R FACTORS & SPECIAL PROVISIONS

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Robert Tremblay, École Polytechnique, Montreal
and
Denis Mitchell, McGill University, Montreal

and their use is greatly appreciated.

Calgary, 2004

Overview

- Development of approach for R factors
- Design and detailing of Seismic Force Resisting Systems (SFRS)
- System limitations
- Special provisions
- Comparison of 1995 and 2004 base shears

R Factors

1995

$$V = \frac{V_e}{R} U$$

V_e – 10%/50 yr. prob

U=0.6 ???

R – ductility factor

2005

$$V = \frac{V_e}{R_d R_o}$$

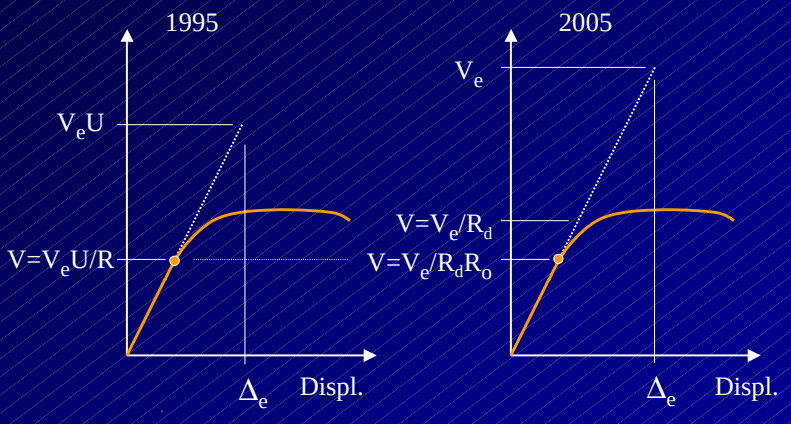
V_e – 2%/50 yr. prob

≅

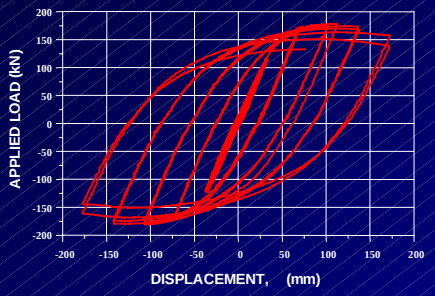
R_d – ductility factor

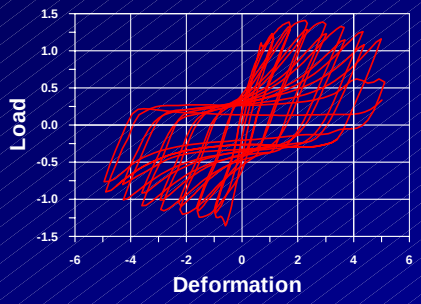
R_o – overstrength factor

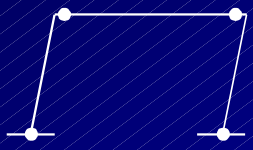
Comparison of design force levels

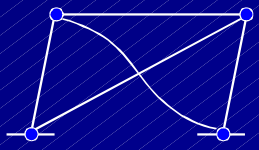


R_d (Ductility) Factor









R_o (Overstrength) Factor

$$R_o = R_{size}\, R_{\phi}\, R_{yield}\, R_{sh}\, R_{mech}$$

R_{size} = rounding of sizes and dimensions

R_{ϕ} = difference between nominal and factored resistance, $1 / \phi$

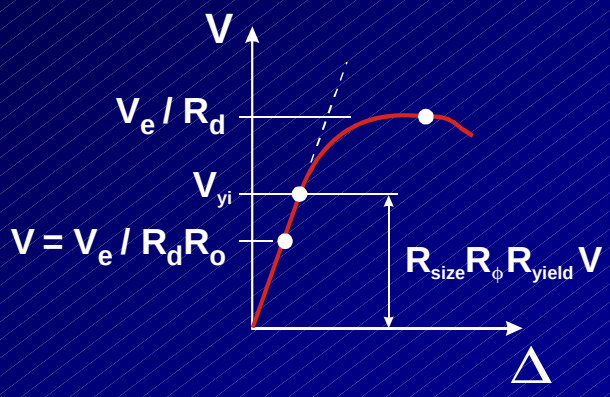
R_{yield} = ratio of actual "yield" to minimum specified "yield"

R_{sh} = overstrength due to strain hardening

R_{mech} = overstrength arising from mobilising full capacity of structure (collapse mechanism)

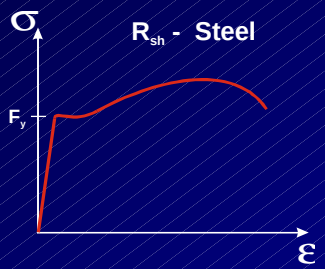
R_o (Overstrength) Factor

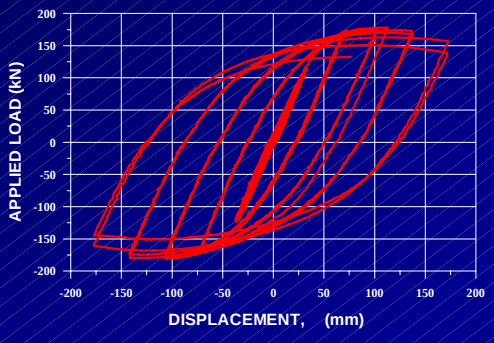
$$R_o = R_{size}\, R_\phi\, R_{yield}\, R_{sh}\, R_{mech}$$



R_o (Overstrength) Factor

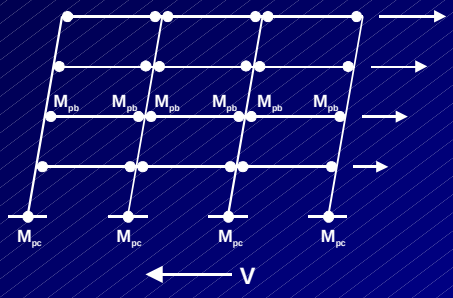
$$R_o = R_{size}\, R_\phi\, R_{yield}\, R_{sh}\, R_{mech}$$

