



BACK GROUND AND EXPERIMENTAL TEST

“Joint Research on Evaluation and Mitigation of Seismic Risk for Composite Masonry Buildings in Bhutan”

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

Department of Culture
Ministry of Home and Cultural Affairs

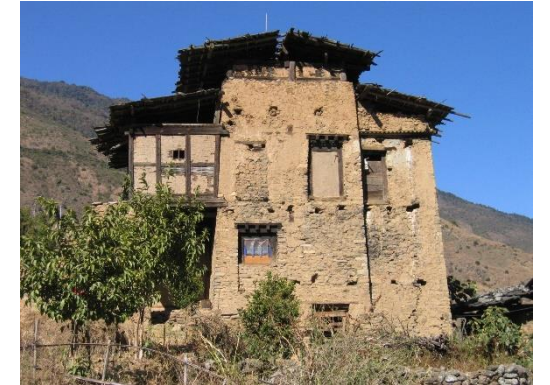
Department of Engineering Services
Ministry of Work and Human Settlement

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.

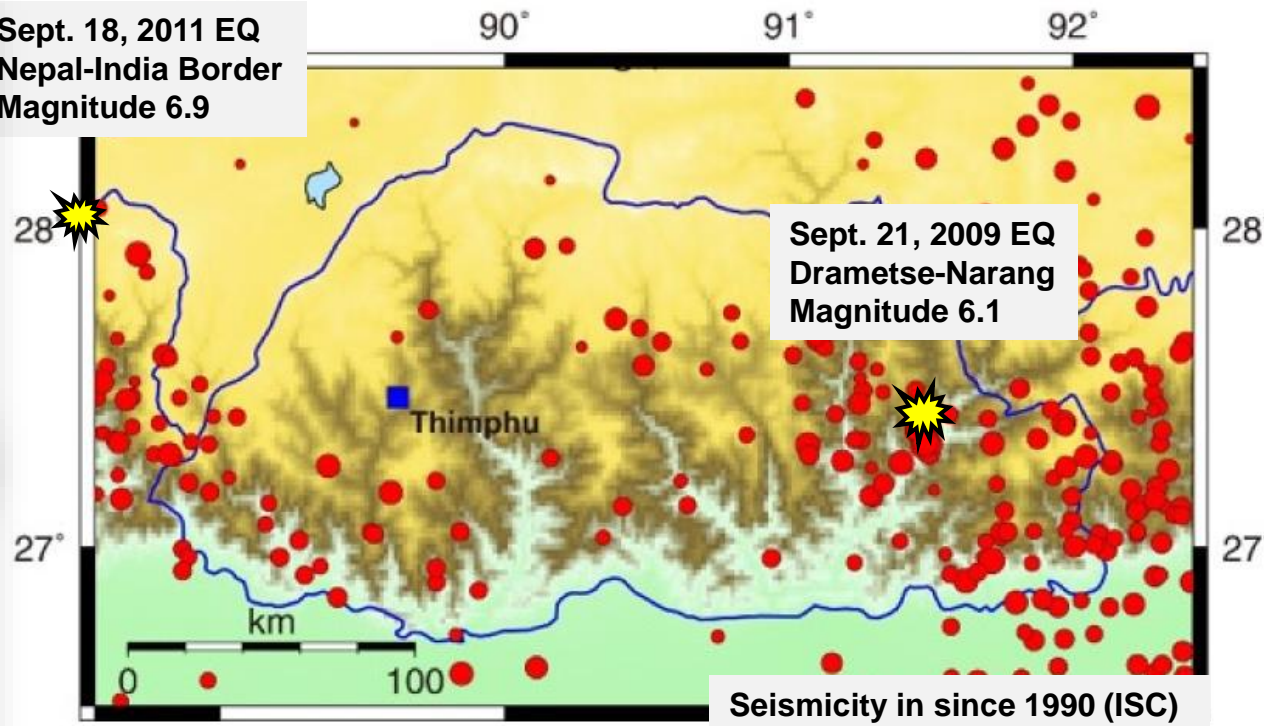
List of Historical Earthquakes that affected Bhutan

	Magni tude	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

	Magni tude	Date	Location (Epicenter)
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

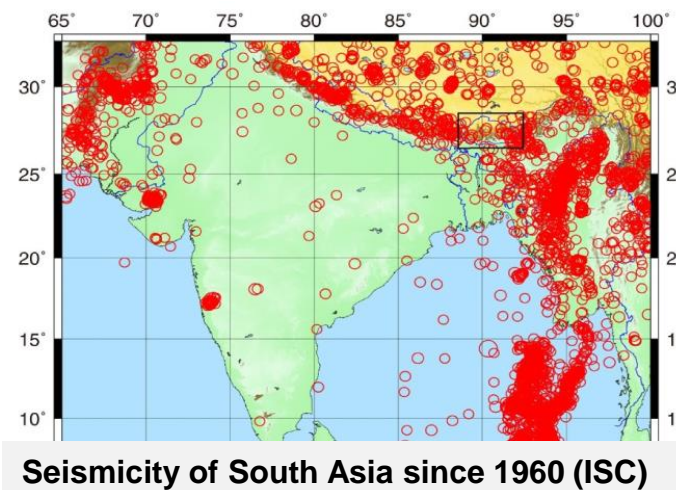
Sept. 18, 2011 EQ
Nepal-India Border
Magnitude 6.9



Based on National
Recovery and
Reconstruction Plan:

2009 EQ: Affected 4950
rural homes

2011 EQ: Affected 6977
rural homes



2009 Earthquake Damage to Rural Houses

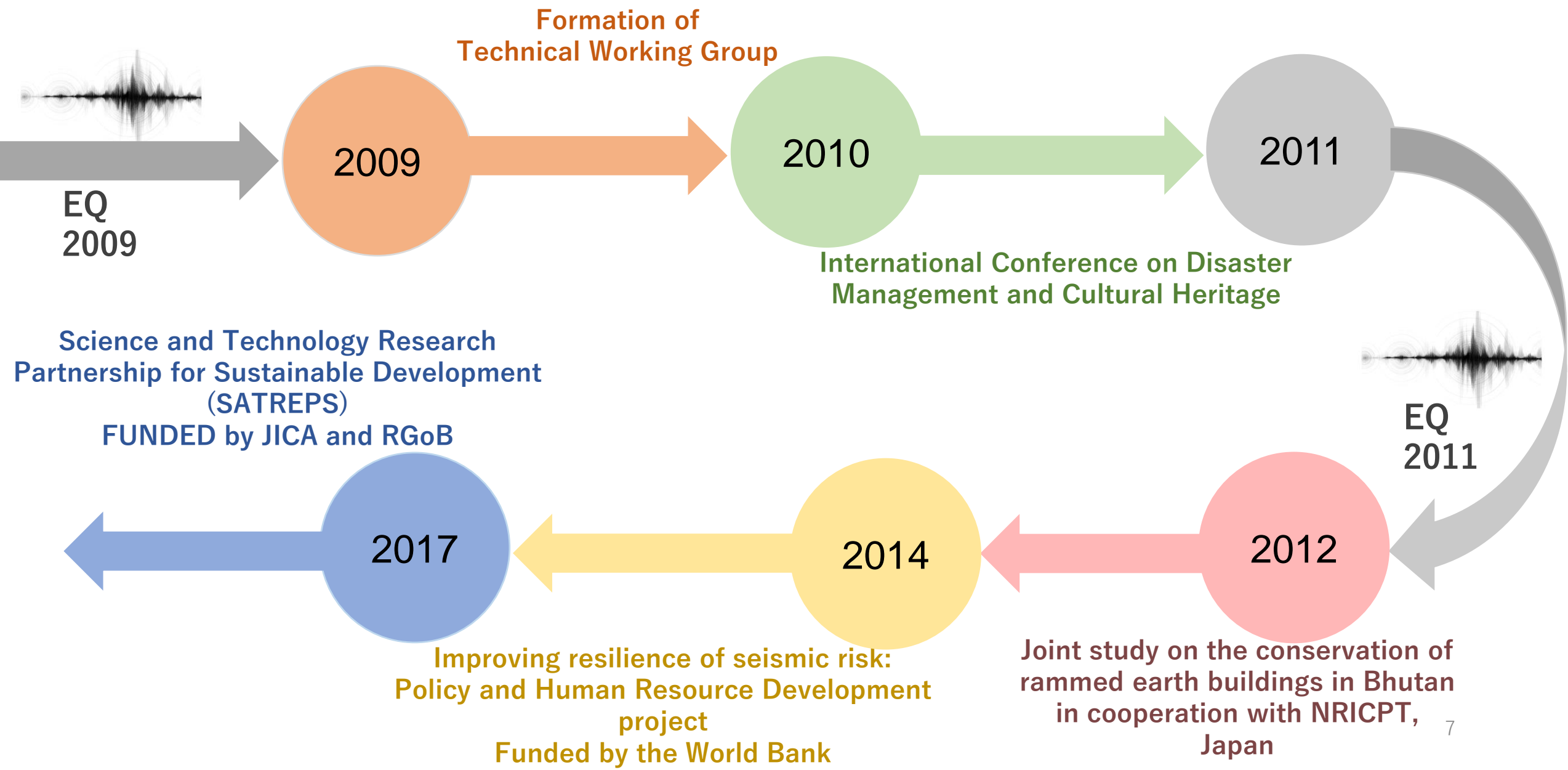
Sl. No	Dzongkhag	Houses Damaged				Dead	Injured
		Beyond Repair	Major Repair	Partial Repair	Minor Repair		
1	Trashiyantse	21	70	400	106		
2	Zhemgang	1			1		
3	Trashigang	147	445	439	572	2	18
4	Pemagatshel	25	24	24	187		3
5	Lhuentse		6	24	87		
6	Mongar	260	331	413	1253	6	18
7	Samdrupjongkhar	7		10	11	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 Substant ial 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 Substanti al 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



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

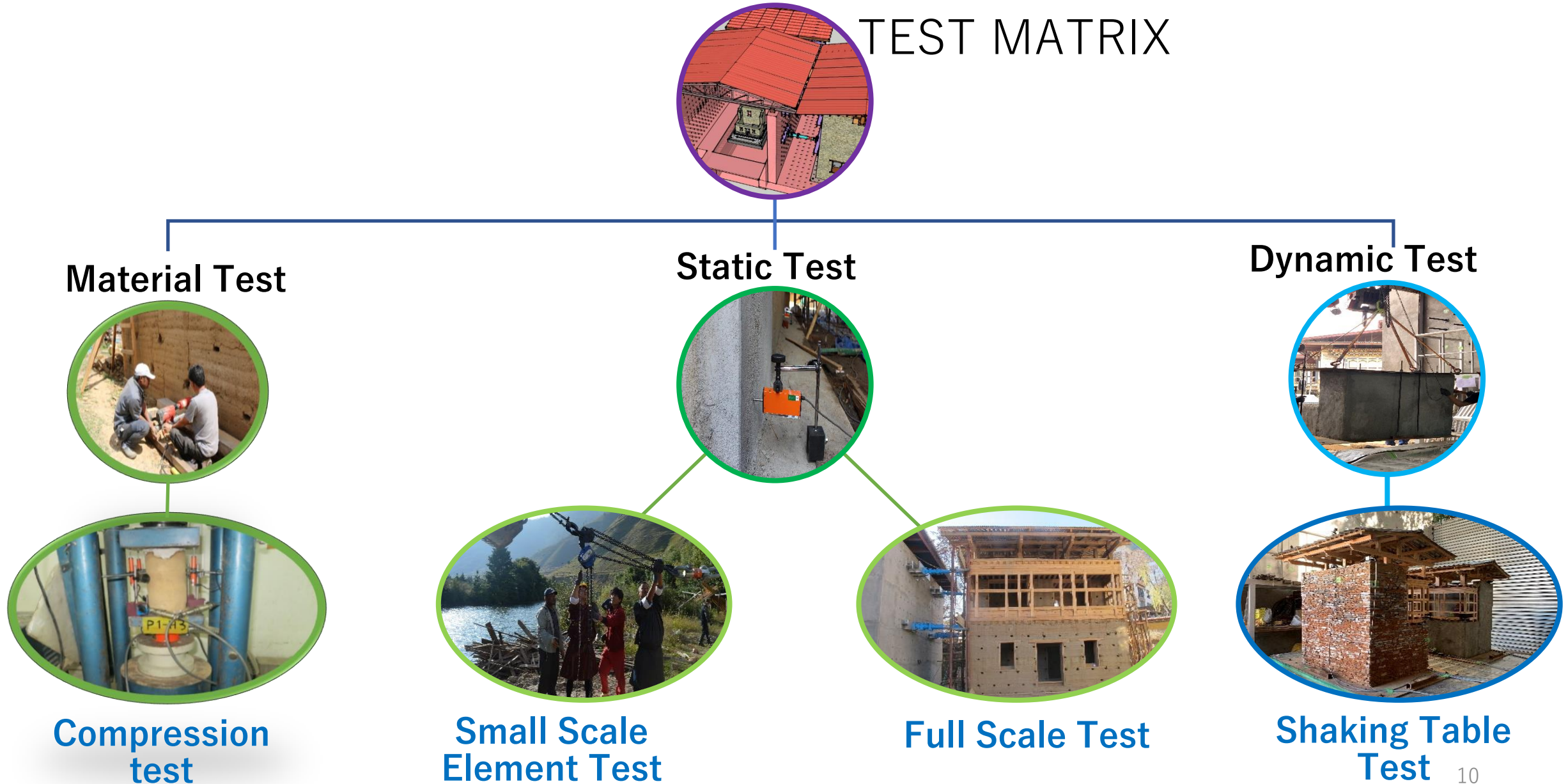
- Tests
- Development of analysis methods
- Development of guidelines

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



Material Test

Conduct the material test of composite masonry buildings.



