BRIDGING GUIDELINES FOR THE PERFORMANCE-BASED SEISMIC RETROFIT OF BRITISH COLUMBIA LOW-RISE SCHOOL BUILDINGS

SECOND EDITION

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PREFACE

These Bridging Guidelines form part of the Ministry of Education program aimed at reducing the overall seismic risk of public school buildings in British Columbia. The intent of these Guidelines is to identify common minimum evaluation and mitigation measures and to ensure that all provincial School Boards have a balanced seismic safety program for their existing stock of buildings.

In May, 2004, the Ministry of Education announced a $1.5 billion seismic mitigation program for the province's school buildings. In March of 2005, the Ministry announced $254 million in funding for the first capital construction phase of this ambitious program. Interim guidelines are needed to bridge the period between the commencement of retrofit design for the first phase of this program and the publication of a more comprehensive, state-of-the-art technical manual for the overall mitigation program.

The long-term goal of this program is to mitigate within a reasonable period of time the risk of seismically deficient buildings in the Ministry's inventory. Effective risk mitigation includes vacating, change of use, removal, disposal and retrofitting. The latter measure is an engineering technique and is the purpose of these guidelines.

Under Section 2.1.1 of the Seismic Mitigation Project Feasibility Study Guidelines issued by the British Columbia Ministry of Education Professional Engineers selected to conduct feasibility studies and develop detailed designs must be trained in the use of the Bridging Guidelines.

Ownership

Disclaimer

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APEGBC Council has endorsed the performance based methodology used by the University of British Columbia in the development of the Ministry of Education's "Guidelines for the Performance Based Seismic Retrofit for British Columbia School Buildings" as good engineering practice.

Acknowledgment

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1.0 PERFORMANCE-BASED EARTHQUAKE RETROFIT GUIDELINES FOR LOW-RISE SCHOOL BUILDINGS - GENERAL REQUIREMENTS

1.1 Introduction

1) These guidelines are for the risk assessment and retrofit design (where necessary) of low-rise school buildings in British Columbia.

2) These guidelines are for school buildings of 1-3 storeys in height above the basement where applicable.

3) These guidelines and associated documents are comprised of the following seven related parts:

   (a) General guidelines as given in this section

   (b) Toolbox method for combining the resistance of different Lateral Deformation Resisting Systems (LDRSs) as given in Section 2

   (c) Specific material guidelines for wood frame, steel, concrete, concrete masonry and clay brick masonry as given in Sections 3-7

   (d) Guidelines for rocking elements in Section 8

   (e) Guidelines for heavy partition walls (Section 9)

   (f) Guidelines for diaphragms and connections as given in Sections 10-11

   (g) Commentary on technical background of guidelines

4) These provisions have been drafted using a performance-based philosophy that complements the 2005 edition of the National Building Code of Canada by providing a rational method for the life safe, cost-effective retrofit design of existing buildings.

5) When the provisions given in these guidelines differ with corresponding provisions in the 2005 edition of the National Building Code of Canada, the provisions of these guidelines take precedence.

6) If a building lies outside the scope of these guidelines, the minimum required factored resistance of the building shall be determined in accordance with the 2005 edition of the National Building Code of Canada using an Importance Factor of 0.8 for risk assessment and an Importance Factor of 1.0 for retrofit design.

7) The life safety philosophy of these guidelines is the protection of life safety through reducing the probability of structural collapse to acceptable levels by the use of rational methods of earthquake damage estimation.

8) The building elements of principal interest in these guidelines are the vertical structural elements that comprise the building's LDRSs. Non-LDRS vertical elements are also of primary consideration in checking drift compatibility.

9) With one exception, the seismic retrofit requirements for non-structural building elements are not addressed in these guidelines. Because of their life safety implications, heavy partition walls are included in the scope of these guidelines.

10) All building code references in these guidelines are to the 2005 edition of the National Building Code of Canada.

1.2 Seismicity

1) The surface design ground motions used in these guidelines have a probability of exceedance of 2% in 50 years (50 percentile).

2) These provisions are for the geographic areas in the province of significant seismicity. Refer to the commentary for details on the six provincial seismic zones.

3) Seismic Zone 1 has the lowest seismicity in the province and is considered to have negligible seismicity.

4) These guidelines are applicable to school buildings located in Seismic Zones 2-5.

5) Assessment and retrofit guidelines for school buildings in Seismic Zone 6 (highest seismicity) is outside the scope of this edition of the Bridging Guidelines. Subduction ground motion is a major consideration in Seismic Zone 6. The appropriate guidelines for Seismic Zone 6 will be provided in a subsequent edition of the guidelines. In the interim, seismic design criteria in Seismic Zone 6 will be provided by APEGBC/UBC at the request of the Ministry on a school by school basis.

1.3 Definitions

1) In these Guidelines

ASPECT RATIO of a building element is the ratio of its height to its length where the height is measured to the top of a rocking pier or to the height of the centre of mass for a rocking cantilever.

BUILDING CODE is the 2005 edition of the National Building Code of Canada.

CANTILEVER is a building element that is free of rock about its base without generating any significant vertical restraint at its top rocking edge.

CLEAR STOREY HEIGHT is the height of the storey over which the majority of horizontal inelastic deformation in that storey occurs.

COLLAPSE occurs when the building experiences a localized or global loss of vertical support of its structural system or lateral collapse of its heavy interior partition walls such that casualties can be inflicted on the building occupants or on persons in the immediate vicinity of the building exterior walls as a direct result of large heavy pieces of falling debris or as an indirect result of fallen debris obstructing egress.

DESIGN GROUND MOTION is a ground motion that conforms to the seismic hazard data given in the 2005 edition of the British Columbia Building Code for a probability of exceedance of 2% in 50 years (50 percentile).

DIAPHRAGM INELASTIC STRAIN LIMIT (DISL) is the maximum permissible lateral inelastic shear deformation for the diaphragm measured over a specific length of the diaphragm where the shear deformation is expressed as a percentage of the length of the diaphragm over which the shear deformation is measured.

DRIFT is the horizontal displacement of the top of a storey relative to the bottom of the storey expressed as a percentage of the clear storey height.

ECCENTRICITY at a given floor or roof level is the distance between the centre of mass and the centre of lateral resistance measured perpendicular to a given direction of ground movement. Eccentricity is typically determined for the orthogonal axes of a building. Eccentricity is expressed as a percentage of the width of the building perpendicular to the building axis. The width of the building is the out-to-out distance of the outermost LRDSs measured perpendicular to the building axis (refer to commentary for clarification).

FACTORED RESISTANCE is the resistance as defined in the corresponding CSA standards referenced in Sections 3-7.

GOVERNING DRIFT LIMIT is the maximum inter-storey inelastic drift permitted in a building such that the maximum drift does not exceed the Instability Drift Limit of any participating LDRS or any load bearing non-LDRS framing element.

HEAVY PARTITION WALLS are vertical non-load bearing walls that are more than two metres in height and that are built of heavy construction materials (e.g. clay masonry, concrete masonry, clay tile, pumice or glass block).

INSTABILITY is accompanied by excessive deformation and can be the precursor to collapse in certain circumstances.

INSTABILITY DRIFT LIMIT (ISDL) is the maximum permissible inelastic drift that limits building structural damage to a level that poses no significant risk of local or global collapse of building structural elements.

INTER-STOREY HEIGHT is the height of the storey measured from the top of its floor slab to the top of the floor slab immediately above that storey.

LATERAL DEFORMATION RESISTING SYSTEM (LDRS) is comprised of the vertical building elements that have similar seismic performance characteristics and that generate resistance to inter-storey horizontal shear deformations in the building.

LOAD BEARING NON-LDRS FRAMING ELEMENT is a building element that supports vertical load and that is not part of any participating LDRS in the building.

PERFORMANCE-BASED ANALYSIS is an analysis that models the full inelastic range of deformations in a building (to point of instability) for a specific earthquake ground motion record.

PIER is a building element that is free of rock about its base but generates significant vertical restraint at its top rocking edge.

REINFORCED MASONRY is concrete masonry with vertical reinforcing steel that meets the minimum reinforcement requirements of this Section 6.

ROCKING occurs when a cantilever or pier building element rocks about its base prior to the development of the maximum lateral resistance of any LDRS comprising that cantilever or pier.

SEISMIC ZONE is a geographic area that has assigned a specific level of seismicity based on the seismic hazard data for a representative community within that seismic zone.

SITE CLASS is the soil type designation defined in Table 4.1.8.4.A of the building code.

SURCHARGE for a wall in a given storey is the weight of the building bearing on the top of the wall. The top of the wall is defined as the vertical location of the wall's top lateral support. Surcharge is expressed as a percentage of the weight of the wall from base of wall to top of wall.

TOOLBOX METHOD is the simplified design procedure given in Section 2 for combining the resistance contributions of different LDRSs in a drift-compatible manner.

UNBLOCKED CONSTRUCTION is where adjacent sheets of OSB, plywood or gypsum wallboard in wood frame construction do not have all four edges nailed.

UNREINFORCED MASONRY is concrete masonry with no vertical reinforcing steel.

1.4 Notations

1) In these guidelines

d = Width or diameter of hollow steel section (mm)

F_c = Diaphragm chord force (kN)

F_x = Lateral force applied at Level x (kN)

f_y = Yield strength of steel (MPa)

ϕ_m = Resistance factor for masonry

ϕ_r = Resistance factor for rocking (0.8)

h = Height of rocking element (height of pier between openings or full height for solid wall) (m)

H = Vertical distance from rocking interface to centre of mass of rocking element (m)

h_i = Height of i^{th} level in building above top of foundations (m)

h_s = Inter-storey height (m)

h_{sc} = Clear storey height (m)

h_x = Height of a given level in building above top of foundations (m)

K_{bm} = Coefficient used to calculate the moment at the base of an LDRS

K_{mr} = Coefficient used to calculate R_{mr}

L = Length of wall or rocking element (m)

L_d = Diaphragm span length between LDRSs that have adequate lateral resistance and connection strength to provide effective diaphragm support (m)

n_b = Number of evenly spaced connections between a vertical bracing element and the unreinforced masonry wall to which the brace is connected

n_c = Number of diaphragm connections

R_c = Factored resistance of connection (kN)

R_e = Factored resistance of LDRS (%W)

R_{eb} = Factored moment resistance of vertical bracing element (kNm)

R_{ed} = Factored resistance of diaphragm parallel to the direction of shaking (kN)

R_{ei} = Sum of the factored resistances of all LDRSs in the i^{th} storey

R_{em} = Factored resistance of member either side of connection (kN)

R_m = Minimum required factored resistance for LDRS (%W) (refer to figures in Sections 3-8)

R_{mb} = Minimum required factored moment resistance of vertical bracing element supporting an unreinforced masonry wall (kNm)

R_{mc} = Minimum factored resistance of connection (kN)

R_{md} = Minimum factored resistance of diaphragm at each end of span length (%W_d)

R_{mr} = Reduced minimum required factored resistance for LDRS (%W)

R_o = Overstrength related force modification factor

R_r = Factored resistance ratio (%) for LDRS

R_{rt} = Sum of R_r values for all building LDRSs

t = Thickness of masonry wall (m)

t_h = Wall thickness of hollow steel section (mm)

V_{rr} = Lateral rocking resistance of wall (kN)

V_{rs} = Lateral sliding resistance of wall (kN)

W = Total weight of building above the mid-height of the first storey of the building (kN)

W_b = Total weight of masonry wall supported by vertical bracing element (kN)

W_d = Weight of walls and parapets supported by diaphragm in addition to self weight of diaphragm for lateral shaking normal to span of diaphragm (kN)

W_i = Weight of i^{th} floor or roof (including 25% snow load) (kN)

W_x = Weight of floor or roof (including 25% snow load) at a given location (kN)

W_1 = Dead load acting at top of wall opening plus factored yield strength of vertical reinforcement (kN)

W_2 = Dead load acting normal to sliding plane (kN)

W_3 = Dead load acting on top uplifted corner of wall (kN)

W_4 = Weight of rocking element (kN)

1.5 List of LDRS

1) Refer to Table 1.1 for a listing of all LDRS included in these guidelines.

