Seismic Upgrade of BC Schools

Performance Based Seismic Assessment and Retrofit

Recent Developments

Presented by:

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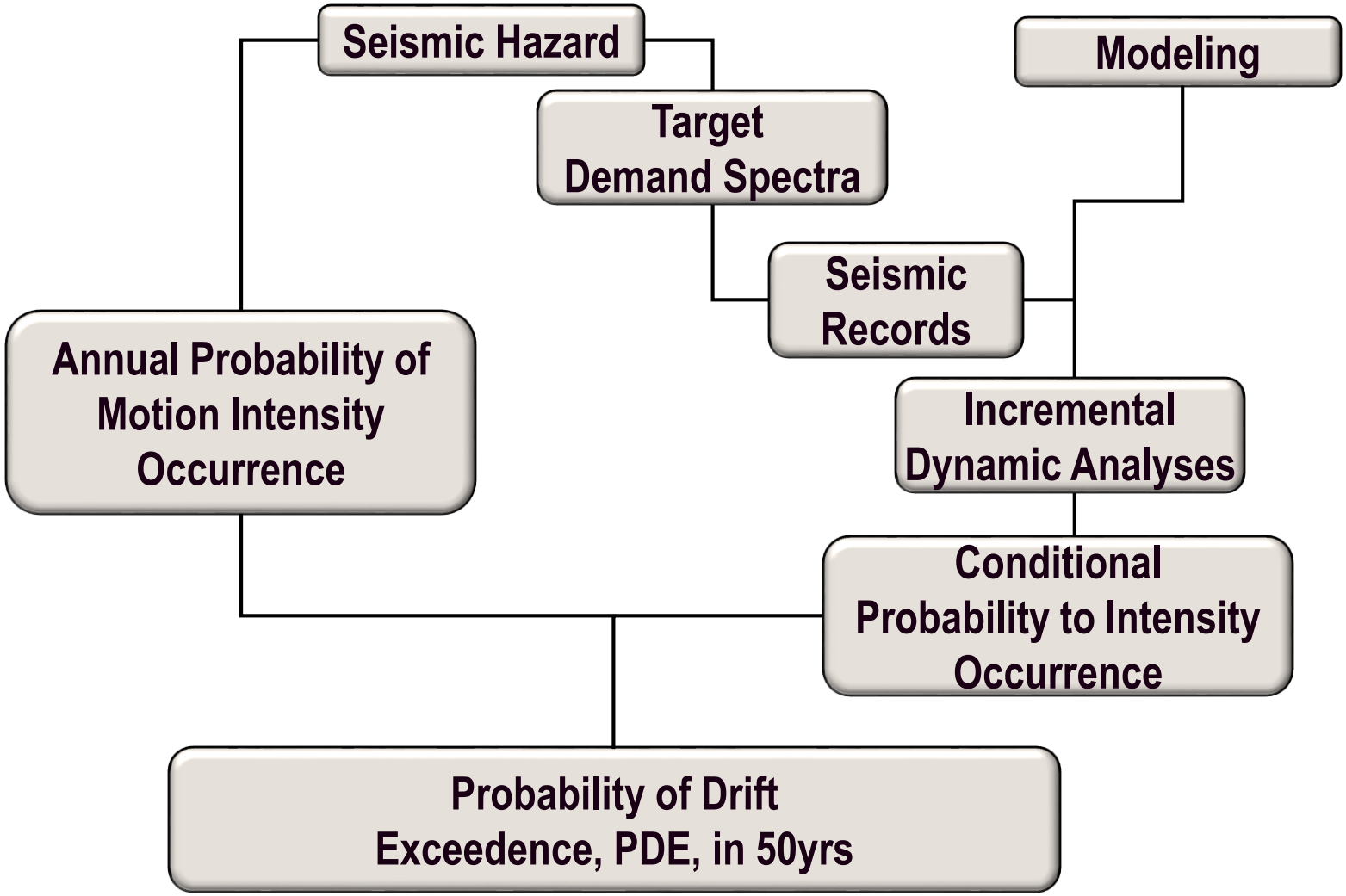
On behalf of the **MoE, UBC, APEGBC, PRC, EPR team** developing the Guidelines

Ausenco

Agenda

- SRG1 review/summary
- SRG2 developments
  - New masonry prototypes M4 – M6
  - Analyzer 2
  - Testing of 4” block
  - Liquefaction Guidelines
  - Post Earthquake Evaluation
- Recent upgrades

Seismic Retrofit Guidelines 1st Edition - Procedure

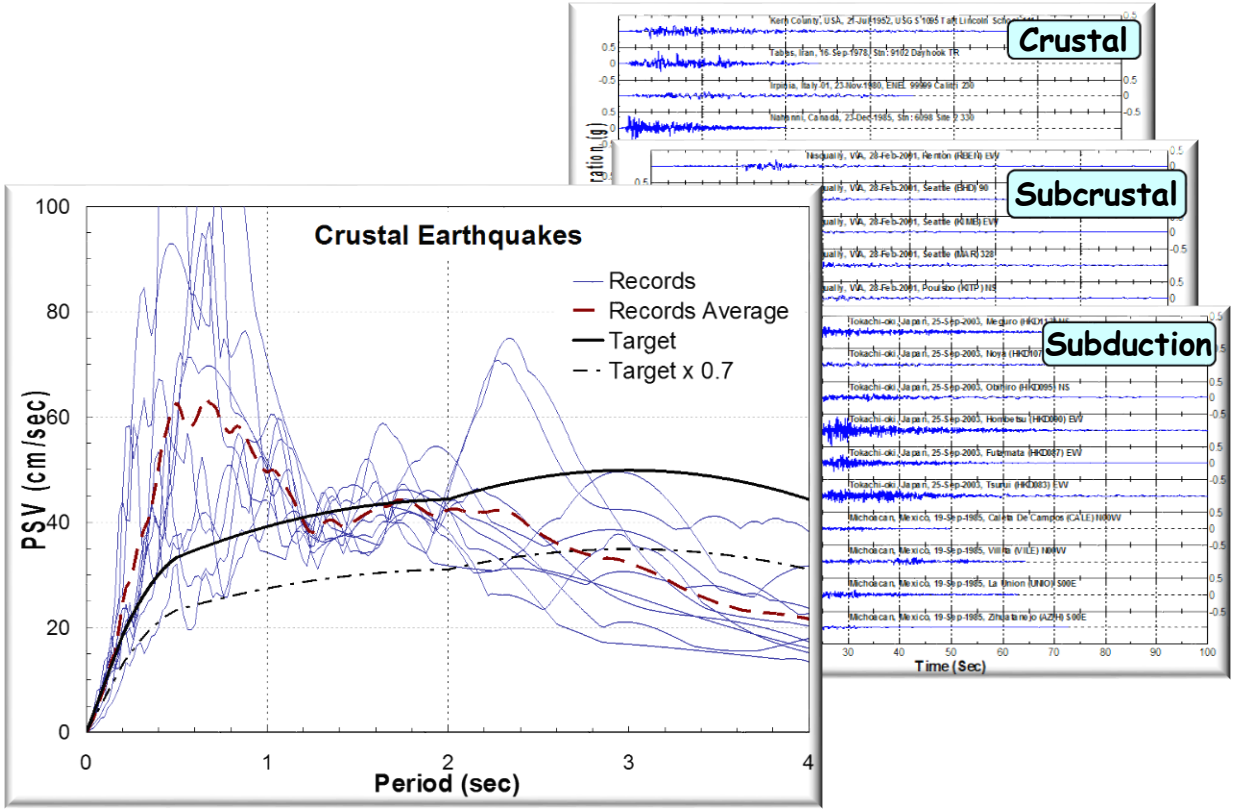


Pre-processing

Seismic Hazard

Target
Demand Spectra

Seismic
Records



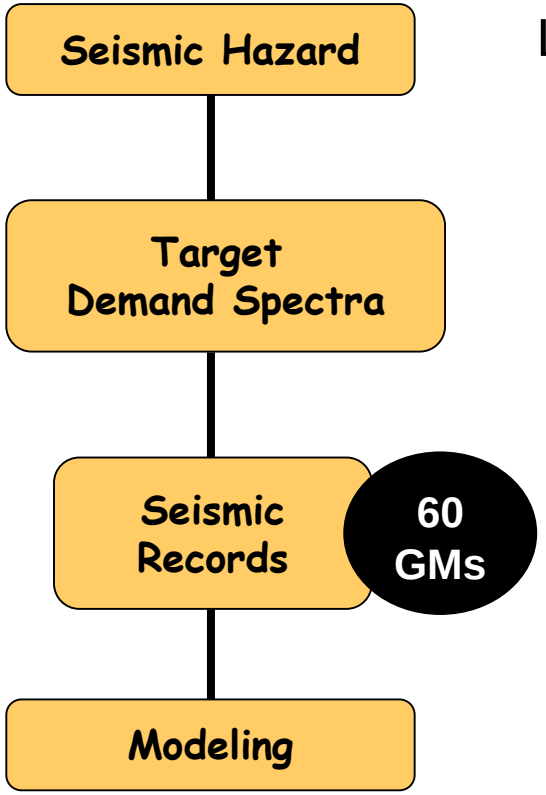
2 Seismicity regions
(High and Moderate Intensities)

10 Ground motions for each of hazard types

Total of 60 ground motions

38 Communities

Pre-processing



Lateral Deformation Resistance System (LDRS)

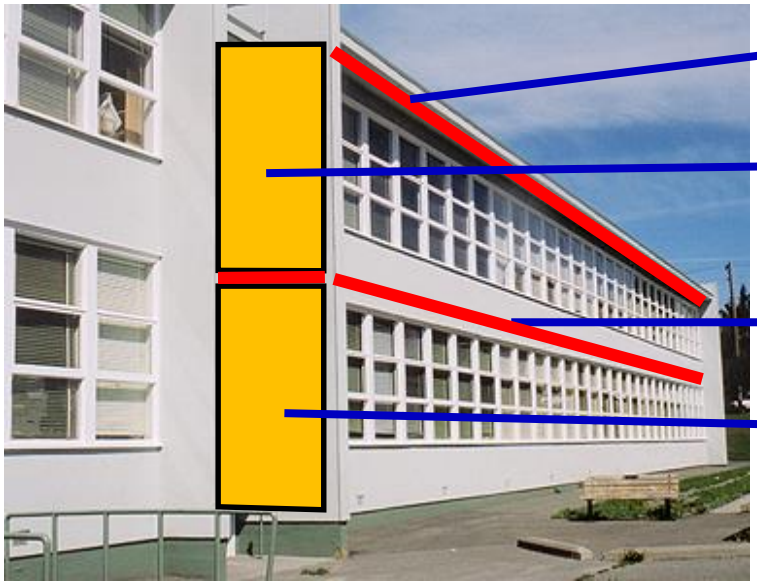
27 Prototypes implemented
- Concrete
- Steel
- Masonry
- Timber
- Brick
- Rocking

