Earthquake Engineering Research Institute

WHE-PAGER Project

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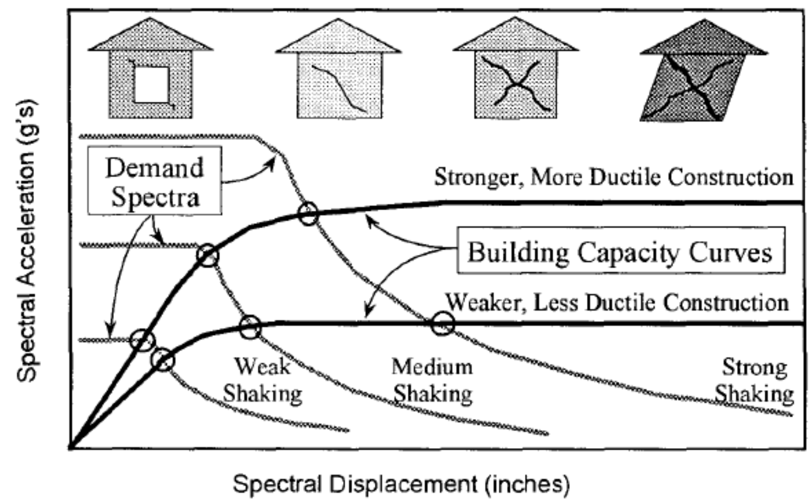
Seismic assessment of building stock and prediction of losses

- Input
  - Classification of buildings
  - Assignment of capacity curves
  - Definition of damage states
  - Definition of demand spectra
  - Evaluation of building response



- Output
  - Fragility curves
  - Damage scenarios

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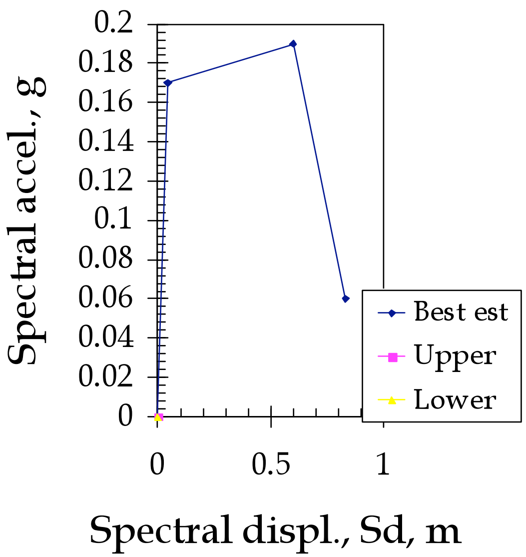
General Methodology

- Building classification by building typology
- If typologies are codified then capacity curves deduced from design standards
- Damage thresholds more difficult but theoretical correlation between damage and drift available for engineered structures
- Correlation of drift capacity and demand from displacement spectra possible
- Distribution of building stock from census by typology and use of lognormal distribution around mean average damage
- Possible calibration of fragility curves with direct damage observations and experimental work.

Request to the analytical phase contributors

- Fill a spreadsheet providing a push over curve defining how far we are form the HAZUS approach



WHE-PAGER PHASE 2: DEVELOPMENT OF ANALYTICAL SEISMIC VULNERABILITY FUNCTIONS

Author:	Hemant B. kaushik
Date:	10-Jul-09
Structure type (describe as broadly as possible):	Non-Ductile Reinforced Concrete Frame without Masonry Infill Walls
Geographic or other limitations:	Northern India, Modern Building Construction
	As per the prevalent method of design of such buildings in India, strength and stiffness of masonry infills is not considered (only Add rows as desired

Choice of pushover curve parameters

	Units	Parameter	
Pushover X-axis:	Sd(m)		Choose spectral displacement (Sd); or Roof displacement (Deltar). State units
Pushover Y-axis:	Sa(g)		Choose spectra acceleration (Sa); or base shear (V). State units.
Elastic damping ratio:	0.05		Small-amplitude damping ratio, fraction of critical
1st mode participation factor:	1.2		PFfR; generally 1.3 to 1.5; same as (effective height)/(total roof height)
Effective mass coefficient:	0.96		alpha1; generally 0.7 to 0.8
Building weight:	1640 kN	Weight of the	W State units

How were these values & pushover points derived? Based on analytical simulations of an intermediate frame of a four storey building. Actual performace of real buildings may be different.
Ref: Kaushik, H.B., Rai, D.C., and Jain, S.K. (2009), "Effectiveness of some strengthening options for masonry-infilled RC frame Add rows as desired

Pushover Curve for this structure type

See Figures 1-4 for sample pushover curves

Pushover curve control point	X	Y	Damping	Comment	
A	0	0	0.13	Damping at P	Control point for plotting purposes
B	0.044	0.17			E.g., yield point?
C	0.6	0.19			E.g., ultimate point?
D	0.83	0.06			E.g., beginning of lower plateau?
E					Add rows as desired

Optional: upper and lower-bound range of pushover curves for this structure type

Upper-bound pushover curve, e.g., 99 out of 100 buildings of this type would have pushover curve inside the area bounded between this curve and the Y-axis?
Author's meaning of "upper bound":
How were these values & pushover points derived?
Add rows as desired

See Figures 1-4 for sample pushover curves

Optional upper-bound pushover curve

Pushover curve control point	X	Y	Damping	Comment	
A	0	0			Control point for plotting purposes
B					E.g., yield point?
C					E.g., ultimate point?
D					E.g., beginning of lower plateau?
E					Add rows as desired

Lower-bound pushover curve, e.g., 99 out of 100 buildings of this type would have pushover curve inside the area bounded between this curve and the X-axis?
Author's meaning of "lower bound":
How were these values & pushover points derived?
Add rows as desired

See Figures 1-4 for sample pushover curves

Optional lower-bound pushover curve

Pushover curve control point	X	Y	Damping	Comment	
A	0	0			Control point for plotting purposes
B					E.g., yield point?
C					E.g., ultimate point?
D					E.g., beginning of lower plateau?
E					Add rows as desired

Other requested parameters

D14		median drift (in same units as pushover X-axis) associated with complete structural damage, i.e., drift with 50% chance that the structural com
B14		logarithmic standard deviation of drift associated with complete structural damage. May need to be guessed
Sdc		the median value of drift (in same units as pushover X-axis) associated with collapse, e.g., Sdc = (roof drift at collapse)/PFfR.
L15		indoor fatality rate given collapse. Many contributors may be unable to provide this value. Porter, Comartin, and Holmes will fill such gaps
PC		mean fraction of building area collapsed, given complete structural damage. Again Porter, Comartin, and Holmes will fill gaps
kshort		If HAZUS-style damping preferred, and author can judge, this is the degradation factor for short-duration (M <= 5.5) events
kmed		If HAZUS-style damping preferred, and author can judge, this is the degradation factor for medium-duration (5.5 < M < 7.5) events
klong		If HAZUS-style damping preferred, and author can judge, this is the degradation factor for long-duration (M >= 7.5) events

Explain how these values were arrived at, providing citations if appropriate
Add rows as desired

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Analytical push-over curves for non-HAZUS structures types

- Identify experimental/analytical curves existing in literature
- Document type of test/analytical procedure, representativeness, etc.
- Use FaMIVE database to extract a number of region/ structure specific curves
- Compare with curves in literature
- Produce fragility curves

PAGER Structure types considered

Sr. No.	PAGER-STR	Description of Structure
8	RS3	Local field stones with lime mortar.
9	RS4	Local field stones with cement mortar, vaulted brick roof and floors
10	DS2	Rectangular cut stone masonry block with lime mortar
11	DS4	Rectangular cut stone masonry block with reinforced concrete floors and roof
12	MS	Massive stone masonry in lime or cement mortar
14	UFB1	Unreinforced brick masonry in mud mortar without timber posts
15	UFB3	Unreinforced brick masonry in lime mortar
16	UFB5	Unreinforced fired brick masonry, cement mortar, but with reinforced concrete floor and roof slabs

Literature -Experimental

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- **[5] Benedetti D., Carydis P., Pezzoli P., 1998,** ‘Shaking Table Tests on 24 Simple Masonry Buildings’ *Earthquake Engineering and Structural Dynamics*: Vol 27: 67-90
- **[6] Magenes G., Calvi G., 1997,** ‘In-Plane Seismic Response of Brick Masonry Walls’
- *Earthquake Engineering and Structural Dynamics*: Vol 26: 1091-1112
- **[7] Tomazevic M.,** ‘Damage as a Measure for Earthquake-Resistant Design of Masonry Structures: Slovenian Experience’, *Can. J. Civ. Eng.* 34: 1403-1412, 2007
- **[8] Tomazevic M., Lutman M., Weiss M., Velechovsky T.,** ‘The Influence of Rigidity of Floors on the Seismic Resistance of Masonry Buildings: Shaking Table Tests of Stone Masonry Houses Summary Report’, *A Report to the Ministry of Science of Republic of Slovenia*
- *Institute for Testing and Research in Materials and Structures, Ljubljana, Slovenia, 1992*
- **[10] Paquette J., Bruneau M.,** ‘Pseudo Dynamic Testing of Unreinforced Masonry Building with Flexible Diaphragm’ *Journal of Structural Engineering*, ASCE, June 2003
- **[11] Yi T., Moon F., Leon R., Kahn L.,** ‘Lateral Load Tests on a Two Storey Unreinforced Masonry Building’ *Journal of Structural Engineering*: ASCE: May 2006
- **[12] Griffith M., Lam N., Wilson J., Doherty K.,** ‘Experimental Investigation of Unreinforced Brick Masonry Walls in Flexure’, *Journal of Structural Engineering,* ASCE, March 2004: 423-432
- **[13] Doherty K., Griffith M., Lam N., Wilson J.,** ‘Displacement-Based Seismic Analysis for Out-of-Plane Bending of Unreinforced Masonry Walls’, *Earthquake Engineering and Structural Dynamics*: 2002: 31: 833-850
- **[14] Degée H., Denoël V., Candeias P., Campos Costa A., Coelho E.,** ‘Experimental Investigation on the Seismic Behaviour of North European Masonry Houses’, *Sismica 2007- 7º Congresso de Sismologia Engenharia Sismica*

