PROJECT OUTLINE AND EXPERIMENTAL TEST

Joint Research Project on
"Evaluation and Mitigation of Seismic Risk for Composite Masonry Buildings in Bhutan"

in the framework of SATREPS
(Science and Technology Research Partnership for Sustainable Development)
2017-2023

Department of Culture
Ministry of Home and Cultural Affairs

Department of Engineering Services
Ministry of Work and Human Settlement

TRADITIONAL CONSTRUCTION PRACTICES IN BHUTAN

1. Rammed earth construction

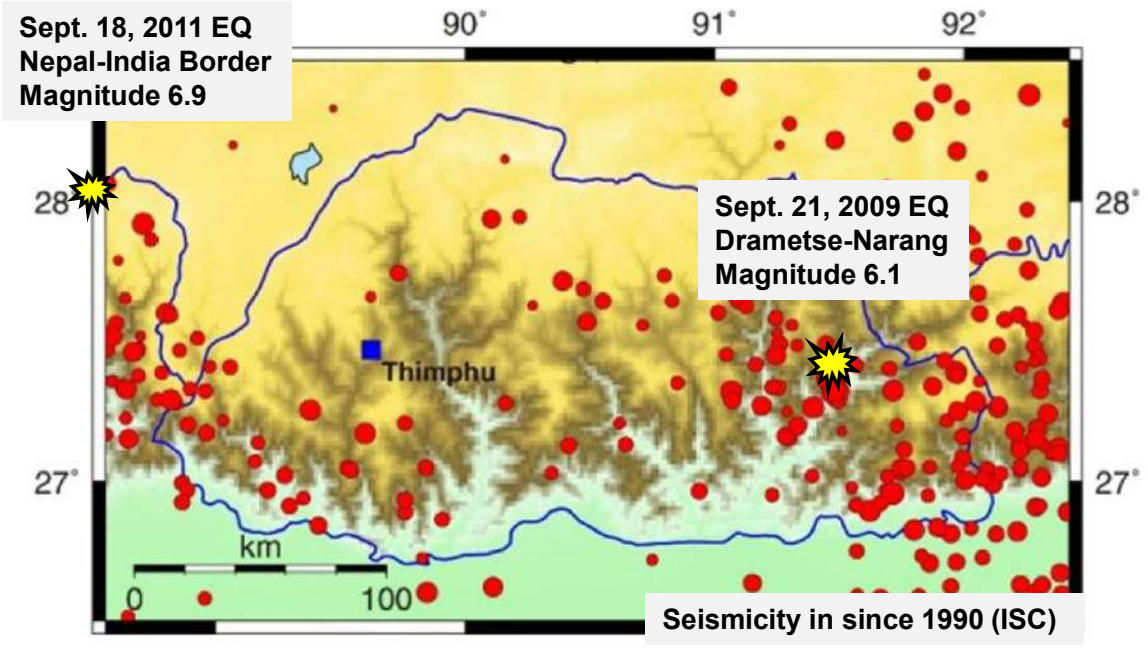
2. Random Stone Masonry Construction

According to National Statistics Bureau (NSB) of Bhutan, **total of 66% of households live in traditional buildings, out of which 83% of households** living in such traditional buildings belong to rural areas.

List of Historical Earthquakes that affected Bhutan

	Magnitude	Date	Location (Epicenter)
1	7.0	1713	Border Between Bhutan and Arunachal Pradesh
2	7.6	11 June 1806	Eastern Bhutan
3	8.0	12 June 1897	60 Km from south of Bhutan in Assam
4	6.5	12 May 1906	Border of Bhutan, India and China
5	5.7	13 August 1910	Border of India and Bhutan
6	8.0	15 January 1934	India and Nepal Border
7	6.7	21 January 1941	South Eastern Bhutan
8	7.3	29 July 1947	India and China Border
9	8.7	15 August 1950	India and China Border
10	6.4	23 Feb 1954	Border of Bhutan, India and China
11	6.6	29 July 1960	Southern Bhutan
12	6.4	19 Nov 1980	North East India
13	6.8	20 August 1988	Nepal
14	5.5	26 Mar 2003	Paro
15	5.0	11 Feb 2006	Arunachal Pradesh, felt in Trashigang
16	5.7	14 Feb 2006	Sikkim
17	5.8, 5.5	24 Feb 2006	Dewathang
18	6.1	21 Sep 2009	Narang, Mongar
19	6.9	18 Sep 2011	Sikkim, India
20	4.5	21 Oct 2011	Bhutan
21	4.6	1 March 2012	Bhutan
22	4.7	10 July 2012	Bhutan
23	4.0	6 June 2013	Bhutan
24	4.3	4 Dec 2013	Bhutan

TRADITIONAL HOUSES: VULNERABLE TO EARTHQUAKES

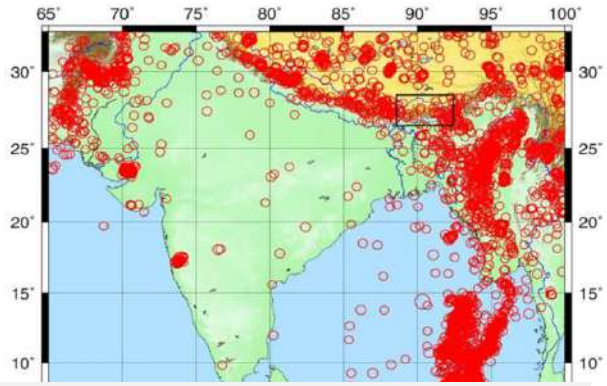


Seismicity in since 1990 (ISC)

Based on National Recovery and Reconstruction Plan:

2009 EQ: Affected 4950 rural homes

2011 EQ: Affected 6977 rural homes



Seismicity of South Asia since 1960 (ISC)

2009 Earthquake Damage to Rural Houses

Sl. No	Dzongkhag	Houses Damaged				Dead	Injured
		Beyond Repair	Major Repair	Partial Repair	Minor Repair		
1	Trashiyantse	21	70	400	106		
2	Zhemgang	1			1		
3	Trashigang	147	445	439	572	2	18
4	Pemagatshel	25	24	24	187		3
5	Lhuentse		6	24	87		
6	Mongar	**260**	**331**	**413**	**1253**	**6**	**18**
7	Samdrupjongkhar	7		10	11	4	
8	Gasa			23			
9	Punakha		5				
10	Chukha				22		
11	Sarpang				2		
12	Tsirang	1	3	2	28		
	Total	**462**	**884**	**1335**	**2269**	**12**	**39**

2011 Earthquake Damage to Rural Houses

	Dzongkhag	Houses Damaged				Dead	Injured
		Cat III Total Collapse	Cat II Substantial to Heavy Damage	Cat I Minor Damage	Total		
1	Bumthang	0	0	62	**62**	0	0
2	Chhukha	18	101	551	**670**	1	0
3	Dagana	12	70	367	**449**	0	0
4	Gasa	5	15	209	**229**	0	0
5	Haa	**200**	**319**	515	**1034**	0	14
6	Lhuentse	0	2	61	**63**	0	0
7	Mongar	4	35	439	**478**	0	0
8	Paro	54	129	837	**1020**	0	0
9	Pemagatshel	1	4	27	**32**	0	0
10	Punakha	3	39	868	**910**	0	0

	Dzongkhag	Houses Damaged				Dead	Injured
		Cat III Total Collapse	Cat II Substantial to Heavy Damage	Cat I Minor Damage	Total		
11	S/jongkhar	0	1	18	**19**	0	0
12	Samtse	81	189	645	**915**	0	0
13	Sarpang	1	3	46	**50**	0	0
14	Thimphu	4	16	336	**356**	0	0
15	Trashigang	0	0	0	**0**	0	0
16	Trashiyangtse	1	15	367	**383**	0	0
17	Trongsa	15	22	21	**58**	0	0
18	Tsirang	0	0	6	**6**	0	0
19	Wangdueg	1	47	145	**193**	0	0
20	Zhemgang	1	1	48	**50**	0	0
	TOTAL	**401**	**1008**	**5568**	**6977**	**1**	**14**

ROAD MAP: LAST ONE DECADE

EQ
2009

2009

Formation of
Technical Working Group

2010

International Conference on Disaster
Management and Cultural Heritage

2011

EQ
2011

2012

Joint study on the conservation of
rammed earth buildings in Bhutan
in cooperation with NRICPT,
Japan

2014

Improving resilience of seismic risk:
Policy and Human Resource Development
project
Funded by the World Bank

2017

Science and Technology Research
Partnership for Sustainable Development
(SATREPS)
FUNDED by JICA and RGoB

PROJECT FRAMEWORK

NAME OF THE PROJECT:
"Project for Evaluation and Mitigation of Seismic Risk for Composite Masonry Buildings in Bhutan"

PROJECT DUTATION: April 2017- March 2023

OVERALL GOAL:
Seismic Technology for disaster mitigation of the composite masonry buildings is disseminated across the country

PROJECT FRAMEWORK:
SATREPS (Science and Technology Research Partnership for Sustainable Development)

FUNDNG AGENCY:
Japan International Cooperation Agency (JICA) and Royal Government of Bhutan

JOINT RESEARCH TEAM

Department of Disaster Management, MoHCA
Department of Culture, MoHCA
Department of Engineering Services, MoWHS
Department of Geology and Mines, MoEA

Nagoya City University
National Institute for Earth and Disaster resilience (NIED)
Kyoto University
Nihon University
Kagawa University
Tohoku University

OUTPUTS OF THE PROJECT

JOINT RESEARCH

OUTPUT 1

Evaluation of seismic risks of composite masonry Buildings

- Development of seismograph network
- Hazard map
- Risk map for 2 pilot sites

OUTPUT 2

Development of seismic technology for constructing and strengthening composite masonry buildings

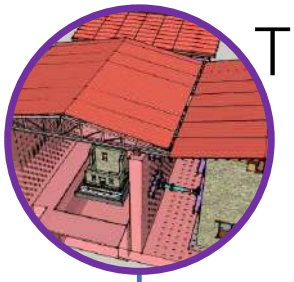
- Tests
- Development of analysis methods
- Development of guidelines

OUTPUT 3

Enhancement of the dissemination mechanism for the seismic technology

- Training programmes
- Public Awareness programmes
- Development of a manual and visual materials

OUTPUT 2: DEVELOPMENT OF SEISMIC TECHNOLOGY



TEST MATRIX

Material Test

Compression test

Static Test

Small Scale Element Test

Full Scale Test

Dynamic Test

Shaking Table Test

Material Test

Conduct the material test of composite masonry buildings.

