

DEVELOPMENT OF VULNERABILITY CURVES OF KEY BUILDING TYPES TO DIFFERENT HAZARDS IN THE PHILIPPINES

B.M. Pacheco, J.Y. Hernandez Jr., E.A.J. Tingatinga, P.P.M. Castro, F.J. Germar, U.P. Ignacio, M.C.L. Pascua, L.R.E. Tan, I.B.O. Villaiba, D.H.M. Aquino, R.E.U. Longalong, R.N. Macuha, W.L. Mata, R.M. Suiza, M.A.H. Zarco

PALIWANAGAN SA UP DILIMAN
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National Institute of Physics
University of the Philippines Diliman



Typhoon "UNDANG" (Agnes) Nov 3-6, 1984 230 kph 895 deaths
Php 1.9 B damage

Typhoon "MILENYO" (Xangsane) Sep 25-29, 2006 150 kph (Gust 160 kph)
45 deaths Php 1.251 B damage

Typhoon "REMING" (Durian) Nov 28-Dec 1, 2006 281 kph (Gust 320 kph)
709 deaths 2,190 injured 753 missing Php 10.89 B damage



Pivotal Question!

- Will you, as private citizens, take steps to increase the capacity of your houses or buildings if you knew beforehand that they are at risk to a particular hazard? Will you reduce (if not minimize) the risk?
- Are our government officials willing to invest resources in improving the condition of existing government infrastructure (buildings, bridges, elevated roads and railways, airports, etc.) if they knew beforehand that these are vulnerable to damage?

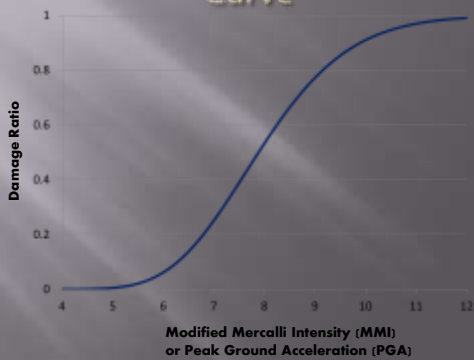
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Definition

- **VULNERABILITY** – the degree of loss to a given element at risk resulting from a given level of hazard (e.g. ground motion intensity, wind speed, depth of inundation). It is defined as the ratio of the cost of damage to the cost of structure and finishes, on a scale of 0 to 1 (or 0 to 100%)
- **VULNERABILITY CURVE** – a plot of the vulnerability of a structure vs. the level of hazard.

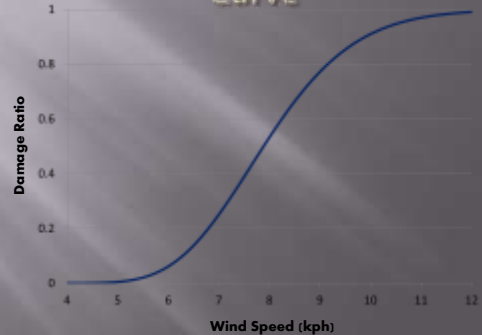
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Sample Earthquake Vulnerability Curve

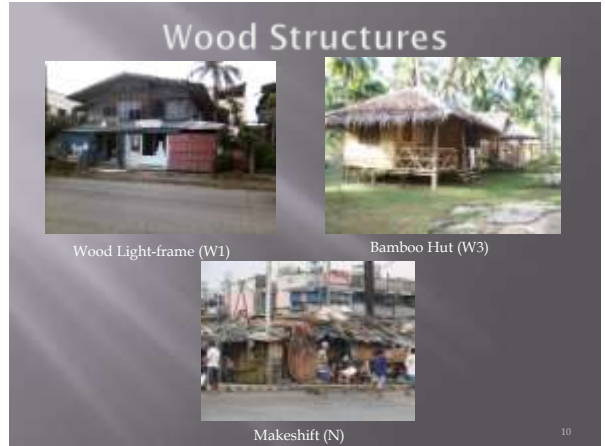
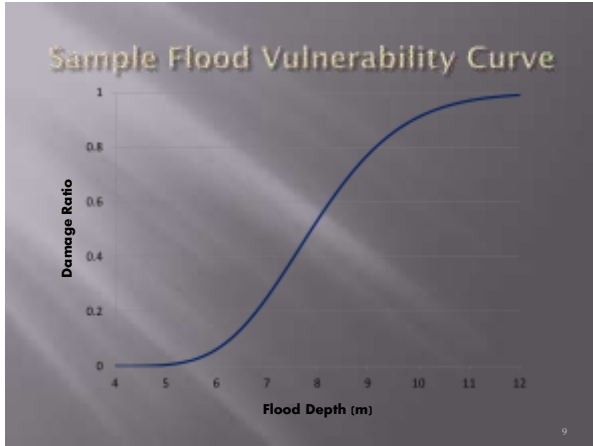


