Prompt Assessment of Global Earthquakes for Response

Data for Reinforced Concrete Building Type in India (C3)

Analytical Study

Nonlinear Static Pushover Analysis

- An internal frame of a four storey RC building
- A four storey RC building

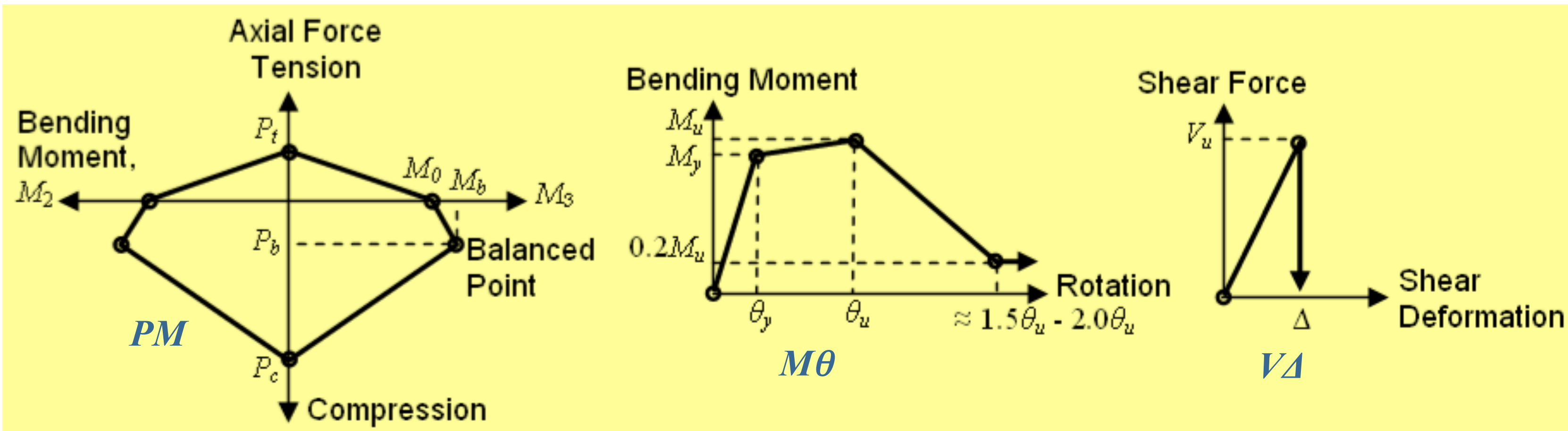
Different Models Analyzed considering Different Configuration of Masonry Infill Walls (based on prevalent design methodology)

- **Bare Frame Model** (without considering strength and stiffness of infill walls in any storey)
- **Fully Infilled Model** (Considering infills in all the stories)
- **Open First Storey Model** (Considering infills in all but first storey)

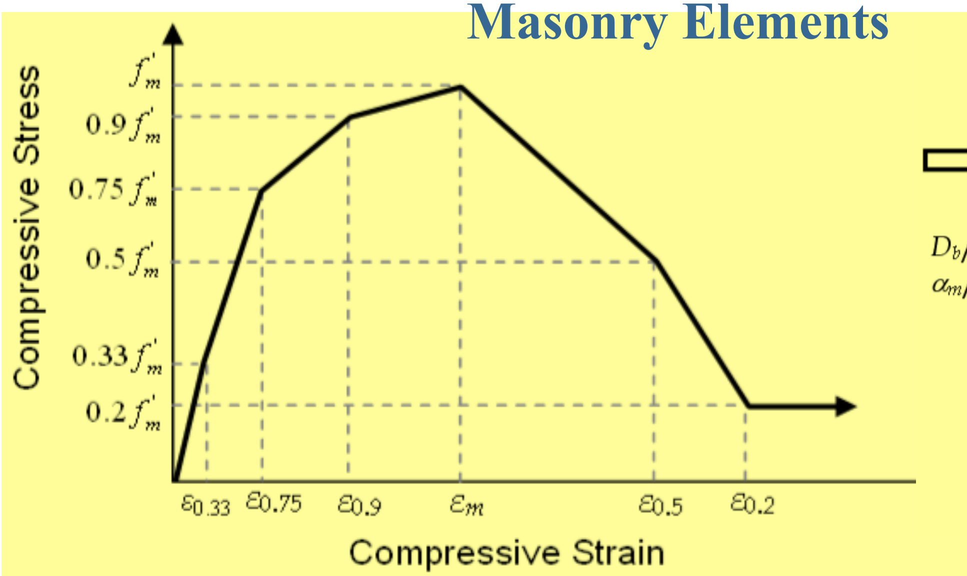
Analysis carried out in SAP2000

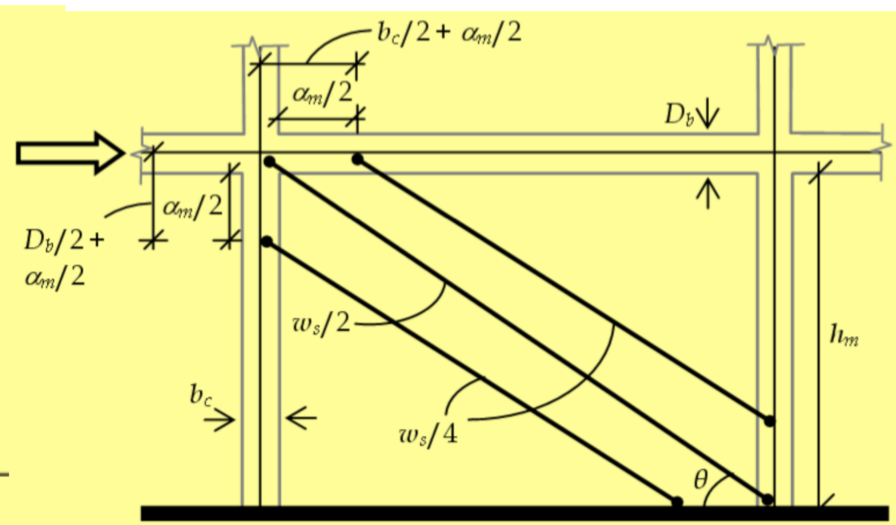
Nonlinear Static Analysis:: Plastic Hinge properties