Coring of cylindrical specimens

Compressive test

Split tensile strength

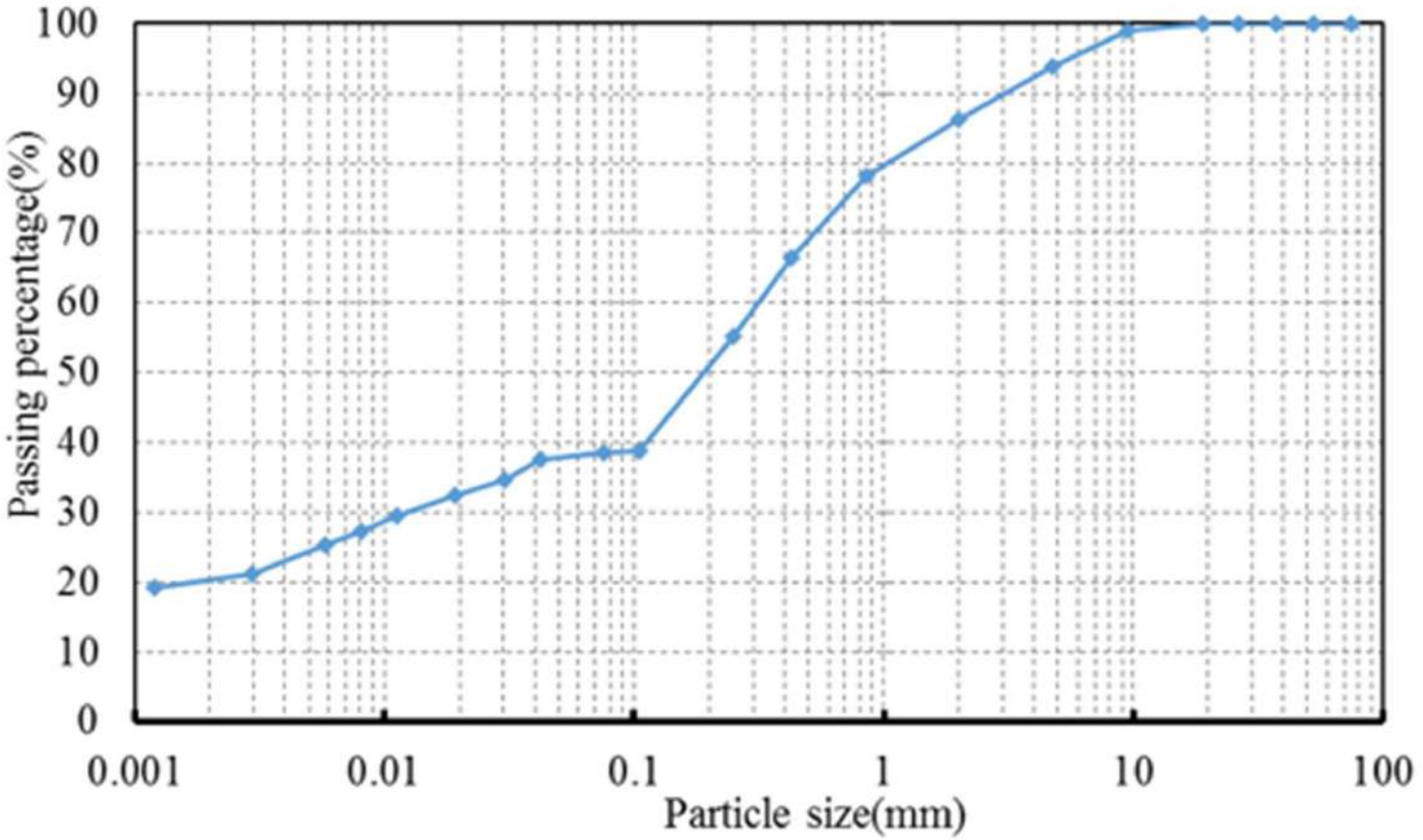
Properties of rammed earth from material characterization tests.

Specimen ID	Bulk density (kg/m³)		Compressive strength (MPa)		Tensile strength (MPa)		Elastic modulus (MPa)	
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
U–RE	2028	97.4	0.85	0.20	0.16	0.04	79.28	25.12
R–RE	1927	97.8	0.49	0.09	0.12	0.04	35.80	17.50

To determine the density, compressive strength, tensile strength and corresponding Young's modulus of elasticity.

Material Test

Grain size distribution for rammed earth soil used in test specimens

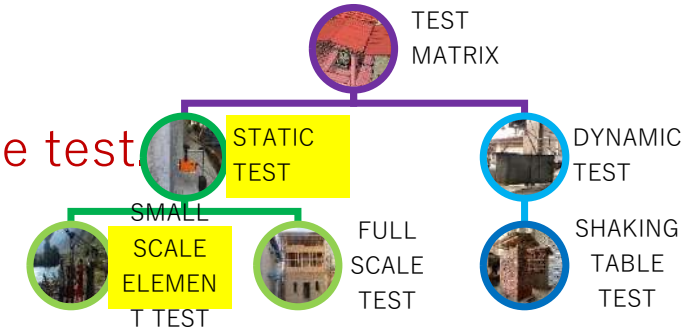


The grain size distribution of the RE used showed a particle size range of **0–10 mm**

Small scale element test

Objectives

- Examination of strength and collapse mechanism.
- Verification on effect of seismic strengthening prior to full-scale test.

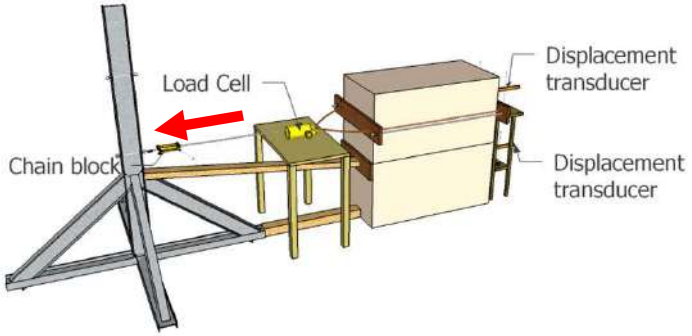


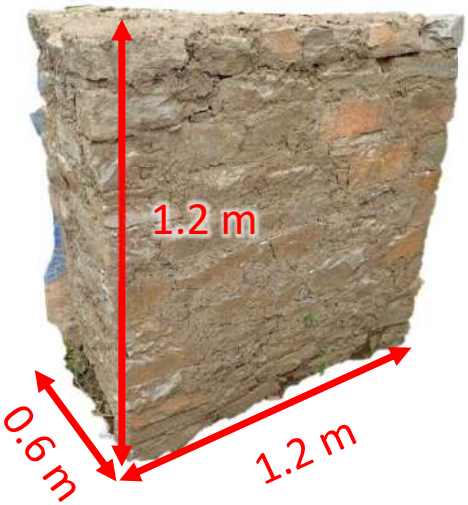
Small scale element test

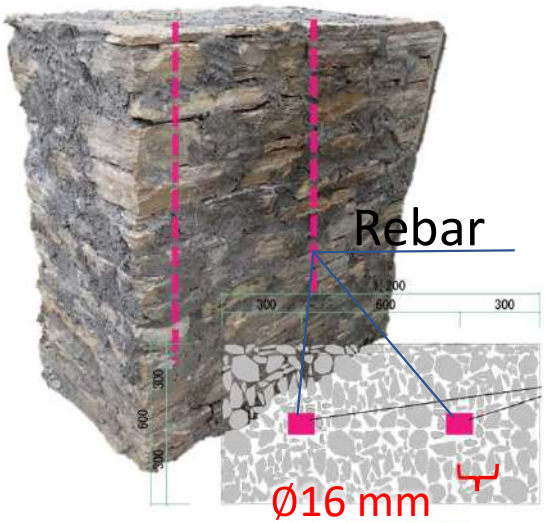
- Rammed Earth
  - Unreinforced
  - Reinforced **(New)**
  - Retrofitted **(Old)**
- Stone Masonry
  - In mud mortar
  - In cement mortar
  - Unreinforced
  - Reinforced **(New)**
  - Retrofitted **(Old)**

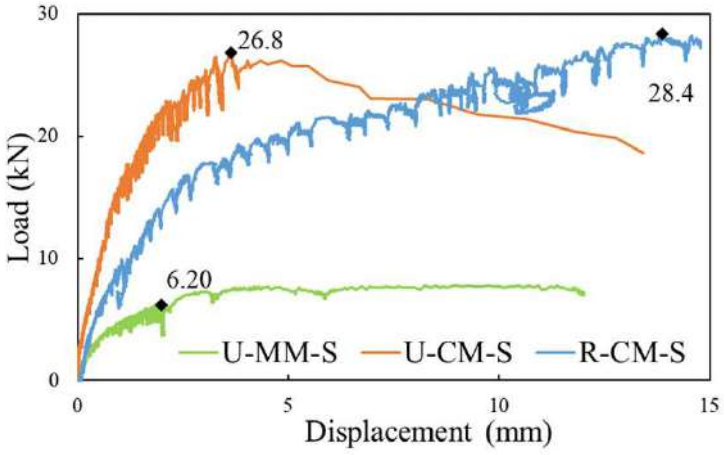
Small scale element test: Stone masonry(inplane)

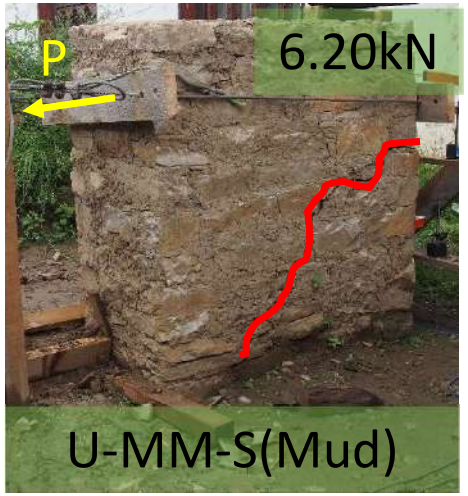
In-plane (2-units)