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Sample Severe Wind Vulnerability Curve



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Steel Moment Frames (S1)



Steel Moment Frames (S1)

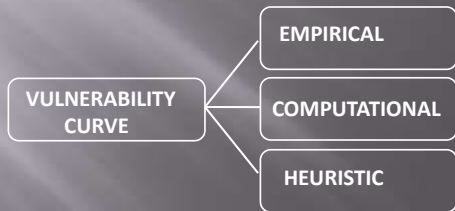


Steel Frames with Cast-in-place Concrete Shear Walls (S4)

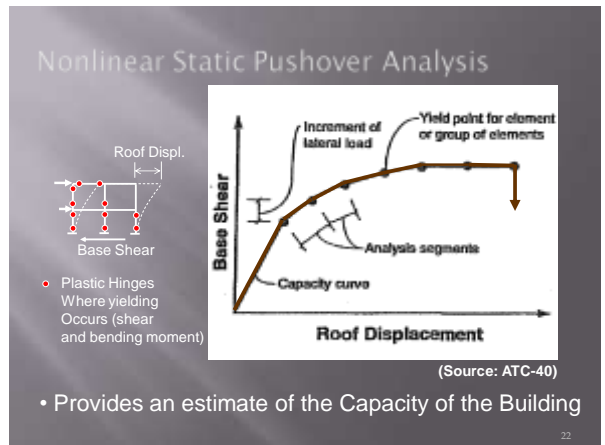
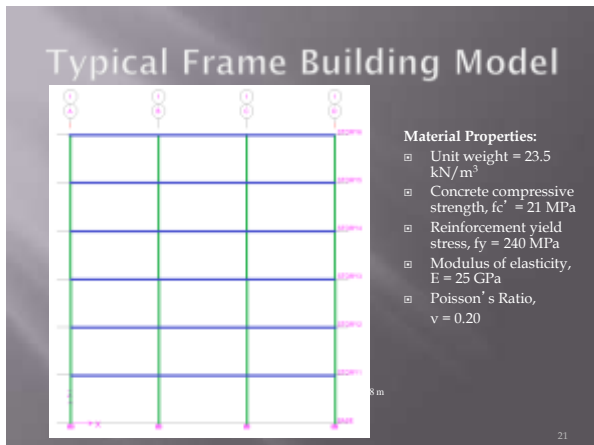
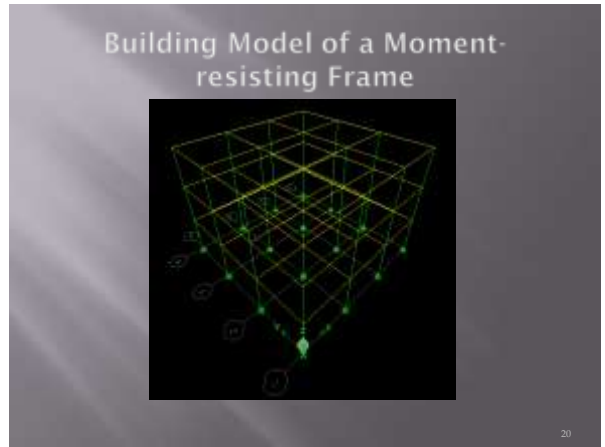
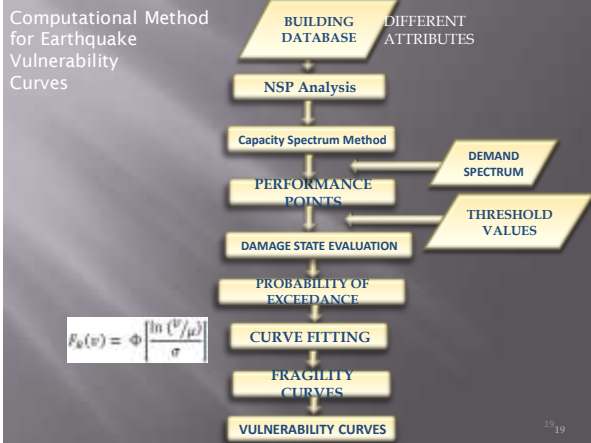
Building Group	Building Type	Structure Type or Description	Seis. Type Code (for IBC)	Seis. Type or Sub-Type Code (for IBC)	Seis. Type or Sub-Type Code (for IBC)
WOOD	WT*	Wood light frame	WT*	WT*	WT*
	WT	Wood	WT	WT	WT
	M	Mass-timber	M	M	M
MASONRY	MW*	Concrete hollow blocks with wood or light metal framing walls	MW*	MW*	MW*
	CM	Concrete hollow blocks	CM	CM	CM
	UM*	Unreinforced masonry bearing walls	UM*	UM*	UM*
	CM*	Reinforced concrete masonry bearing walls	CM*	CM*	CM*
CONCRETE	EW*	Reinforced concrete moment frames with wood or light metal	EW*	EW*	EW*
	CF*	Reinforced concrete moment frames	CF*	CF*	CF*
	CH	Concrete shear walls and frames	CH	CH	CH
	PCJ	Precast frame	PCJ	PCJ	PCJ
	SC*	Steel moment frame	SC*	SC*	SC*
STEEL	ST*	Light metal frame	ST*	ST*	ST*
	SF	Steel frame with cast-in-place concrete shear walls	SF	SF	SF
	SF	Steel frame with cast-in-place concrete shear walls	SF	SF	SF