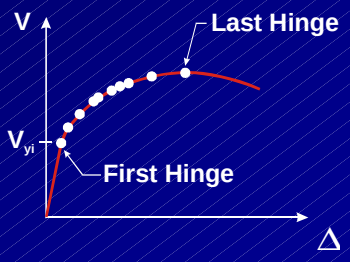




R_o (Overstrength) Factor

$$R_o = R_{size}\, R_\phi\, R_{yield}\, R_{sh}\, R_{mech}$$

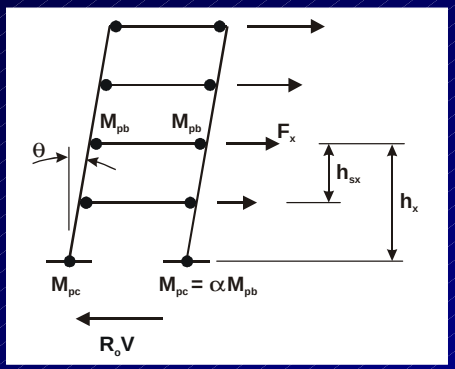




Capacity design:

$$M_{pc} = \alpha M_{pb}$$

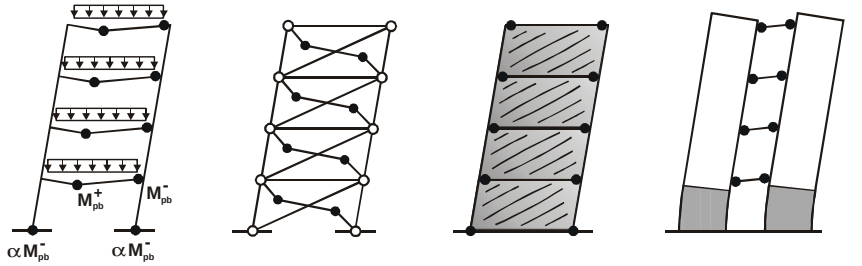
R_o (Overstrength) Factor



$$R_{mech} = \frac{N + \alpha}{N + 1}$$

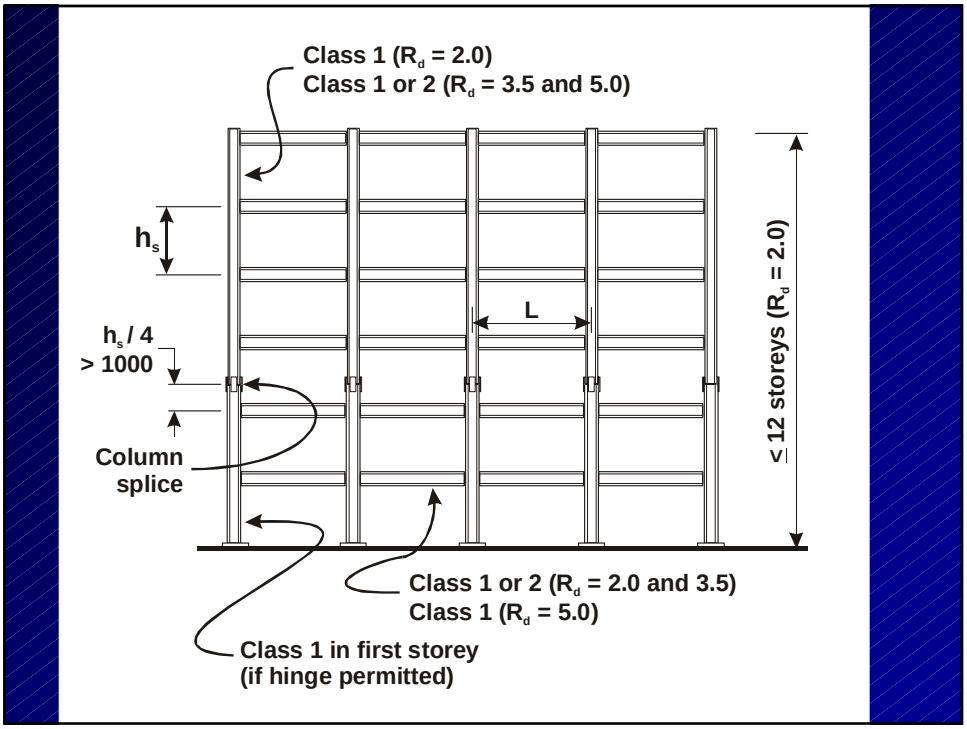
R_o (Overstrength) Factor

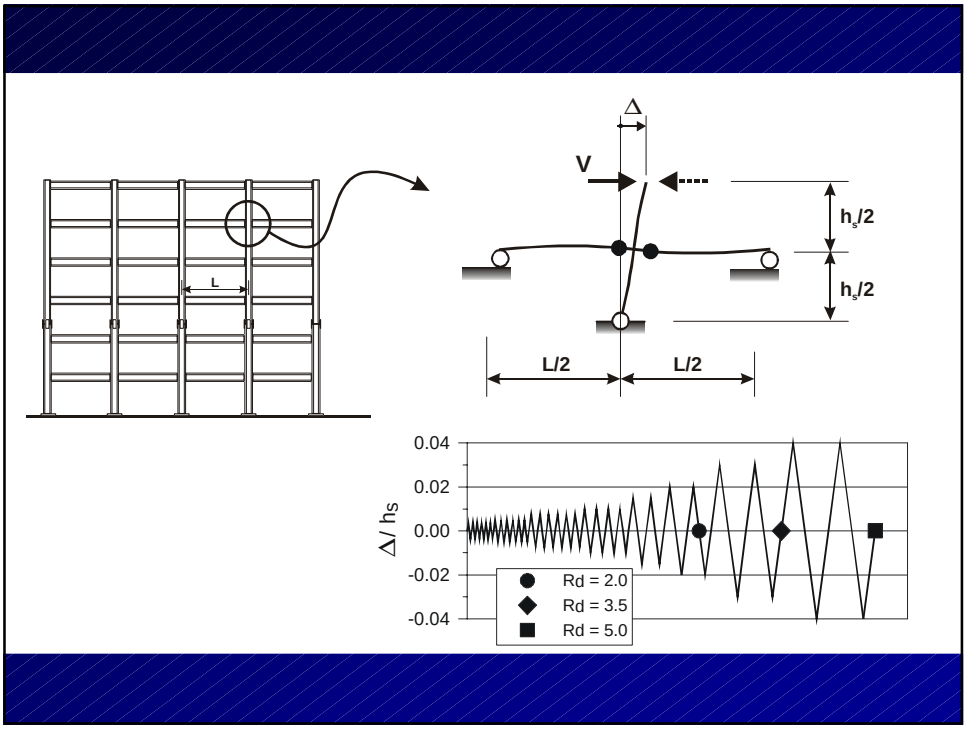
R_o depends on the system :

