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

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

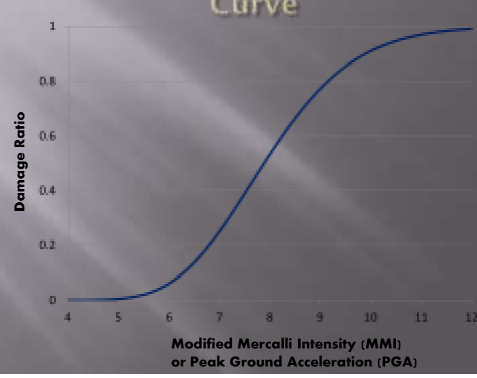
Pivotal Question!

- 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?

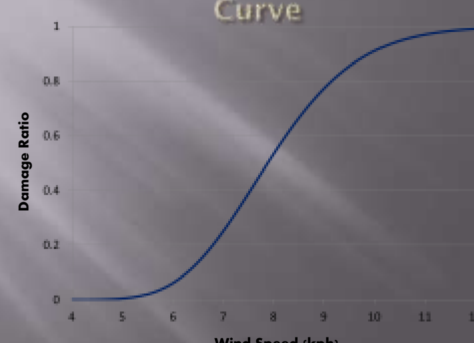
Definition

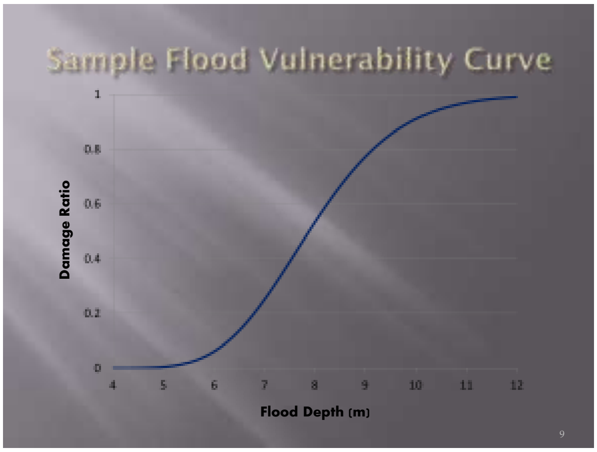
- **VULNERABILITY** – the degree of loss to a given element at risk resulting from a given level of hazard (e.g. ground motion intensity, wind speed, depth of inundation). It is defined as the ratio of the cost of damage to the cost of structure and finishes, on a scale of 0 to 1 (or 0 to 100%)
- **VULNERABILITY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

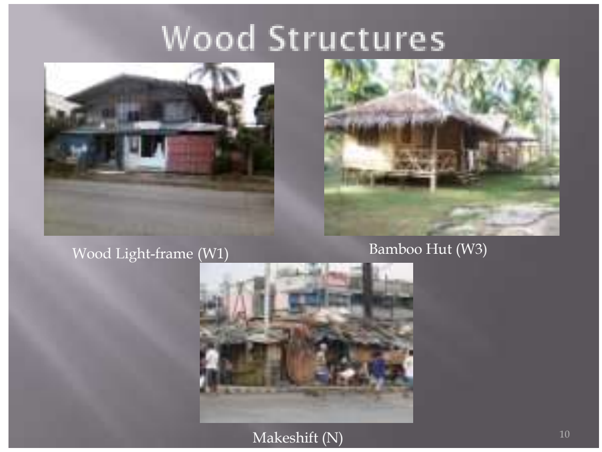
Sample Earthquake Vulnerability Curve



Sample Severe Wind Vulnerability Curve




Sample Flood Vulnerability Curve
Damage Ratio
1
0.8
0.6
0.4
0.2
0
4
5
6
7
8
9
10
11
12
Flood Depth (m)
9


Wood Structures
Wood Light-frame (W1)
Bamboo Hut (W3)
Makeshift (N)
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Masonry Structures
Concrete Hollow Block (CHB)
Unreinforced Masonry (URM) Walls
Unreinforced Adobe (URA) Walls
Concrete Hollow Blocks with Wood
or Light Metal (MWS)
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Concrete Structures
Reinforced Concrete Moment Frame (C1)
Reinforced Concrete Frames with Wood
or Light Metal (CWS)
Concrete Shear Walls and Frames (C4)
12