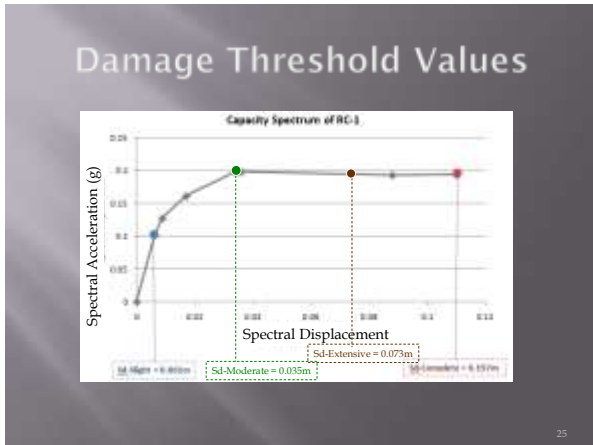
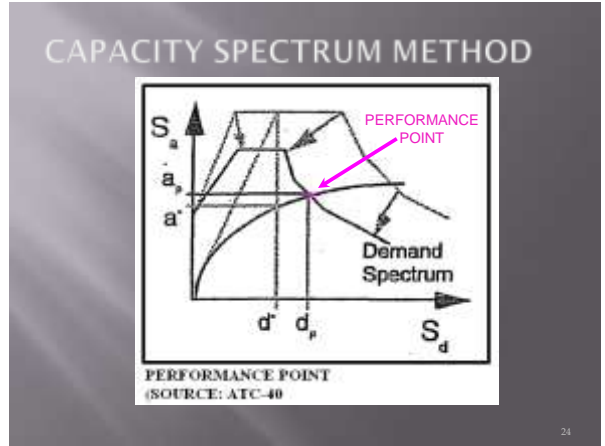
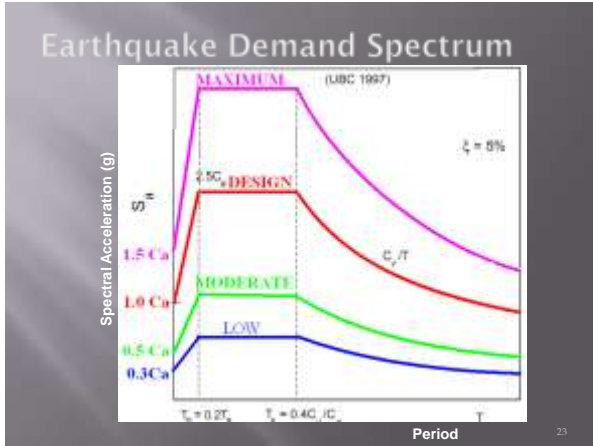
Building typology