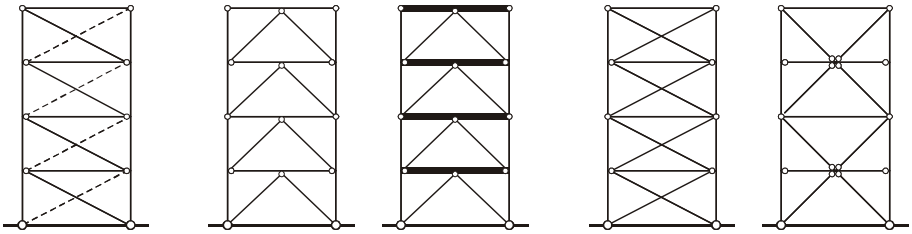


R Factors - Steel

System	Cat.	R_d	R_o	R_dR_o	R/U
Moment Resisting Frames	D	5.0	1.5	7.5	6.7
	MD	3.5	1.5	5.3	5.0
	LD	2.0	1.3	2.6	-
Concentrically braced frames	MD	3.0	1.5	4.5	5.0
	LD	2.0	1.3	2.6	3.3
Eccentrically braced frames	D	4.0	1.7	6.8	6.7
Plate walls	D	5.0	1.6	8.0	6.7
	LD	2.0	1.5	3.0	3.3
	-				
Conventional constr.		1.5	1.3	2.0	2.5


Class 1 (R_d = 2.0)
Class 1 or 2 (R_d = 3.5 and 5.0)
h_s
h_s / 4
> 1000
Column
splice
L
≤ 12 storeys (R_d = 2.0)
Class 1 or 2 (R_d = 2.0 and 3.5)
Class 1 (R_d = 5.0)
Class 1 in first storey
(if hinge permitted)


L
Δ
V
h_s/2
h_s/2
L/2
L/2
0.04
0.02
0.00
-0.02
-0.04
Δ/ h_s
Rd = 2.0
Rd = 3.5
Rd = 5.0



Tension-only bracing

Chevron or V-bracing

"Weak beam" design

"Strong beam" design

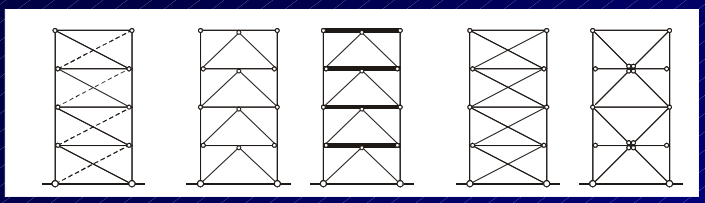
Tension-compression bracing

≤ 8 storeys (R_d = 2.0)
≤ 4 storeys (R_d = 3.0)

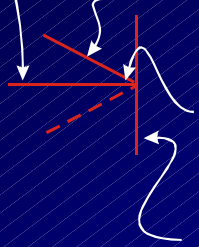
≤ 4 storeys

≤ 12 storeys (R_d = 2.0)
≤ 8 storeys (R_d = 3.0)

≤ 12 storeys (R_d = 2.0)
≤ 8 storeys (R_d = 3.0)



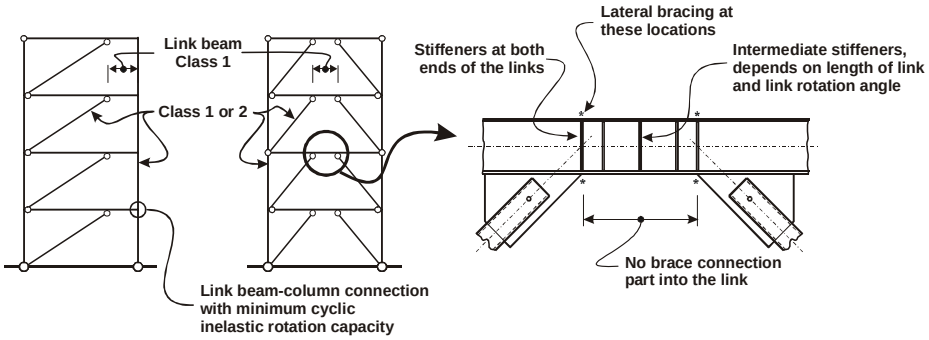
- Class 1 (if hinge permitted)

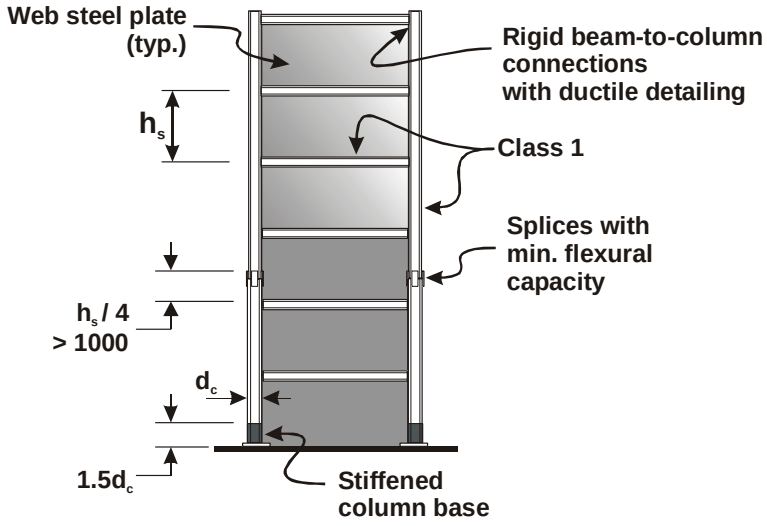


- KL/r ≤ 200 (300 for 1- and 2-storey tension-only bracing & R_d = 2.0)
- Maximum b/t ratio, depends on KL/r, R_d, and seismic zone
- Special stitch detailing for built-up cross-sections

- Brace connections with ductile rotational behaviour or minimum flexural strength (except for low seismic zone, KL/r > 100, & R_d = 2.0)

- Class 1 or 2
- Continuous and constant cross-section over 2 storeys (4 storeys for tension-only bracing & R_d = 3.0)


Link beam
Class 1
Class 1 or 2
Link beam-column connection
with minimum cyclic
inelastic rotation capacity
Lateral bracing at
these locations
Stiffeners at both
ends of the links
Intermediate stiffeners,
depends on length of link
and link rotation angle
No brace connection
part into the link


Web steel plate
(typ.)
Rigid beam-to-column
connections
with ductile detailing
h_s
Class 1
Splices with
min. flexural
capacity
h_s / 4
> 1000
d_c
1.5d_c
Stiffened
column base

R_o Factors - Steel

System	Cat.	Calculation of R_o						Proposed R_o
		R_{size}	R_ϕ	R_{yield}	R_{sh}	R_{mech}	R_o	
Moment resisting frames	D	1.05	1.11	1.10	1.15	1.00	1.47	1.5
	MD	1.05	1.11	1.10	1.15	1.00	1.47	1.5
	LD	1.05	1.11	1.10	1.05	1.00	1.35	1.3
Concentrically braced frames	MD	1.05	1.11	1.10	1.05	1.10	1.48	1.5
	LD	1.05	1.11	1.10	1.05	1.00	1.35	1.3
Eccentrically braces frames	D	1.05	1.11	1.10	1.15	1.00	1.47	1.5
Plate walls	D	1.10	1.11	1.10	1.10	1.10	1.63	1.6
	LD	1.10	1.11	1.10	1.05	1.05	1.48	1.5
Conventional constr.	-	1.05	1.11	1.10	1.00	1.00	1.28	1.3