RC Elements



Masonry Elements

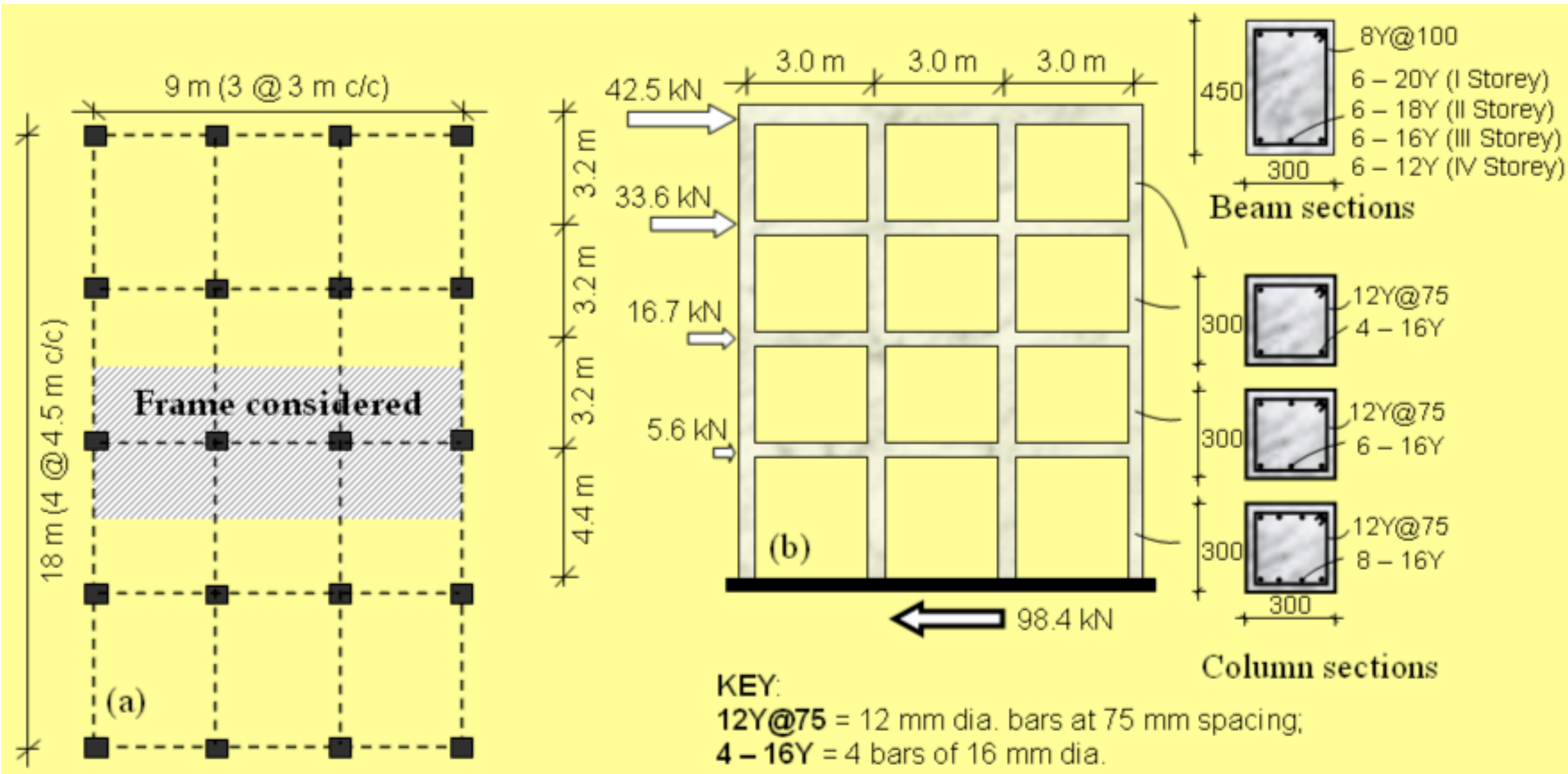




Study of a Four Storey Frame

Building Frame Considered: Seismic zone IV, Medium Soil, 14 m high,

LL: 2.0 kN/m2 at floors, 0.75 kN/m2 at roof

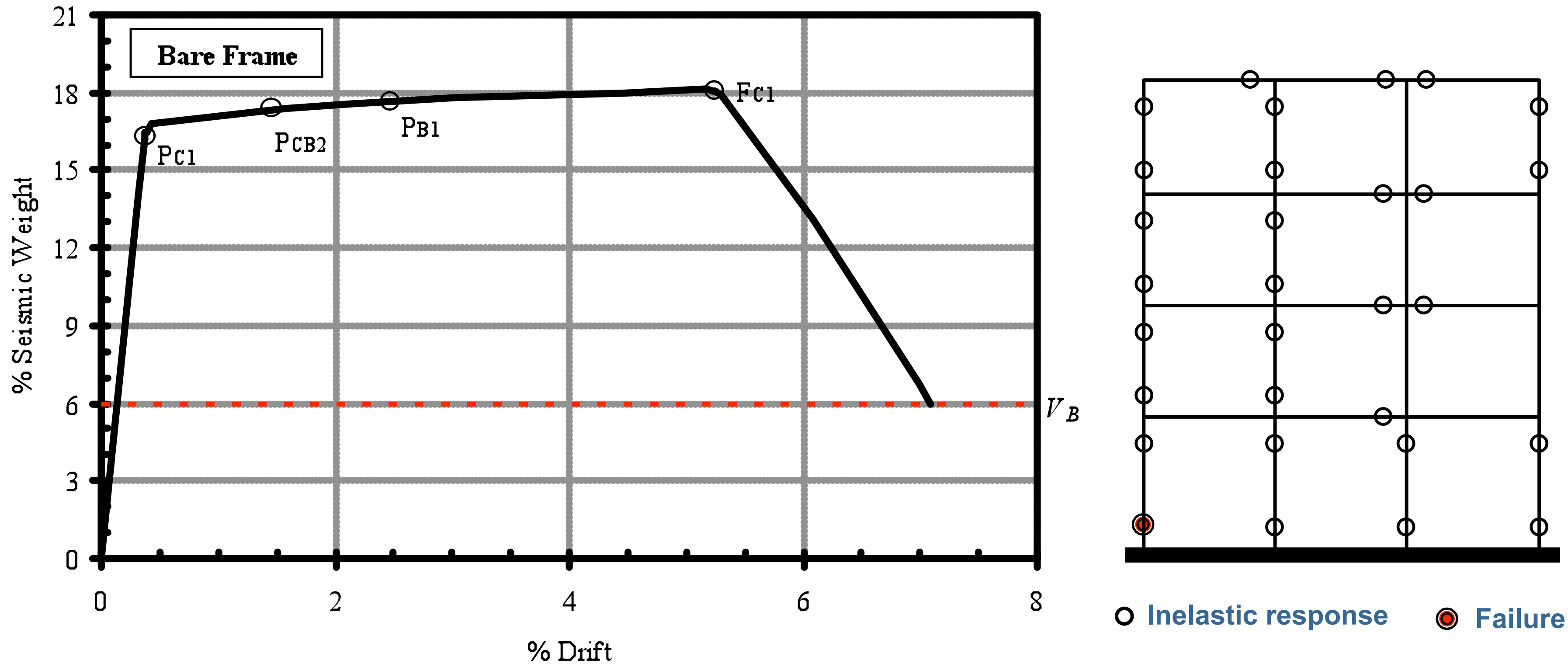


Plan

Elevation and designed RC sections

Four Storey Frame…

Bare Frame (including only weight of infills)

