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Exploring the Earth

PAGER Project Phase III:

Development of Seismic Capacity Curves for Claybrick Masonry Buildings in India

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Failure mechanisms

Typical views of failure of masonry buildings with rigid flat floors/roofs after past earthquakes in India:

1997 Jabalpur earthquake
(*World Housing Encyclopedia*)

2001 Bhuj earthquake

2001 Bhuj earthquake

Failure mechanisms

⇨ experience from past Indian earthquakes showed that URM structures with rigid roof systems and adequate bearing of walls:

a) generally out-of-plane failure is avoided
b) building behaves as a monolithic box
c) horizontal and diagonal cracks result from inadequate in-plane shear resistance leading to degradation of stiffness and strength

⇨ primary mechanisms of inplane failure modes for URM structures:

(1) sliding shear failure

→ separation of wall into parts along the bed joints, which slide relative to each other

(2) diagonal shear failure

→ if principle tensile stresses (axial and lateral loads) exceed the tensile strength of masonry, diagonal cracking may occur along mortar joints and/or in masonry units

(3) rocking failure

→ occurs in relatively slender piers; as horizontal load increases, bed joints crack on tension side, and failure of wall occurs when the stress on compression side of the wall reaches the compressive strength of the masonry

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How to model typical URM structures considering multi-irregularities?

socio-economic level of residents:
middle to high income

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... or even these ?

Analysis of existing masonry buildings

(1) Selection of representative building plans:

→ based on random sample survey eight building plans for each socio-economic group (high, upper middle, middle, low inclome class) have been selected
⇒ 32 model plans

→ main parameters expected to influence resistance:
- amount of wall area per floor area in each direction, $\hat{a}$
- eccentricity (distance between center of mass and center of rigidity) as a ratio of the dimension of the building, in the direction of earthquake, $\hat{e}$

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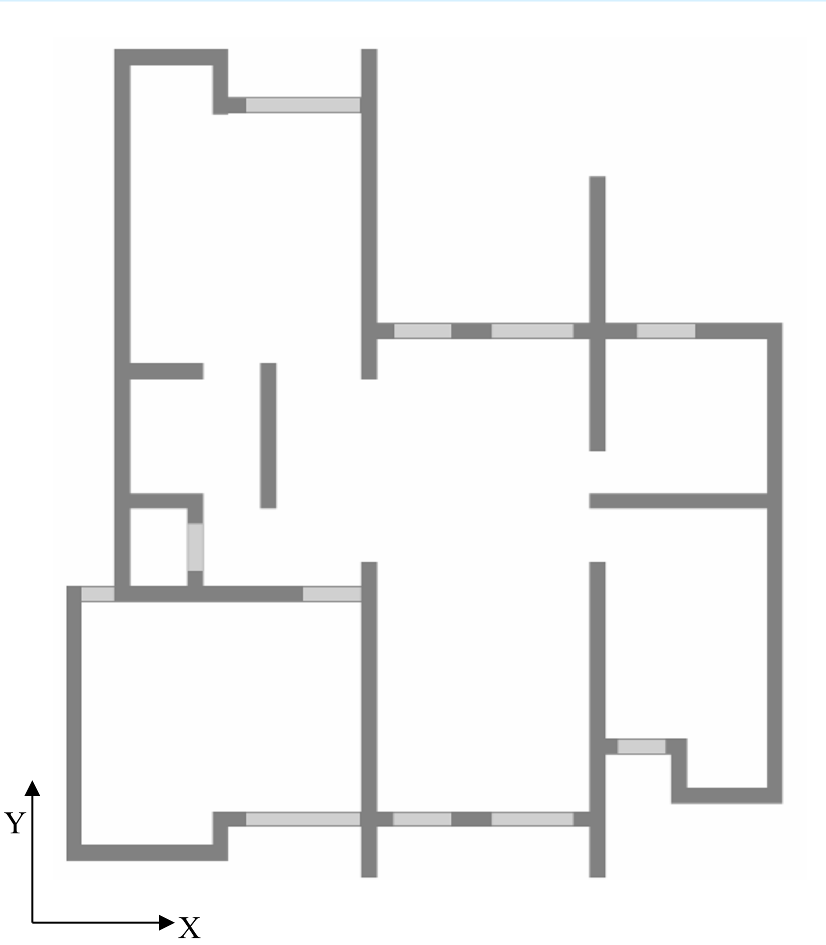
(1) Selection of representative building plans *(cont'd)*:

→ out of the 32 model plans, five plans (Case 1 to 5) were selected for nonlinear 'pushover' analysis

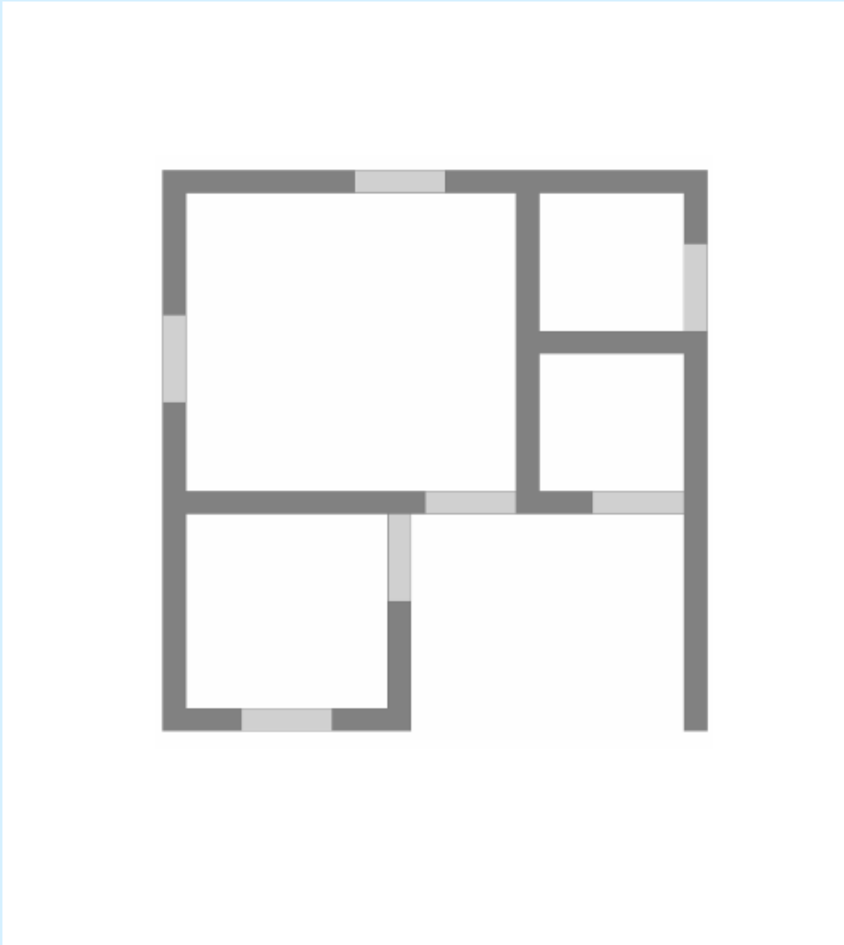
Case	**Dir.**	**Plan No.**	**Socio-economic level**	$\hat{a}$	$\hat{e}$	**Selection criteria**
1	Y	28	upper middle and high	7.24	4.20	$\hat{a}$ and $\hat{e}$ close to Mean
2	X	6	slum and low income	7.64	9.88	$\hat{a}$ close to Mean and $\hat{e}$ close to Mean+σ
3	X	31	upper middle and high	7.84	0.01	$\hat{a}$ close to Mean and $\hat{e}$ close to Mean–σ
4	Y	8	slum and low income	10.93	4.23	$\hat{a}$ close to Mean+σ and $\hat{e}$ close to Mean
5	X	10	lower middle income	5.49	4.63	$\hat{a}$ close to Mean–σ and $\hat{e}$ close to Mean