1.6 Minimum Building Structural Requirements

1) The minimum seismic performance requirements for a school building in these guidelines are as follows:

(a) Acceptable life safety risk of LDRSs
(b) Load path well defined and of adequate strength (diaphragms and connections)
(c) Non-LDRS drift compatibility
(d) Adequate restraint of heavy partition walls

1.7 Load Path

1) The building shall be designed with clearly defined load paths to transfer seismic forces from foundation to roof.

1.8 Assessment and Retrofit Design

1) The first step in using these guidelines is to determine if the building has adequate lateral resistance to behave seismically in a life-safe manner. This first step is a risk assessment. A building poses an acceptable level of risk if the assessment procedure given in Section 2.3 determines that R_{rt}, the sum of the factored resistance ratios (R_r) for all LDRSs, equals or exceeds 100%. Note that the R_r value for each LDRS is based on the assessment values given in the figures of Sections 3-8 (different constructon materials).

2) The second step is to determine the retrofit requirements if a building does not meet the minimum life safety requirement as specified in Sentence (1). The retrofit design check also uses the procedure in Section 2.3. This second step uses the retrofit design

values rather than the assessment values as given in the figures of Sections 3-8. The retrofit design is acceptable if R_{rt}, the sum of the factored resistance ratios (R_r) of all LDRSs in the retrofitted building, both existing and new, equals or exceeds 100%.

3) For a multi-storey low-rise building, the recommended minimum lateral factored resistance of the top storey of the retrofitted building is 67% of that of the first storey.

4) For a three storey low-rise building, the lateral factored resistance of the second storey of the retrofitted building shall be equal to the average of lateral factored resistances of the first and top storeys.

1.9 Calculation of Lateral Resistance

1) The lateral factored resistance of existing and new construction shall be calculated in accordance with Sections 3-8.

2) Each LDRS needs to be checked to ensure that rocking does not govern. Refer to Section 8 for details.

3) The condition of existing materials contributing to the lateral resistance provisions of Section 1.8 shall be assessed to confirm that there has been no significant structural deterioration that would significantly reduce the calculated resistance.

1.10 Vertical Force Distribution

1) The LDRS minimum required factored lateral resistance ($R_m \times W$) for the first storey of a building shall be distributed over the height of the building in accordance with Equation (1-1).

$$F_x = \frac{R_m \cdot W \cdot W_x \cdot h_x^2}{100 \cdot \sum W_i \cdot h_i^2} \qquad (1\text{-}1)$$

2) The minimum required factored resistance R_m of an LDRS above the first storey shall be set equal to the sum of the F_x forces calculated in Sentence (1) for all floor and roof diaphragms above the level being considered.

1.11 Base Moment

1) The factored moment at the base of an LDRS is to be calculated in accordance with Equation (1-2).

$$M_b = \sum K_{bm} \cdot R_{ei} \cdot h_i \tag{1-2}$$

2) Values of the coefficient K_{bm} are given in Sections 3-6. Assume K_{bm} = 1.0 for all other cases.

1.12 Drift Compatibility

1) All LDRS and non-LDRS elements within a building shall be drift compatible.

2) Load-bearing non-LDRS framing elements shall be capable of maintaining their support of vertical load for inelastic building deformations up to the Governing Drift Limit. Refer to Section A5.5 in the Commentary for the specific drift compatibility requirements for reinforced concrete.

1.13 Adjacency

1) Two adjacent buildings separated by a horizontal distance less than the square root of the sum of the squares of their respective Governing Drift Limits shall be designed in accordance with one of the following three options:

(a) Increase separation to avoid pounding
(b) Stiffening buildings to minimize pounding
(c) Connecting buildings to ensure drift compatibility

1.14 Irregularity

1) These guidelines are applicable for irregular low-rise buildings provided the buildings have a well-defined load path as noted in Section 1.7.

2) Refer to Sentence 10.6(2) for the limitations on the maximum plan eccentricities of buildings.

1.15 Site Response Analysis

1) The site seismic response classification or Site Class is defined in Table 4.1.8.4A of the building code.

2) Site response analysis is recommended for large buildings founded on Site Class E soils when such analysis has the potential to substantially reduce retrofit costs.

1.16 Liquefaction

1) Liquefaction has the potential for posing an unacceptable life safety risk for vulnerable buildings. Refer to commentary for guidance on this issue.

Table 1.1 List of LDRSs

Material Group	Prototype No.	Prototype Description and Failure Mode	ISDL	R_o
Wood	W-1	Blocked OSB/plywood shearwall	4.0%	1.7
	W-2	Unblocked OSB/plywood shearwall	4.0%	1.7
Steel	S-1	Concentric braced frame (tension only)	4.0%	1.3
	S-2	Concentric braced frame (tension/compression)	1.0-2.5%	1.3
	S-3	Eccentric braced frame	4.0%	1.5
	S-4	Moment frame (moderately ductile)	4.0%	1.5
Concrete Masonry	M-1	In-plane unreinforced shearwall bed-joint sliding	1.5%	1.5
	M-2	In-plane reinforced masonry	1.5%	1.5
Reinforced Concrete	C-1	Shearwall (moderately ductile)	2.0%	1.4
	C-2	Shearwall (conventional construction)	1.5%	1.3
	C-3	Moment frame (ductile)	4.0%	1.7
	C-4	Moment frame (moderately ductile)	4.0%	1.4
	C-5	Moment frame (conventional construction)	4.0%	1.3
Clay Brick Masonry	B-1	In-plane shearwall bed-joint sliding	1.0%	1.5
Rocking	R-1	Low Aspect Ratio Rocking Element	4.0%	1.0
	R-2	Medium Aspect Ratio Rocking Element	4.0%	1.0
	R-3	Higher Aspect Ratio Rocking Element	4.0%	1.0

Table 1.2 List of Diaphragm Prototypes

Material Group	Prototype No.	Diaphragm Description	R_o
Wood	D-1	Blocked OSB/plywood	1.70
	D-2	Unblocked OSB/plywood	1.70
Steel	D-3	Steel Deck - Type A	1.67
	D-4	Steel Deck - Type B	1.67
	D-5	Steel Braced Frame (Tension Only)	1.30
	D-6	Steel Braced Frame (Tension/Compression)	1.30

2.0 TOOLBOX METHOD

2.1 Introduction

1) This Section provides the details for the Toolbox method, a simplified method for combining resistance contributions from mixed lateral systems within a low-rise building in a drift-compatible manner. This method of combining resistance contributions from mixed lateral systems is based on the ability of the mixed lateral systems to redistribute inertia mass within their group.

2) Low-rise school buildings often comprise more than one LDRS. These guidelines present the minimum factored resistance requirements in a format that permits the design engineer to treat each LDRS individually and then combine the LDRSs in a drift-compatible manner for overall building performance.

3) The Toolbox method is intended for both risk assessment and retrofit design.

2.2 Valid Application of Toolbox Method

1) Toolbox Method is only valid for application to a group of LDRSs that meet one of the following requirements:

(a) LDRSs interconnected by a concrete diaphragm that meets the requirements of Sentence 10.6(1).

or (b) LDRSs spaced on more than 5 metres apart and interconnected by a wood, steel deck or horizontal steel frame diaphragm that meets the requirements of Section 10.

or (c) LDRSs interconnected by drag struts in a line parallel to the direction of shaking.

2) For a group of LDRSs that meet the requirements of Sentence (1), the inertia mass can be considered to be effectively redistributed between the individual LRDSs interconnected by the diaphragm or the drag struts.

2.3 Procedure to Determine Minimum Factored Resistance Requirements for Group of LDRSs

1) For a group of LDRSs that comply with the requirements of Sentence 2.2(1), assess the level of risk or the adequacy of the retrofit design by implementing the following procedure:

(a) Determine the total inertia mass to be laterally supported by the LDRSs.

(b) Determine the Governing Drift Limits (GDL) for the LDRSs and the load bearing non-LDRS framing elements within the group. The GDL is set equal to the lowest ISDL value for participating LDRSs and load bearing non-LDRS framing elements.

(c) Determine the factored resistance R_e of each individual LDRS within the group at the mid-height of the first storey of the building.

(d) For the GDL determined in (b), determine the minimum required factored resistance R_m of each individual LDRS within the group at the mid-height of the first storey of the building (refer to Sections 3-8 for minimum required factored resistance tables).

(e) Calculate the factored resistance ratio R_r (%) for each LDRS in the group as below:

$$R_r = \frac{R_e \times 100}{R_m} \qquad (1\text{-}1)$$

In Equation (1-1), the R_m values are those for either risk assessment or retrofit design. Sections 3-8 provide these R_m values.

(f) Calculate R_{rt}, the accumulated total of the R_r values for all LDRSs in the group.

(g) For a satisfactory level of risk for the group of LDRSs, R_{rt} must equal or exceed 100% (based on risk assesssment values of R_m given in Sections 3-8). If R_{rt} is less than 100% for risk assessment, the building requires upgrading.

(h) For a satisfactory retrofit design for the group of LDRSs, R_{rt} must equal or exceed 100% (based on the retrofit design values of R_m given in Sections 3-8). If R_{rt} is less than 100% for retrofit design, one or more LDRSs will require further upgrading until R_{rt} equals or exceeds 100%.

3.0 PERFORMANCE-BASED EARTHQUAKE RETROFIT GUIDELINES FOR LOW-RISE WOOD FRAME SCHOOL BUILDINGS

3.1 Prototypes

1) These guidelines include the following forms of wood frame construction (prototypes) for low-rise school buildings:

   (a) Prototype W-1 for blocked OSB, blocked plywood or diagonal board shearwalls
   (b) Prototype W-2 for unblocked OSB, unblocked plywood or unblocked gypsum wallboard shearwalls or horizontal board sheathing

2) Refer to Section 8 to check that wood frame LDRSs are not governed by rocking.

3.2 Minimum Required Lateral Factored Resistance R_m

1) Minimum required lateral factored resistance R_m for the risk assessment of a low-rise wood frame building is set equal to 80% of the corresponding value obtained from Figure 3-1 to Figure 3-3.

2) Minimum required lateral factored resistance R_m for the retrofit design of a low-rise wood frame building is obtained from Figure 3-1 to Figure 3-3.

3) The value of R_m, the minimum required lateral factored resistance determined from Sentence (1) or Sentence (2), can be reduced to the value R_{mr} in accordance with Equation (3-1) for clear storey heights between 3.0 metres and 4.0 metres.

$$R_{mr} = K_{mr} \cdot R_m \qquad (3\text{-}1)$$

where $K_{mr} = 1.75 - \frac{h_{sc}}{4.0}$

3.3 Calculation of Lateral Resistance

1) The calculation of the lateral resistance of wood frame buildings shall comply with CAN/CSA-086-01.

2) The factored resistance ratio R_r for unblocked gypsum wallboard shall not exceed 50% of R_{rt} value for the retrofitted building.

3) The factored resistance ratio R_r for horizontal boards shall not exceed 50% of R_{rt} value for the assessed building.

3.4 Wood Frame Base Moments

1) For Seismic Zones 3-5, the overturning moment at the base of a wood frame LDRS is to be calculated in accordance with Sentence 1.11(1) using:

K_{bm} = 1.0 for one storey

K_{bm} = 0.8 for two storeys

K_{bm} = 0.7 for three storeys

3.5 Strength of Existing Materials

1) The lateral factored resistances of selected existing materials for risk assessment and retrofit design are given in Table 3.1.