42 Resistance Levels

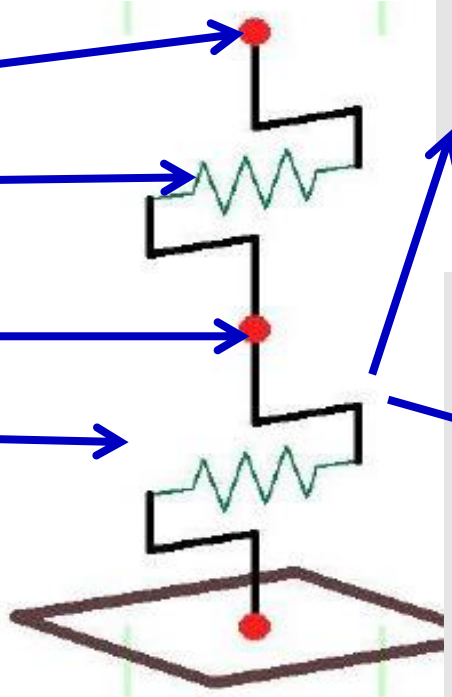
3 Heights

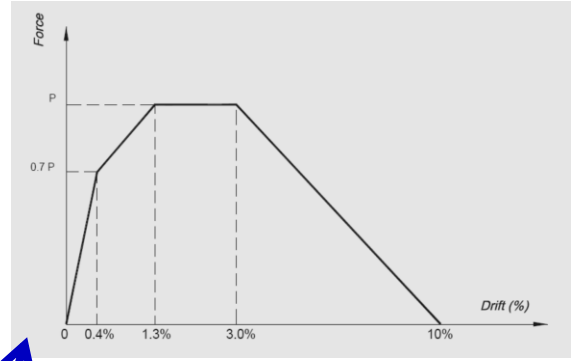
Total 3402 models

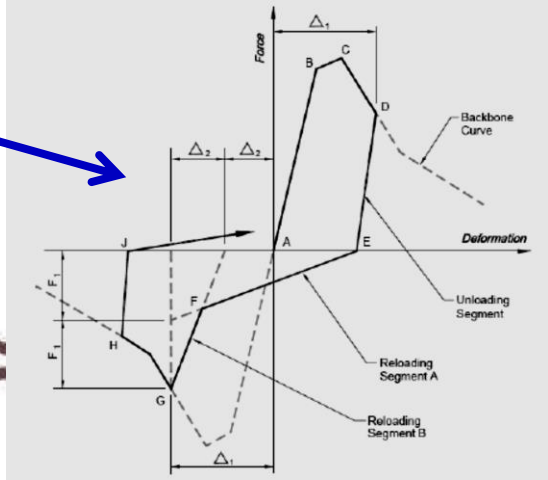
Simplified Model of an LDRS



Typical Building

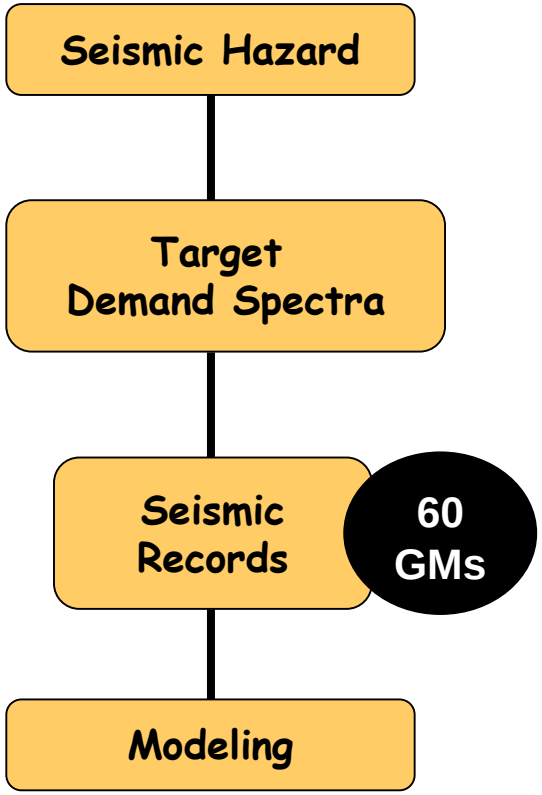






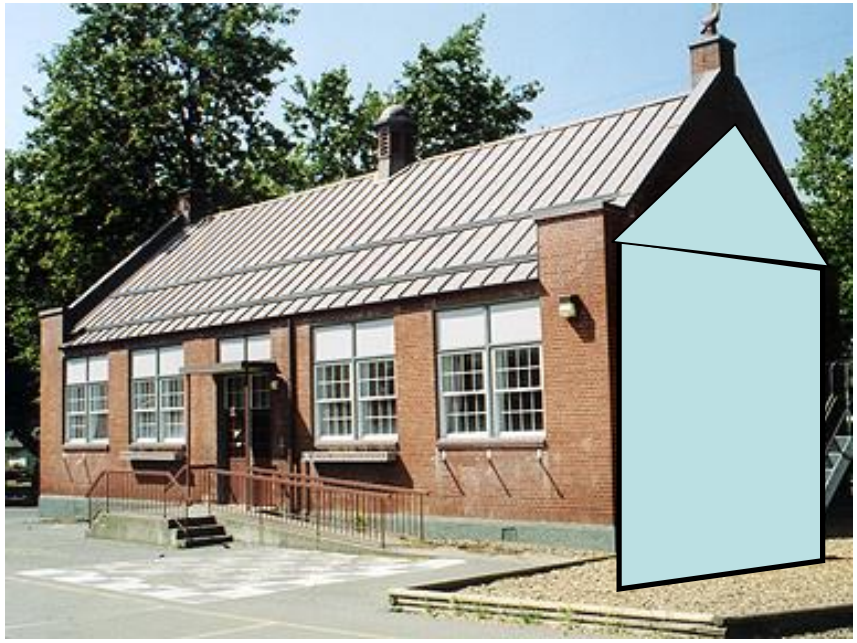
2 DOF System:
2 Shear springs + 2 Lumped masses

Pre-processing

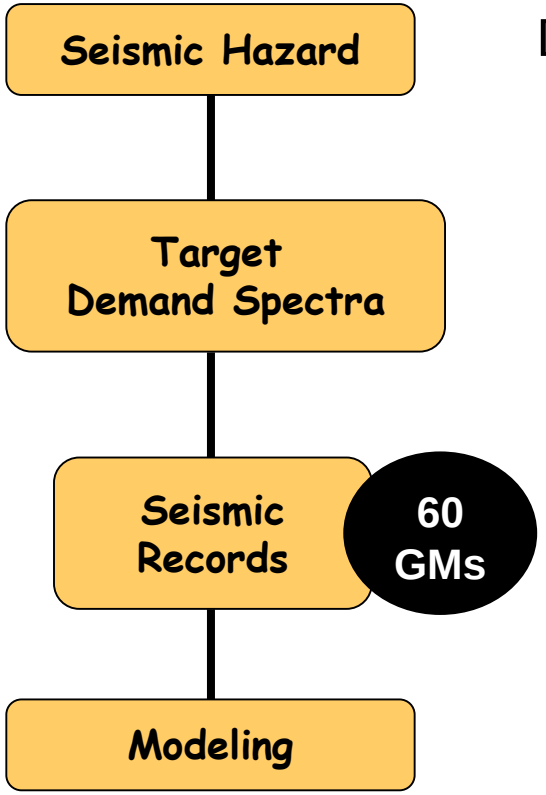


Out-of-plane: Unreinforced masonry/brick walls

- 4 URM prototypes
- Different heights, thickness, and surcharges
- Total 359 models