Methods for Deriving Vulnerability Curves



Computational Methods



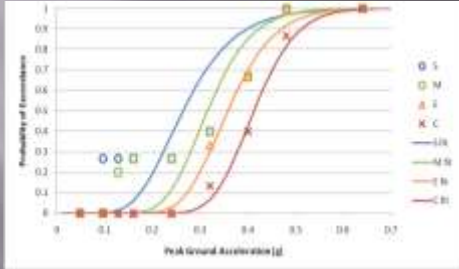


Damage Probability Matrix

PGA	Number of Models Exceeding a Damage State				Probability of Exceeding a Damage State			
	Slight	Moderate	Extensive	Complete	Slight	Moderate	Extensive	Complete
0.048	0	0	0	0	0	0	0	0
0.096	4	0	0	0	0.267	0	0	0
0.128	4	3	0	0	0.267	0.2	0	0
0.16	4	4	0	0	0.267	0.267	0	0
0.24	4	4	0	0	0.267	0.267	0	0
0.32	6	6	5	2	0.4	0.4	0.333	0.133
0.4	10	10	10	6	0.667	0.667	0.667	0.4
0.48	15	15	15	13	1	1	1	0.867
0.64	15	15	15	15	1	1	1	1

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Fragility Curves



- Using the fitted fragility curves, the vulnerability curves can be derived

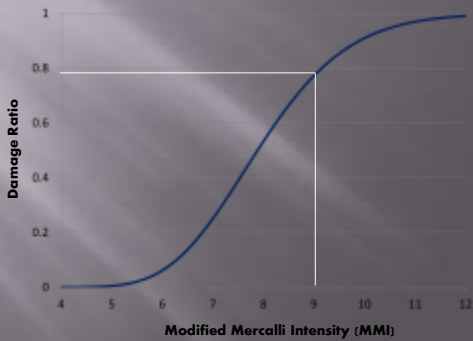
$$P_{v,GMI} = \sum D_i * P_{F,i}$$

- Where,
- $P_{v,GMI}$ = damage probability at a certain GMI.
 - $P_{F,i}$ = Probability of a structure being in a certain damage state i (from Fragility Curves).
 - D_i = Damage index for a certain damage state i from HAZUS.

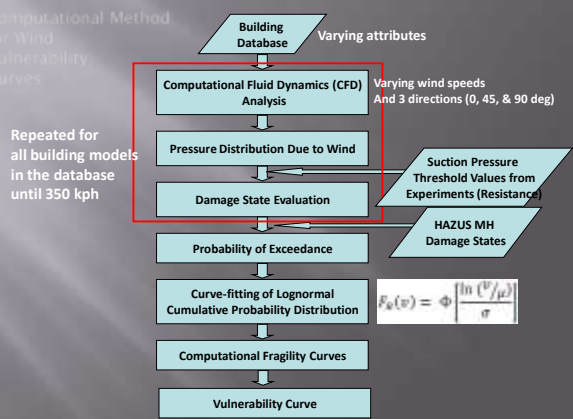
Damage States	Damage Ranges (%)	Damage Indices (%)
None	0-2	1
Slight	2-10	6
Moderate	10-50	30
Extensive	50-100	75
Complete	100	100

