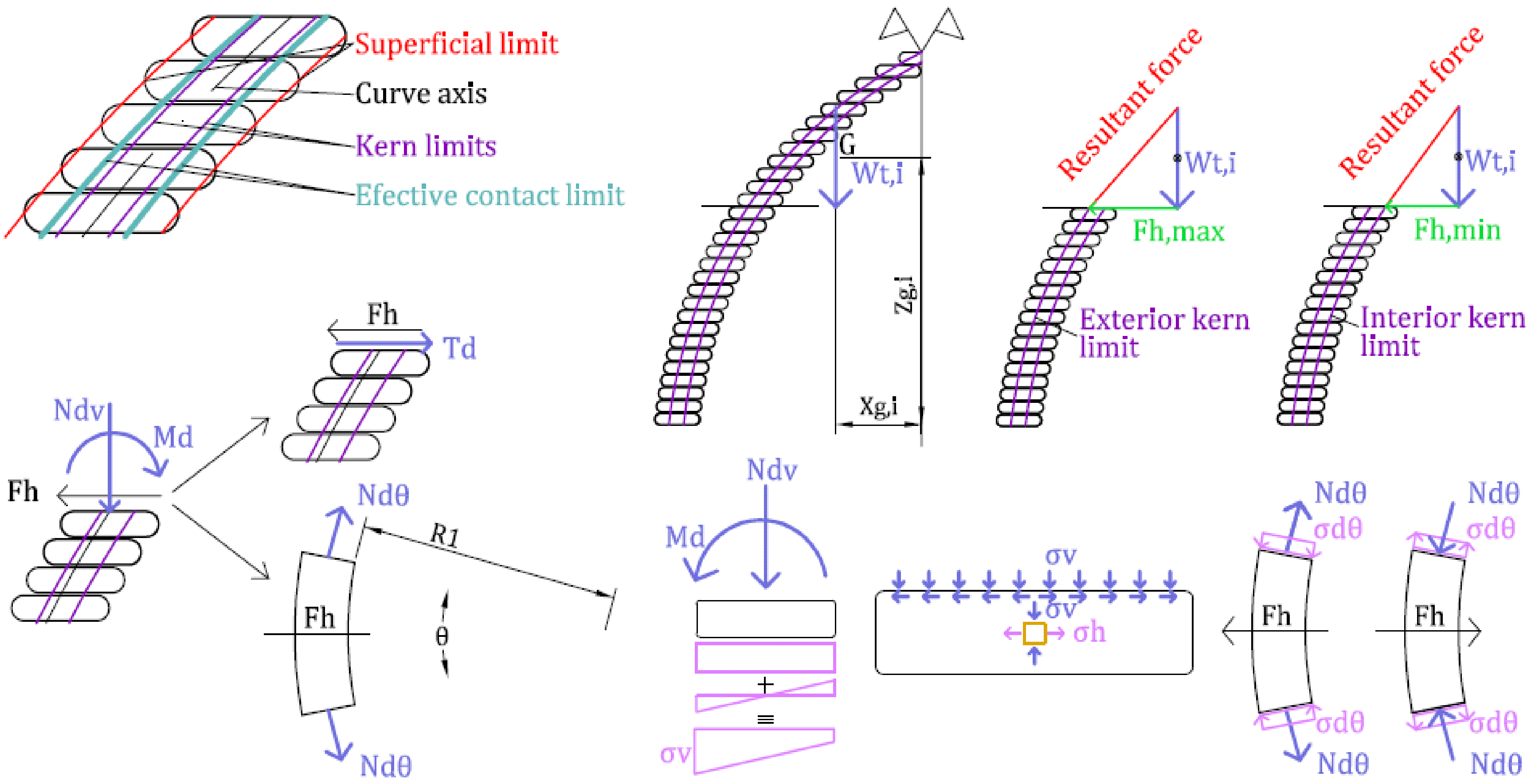
- Local failures mechanisms



Roll-Over | Slipping | Vertical compression | Bag Tearing | Adobe failures and bag failures

DOME METHOD(2)