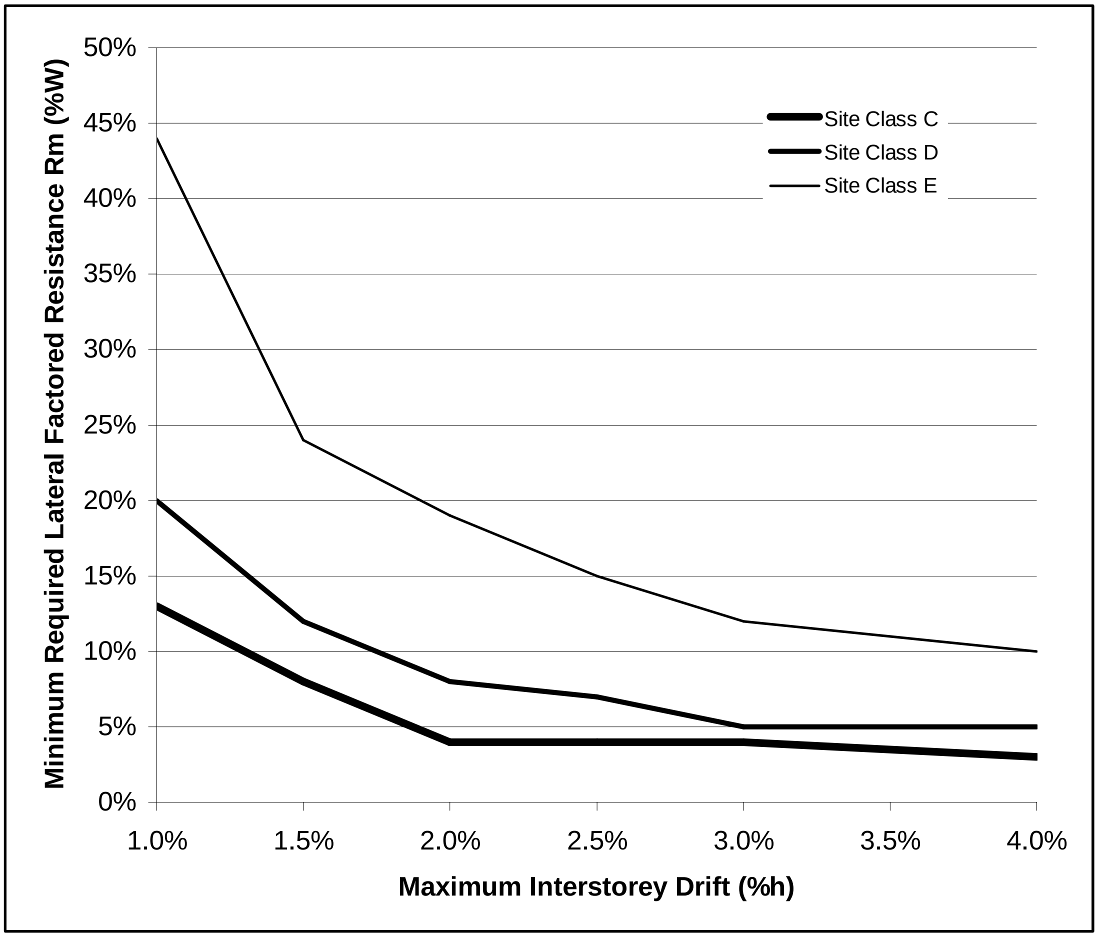
2) Refer to Table A.3-1 in Section A3.5 of the Commentary for the minimum construction requirements (including nailing) for the existing materials listed in Table 3.1.

Table 3.1 Lateral Factored Resistance of Selected Existing Materials

No.	Sheathing or Finish	Factored Resistance	
		Assessment	*Retrofit*
1	Unblocked OSB or plywood	3.5 kN/m	3.5 kN/m
2	Gypsum wallboard	1.1 kN/m/side	1.1 kN/m/side
3	Horizontal boards	0.6 kN/m/side	*NP*

Note: *NP* = Not Permitted

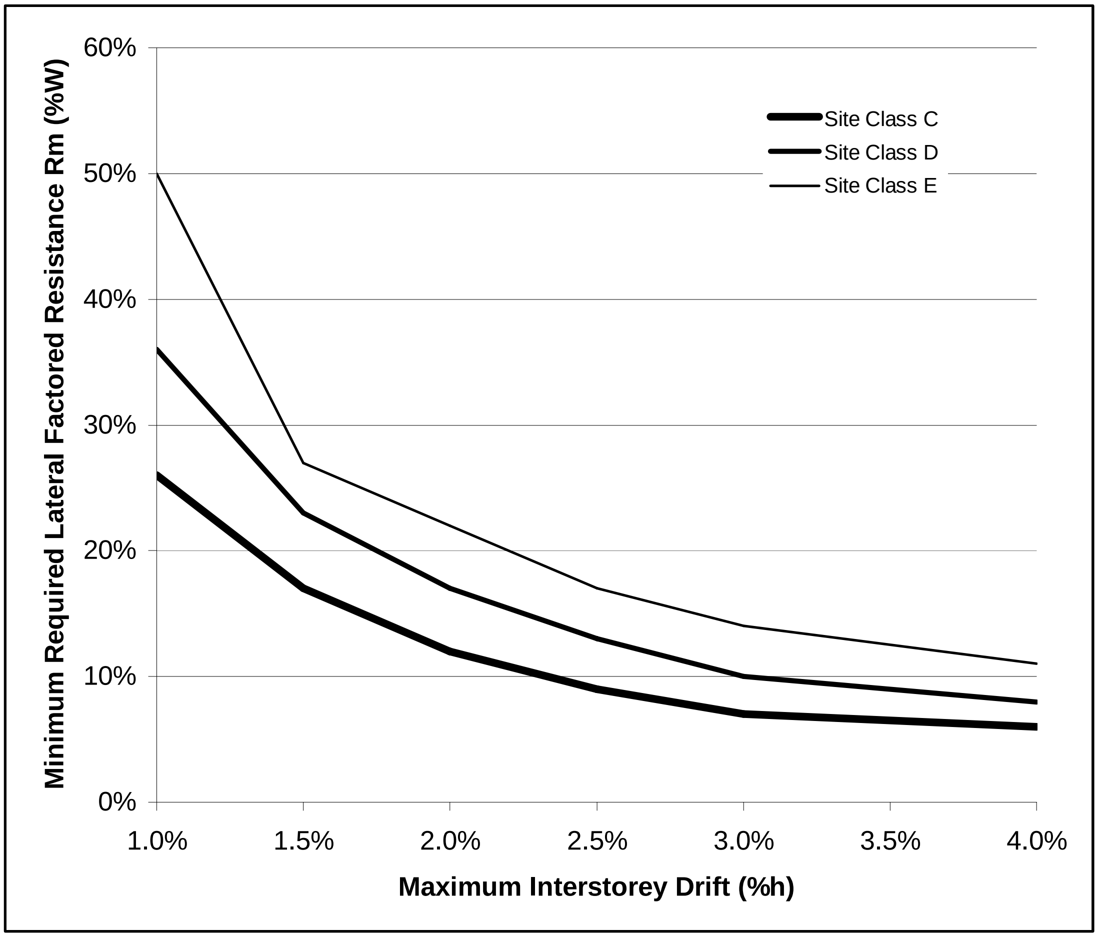
W-1 Zone 2



Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	13%	8%	4%	4%	4%	3%
D	20%	12%	8%	7%	5%	5%
E	44%	24%	19%	15%	12%	10%

Figure 3-1(a) *Minimum Required Lateral Factored Resistance R_m (%W)*
Wood Prototype W-1 Blocked OSB/Plywood
Seismic Zone 2 (Princeton)

W-1 Zone 3

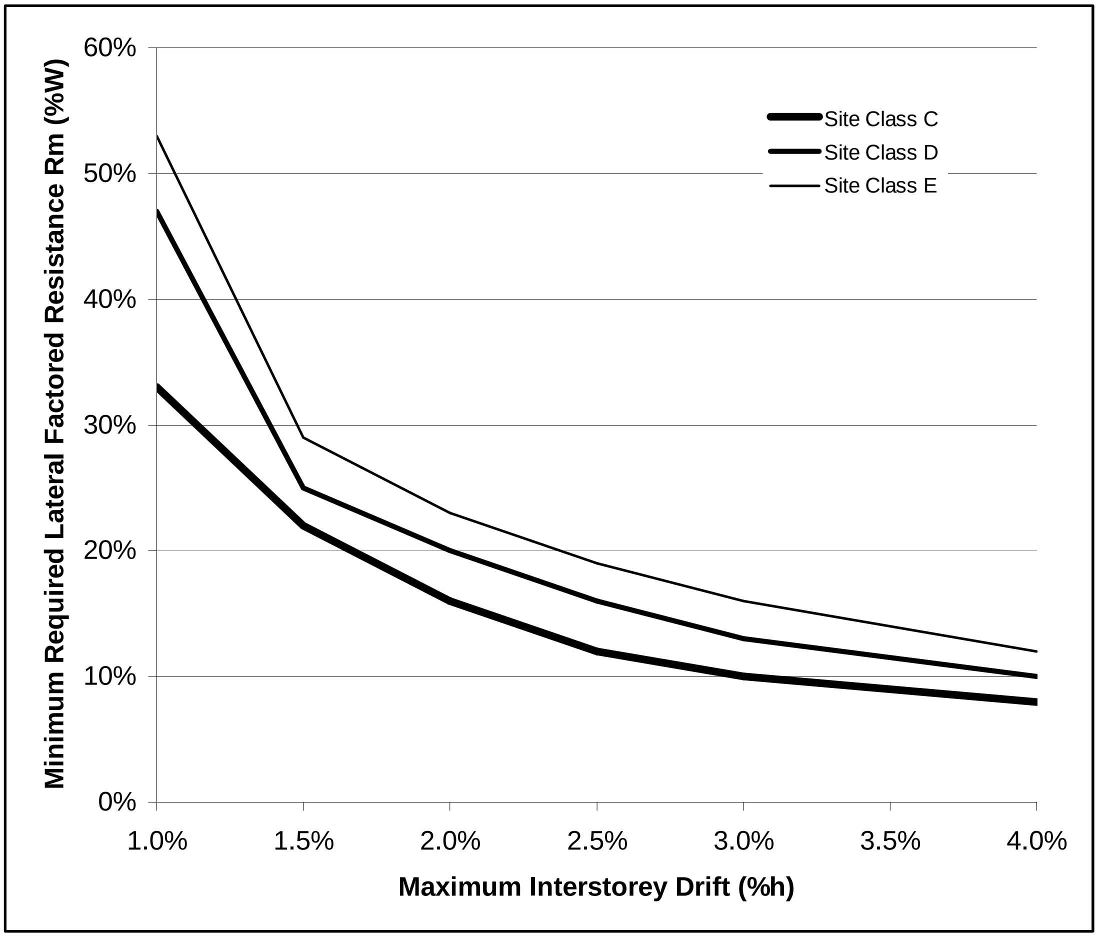


Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	26%	17%	12%	9%	7%	6%
D	36%	23%	17%	13%	10%	8%
E	50%	27%	22%	17%	14%	11%

Figure 3-1(b)

Minimum Required Lateral Factored Resistance R_m (%W)
Wood Prototype W-1 Blocked OSB/Plywood
Seismic Zone 3 (Chilliwack)