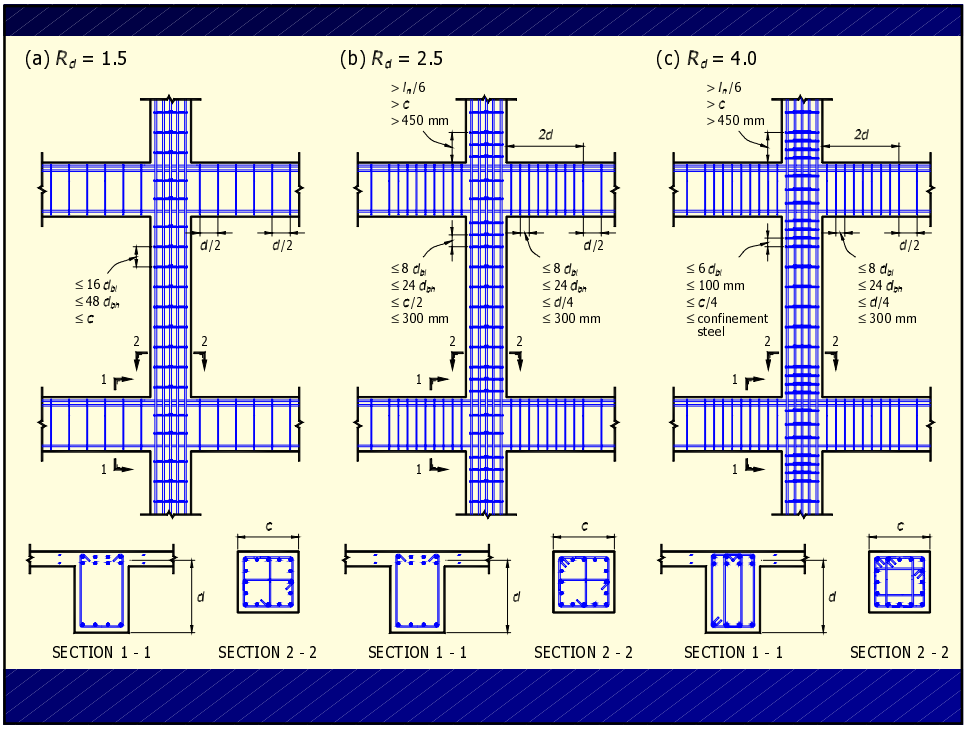
R Factors - Steel

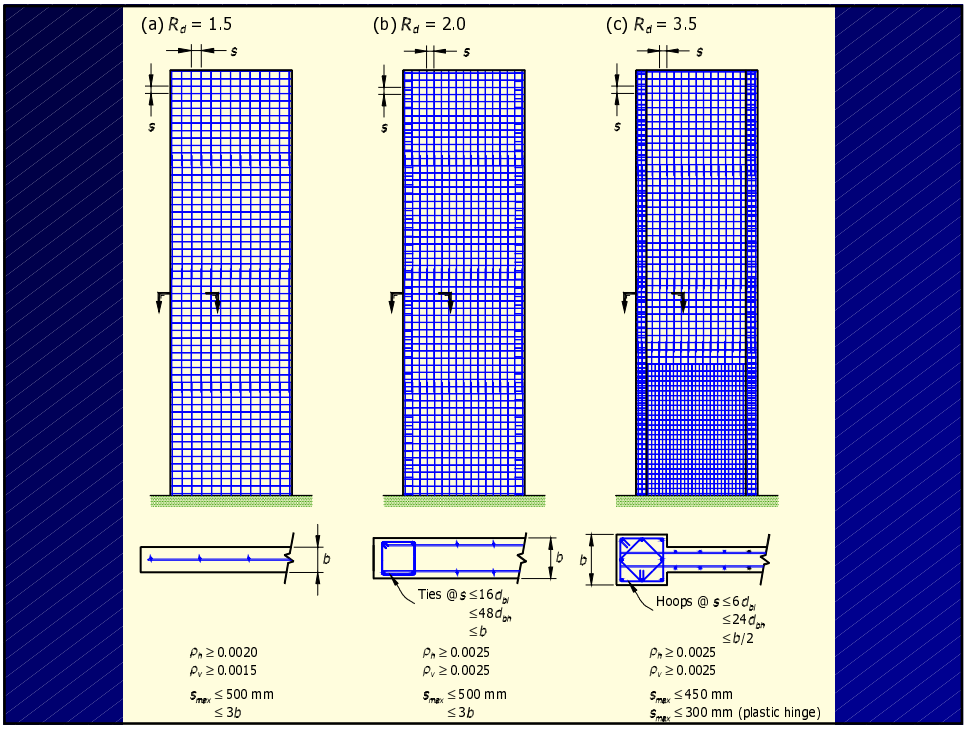
System	Cat.	R_d	R_o	R_dR_o	R/U
Moment Resisting Frames	D	5.0	1.5	7.5	6.7
	MD	3.5	1.5	5.3	5.0
	LD	2.0	1.3	2.6	-
Concentrically braced frames	MD	3.0	1.5	4.5	5.0
	LD	2.0	1.3	2.6	3.3
Eccentrically braced frames	D	4.0	1.7	6.8	6.7
Plate walls	D	5.0	1.6	8.0	6.7
	LD	2.0	1.5	3.0	3.3
	-				
Conventional constr.		1.5	1.3	2.0	2.5