- Forces and stresses computation



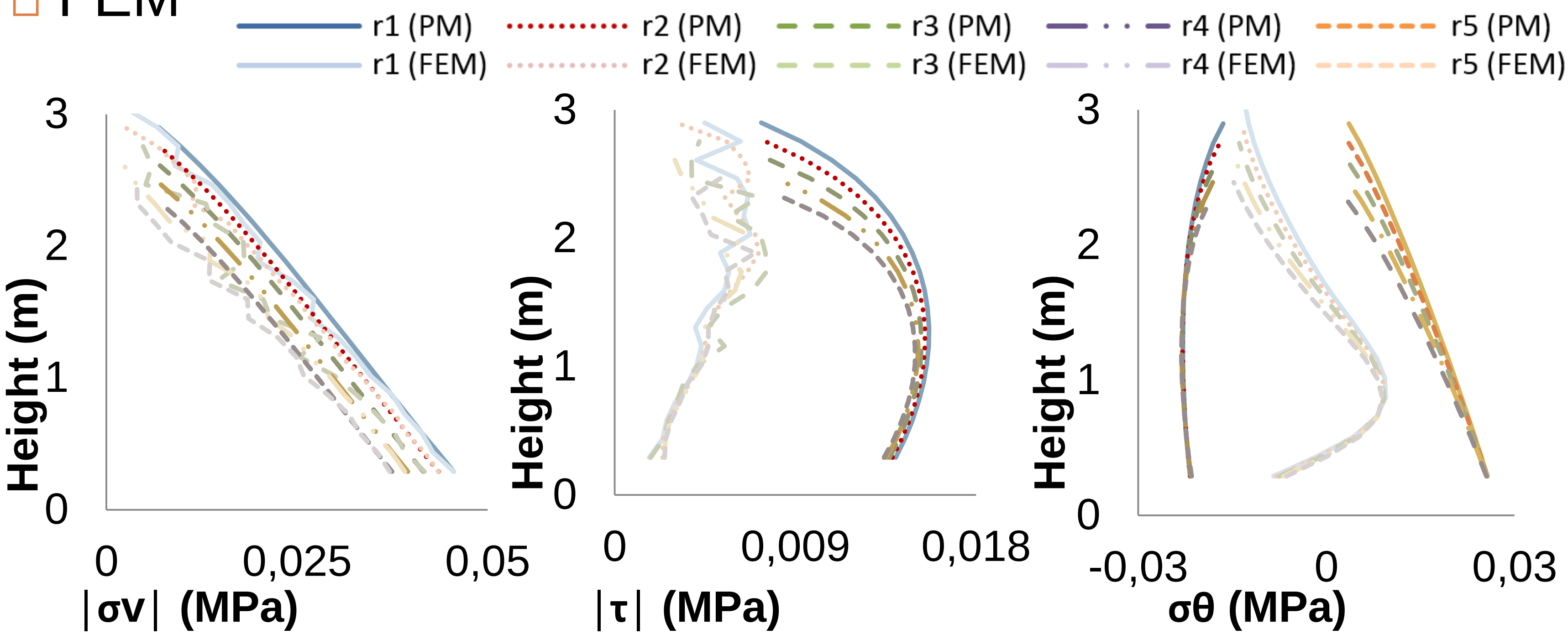
DOME METHOD(3)

Table 1. Structural check for earthbag or superadobe domes

Nature	Mechanism	Verification	D_S	C_A	$C_{A\&B}$
Global stability	Roll-over	$W_{t,1}\gamma_{G1}/RE_1 \geq q_{wind}H^2\gamma_{Q2}/2$	M	M	M
	Slipping	$(c_{bw}A_{z,ef,base} + N_{k,base}\mu) \geq q_{wind}H\gamma_{Q2}$	M	M	M
	Collapse	$f_{base} \geq \sigma_{d,v,1}$	M	M	M
	Buckling	$E_{adobe}b_i/4H \geq \sigma_{d,v,max}$	M	M	M
Local stability	Roll-over	$N_{k,v,i}(R_{kl,ext,i} - RE_i) + W_ib_i\gamma_{G1}/2 \geq T_{d,i}h$ $T_{k,i}h + W_i\gamma_{G1}(RC_i - RI_{i-1}) \geq N_{d,v,i}(R_{kl,int,i} - RI_{i-1})$	M M	M M	M M
	Slipping	$c_{bw}A_{z,ef,i}/\gamma_{wire} + N_{k,v,i}\mu \geq T_{d,i}{}^*$	M		
Local strength of the material	Bag tear	$T_{tear} \geq T_{d,i} - N_{d,i}\mu$			R
	Adobe failure	$-f_{adobe} \geq \sigma_{d,ext,max,i}$ $-f_{adobe} \geq \sigma_{d,\theta,c,i}$ $f_{adobe,t} \geq \sigma_{d,\theta,t,i}{}^{**}$	M	M M* M*	M M*
	Bag failure	$2K_pT_{bag}/(h\gamma_{bag}) \geq \sigma_{d,ext,max,i}$ $T_{bag}(b_i + h)/(b_ih\gamma_{bag}) \geq \sigma_{d,\theta,t,i}$			M M**,*

