Experimental Study of Cement Mortar-Steel Fiber Reinforced Rammed Earth Wall

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- Background
- Introduction of Rammed Earth
- Numerical Analysis by FEM
- Experimental study
  - Wall Model Design
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  - The CMSF Reinforcement
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- Conclusions

1、Background

Snow and frozen rain disaster

2008, South China

Houses destroyed /Severely damaged

2、Introduction of Rammed Earth

2.1 Examples of Rammed Earth Structure

Tulou in Fujian

Peifeng Pagoda,
Qing Dynasty

Old houses in Guangdong

2.2 Applications in Ancient China

Straight Highway of Empire Qin

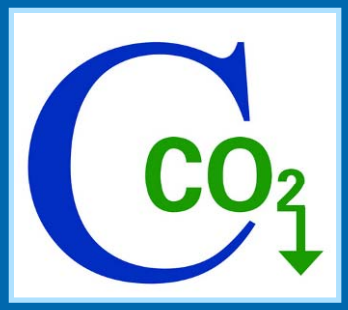
Jiaoshan emplacement, Jiangsu

Tongwan Castle, Shaanxi
The Northern and Southern Dynasties

Coffin in the Tomb, Guangxi

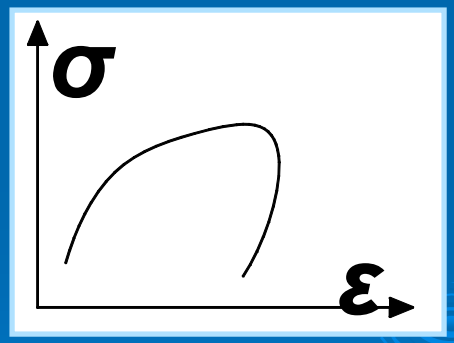
2.3 Advantage of Rammed Earth Material

- Low-carbon property



- Convenient availability

- Good mechanical characteristic



- Economical

2.4 Composition of Rammed Earth

Lime

Yellow Clay

Sand

Rammed earth

3、Numerical Analysis

3.1 Similarity Principle

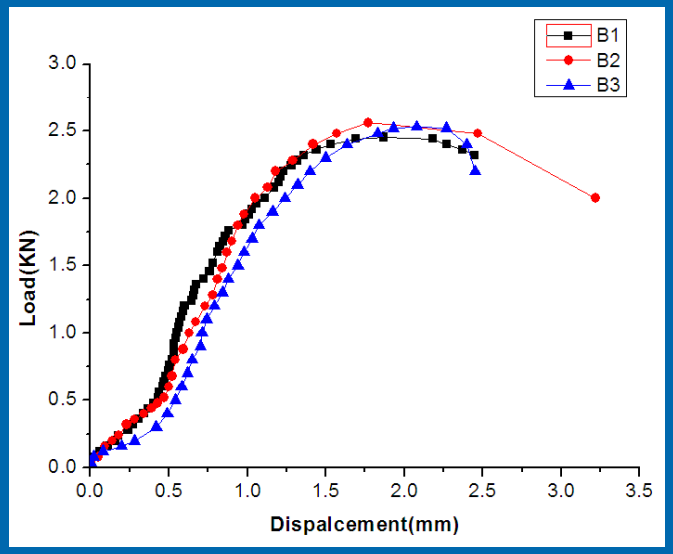
	Practical	Model	Similarity Constant
Height	3000mm	1500mm	$S_H = 1/2$
Width	4000mm	2000mm	$S_B = 1/2$
Thickness	240mm	240mm	$S_T = 1$
Ultimate Stress	σ_p	σ_m	$S_\sigma = 1$
Ultimate Capacity	F_p	F_m	$S_F = S_\sigma S_B S_T = 1/2$

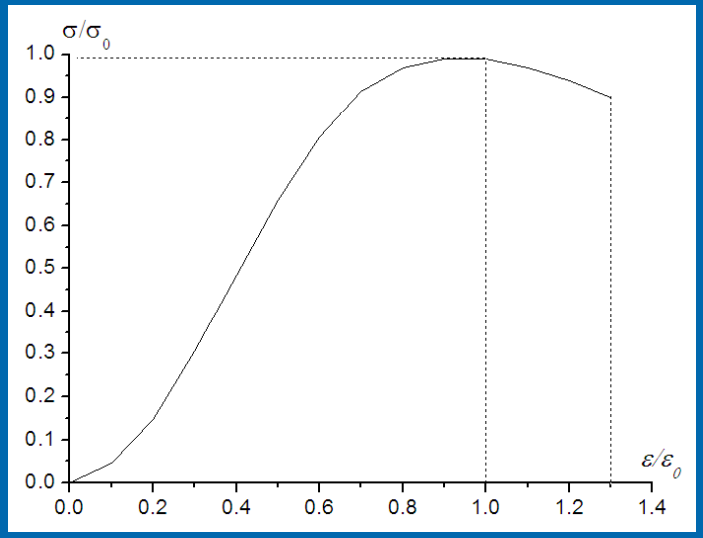
3.2 Material Parameters

Sample	Length (mm)	Failure load (KN)	Compressive strengths (Kpa)	Mean value (Kpa)
B1	70	2.45	500	
B2	71	2.56	522	512.7
B3	71	2.53	516	