Steel Moment Frames (S1)

Steel Moment Frames (S1)

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

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Building typology

Building Group	Building Type	Structural Type or Description	Bldg. Type Code (for EQ)	Bldg. Type or Sub-Type Code (for FL)	Bldg. Type or Sub-Type Code (for WI)
WOOD	W1*	Wood, light frame	W1-L	W1-L-1, W1-L-2	W1-L
	W3	Bamboo	W3-L	W3-L	W3-L
	N	Makeshift	N-L	N-L-1, N-L-2	N-L
MASONRY	MWS	Concrete hollow blocks with wood or light metal	MWS-L	MWS-L	MWS-L-W, MWS-L-S
	CHB	Concrete hollow blocks	CHB-L	CHB-L-1, CHB-L-2	CHB-L
	URM*	Unreinforced masonry bearing walls	URM-L		
CONCRETE	CWS	Reinforced concrete moment frames with wood or light metal	CWS-L	CWS-L	CWS-L-W, CWS-L-S
	C1*	Reinforced concrete moment frames	[illegible]	C1-L-1, C1-L-2, C1-M	C1-L-W, C1-L-S, C1-M
	C4	Concrete shear walls and frames	C4-M, [illegible]		
	PC2	Precast Frame	PC2-L, PC2-M		
STEEL	S1*	Steel moment frame	S1-L, S1-M	S1-L-1, S1-L-2, S1-M	S1-L, S1-M
	S3*	Light metal frame	S3-L		S3-L
	S4*	Steel frame with cast-in-place concrete shear walls	S4-M		
Total types or sub-types for hazard component			17	[illegible]	[illegible]

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Methods for Deriving Vulnerability Curves

VULNERABILITY CURVE
- EMPIRICAL
- COMPUTATIONAL
- HEURISTIC

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Computational Methods

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Computational Method for Earthquake Vulnerability Curves

$$F_R(v) = \Phi\left[\frac{\ln(v/\mu)}{\sigma}\right]$$

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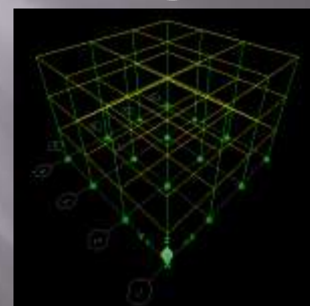
Building Model of a Moment-resisting Frame



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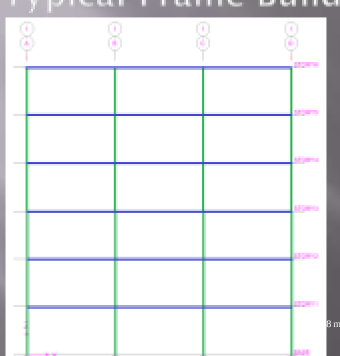
Typical Frame Building Model



Material Properties:

- Unit weight = 23.5 kN/m^3
- Concrete compressive strength, fc' = 21 MPa
- Reinforcement yield stress, fy = 240 MPa
- Modulus of elasticity, E = 25 GPa
- Poisson's Ratio, v = 0.20

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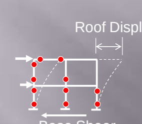
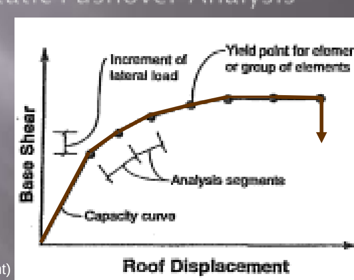
Nonlinear Static Pushover Analysis



- Plastic Hinges Where yielding Occurs (shear and bending moment)



(Source: ATC-40)

- Provides an estimate of the Capacity of the Building

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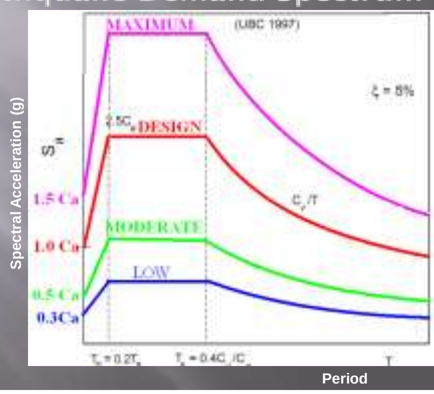
Earthquake Demand Spectrum