Pre-processing



Diaphragms

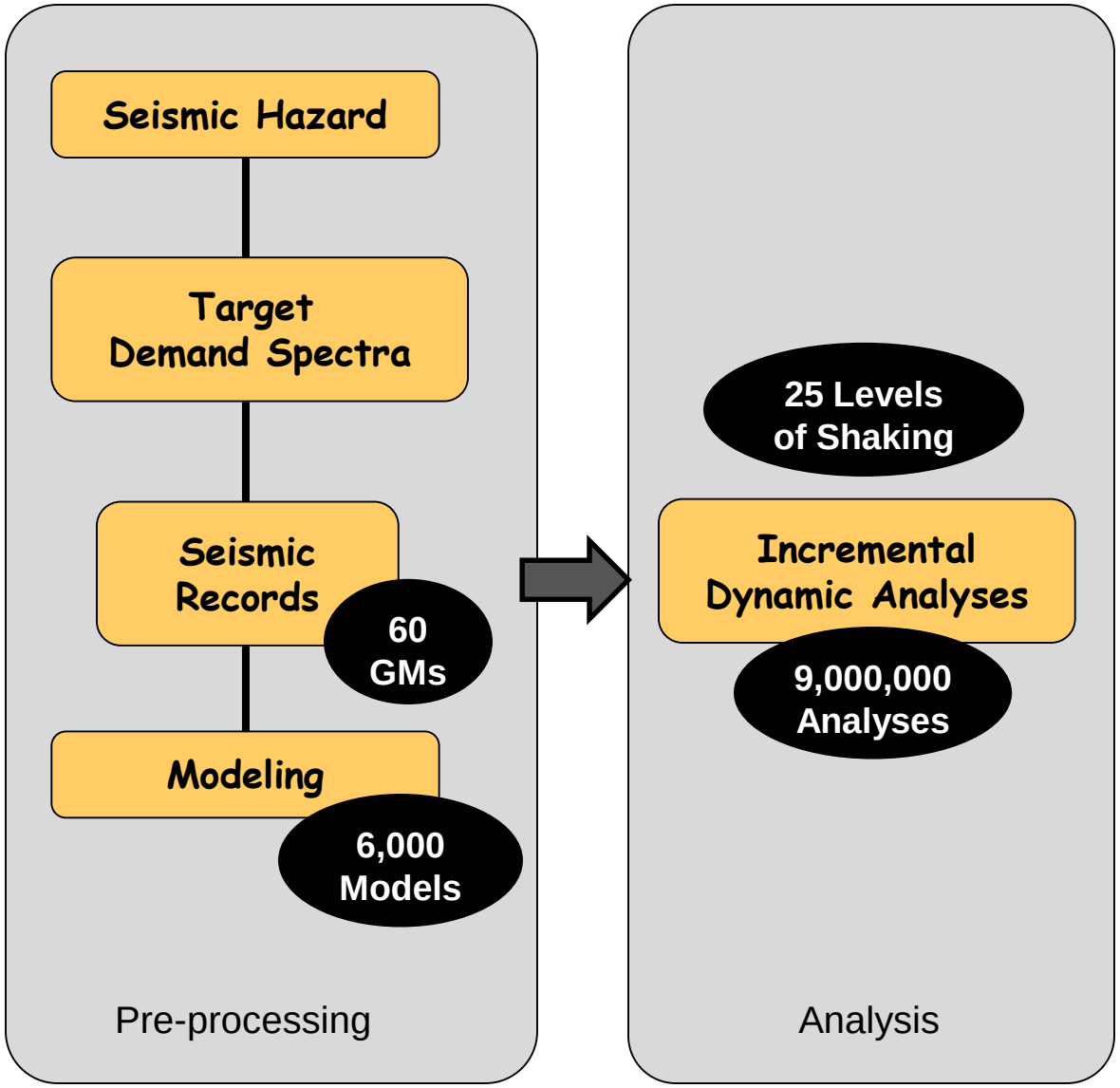
6 Prototypes
- Timber
- Metal decking

5 Span lengths

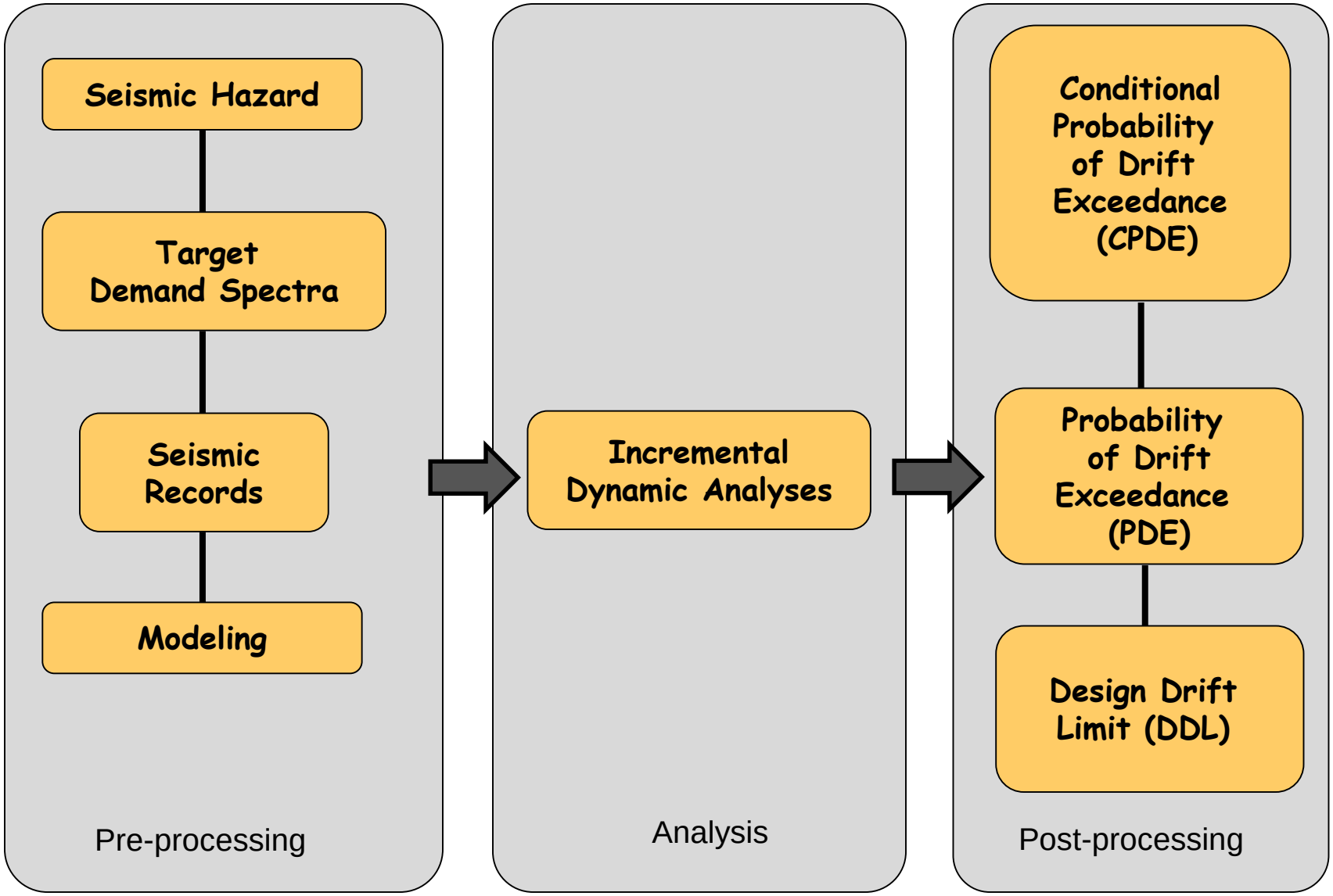
42 Resistance levels

Total 1260 models

Analysis


Seismic Hazard
Target Demand Spectra
Seismic Records
60 GMs
Modeling
6,000 Models
Pre-processing
25 Levels of Shaking
Incremental Dynamic Analyses
9,000,000 Analyses
Analysis

Post-processing



Priority Retrofit Ratings

Priority Retrofit Ranking	Maximum PDE
H1 – High Level 1	> 10%
H2 – High Level 2	10% >= PDE > 7%
H3 – High Level 3	7% >= PDE > 5%
M – Medium	5% >= PDE > 2%
L – Low (No Retrofit Req'd)	<= 2%

Seismic Performance Analyzer

British Columbia Ministry of Education Seismic Mitigation Program

Introduction | LDRS Analysis | Out-of-Plane Analysis | Diaphragm Analysis | Help | Contact

Risk Assessment | Retrofit Design

LDRS Analysis - Risk Assessment

Community	Victoria	**Factored Resistance**	3
Soil Type	Site Class D/E/F	**Storey Height (mm) 1000mm - 6000mm**	3300
Prototype	W-2	**Design Drift Limit**	2.75%

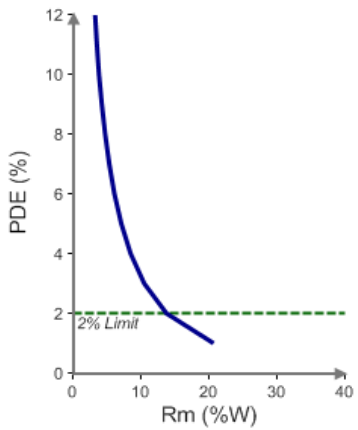
ANALYSIS

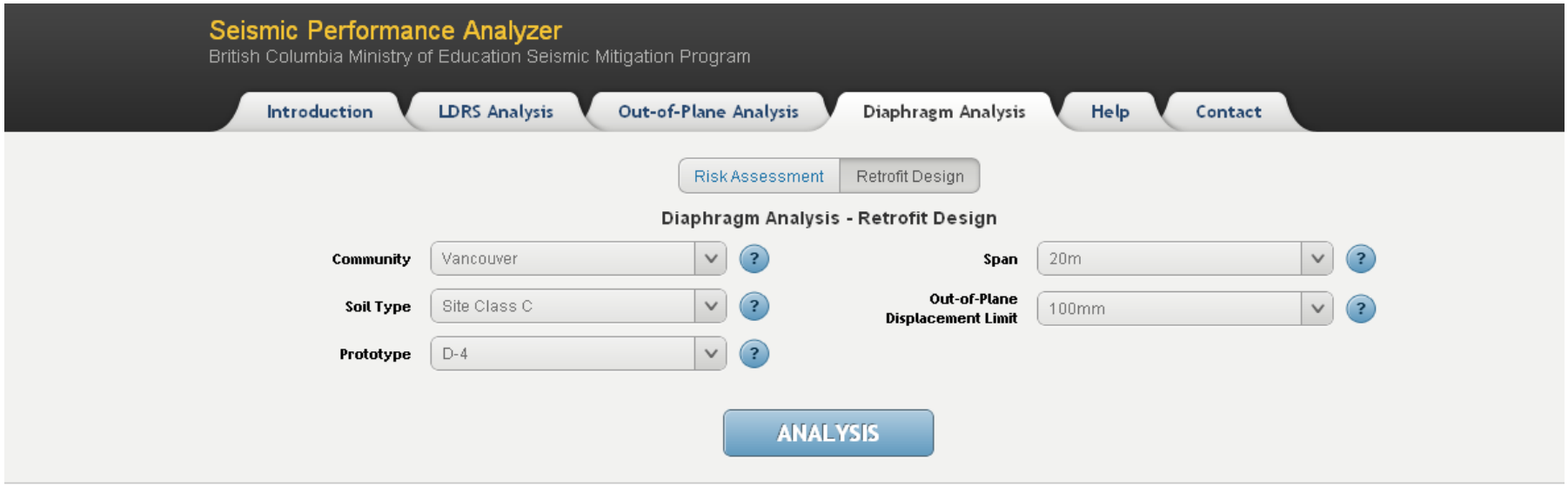
LDRS Risk Assessment Results

Print PDF

Risk Assessment Analysis Result	
PDE = 12.8%	
Retrofit Priority Ranking	H1

Analysis Results	
PDE	Rm
10.0%	3.8%W
7.0%	5.3%W
5.0%	7.1%W
3.0%	10.5%W
2.0%	13.7%W
1.0%	20.7%W