Coring of cylindrical specimens



Compressive test



Split tensile strength

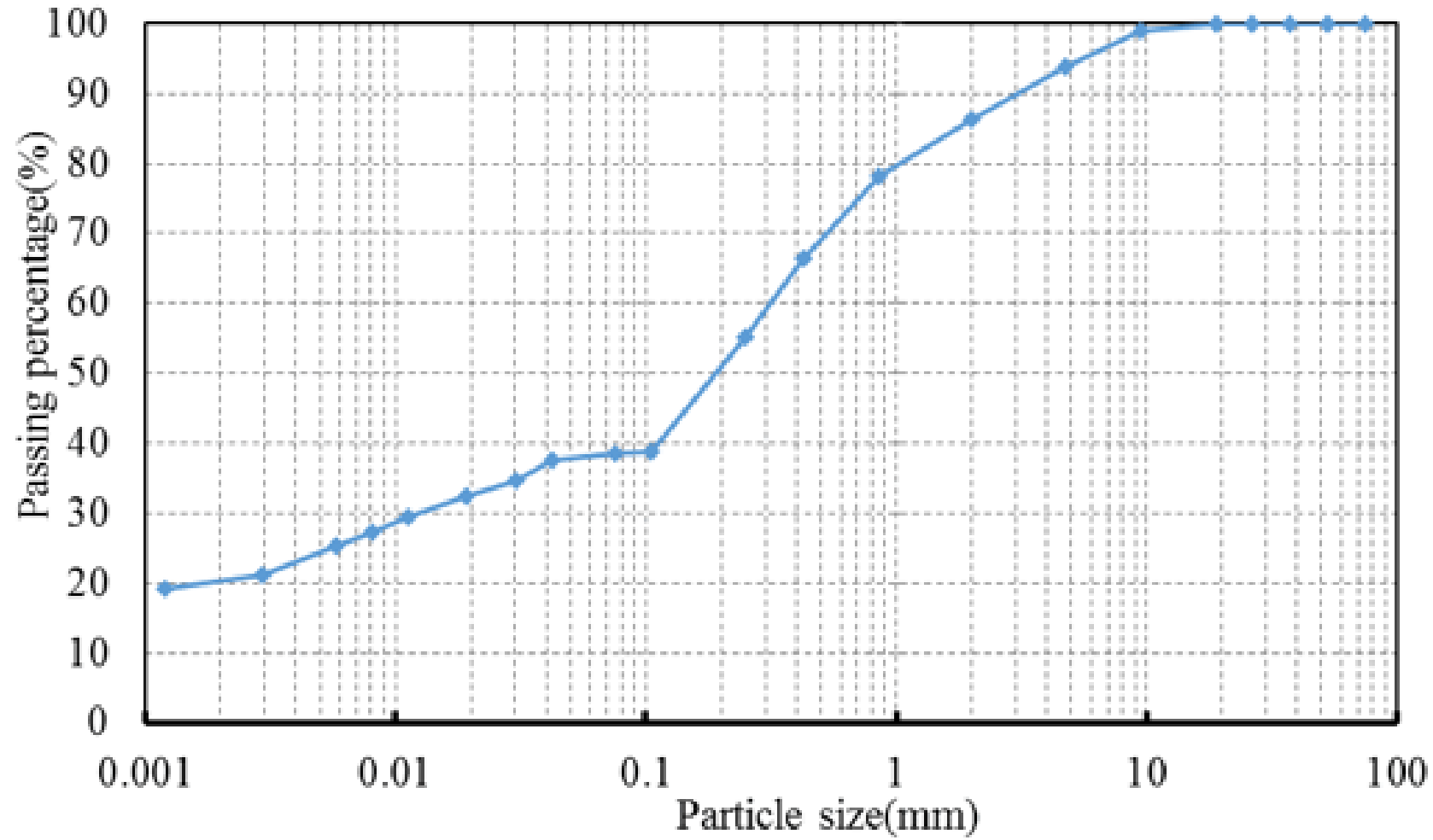
Properties of rammed earth from material characterization tests.

Specimen ID	Bulk density (kg/m ³)		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

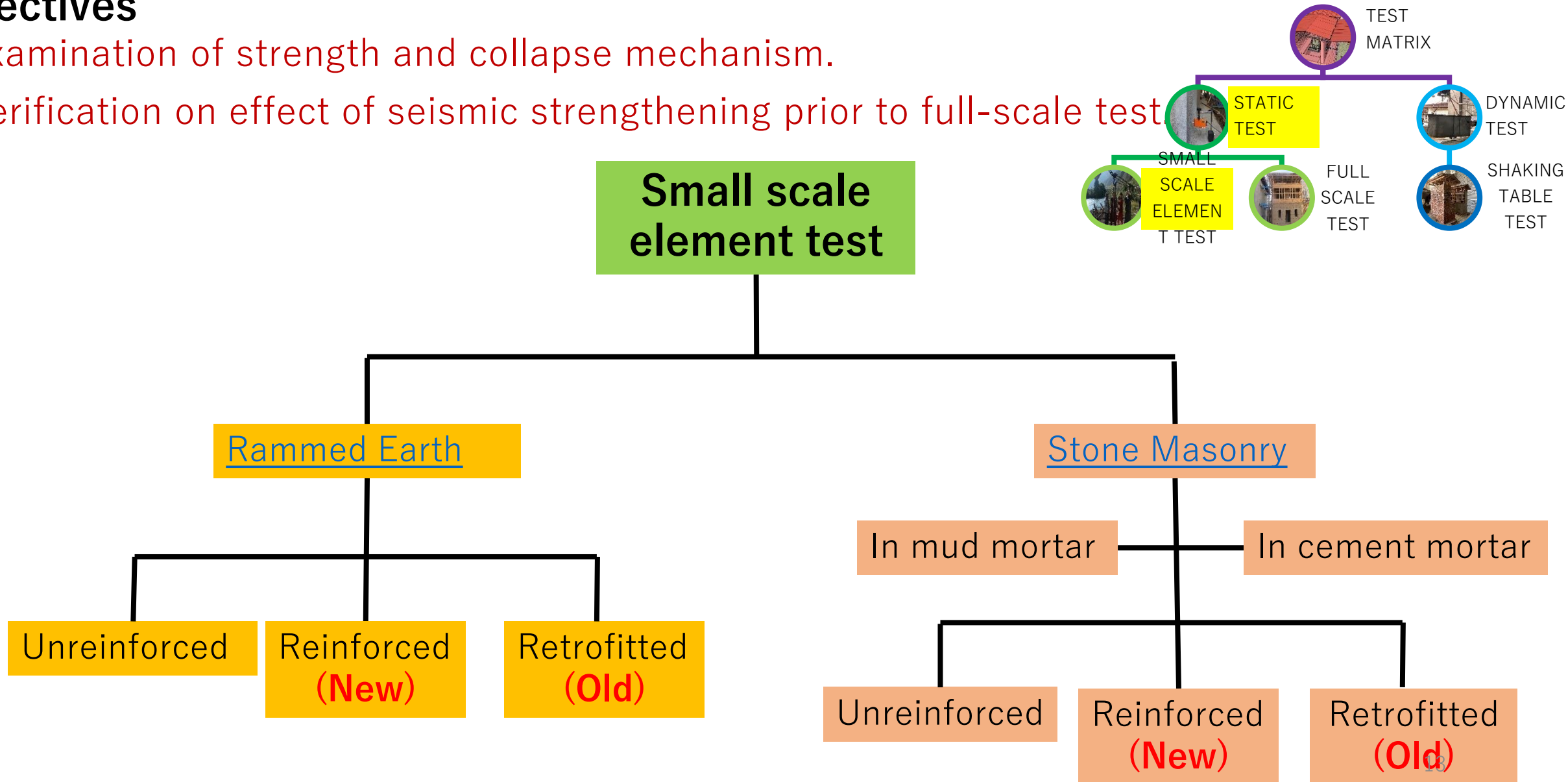


The grain size distribution of the RE used showed a particle size range of **0–10 mm**