Damage index at different damage states

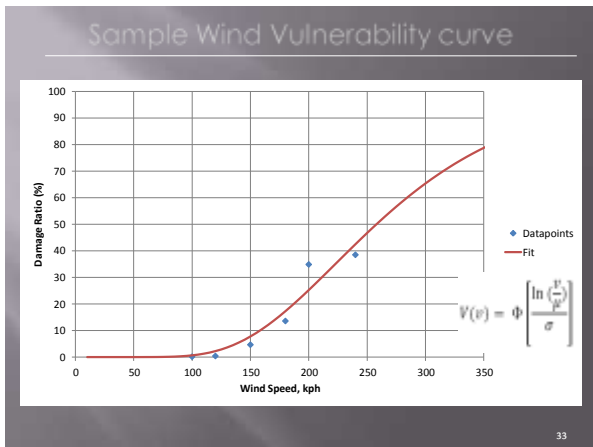
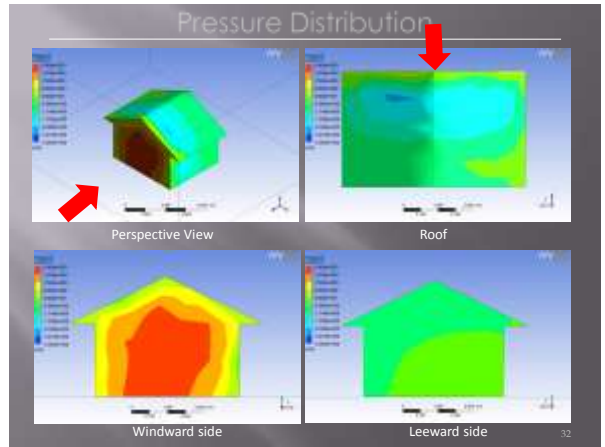
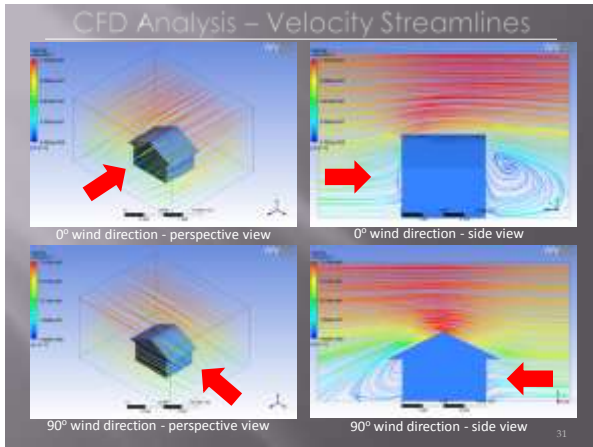
Earthquake Vulnerability Curve



Computational Method for Wind Vulnerability Curves



Repeated for all building models in the database until 350 kph



Heuristic Method

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Survey form used for Earthquake Vulnerability Curves

Name: _____
 Affiliation: _____
 Designation: _____
 (Consultant) _____ (Project Manager) _____ (Designer) _____ (Faculty Member) _____
 Other's Please specify: _____
 Work experience at designation (number of years): _____
 Specialization: ___ Low-rise RC ___ High-rise RC ___ Low-rise Steel ___ High-rise Steel ___ Other: _____

Survey of Extent of Damage for Different Building Types Under Different Ground Motion Intensities (GMI)

Our team from the CPJ School of Engineering is in the development of fragility curves for different

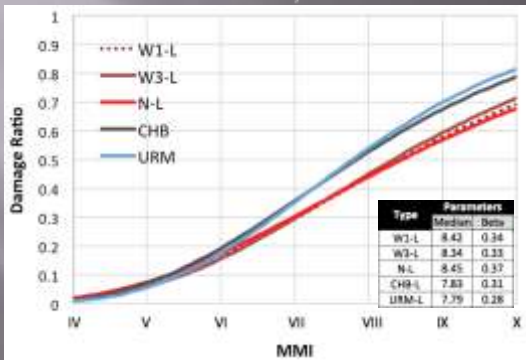
W1-L Building Type: Wood Frame with Area < 100 sq. m. (2-3 stories)
 These are typically single or multi-family dwellings. The structural members of these buildings is repetitive framing by wood joists or studs or wood stud walls. Such are light and narrow one story floor of these buildings, especially the single-family residential, are not engineered but constructed in accordance with "conventional construction" practices of building codes. Hence, they usually have the components of a lateral force-resisting system such as shear walls, braced frames, central cores or braced frames, etc. The components are roof panels and floor slabs may be sheathed with wood, plaster or Masonry sheathing, walls are sheathed with sheath, plaster, stone, plaster, gypsum board, concrete block, or Masonry or masonry partitions walls sheathed with plaster or gypsum board.