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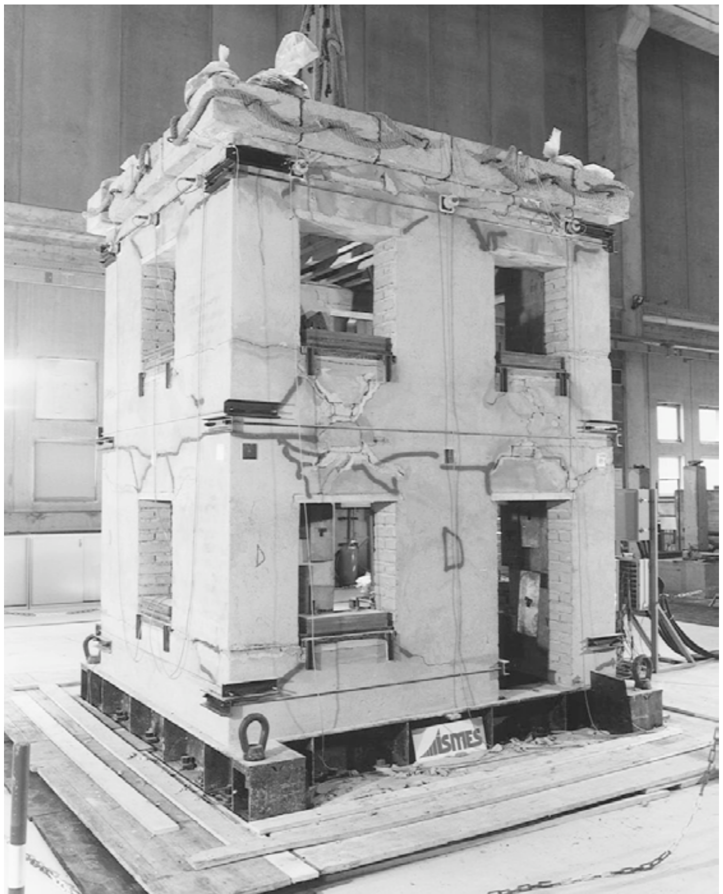
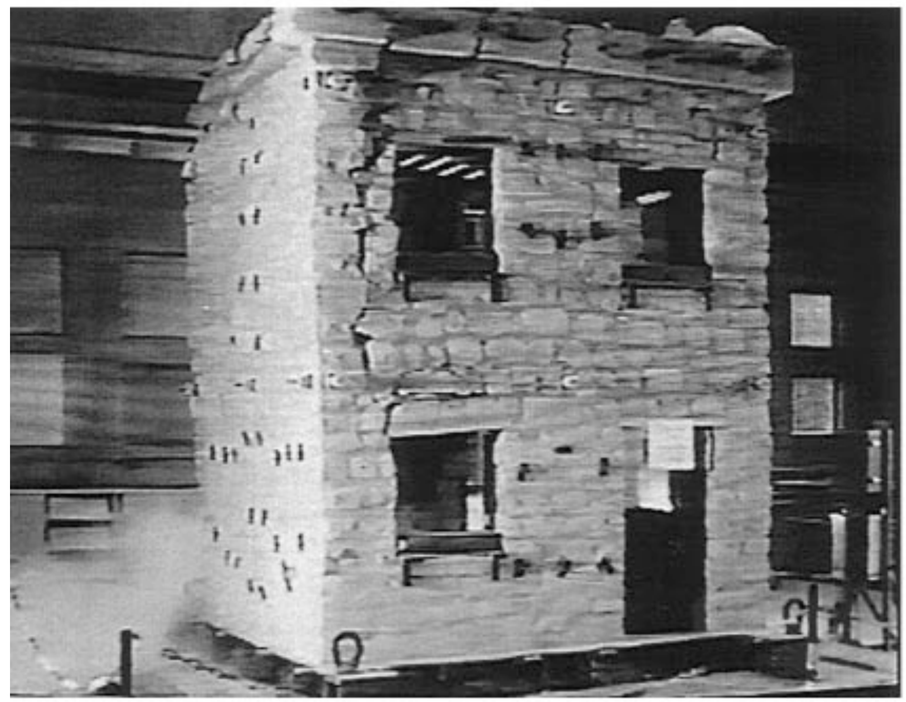
Benedetti et al. 1998

Brick masonry UFB3



Rubble masonry DS2



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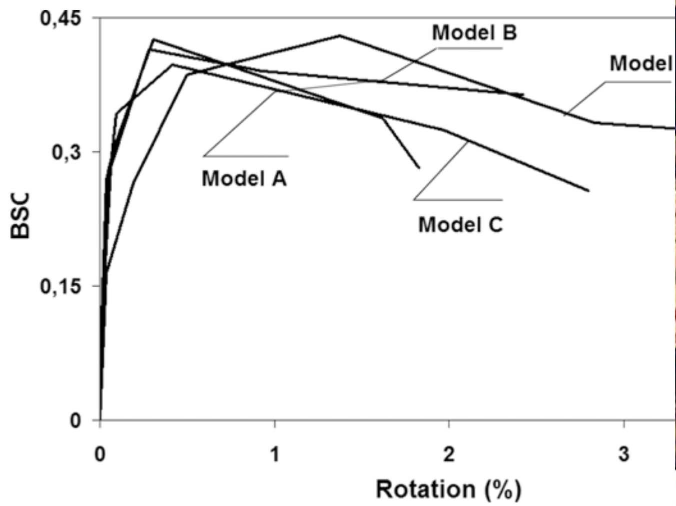
Tomazevic &Lutman 2004

Rubble stone

RS4



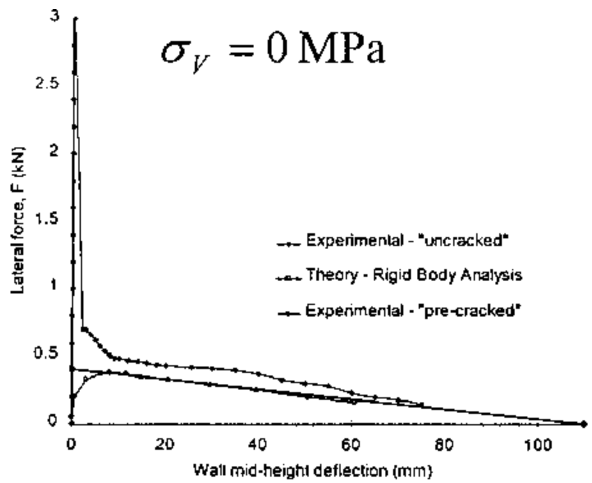
Model A: without wall ties

Model C: with wall ties

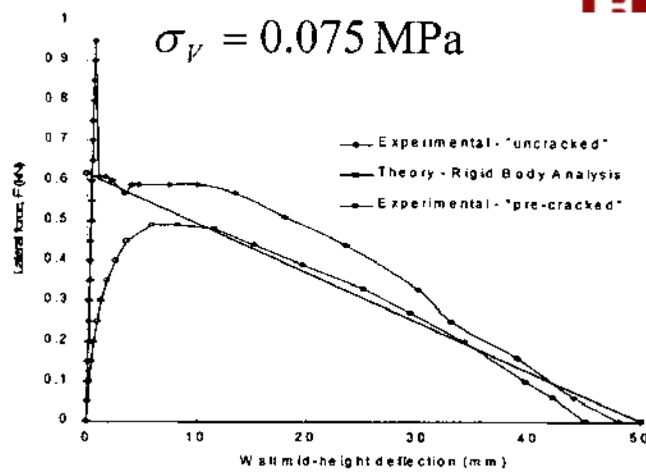
Literature Analytical

- **[15] D'Ayala D., 2005,** 'Force and Displacement Based Vulnerability Assessment for Traditional Buildings', *Bulletin of Earthquake Engineering*: 2005:3:235-265
- **[16] Cattari S., Lagomarsino S., 2006,** 'Non-Linear Analysis of Mixed Masonry and Reinforced Concrete Buildings' ,*First European Conference on Earthquake Engineering and Seismology, Geneva, Switzerland, 3-8th September 2006*: Paper no. 927
- **[17] Penelis G.,** 'An Efficient Approach for Pushover Analysis of Unreinforced Masonry (URM) Structures', *Journal of Earthquake Engineering*: Vol 10: No.3: 2006: 359-379
- **[18] Penelis G., Kappos A., Stylianidis K., 2003,** 'Assessment of the seismic vulnerability of unreinforced masonry buildings', *Structural Studies, Repairs and Maintenance of Heritage Architecture VIII*: 575-584
- **[19] Salonikios T., Karakostas C., Lekidis V., Anthoine A.,** 'Comparative Inelastic Pushover Analysis of Masonry Frames', *Engineering Structures 25*: 2003: 1515-1523
- **[20] Kappos A., Panagopoulos G., Panagiotopoulous C., Penelis G.,** 'A Hybrid Method Method for the Vulnerability Assessment of RC and URM Buildings', *Bull Earthquake Eng*: (2006): 4: 391-413
- **[21] Barbat A.,** 'Performance of Buildings Under Earthquakes in Barcelona, Spain' *Computer-Aided Civil and Infrastructure Engineering*: 21: (2006): 573-593

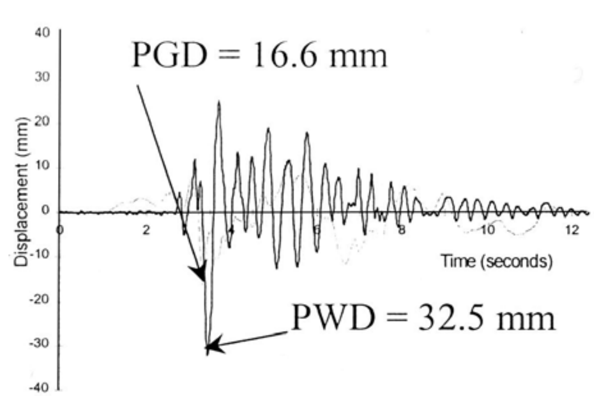
Griffith et al. (2004)