Small scale element test

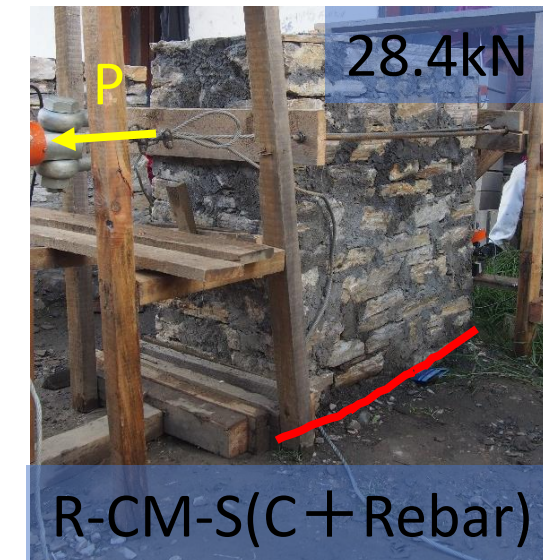
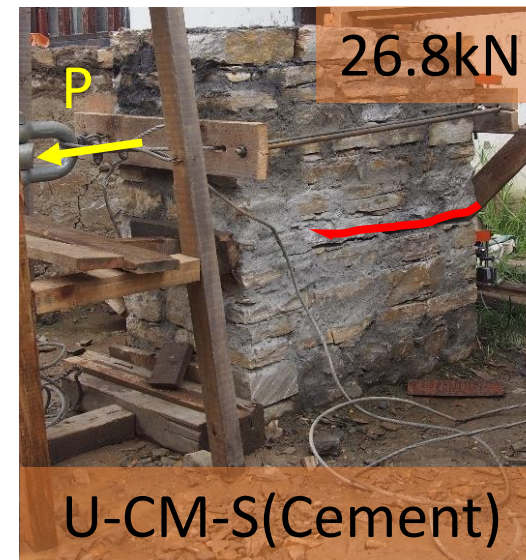
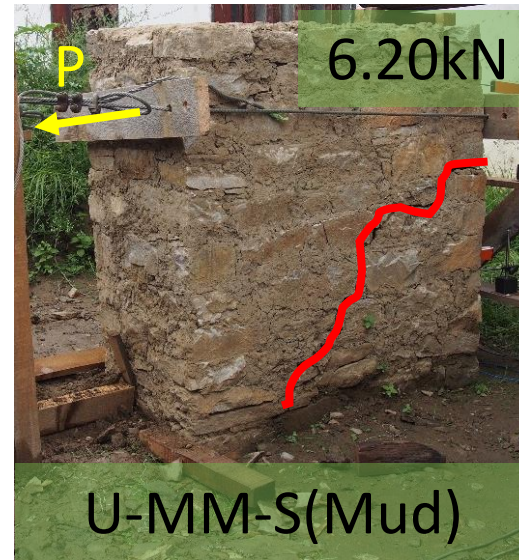
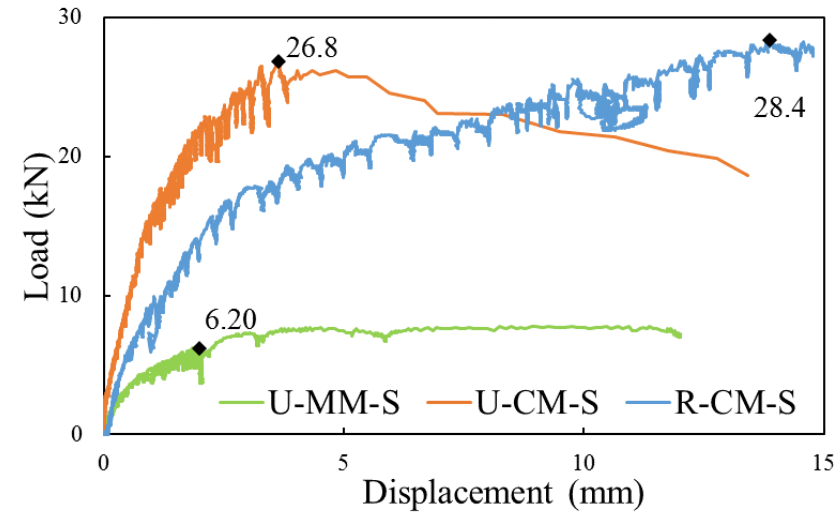
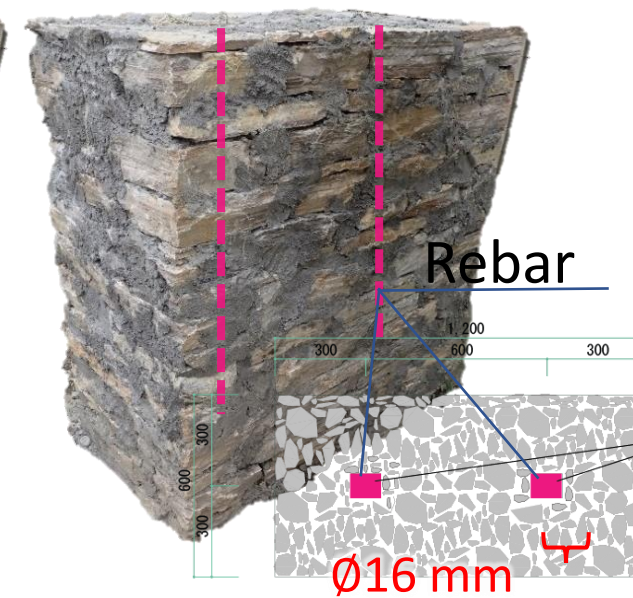
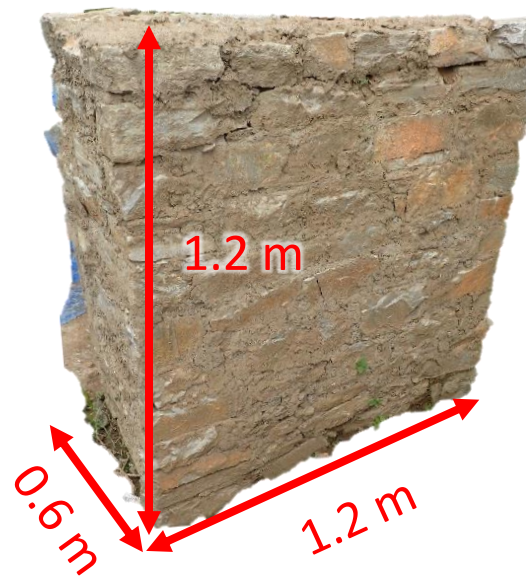
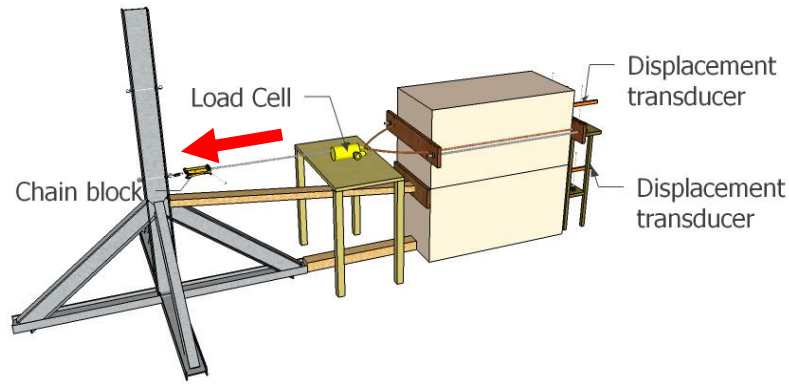
Objectives

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



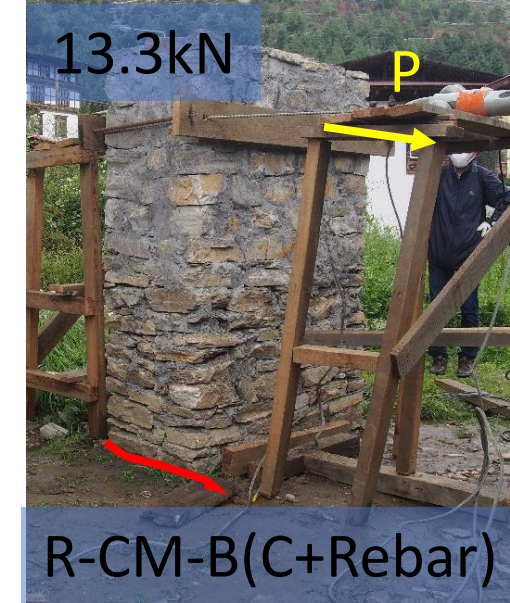
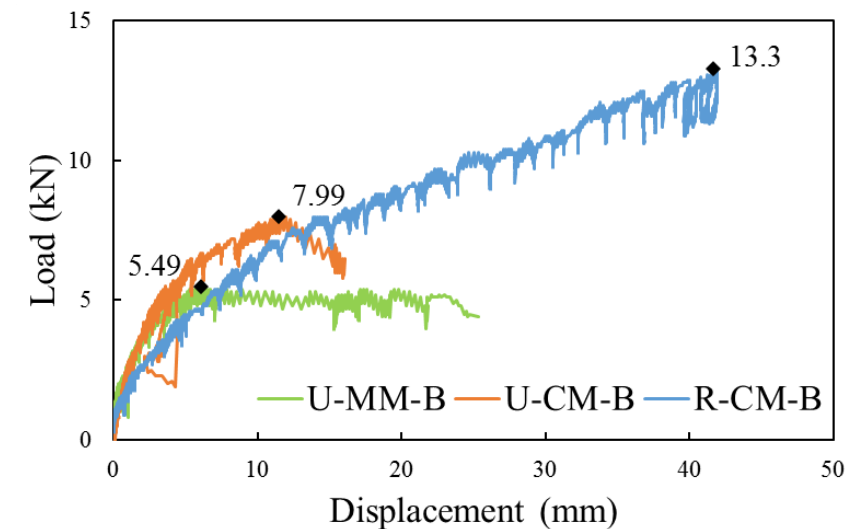
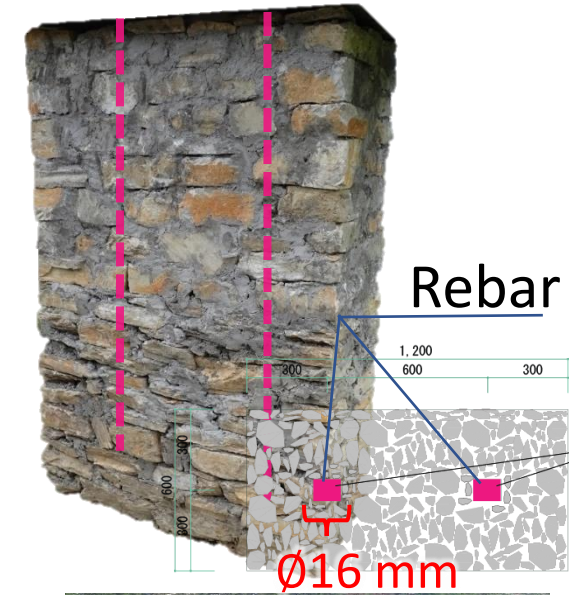
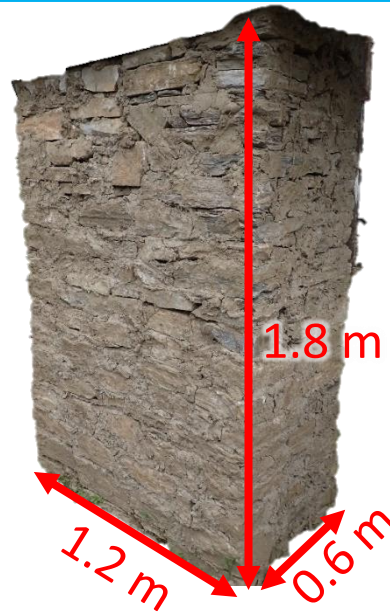
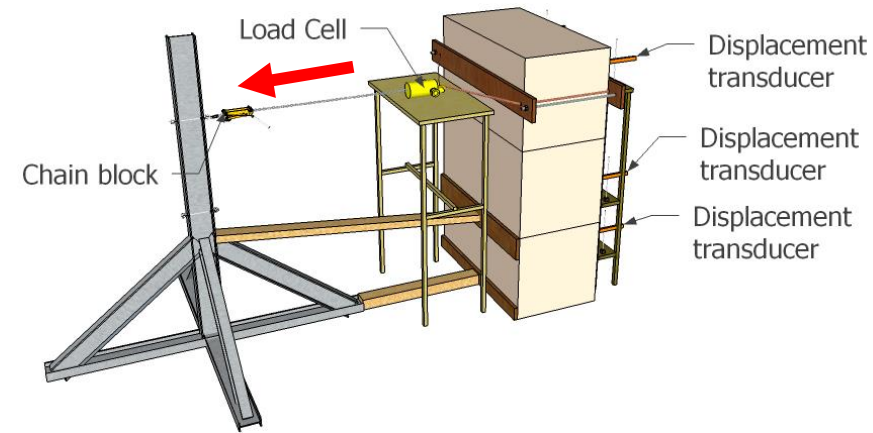
Small scale element test: Stone masonry(inplane)

In-plane (2-units)