(1) Selection of representative building plans *(cont'd)*:

→ Case 1



→ Case 2



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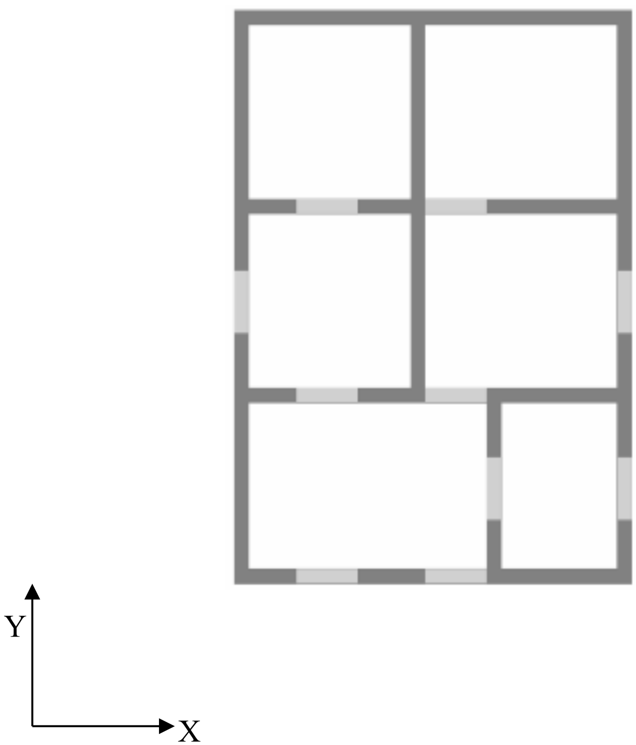
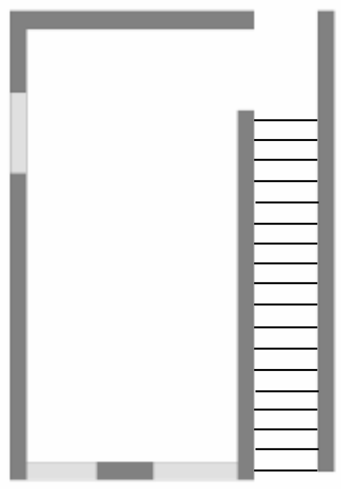
(1) Selection of representative building plans *(cont'd)*:

→ Case 3



→ Case 4



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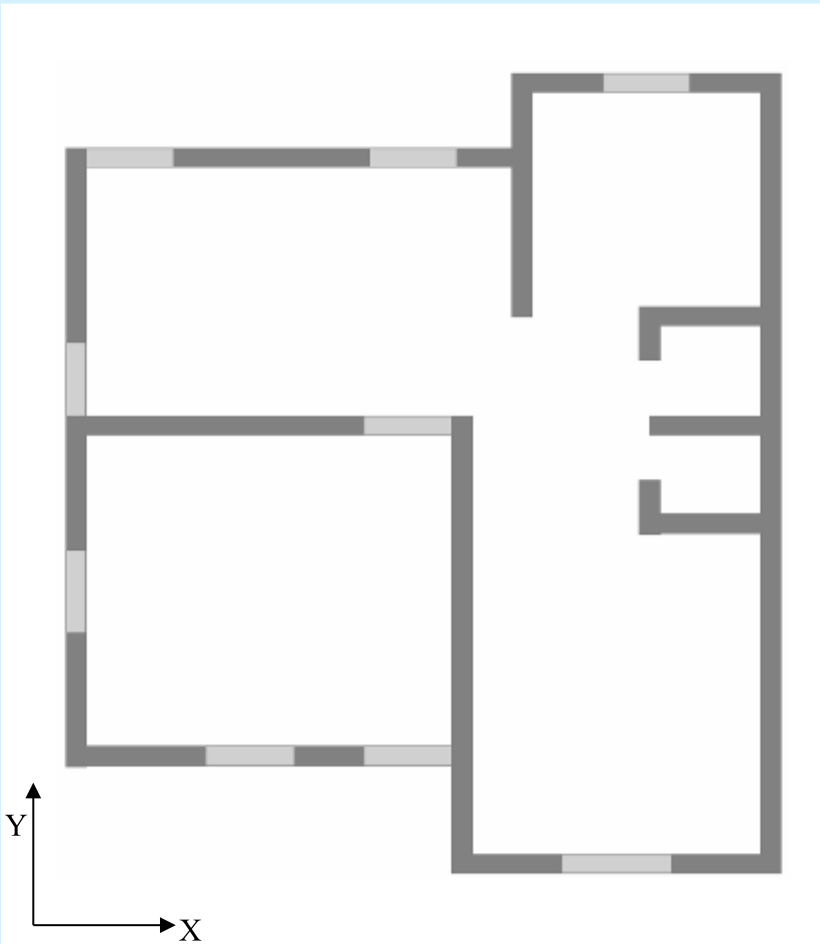
(1) Selection of representative building plans *(cont'd)*:

→ Case 5



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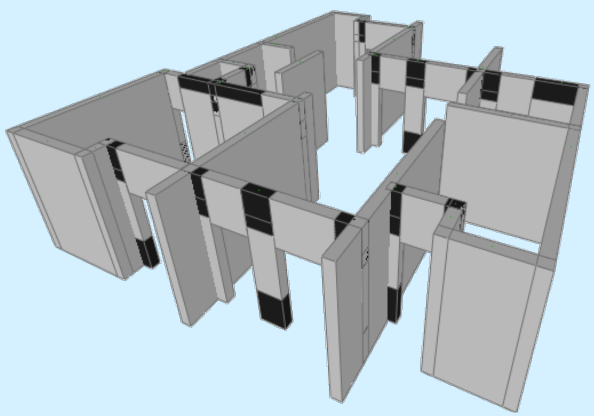
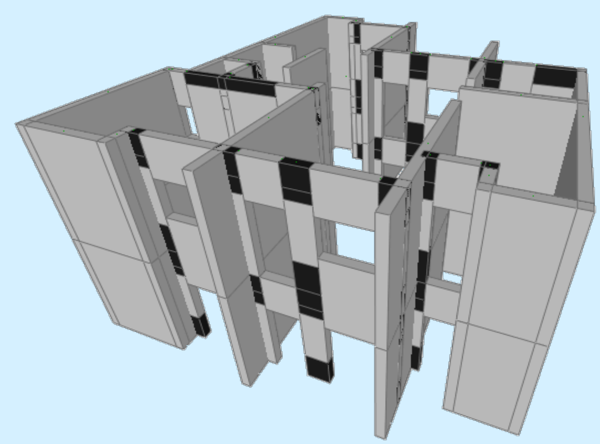
(2) Modeling of representative buildings:

→ material properties of claybrick masonry with different types of mortar:

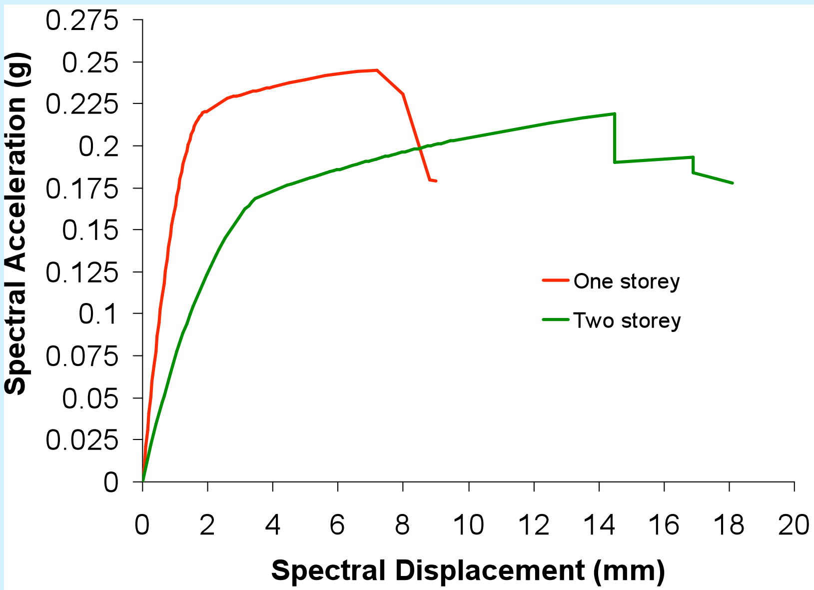
Mortar type	Compressive strength [*MPa*]	Shear strength [*MPa*]	Elastic modulus [*MPa*]	Reference
1:6 cement-sand	6.00	0.39	2,000	ISET (2001)
1:2 lime-surkhi	5.87	0.25	990	Krishna & Chandra (1965)
clay mud	4.75	0.08	420	