Diaphragm Retrofit Design Results

Print PDF

Diaphragm Retrofit Design Analysis Results

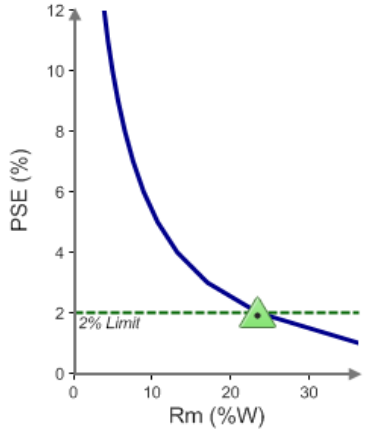
Rmd(%w) = 23.4%

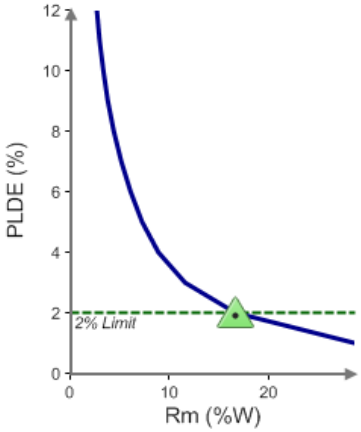
Shear Strain Check

Rmd(%w) = 23.4%

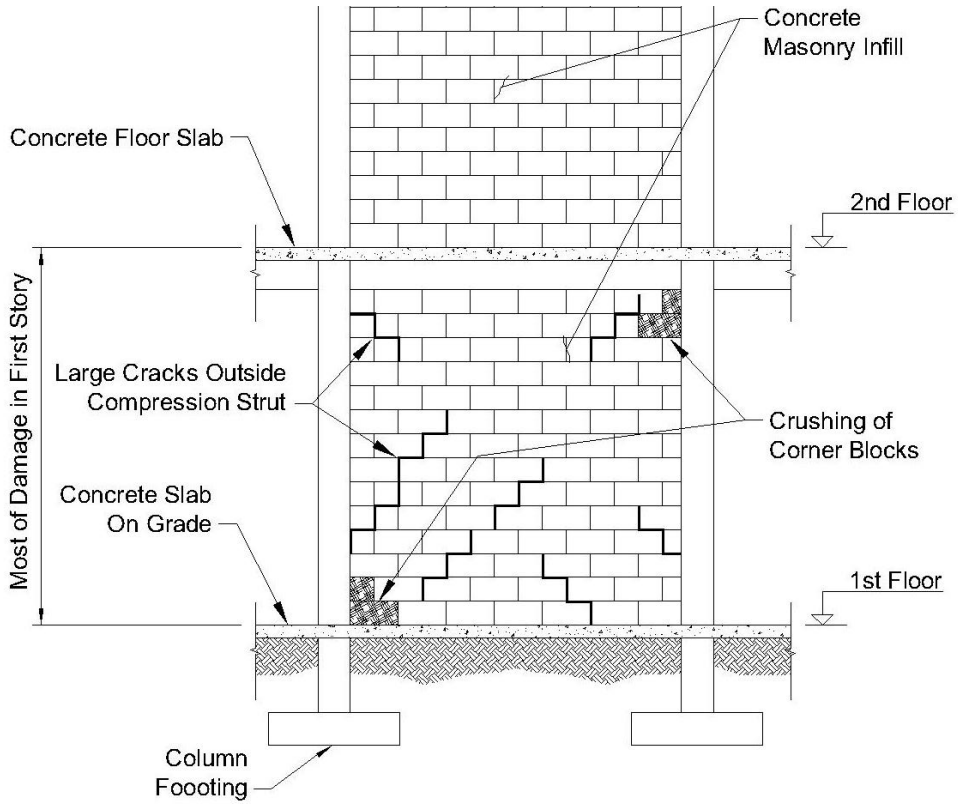
Displacement Check

Rmd(%w) = 16.6%



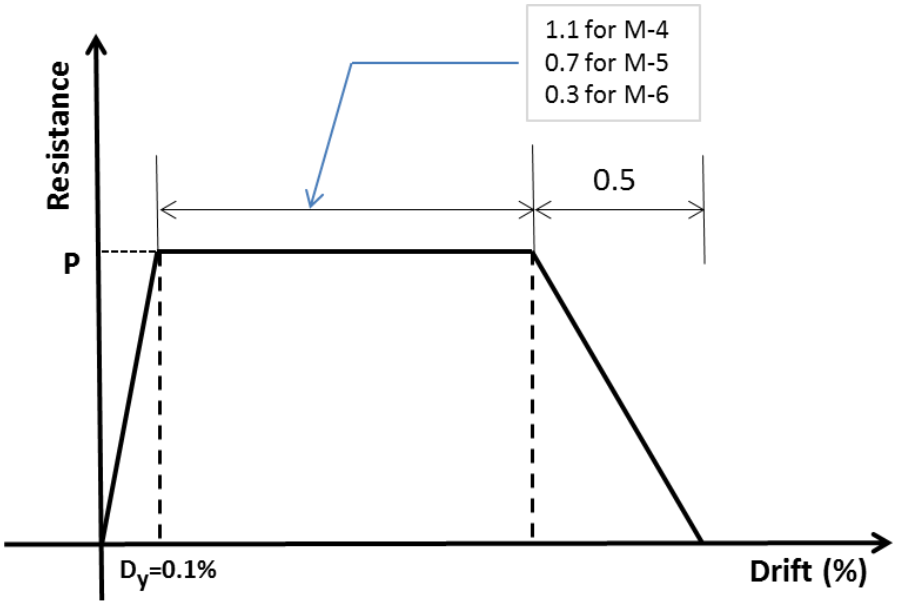


SRG2: New Masonry Infill Prototypes, M4, M5, M6



$ß = \frac{Vr}{Vm}$	Aspect Ratio (AR)	Masonry Infill Prototype
ß ≥ 1.3	2.5 > AR ≥ 1.0	M-4
	1.0 > AR ≥ 0.5	M-5
1.3 > ß ≥ 0.7	2.5 > AR ≥ 1.0	M-5
	1.0 > AR ≥ 0.5	M-6
ß < 0.7	2.5 > AR ≥ 0.5	M-6

Notes:
(1) Aspect Ratio (AR) is ratio of wall height / length.

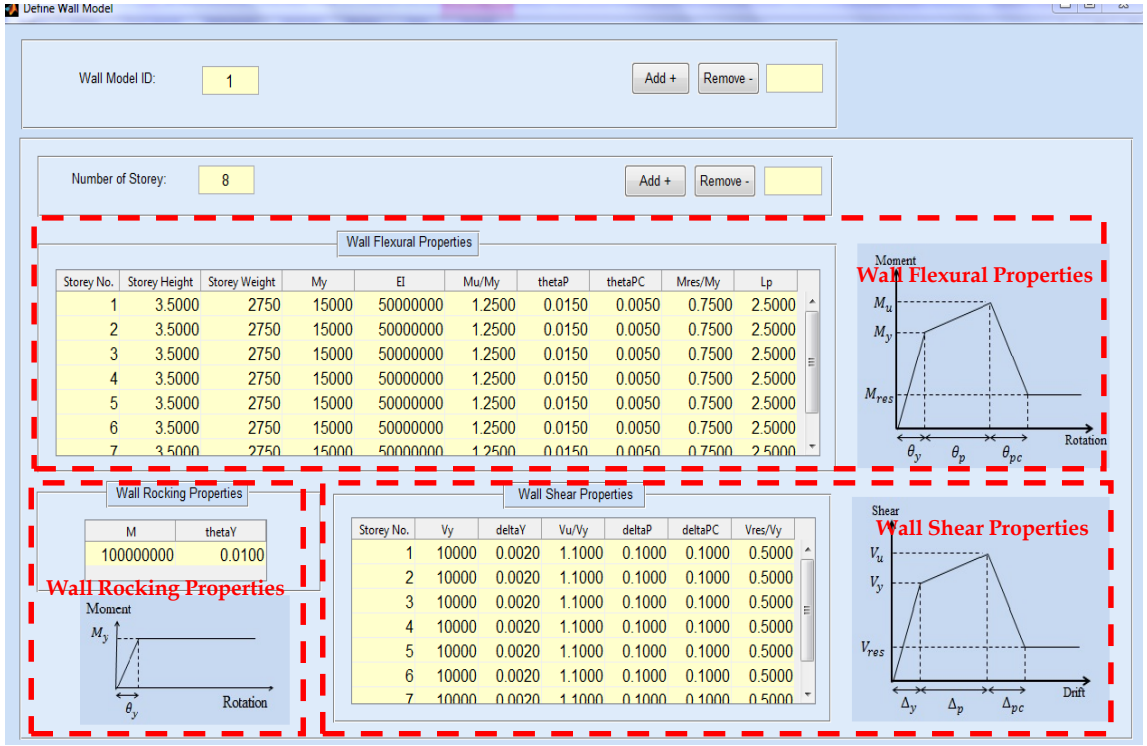


Vancouver, Height = 3000mm, Site Class C

Prototype	Design Drift Limit (DDL)	Required Factored Resistance, Rm (%Ws)
M-4	0.75%	21.2%
M-5	0.50%	25.0%
M-6	0.25%	31.2%

Seismic Performance Analyzer 2

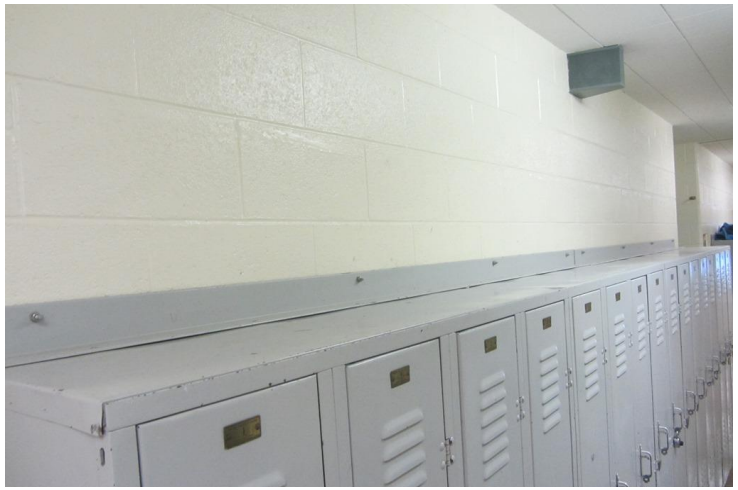
- Suitable for mid-rise buildings
- Building specific
  - nonlinear dynamic analysis under suites of earthquakes of various intensities in a fast and computationally efficient manner.
- optimal use of parallel processing capabilities.
- UBC is developing a web-based version of Analyzer 2



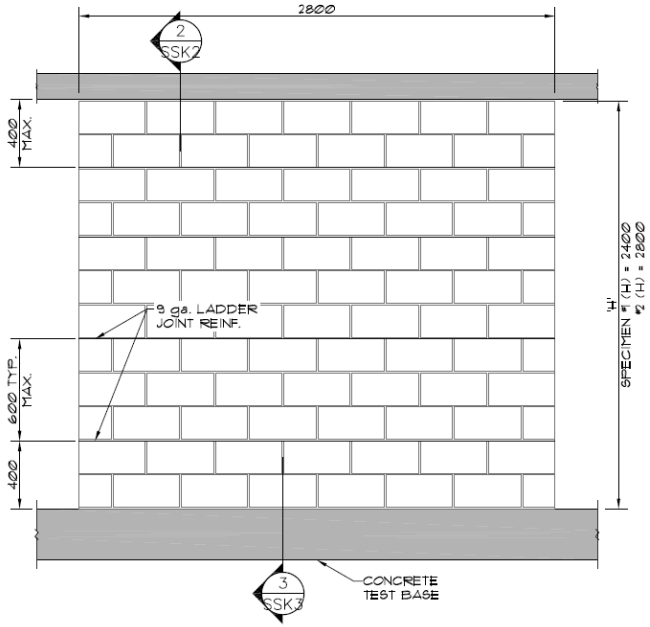
Analyzer 2 Shearwall model including flexural, shear and rocking nonlinearity

Out-of-Plane Testing
4” (100mm) Block Partition Walls

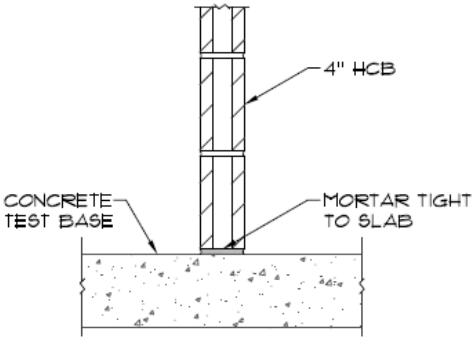
- significant amount of unreinforced, unrestrained hollow concrete block walls
- current costs: $150 - $200 /m2 to replace or restrain
- need an effective, economical, efficient retrofit
- one side application if possible
- test various retrofit concepts
- UBC shake table tests to start September 2013



Wall Details



- built in lab by skilled field masons
- using 4” HCB; normal weight and Type S (10MPa) Mortar
- test 1.6m or 3.0m widths
- test 2.4m or 2.8m heights
- bottom of wall unrestrained; mortared to base only

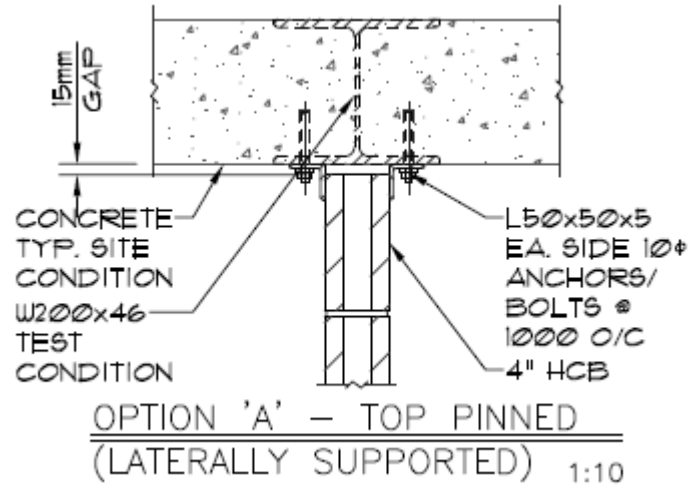


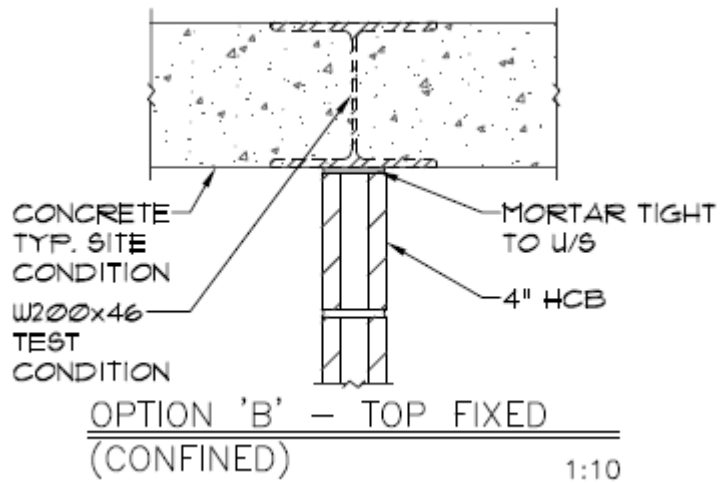
Retrofit Concept 1: Top Restraint

two types of top restraint

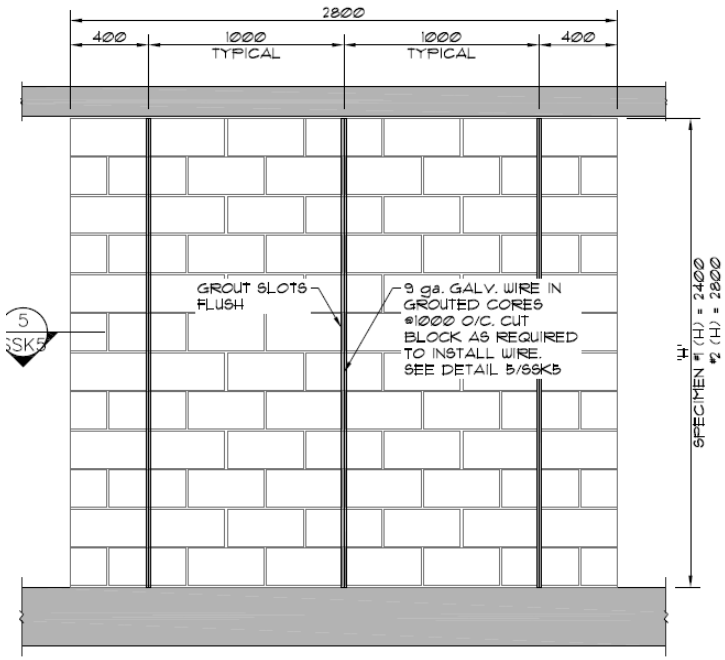
(A) will place 400mm sections of steel angle every 1000mm along length of wall; effectively creating a pin at the top