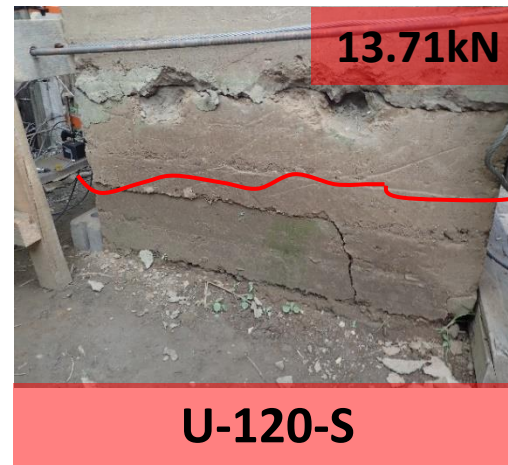
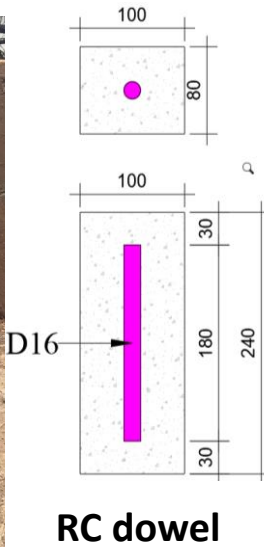
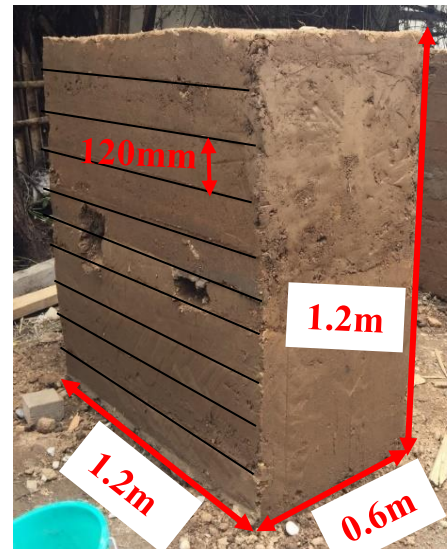
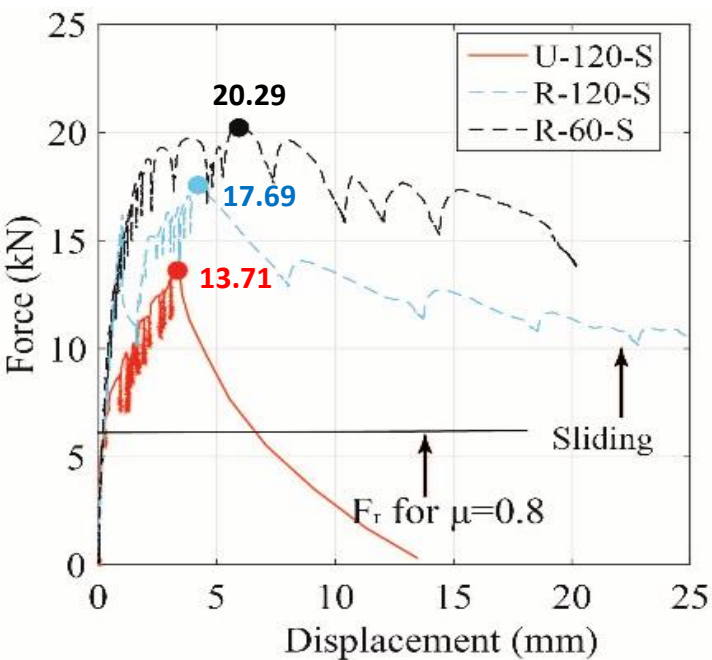
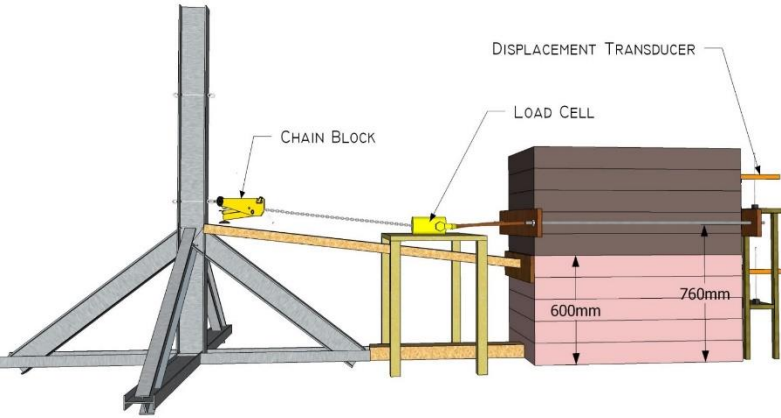
Small scale element test: Stone masonry(out of plane)

Out-of-plane (3-units)

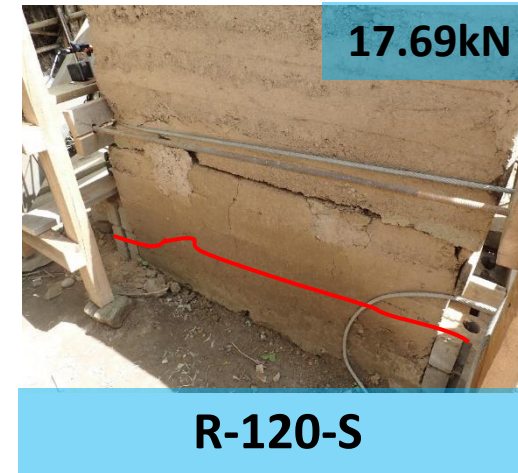


Small scale element test: Rammed earth (in plane)

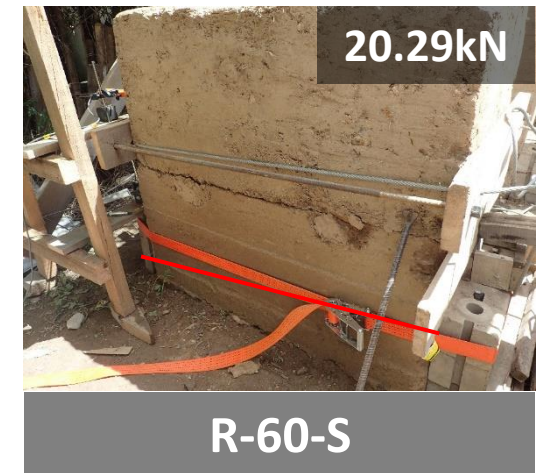
In-plane (2-units)



- Unreinforced
- Layer thickness-120



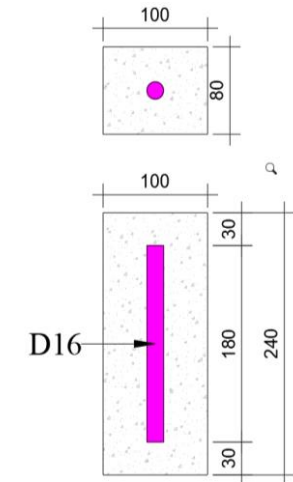
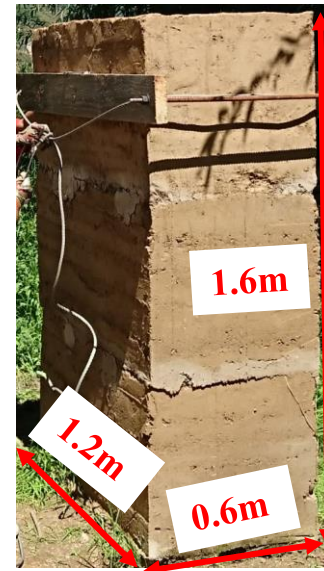
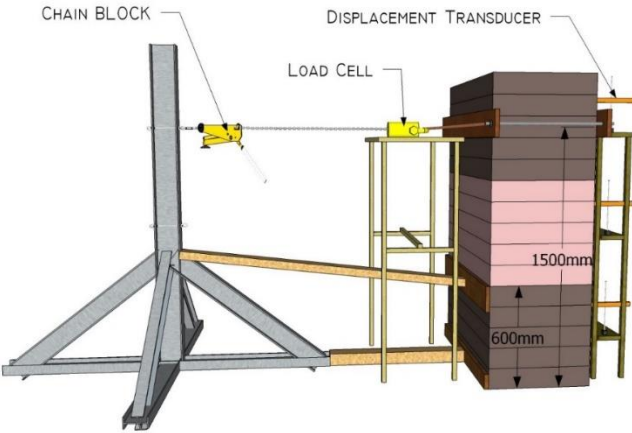
- RC dowel
- Layer thickness-120



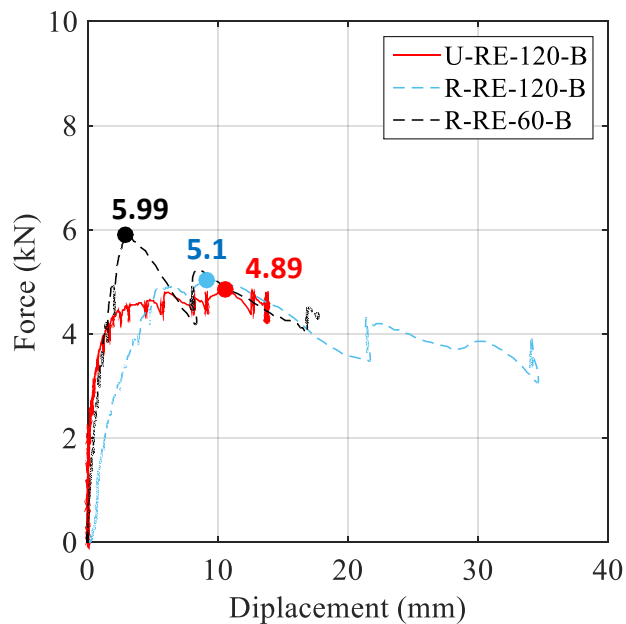
- RC dowel
- Layer thickness-60

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

Out-of-plane (3-units)