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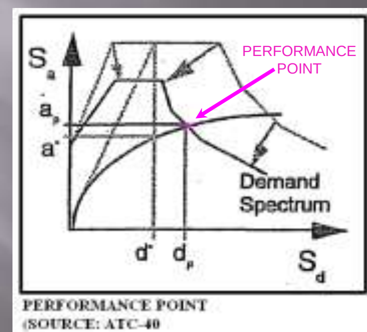
CAPACITY SPECTRUM METHOD



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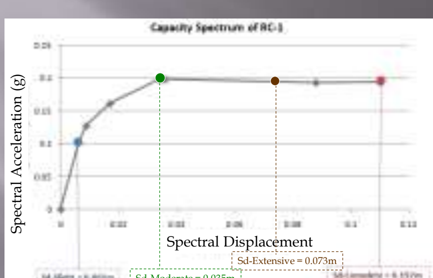
Damage Threshold Values



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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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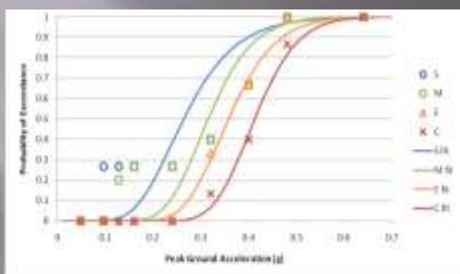
Fragility Curves



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

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

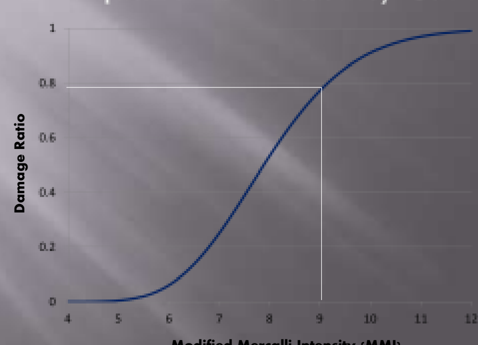
Where,

- $P_{v,GMI}$ = 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.

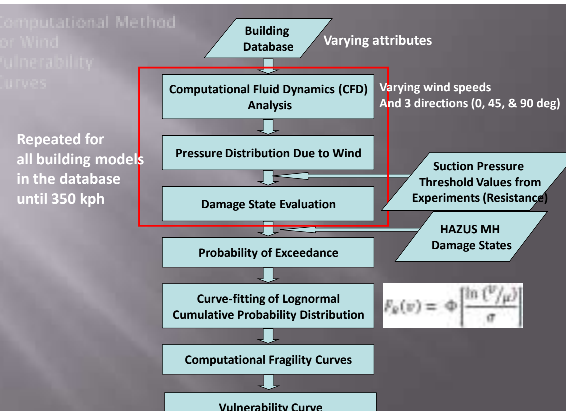
Damage States	Damage Ranges (%)	Damage Indices (%)
None	0-2	1
Slight	2-10	6
Moderate	10-50	30
Extensive	50-100	75
Complete	100	100