W-1 Zone 4

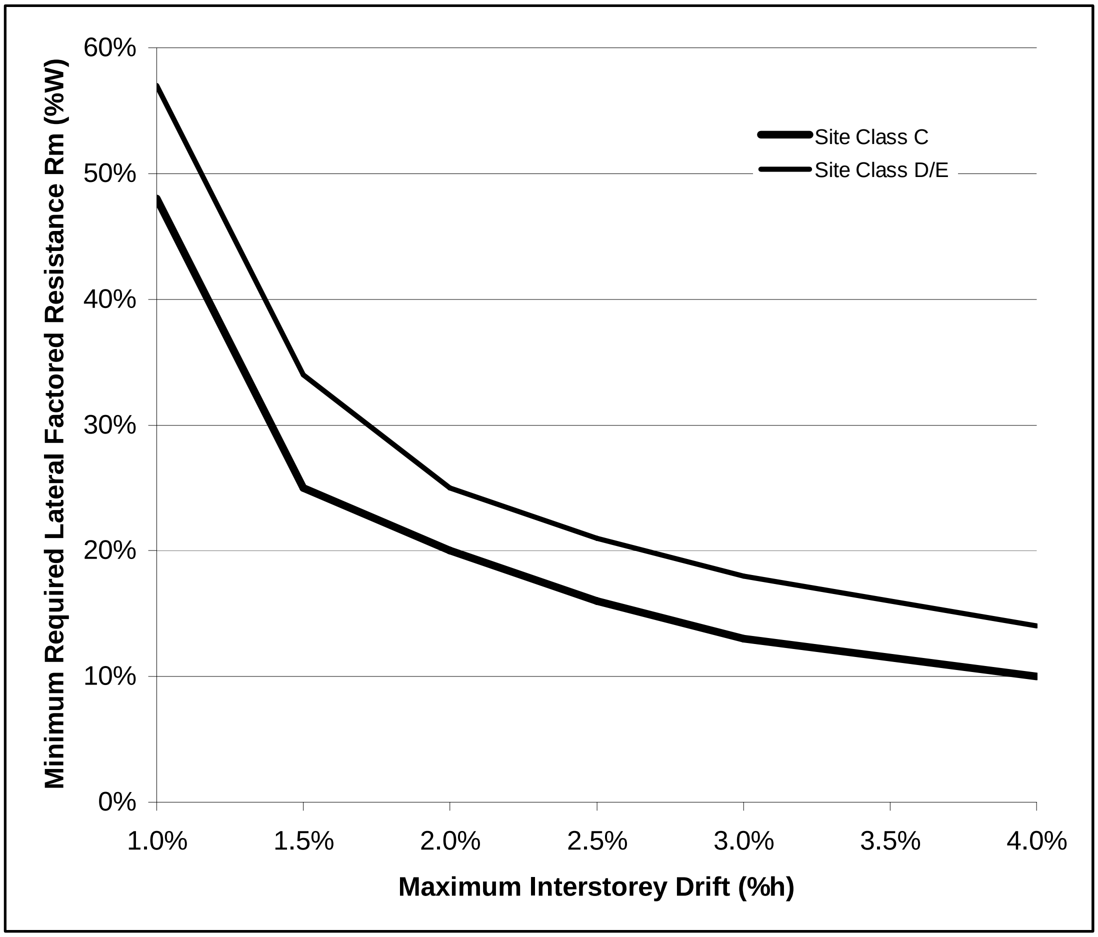


Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	33%	22%	16%	12%	10%	8%
D	47%	25%	20%	16%	13%	10%
E	53%	29%	23%	19%	16%	12%

Figure 3-1(c)

Minimum Required Lateral Factored Resistance R_m (%W)
Wood Prototype W-1 Blocked OSB/Plywood
Seismic Zone 4 (Vancouver)

W-1 Zone 5

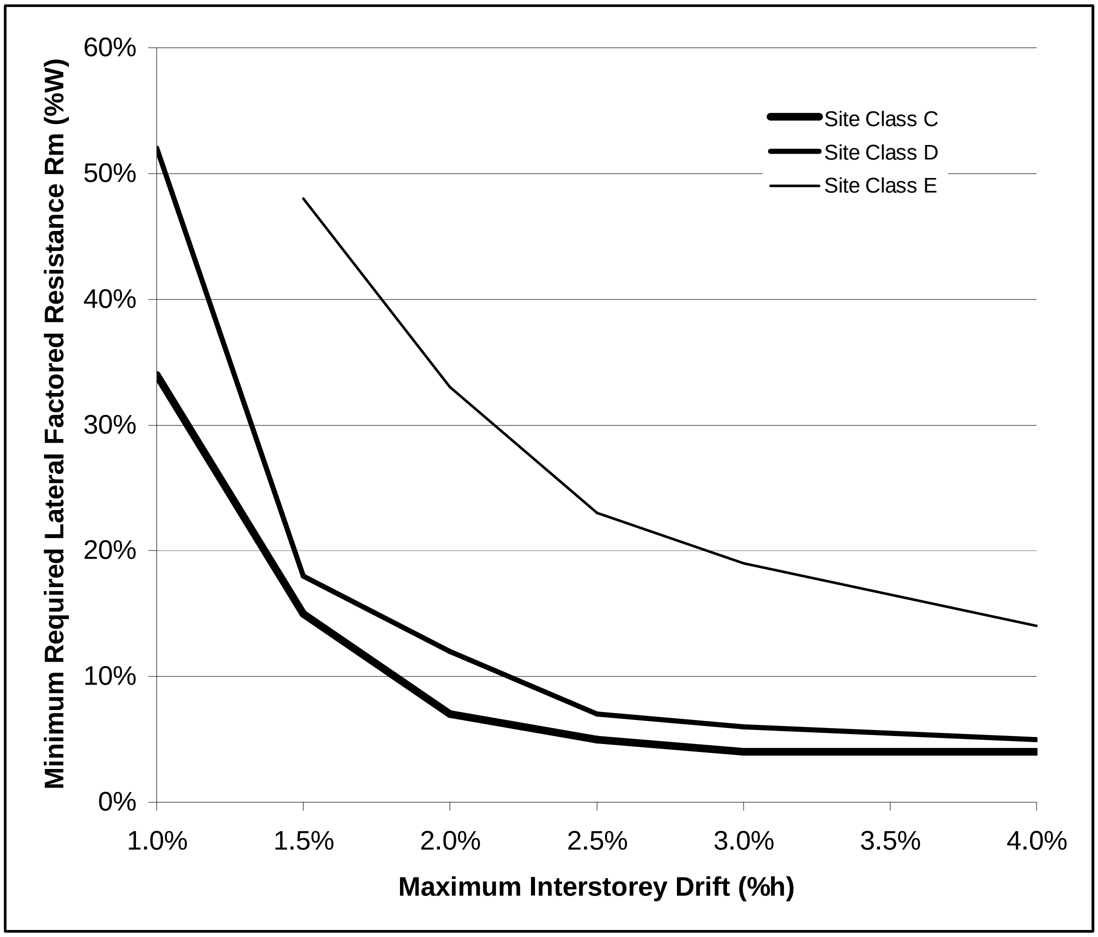


Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	48%	25%	20%	16%	13%	10%
D	57%	34%	25%	21%	18%	14%
E	57%	34%	25%	21%	18%	14%

Figure 3-1(d)

Minimum Required Lateral Factored Resistance R_m (%W)
Wood Prototype W-1 Blocked OSB/Plywood
Seismic Zone 5 (Victoria)

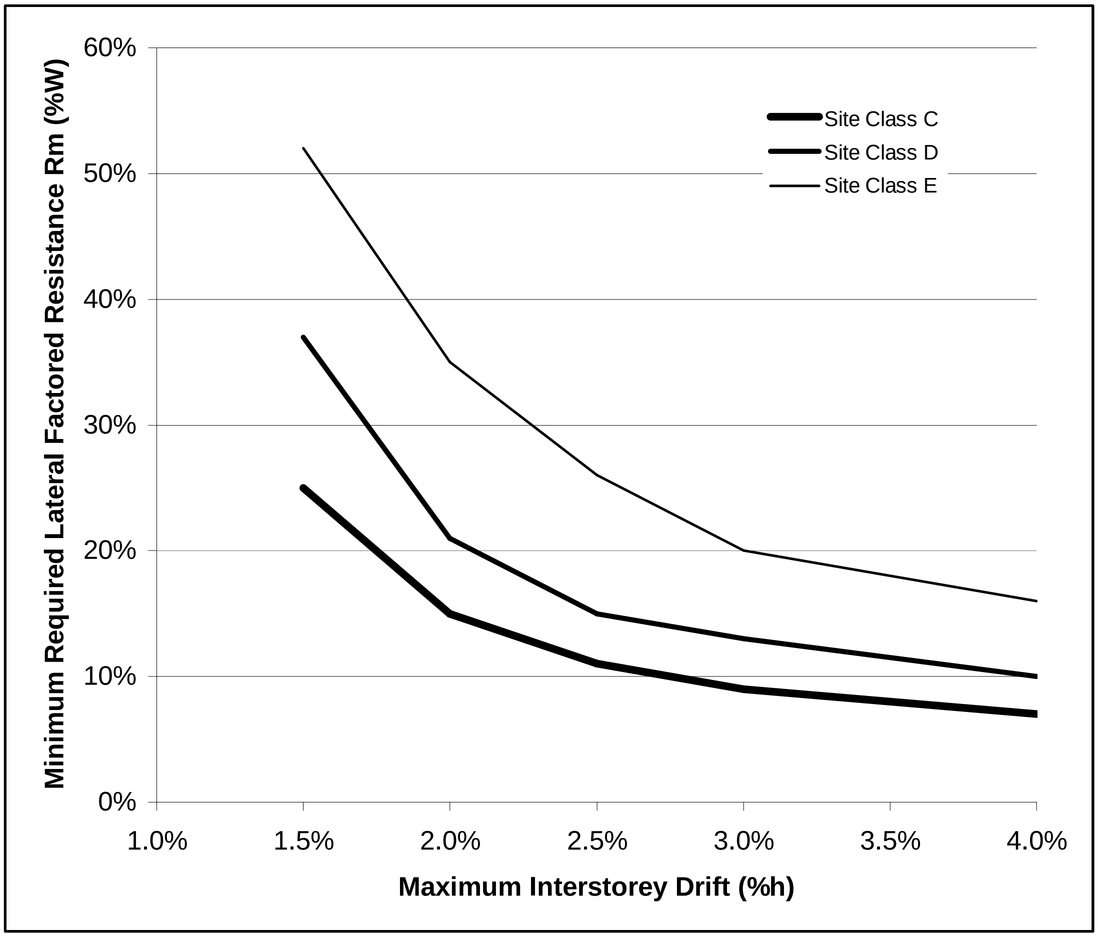
W-2 Zone 2



Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	34%	15%	7%	5%	4%	4%
D	52%	18%	12%	7%	6%	5%
E	NR	48%	33%	23%	19%	14%

Figure 3-2(a) *Minimum Required Lateral Factored Resistance R_m (%W)*
Wood Prototype W-2 Unblocked OSB/Plywood
Seismic Zone 2 (Princeton)