Damage Level	V		VI		VII		VIII		IX		Conf. Level	
	0.05g-0.10g	0.10g-0.15g	0.15g-0.20g	0.20g-0.25g	0.25g-0.30g	0.30g-0.35g	0.35g-0.40g	0.40g-0.50g	0.50g-0.60g			
1	34	20	38	60	100	100	70	26	30	60	100	100
2	10	5	10	15	30	80	70	5	10	20	50	80
3	8	3	40	60	100	100	100	70	80	85	95	100
4	3	2	10	20	30	35	40	35	35	45	50	50
5	2	1	10	20	30	40	40	30	15	20	25	30
6	1	1	5	10	20	30	30	20	10	15	20	20
7	1	1	5	10	20	30	30	20	10	15	20	20
8	1	1	5	10	20	30	30	20	10	15	20	20
9	1	1	5	10	20	30	30	20	10	15	20	20
10	1	1	5	10	20	30	30	20	10	15	20	20
11	1	1	5	10	20	30	30	20	10	15	20	20
12	1	1	5	10	20	30	30	20	10	15	20	20
13	1	1	5	10	20	30	30	20	10	15	20	20
14	1	1	5	10	20	30	30	20	10	15	20	20
15	1	1	5	10	20	30	30	20	10	15	20	20

Sample Responses

ID	Yrs	W1-L					W3-L					N-L					
		V	VI	VII	VIII	IX	V	VI	VII	VIII	IX	V	VI	VII	VIII	IX	
A	35	5	10	15	30	40	5	15	30	40	10	5	15	30	40	10	
B	1	0	5	15	30	60	0	10	20	40	60	60	30	30	10	60	
D	10	0	5	10	20	20	0	0	5	10	10	10	15	20	30	100	
G	27	5	10	20	35	45	10	10	10	30	40	15	15	15	25	30	
H	1	20	30	40	55	67	25	35	45	58	70	25	33	43	53	65	
L	4	5	25	60	90	95	6	30	75	95	100	4	25	70	90	90	
Q	11	3	10	20	30	50	10	12	14	16	20	3	50	60	70	90	
S	6	2	5	15	30	50	2	16	30	50	70	3	20	30	60	85	
T	1	0	5	10	25	25	0	0	0	5	10	0	0	0	0	1	
V	21	20	30	60						40	60				40	60	
W	20	5	10	20	30	50	2	5	10	25	30	5	10	15	20	40	
X	1	34	20	38	60	100	100	70	26	30	60	100	100	70	26	30	60
Z	10	5	10	15	30	80	70	5	10	20	50	80	80	5	10	30	40
3	8	3	40	60	100	100	100	70	80	85	95	100	100	70	80	85	95
5	3	10	20	30	35	40	35	35	45	50	60	20	30	40	45	50	
6	20	10	20	30	40	60	70	5	10	15	20	25	30	40	50	100	
7	11	5	20	40	60	80	100	5	20	40	60	80	5	20	40	60	
8	20	10	20	40	50	100	70	10	30	50	70	100	80	20	40	60	
9	6	75	78	85	85	90	80	83	86	89	90	90	81	84	87	89	
10	2.5	5	11	25	34	42	40	25	33	39	43	53	53	20	28	32	
11	2	10	25	40	60	80	60	25	30	50	80	80	20	30	45	70	
12	2	4	9	20	30	50	60	5	9	20	30	50	7	9	18	40	
13	3			100						100					100		
14	2	10	10	10	10	30	80	10	10	20	30	80	10	20	20	30	
15	2	7	10	12	15	20	40	8	10	15	18	20	40	15	18	20	

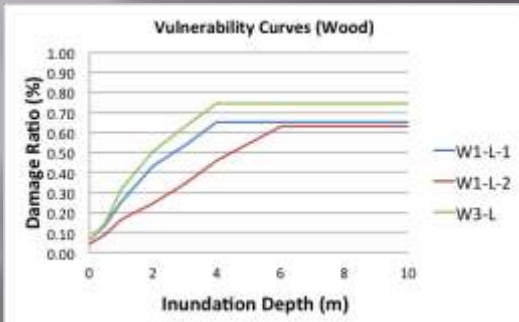
Sample Heuristic Earthquake Vulnerability Curves