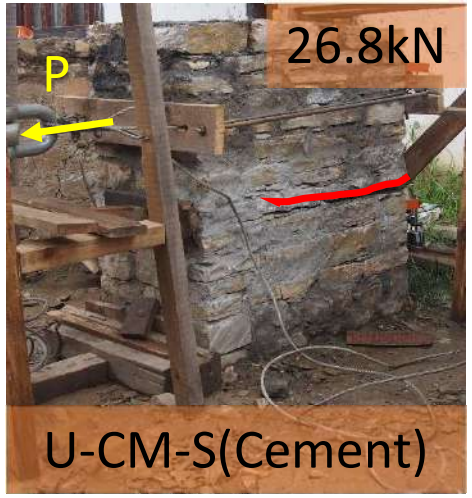


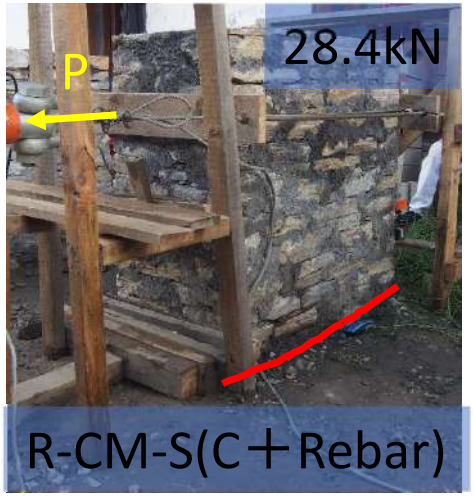






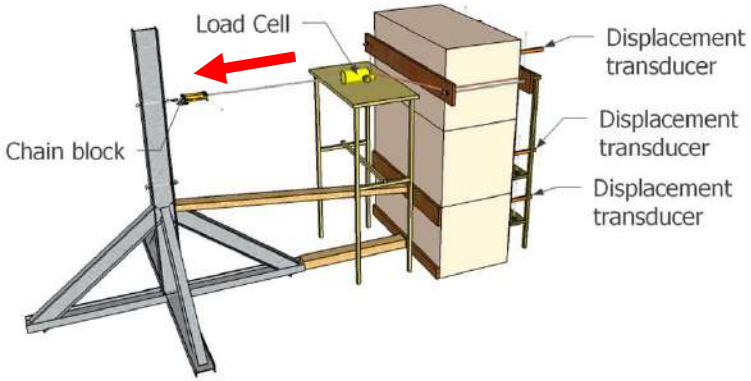


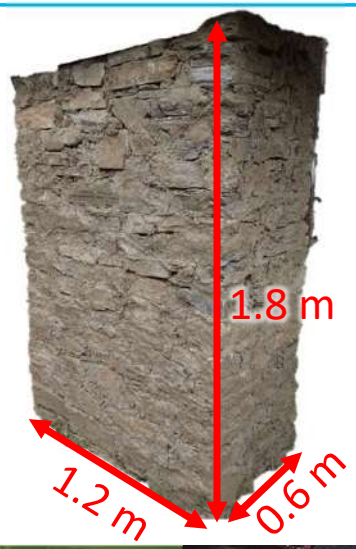


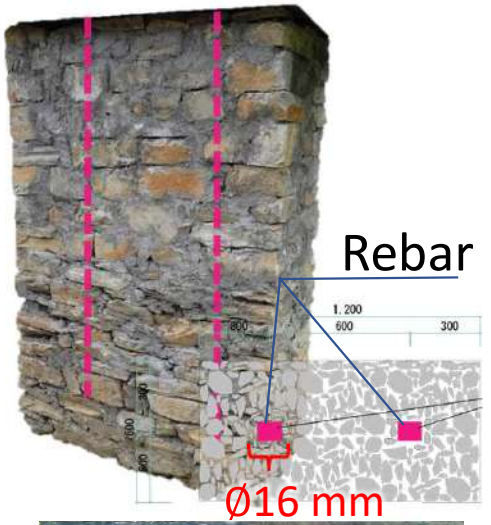


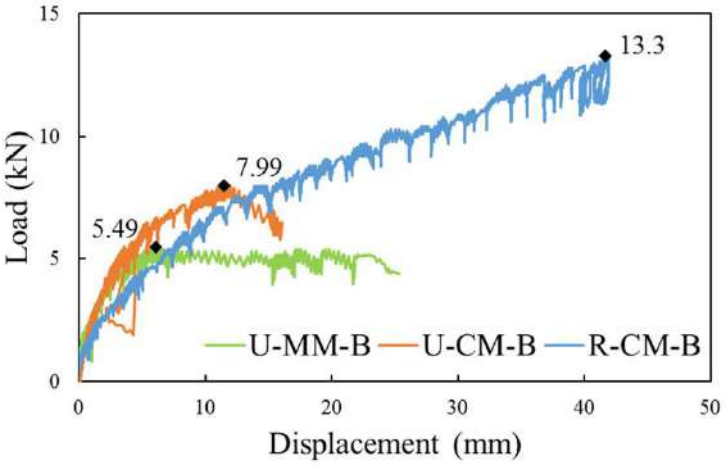
Small scale element test: Stone masonry(out of plane)

Out-of-plane (3-units)



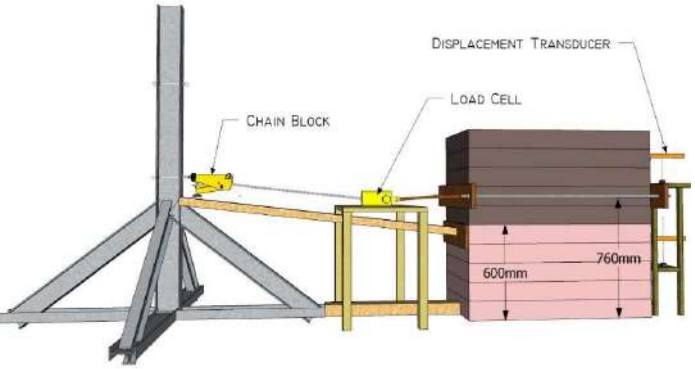


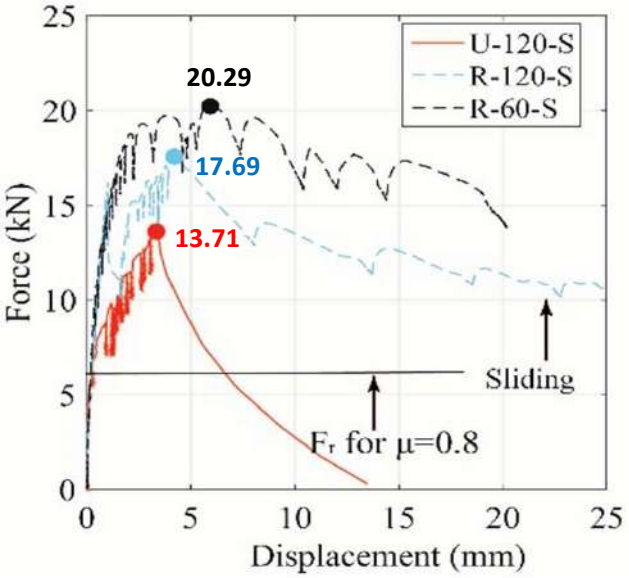


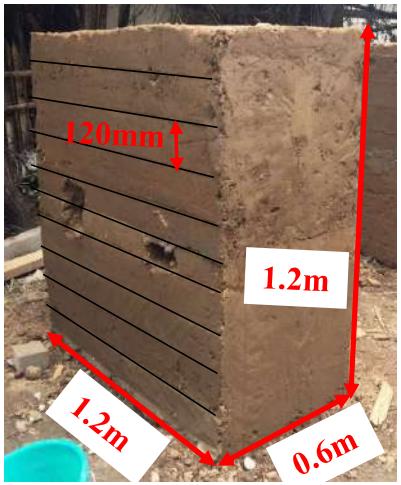


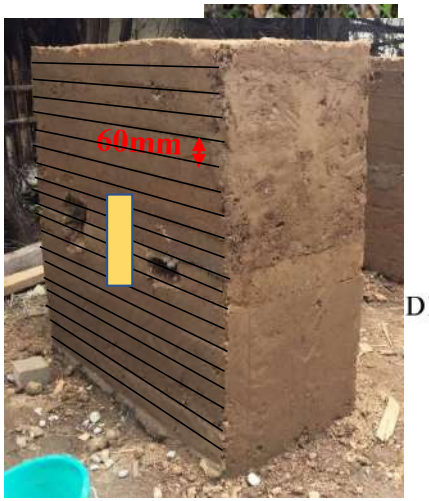
Small scale element test: Rammed earth (in plane)

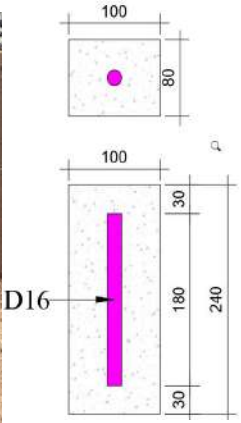
In-plane (2-units)







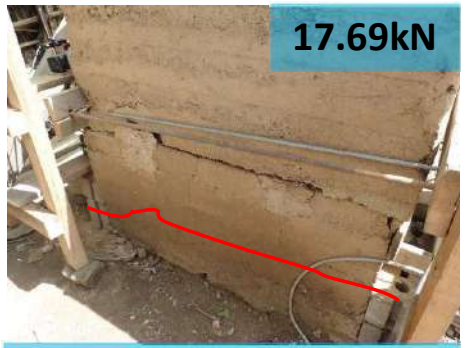




RC dowel

U-120-S

- Unreinforced
- Layer thickness-120



R-120-S

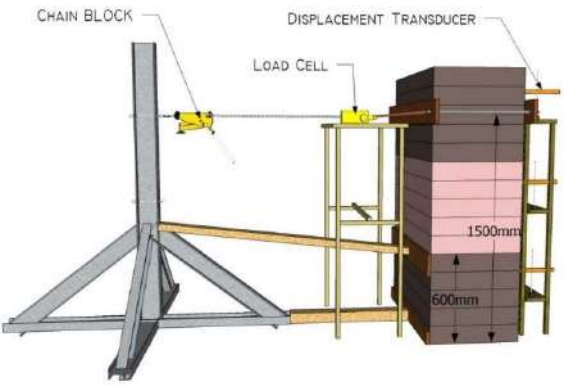
- RC dowel
- Layer thickness-120

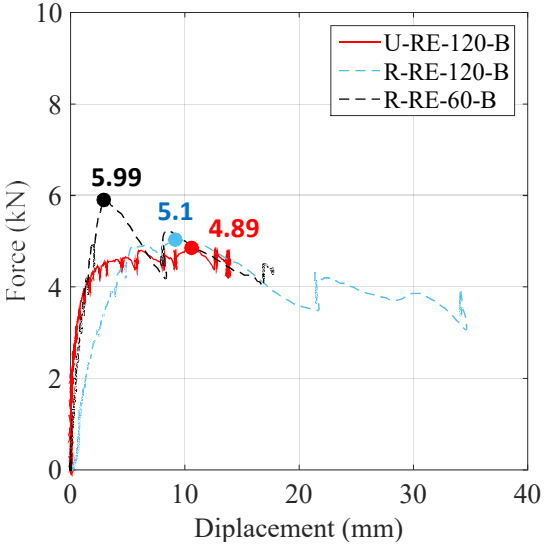
R-60-S

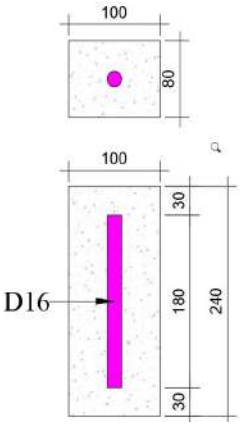
- RC dowel
- Layer thickness-60

Small scale element test: Rammed earth (out of plane)