W-2 Zone 3

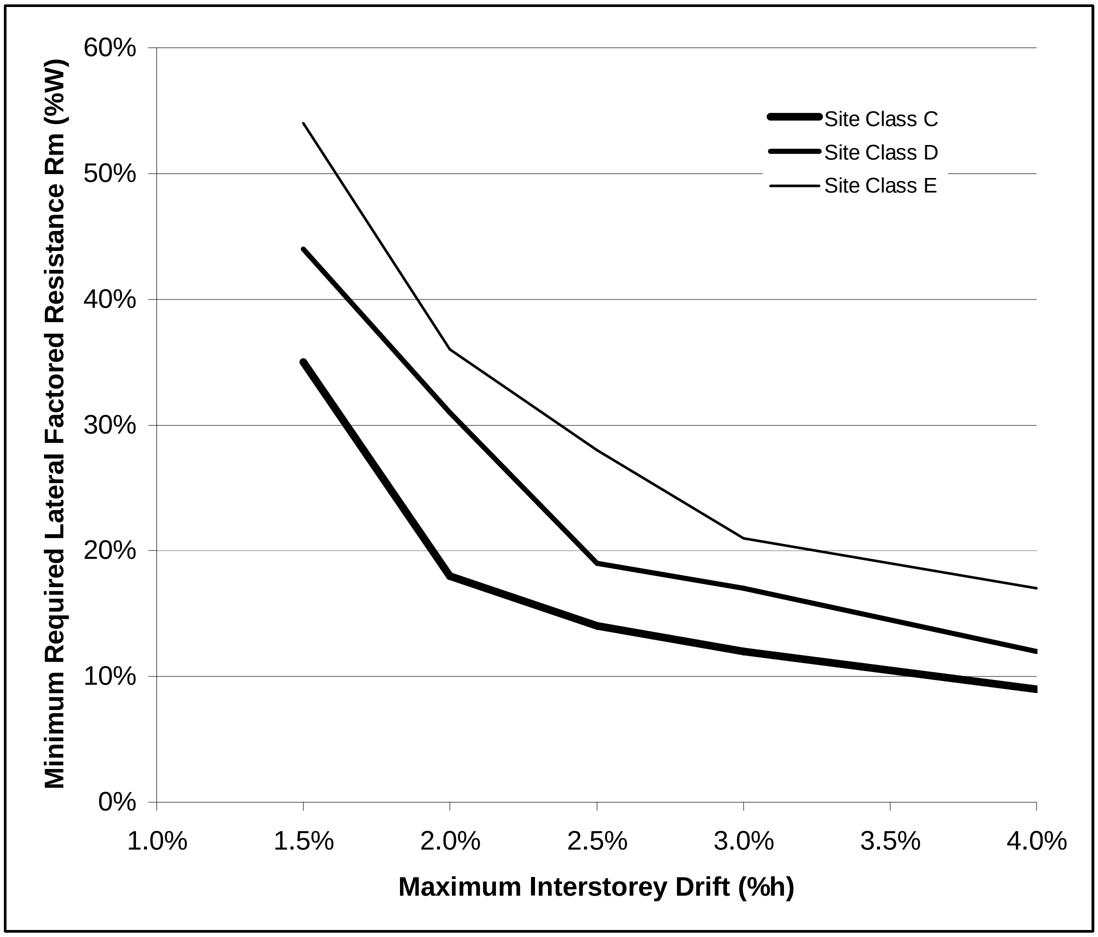


Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	NR	25%	15%	11%	9%	7%
D	NR	37%	21%	15%	13%	10%
E	NR	52%	35%	26%	20%	16%

Figure 3-2(b)

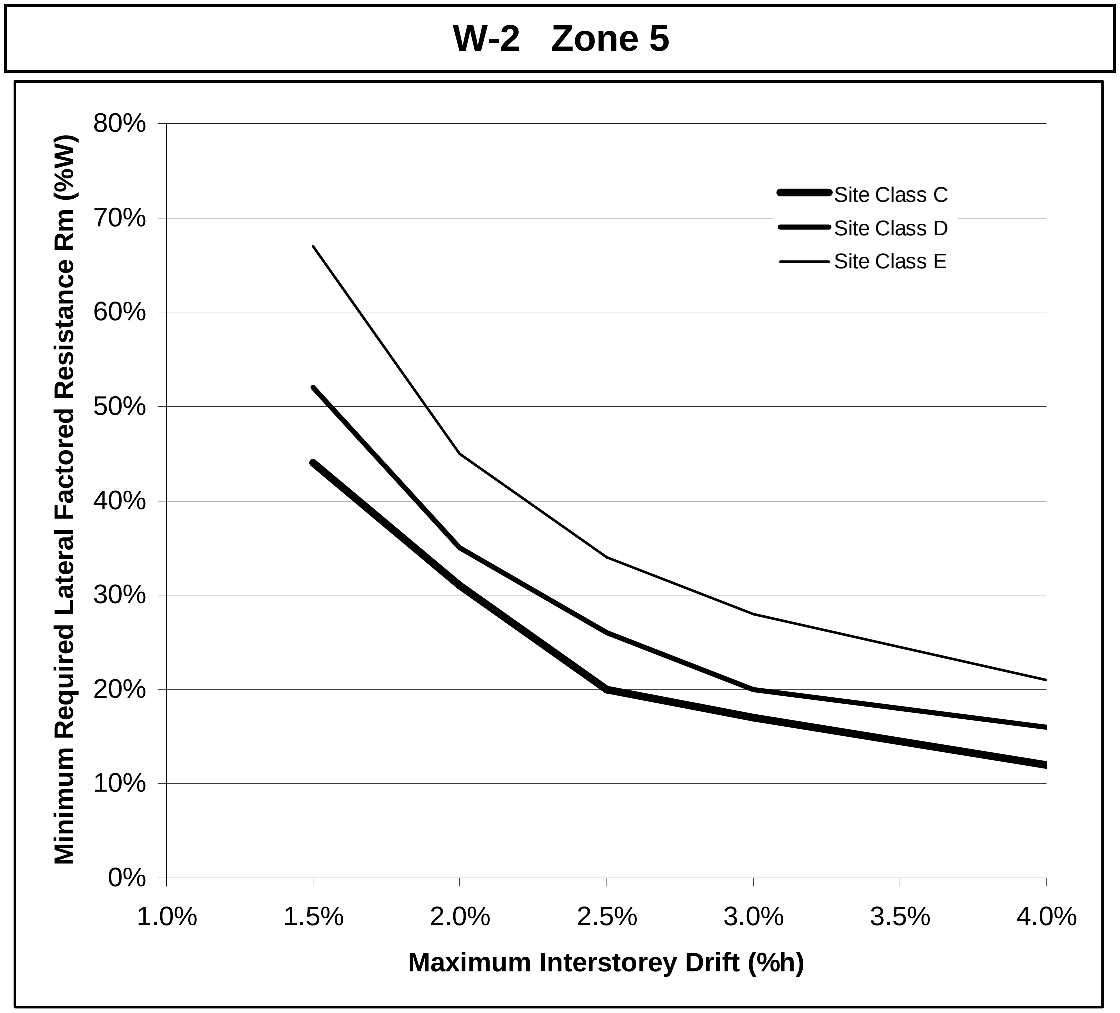
Minimum Required Lateral Factored Resistance R_m (%W)
Wood Prototype W-2 Unblocked OSB/Plywood
Seismic Zone 3 (Chilliwack)

W-2 Zone 4



Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	NR	35%	18%	14%	12%	9%
D	NR	44%	31%	19%	17%	12%
E	NR	54%	36%	28%	21%	17%

Figure 3-2(c) *Minimum Required Lateral Factored Resistance R_m (%W)*
Wood Prototype W-2 Unblocked OSB/Plywood
Seismic Zone 4 (Vancouver)



Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	NR	44%	31%	20%	17%	12%
D	NR	52%	35%	26%	20%	16%
E	NR	67%	45%	34%	28%	21%

Figure 3-2(d) *Minimum Required Lateral Factored Resistance R_m (%W)*
Wood Prototype W-2 Unblocked OSB/Plywood
Seismic Zone 5 (Victoria)

4.0 PERFORMANCE-BASED EARTHQUAKE RETROFIT GUIDELINES FOR LOW-RISE STEEL SCHOOL BUILDINGS

4.1 Prototypes

1) These guidelines include the following forms of steel construction (prototypes) for low-rise school buildings:

    (a) Prototype S-1 for concentrically braced steel frames with tension bracing only
    (b) Prototype S-2 for concentrically braced steel frames with tension/compression bracing
    (c) Prototype S-3 for eccentrically braced steel frames
    (d) Prototype S-4 for moderately ductile steel moment-resisting frames

2) For prototype S-2, a single tension/compression brace is not permitted in a single bay or adjacent bays no more than 5 metres apart. Tension/compression braces must be provided in pairs. Refer to Figure A.4-1 in Section A4 of the commentary for an illustration of this brace pairing requirement. A single tension/compression brace is:

    (a) not recommended for inclusion in the assessment of risk
    (b) not permitted for inclusion in the retrofit design

3) Unless a detailed analysis indicates otherwise, chevron braces are to be considered to have a negligible contribution in the assessment of risk. Refer to Section A4 of the Commentary for suggested method of upgrading for inclusion in the retrofit design.

4) Refer to Section 8 to check that steel LDRSs are not governed by rocking (including footing uplift).

5) ISDL values for Prototype S-2 with hollow section braces are given in Table 4.1.

6) The guidelines in this section are contingent on compliance with the minimum building structural requirements of Section 1.6 and the load path requirements of Section 1.7. Connections, drag struts and similar load path detailing must all be fully compliant.

4.2 Minimum Required Lateral Factored Resistance R_m

1) Minimum required lateral factored resistance R_m for the risk assessment of a low-rise steel building is set equal to 80% of the corresponding value obtained from Figure 4-1 to Figure 4-4.

2) Minimum required lateral factored resistance R_m for the retrofit design of a low-rise steel building is obtained from Figure 4-1 to Figure 4-4.

3) For Prototype S-2, the minimum required lateral factored resistance given in Figure 4-2 is the horizontal component of the resistance of the tension brace that has the lesser tension resistance in the brace pair. Refer to the Section A4 of the Commentary for clarification of this definition.

4) The value of R_m, the minimum required lateral factored resistance determined from Sentence (1) or Sentence (2), can be reduced to the value R_{mr} in accordance with Equation (4-1) for clear storey heights between 3.0 metres and 4.0 metres.

$$R_{mr} = K_{mr} \cdot R_m \tag{4-1}$$

where $K_{mr} = 1.45 - \dfrac{h_{sc}}{6.67}$

4.3 Calculation of Lateral Resistance

1) The calculation of the lateral resistance of steel buildings shall comply with CAN/CSA-S16-01.

2) Strength of columns in steel moment frames and braced steel frames shall exceed the maximum force that can be generated by frame action and gravity loads.

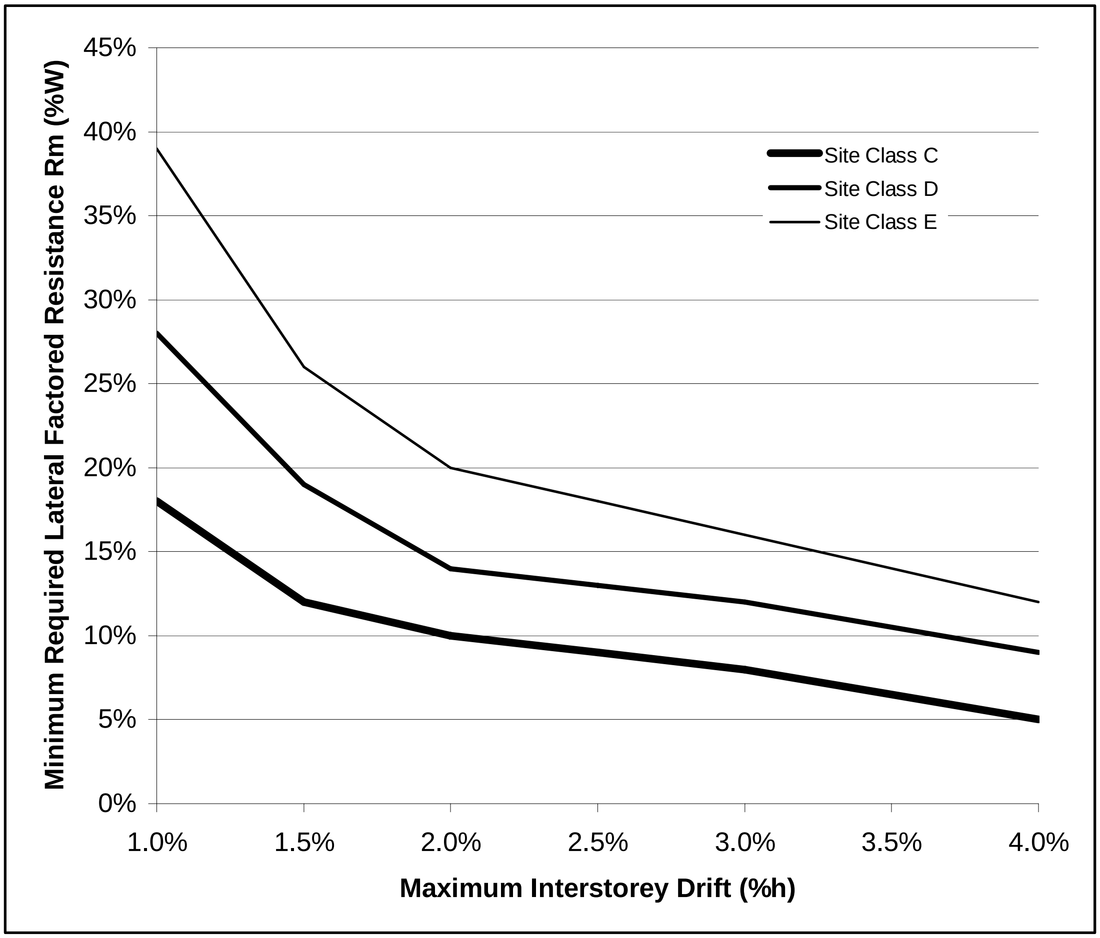
4.4 Steel Base Moments

1) Overturning moment at the base of a steel LDRS is to be calculated in accordance with Sentence 1.11(1) using K_{bm} = 1.0 for 1-3 storeys and all seismic zones.