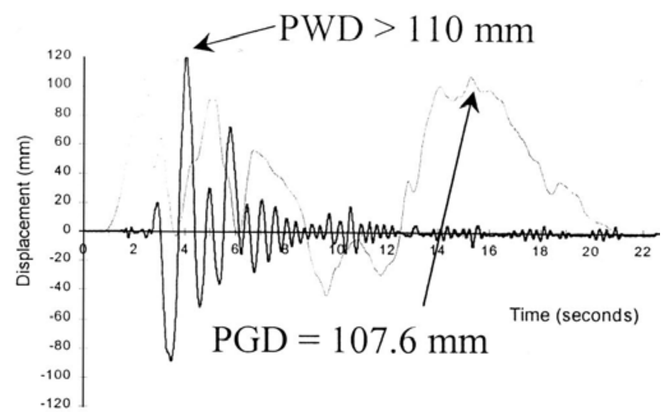
(a) 110 mm thick wall



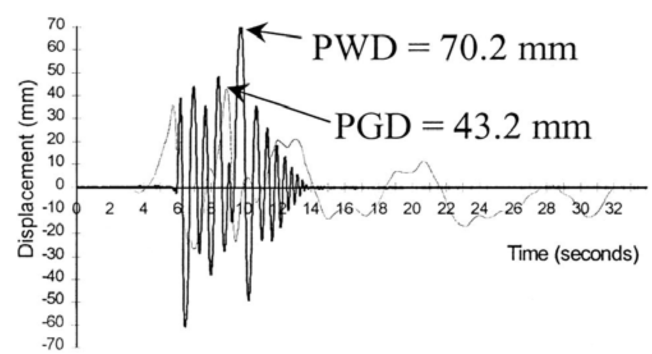
(b) 50 mm thick wall



(a) 4 x Nahini



(b) 0.66 x El Centro



(c) 0.8 x Pacoima Dam

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Regions

- Italy

Turkey

- Iraq

Nepal

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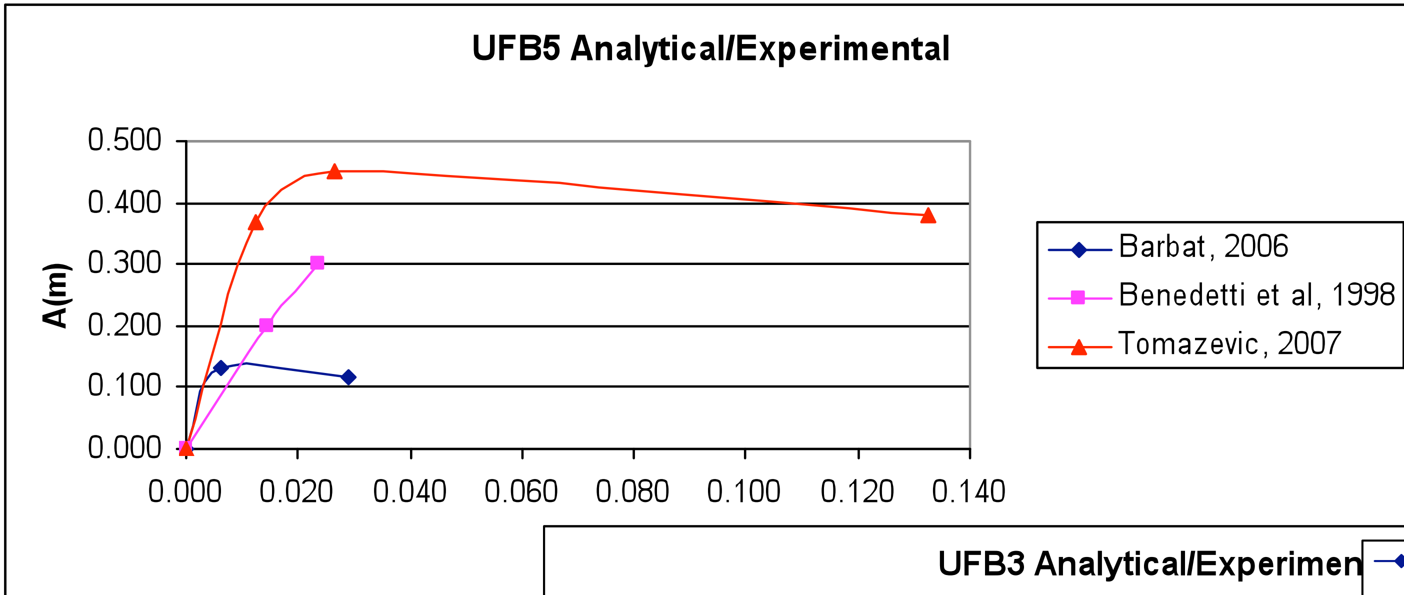
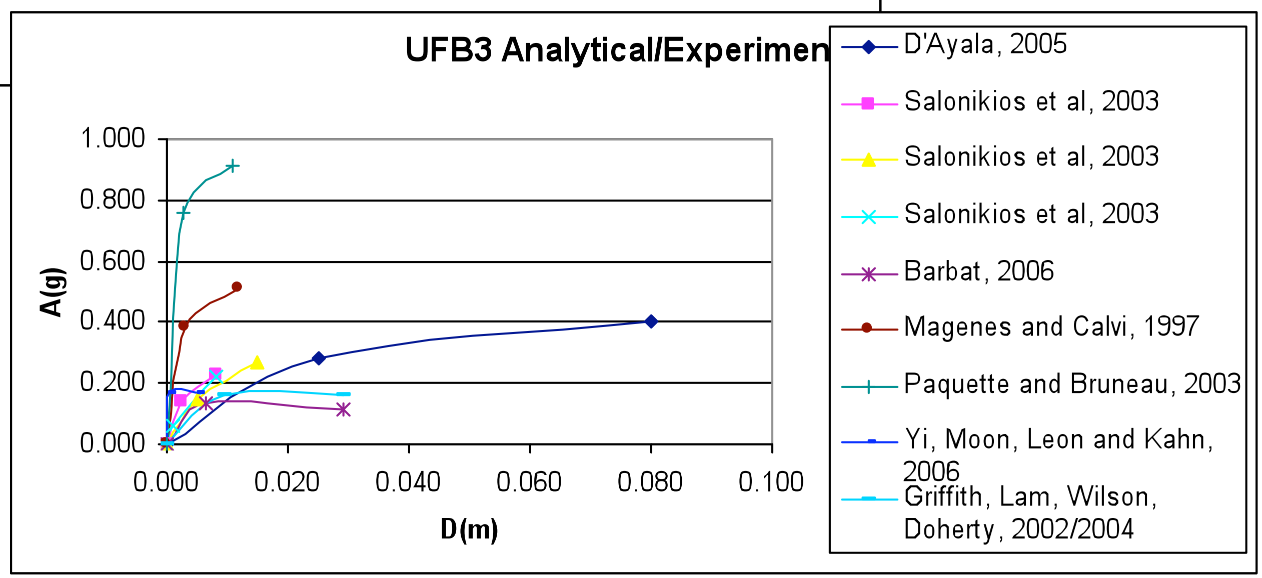
Literature Push-over Curves





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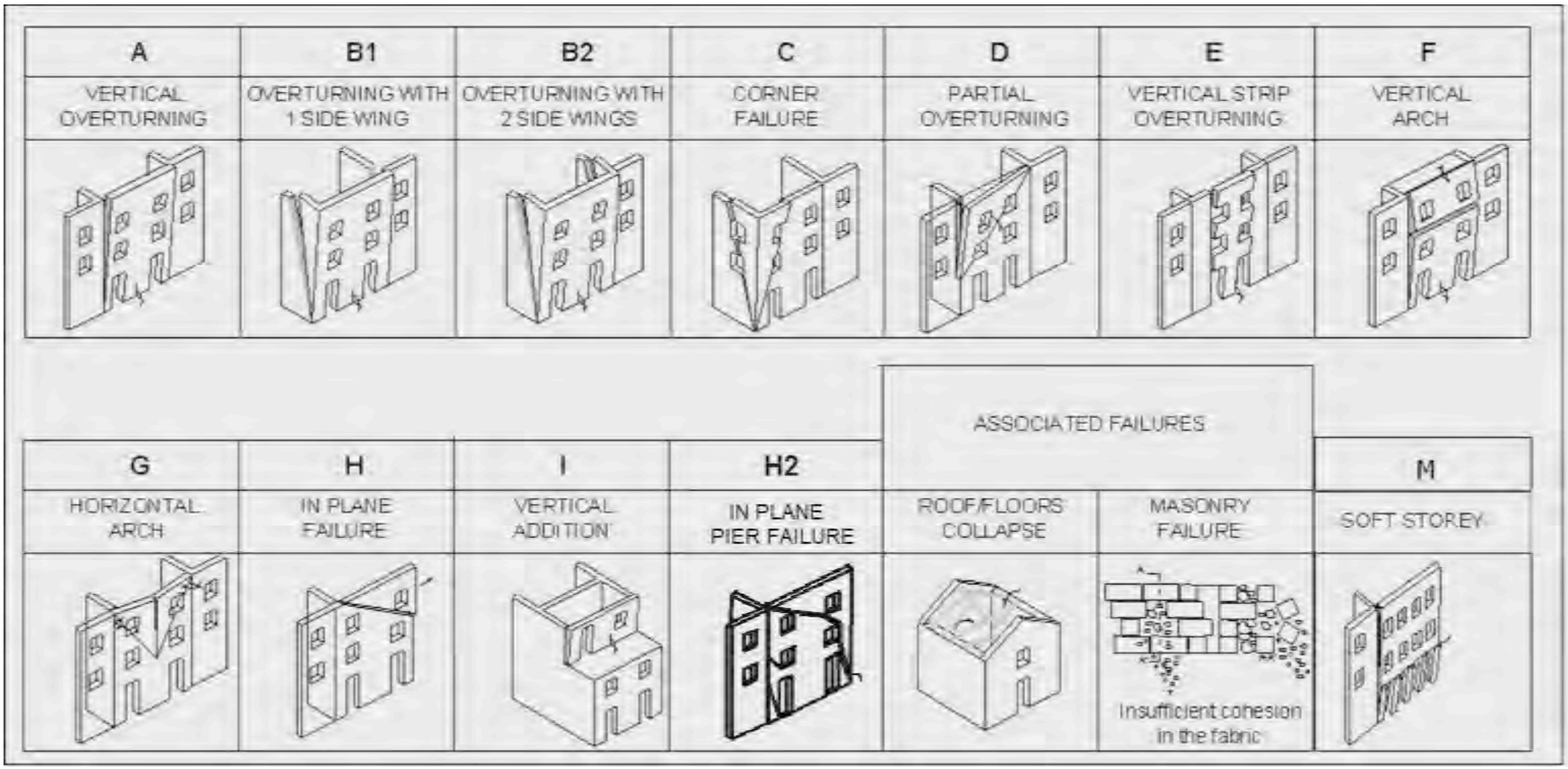
Mechanisms of collapse

- Friction, identification of cracks by sliding or overturning
- Connections with other structural elements



Displacement based assessment

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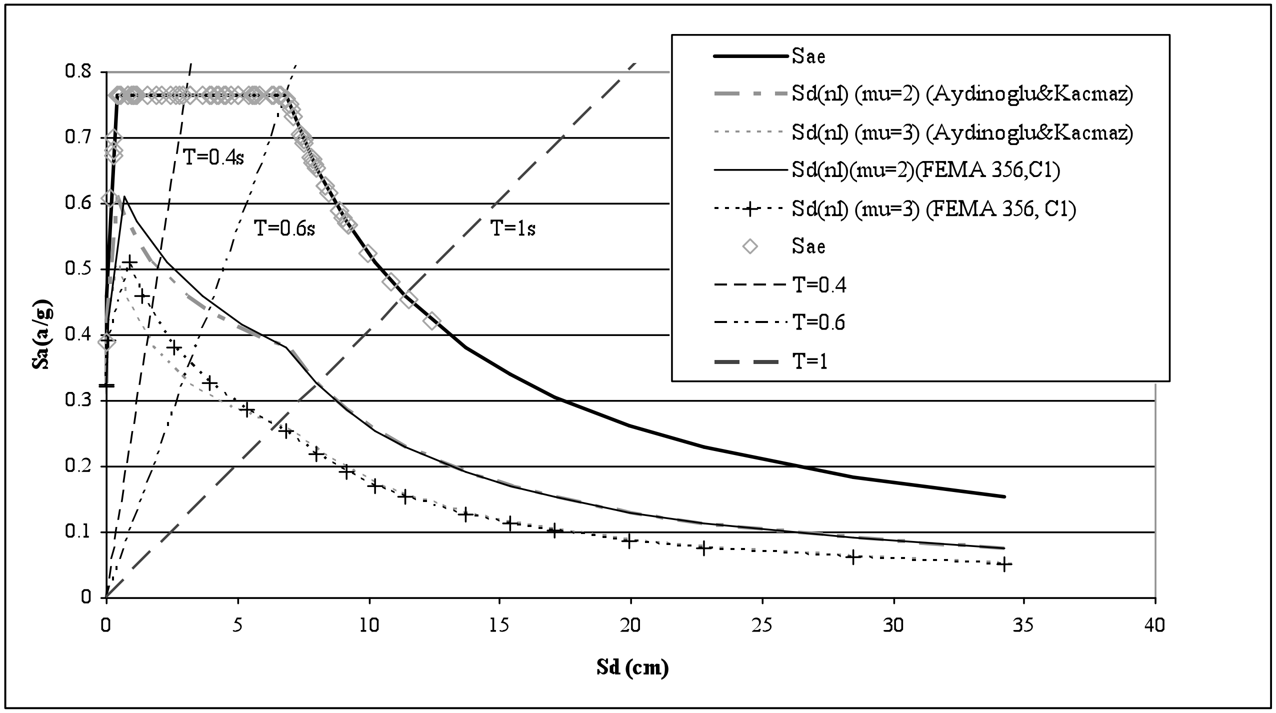
- Choice of appropriate non linear spectrum:
  - Deterministic event ⇒ site specific PGA
  - Ductility ⇒ Strength reduction factor
  - Displacement reduction factors:

$$R = \begin{cases} c_1(\mu - 1)\dfrac{T}{T_g} + 1 & \dfrac{T}{T_g} \le 1 \\ c_1(\mu - 1) + 1 & \dfrac{T}{T_g} > 1 \end{cases}$$

$$S_{dar} = \begin{cases} \left[1 + (R-1)T_g / T\right] / R & T < T_g \\ 1 & T > T_g \end{cases}$$

$$S_{dar} = 1 + \frac{(R_y - 1)^2}{300} + \frac{1}{10T^2} e^{-20\frac{\sqrt{T}}{R_y^2}}$$