Sample Survey Form used for Flood Vulnerability Curve

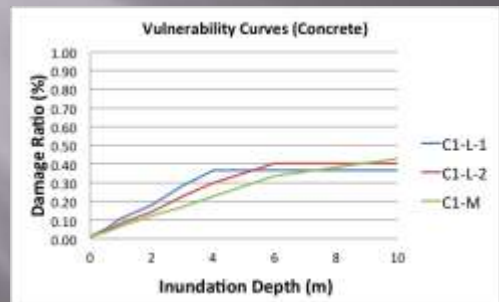
Depth	0 m	0.5 m	1 m	2 m	3 m	4 m	6 m	10 m
Damage Ratio (%)	-----	-----	-----	-----	-----	-----	-----	-----

Vulnerability Curves for Wood Structures



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Vulnerability Curves for Concrete Structures



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Empirical Method

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Methodology used for Empirical Earthquake Vulnerability Curve

1. Collection of **building damage observations** due to recent/historical earthquakes from published papers, field reports, etc.
(Obtained the report from PHIVOLCS and GA last November 12, 2012)
2. Classification and **extraction of useful data** for the building types.
 - ❖ For CHB or MWS, key phrases like "concrete hollow blocks", "residential house" (without description if it is reinforced concrete), and "masonry" were used as identifiers.

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Methodology

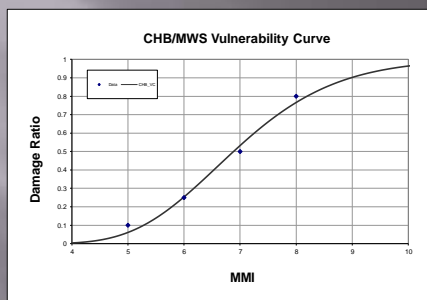
- ❖ For URA or URM, key phrases like “church” were used. Validation of building type using available photos and descriptions (in the internet).
- 3. **Assignment**, based on the descriptions of building damage for several earthquakes, of **damage ratio** for each recorded earthquake intensity.
- 4. Development of the **vulnerability curve** for each type

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Data for CHB/MWS

Event Name	Date	Location	Intensity (MMI)	Damage Description	Source	Range of Damage Ratio
Algeria Earthquake	1786 AD	Algeria	5	Extensive - The damaged houses were largely wooden and some were poorly built masonry buildings. Of these masonry built ones some failed in the toping of masonry/masonry walls, and destruction of the roof.	Assessment of 1972	5-15
North-Eastern Chilean Earthquake	2010 AD	Chile	7	Extensive - In regular URM masonry walls were observed of regular masonry masonry. The building made of hollow blocks suffered cracks in the wall and facade walls.	Assessment of 2009	30-70
Eastern Chilean Earthquake	1730 AD	Chile	7	Extensive - In Chilean URM masonry walls were observed in some houses. Commercial buildings were observed.	Assessment of 1988	30-70
Western Earthquake			7	Extensive - In Mexico (URM VI), many houses were damaged by the fore shock that was considered as masonry cracks on walls and floors. Based on field investigation, many concrete or semi-concrete houses in Palenque (URM VI) and Dinastang (URM VI) suffered severe damage 7.	PHVOLCE, 2003	30-70
Western Earthquake			7	Most of the damaged buildings were either masonry built or lacked the necessary reinforcement to resist strong ground shaking. About 3,000 units of houses, buildings and churches were affected and 3 damaged while a total of 100 were totally collapsed including two historical churches built centuries ago.	PHVOLCE, 2003	30-70
Eastern Chilean Earthquake	1978 AD	Chile	8	Extensive - Many buildings located in rural areas or URM masonry built masonry with masonry masonry and some in the masonry of the masonry. Not masonry or masonry masonry but masonry for masonry. Some of these buildings masonry masonry. It is not clear for buildings collapsed but at least 11 buildings were masonry.	Assessment of 1978	60-100
Eastern Chilean Earthquake	1922 AD	Chile	8	Extensive - In Palenque (URM VI) was observed that masonry masonry buildings with masonry masonry masonry were destroyed.	Assessment of 1988	60-100