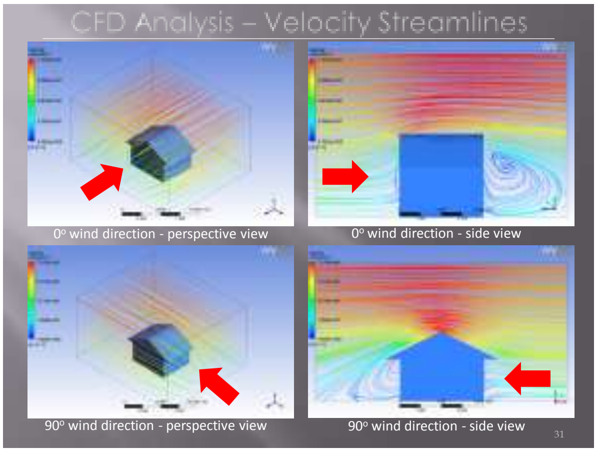
Damage index at different damage states

Earthquake Vulnerability Curve



Computational Method for Wind Vulnerability Curves




CFD Analysis – Velocity Streamlines
0° wind direction - perspective view
0° wind direction - side view
90° wind direction - perspective view
90° wind direction - side view
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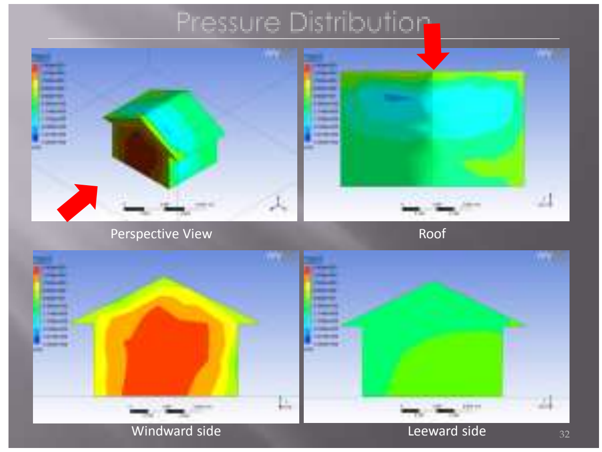
Pressure Distribution
Perspective View
Roof
Windward side
Leeward side
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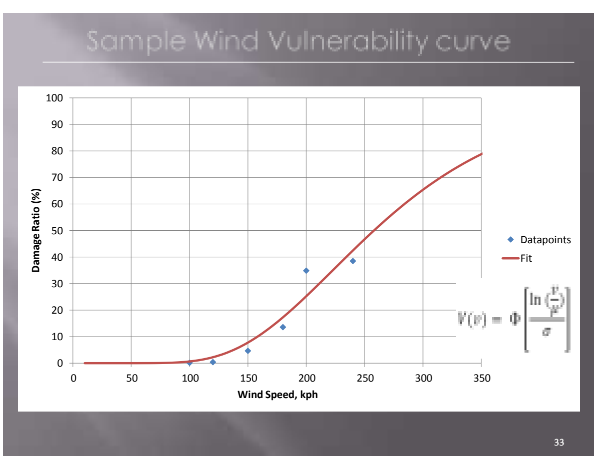