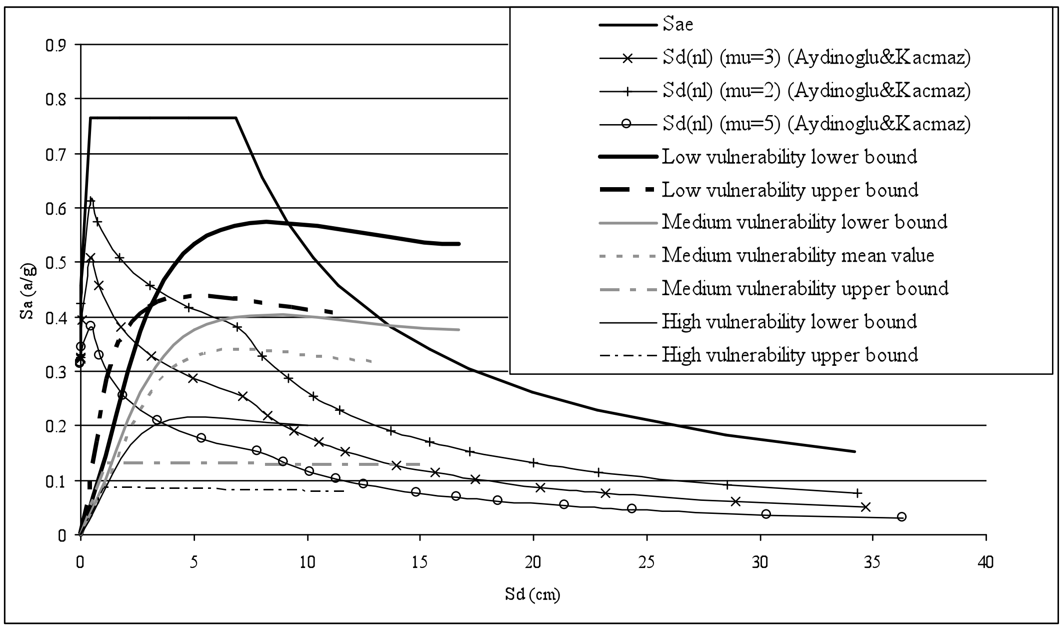
Capacity curves for vulnerability classes

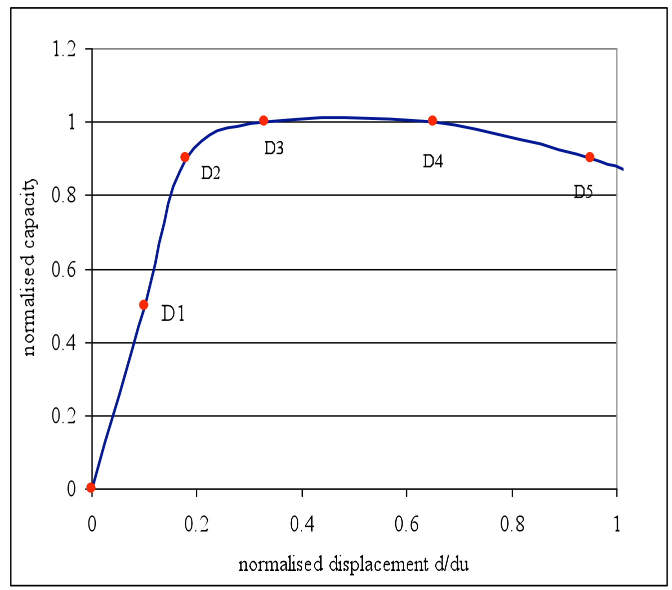
- Define peak strength as collapse load factor
- Define natural period as ratio of effective stiffness and mass
- Define elastic limit displacement as
- Define Δ_u as loss of equilibrium for given mechanism
- Typical ductility range $3 < \mu < 10$

$$a_y = \lambda$$

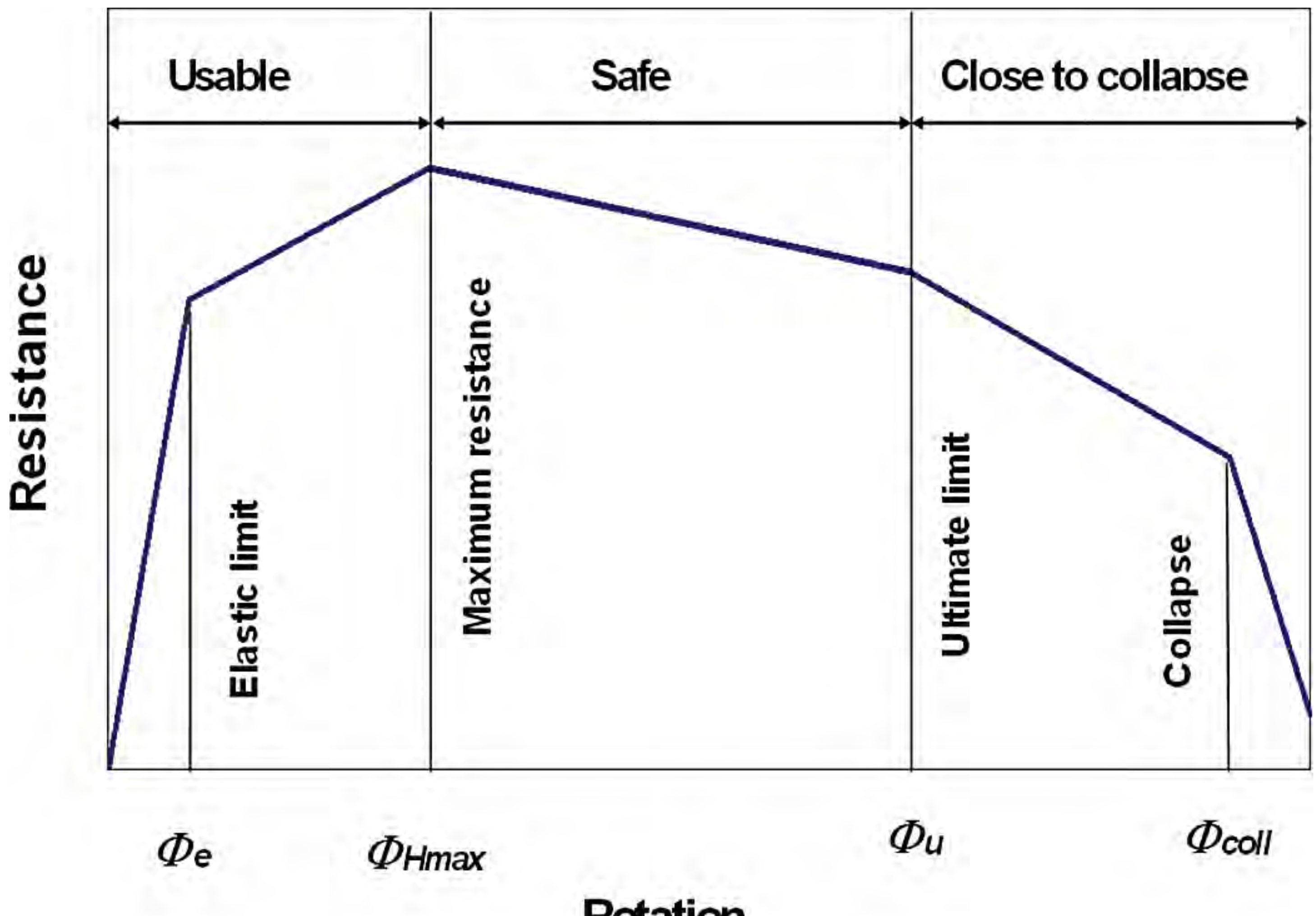
$$T = \sqrt{\frac{m_{eff}}{K_{eff}}}$$

$$\Delta_y = \frac{a_y}{4\pi^2} T^2$$





Tomazevic &Lutman 2004



Italy, Serravalle

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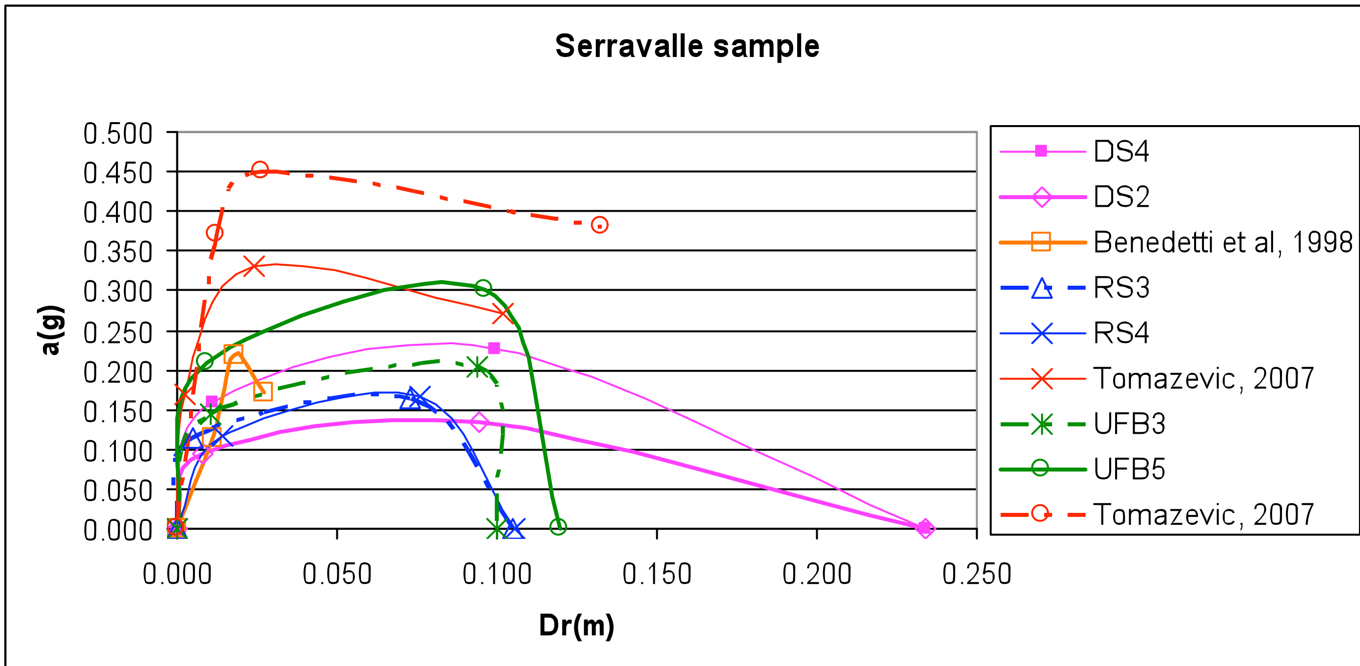
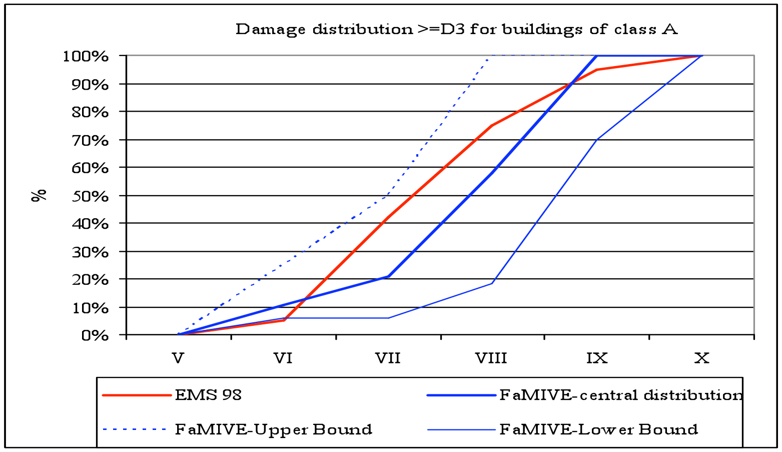
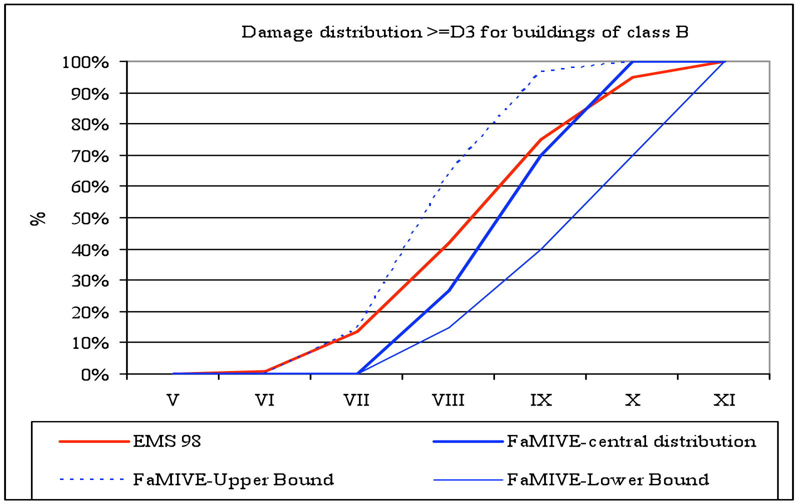
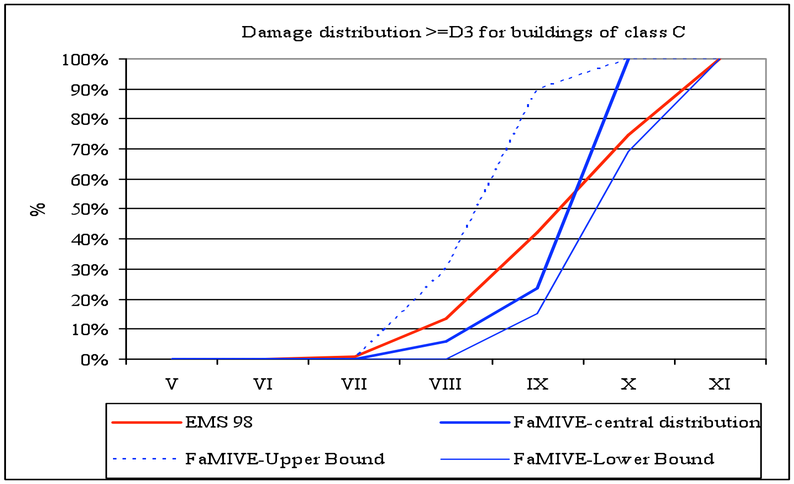