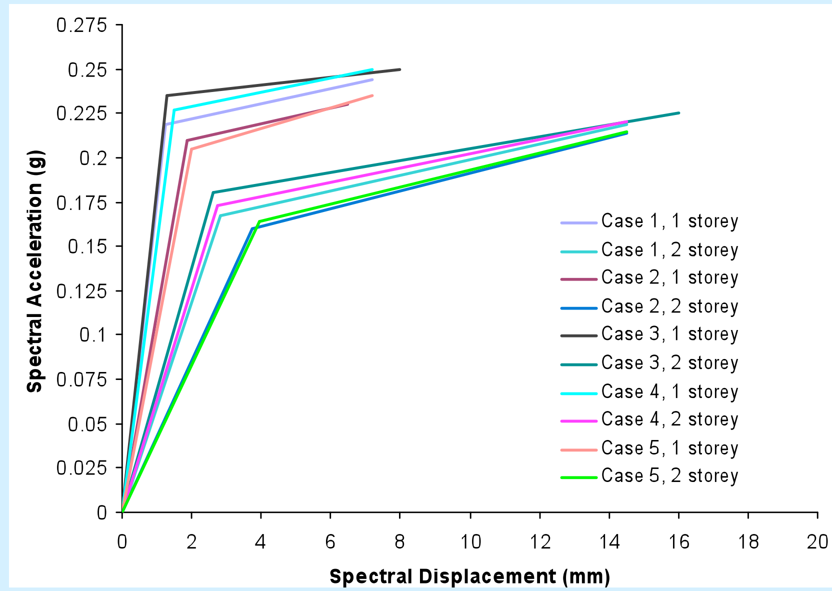
→ pushover analyses are conducted in the concerned direction of the five Cases, both for one and two-storied buildings





(3) Pushover analysis for Cases 1 - 5:





e.g. **Case 1**
1:6 cement-sand mortar ⇒ **Bilinearized form**

→ effect of **plan shape** variation is *negligible* compared with variation in **story number**