Table 4.1 Drift Limits for Concentrically Braced Steel Frames with Hollow Section Braces

Brace Section	Brace Axial Load	ISDL	Requirements
Hollow Rectangular	Tension or compression	2.5%	$\frac{d}{t_h} \leq \frac{240}{\sqrt{f_y}}$
		1.0%	$\frac{d}{t_h} > \frac{500}{\sqrt{f_y}}$
		Linear Interpolation	$\frac{500}{\sqrt{f_y}} \geq \frac{d}{t_h} > \frac{240}{\sqrt{f_y}}$
Hollow Circular	Tension or compression	2.5%	$\frac{d}{t_h} \leq \frac{10300}{f_y}$
		1.0%	$\frac{d}{t_h} > \frac{41400}{f_y}$
		Linear Interpolation	$\frac{41400}{f_y} \geq \frac{d}{t_h} > \frac{10300}{f_y}$

S-1 Zone 2

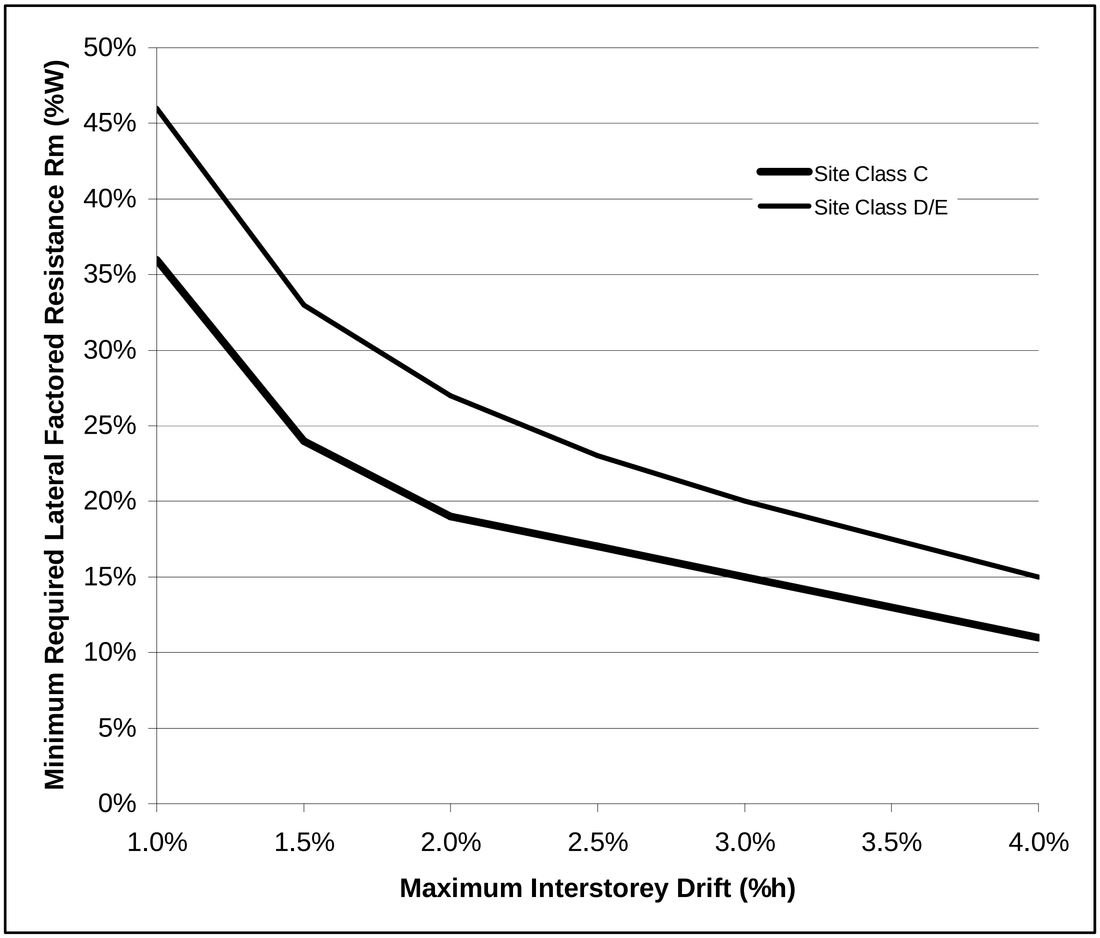


Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	18%	12%	10%	9%	8%	5%
D	28%	19%	14%	13%	12%	9%
E	39%	26%	20%	18%	16%	12%

Figure 4-1(a)

Minimum Required Lateral Factored Resistance R_m (%W)
Steel Prototype S-1 Concentric Braced Frame (Tension Only)
Seismic Zone 2 (Princeton)

S-1 Zone 3

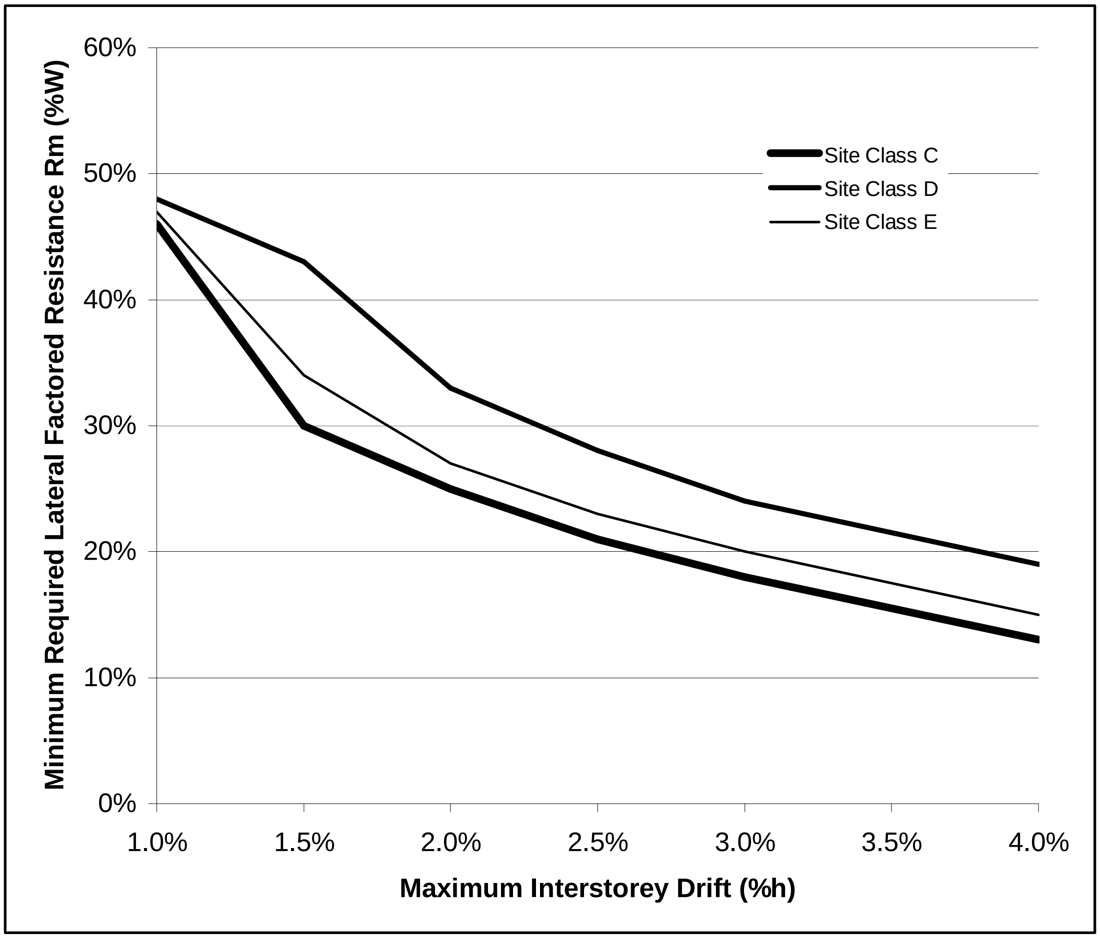


Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	36%	24%	19%	17%	15%	11%
D	46%	33%	27%	23%	20%	15%
E	46%	33%	27%	23%	20%	15%

Figure 4-1(b)

Minimum Required Lateral Factored Resistance R_m (%W)
Steel Prototype S-1 Concentric Braced Frame (Tension Only)
Seismic Zone 3 (Chilliwack)

S-1 Zone 4

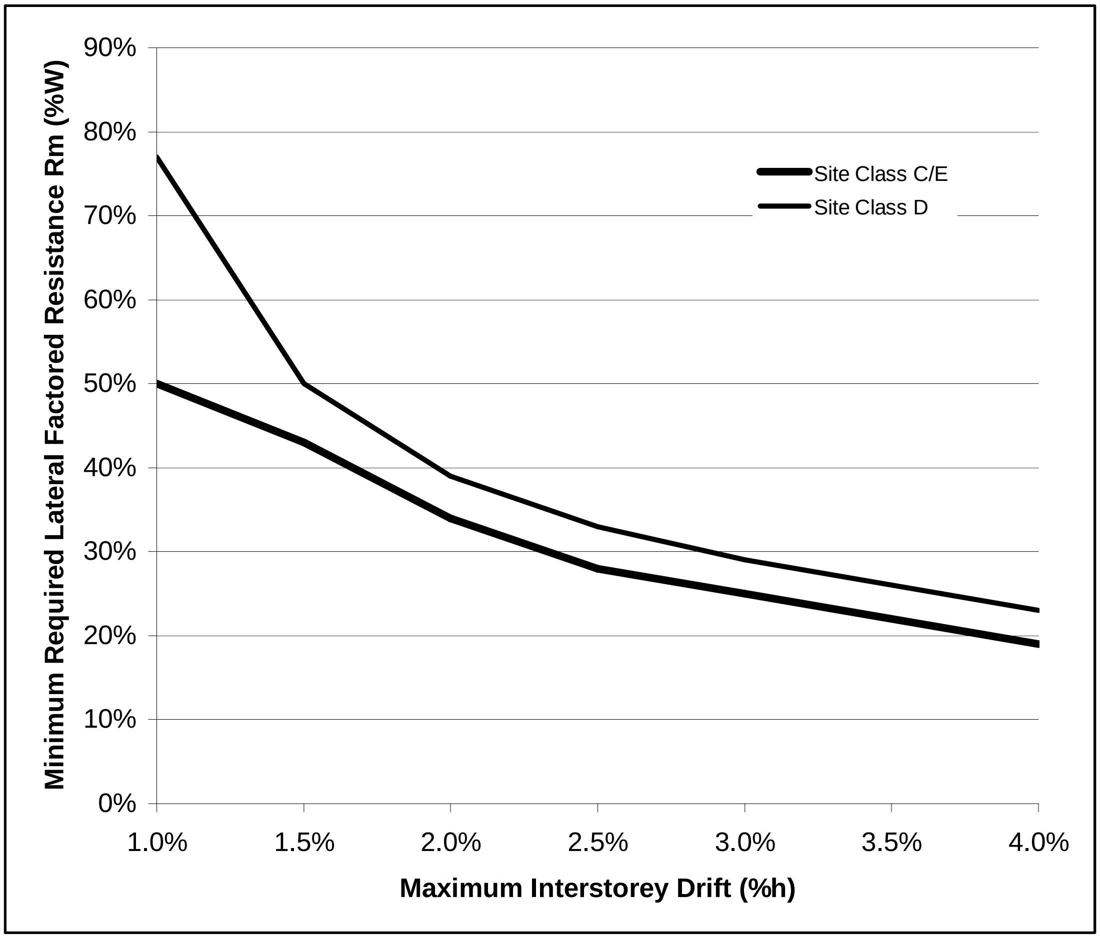


Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	46%	30%	25%	21%	18%	13%
D	48%	43%	33%	28%	24%	19%
E	47%	34%	27%	23%	20%	15%