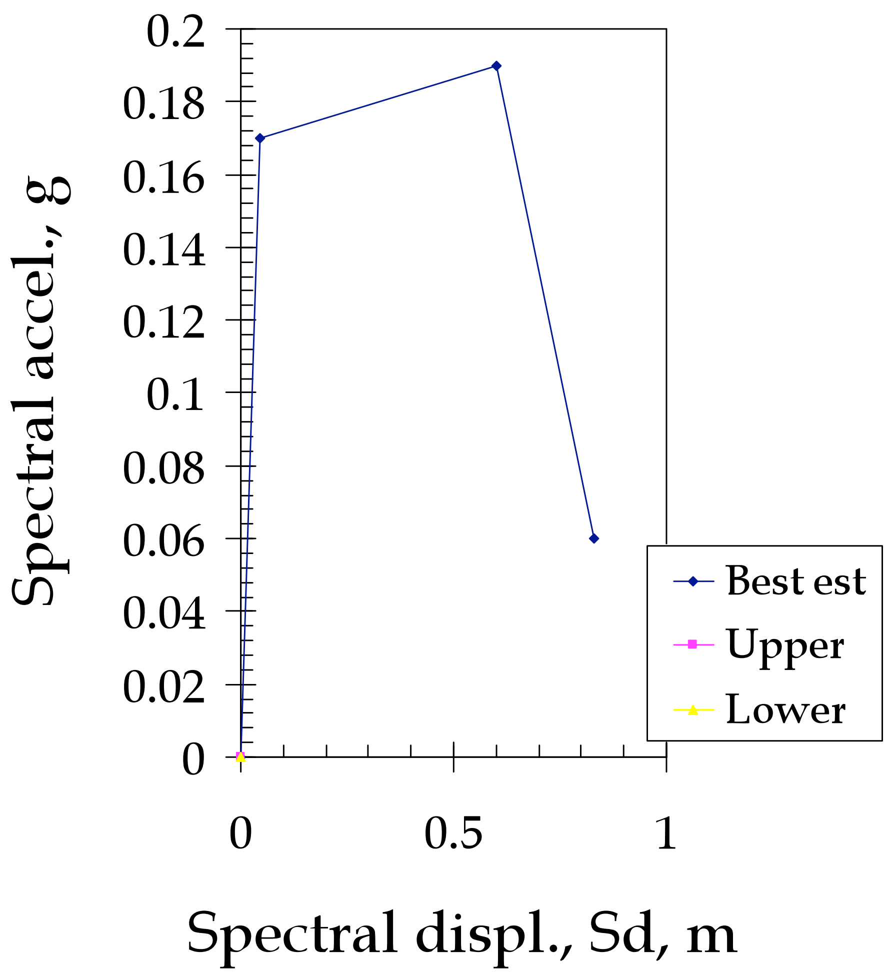


Pushover Curve and Location of Plastic Hinges

- Flexural Failure of the Frame
- Damage well distributed along height

Four Storey Frame… PAGER SHEET

Bare Frame (including only weight of infills)



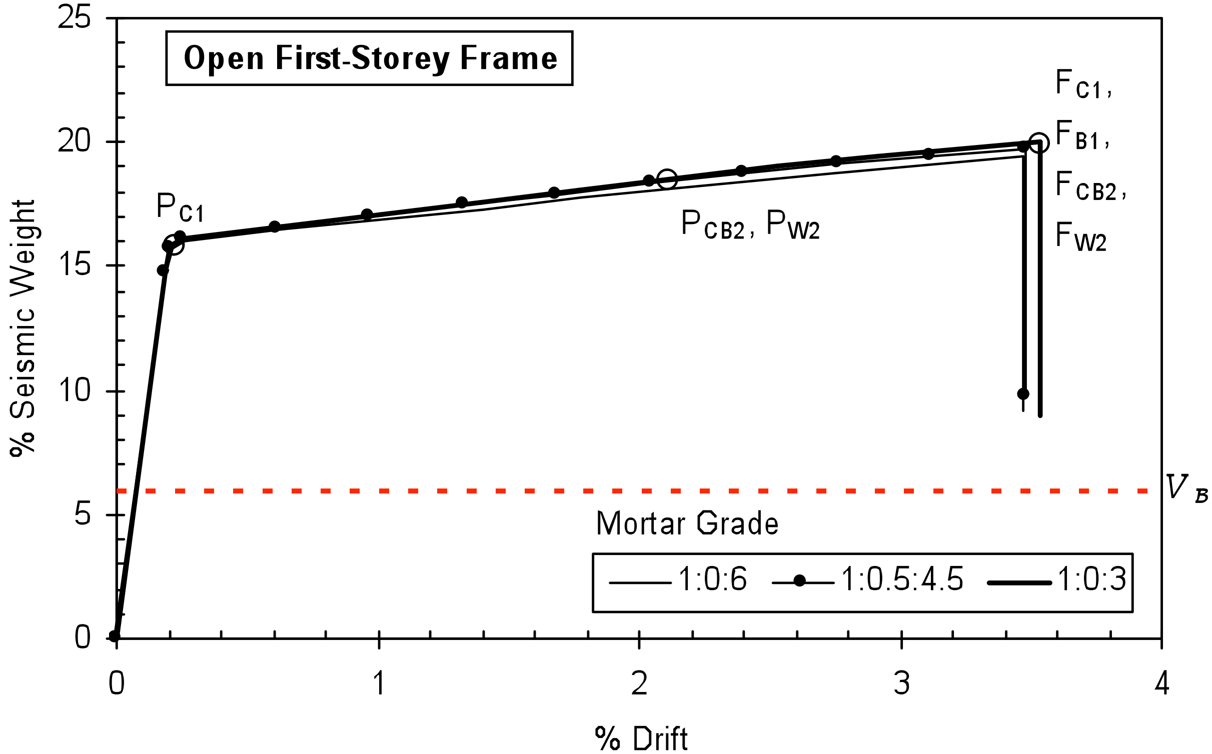
Four Storey Frame… PAGER SHEET

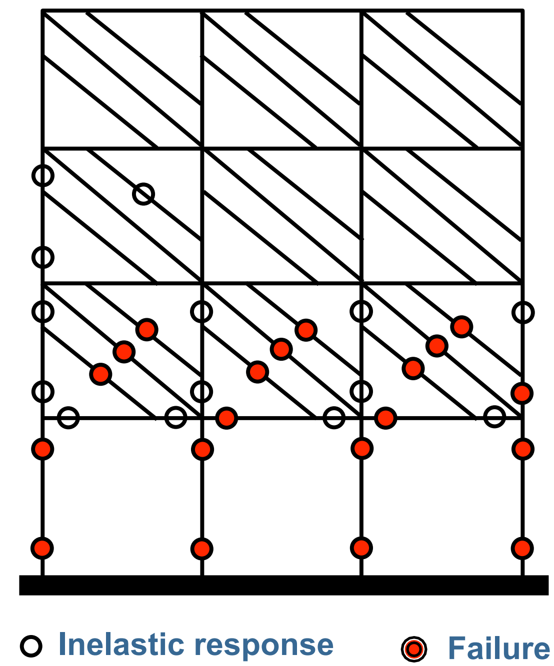
Bare Frame (including only weight of infills)

1		WHE-PAGER PHASE 2: DEVELOPMENT OF ANALYTICAL SEISMIC VULNERABILITY FUNC				
2						
3	Author:	Hemant B. kaushik				
4	Date:	10-Jul-09				
5	Structure type (describe as broadly as possible):	Non-Ductile Reinforced Concrete Frame without Masonry Infill Walls				
6	Geographic or other limitations:	Northern India, Modern Building Construction				
7		As per the prevalent method of design of such buildings in India, strength and stiffness of masonry infills i				
8						
9		Choice of pushover curve parameters				
10		Units	Parameter			
11	Pushover X-axis:	Sd(m)		Choose spectral displacement (Sd); or Roof displacement (Deltar). State unit		
12	Pushover Y-axis:	Sa(g)		Choose spectra acceleration (Sa); or base shear (V). State units.		
13	Elastic damping ratio:	0.05		Small-amplitude damping ratio, fraction of critical		
14	1st mode participation factor:	1.2		PFfR; generally 1.3 to 1.5; same as (effective height)/(total roof height)		
15	Effective mass coefficient:	0.96		alpha1; generally 0.7 to 0.8		
16	Building weight:	1640 kN	Weight of the	W State units		
17	How were these values & pushover points derived?	Based on analytical simulations of an intermediate frame of a four storey building. Actual performance of re				
18		Ref: Kaushik, H.B., Rai, D.C., and Jain, S.K. (2009), "Effectiveness of some strengthening options for ma				
19		Pushover Curve for this structure type				
20		See Figures 1-4 for sample pushover curves				
21	Pushover curve control point	X	Y	Damping	Comment	
22	A	0	0	0.13	Damping at F	Control point for plotting purposes
23	B	0.044	0.17			E.g., yield point?
24	C	0.6	0.19			E.g., ultimate point?
25	D	0.83	0.06			E.g., beginning of lower plateau?
26	E					Add rows as desired
27						