Out-of-plane (3-units)







RC dowel

U-120-B

- Unreinforced
- Layer thickness-120

R-120-B

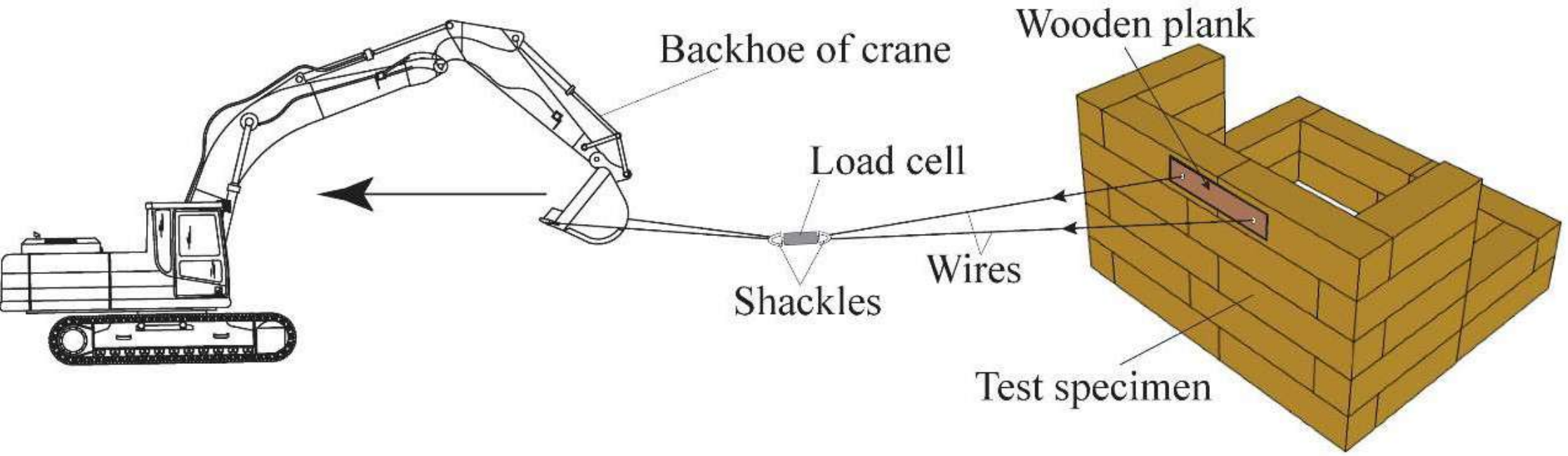
- RC dowel
- Layer thickness-120

R-60-B

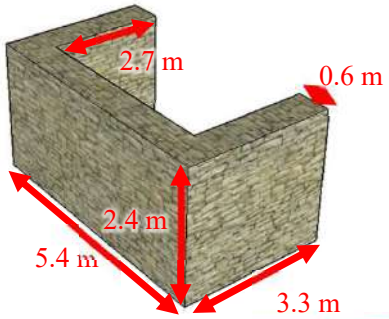
- RC dowel
- Layer thickness-60

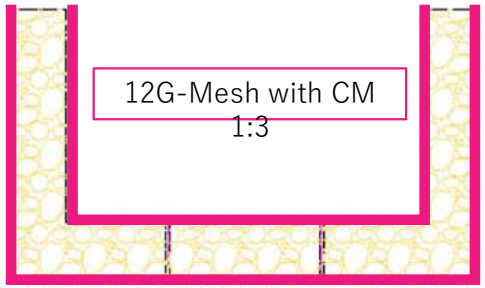
PULL DOWN TEST

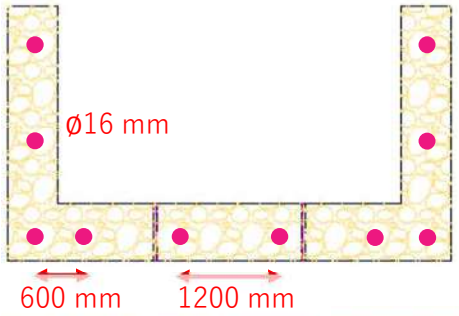
Test set up

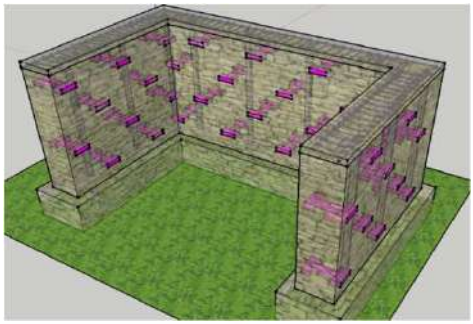


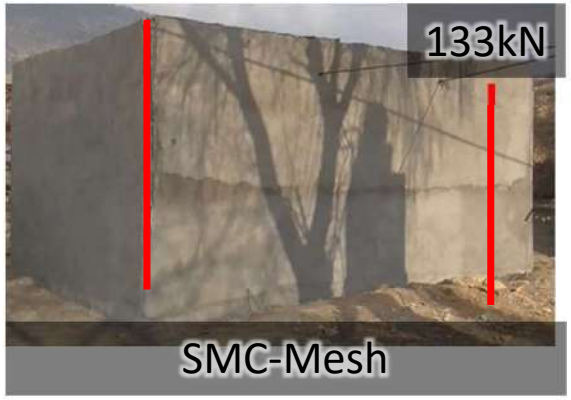
PULL DOWN TEST: Stone masonry in cement mortar(out-of-plane)

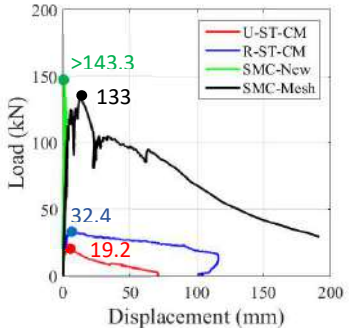


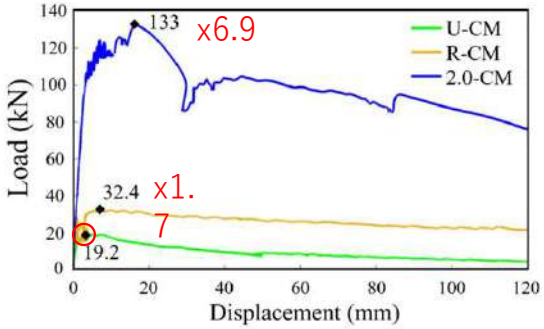




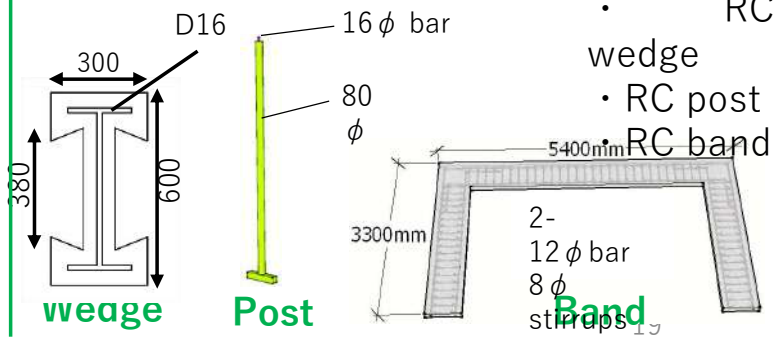






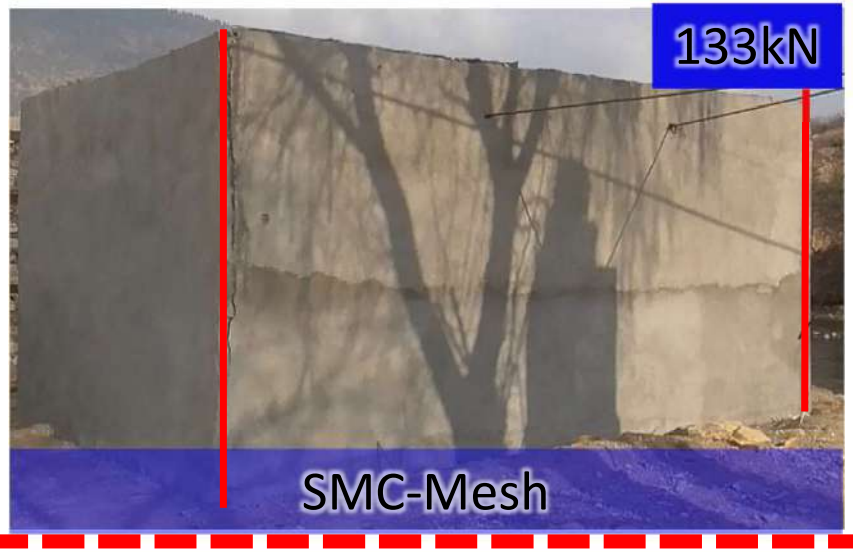


・Vertical bar
ϕ 16
(no concrete wrapping)

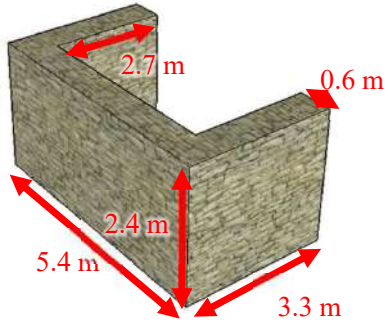


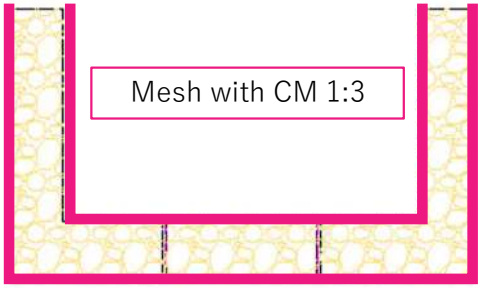
・RC wedge
・RC post
・RC band

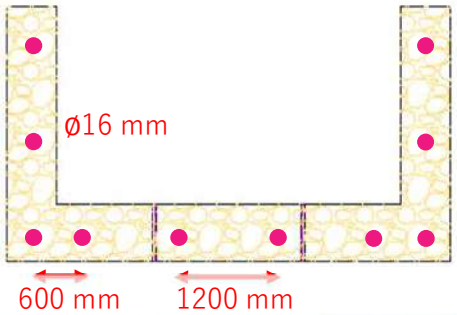
PULL DOWN TEST: STONE MASONRY IN CEMENT MORTAR