Serravalle, Italy, Correlation of FaMIVE and EMS'98, Stonework

Procedure	EMS98 grade A	EMS98 grade B	EMS98 grade C
VULNUS	High and Very High	Medium	Low and Very Low
FaMIVE	Estreme and High	Medium	Low







Turkey, Fener-Balat

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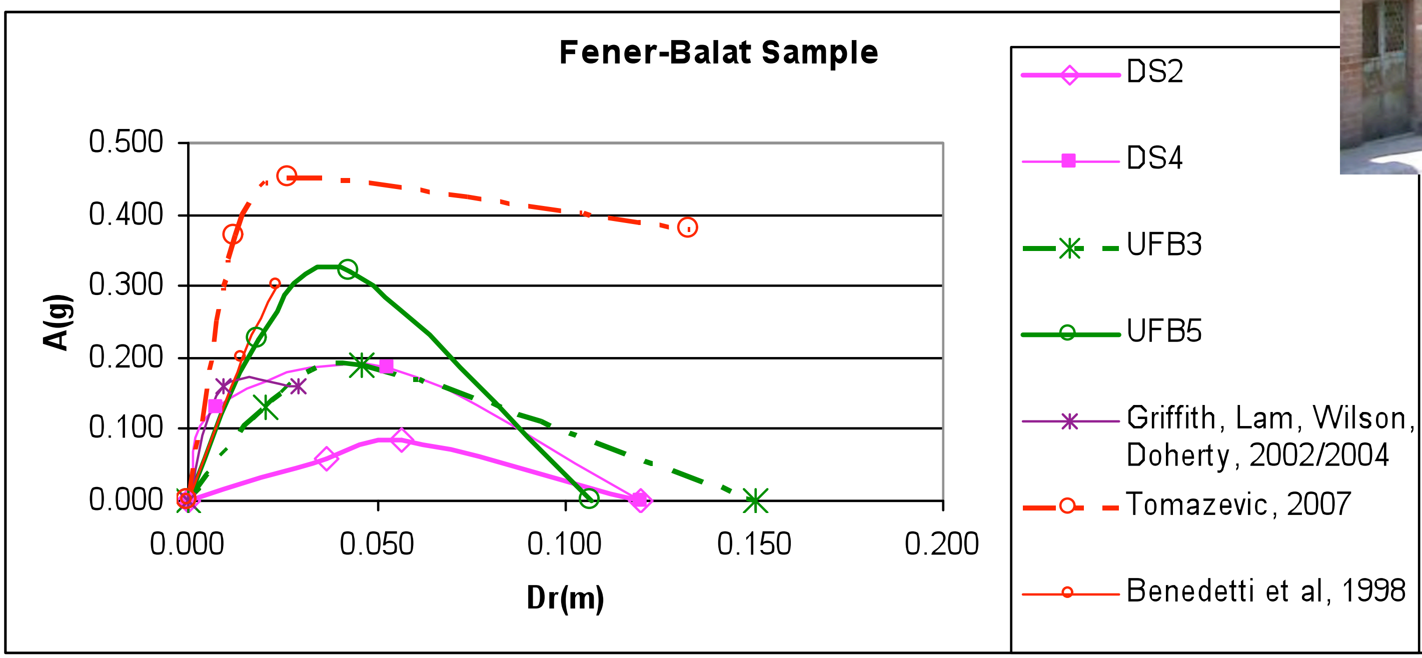

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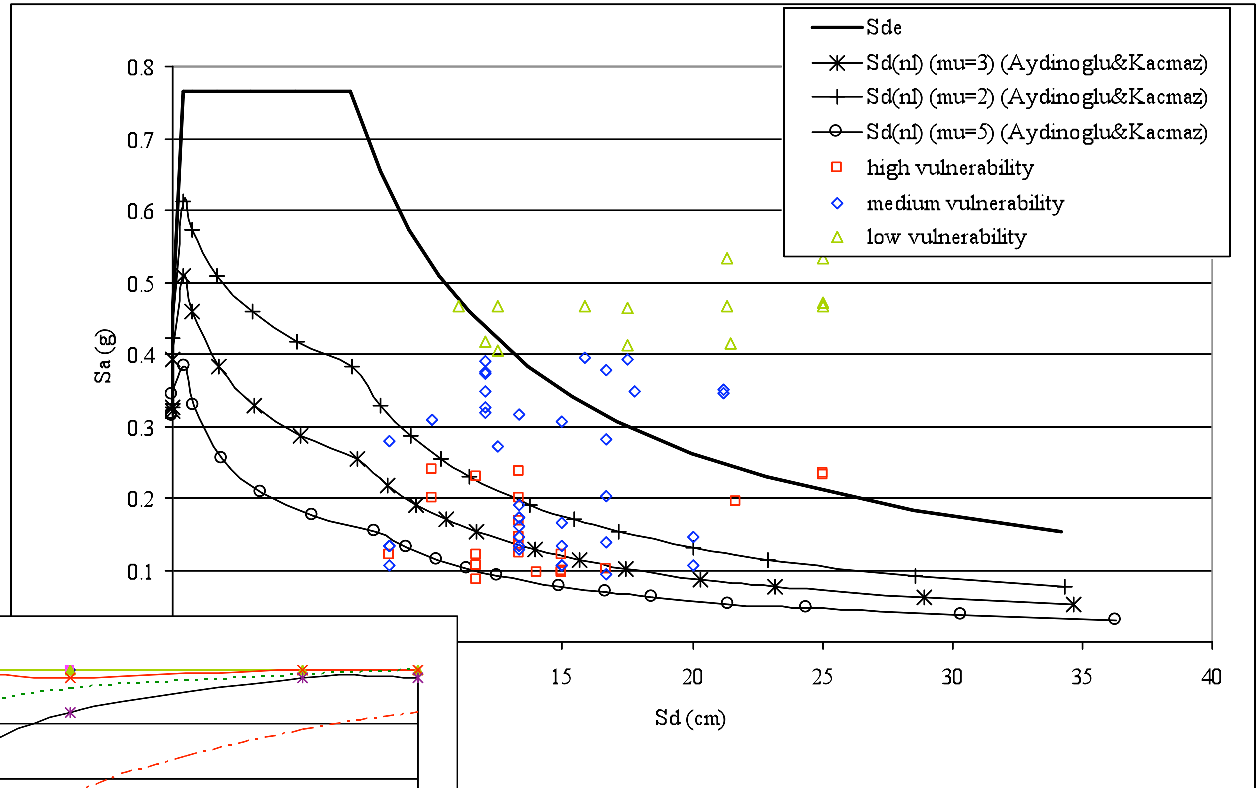
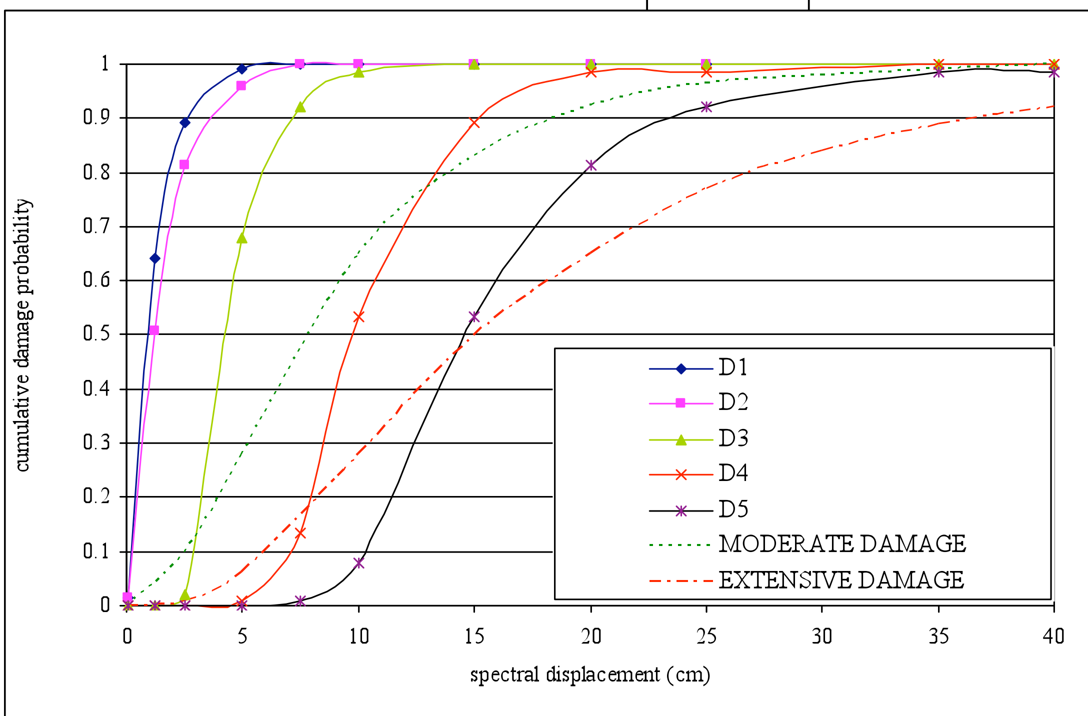
Displacement based damage scenario





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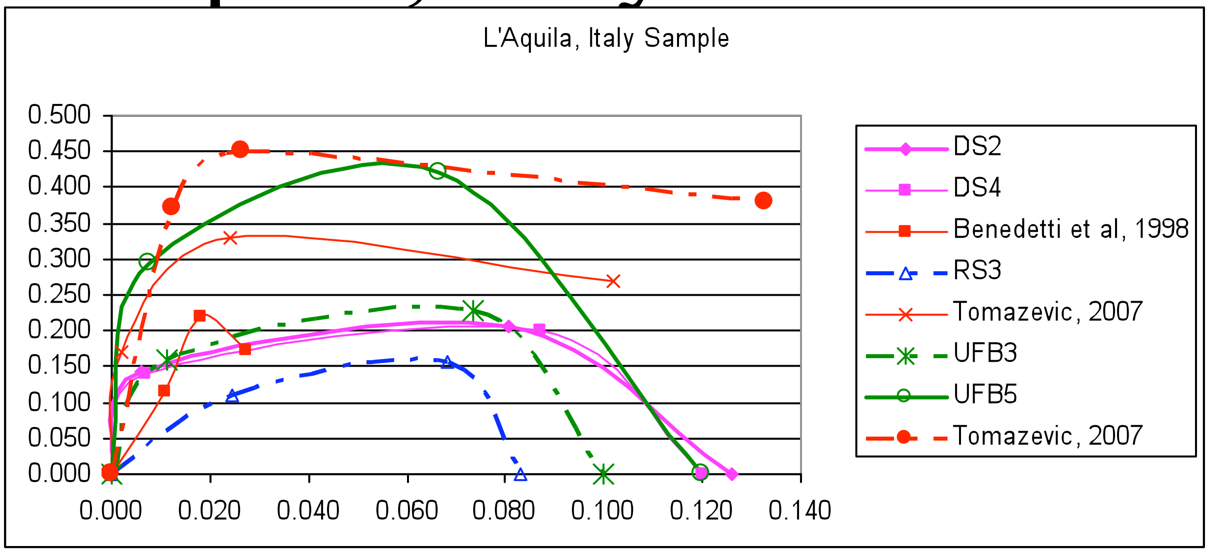
L’Aquila, Italy