Four Storey Frame…

Open First Storey Frame



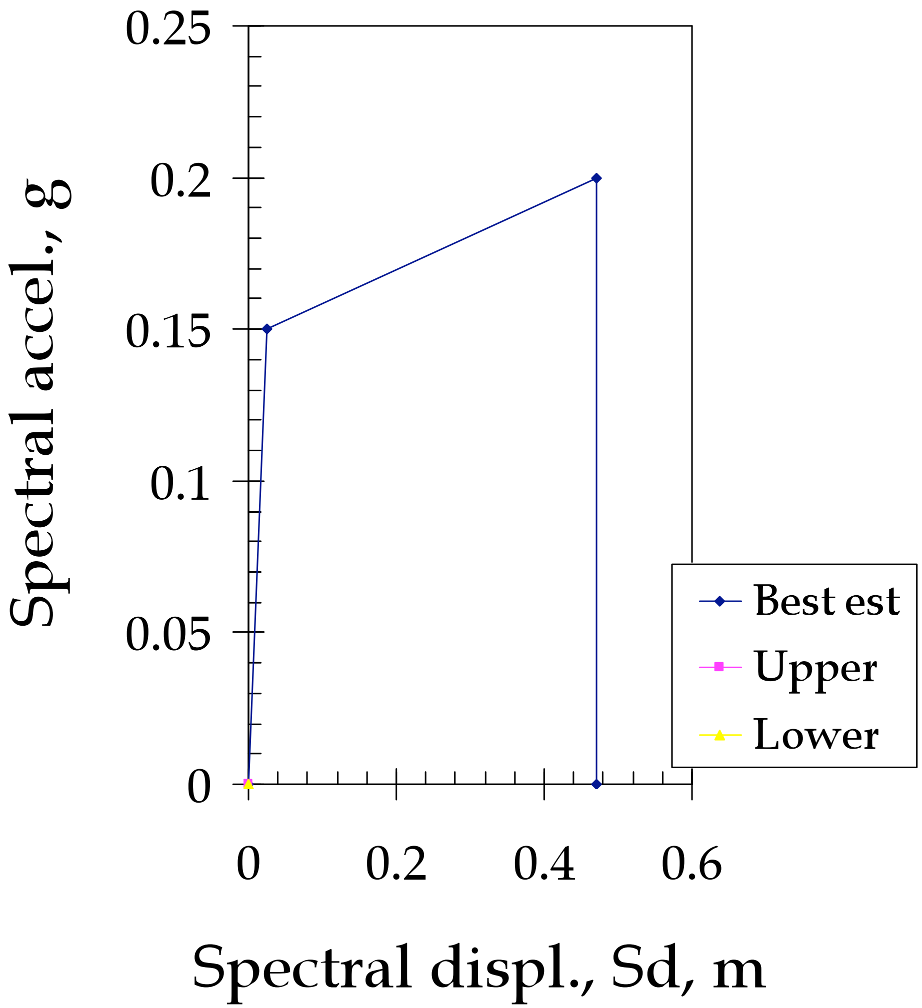


Pushover Curve and Location of Plastic Hinges

- No masonry infills in the first storey
- Lateral deformations accumulate at first storey
- Collapse due to shear failure of first storey columns and beams