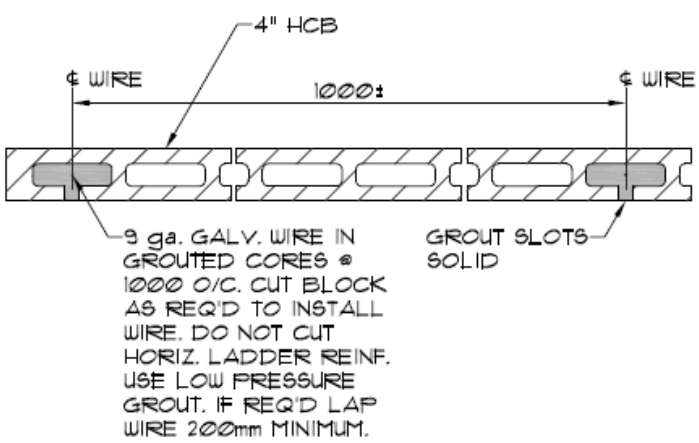
(B) will have masons install mortar between top of wall and underside of floor to effectively create a fixed detail





Retrofit Concept 2: Grouted Wire

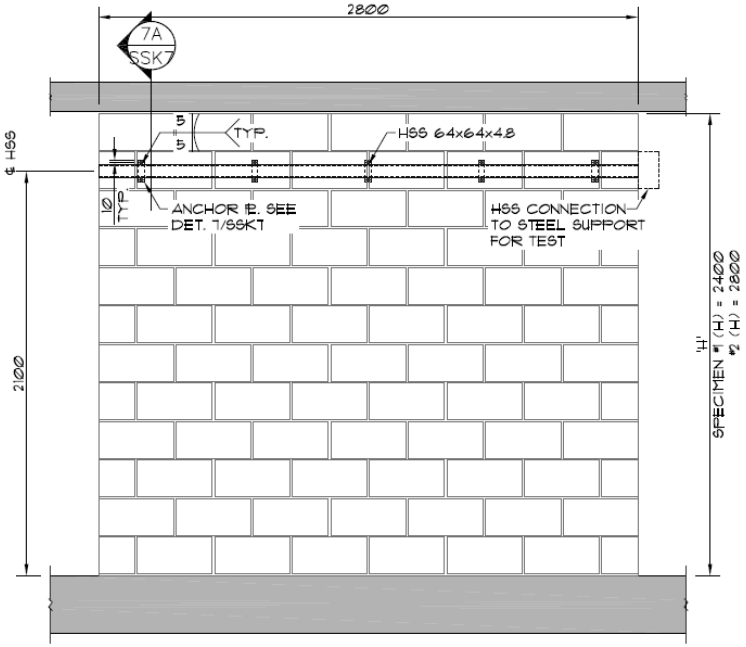


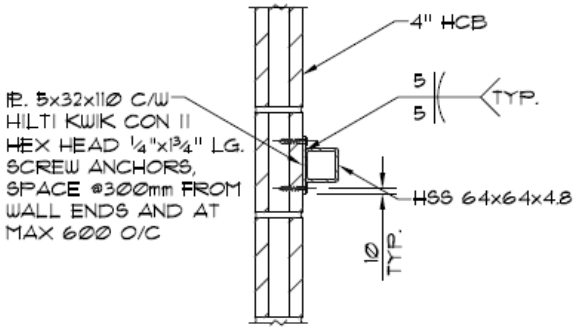


- cut slots or holes at 1m spacing
- install 9 ga. galvanized wire through slots/holes and grout top to bottom
- concept is to minimize cutting by using a flexible wire that still gives enough resistance to OOP failure

Retrofit Concept 3: Horizontal Restraint

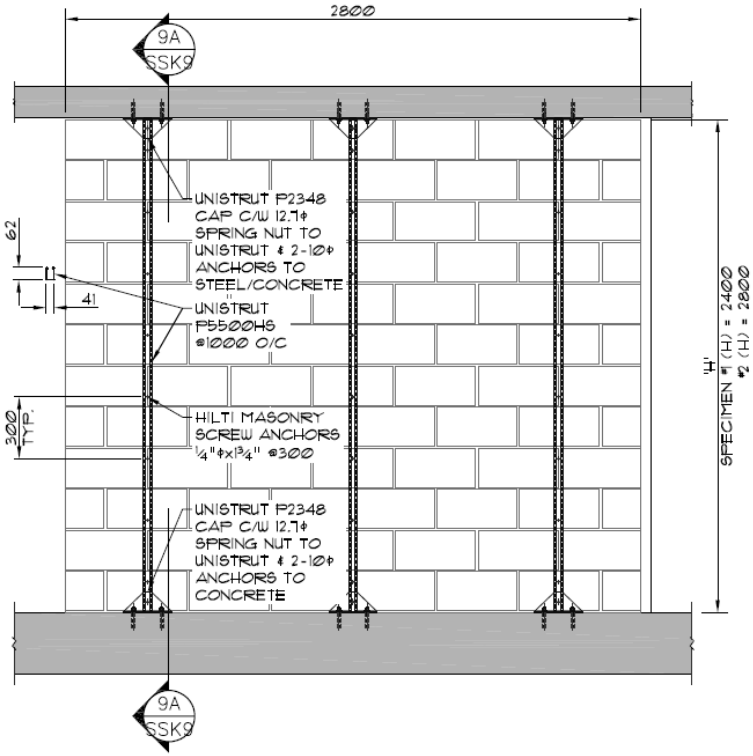
- HSS section along length of wall, above typical door height
- Reduces the free height of the wall
- HSS is anchored to wall every 600mm

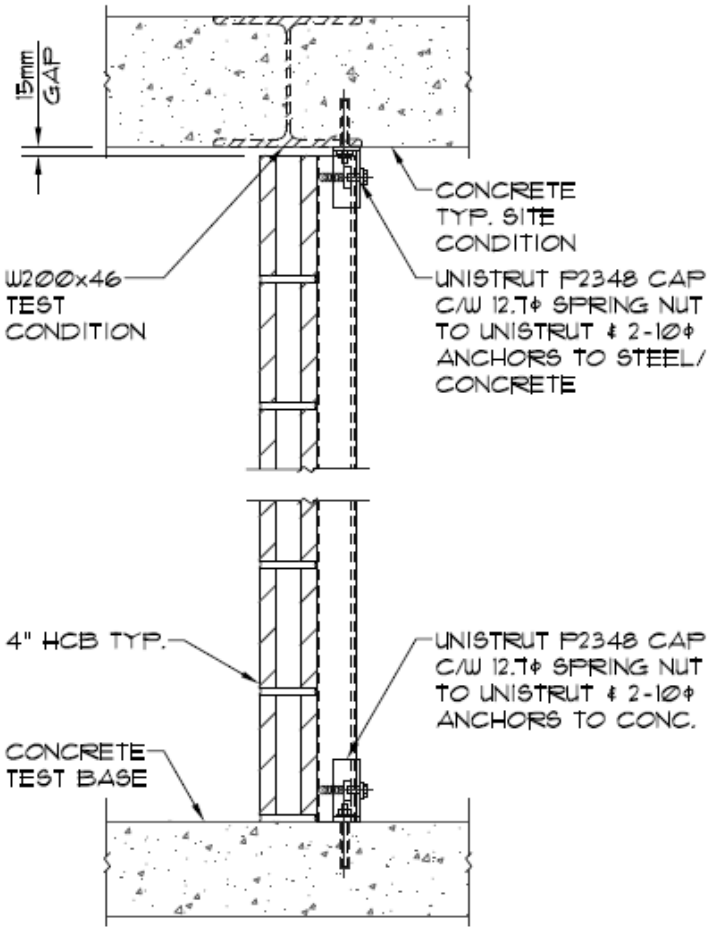




HORIZONTAL RESTRAINT
(FOR TEST CONDITION) 1:10

Retrofit Concept #4: Vertical Strongbacks



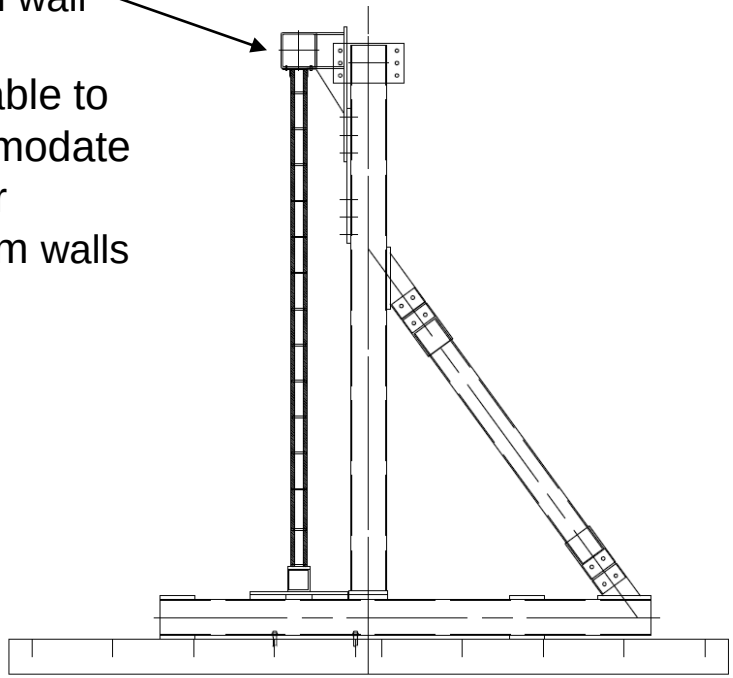


- vertical uni-strut type strongbacks
- connected to floor and underside of slab
- anchored to wall along the height
- Installed every 1000mm