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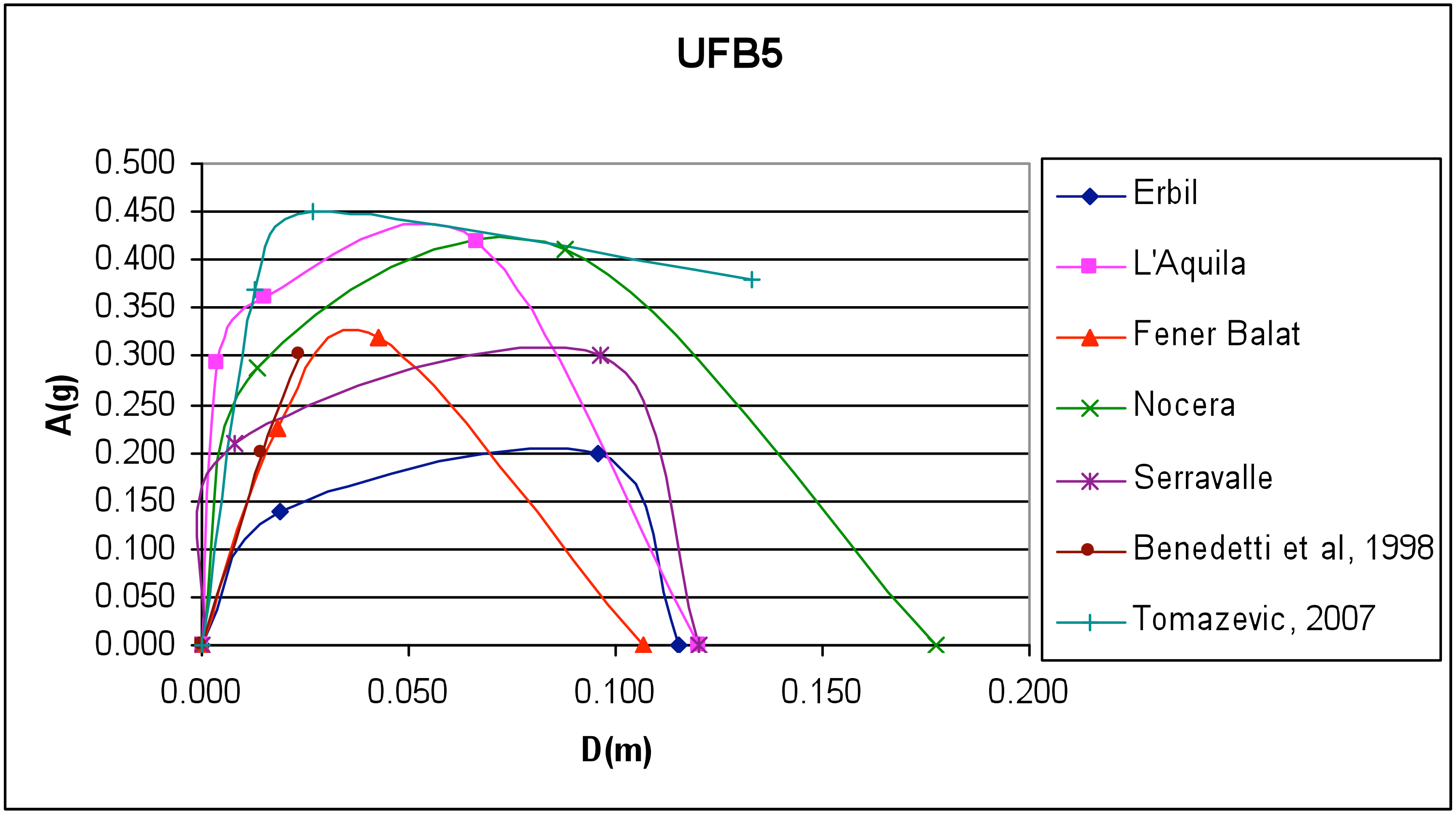
Comparison FaMIVE experimental for UFB5



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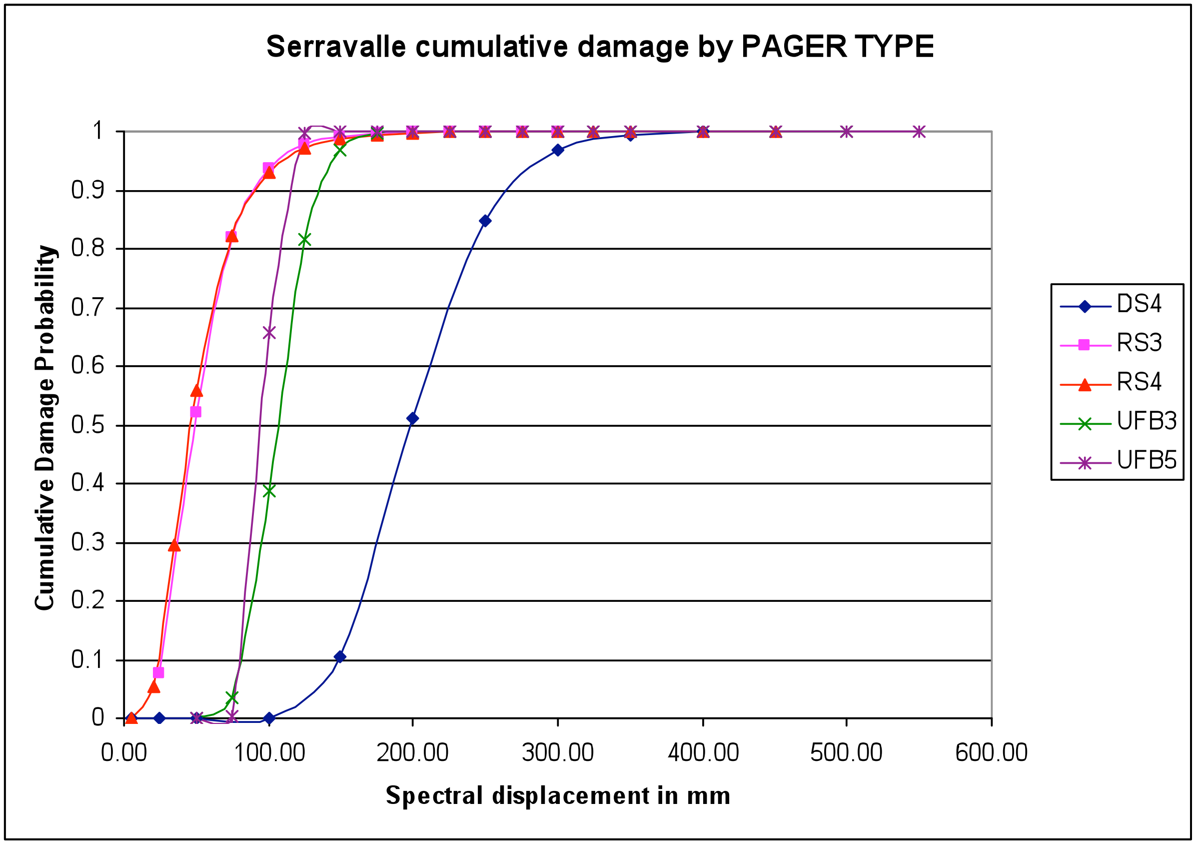
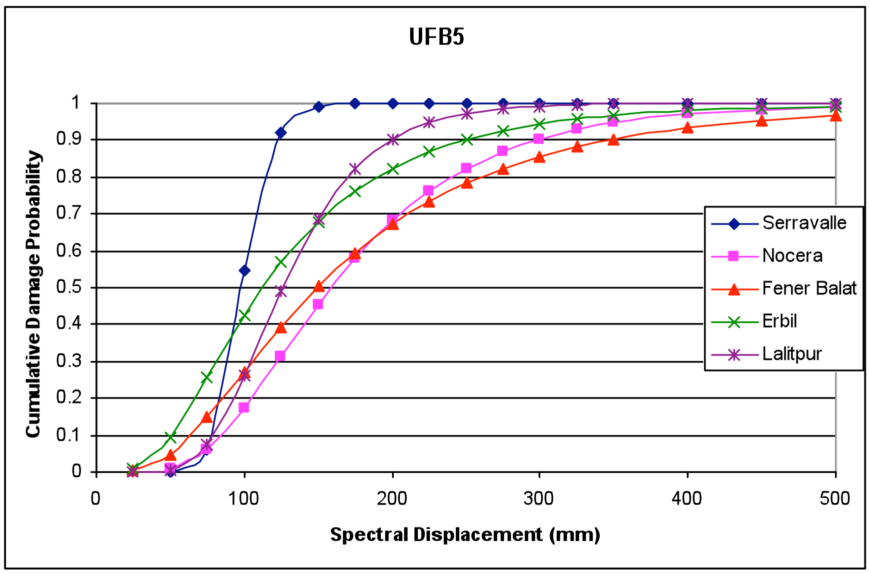
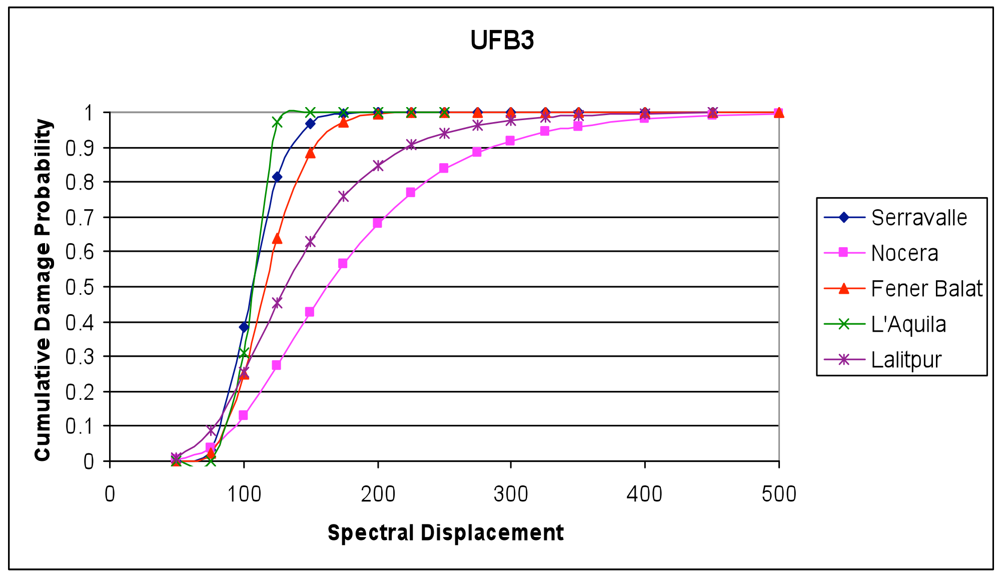
Cumulative total damage probability