Four Storey Frame… PAGER SHEET

Open First Storey Frame



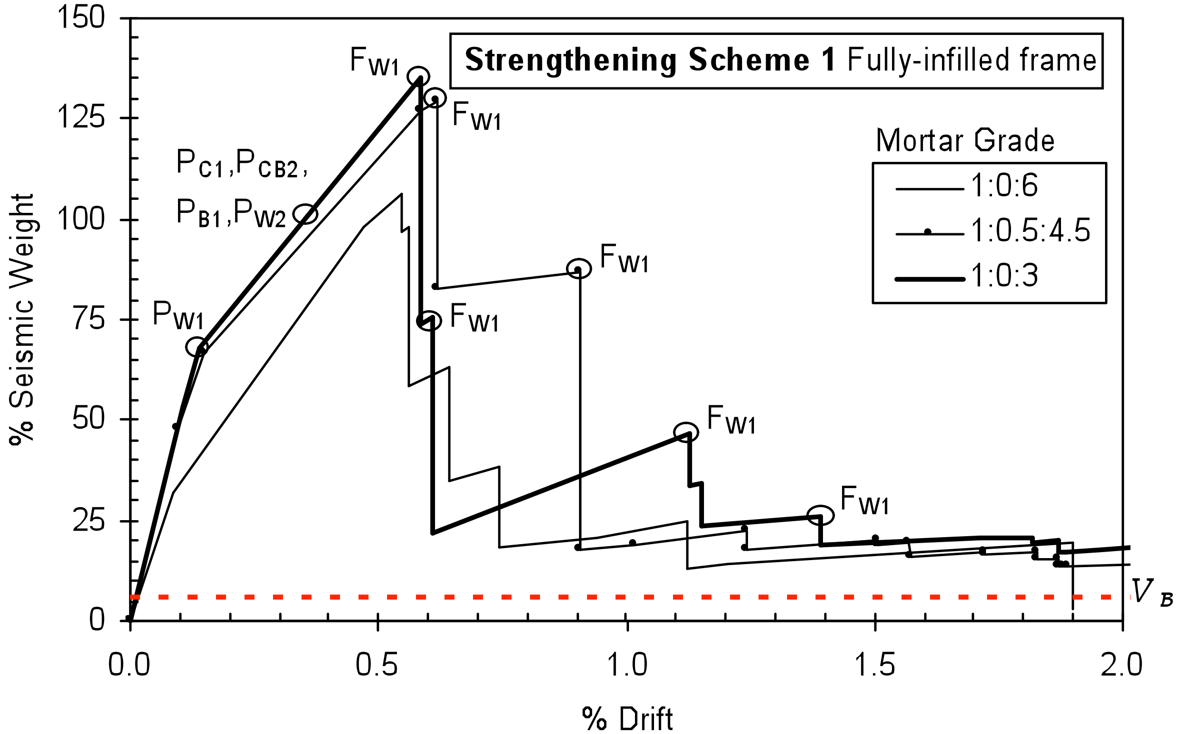
Four Storey Frame… PAGER SHEET

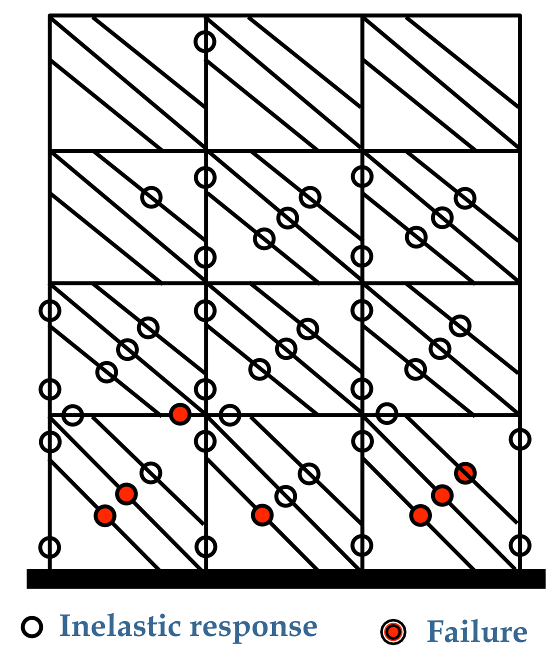
Open First Storey Frame

1	WHE-PAGER PHASE 2: DEVELOPMENT OF ANALYTICAL SEISMIC VULNERABILITY FUNCT					
2						
3	Author:	Hemant B. kaushik				
4	Date:	10-Jul-09				
5	Structure type (describe as broadly as possible):	Non-Ductile Reinforced Concrete Frame with Open First Storey				
6	Geographic or other limitations:	Northern India, Modern Building Construction				
7		The building was originally designed without considering strength and stiffness of masonry infills. Large nu				
8						
9	**Choice of pushover curve parameters**					
10		Units	Parameter			
11	Pushover X-axis:	Sd(m)		Choose spectral displacement (Sd); or Roof displacement (Deltar). State units		
12	Pushover Y-axis:	Sa(g)		Choose spectra acceleration (Sa); or base shear (V). State units.		
13	Elastic damping ratio:	0.05		Small-amplitude damping ratio, fraction of critical		
14	1st mode participation factor:	1.04		PFfR; generally 1.3 to 1.5; same as (effective height)/(total roof height)		
15	Effective mass coefficient:	1		alpha1; generally 0.7 to 0.8		
16	Building weight:	1640 kN	Weight of the	W State units		
17	How were these values & pushover points derived?	Based on analytical simulations of an intermediate frame of a four storey building. Actual performace of rea				
18		Ref: Kaushik, H.B., Rai, D.C., and Jain, S.K. (2009), "Effectiveness of some strengthening options for mas				
19	**Pushover Curve for this structure type**					
20		See Figures 1-4 for sample pushover curves				
21	Pushover curve control point	X	Y	Damping	Comment	
22	A	0	0	0.175	Damping at F	Control point for plotting purposes
23	B	0.024	0.15		Yield Point	E.g., yield point?
24	C	0.47	0.2		Ultimate Poin	E.g., ultimate point?
25	D	0.47	0		Collapse	E.g., beginning of lower plateau?
26	E					Add rows as desired
27						

Four Storey Frame…

Fully-Infilled Frame



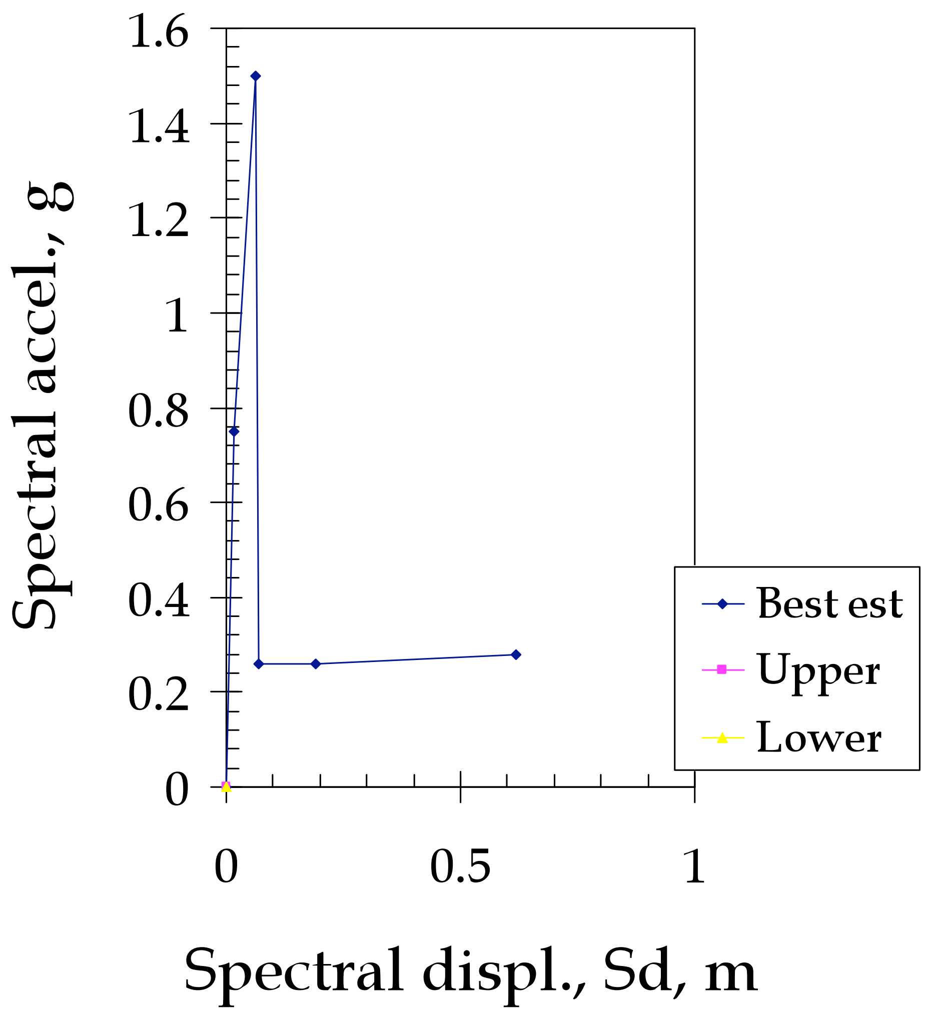


Pushover Curve and Location of Plastic Hinges

- Masonry infills in all the stories; I storey infills fail very early
- Abrupt reduction in lateral strength after failure of infills in I storey
- Very stiff structure, lateral deformations uniformly distributed along height
- Collapse due to shear failure of first storey columns and beams

Four Storey Frame… PAGER SHEET

Fully-Infilled Frame (1:0:3)