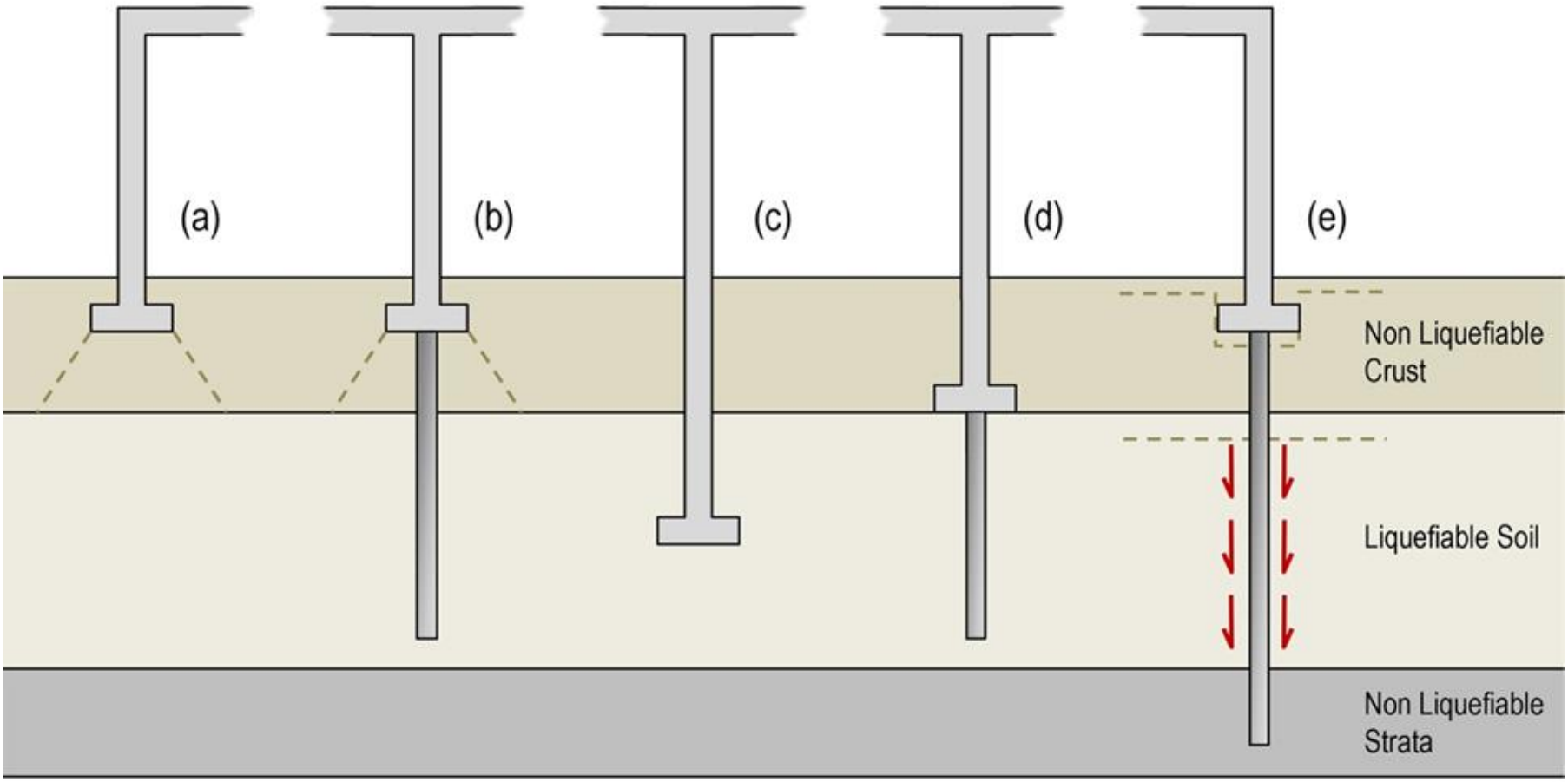
Shake-table Tests

HSS 203x203
at top of wall

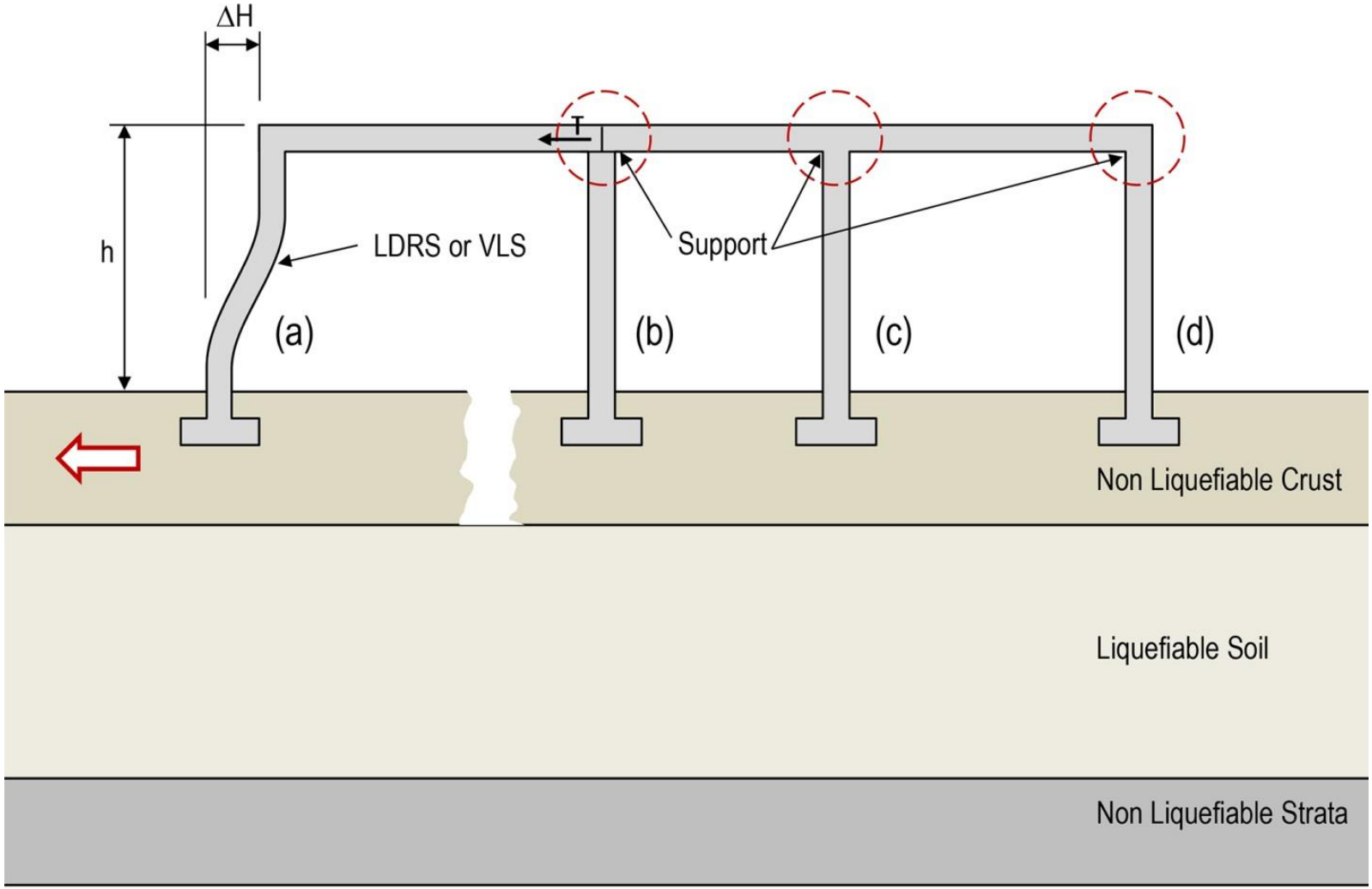
Adjustable to
accommodate
2800 or
2400mm walls



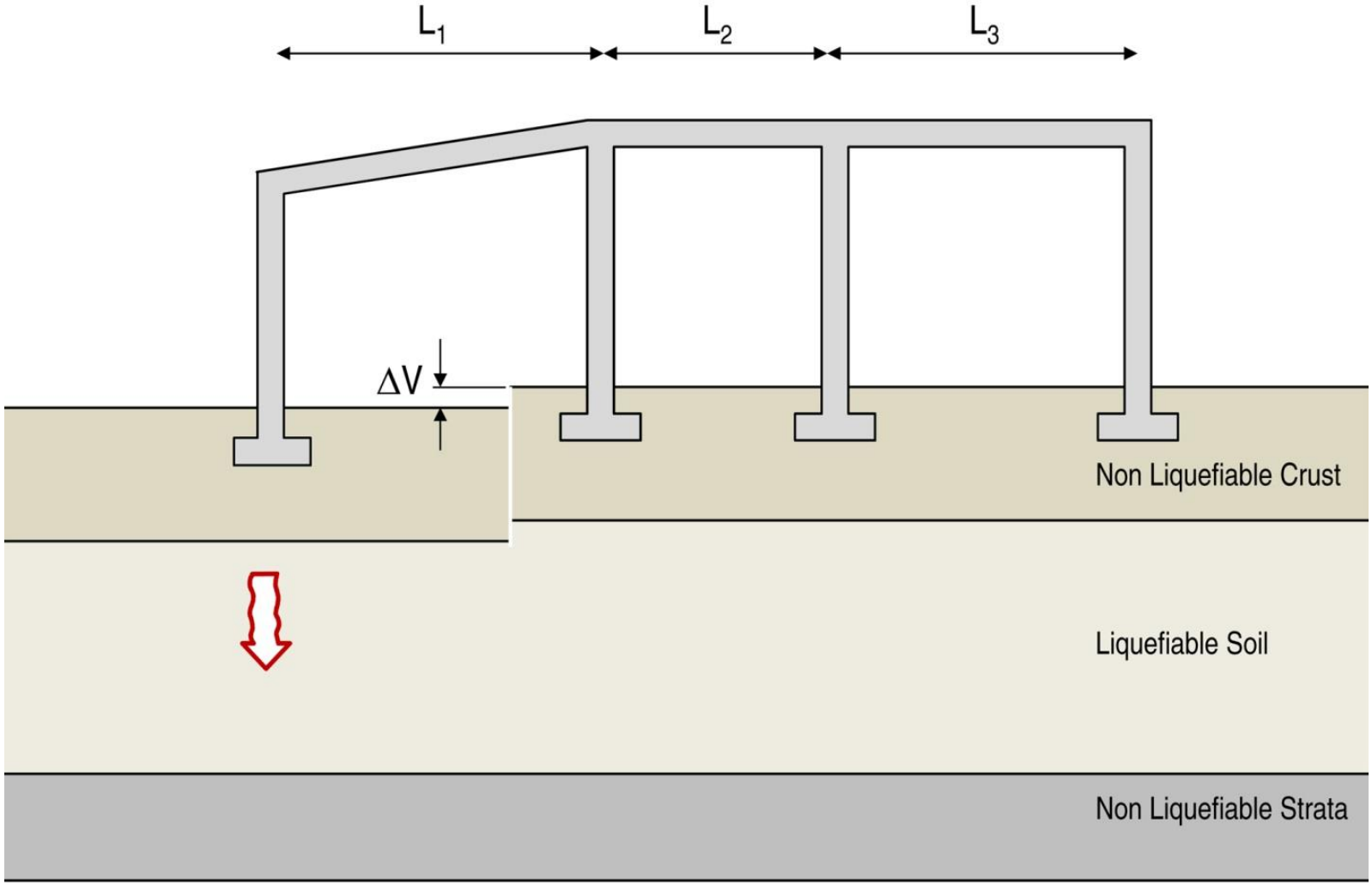
Liquefaction Guidelines



Differential Lateral Movement



Differential Vertical Movement



Liquefaction Guidelines

Liquefaction Drift Limit (LDL) shall accommodate the following three components:

- Residual Drift (RD)
- Effective Drift demand due to lateral soil (horizontal) spreading effects (EDH)
- Effective Drift demand due to differential vertical soil settlement effects (EDV)