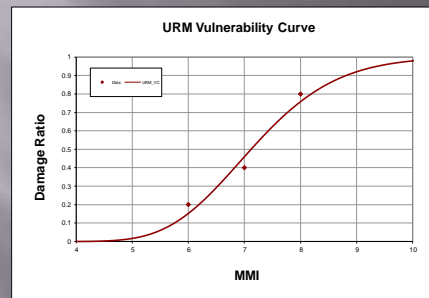
CHB/MWS Vulnerability Curve



Median: 6.88
Beta: 0.21

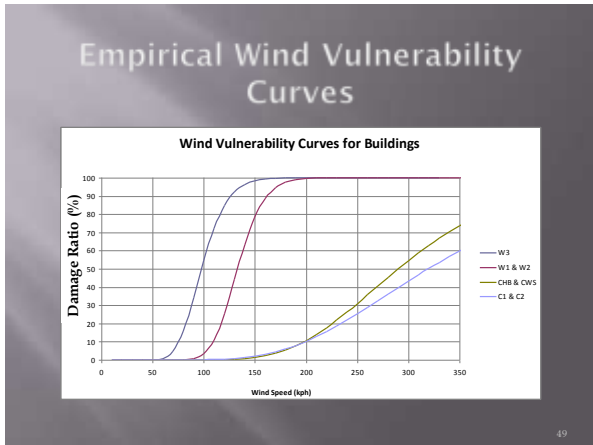
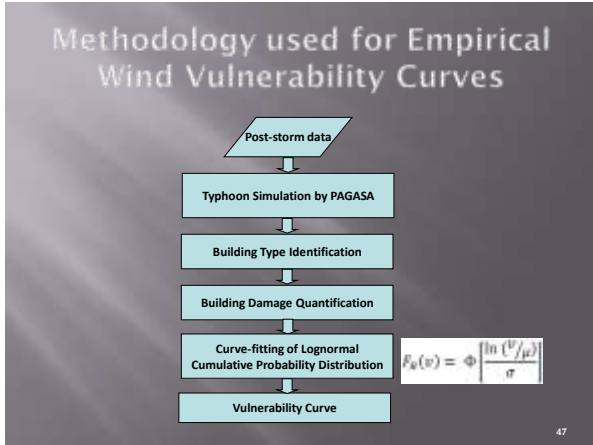
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URM Vulnerability Curve



Median: 7.12
Beta: 0.17

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Summary

- Vulnerability curves were developed for each building type using the 3 methods (computational, heuristic, and empirical) for earthquake, severe wind, and flood hazards.
- The vulnerability curves can now be used to estimate the risk to our existing building stock.

Building Group	Building Type	Structural Type or Description	Emp. Type Code for EQ	Emp. Type Code for W	Emp. Type Code for F
WOOD	W1*	Wood light frame	W1L	W1L-W	W1L-F
	W2	Medium	W2L	W2L-W	W2L-F
	W	Massive	W	W-W	W-F
MAJORITY	MWE	Concrete hollow tubular with wood or light metal	MWE-L	MWE-L-W	MWE-L-F
	CHB	Concrete hollow tubular	CHB-L	CHB-L-W	CHB-L-F
	UMSF	Unreinforced masonry bearing walls	UMSF-L	UMSF-L-W	UMSF-L-F
	CWS	Reinforced concrete structural frames with wood or light metal	CWS-L	CWS-L-W	CWS-L-F
CONCRETE	C1*	Reinforced concrete moment frames	C1L	C1L-W	C1L-F
	C4	Concrete shear walls and frames	C4L	C4L-W	C4L-F
	PCF	Precast Frame	PCFL	PCFL-W	PCFL-F
STEEL	S1*	Steel moment frame	S1L	S1L-W	S1L-F
	S2*	Light metal frame	S2L	S2L-W	S2L-F
	S4*	Steel frame with cast-in-place concrete shear walls	S4L	S4L-W	S4L-F

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Thank you for your kind
attention!

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