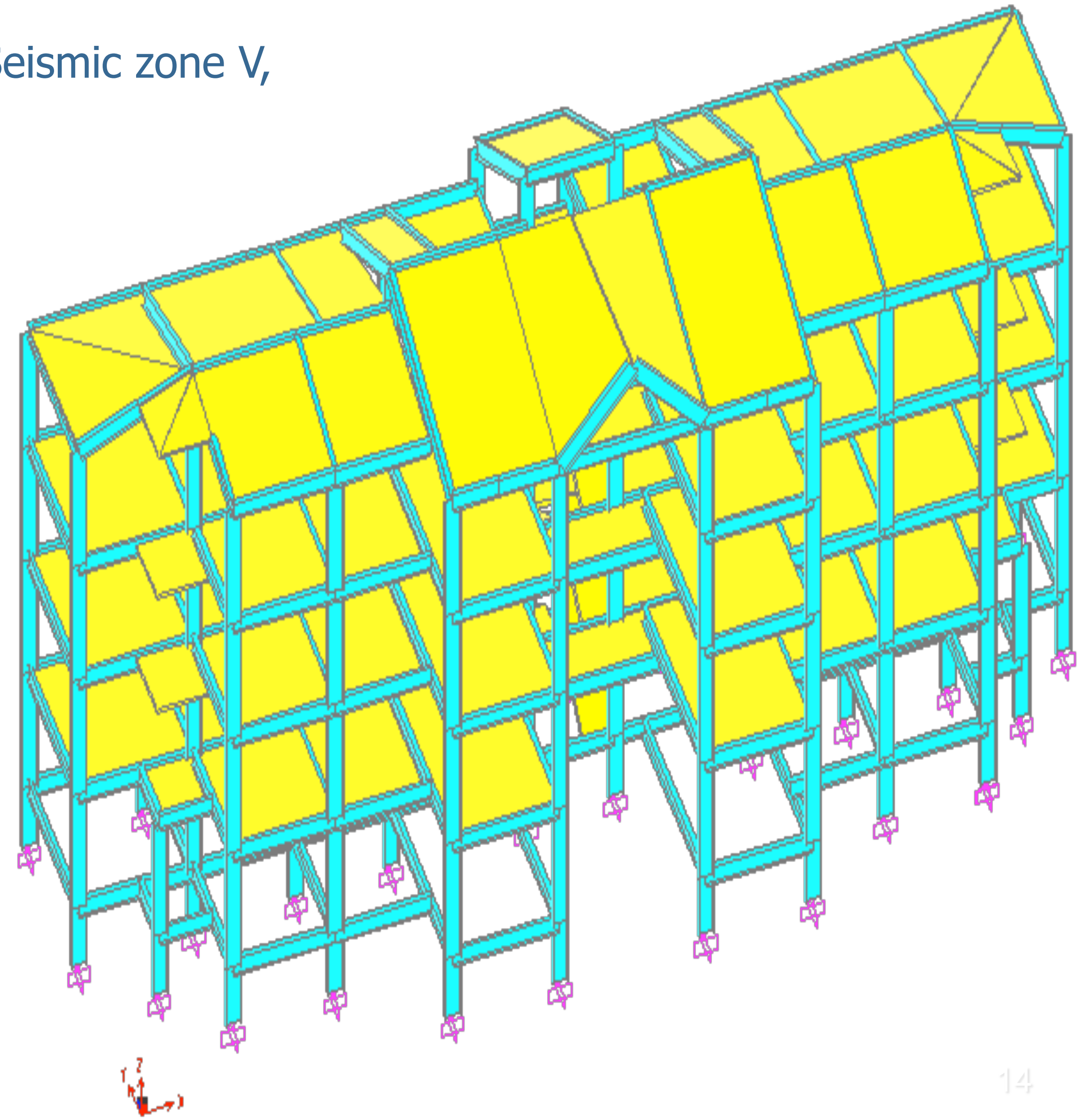
Four Storey Frame… PAGER SHEET

Fully-Infilled Frame (1:0:3)

1	WHE-PAGER PHASE 2: DEVELOPMENT OF ANALYTICAL SEISMIC VULNERABILITY FUNCTIO					
2						
3	Author:	Hemant B. kaushik				
4	Date:	10-Jul-09				
5	Structure type (describe as broadly as possible):	Non-Ductile Reinforced Concrete Frame with Masonry Infill Walls in all Storeys				
6	Geographic or other limitations:	Northern India, Modern Building Construction				
7		The building was originally designed without considering strength and stiffness of masonry infills. However, in				
8						
9	**Choice of pushover curve parameters**					
10		Units	Parameter			
11	Pushover X-axis:	Sd(m)		Choose spectral displacement (Sd); or Roof displacement (Deltar). State units		
12	Pushover Y-axis:	Sa(g)		Choose spectra acceleration (Sa); or base shear (V). State units.		
13	Elastic damping ratio:	0.05		Small-amplitude damping ratio, fraction of critical		
14	1st mode participation factor:	1.3		PFfR; generally 1.3 to 1.5; same as (effective height)/(total roof height)		
15	Effective mass coefficient:	0.91		alpha1; generally 0.7 to 0.8		
16	Building weight:	1640 kN	Weight of the	W State units		
17	How were these values & pushover points derived?	Based on analytical simulations of an intermediate frame of a four storey building. Actual performace of real bu				
18		Ref: Kaushik, H.B., Rai, D.C., and Jain, S.K. (2009), "Effectiveness of some strengthening options for masonr				
19	**Pushover Curve for this structure type**					
20		See Figures 1-4 for sample pushover curves				
21	Pushover curve control point	X	Y	Damping	Comment	
22	A	0	0	0.055	Damping at F	Control point for plotting purposes
23	B	0.015	0.75		Yield Point	E.g., yield point?
24	C	0.063	1.5		Ultimate Poin	E.g., ultimate point?
25	D	0.07	0.26		Beginning of l	E.g., beginning of lower plateau?
26	E	0.19	0.26		Lower Plateau	Add rows as desired
27		0.62	0.28		Collapse	
28						

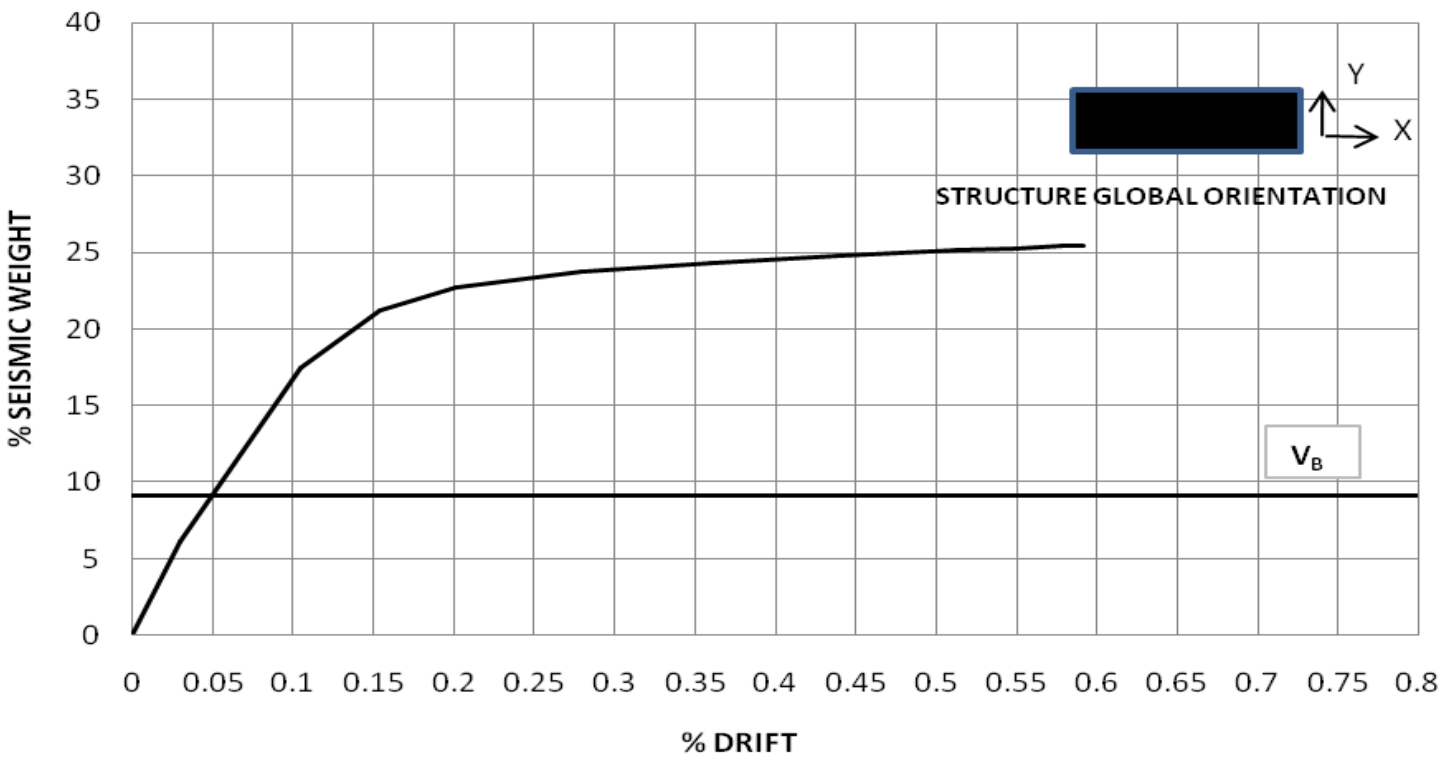
Four Storey Building

Building Considered: Seismic zone V,
Foundation on Rock
30.3 m Long and 9.4 m wide