Figure 4-1(c)

Minimum Required Lateral Factored Resistance R_m (%W)
Steel Prototype S-1 Concentric Braced Frame (Tension Only)
Seismic Zone 4 (Vancouver)

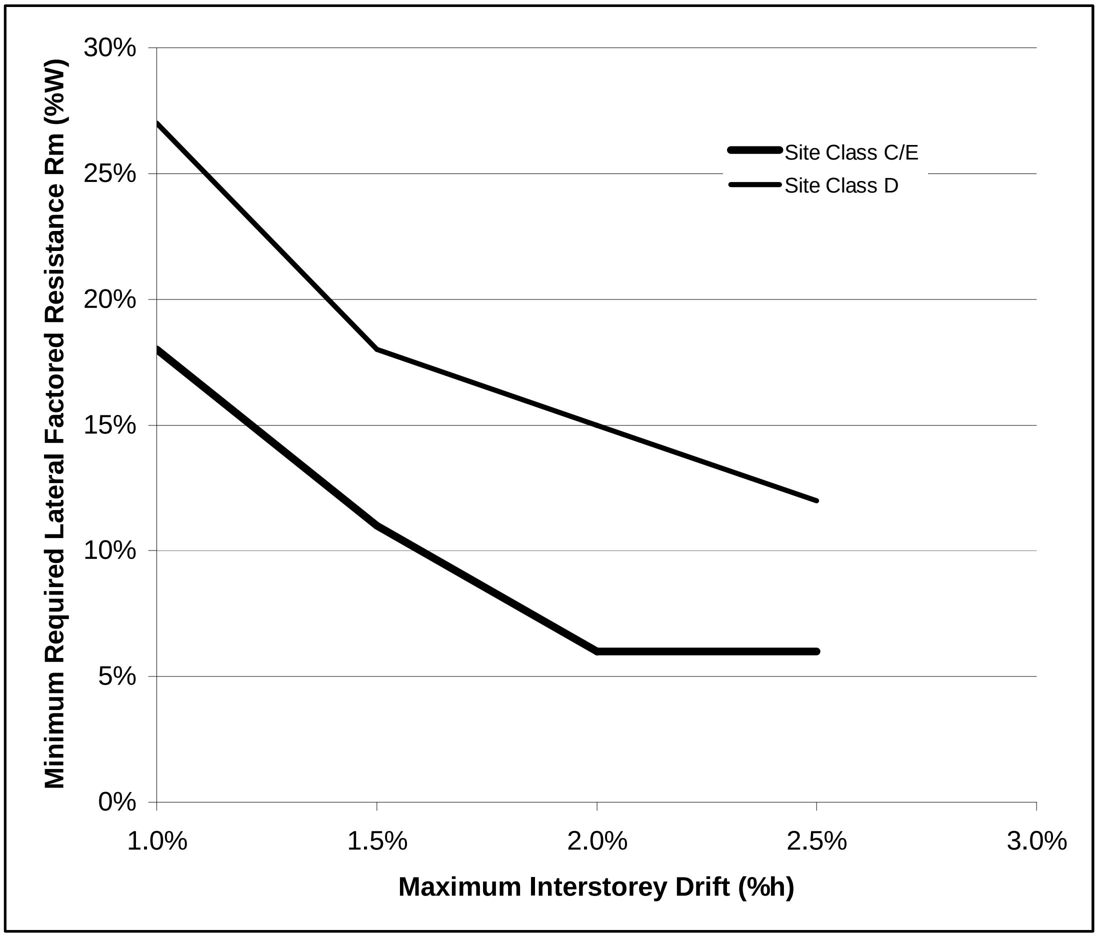
S-1 Zone 5



Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	50%	43%	34%	28%	25%	19%
D	77%	50%	39%	33%	29%	23%
E	50%	43%	34%	28%	25%	19%

Figure 4-1(d) *Minimum Required Lateral Factored Resistance R_m (%W)*
Steel Prototype S-1 Concentric Braced Frame (Tension Only)
Seismic Zone 5 (Victoria)

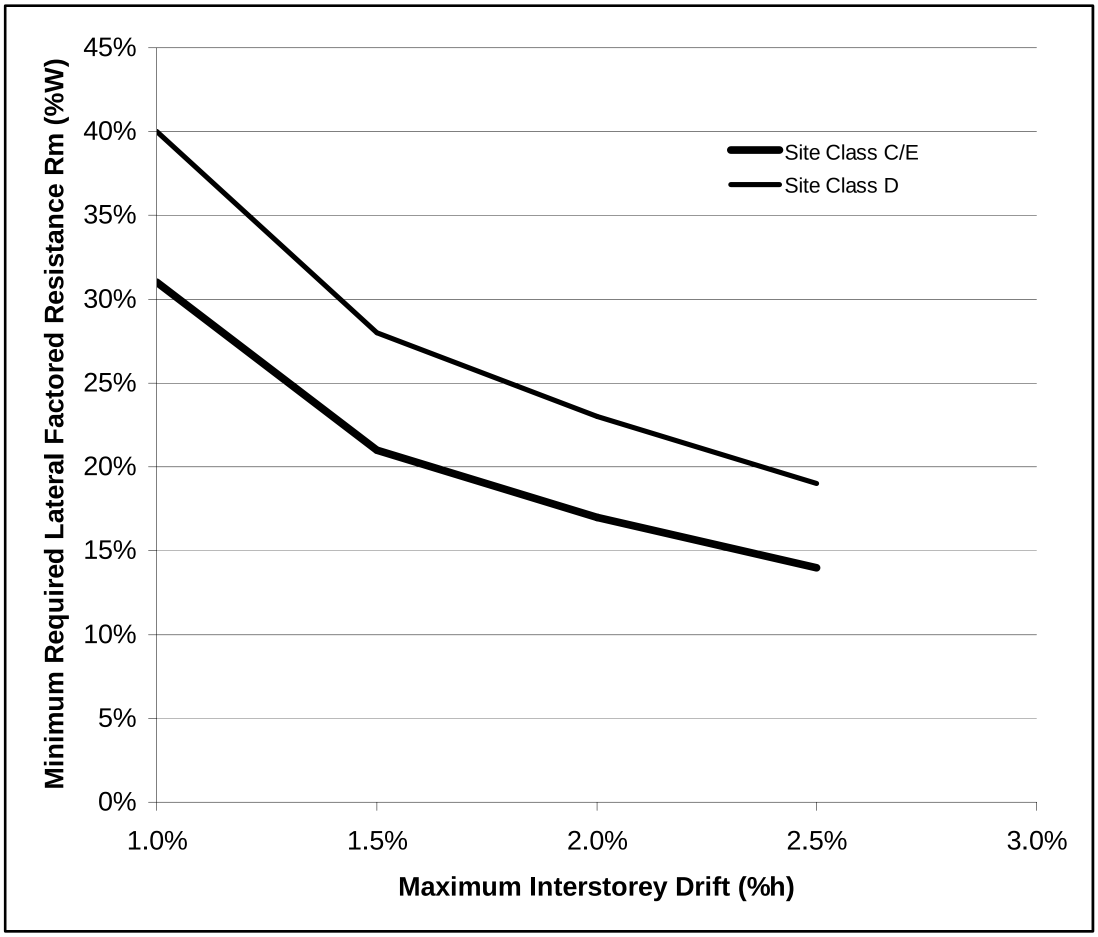
S-2 Zone 2



Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	18%	11%	6%	6%	NP	NP
D	27%	18%	15%	12%	NP	NP
E	27%	18%	15%	12%	NP	NP

Figure 4-2(a) *Minimum Required Lateral Factored Resistance R_m (%W)*
Steel Prototype S-2 Concentric Braced Frame (Tens./Comp.)
Seismic Zone 2 (Princeton)

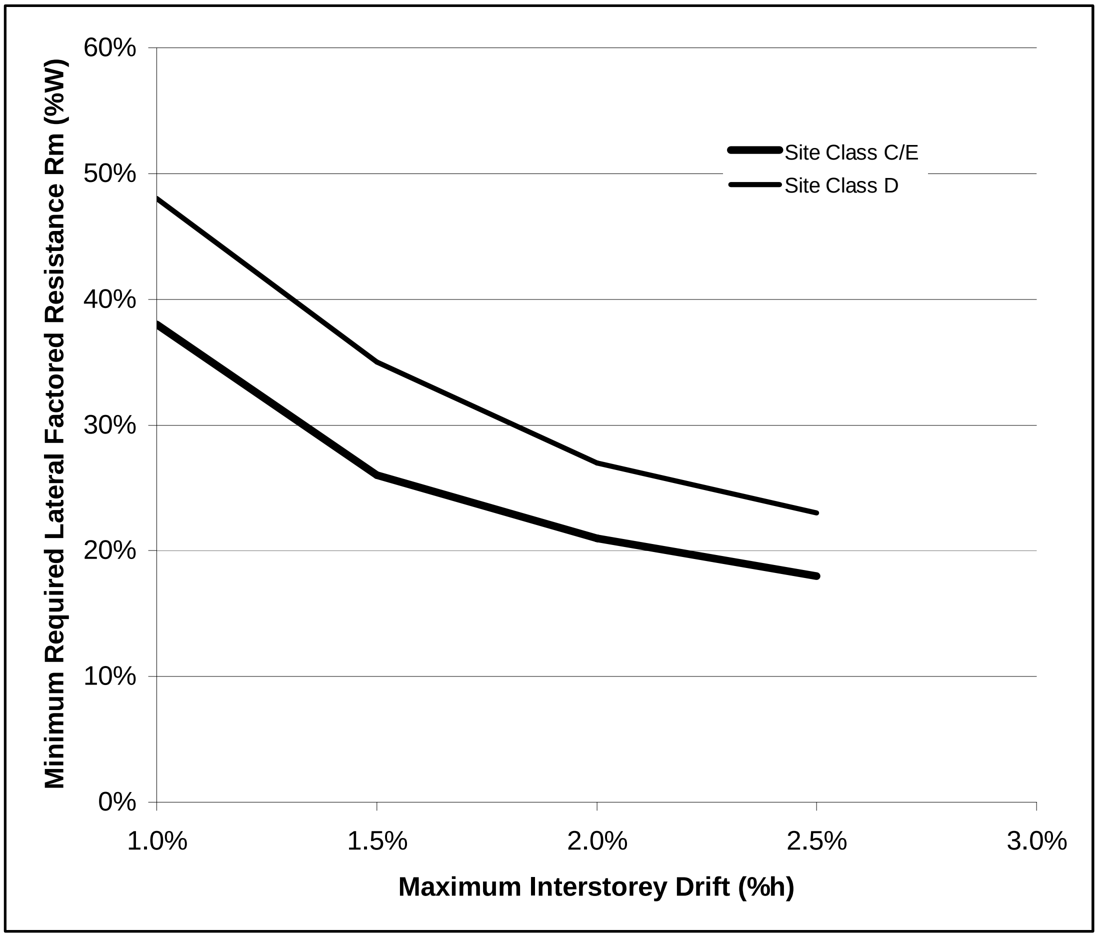
S-2 Zone 3



Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	31%	21%	17%	14%	NP	NP
D	40%	28%	23%	19%	NP	NP
E	31%	21%	17%	14%	NP	NP