Water content w%	Dry density ρ_d(kg/m^3)	Cohesion（Kpa）	Friction angle（°）
19.5	1780	110.54	14.9

3.3 Constitutive Model





Least Square Method

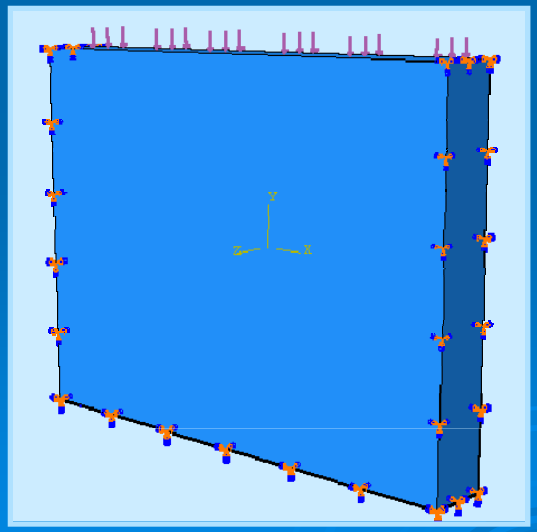
$$\frac{\sigma}{\sigma_0} = 3\left(\frac{\varepsilon}{\varepsilon_0}\right)^4 - 8.78\left(\frac{\varepsilon}{\varepsilon_0}\right)^3 + 7.33\left(\frac{\varepsilon}{\varepsilon_0}\right)^2 - 0.62\left(\frac{\varepsilon}{\varepsilon_0}\right)$$

3.4 Numerical Analysis

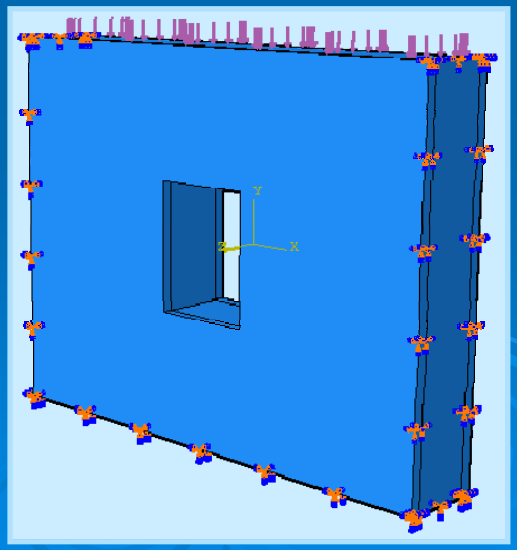
Parameters of the wall models

Model	Height×Width×Thickness	Window hole	Cement mortar in reinforcement
M1	1500×2000×240mm^3	none	none
M2	1500×2000×240mm^3	400×500mm^2	none
M3	1500×2000×240mm^3	none	40mm(two sides)
M4	1500×2000×240mm^3	400×500mm^2	40mm(two sides)