RC dowel



- Unreinforced
- Layer thickness-120



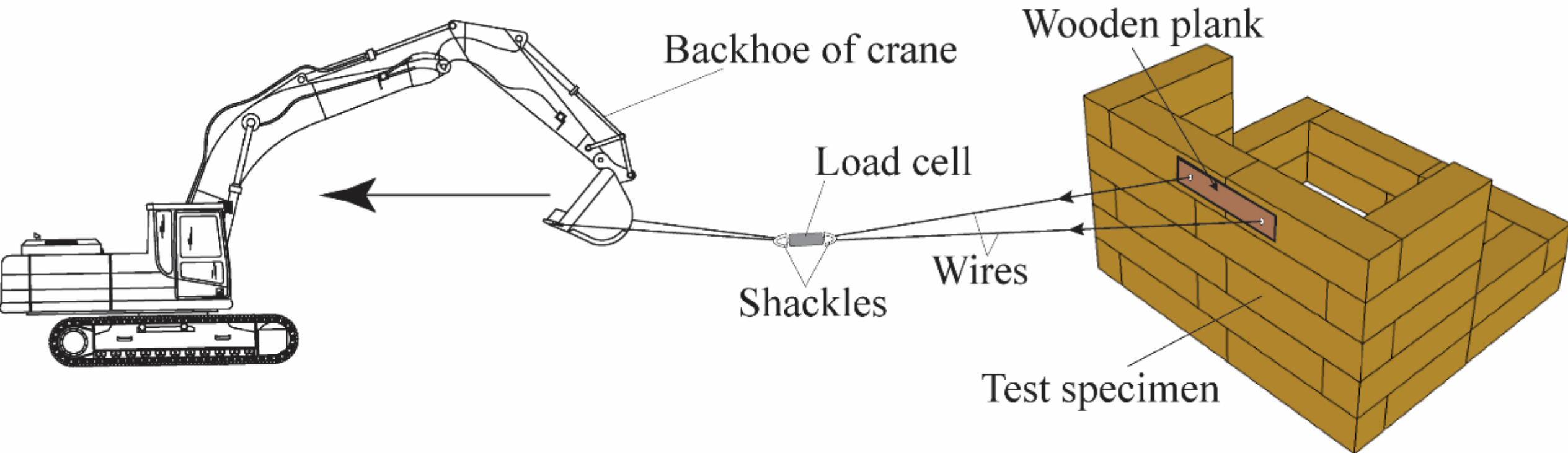
- RC dowel
- Layer thickness-120



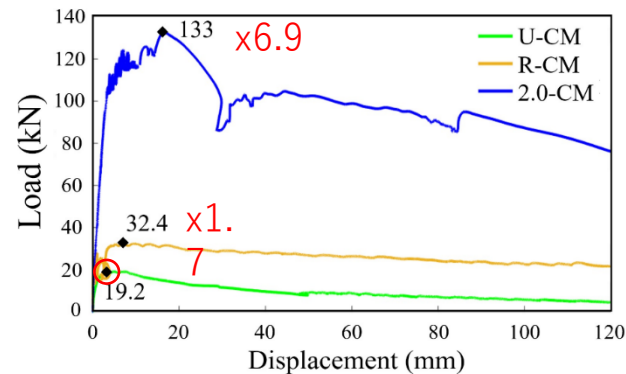
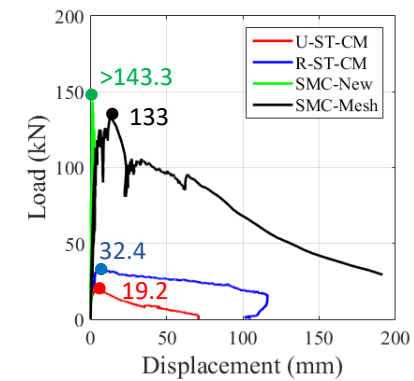
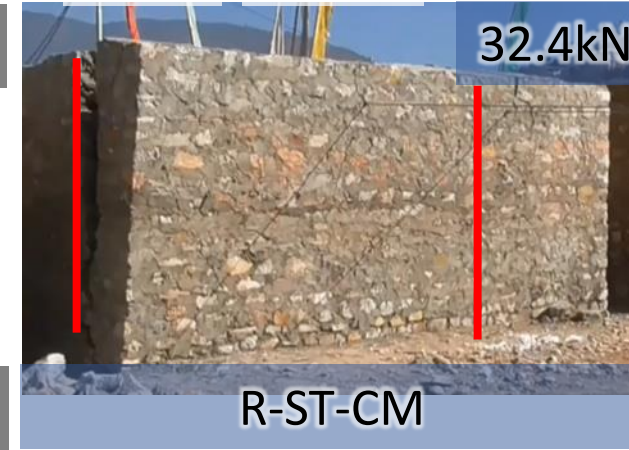
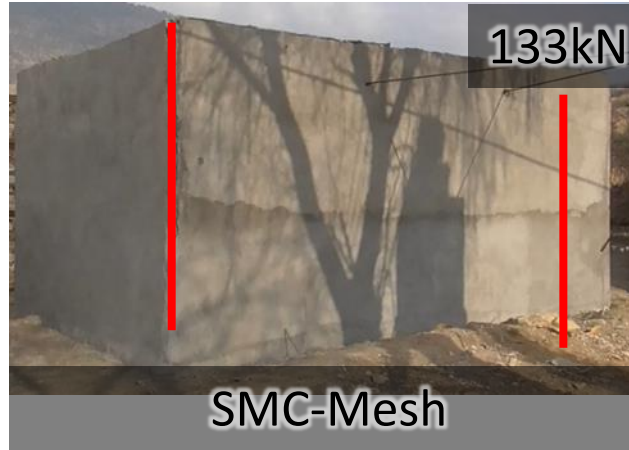
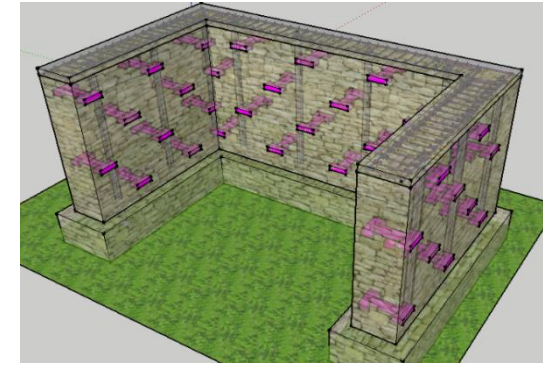
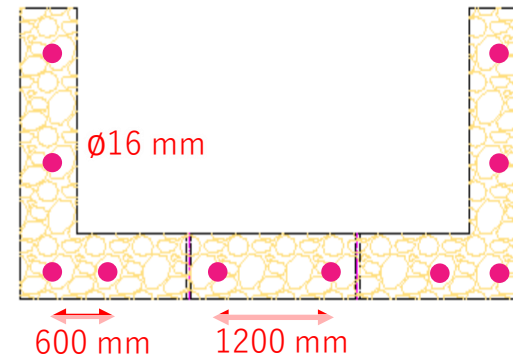
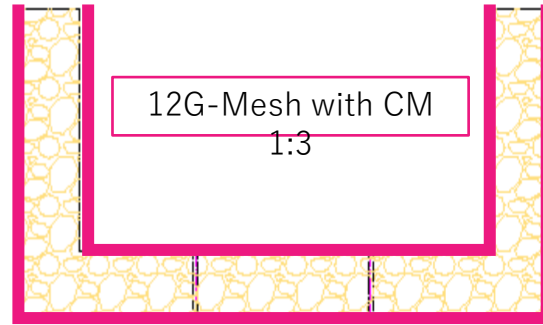
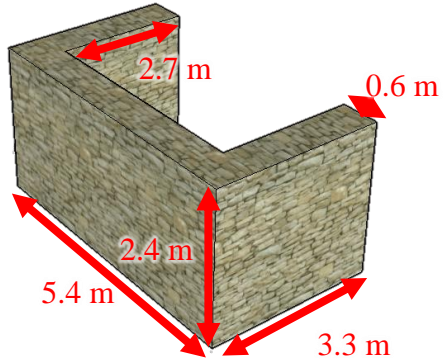
- RC dowel
- Layer thickness-60

PULL DOWN TEST

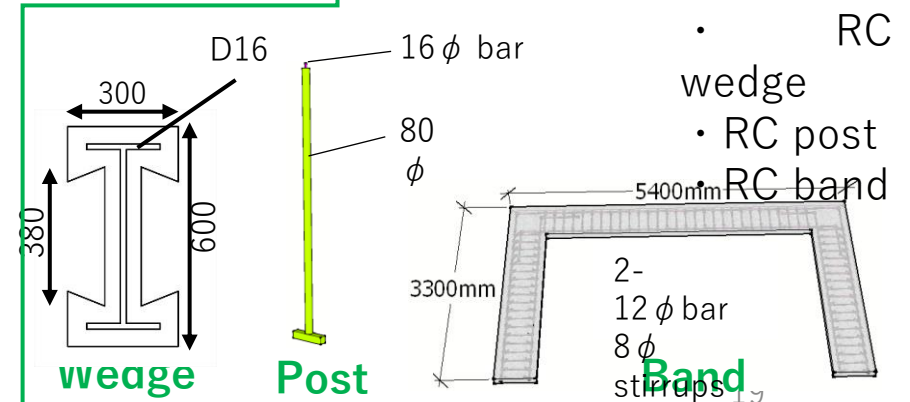
Test set up



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



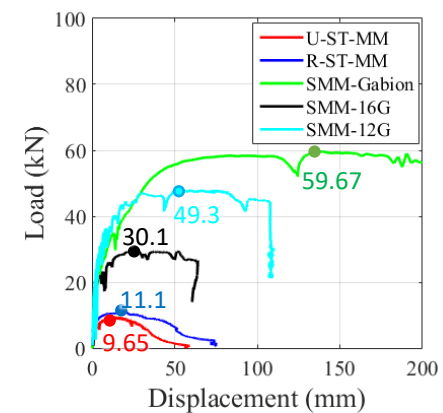
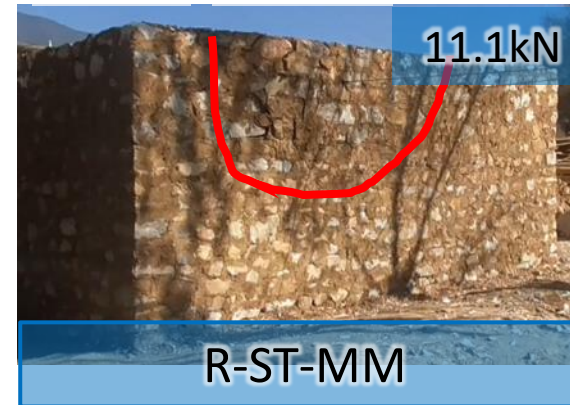
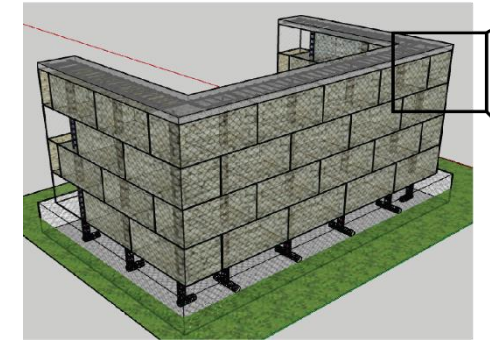
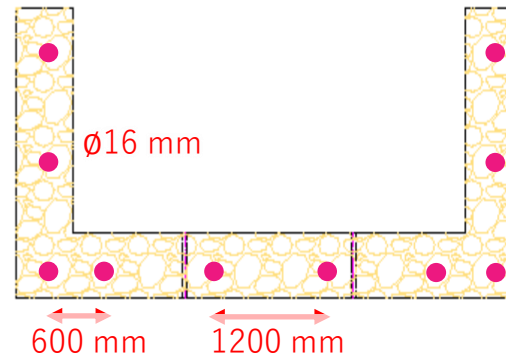
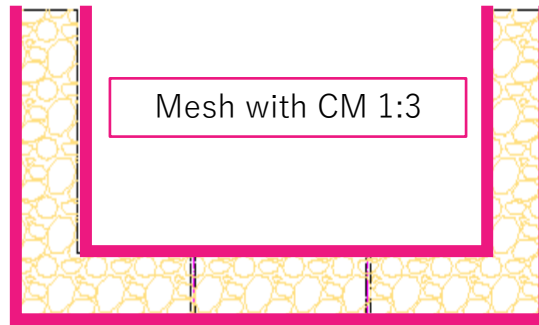
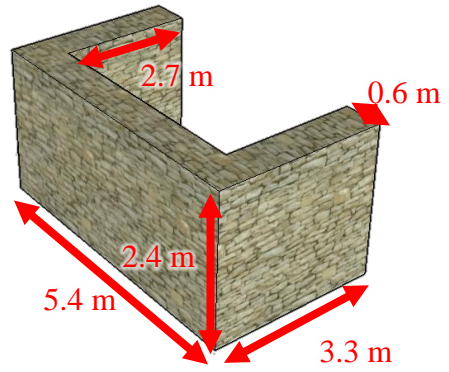
- Vertical bar $\phi 16$ (no concrete wrapping)



PULL DOWN TEST: STONE MASONRY IN CEMENT MORTAR

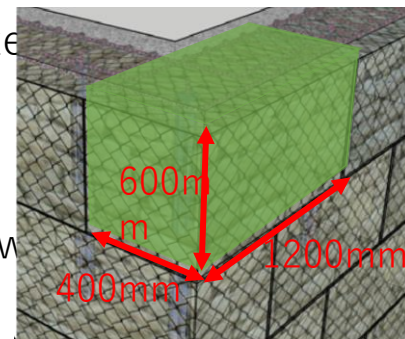


PULL DOWN TEST: Stone masonry in mud mortar(out-of-plane)

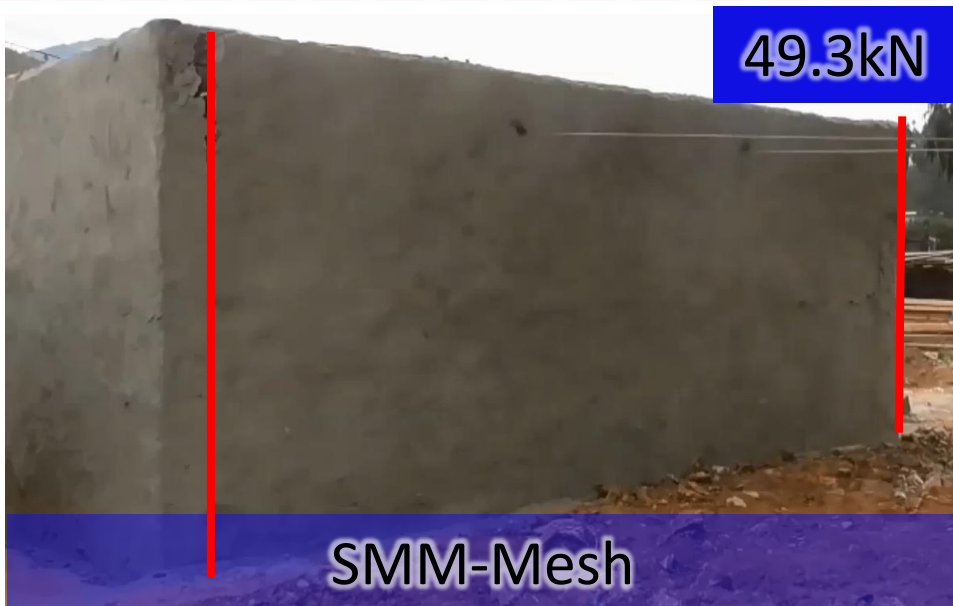
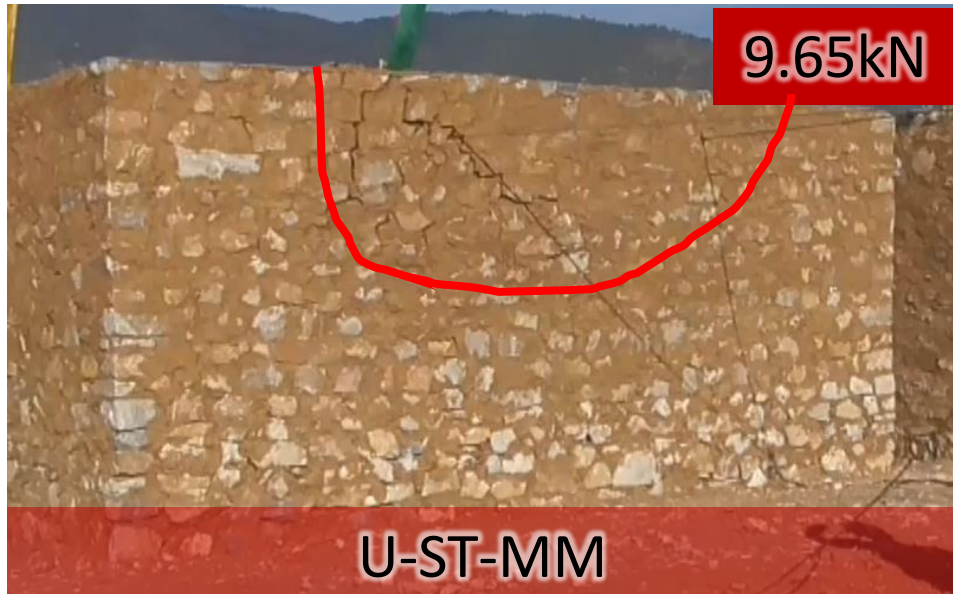