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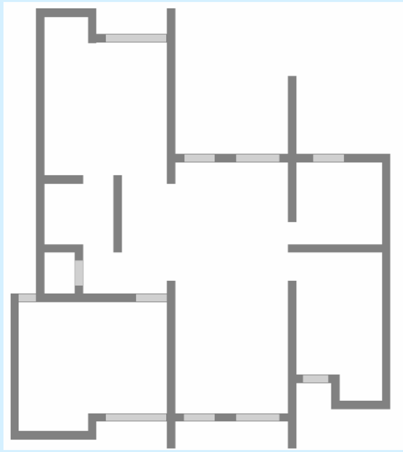
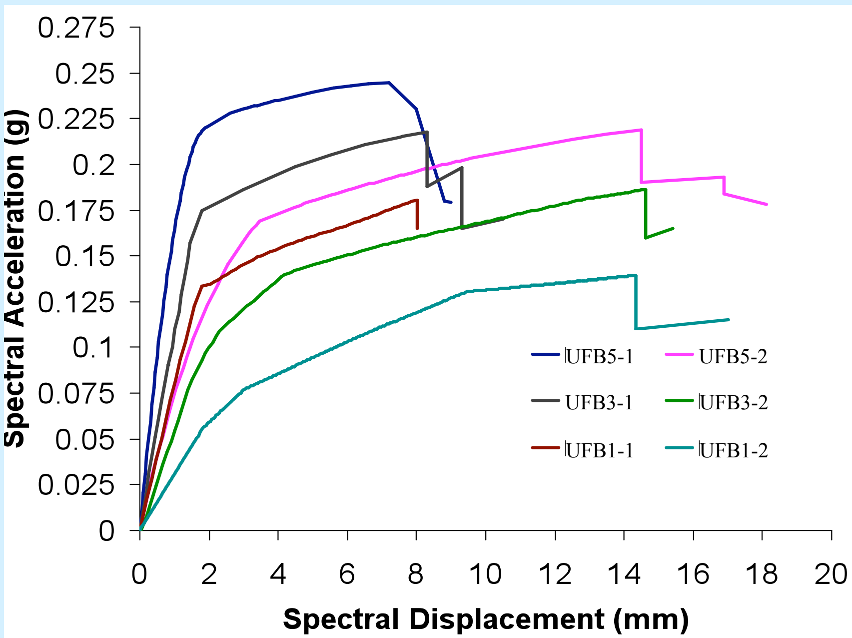
(4) Pushover analysis for Case 1 and different mortar types:

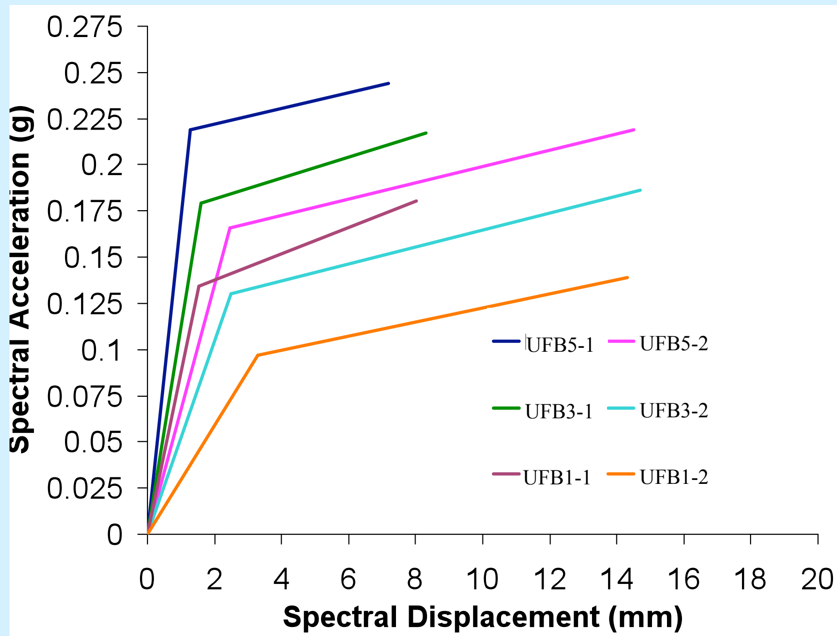


Pager MBT	Mortar	Period [*sec*]	Yield point		Ultimate point	
			S_{dy} [*mm*]	S_{ay} [*g*]	S_{du} [*mm*]	S_{au} [*g*]
UFB5-1	cement	0.14	1.27	0.22	7.5	0.25
UFB5-2		0.23	2.46	0.16	14.5	0.22
UFB3-1	lime surkhi	0.16	1.6	0.17	8.3	0.22
UFB3-2		0.28	2.5	0.13	14.6	0.18
UFB1-1	clay mud	0.2	1.54	0.134	8.0	0.18
UFB1-2		0.36	3.3	0.096	14.3	0.14

(4) Pushover analysis for Case 1 and different mortar types:



(a) curvilinear form



(b) bi-linearised form