M1

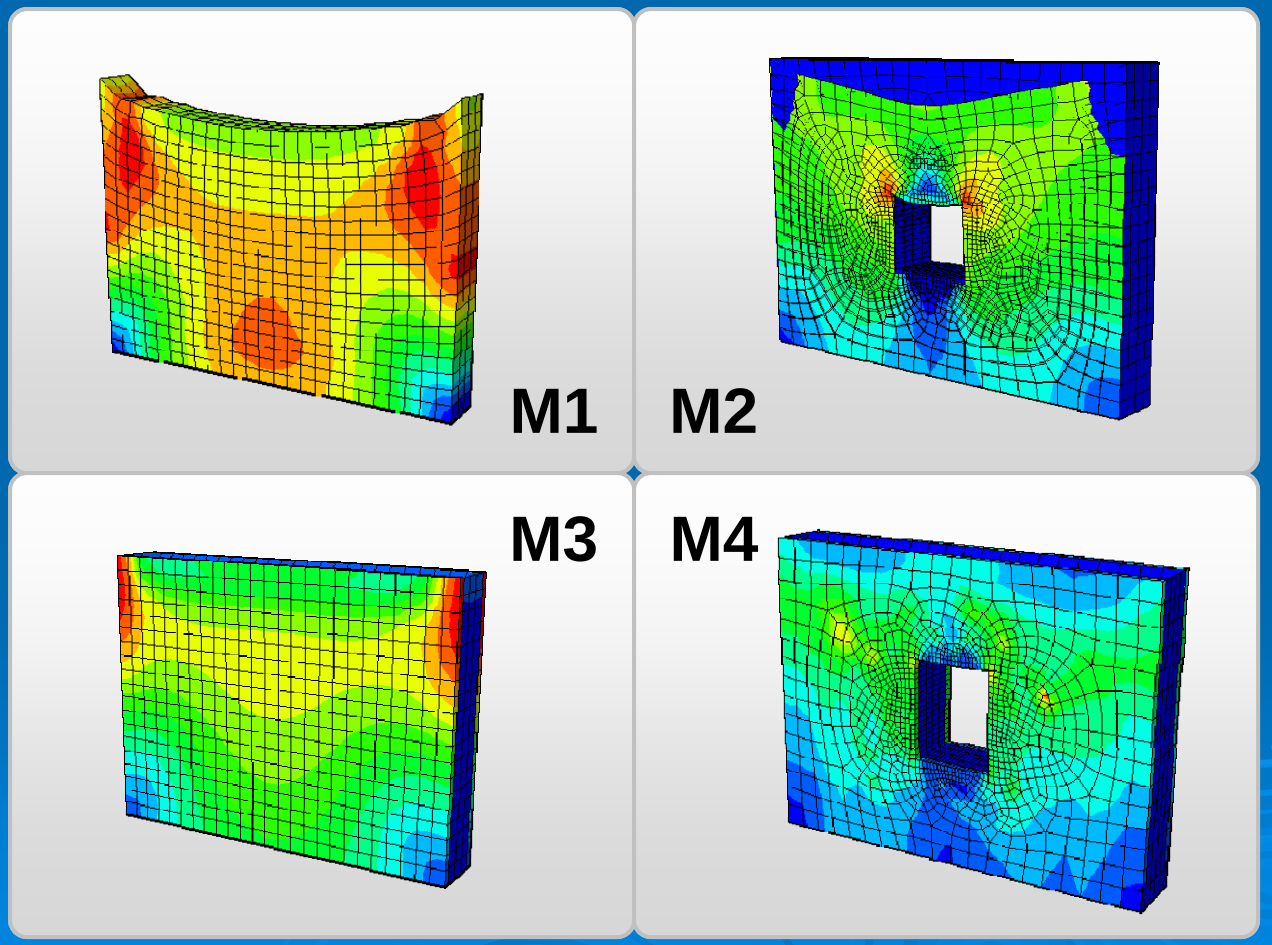


M4



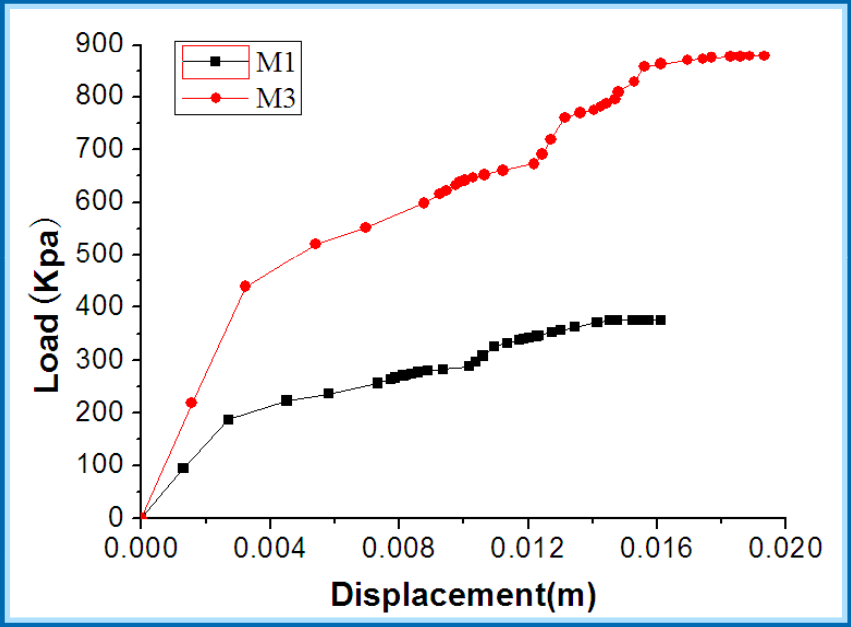
3.5 Numerical Results and Analysis

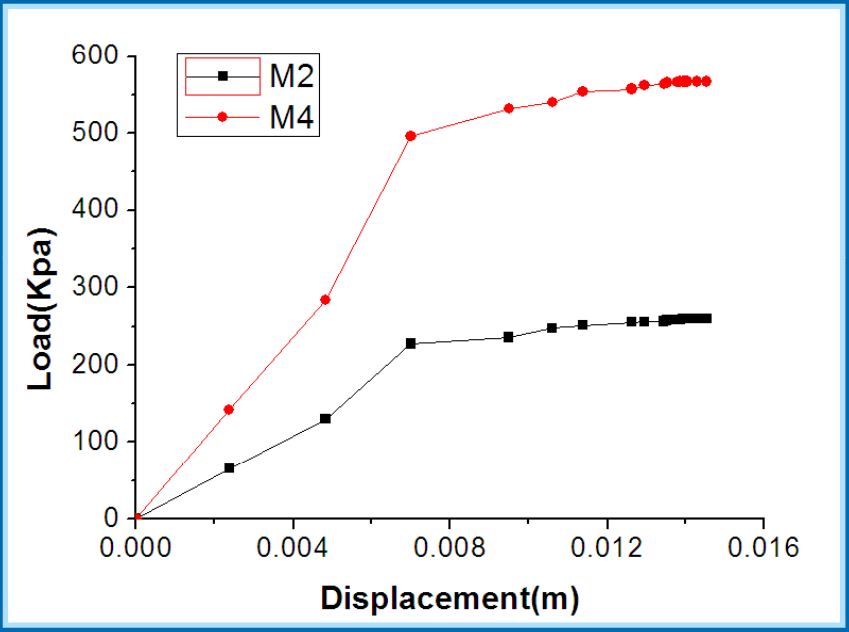
Von Mises stress of the four models



3.6 Numerical Results and Analysis

Finite element analytical results before and after reinforcement





Model description	Ultimate bearing capacity before reinforcement (Kpa)	Ultimate bearing capacity after reinforcement(Kpa)	Increasing percentage (%)
Single wall	375	878	134
Wall with window hole	260	567	117

4、Experimental study

4.1 Wall Model Designing

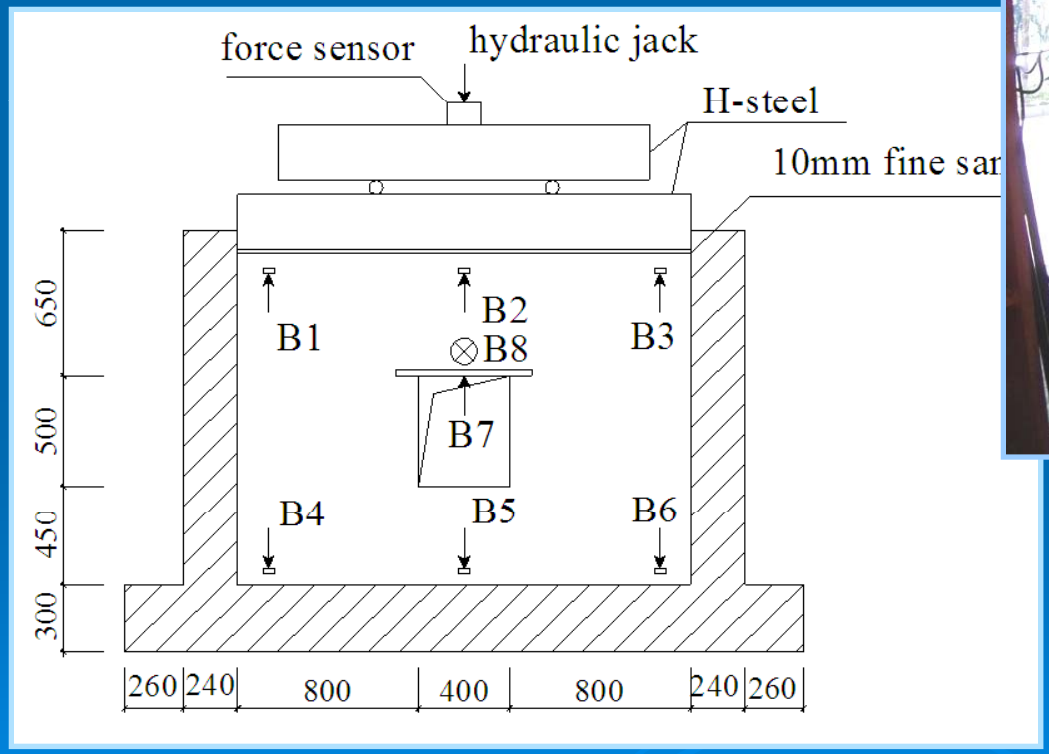
Walls	Sand:Soil:Lime	Height*Width*Thickness	Window Hole
W1	3:1:0.6	1500*2000*240mm^3	0
W2	3:1:0.6	1500*2000*240mm^3	1
W3	3:1:1	1500*2000*240mm^3	0