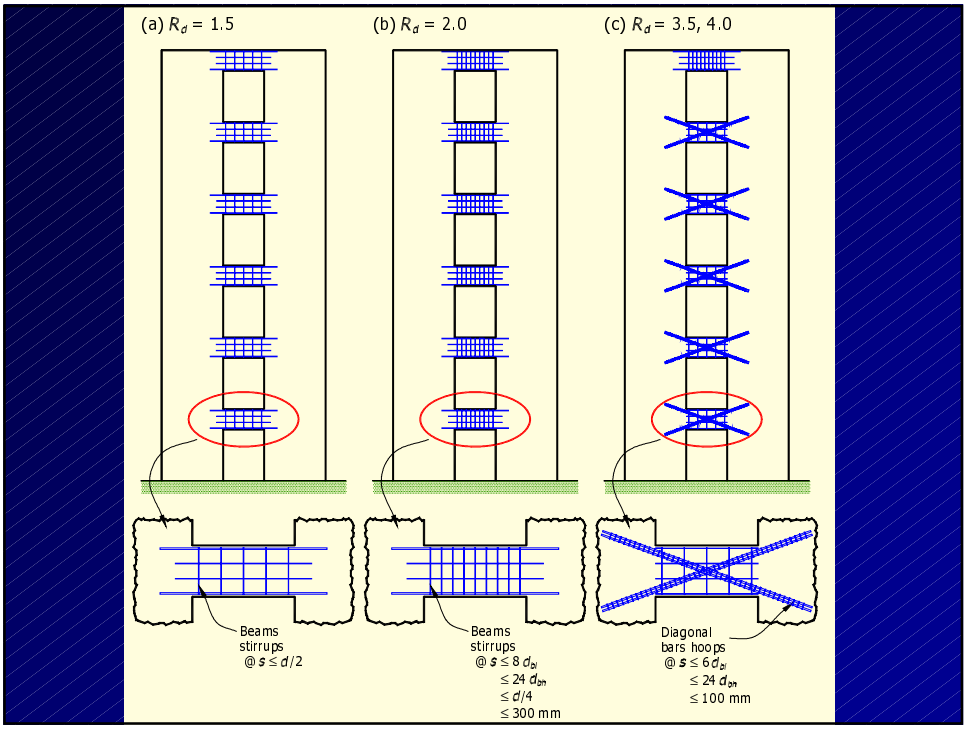
R Factors - Concrete

System	Cat.	R_d	R_o	R_dR_o
Moment Resisting Frames	D	4.0	1.7	6.8
	MD	2.5	1.4	3.5
Coupled walls	D	4.0	1.7	6.8
	D[(1)]	3.5	1.7	6.0
Shear walls	D	3.5	1.6	5.6
	MD	2.0	1.4	2.8
Conventional constr.[(2)]	-	1.5	1.3	2.0

[(1)] Ductile partially coupled wall
[(2)] Structures designed in accordance with CSA-A23.3 Cl. 1-20




(a) R_d = 1.5
(b) R_d = 2.0
(c) R_d = 3.5
s
b
Ties @ $s \le 16 d_{bl}$
$\le 48 d_{bh}$
$\le b$
Hoops @ $s \le 6 d_{bl}$
$\le 24 d_{bh}$
$\le b/2$
$\rho_h \ge 0.0020$
$\rho_v \ge 0.0015$
$s_{max} \le 500$ mm
$\le 3b$
$\rho_h \ge 0.0025$
$\rho_v \ge 0.0025$
$s_{max} \le 500$ mm
$\le 3b$
$\rho_h \ge 0.0025$
$\rho_v \ge 0.0025$
$s_{max} \le 450$ mm
$s_{max} \le 300$ mm (plastic hinge)


(a) R_d = 1.5
(b) R_d = 2.0
(c) R_d = 3.5, 4.0
Beams
stirrups
@ $s \le d/2$
Beams
stirrups
@ $s \le 8 d_{bl}$
$\le 24 d_{bh}$
$\le d/4$
≤ 300 mm
Diagonal
bars hoops
@ $s \le 6 d_{bl}$
$\le 24 d_{bh}$
≤ 100 mm

R_o Factors - Concrete

System	Cat.	Calculation of R_o						Proposed R_o
		R_{size}	R_ϕ	R_{yield}	R_{sh}	R_{mech}	R_o	
Moment resisting frames	D	1.05	1.18	1.05	1.25	1.05	1.71	1.7
	MD	1.05	1.18	1.05	1.10	1.00	1.43	1.4
Coupled walls[1]	D	1.05	1.18	1.05	1.25	1.05	1.71	1.7
	D[1]	1.05	1.18	1.05	1.25	1.05	1.71	1.7
Shear walls[2]	D	1.05	1.18	1.05	1.25	1.00	1.63	1.6
	MD	1.05	1.18	1.05	1.10	1.00	1.43	1.4
Conventional constr.	-	1.05	1.18	1.05	1.00	1.00	1.30	1.3

[1] Ductile partially coupled walls
[2] Structures designed in accordance with CSA-A23.3, Cl. 1-20

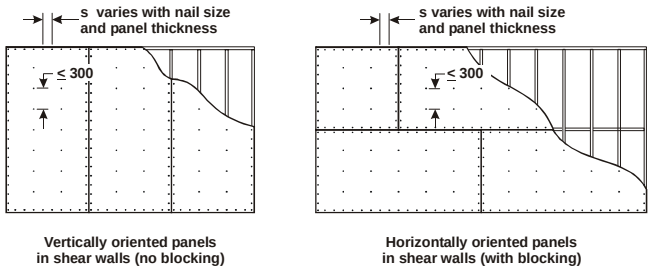
R Factors - Concrete

System	Cat.	R_d	R_o	R_dR_o
Moment Resisting Frames	D	4.0	1.7	6.8
	MD	2.5	1.4	3.5
Coupled walls	D	4.0	1.7	6.8
	D[1]	3.5	1.7	6.0
Shear walls	D	3.5	1.6	5.6
	MD	2.0	1.4	2.8
Conventional constr.[2]	-	1.5	1.3	2.0

[1] Ductile partially coupled wall
[2] Structures designed in accordance with CSA-A23.3 Cl. 1-20

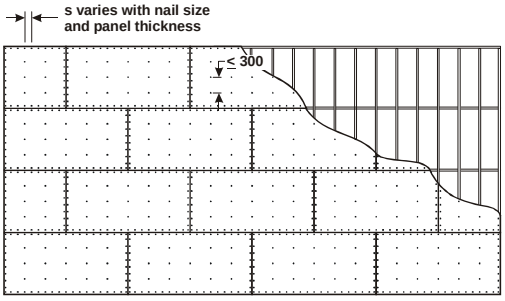
R Factors - Timber

System	Cat.	R_d	R_o	R_dR_o	R/U
Shear walls with wood based panels	D	3.0	1.7	5.1	5.0
Shear walls with wood based and gypsum panels	MD	2.0	1.7	3.4	-
Braced or moment resisting frames with ductile connections	MD LD	2.0 1.5	1.7 1.7	3.4 2.5	3.3