• Vertical bar $\phi 16$
(no concrete wrapping)

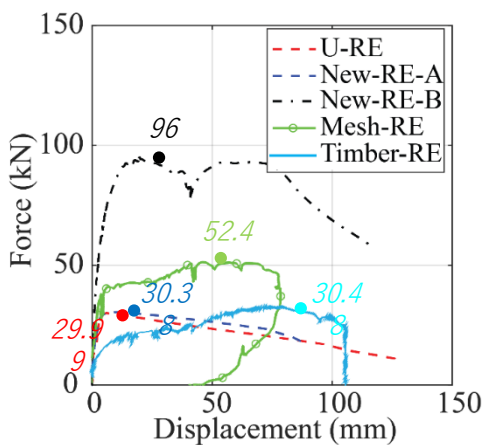
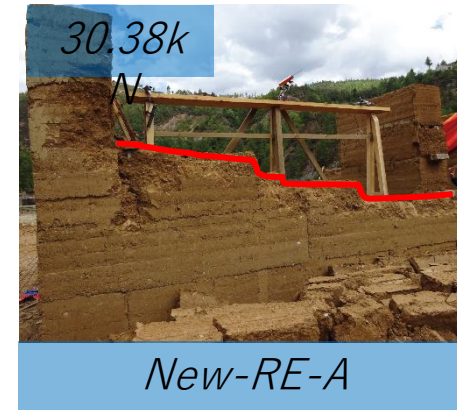
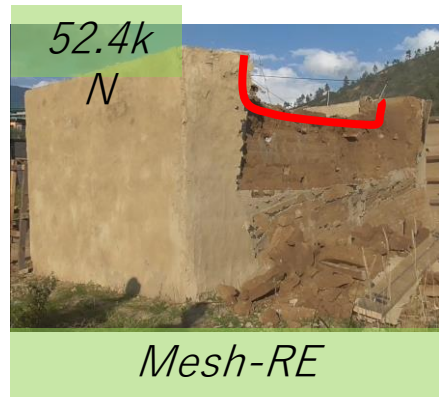
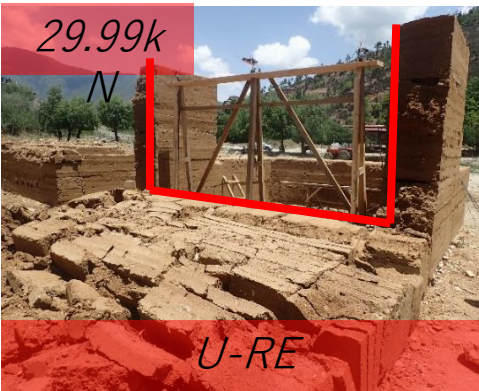
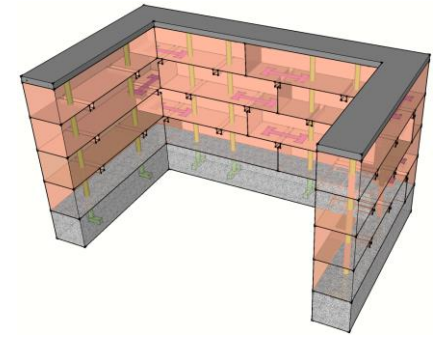
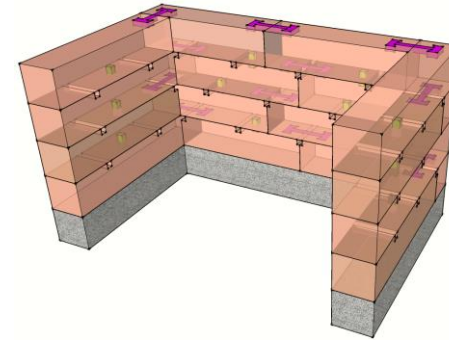
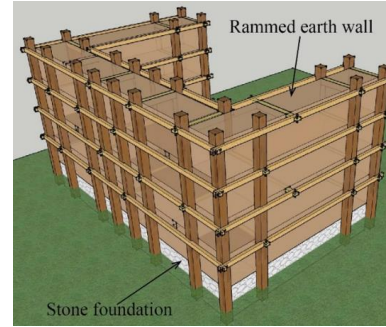
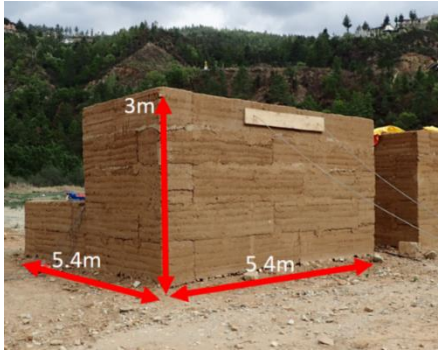
• Gabion mesh box $\phi 1.2\text{mm}$
• RC post*
• RC band*
(* refer SMC_New)



PULL DOWN TEST: STONE MASONRY IN MUD MORTAR



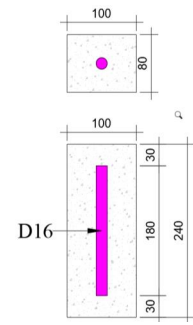
PULL DOWN TEST: Rammed earth (out-of-plane)



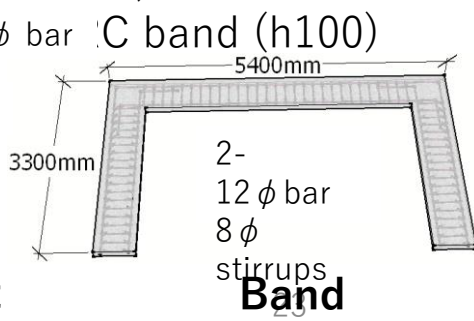
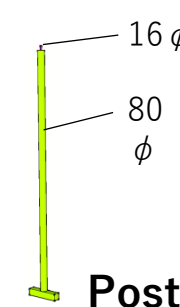
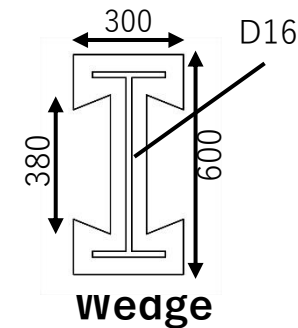
- 16G - Mesh
- 1cement:4mud

- RC wedges
- RC dowels

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



Dowel



Conclusions

Rammed earth

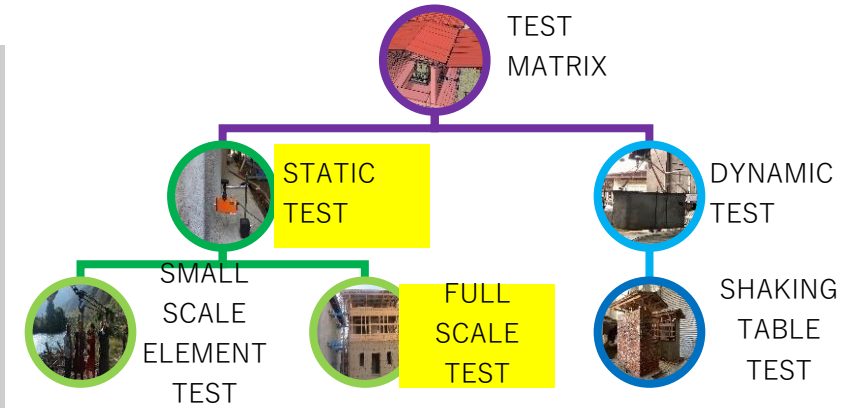
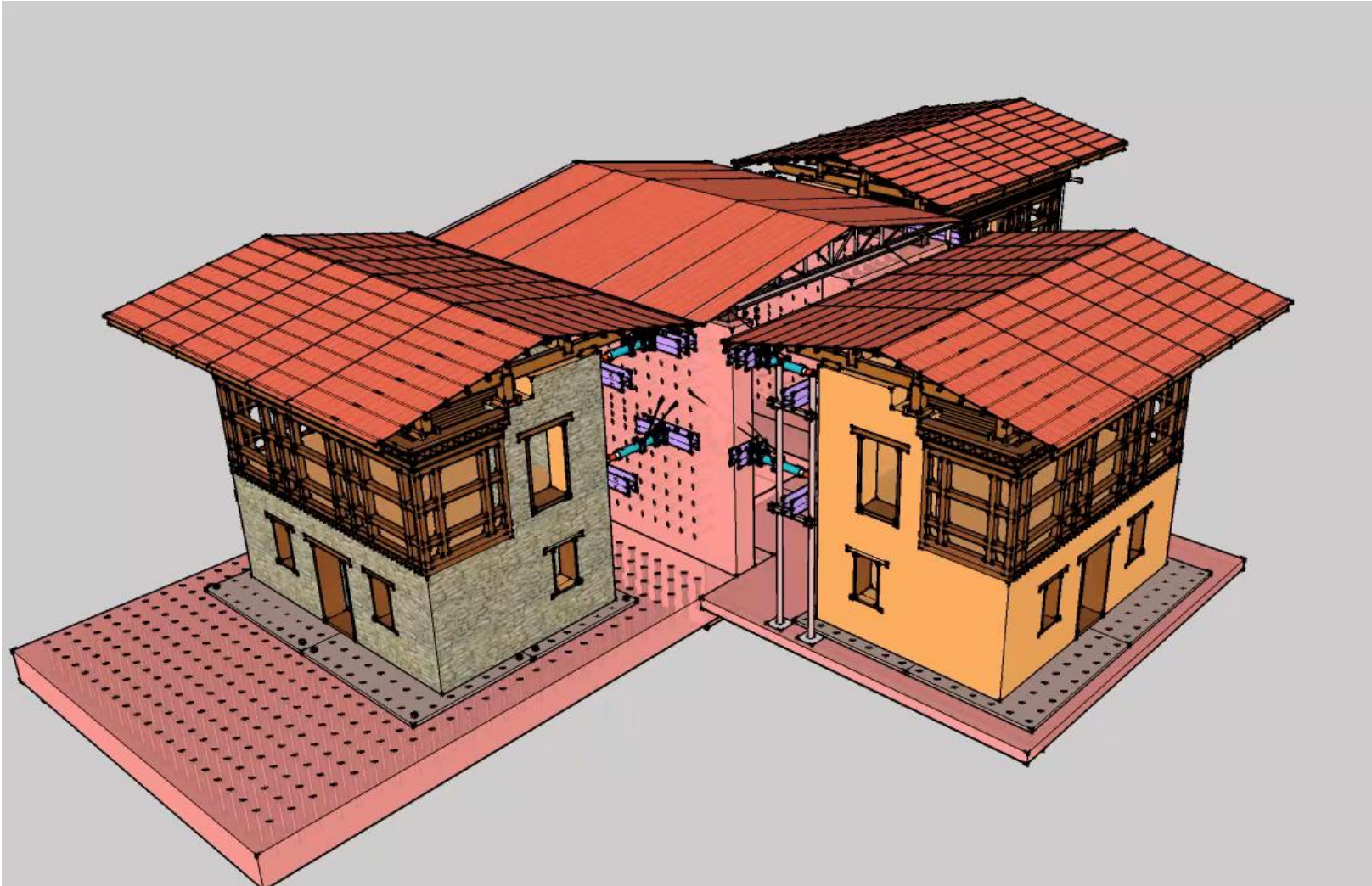
- RE-New > **3.2** x U-RE
- RE-16G > **1.75** x U-RE