Note: The proportion in the table is measured in mass

General configuration of the experimental device

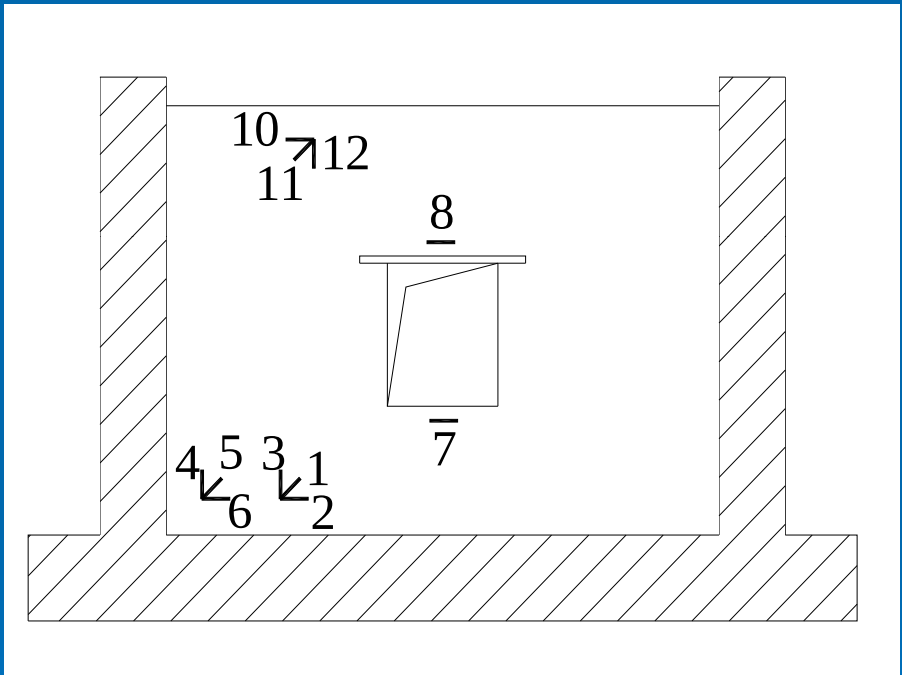
4.2 Loading System

4.3 Data Collection



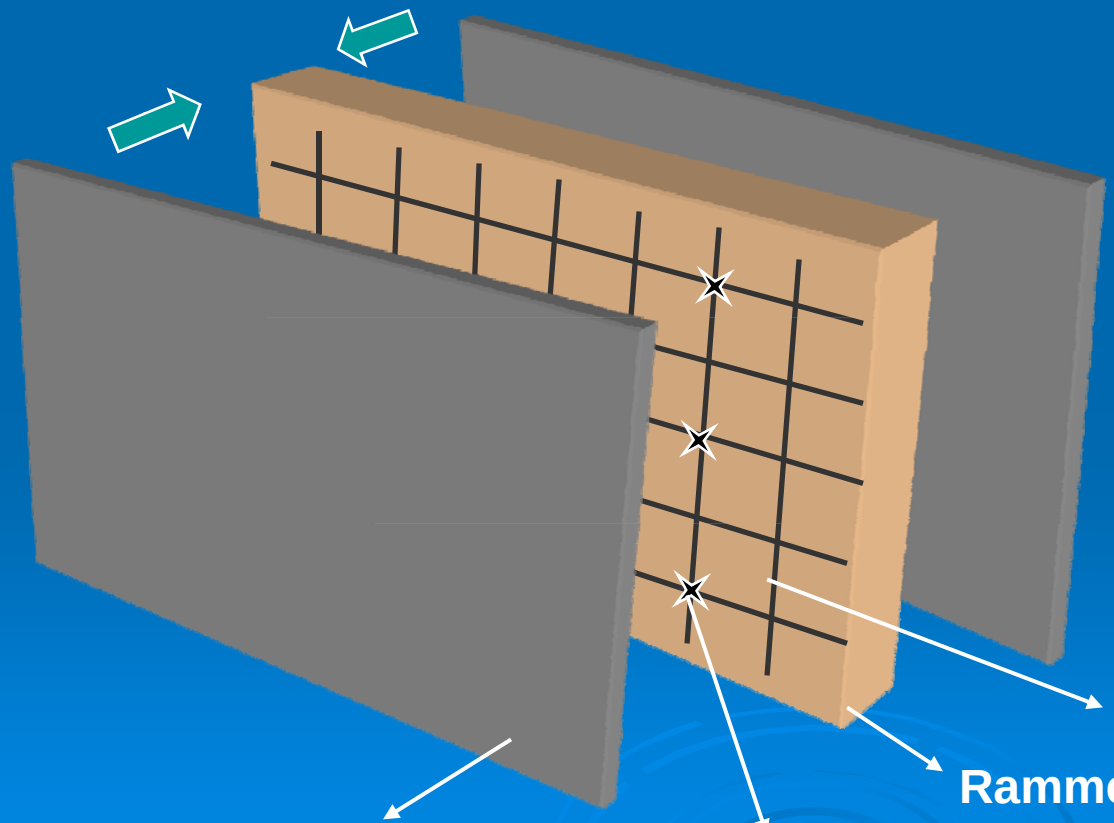
Dial gauges

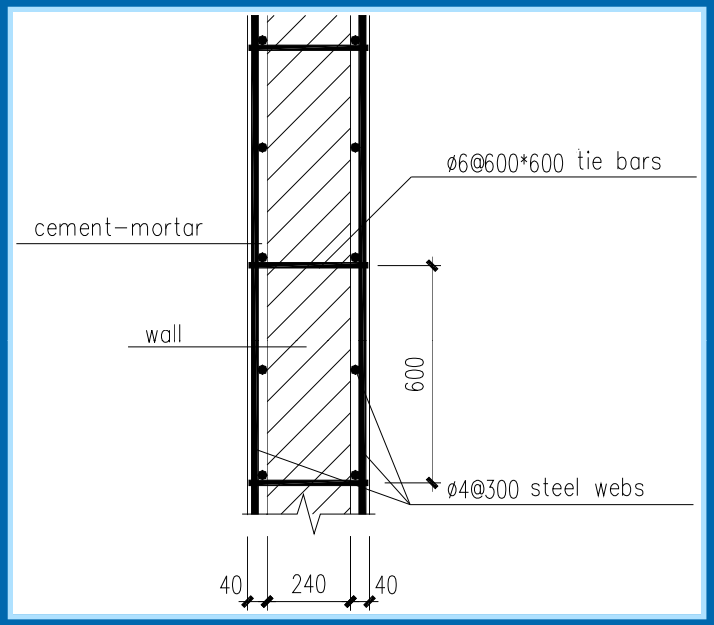
4.3 Data Collection



Strain rosettes