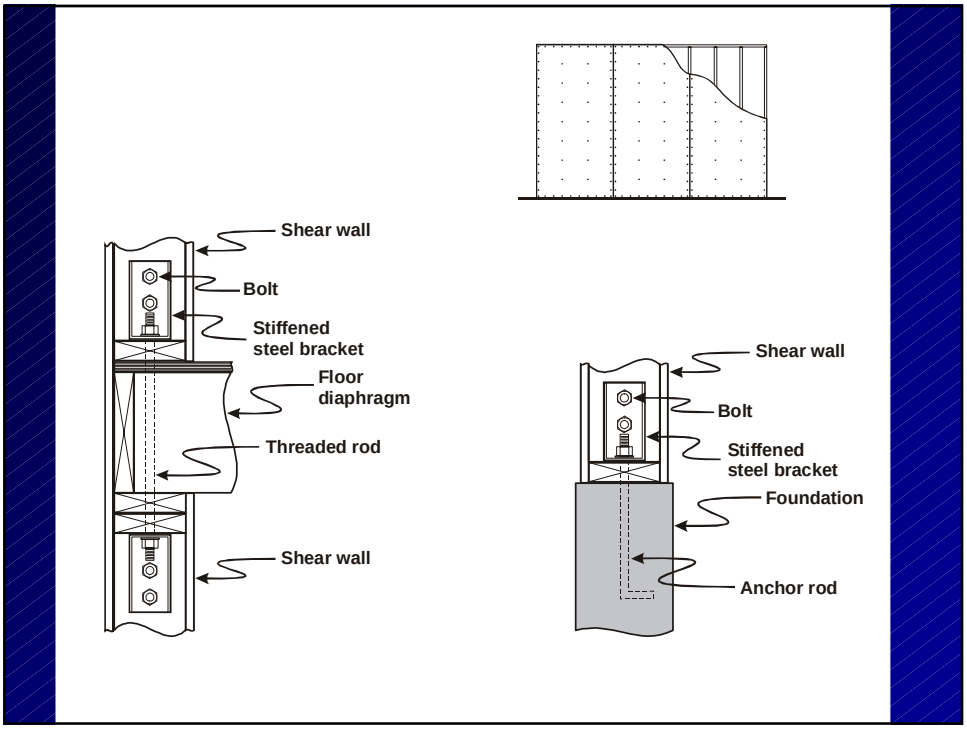


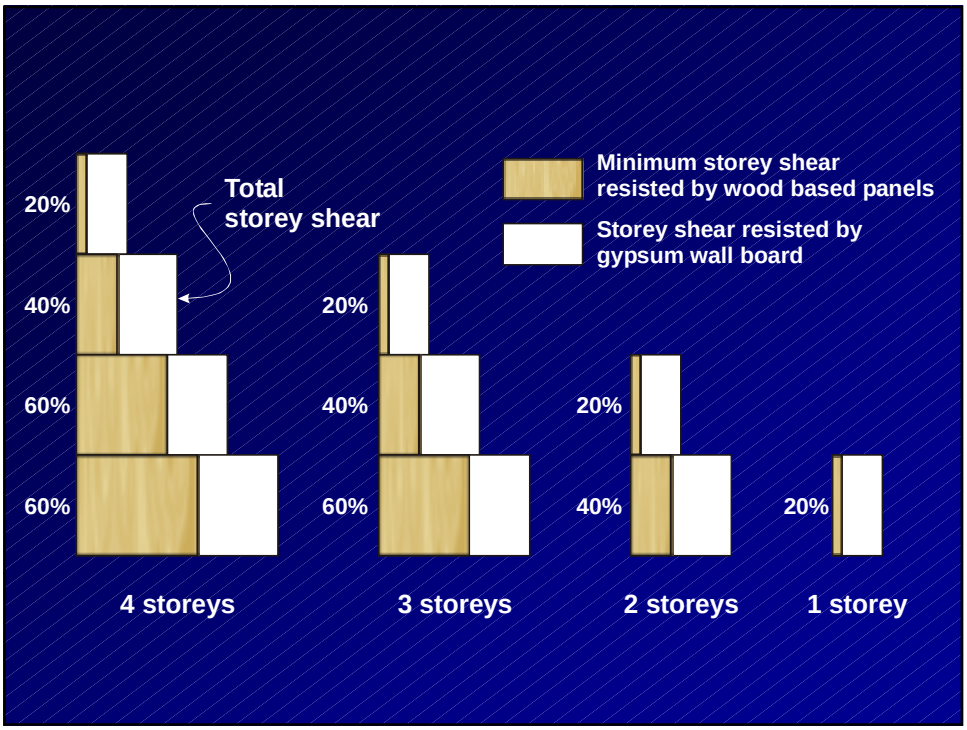
Vertically oriented panels in shear walls (no blocking)

Horizontally oriented panels in shear walls (with blocking)



Horizontally oriented panels in shear walls (with blocking)


Shear wall
Bolt
Stiffened steel bracket
Floor diaphragm
Threaded rod
Shear wall
Shear wall
Bolt
Stiffened steel bracket
Foundation
Anchor rod


Total storey shear
Minimum storey shear resisted by wood based panels
Storey shear resisted by gypsum wall board
20%
40%
60%
60%
20%
40%
60%
20%
40%
20%
4 storeys
3 storeys
2 storeys
1 storey

R_o Factors - Timber

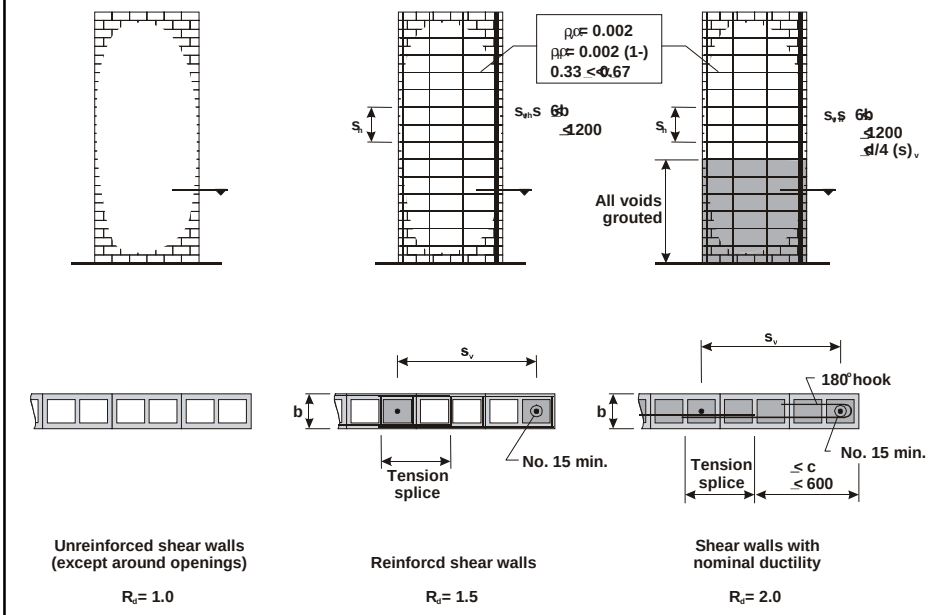
System	Cat.	Calculation of R_o						Proposed R_o
		R_{size}	R_ϕ	R_{yield}	R_{sh}	R_{mech}	R_o	
Nailed shear panels with wood-based panels	D	1.15	1.43	1.00	1.05	1.00	1.73	1.7
Shear walls with wood-based and gypsum panels in combination	MD	1.15	1.43	1.00	1.05	1.00	1.73	1.7
Braced or moment resisting frames	MD	1.05	1.43	1.00	1.00	1.00	1.50	1.5
	LD	1.05	1.43	1.00	1.00	1.00	1.50	1.5