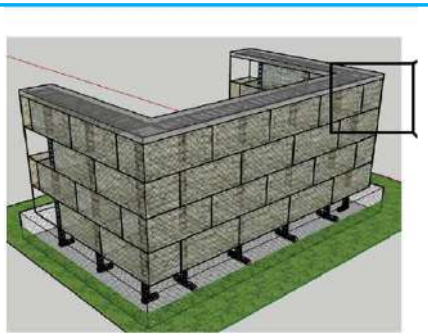


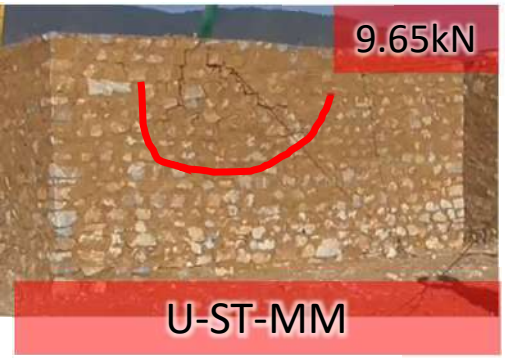
PULL DOWN TEST: Stone masonry in mud mortar(out-of-plane)

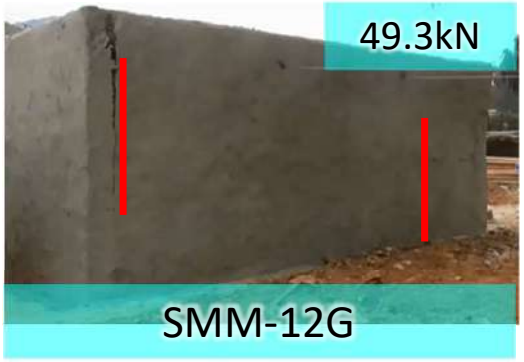


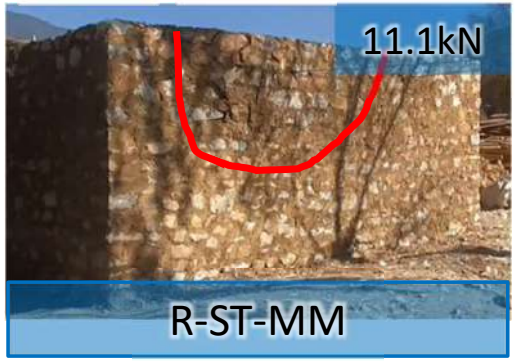


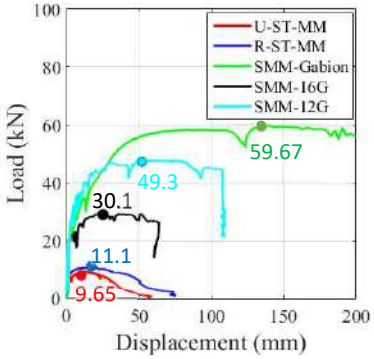






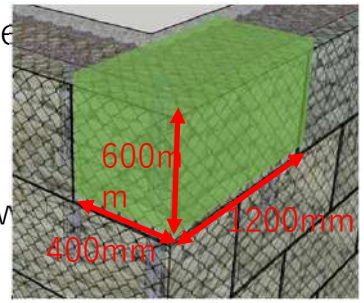




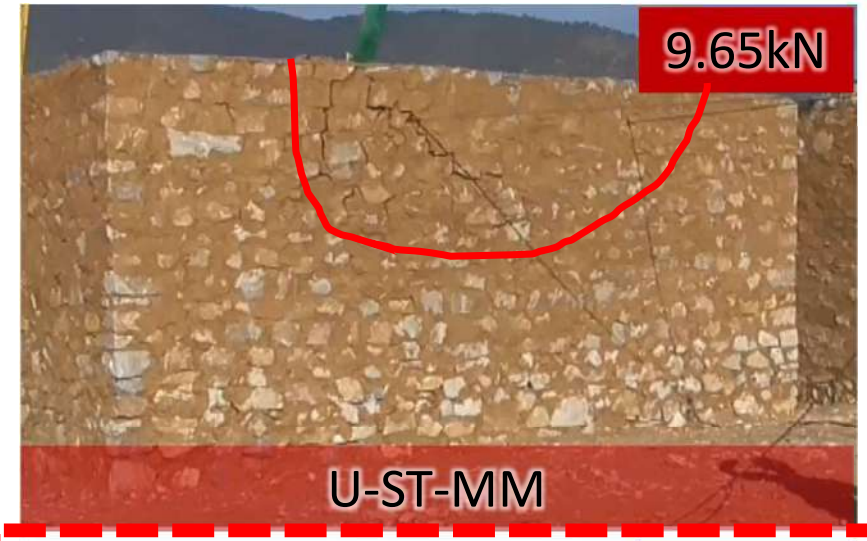


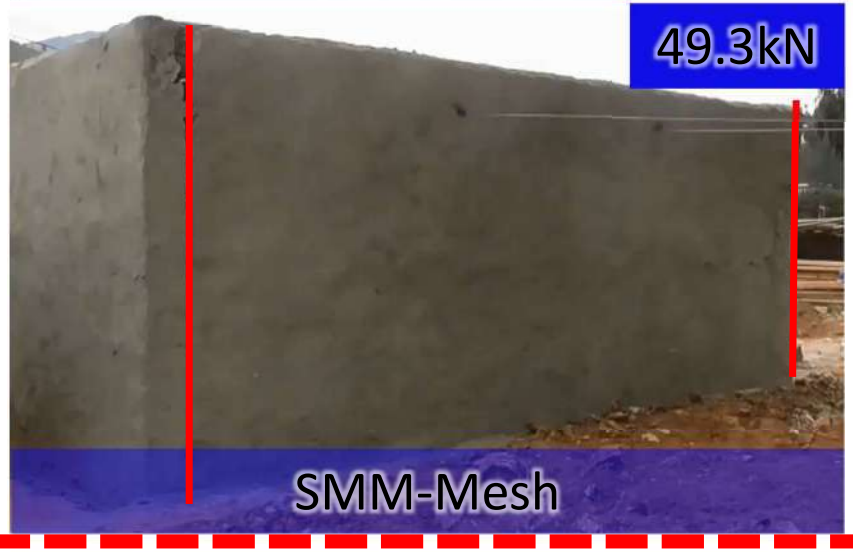
・Vertical bar ϕ 16 (no concrete wrapping)

・Gabion mesh boxe ϕ 1.2mm
・RC post*
・RC band*
(* refer SMC_New

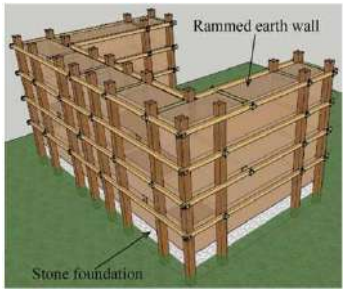


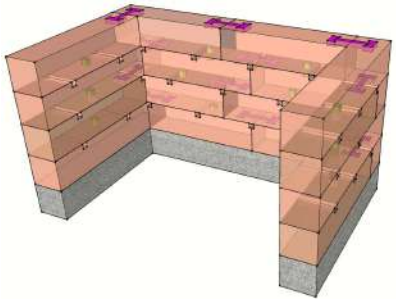
PULL DOWN TEST: STONE MASONRY IN MUD MORTAR

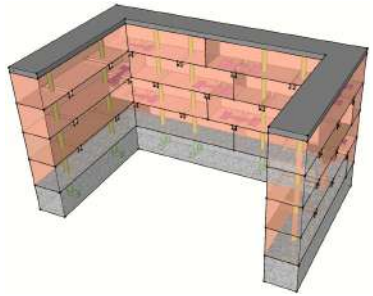


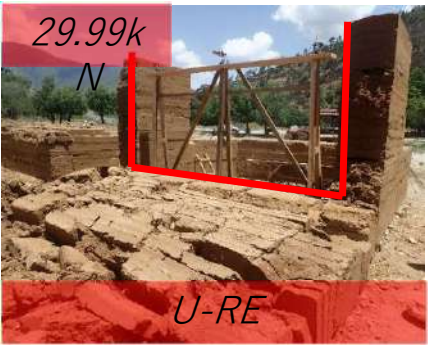


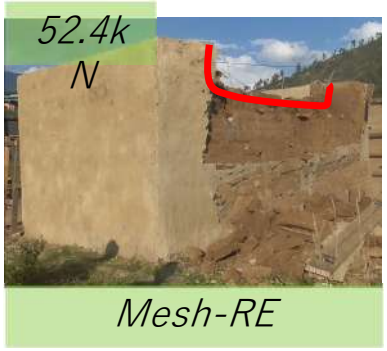
PULL DOWN TEST: Rammed earth (out-of-plane)

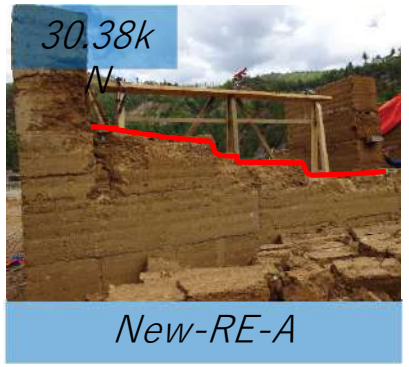


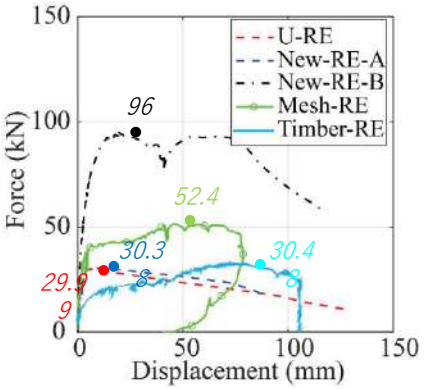






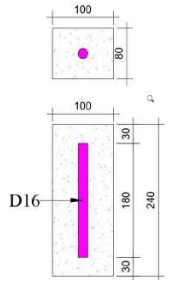




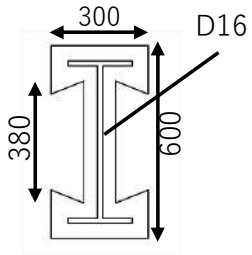


- 16G -Mesh
- 1cement:4mud

- RC wedges
- RC dowels

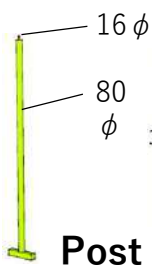


Dowel

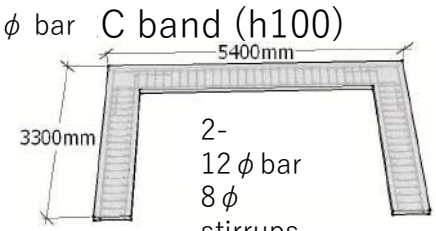


Wedge

- RC wedges
- RC posts (80 ϕ, 16 ϕ bar)