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 verify its effectiveness

FULL-SCALE TEST

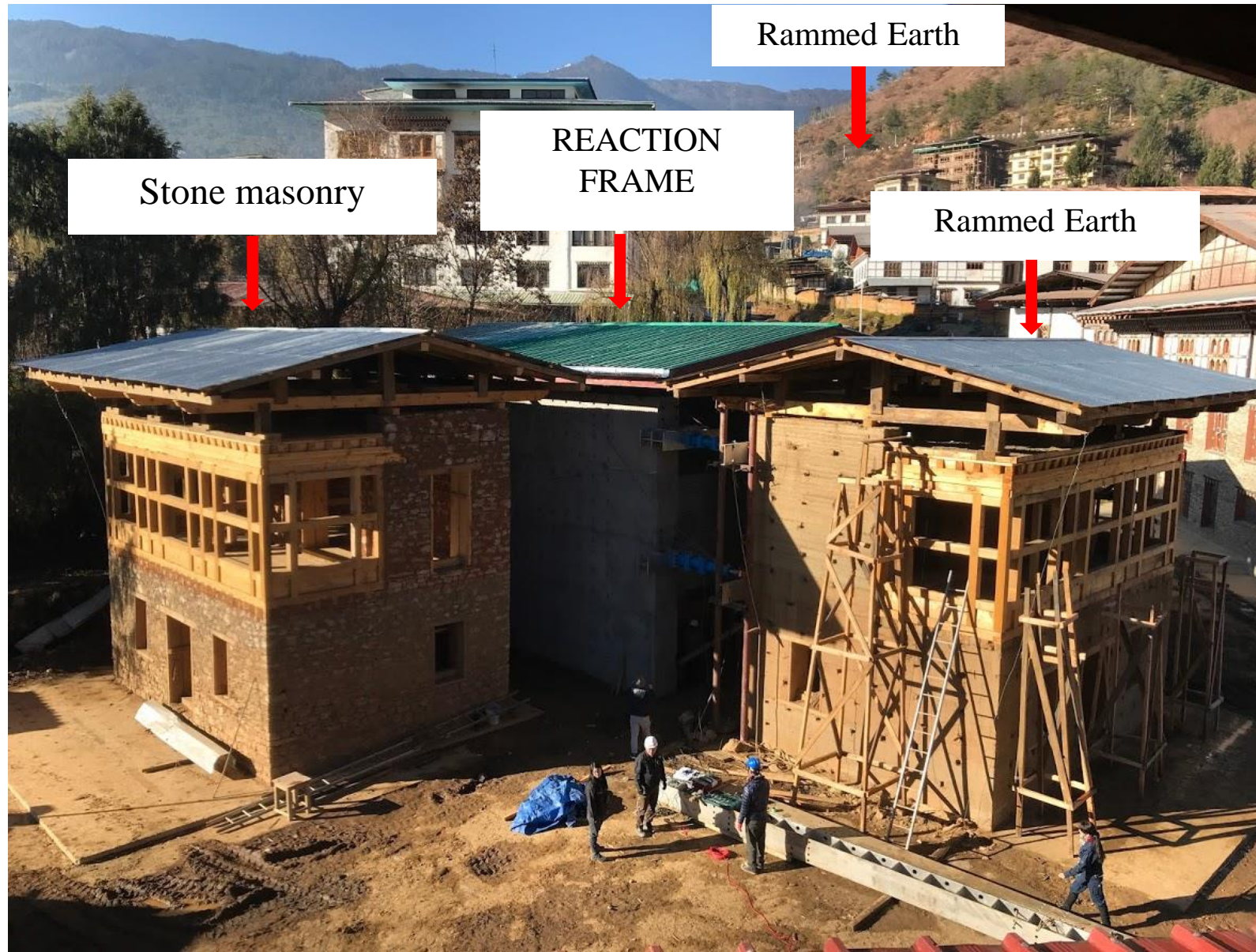


Objectives

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

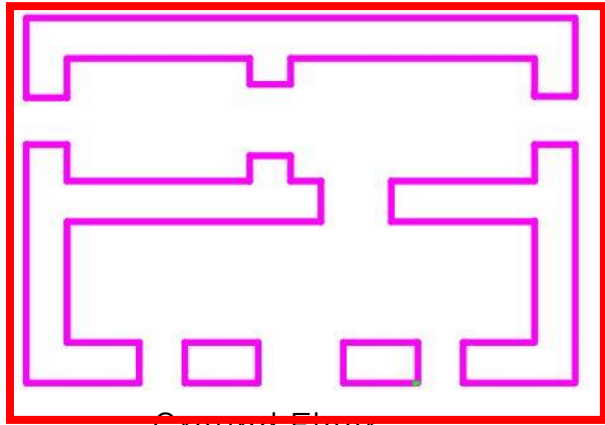
FULL SCALE TEST

Overview

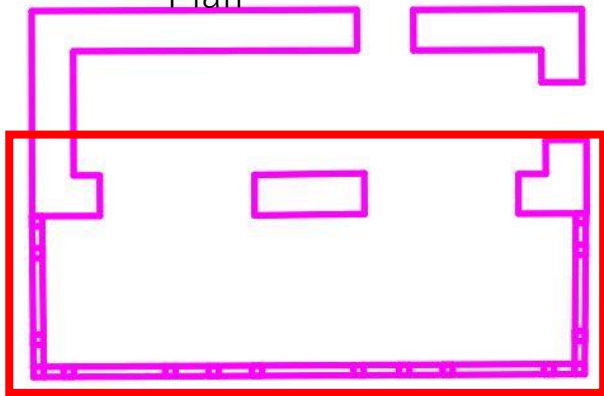


FULL SCALE TEST

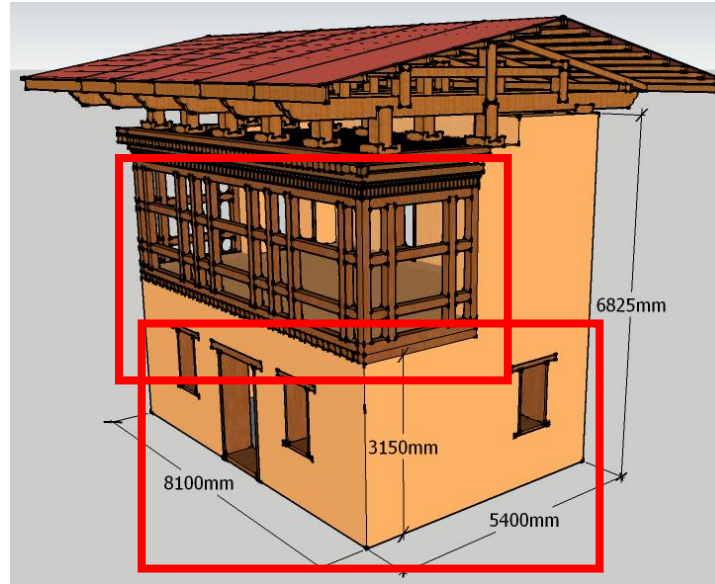
Specimen Details



Ground Floor Plan



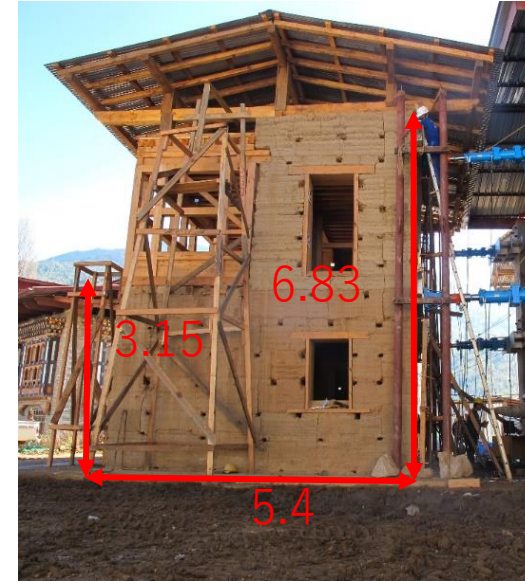
First Floor Plan



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



Retrofitting time: **3 weeks**

Mesh Layo

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



Cement plaster (CM



Completion of



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



bracing

FULL SCALE TEST

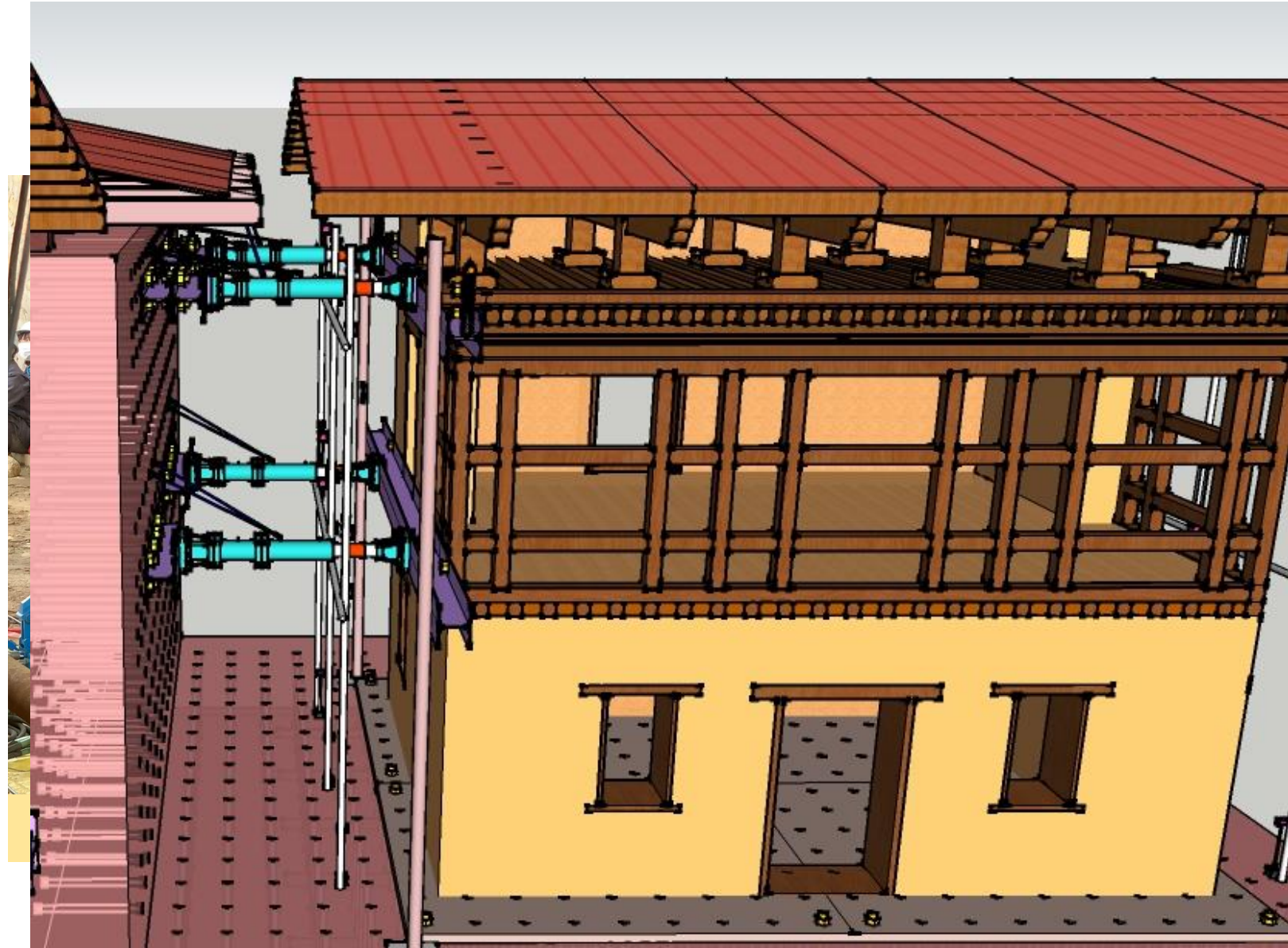
SET UP AND INSTRUMENTATION



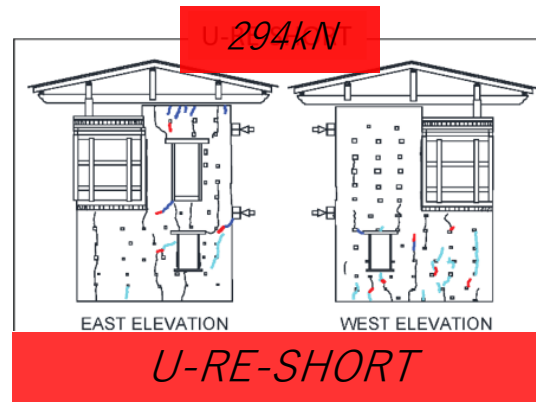
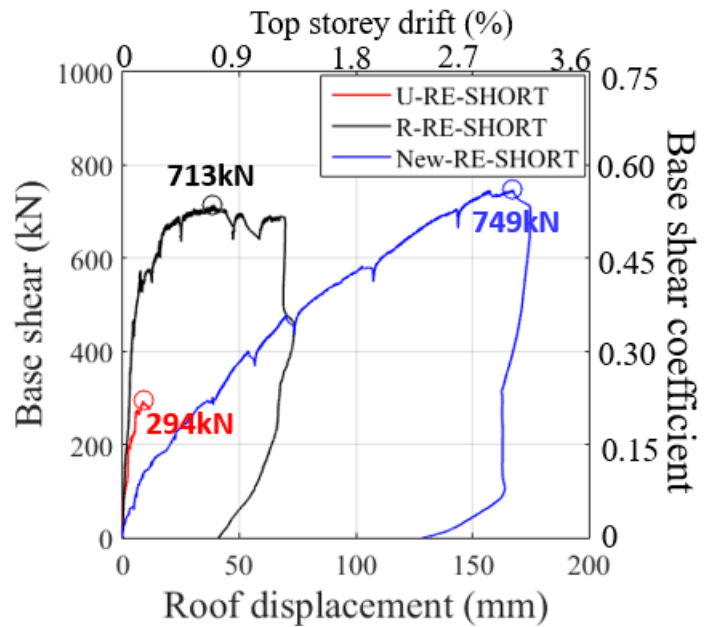
Fixing H-sections