Sample Wind Vulnerability curve
Damage Ratio (%)
Wind Speed, kph
Datapoints
Fit
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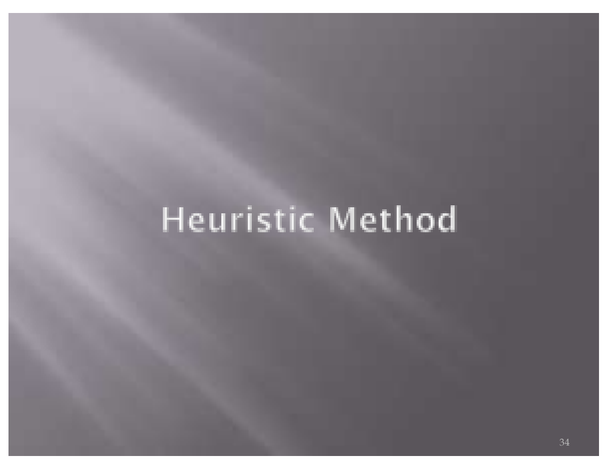
Heuristic Method
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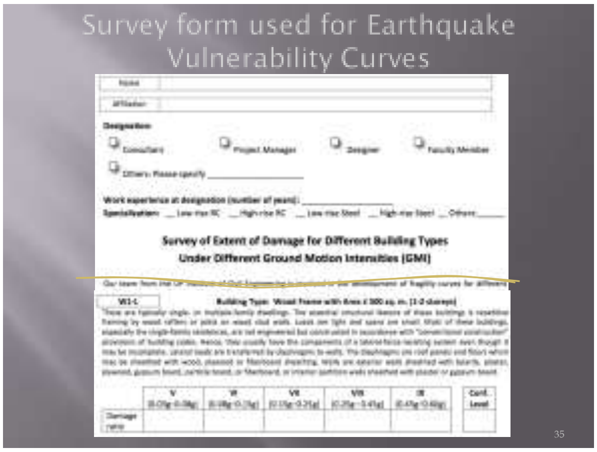
Survey form used for Earthquake Vulnerability Curves
Survey of Extent of Damage for Different Building Types
Under Different Ground Motion Intensities (GMI)
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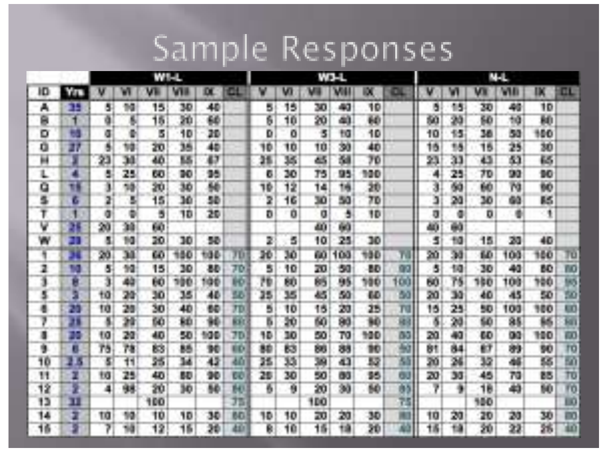
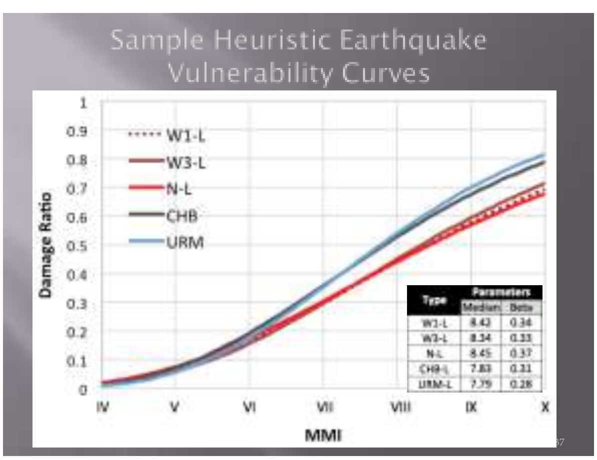
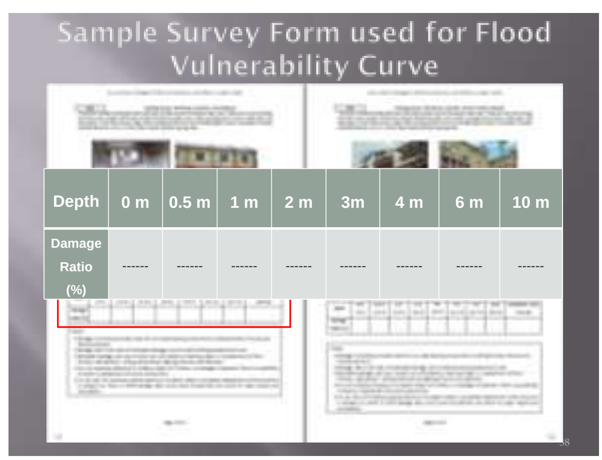