Post



Band

Conclusions

Rammed earth

- RE-New > **3.2** x U-RE
- RE-16G > **1.75** x U-RE

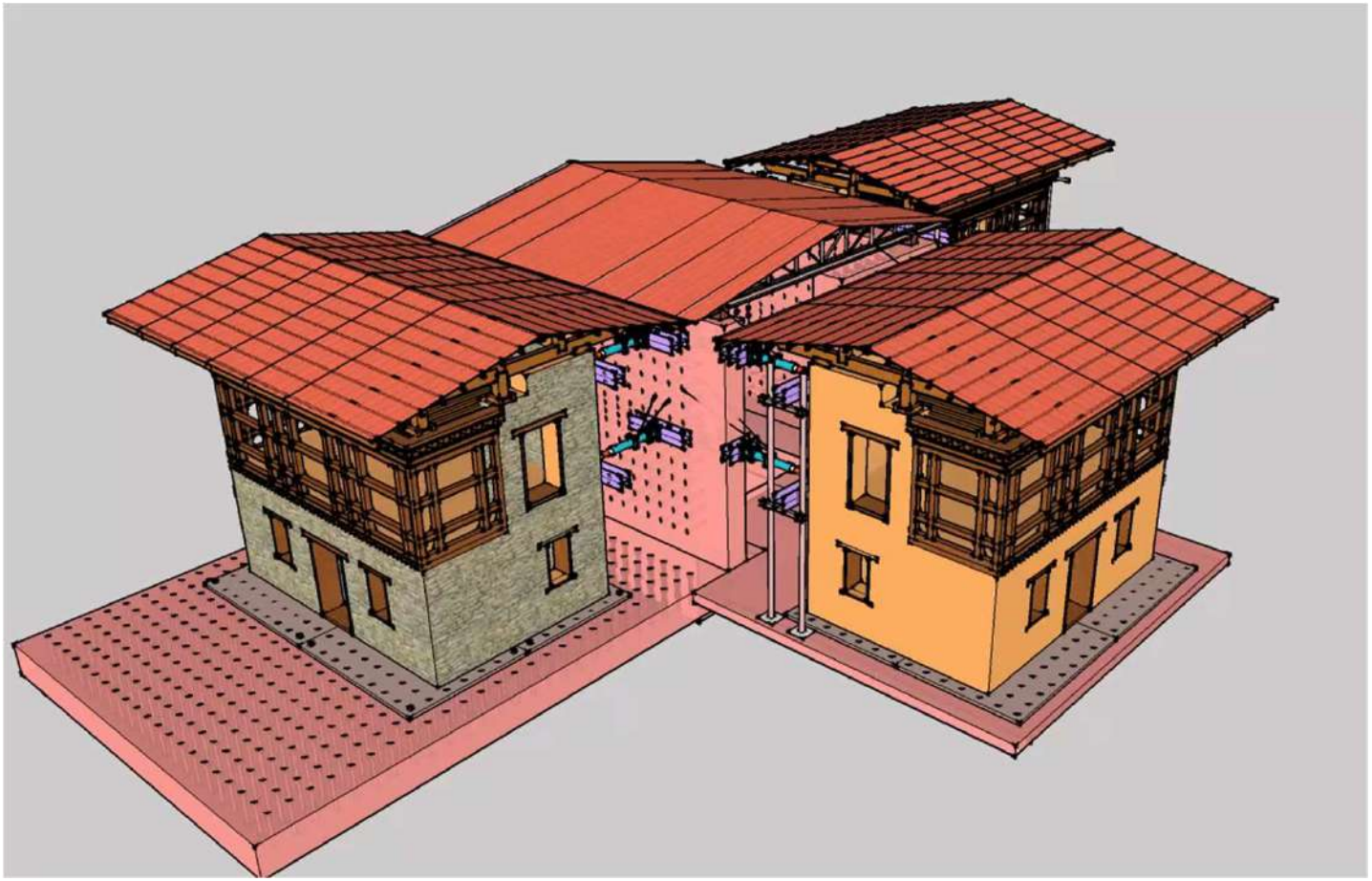
Stone Masonry

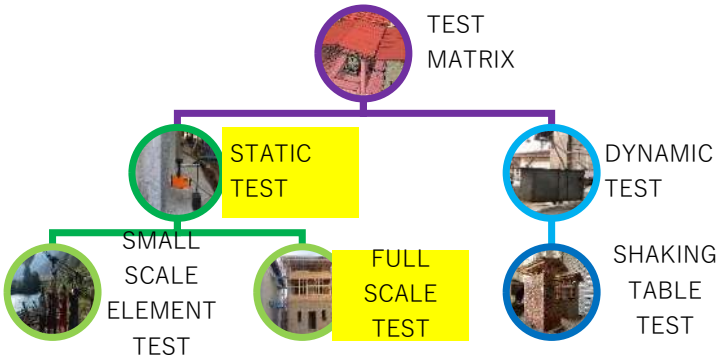
- SMC-New > **7.46** x U-ST-CM
- SMC-Mesh > **6.93** x U-ST-CM

- SMM-New > **6.77** x U-ST-MM
- SMM-Mesh > **5.11** x U-ST-MM

Decided to use those strengthening techniques in full-scale buildings to further verity its effectiveness

FULL-SCALE TEST



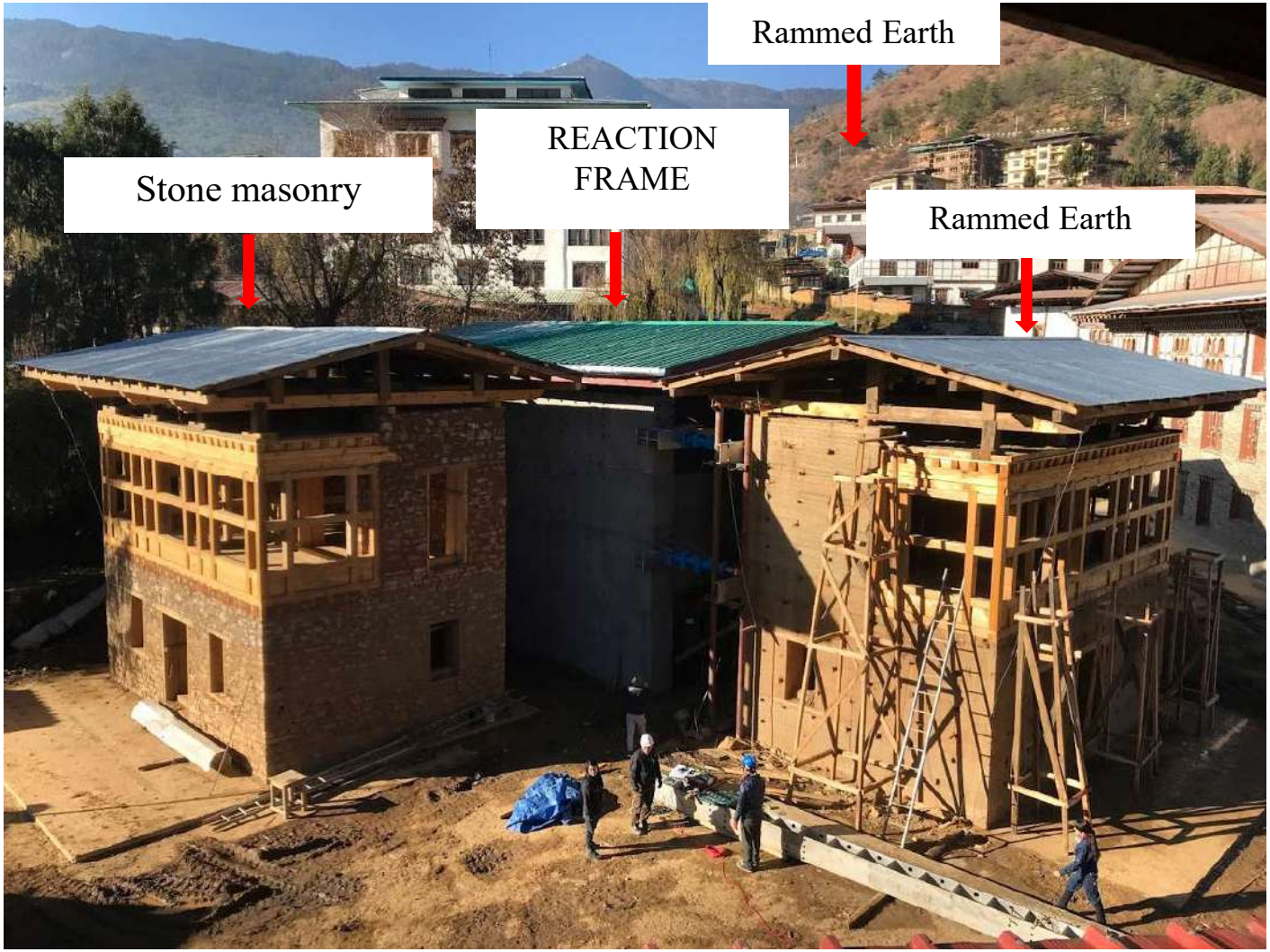


Objectives

- Examination of strength and collapse mechanism.
- Verification on effect of seismic strengthening.