Cumulative distribution over the whole sample for UFB3 and UFB5





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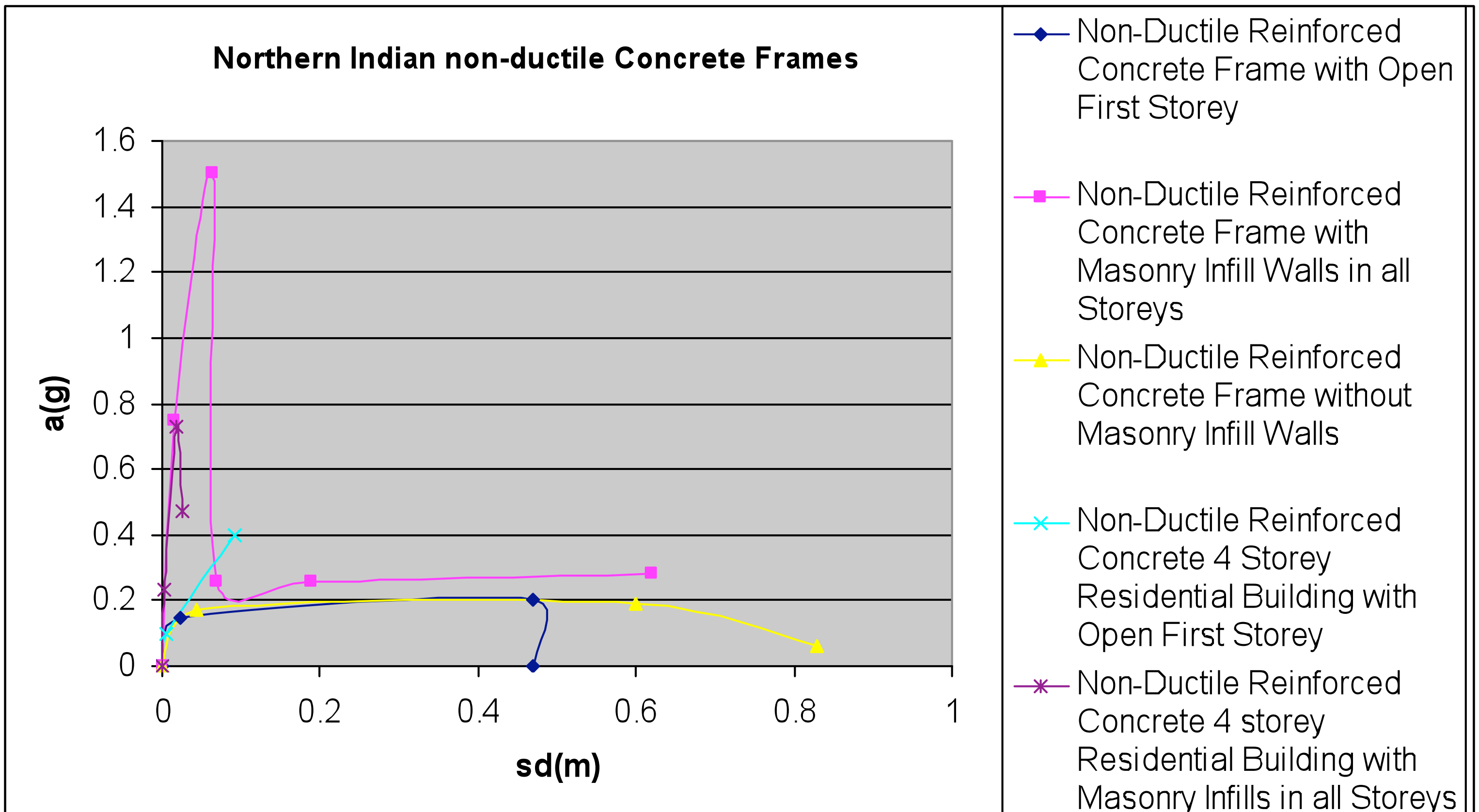
Indian Data Concrete structures C3M



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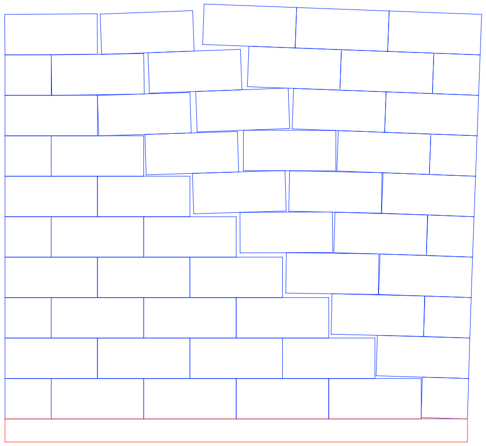
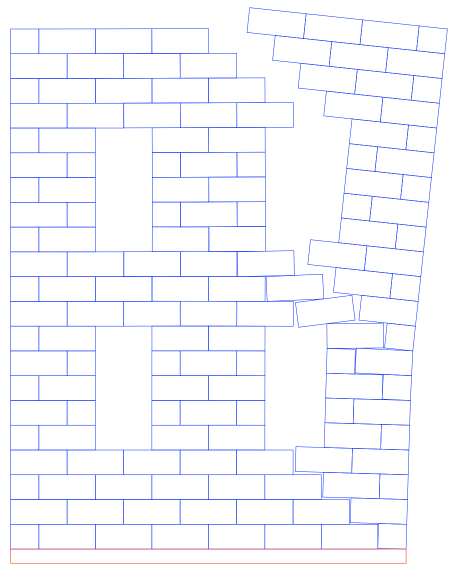
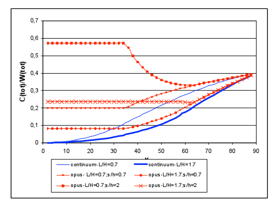
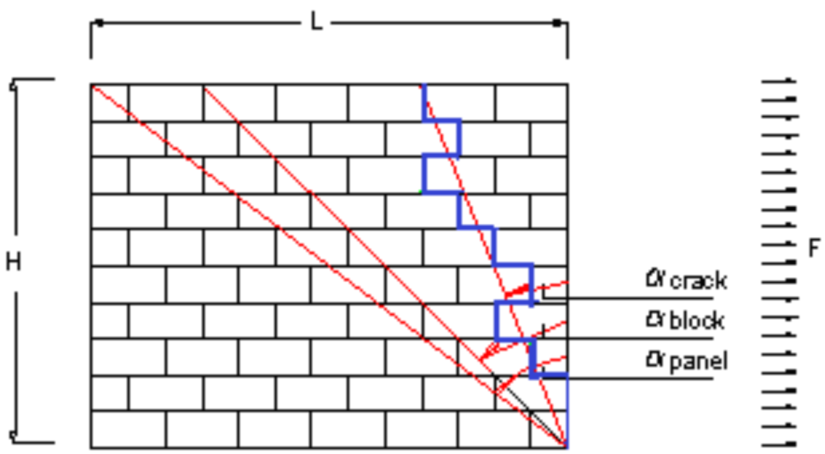
Friction model









Input: electronic survey form

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INSPECTION FORM FOR THE SURVEY OF ORDINARY BUILDINGS

Town: Lalitpur | Build.: 525 | Cad. sheet: | Type of use: R | Date: 11/13/02
Address: | Particel n.: | %of use: 70 | Surveyor:

1 URBANISTIC DATA — reliability ---> H

1-1 Block access and escape routes	g	1-4 Position of building within the block	C
1-2 Shape and composition of the block	6	1-5 Connection of façade to adjacent walls	1C
1-3 Number of buildings in the block	10	1-6 Foundation soil	3

2 GEOMETRIC CHARACTERISTICS OF THE FAÇADE — reliability ---> M

2-1 Facade orientation	E	2-5 Total height of the facade	7.2
2-2 Number of storeys of the building	4	2-6 Presence of gable	0
2-3 Number of storeys of the facade	4	2-7 Gable height (if present)	0
2-4 Length of the facade	3	2-8 Additional corner in the facade	0

3 GEOMETRIC CHARACTERISTICS OF OPENINGS — reliability ---> H

3-1 Number of openings per storey

storeys	4	3	2	1	0
openings	1	1	1	1	

3-2 Average opening dimensions: b 1, h 1.5

3-3 Openings layout: disp. CV, n.s. 4
3-4 Lateral pier: left N, right R
3-5 Height of upper horizontal spandrel: 0.3
3-6 Lintel: type I, Length 1.2, Material W

4 PLAN GEOMETRIC CHARACTERISTICS — reliability ---> M

4-1 Thickness at basis of facade wall	0.45	4-4 N. int. bearing walls // to the facade	1
4-2 Thickness reduction at the top (%)	0.8	4-5 Total length perp. to the facade	7.2
4-3 N. int. bearing walls perp. to facade		4-6 internal wall perp. to back façade	

5 STRUCTURAL CHARACTERISTICS — reliability ---> M

5-1 N. storeys with vaulted structures	0	5-7 Level of maintenance of masonry	M
5-2 Horizontal structure typology	A2	5-8 Connection at edges (left / right)	B / G
5-3 Direction of hor. Structure	O	5-9 Out of verticality	
5-4 Roof structure typology	A3	5-10 pegs/wall plate/timber bands	
5-5 Direction of roof	O		
5-6 Masonry type	B2		
5-6b mortar type	1		

storey	4	3	2	1	0
pegs		4			
wall plate		A2	A2	A2	
timber bands					

6 FURTHER VULNERABILITY ELEMENTS — reliability --->

6-1 Presence of vertical addition	yes	6-3 Specific weight alteration% (+/-)	1
6-2 Dimensions of vertical addition	H 2, t 0.25	6-4 Chimney flue within the façade wall	
6-5 Roof overhanging	L 0.8, no. of struts 6	6-6 Settlement	entity 0.2, position R
6-7 Jetting out	L 0.5, t 0.2, no.of stories 1	6-8 Presence of dalan	L 2.5, no. of pillars 4

7 DAMAGE LEVEL AND MECHANISMS IDENTIFICATIONS — reliability --->

7-1 Mechanisms identification

Class	Type	D. level
A		
B		
C		
D		
E		
F		
G		
H		
I		
L		

Other kind of damage or failure not identified

7-2 Crack pattern description — no of storeys

Horizontal cracks		
Vertical cracks		
Corner cracks		
Diagonal cracks		
Masonry failure		

7-3 Damage extention (% of facade)

7-4 Earthquake damage — Year

Notes

Output for one façade

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TOWN	lalitpur
BUILDING NUMBER	196
POSITION OF BUILDING IN THE BLOCK	c
FAÇADE ORIENTATION	w
NUMBER OF STOREYS OF FAÇADE	5
H tot	12.6
L tot	6
Thicness at basis	0.35
Thickness at top	0.245
Connection at edges	yes
	yes
Roof typology	d
Flors typology	d
masonry quality	B2

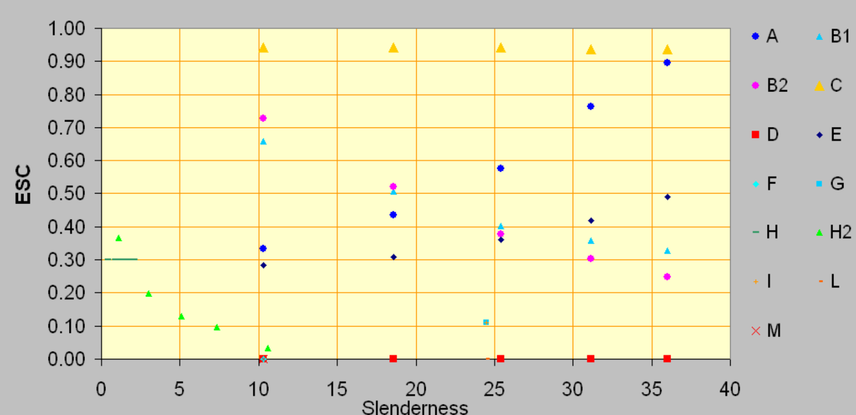
						OUT OF PLANE MECHANISMS						ARCH EFFECT		IN PLANE MECHANISMS		PARTIAL MECHANISMS		DALAN
Storeys	Strengthening devices	Slenderness H/L	slenderness L/t	piers slenderness	Slenderness H/t	A	B1	B2	C	D	E	F	G	H	H2	I	L	M
5	0	0.42	24.49	0.800	10.286	0.33	0.66	0.73	0.94		0.28		0.11	0.30	0.37		---	---
4	0	0.84		3.769	18.581	0.43	0.51	0.52	0.94		0.31			0.3	0.1993757			
3	0	1.26		6.131	25.412	0.57	0.40	0.38	0.94		0.36			0.3	0.1284044			
2	0	1.68		8.494	31.135	0.76	0.36	0.30	0.94		0.42			0.3	0.0961495			
1	0	2.10		26.489	36.000	0.90	0.33	0.25	0.94		0.49			0.3	0.0321408			