Sample Responses
W1-L
W3-L
N-L


Sample Heuristic Earthquake Vulnerability Curves
Damage Ratio
MMI
W1-L
W3-L
N-L
CHB
URM
Type
Parameters
Median
Beta
W1-L 8.42 0.34
W3-L 8.34 0.33
N-L 8.45 0.37
CHB-L 7.83 0.31
URM-L 7.79 0.28
IV V VI VII VIII IX X


Sample Survey Form used for Flood Vulnerability Curve
Depth | 0 m | 0.5 m | 1 m | 2 m | 3m | 4 m | 6 m | 10 m
Damage Ratio (%) | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------

Vulnerability Curves for Wood Structures

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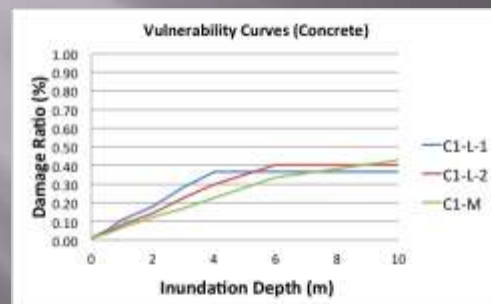
Vulnerability Curves for Concrete Structures



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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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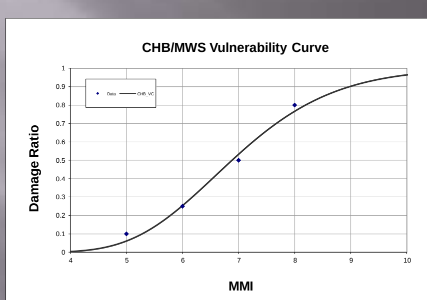
Data for CHB/MWS

CHB/MWS Vulnerability Curve



Median	6.88
Beta	0.21

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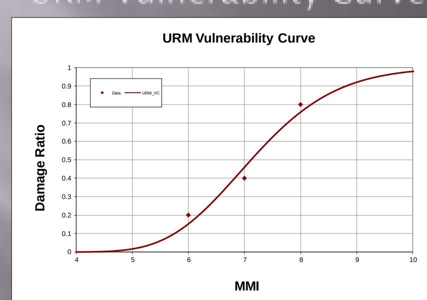
URM Vulnerability Curve



Median	7.12
Beta	0.17

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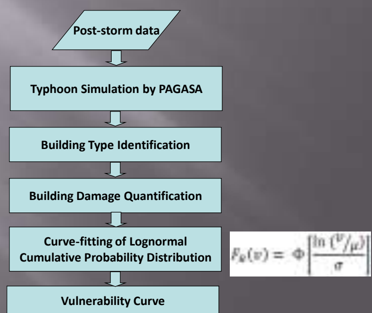
Methodology used for Empirical Wind Vulnerability Curves



$$F_R(v) = \Phi\left[\frac{\ln\left(v/\mu\right)}{\sigma}\right]$$

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Sample Photos of Damaged Structures after a Typhoon

Typhoon Melenyo
Maximum gust = 65 mps= 234kph

65% Damage

Typhoon Pedring
Maximum gust = 61mps = 219.6kph

55% Damage

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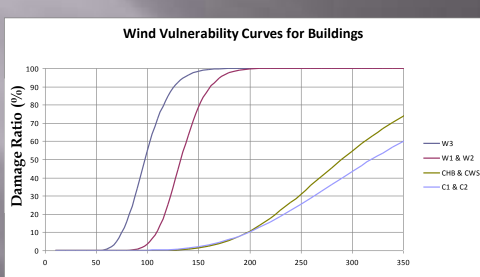
Empirical Wind Vulnerability Curves



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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	Bldg. Type Code (for EQ)	Bldg. Type or Sub-Type Code (for FL)	Bldg. Type or Sub-Type Code (for WI)
WOOD	W1*	Wood, light frame	W1-L	W1-L-1, W1-L-2	W1-L
	W3	Bamboo	W3-L	W3-L	W3-L
	N	Makeshift	N-L	N-L-1, N-L-2	N-L
MASONRY	MWS	Concrete hollow blocks with wood or light metal	MWS-L	MWS-L	MWS-L-W, MWS-L-S
	CHB	Concrete hollow blocks	CHB-L	CHB-L-1, CHB-L-2	CHB-L
	URM*	Unreinforced masonry bearing walls	URM-L		
CONCRETE	CWS	Reinforced concrete moment frames with wood or light metal	CWS-L	CWS-L	CWS-L-W, CWS-L-S
	C1*	Reinforced concrete moment frames	C1-L, C1-M	C1-L-1, C1-L-2, C1-M	C1-L-W, C1-L-S, C1-M
	C4	Concrete shear walls and frames	C4-M, C4-H		
	PC3	Precast Frame	PC3-L, PC3-M		
STEEL	S1*	Steel moment frame	S1-L, S1-M	S1-L-1, S1-L-2, S1-M	S1-L, S1-M
	S3*	Light metal frame	S3-L		S3-L
	S4*	Steel frame with cast-in-place concrete shear walls	S4-M		
Total types or sub-types for hazard component			17	[illegible]	[illegible]

Acknowledgment

The authors would like to acknowledge and thank PAGASA, PHIVOLCS, CSCAND, Geosciences Australia (GA), and Australian Aid (AusAid) for their collaboration and financial support of this project.

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Thank you for your kind attention!

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