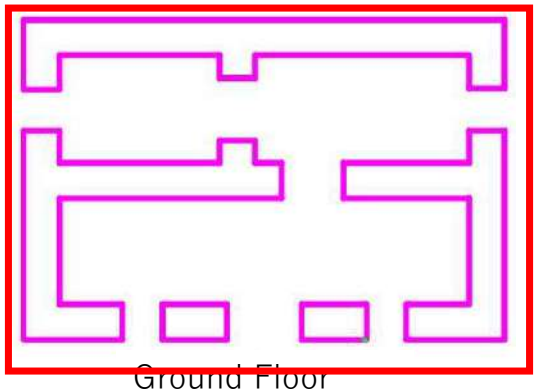
FULL SCALE TEST

Overview

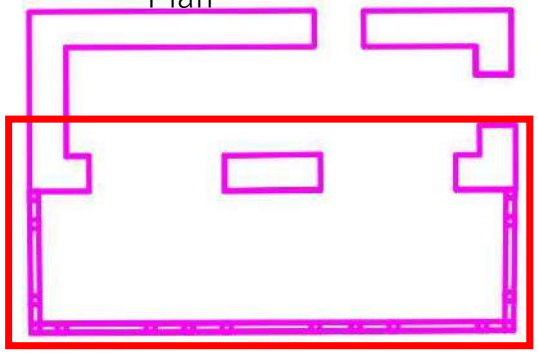


FULL SCALE TEST

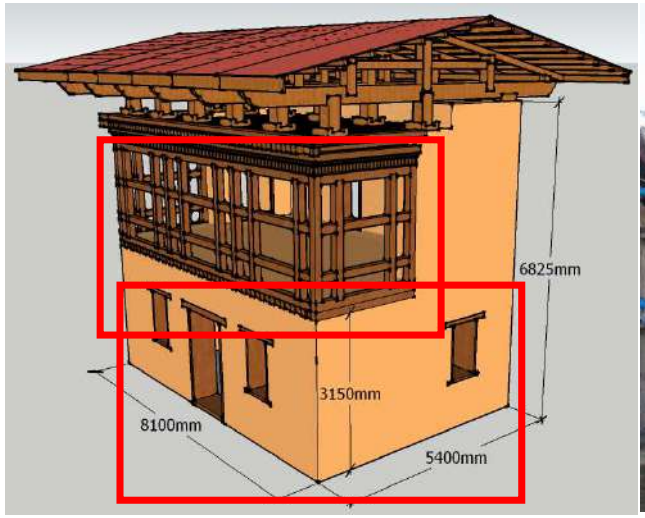
Specimen Details



Ground Floor Plan



First Floor Plan



Isometric View

Front View

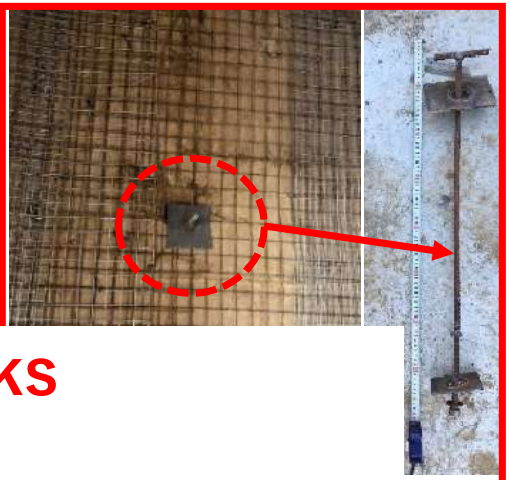
Side View

- Represents typical Bhutanese building
- 2-storied building
- Floor plan: 8.1x5.4 sqm
- GF: Solid wall with small openings
- FF: Large opening in the front

FULL SCALE TEST

Retrofitting method rammed earth

Mesh Layo



Retrofitting time: **3 weeks**

Retrofitting cost: **20%** of the building cost

Cement plaster (CM 1:3)