4.4 Cement Mortar-steel Fiber Reinforcement





4.5 Failure Characteristics

Before reinforcement :

For W1

Crack in the upper boundary

Crack grows rapidly

For W2, W3

Cracks on both sides of the upper corner

Separation from the frame

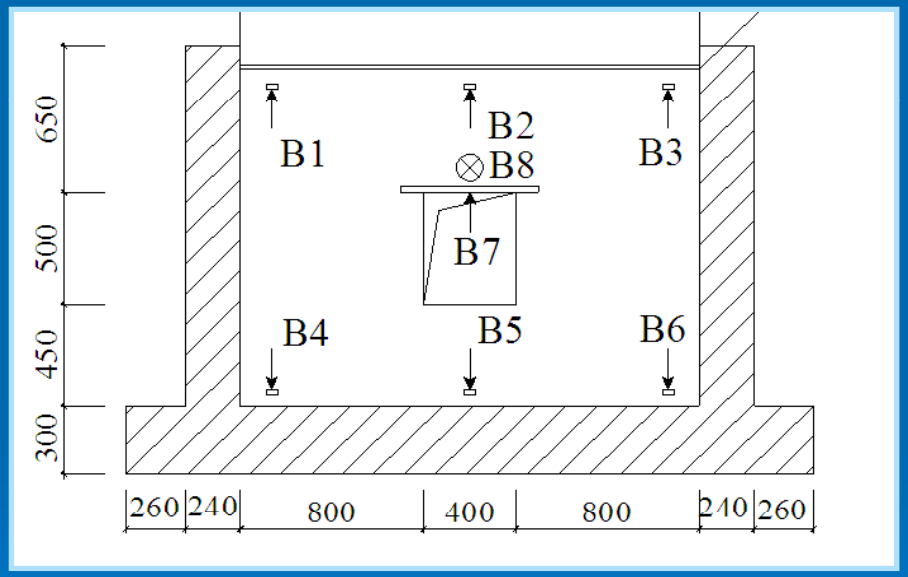
4.5 Failure Characteristics

After reinforcement :