R Factors - Timber

System	Cat.	R_d	R_o	R_dR_o	R/U
Shear walls with wood based panels	D	3.0	1.7	5.1	5.0
Shear walls with wood based and gypsum panels	MD	2.0	1.7	3.4	-
Braced or moment resisting frames with ductile connections	MD	2.0	1.7	3.4	3.3
	LD	1.5	1.7	2.5	

R Factors - Masonry

System	Cat.	R_d	R_o	R_dR_o
Shear walls	MD	2.0	1.5	3.0
	LD	1.5	1.5	2.3
Moment resisting frames	LD	1.5	1.5	2.3
Unreinforced masonry	-	1.0	1.0	1.0



R_o Factors - Masonry

System	Cat.	Calculation of R_o						Proposed R_o
		R_{size}	R_ϕ	R_{yield}	R_{sh}	R_{mech}	R_o	
Reinforced masonry	MD	1.15	1.18	1.10	1.00	1.00	1.49	1.5
	LD	1.15	1.18	1.10	1.00	1.00	1.49	1.5
Moment resisting frame	LD	1.15	1.18	1.10	1.00	1.00	1.49	1.5
Unreinforced masonry	-	1.00	1.00	1.00	1.00	1.00	1.00	1.0

R Factors - Masonry

System	Cat.	R_d	R_o	R_dR_o
Shear walls	MD	2.0	1.5	3.0
	LD	1.5	1.5	2.3
Moment resisting frames	LD	1.5	1.5	2.3
Unreinforced masonry	-	1.0	1.0	1.0

System Restrictions – height, m

TYPE OF SFRS	R_d	R_o	R_dR_o	RESTRICTIONS Cases where $IF_aS_a(0.2)$			
				<0.2	≥0.2 to <0.35	≥0.35 to ≤0.75	>0.75
Steel structures designed and detailed according to CSA S16-2001							
Ductile moment resisting frames	5.0	1.5	7.5	NL	NL	NL	NL
Moderately ductile MRF	3.5	1.5	5.3	NL	NL	NL	NL
Limited ductility MRF	2.0	1.3	2.6	NL	NL	60	NP
Moderately ductile CBF							
• Chevron & other braces	3.0	1.3	3.9	NL	NL	40	40
• Tension only braces	3.0	1.3	3.9	NL	NL	20	20
Limited ductility CBF	2.0	1.3	2.6	NL	NL	60	60
Ductile EBF	4.0	1.5	6.0	NL	NL	NL	NL
Ductile frame plate shearwall	5.0	1.6	8.0	NL	NL	NL	NL
Moderately ductile plate shearwall	2.0	1.5	3.0	NL	NL	60	60
Conventional construction	1.5	1.3	2.0	NL	NL	15	15

TYPE OF SFRS	R_d	R_o	R_dR_o	RESTRICTIONS Cases where $IF_aS_a(0.2)$			
				<0.2	≥0.2 to <0.35	≥0.35 to ≤0.75	>0.75
Concrete structures designed and detailed according to CSA A23.3-xx							
Ductile MRF	4.0	1.7	6.8	NL	NL	NL	NL
Moderately ductile MRF	2.5	1.4	3.5	NL	NL	60	40
Ductile coupled wall	4.0	1.7	6.8	NL	NL	NL	NL
Ductile partially coupled wall	3.5	1.7	6.0	NL	NL	NL	NL
Ductile shearwall	3.5	1.6	5.6	NL	NL	NL	NL
Moderately ductile shearwall	2.0	1.4	2.8	NL	NL	NL	60
Conventional construction							
• MRF	1.5	1.3	2.0	NL	NL	15	NP
• Shear wall	1.5	1.3	2.0	NL	NL	40	30

TYPE OF SFRS	R_d	R_o	R_dR_o	RESTRICTIONS Cases where $IF_aS_a(0.2)$			
				<0.2	≥0.2 to <0.35	≥0.35 to ≤0.75	>0.75
Timber structures designed and detailed according to CSA 086-xx							
Shearwalls							
• Nailed-wood based panels	3.0	1.7	5.1	NL	NL	30	20
• Nailed-wood & gypsum panels	2.0	1.7	3.4	NL	NL	20	20
Frames with ductile connections							
• Moderate ductility	2.0	1.5	3.0	NL	NL	20	20
• Limited ductility	1.5	1.5	2.3	NL	NL	15	15
Masonry structures designed and detailed according to CSA S304.1-xx							
Moderately ductile shearwall	2.0	1.5	3.0	NL	NL	60	40
Limited ductile shearwall	1.5	1.5	2.3	NL	NL	40	30
Conventional construction							
• Shearwalls	1.5	1.5	2.3	NL	60	30	15
• Moment resisting frames	1.5	1.5	2.3	NL	30	NP	NP
Unreinforced masonry	1.0	1.0	1.0	30	15	NP	NP

Other System Restrictions

- **Post-disaster buildings**
  - **$R_d \geq 2.0$**
  - **Not have certain irregularities**
  - **Walls must be continuous from top to foundation**

    when $I_EF_aS_a(1) > 0.25$ and $T > 1.0$

Combination of systems

- For different systems in the same direction, use lowest R_dR_o.
- For vertical combination of different systems, use lowest R_dR_o of the storeys above. The systems below must be designed for the actual capacity of the systems above.

Upper Bound on Capacity Design

Design forces in elements of SFRS need not exceed:

- elastic forces (V_e)
- but may be limited by the rocking capacity of the foundation
- Foundation rocking capacity need not exceed that corresponding to $R_dR_o=2$

Design of Diaphragms

Design for :

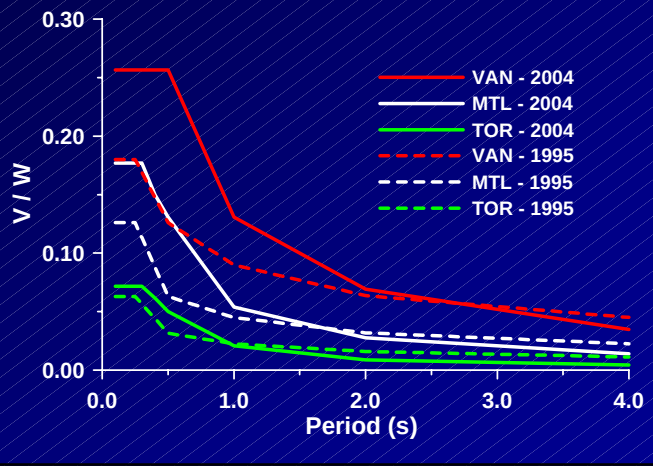
- **forces from analysis**
- **forces corresponding to capacity of SFRS**
- **Transfer of forces between elements of SFRS**
- **minimum force equal to V / N**
- **load path around openings**

no longer considered as a non-structural component !