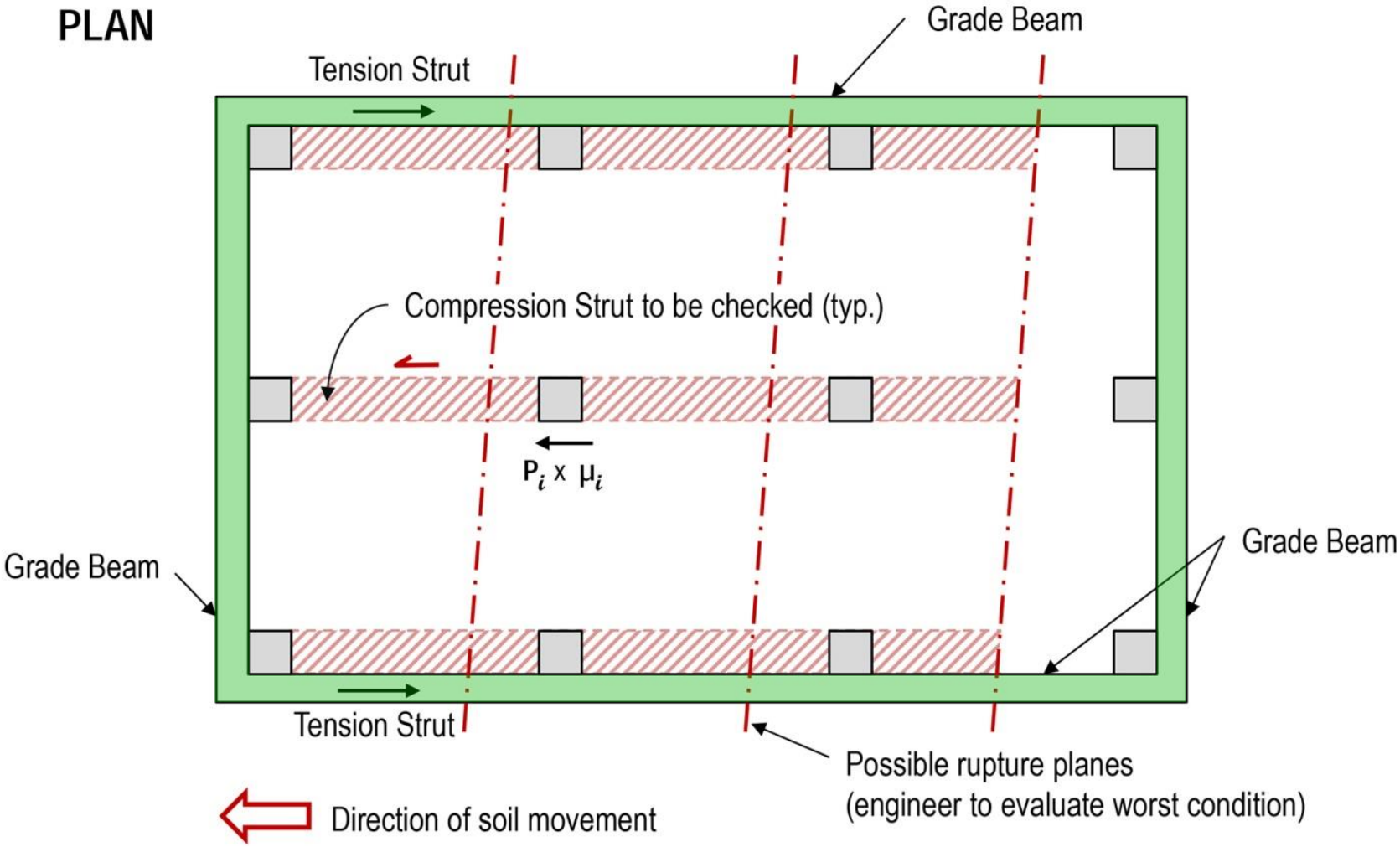
$$\mathbf{RD + EDH + EDV < LDL}$$

$$\mathbf{RD = 20\%\ DDL}$$

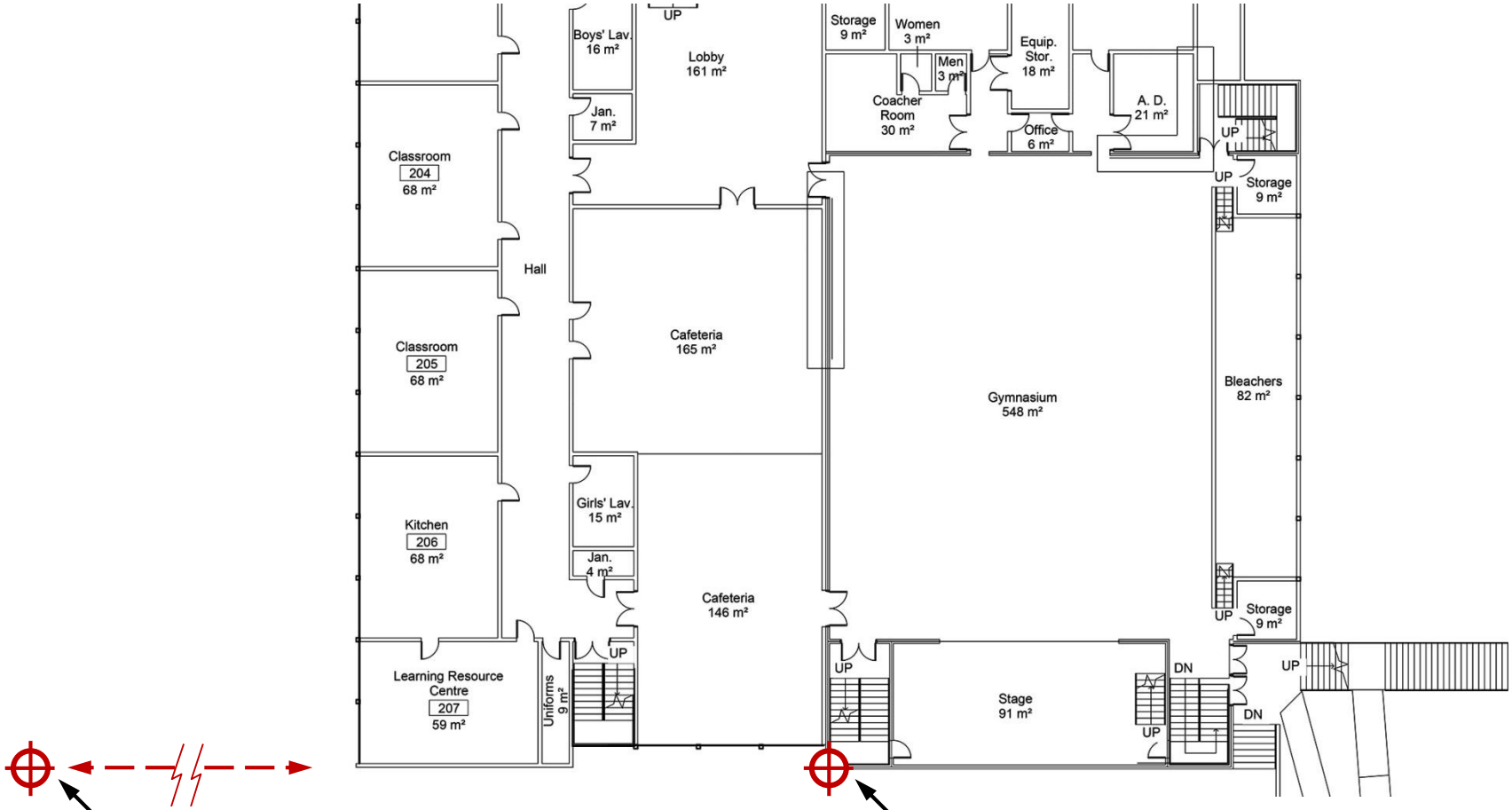
$$\mathbf{EDH = \Delta H / h}$$

$$\mathbf{EDV = \Delta V / L}$$

Perimeter Ring to Constrain ΔH



Post-Earthquake Evaluation



Location of P-wave instrumentation and strong motion instrumentation

Location of strong motion instrumentation, intersection of 2 LDRS, top of walls

Post-Earthquake Evaluation

TABLE 1 - INSTRUMENTED DATA		
DATA DESCRIPTION	EAST/WEST	NORTH/SOUTH
HAZARD TYPE		
MAXIMUM LEVEL OF SHAKING		
PEAK DRIFT		

TABLE 2 - "THRESHOLD" SHAKING FOR CRUSTAL GROUND MOTIONS			
ELEMENT SHAKING NO.	ELEMENT DESCRIPTION	EAST/WEST SHAKING	NORTH/SOUTH SHAKING
2	NEW HORIZONTAL PLYWOOD SHEARWALLS	120%	90%
3	NEW CONCRETE SHEARWALLS	130%	120%
4	GLULAM BEAM CONNECTIONS	120%	130%
5	GLULAM BEAM STEEL PLATE CONNECTIONS	160%	110%
6	NEW STEEL PLEDESTAL	130%	110%

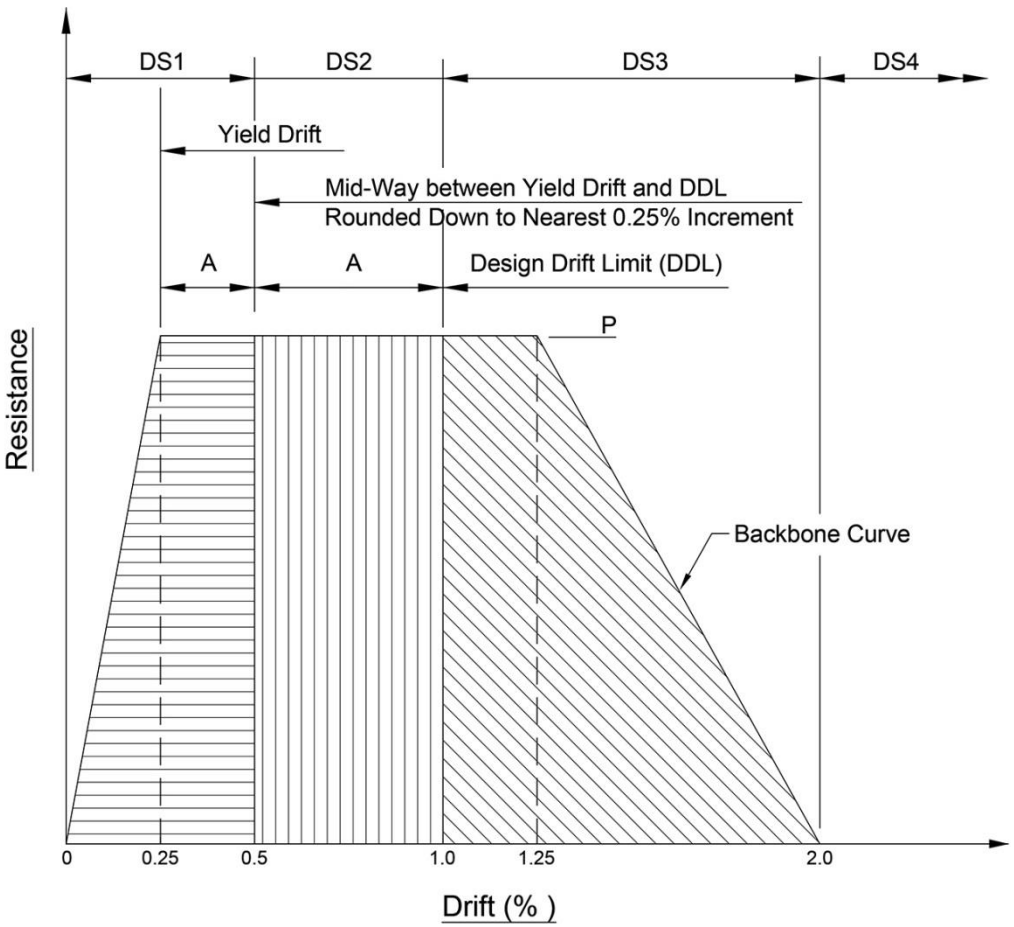
TABLE 3 - "THRESHOLD" SHAKING FOR SUB-CRUSTAL GROUND MOTIONS			
ELEMENT SHAKING NO.	ELEMENT DESCRIPTION	EAST/WEST SHAKING	NORTH/SOUTH SHAKING
2	NEW HORIZONTAL PLYWOOD SHEARWALLS	130%	100%
3	NEW CONCRETE SHEARWALLS	150%	130%
4	GLULAM BEAM CONNECTIONS	150%	140%
5	GLULAM BEAM STEEL PLATE CONNECTIONS	180%	120%
6	NEW STEEL PLEDESTAL	150%	120%