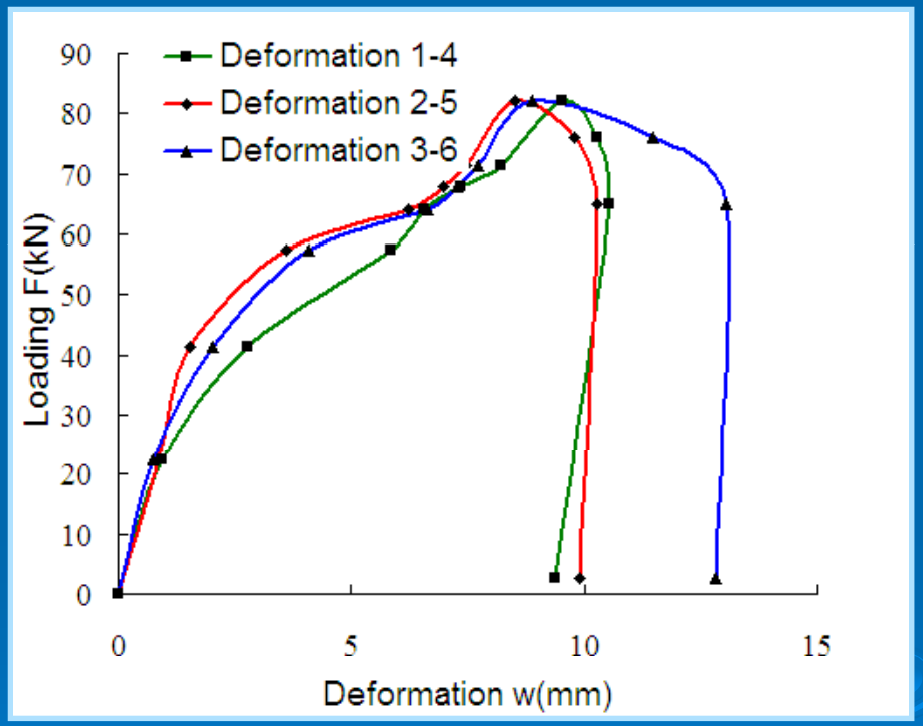
Cohesive failure of the rammed earth wall