Base shear comparison

Steel CBFs with Limited Ductility, R_d = 2.0

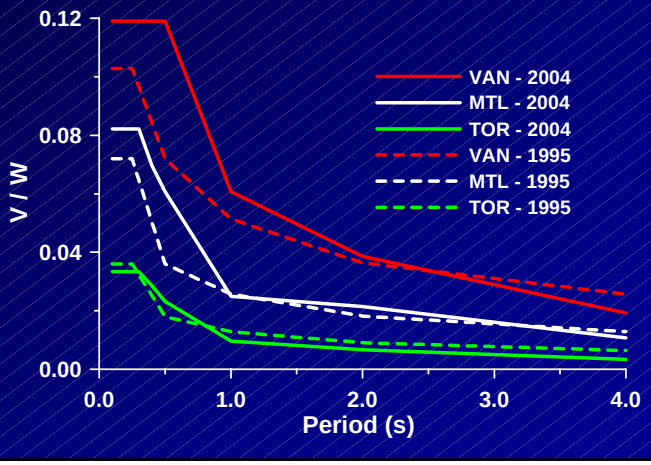
Soil Class C



Base shear comparison

R/C Ductile shear walls, R_d = 3.5

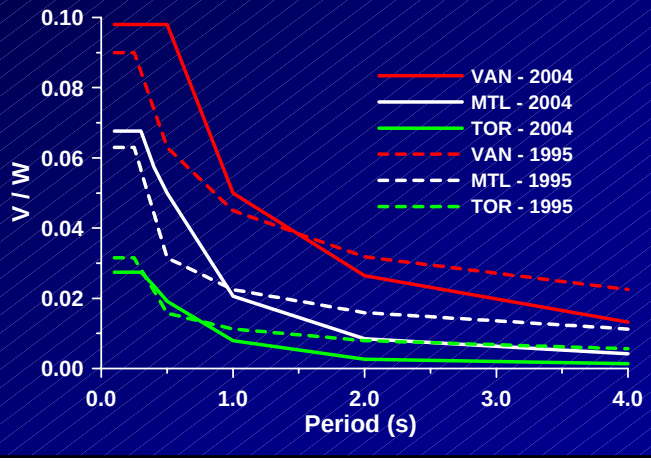
Soil Class C



Base shear comparison

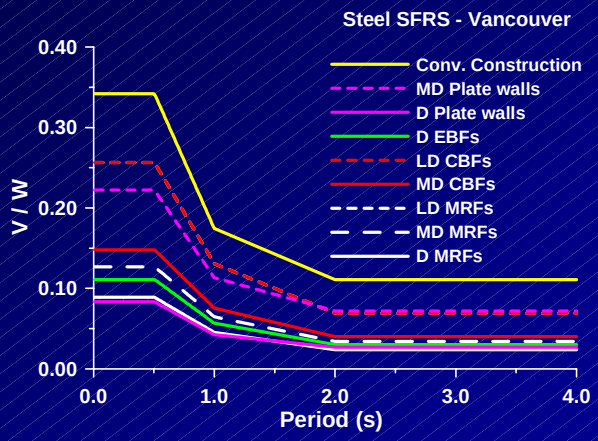
R/C Ductile coupled walls, R_d = 4.0

Soil Class C



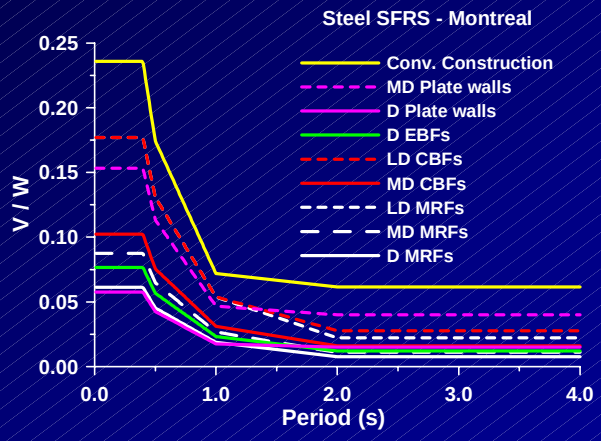
Influence of R_dR_o (Steel SFRS)

Vancouver, Soil Class C



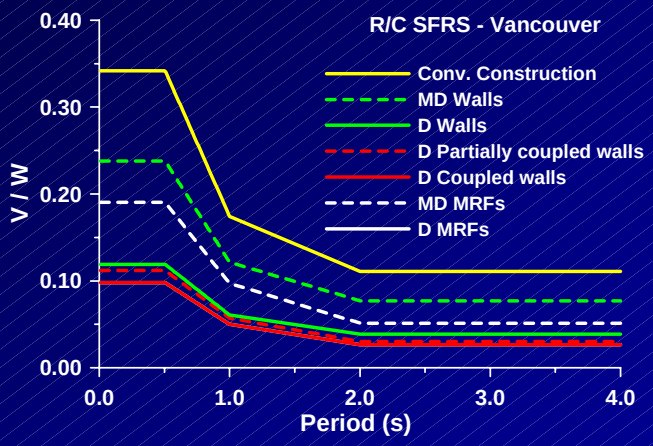
Influence of R_dR_o (Steel SFRS)

Montreal, Soil Class C



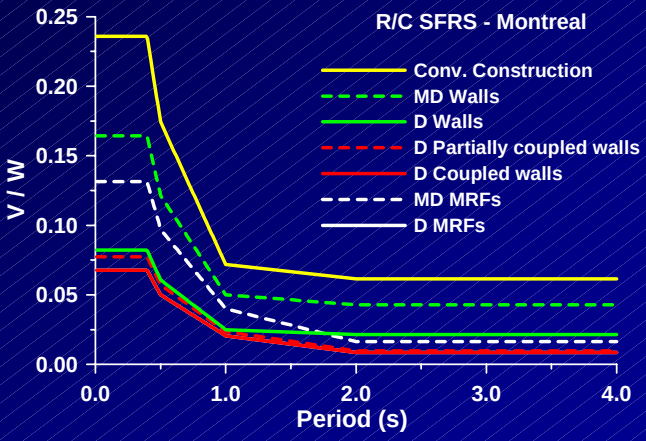
Influence of R_dR_o (R/C SFRS)

Vancouver, Soil Class C



Influence of R_dR_o (R/C SFRS)

Montreal, Soil Class C



The End