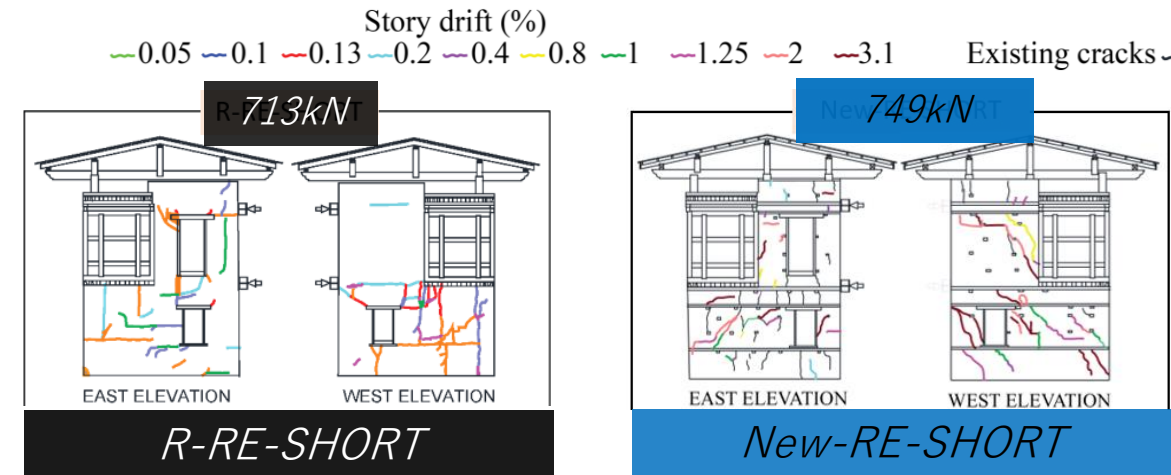
Fixing jacks



Rammed Earth : Full-scale test



- Unreinforced



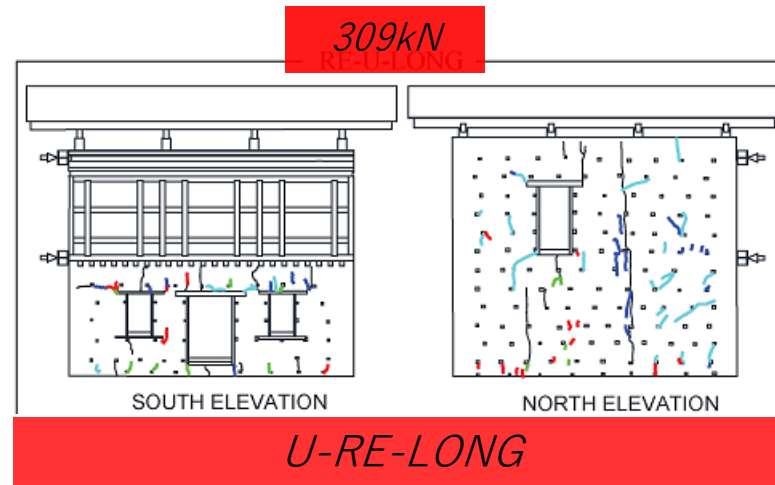
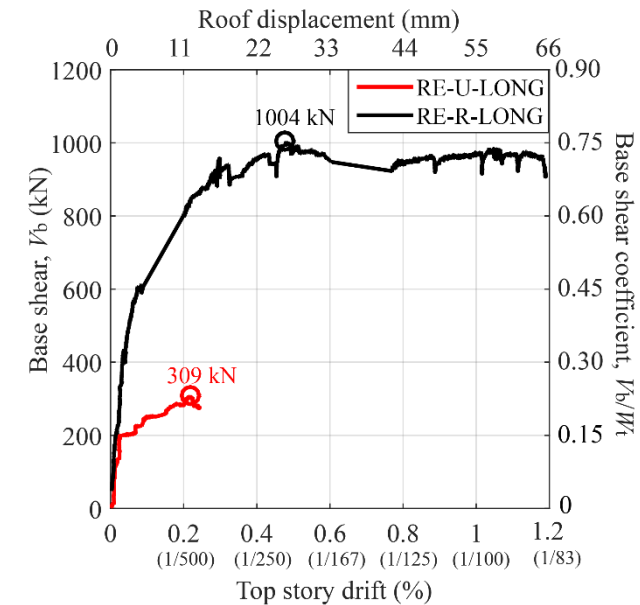
- Mesh (12G+16G)
- CM 1:3

- RC post (80 ϕ ; 12 ϕ)
- RC band

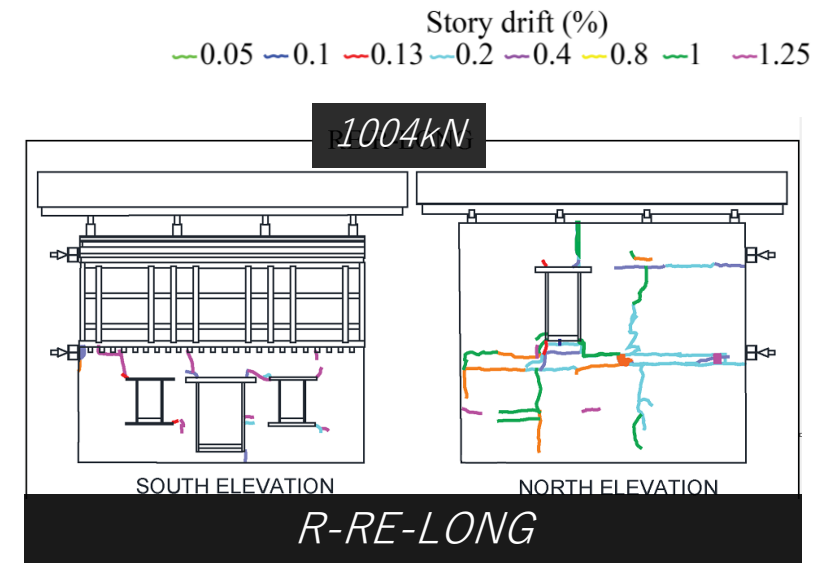
Rammed Earth : Full-scale test



Main mesh: 12G
Lapping mesh:
16G

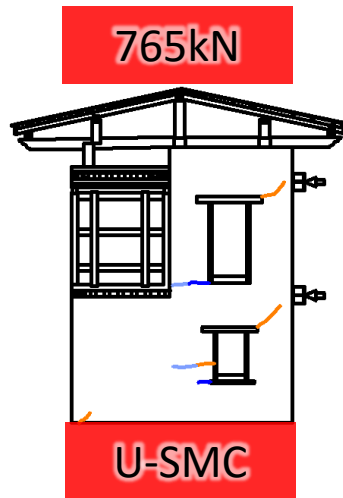
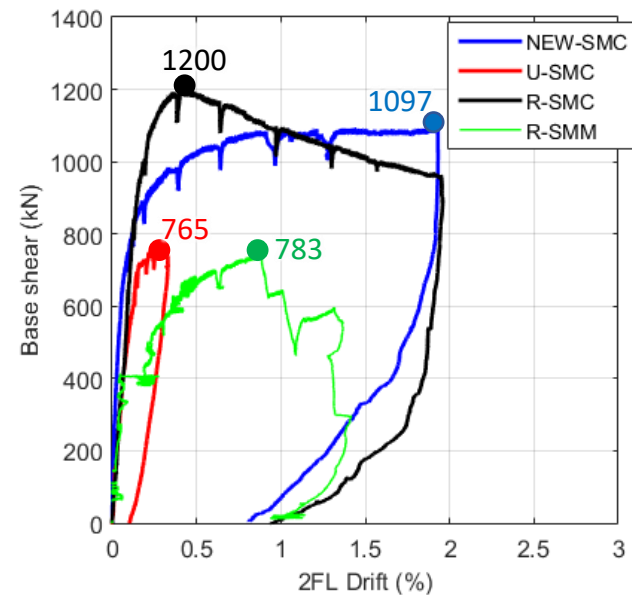
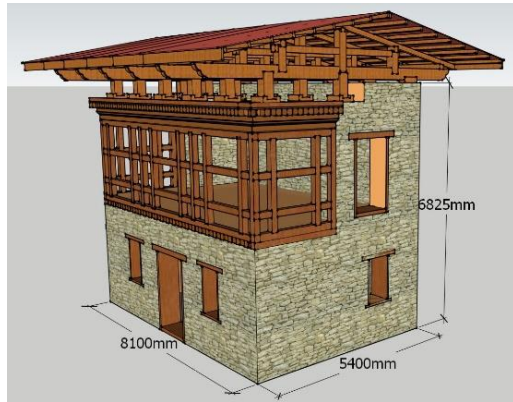


- Unreinforced



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

FULL-SCALE TEST: STONE MASONRY (SHORT SPAN)



- Unreinforced
- CM1:3



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



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



- 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.

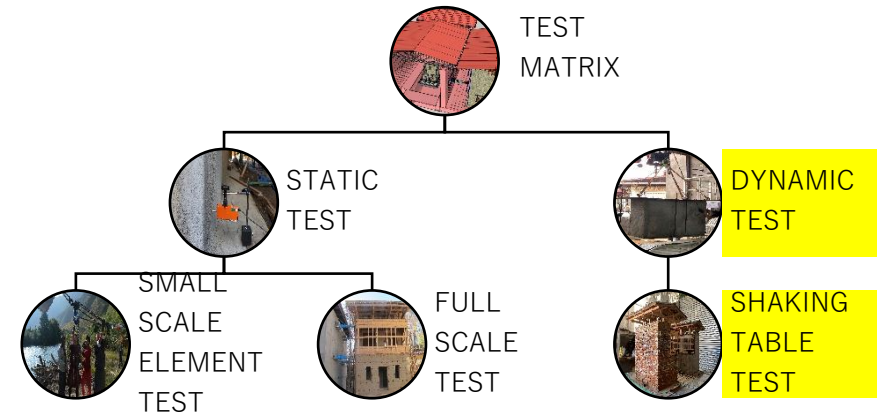
RC dowels, wedges and RC bands are recommended in new construction

Mesh is recommended to retrofit the existing buildings

SHAKING TABLE SYSTEM

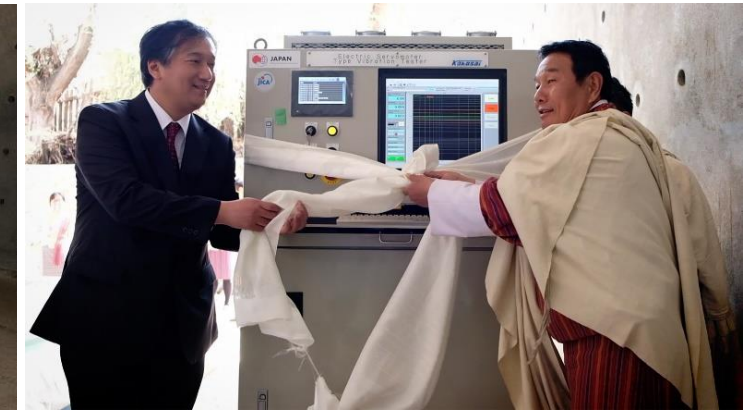
OBJECTIVES

- 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 cement 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”