Four Storey Building…

Open First Storey Building

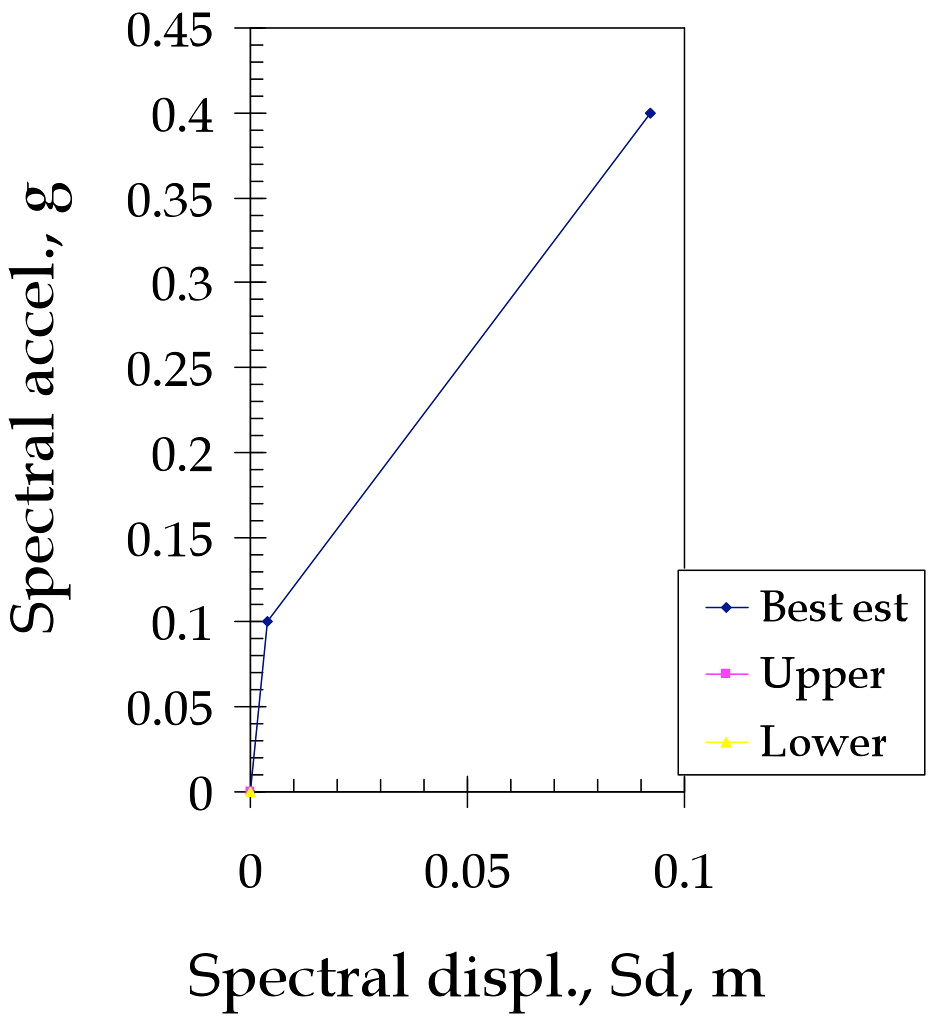


Pushover Curve

- No masonry infills in the first storey
- Lateral deformations accumulate at first storey
- Analysis could not be completed after failure of a few first storey columns and beams