VERIFICATION(1)

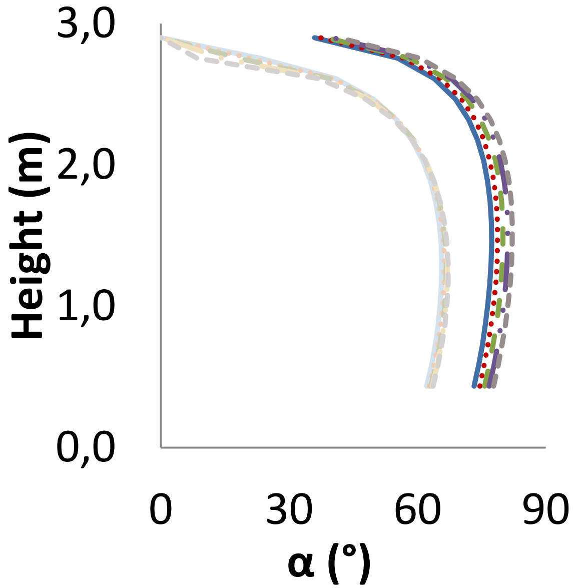
- FEM



- TNO Diana 9.3
- Axisymetric model
- Triangular elements for bags
- 8e4 elements
- Elasto-plastic model (compression)
- Brittle failure (tension)
- Interface elementn joins
- Coulomb friction model

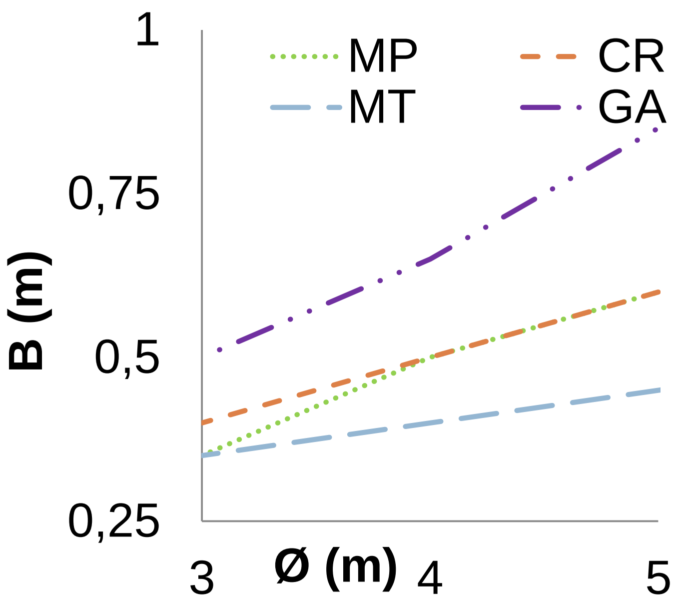
VERIFICATION(2)

- Corbelling theory



Recommendation
70º<α<80º

- Current Rules (CR)
- Membrane Theory (MT)
- Graphical Analysis (GA)
- Method Proposed (MP)



CONCLUSIONS(1)

- The MP strong points:
  - Discreate geometry
  - Material properties
  - Hoop Stresses
  - Easy to implement
  - Method → Optimization diagrams
- Verified with FEM
- Other domes theorys
  - Membrane theory → Understimation
  - Graphical analisys → Overstimation
  - Current experimental rules → Overstimation

- Future work:
  - Validation
  - Local cheks
  - Opt. curvature

CONCLUSIONS(2)

- Critical Failures:
  - Roll-over towards the outside close to the bottom
  - Slipping on top
- Oversize may reduce the safety factor (for discontinous domes)
- The MP sets the basis for future design code for earthbag walls and domes
- Positive social impact in emergency and humanitarian crisis situations

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