Separation to the original wall

4.6 Strain and Deformation Analysis

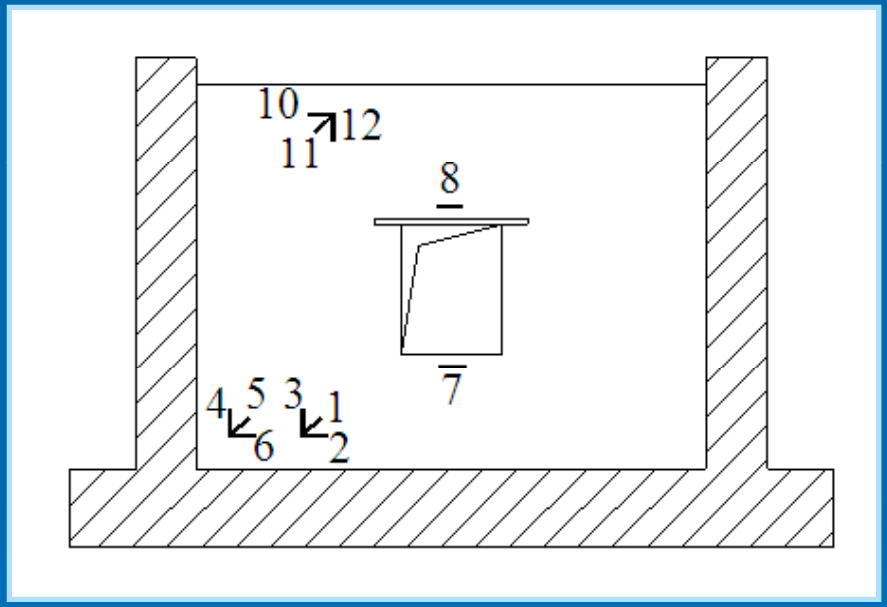


Distribution of Dial Gauges

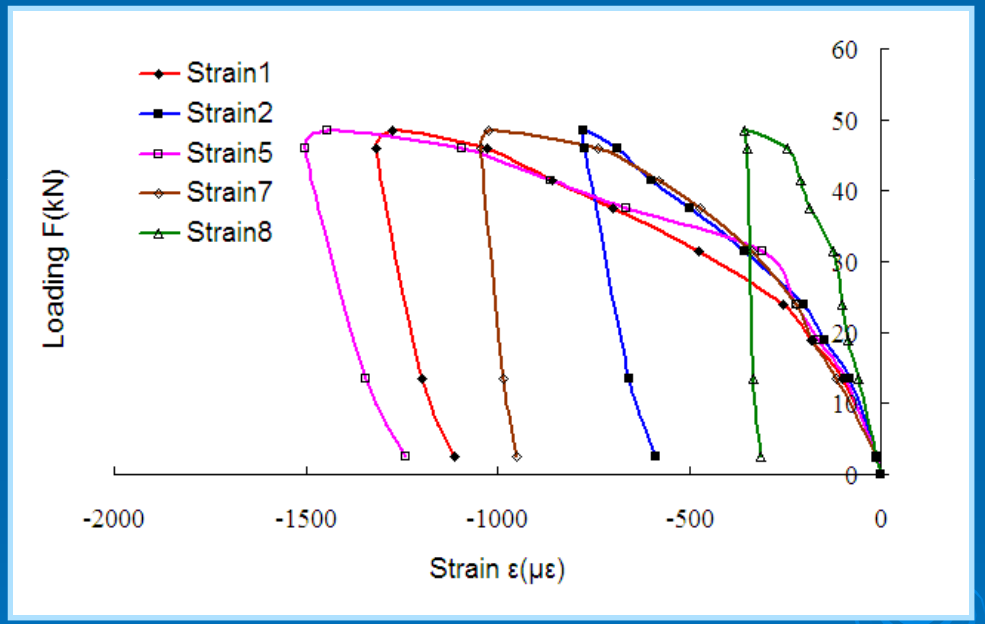


Loading-Deformation Curve of W3

4.6 Strain and Deformation Analysis



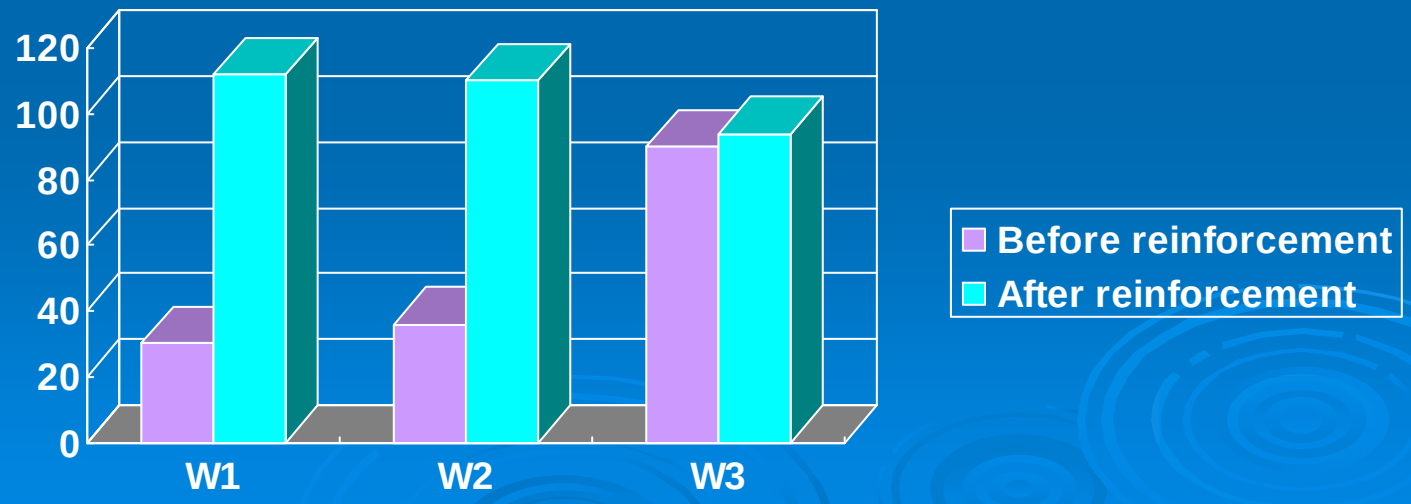
Distribution of Strain Rosettes



Loading-Strain Curve of W2

4.7 Test Results

Walls	Cracking load (kN)	Ultimate bearing capacity (kN)	Raising in ultimate bearing capacity (%)
W1	30	30	-
W1'	38	112	373%
W2	13	36	-
W2'	80	110	306%
W3	55	90	-
W3'	69	94	104%



5. Conclusions

- Cement mortar-steel fiber reinforcement is effective to improve the ultimate bearing capacity of rammed earth wall.
- Lime helps to improve the strength of rammed earth wall.
- Boundary conditions affects the final results on the ultimate bearing capacity of the model.
- The separation of mortar layer from the original wall is due to rammed earth cohesive failure.
- The FEM results are expected to compare with the test results of the corresponding scaled model, and further studies are expected.

Thank you!