TABLE 4 - "THRESHOLD" SHAKING FOR SUBDUCTION GROUND MOTIONS			
ELEMENT SHAKING NO.	ELEMENT DESCRIPTION	EAST/WEST SHAKING	NORTH/SOUTH SHAKING
2	NEW HORIZONTAL PLYWOOD SHEARWALLS	140%	110%
3	NEW CONCRETE SHEARWALLS	150%	140%
4	GLULAM BEAM CONNECTIONS	140%	150%
5	GLULAM BEAM STEEL PLATE CONNECTIONS	180%	130%
6	NEW STEEL PLEDESTAL	150%	130%

- Reference is 100% of 2% in 50yr motion

Post-Earthquake Evaluation

TABLE 1: DAMAGE STATES FOR CONCRETE SHEARWALLS FOR N/S & E/W SHAKING		
DAMAGE STATE	DRIFT RANGE D (%)	DAMAGE OBSERVATIONS
DS1	D <= 0.5%	(a) No signifcant spalling (b) No significant shear cracking (c) Flexural cracks <= 3mm in width (d) No interface movement at base of shearwall
DS2	0.5% < D <= 1.0%	(a) Some limited spalling (b) No significant shear cracking (c) Flexural cracks < 6mm in width (d) No interface movement at base of shearwall
DS3	1.0% < D <= 2.0%	(a) Significant spalling (b) Flexural cracks <= 10mm in width (c) Limited Interface < 2mm at base of shearwall (d) Residual Drift <= 1.0%
DS4	D > 2.0%	(a) Significant spalling (b) Flexural cracks > 10mm in width (c) Interface movement >= 2 at base of shearwall (d) Residual Drift > 1.0%

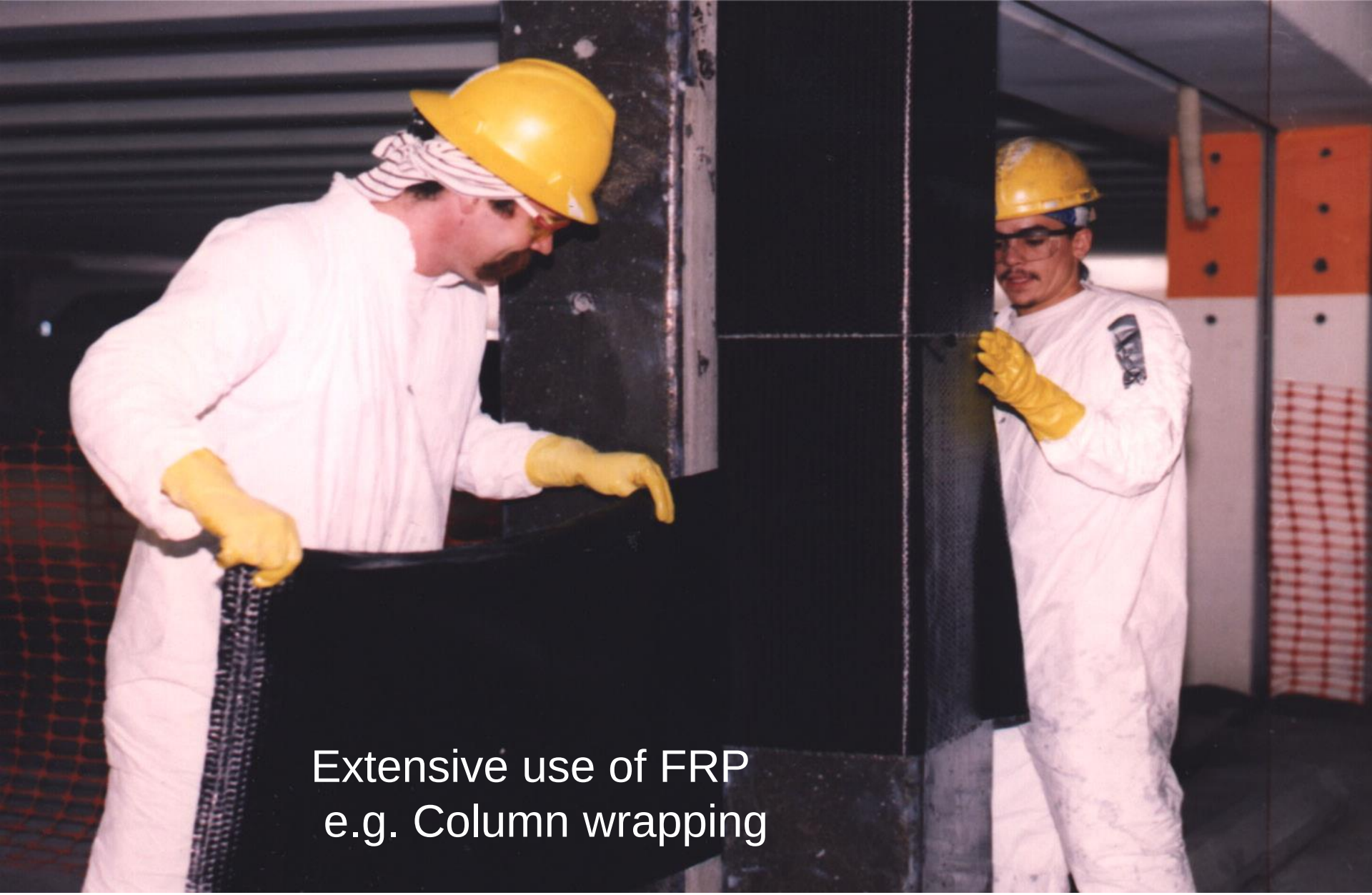


DAMAGE STATES FOR PROTOTYPE C-6
(CONCRETE SHEARWALL IN FLEXURE)

External Concrete Retrofit

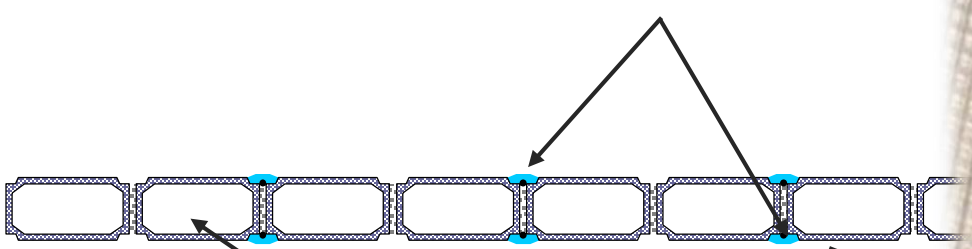
Burnaby High School – Before

Burnaby High School – After with External Upgrade Scheme


Extensive use of FRP
e.g. Column wrapping

FRP to Upgrade Glass Block 'Windows'

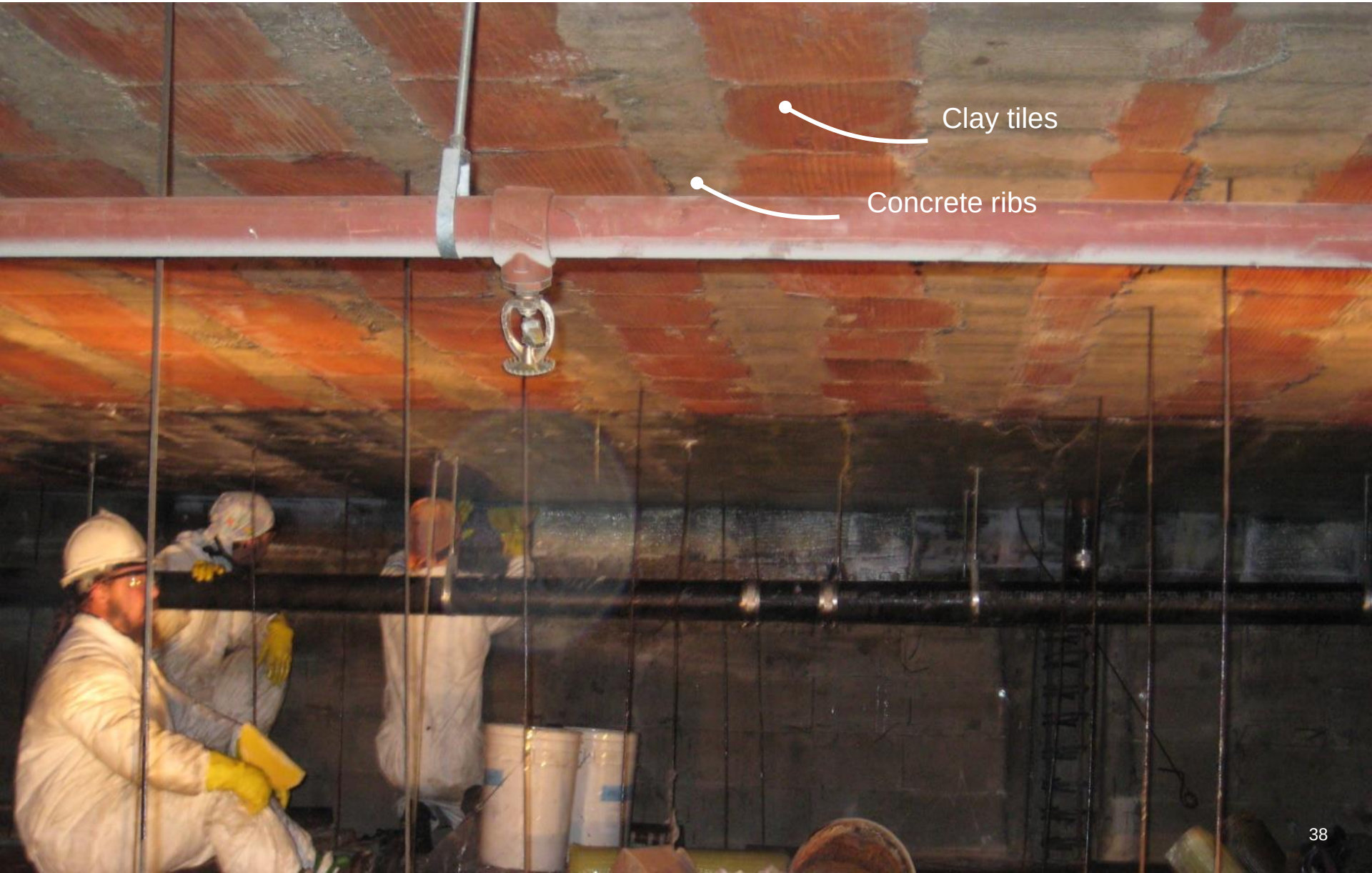
6mm dia. glass fibre rods



Glass blocks

FRP Upgrade of Concrete Wall

Diaphragm Shear Upgrade - Before



Diaphragm Shear Upgrade – After installation of FRP

Hundreds Board
September
Happy Birthday!
The Alphabet
E.J. Hughes

A216

y = 2f(x-1)
P28