Completion of plaster

X-shaped timber

FULL SCALE TEST

Reinforcing method_Rammed Earth/Stone Masonry

Reinforcing cost:
20% of the building cost

FULL SCALE TEST

Retrofitting method_stone masonry building

Mesh Layout in walls and

U-hook

Applying cement plaster (CM

Complete specimen

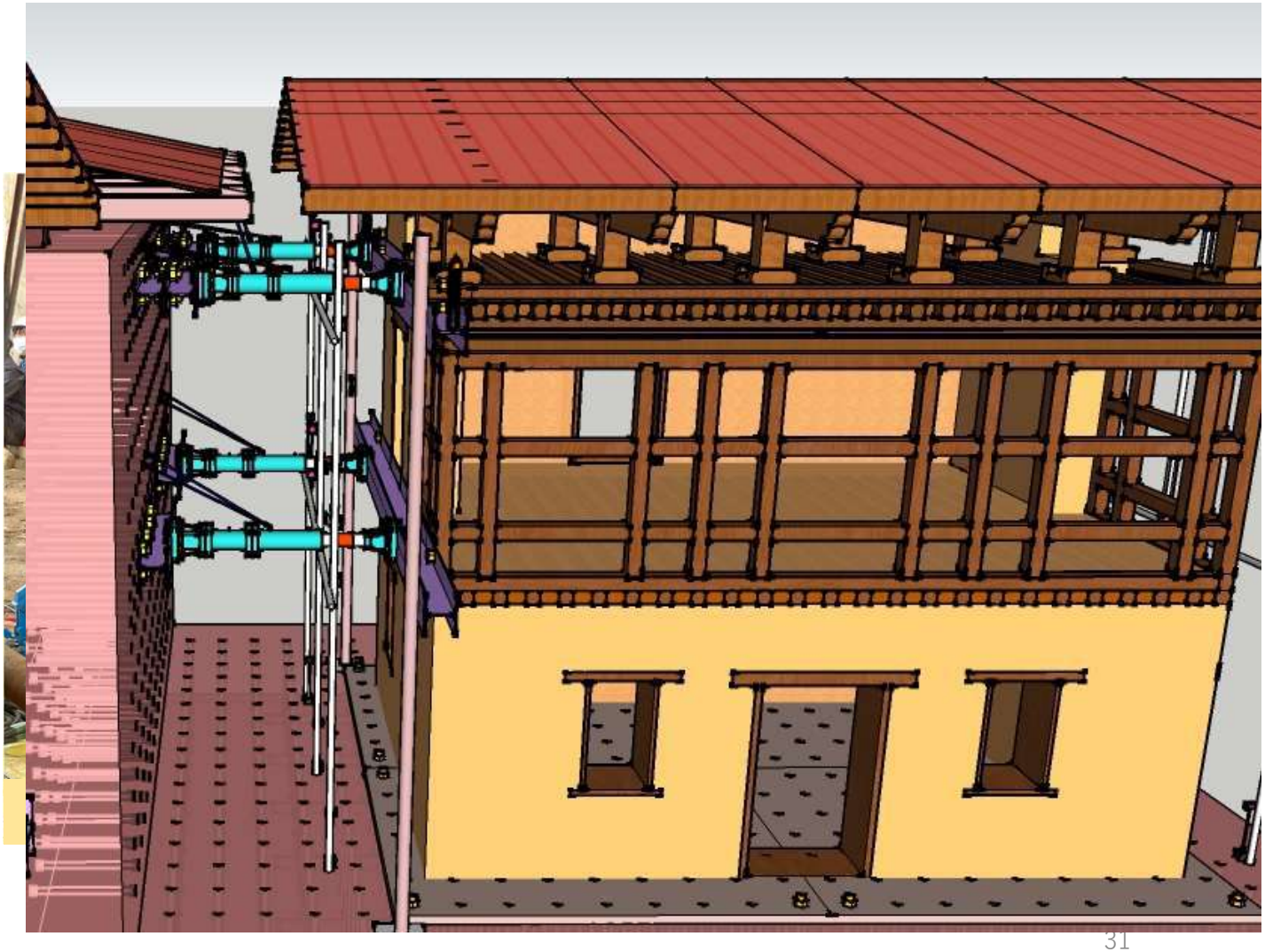
X-shaped timber

FULL SCALE TEST

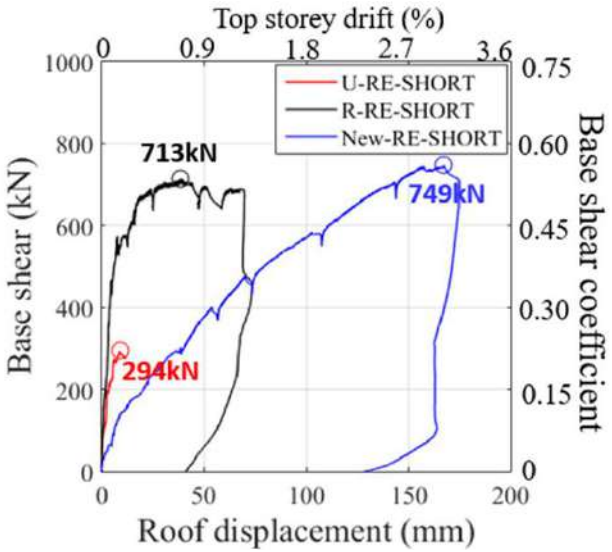
SET UP AND INSTRMENTATION

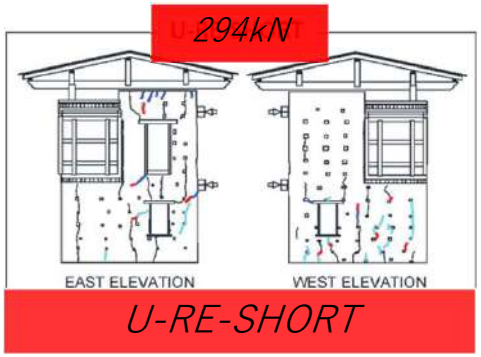
Fixing H-sections

Fixing jacks

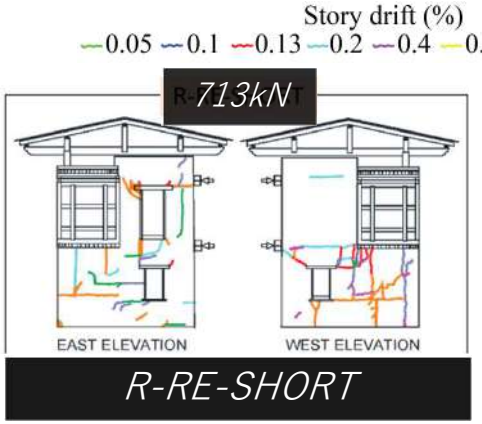


Rammed Earth : Full-scale test

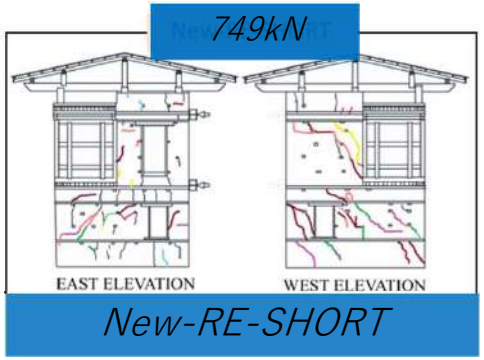




- Unreinforced



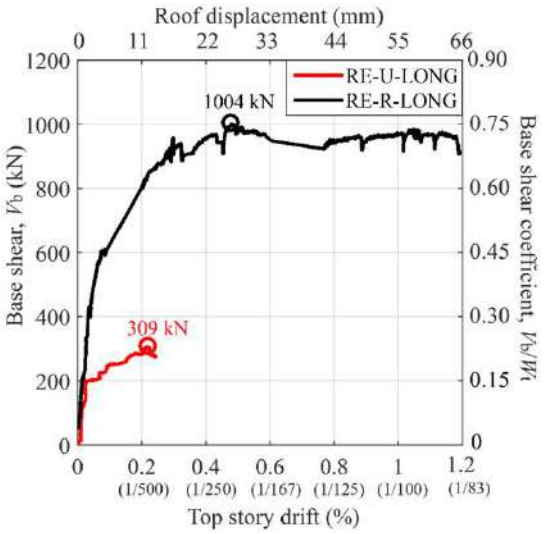
- Mesh (12G+16G)
- CM 1:3

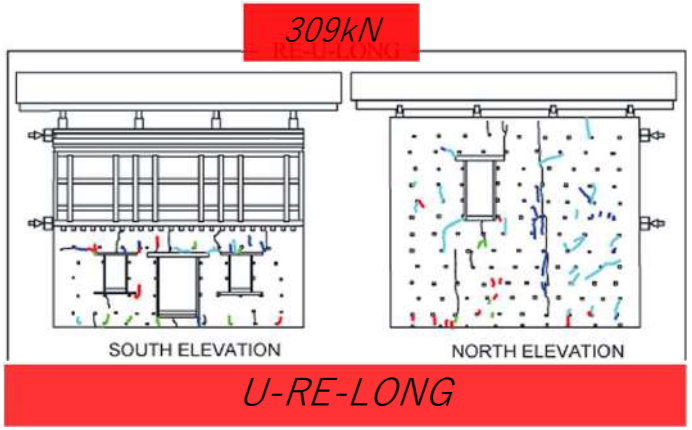


- RC post (80 ϕ ; 12 ϕ)
- RC band

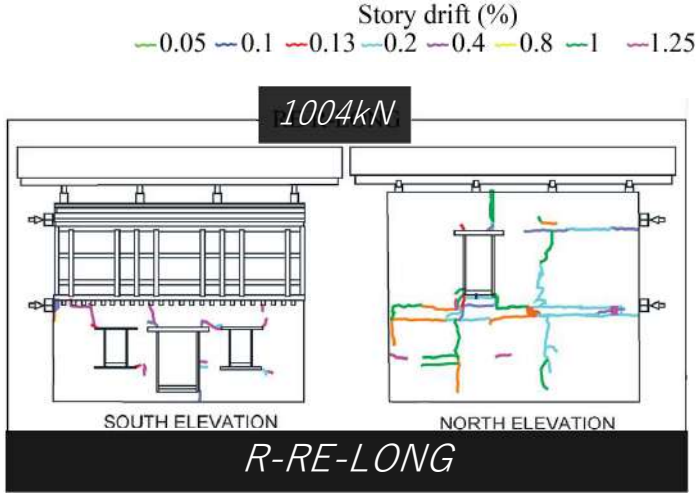
Rammed Earth : Full-scale test

Main mesh: 12G
Lapping mesh: 16G



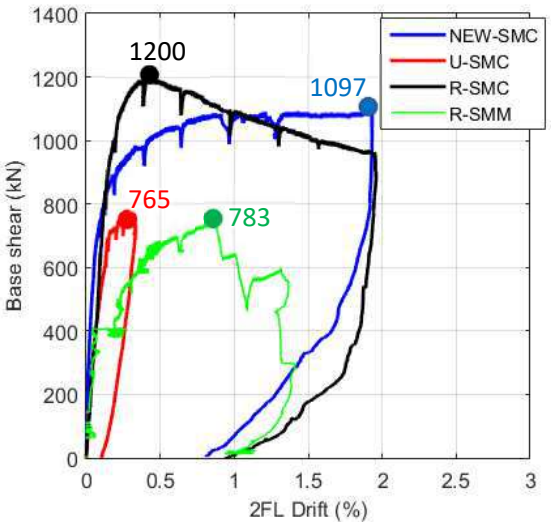


- Unreinforced

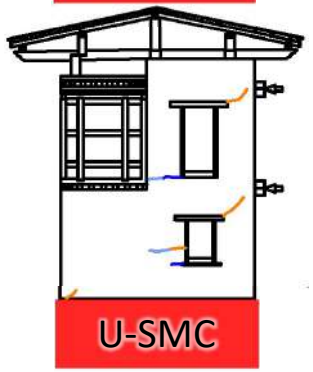


- Mesh (12G+16G)
- CM 1:3

FULL-SCALE TEST: STONE MASONRY (SHORT SPAN)



765kN



U-SMC

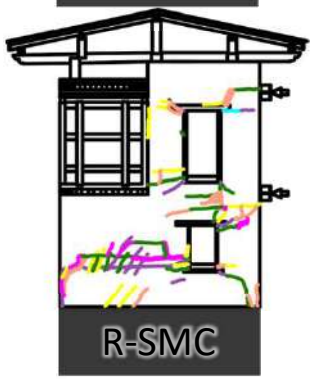
- Unreinforced
- CM1:3

783kN

R-SMM

- Mesh (12G+16G)
- Mud mortar

1200kN



R-SMC

- Mesh (12G+16G)
- CM1:3

1097kN

NEW-SMC

- RC post (80 ϕ ; 12 ϕ)
- RC band
- CM1:3

FULL SCALE TEST

Conclusions

Rammed earth

- RE-New > **2.55** x U-RE
- RE-16G > **2.4** x U-RE

Stone Masonry

- SMC-New > **1.5** x U-ST-CM

1. The proposed **strengthening measures** **enhanced** the **strength** of **composite masonry buildings.**
2. **Controlled** the **failure patterns** of **the wall**.
3. It also **united** the **building structure** into **one component**.

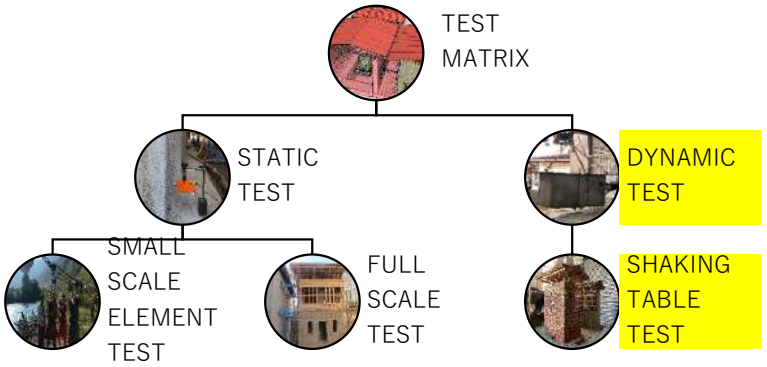
RC dowels, wedges and RC bands are recommended in new construction

Mesh is recommended to retrofit the existing buildings

SHAKING TABLE SYSTEM

OBJECTIVES

- Relationship between input earthquake and response.
- Verification and effect of seismic strengthening.
- Examination of strength and collapse mechanism.
- Visual educational materials for public awareness.



SPECIFICATIONS	
SIZE	3m x 3m
STROKE	± 150mm
FREQUENCY	0.1 Hz – 5Hz
PGA	0.5G
WEIGHT LIMITATION	10 tonnes

SHAKING TABLE TEST_RAMMED EARTH

LIST OF TEST : SMALL SCALE ELEMENT TEST

	Stone Masonry	Rammed Earth
Inplane Test	1).Unreinforced mud Mortar	1).Unreinforced layer thickness-120
	2).Unreinforced cement Mortar	2).Reinforced RC dowel layer thickness-120
	3).Reinforced cement mortar	3).Reinforced RC dowel layer thickness-60
Out of Plane	4).Unreinforced mud Mortar	4).Unreinforced layer thickness-120
	5).Unreinforced cement Mortar	5).Reinforced RC dowel layer thickness-120
	6).Reinforced cement mortar	6).Reinforced RC dowel layer thickness-60

LIST OF TEST : SMALL SCALE ELEMENT TEST(PULLDOWN TEST)

STONE MASONRY	RAMMED EARTH
1).Unreinforced cement mortar	1).Unreinforced rammed earth
2).Mesh Retrofitted cement mortar	2).Mesh retrofitted rammed earth
3).Reinforced cement mortar (vertical rebar without cover)	3).Timber retrofitted rammed earth
4).Reinforced cement mortar (Wedge, post and rc band)	4).Reinforced rammed earth with RC dowel and wedge
	5).Reinforced rammed earth with RC wedge, post and band
5).Unreinforced mud mortar	
6).Mesh Retrofitted mud mortar	
7).Reinforced mud mortar (vertical rebar without cover)	
8).Gabion mud mortar (Wedge, post and rc band)	

LIST OF TEST : FULLSCALE TEST

	STONE MASONRY	RAMMED EARTH
Short direction	1).Unreinforced cement mortar	1).Unreinforced rammed earth
	2).Mesh retrofitted mud mortar	2).Mesh retrofitted rammed earth
	3).Mesh retrofitted cement mortar	3).Reinforced rammed earth with RC post and band
	4).Reinforced cement mortar (rc post, band)	4).Torsion wire retrofitted rammed earth
Long direction		5).Unreinforced rammed earth
		6).Mesh retrofitted rammed earth

LIST OF TEST : SHAKING TABLE TEST

	STONE MASONRY	RAMMED EARTH
Short direction	1).Unreinforced mud mortar (2 nos)	1).Unreinforced Rammed earth (2 nos)
	2).Mesh retrofitted mud mortar (2 nos)	2).Retrofitted Rammed earth (2 nos)
	3).Unreinforced cememt mortar	
	4).Unreinforced cement mortar with through stones	
Long direction	5).Unreinforced stone masonry (1 nos)	3).Unreinforced Rammed earth (1 nos)
	6).Retrofitted stone masonry (1 nos)	4).Retrofitted Rammed earth (1 nos)

KADRINCHELA

THANK YOU FOR YOUR ATTENTION

SATREPS PROJECT
"Evaluation and Mitigation of Seismic Risk for Composite Masonry Buildings in Bhutan"