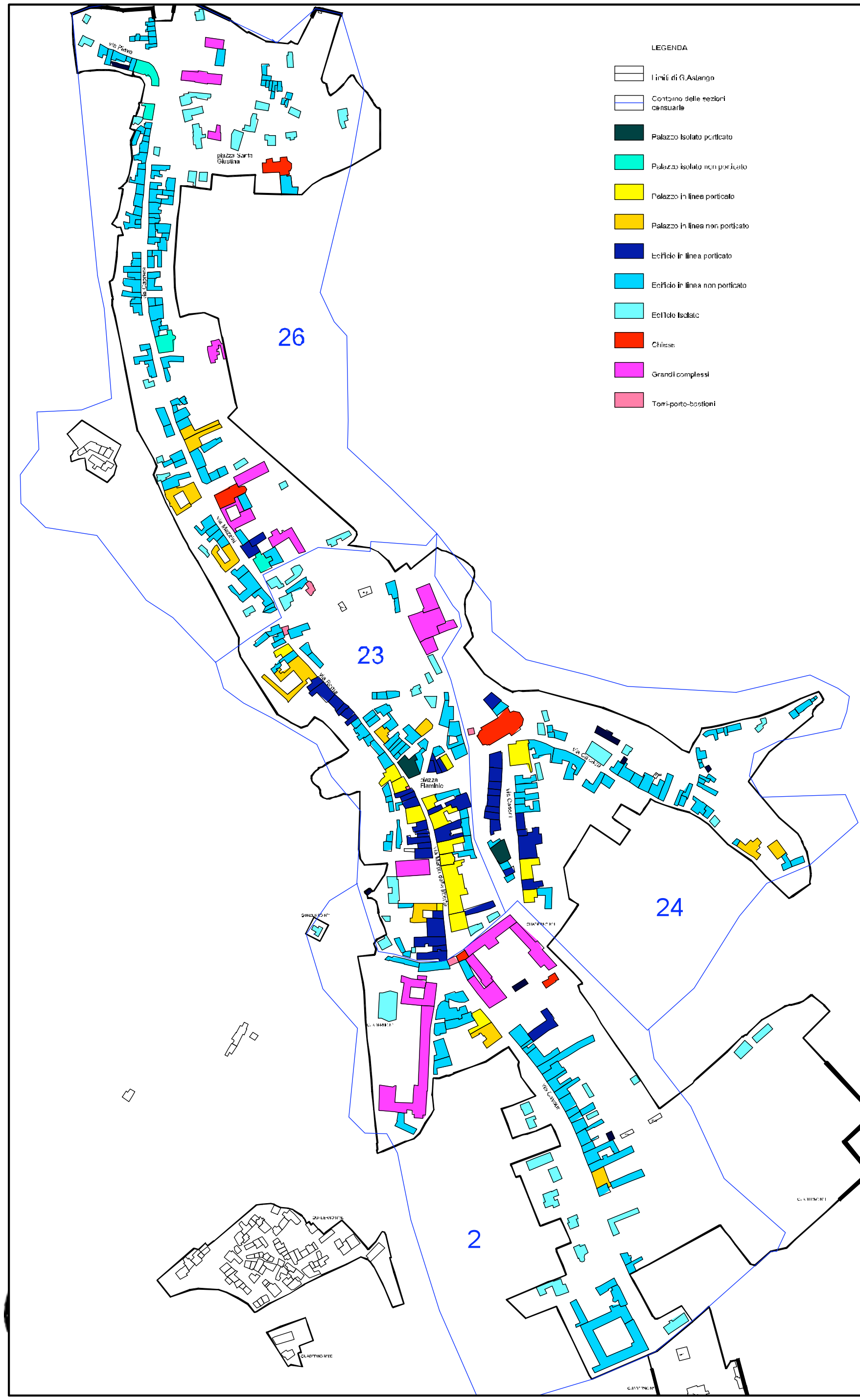
PARTIAL RESULTS

	OUT OF PLANE MECHANISMS			ARCH EFFECT			IN PLANE MECHANISMS			DALAN MECHANISM		
	LOWER BOUND	CENTRAL VALUE	UPPER BOUND	LOWER BOUND	CENTRAL VALUE	UPPER BOUND	LOWER BOUND	CENTRAL VALUE	UPPER BOUND	LOWER BOUND	CENTRAL VALUE	UPPER BOUND
ESC	0.24	0.25	0.26	0.10	0.11	0.12	0.03	0.03	0.03	---	---	---
VULNERABILTY INDEX	4.25	4.04	3.84	9.57	9.09	8.66	32.75	31.11	29.63	---	---	---
DAMAGE INDEX	1.50	1.50	1.50	0.32	0.32	0.32	1.12	1.12	1.12	---	---	---
FAILURE MECHANISMS		B2			G			H2			---	
VULNERABILITY CLASS	MEDIUM	MEDIUM	MEDIUM	MEDIUM	MEDIUM	MEDIUM	VERY HIGH	VERY HIGH	VERY HIGH	---	---	---

FINAL RESULTS

LOWER BOUND	CENTRAL VALUE	UPPER BOUND	
0.03	0.03	0.03	ESC
32.75	31.11	29.63	VULNERABILTY INDEX
1.12	1.12	1.12	DAMAGE INDEX
	H2		FAILURE MECHANISMS
VERY HIGH	VERY HIGH	VERY HIGH	FINAL VULNERABILITY
	5		number of storeys
	62		crack angle
	---		NOTES
	---		MASONRY FABRIC
	---		ROOF FAILURE
	failure of floors		
	4	n.storeys	FLOORS FALIURE





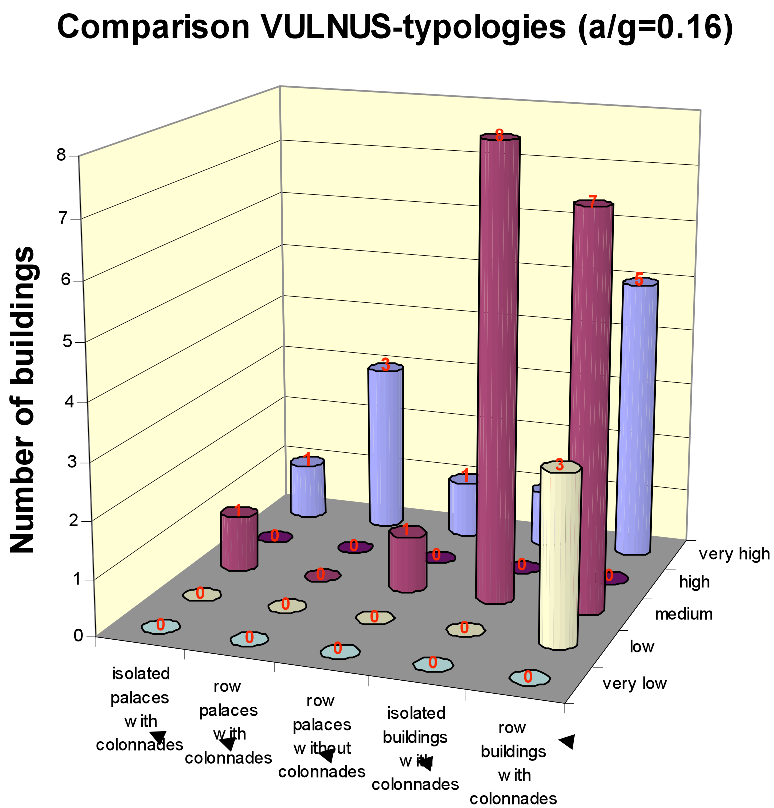
Earthquake Engineering Research Institute

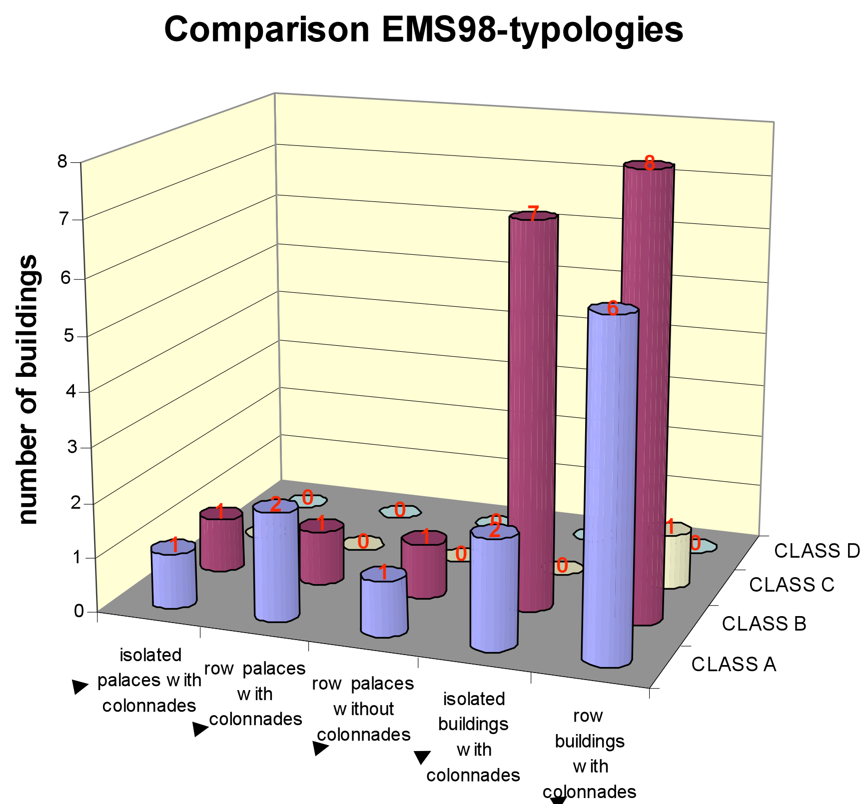
CLASSIFICATION OF BUILDING TYPOLOGIES in Vittorio Veneto

Serravalle

Earthquake Engineering Research Institute

VULNERABILITY (VULNUS) and EMS 98 VULNERABILITY Class for different Typologies





Conclusions

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•Traditional buildings are generally classified as class B of the EMS98 with subset in class A when structural deficiencies are present, and subset in class C when strengthening is effective.
•It is feasible to use a consistent structural approach to define fragility curves for force based vulnerability assessment by typologies.
•It is also feasible to derive a displacement based vulnerability analysis using ultimate displacement capacity and demand. This highly relies on accurate estimate of ductility.
•Such analyses can be used to identify cluster of buildings with deficiency in need of upgrading
•Vulnerability of the single building depends on several variables but most important are elements directly enhancing or reducing vulnerability and allowing or preventing collapse mechanisms, hence direct observation is essential
•Accurate analysis of the structural details in a given building sample allows to identify indigenous strengthening techniques which are effective and organic
• Comparison with EMS98 and HAZUS curves show that FAMIVE classes are more homogenous and do not necessarily respond to normal distribution models.
• For the brickwork good constructional details correlation is shown among samples in Nepal and Turkey, for instance, providing some scope for generalisation.
• For stone masonry performance is more strictly related to fabric quality hence more difficult to generalise.