Four Storey Building… PAGER SHEET

Open First Storey Building



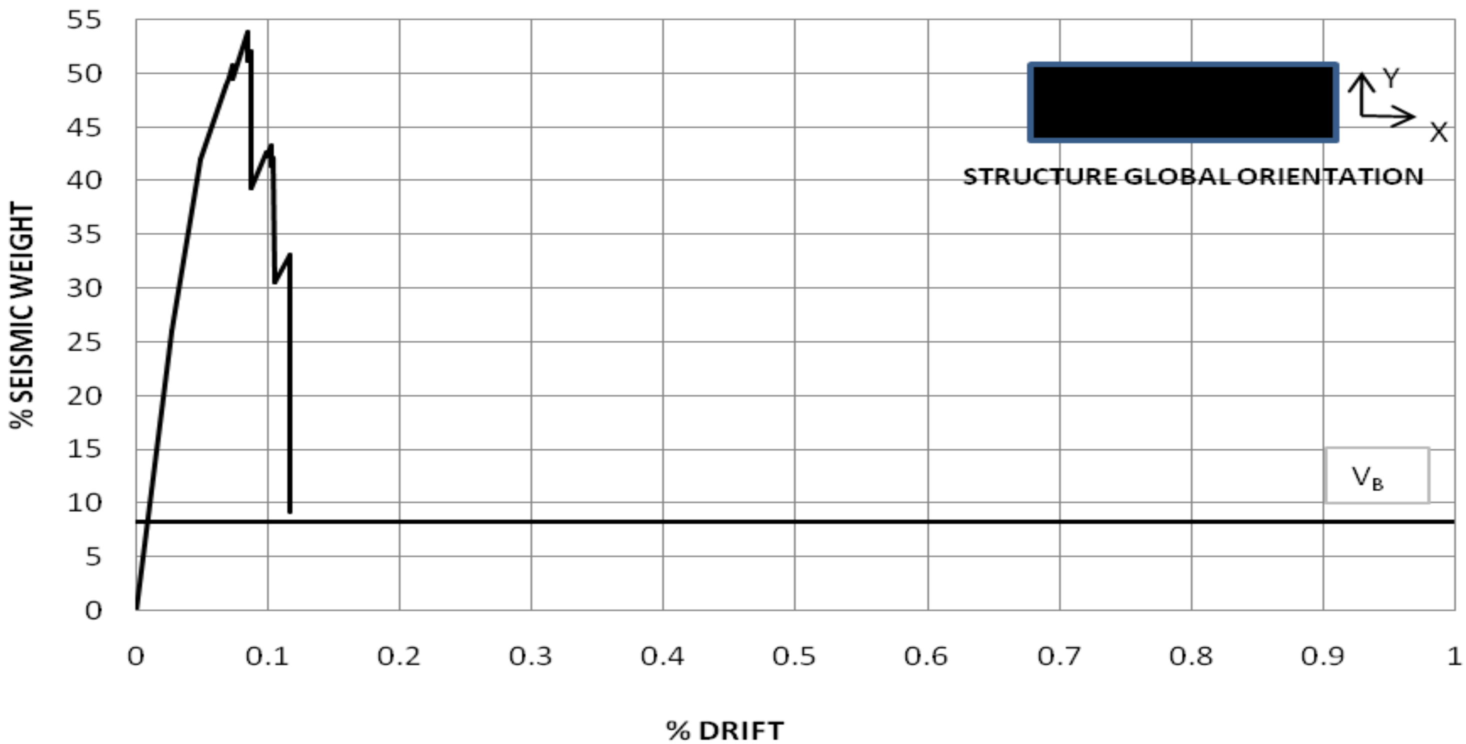
Four Storey Building… PAGER SHEET

Open First Storey Building

	A	B	C	D	E	F
1	WHE-PAGER PHASE 2: DEVELOPMENT OF ANALYTICAL SEISMIC VULNERABILITY FUNCTIO					
2						
3	Author:	Hemant B. kaushik				
4	Date:	10-Jul-09				
5	Structure type (describe as broadly as possible):	Non-Ductile Reinforced Concrete 4 Storey Residential Building with Open First Storey				
6	Geographic or other limitations:	North-eastern India, Modern Building Construction, Nonductile detailing				
7		The building was originally designed without considering strength and stiffness of masonry infills. Large numbe				
8						
9	**Choice of pushover curve parameters**					
10		Units	Parameter			
11	Pushover X-axis:	Sd(m)		Choose spectral displacement (Sd); or Roof displacement (Deltar). State units		
12	Pushover Y-axis:	Sa(g)		Choose spectra acceleration (Sa); or base shear (V). State units.		
13	Elastic damping ratio:	0.05		Small-amplitude damping ratio, fraction of critical		
14	1st mode participation factor:	0.9		PFfR; generally 1.3 to 1.5; same as (effective height)/(total roof height)		
15	Effective mass coefficient:	0.65		alpha1; generally 0.7 to 0.8		
16	Building weight:	13000 kN	Weight of the	W State units		
17	How were these values & pushover points derived?	Based on analytical simulations of a four storey residential building in Guwahati, Assam, India. Actual perform				
18		Ref: Bhattacharya, S.K. (2009), "Strengthening of existing open ground-storey reinforced concrete buildings",				
19	**Pushover Curve for this structure type**					
20		See Figures 1-4 for sample pushover curves				
21	Pushover curve control point	X	Y	Damping	Comment	
22	A	0	0	0.06	Damping at F	Control point for plotting purposes
23	B	0.004	0.1		Yield Point	E.g., yield point?
24	C	0.092	0.4		Ultimate Poin	E.g., ultimate point?
25	D	0.092	0.4		Collapse	E.g., beginning of lower plateau?
26	E					Add rows as desired
27		Analysis could not be continued after Point D due to failure of many columns in the open first storey of the bu				

Four Storey Building…

Fully Infilled Building

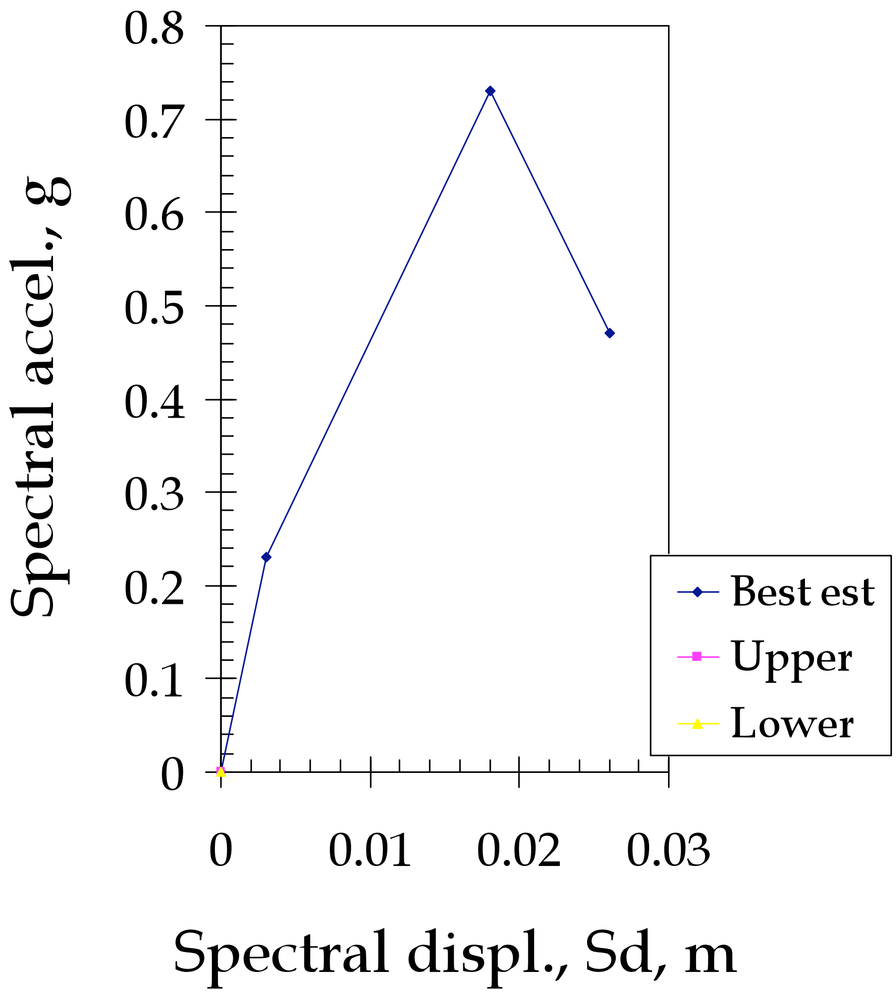


Pushover Curve

- Masonry infills in all the stories; I storey infills fail very early
- Abrupt reduction in lateral strength after failure of infills in I storey
- Very stiff structure, lateral deformations uniformly distributed along height
- Analysis could not be completed after failure of I storey infills

Four Storey Building… PAGER SHEET

Fully Infilled Building



Four Storey Building… PAGER SHEET

Fully Infilled Building

1	WHE-PAGER PHASE 2: DEVELOPMENT OF ANALYTICAL SEISMIC VULNERABILITY FUNCTI					
2						
3	Author:	Hemant B. kaushik				
4	Date:	10-Jul-09				
5	Structure type (describe as broadly as possible):	Non-Ductile Reinforced Concrete 4 storey Residential Building with Masonry Infills in all Storeys				
6	Geographic or other limitations:	North-eastern India, Modern Building Construction, Nonductile detailing				
7		The building was originally designed without considering strength and stiffness of masonry infills. However, ir				
8						
9	Choice of pushover curve parameters					
10		Units	Parameter			
11	Pushover X-axis:	Deltar(m)		Choose spectral displacement (Sd); or Roof displacement (Deltar). State units		
12	Pushover Y-axis:	V(m)		Choose spectra acceleration (Sa); or base shear (V). State units.		
13	Elastic damping ratio:	0.05		Small-amplitude damping ratio, fraction of critical		
14	1st mode participation factor:	0.87		PFfR; generally 1.3 to 1.5; same as (effective height)/(total roof height)		
15	Effective mass coefficient:	0.72		alpha1; generally 0.7 to 0.8		
16	Building weight:	13000 kN	Weight of the	W State units		
17	How were these values & pushover points derived?	Based on analytical simulations of a four storey residential building in Guwahati, Assam, India. Actual perfor				
18		Ref: Bhattacharya, S.K. (2009), "Strengthening of existing open ground-storey reinforced concrete buildings"				
19	Pushover Curve for this structure type					
20		See Figures 1-4 for sample pushover curves				
21	Pushover curve control point	X	Y	Damping	Comment	
22	A	0	0	0.05	Damping at F	Control point for plotting purposes
23	B	0.003	0.23		Yield Point	E.g., yield point?
24	C	0.018	0.73		Ultimate Poin	E.g., ultimate point?
25	D	0.026	0.47		Beginning of l	E.g., beginning of lower plateau?
26	E					Add rows as desired
27		Analysis could not be continued after Point D due to significant reduction in lateral load carrying capacity of				

Limitations of the Study

- Results based on analytical simulations of typical RC buildings constructed in India.

- Strength and stiffness of masonry infill walls was not considered **while designing the structure**; only weight was considered (Prevalent design philosophy in India).

- In nonlinear analyses, compressive strut action was assumed in the masonry infills.

- Soil – Structure interaction was not considered. Buildings were assumed to be fixed at the bottom of foundation.

- Nonlinearity in RC slabs and Staircase was not considered.

Therefore, behaviour and performance of actual buildings may differ from these analytical results.