Figure 4-2(b)
Minimum Required Lateral Factored Resistance R_m (%W)
Steel Prototype S-2 Concentric Braced Frame (Tens./Comp.)
Seismic Zone 3 (Chilliwack)

S-2 Zone 4

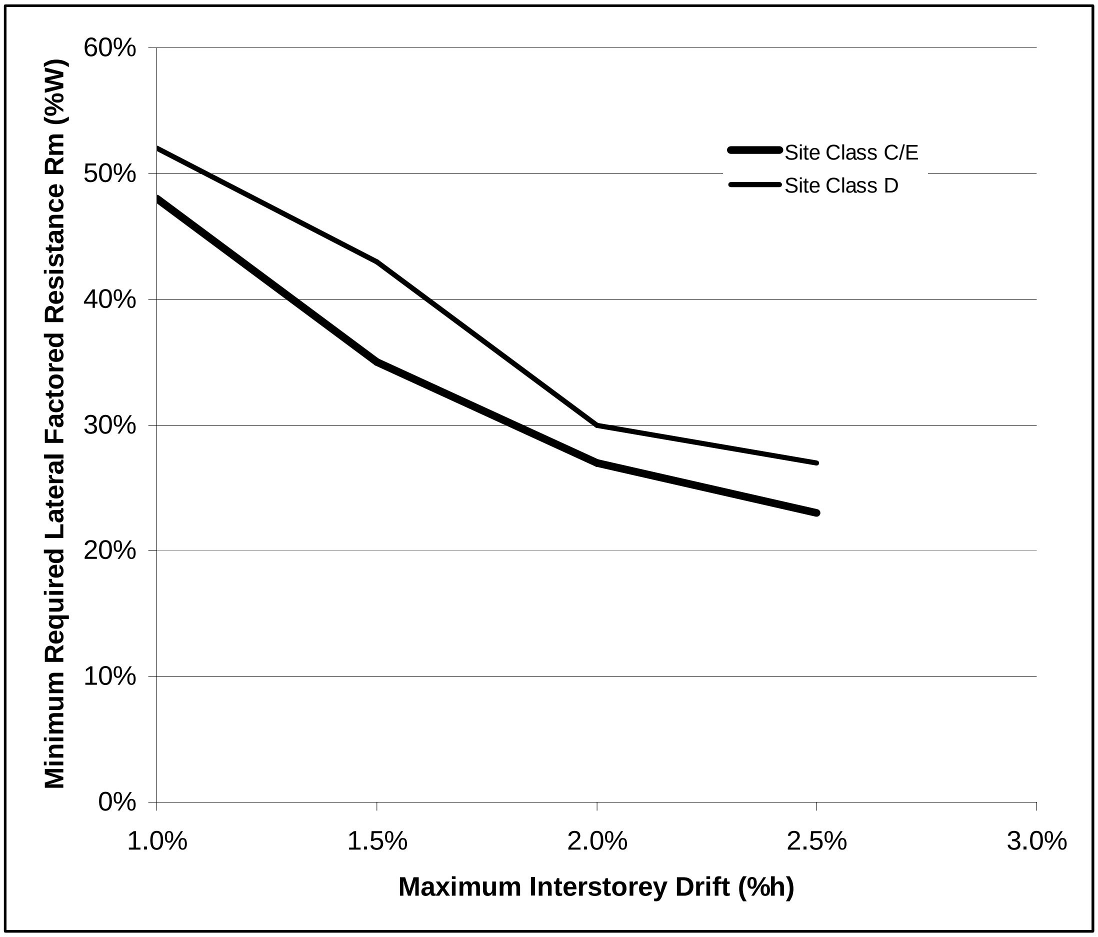


Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	38%	26%	21%	18%	NP	NP
D	48%	35%	27%	23%	NP	NP
E	38%	26%	21%	18%	NP	NP

Figure 4-2(c)

Minimum Required Lateral Factored Resistance R_m (%W)
Steel Prototype S-2 Concentric Braced Frame (Tens./Comp.)
Seismic Zone 4 (Vancouver)

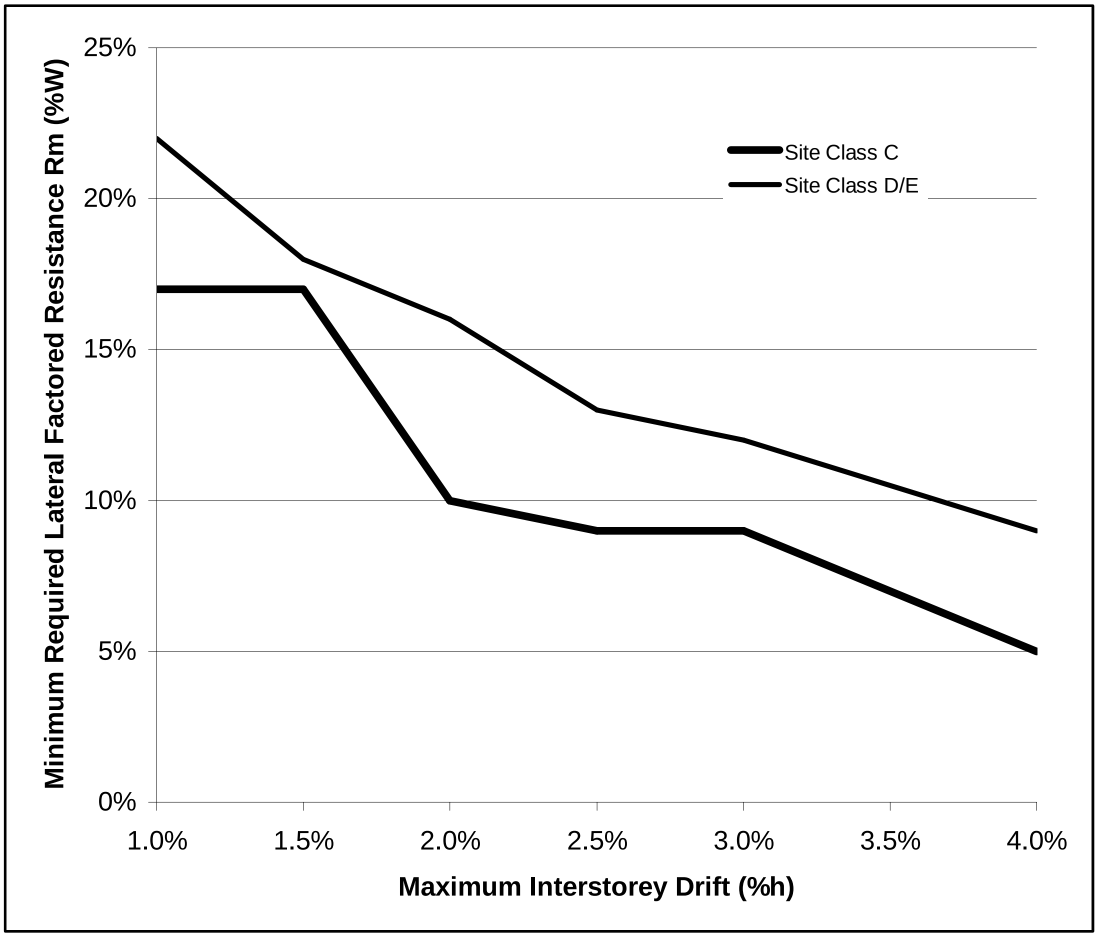
S-2 Zone 5



Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	48%	35%	27%	23%	NP	NP
D	52%	43%	30%	27%	NP	NP
E	48%	35%	27%	23%	NP	NP

Figure 4-2(d) *Minimum Required Lateral Factored Resistance R_m (%W)*
Steel Prototype S-2 Concentric Braced Frame (Tens./Comp.)
Seismic Zone 5 (Victoria)

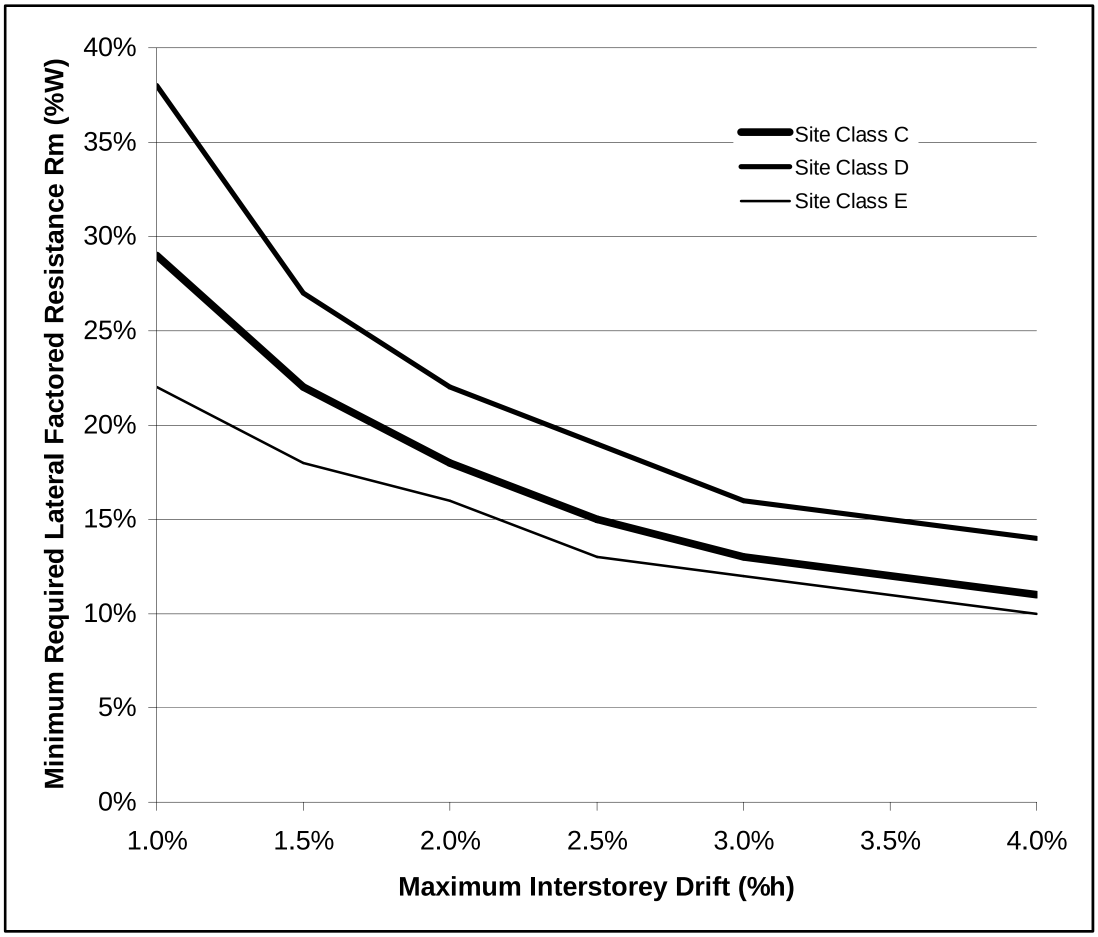
S-3 Zone 2



Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	17%	17%	10%	9%	9%	5%
D	22%	18%	16%	13%	12%	9%
E	22%	18%	16%	13%	12%	9%

Figure 4-3(a) *Minimum Required Lateral Factored Resistance R_m (%W)*
Steel Prototype S-3 Eccentric Braced Frame
Seismic Zone 2 (Princeton)

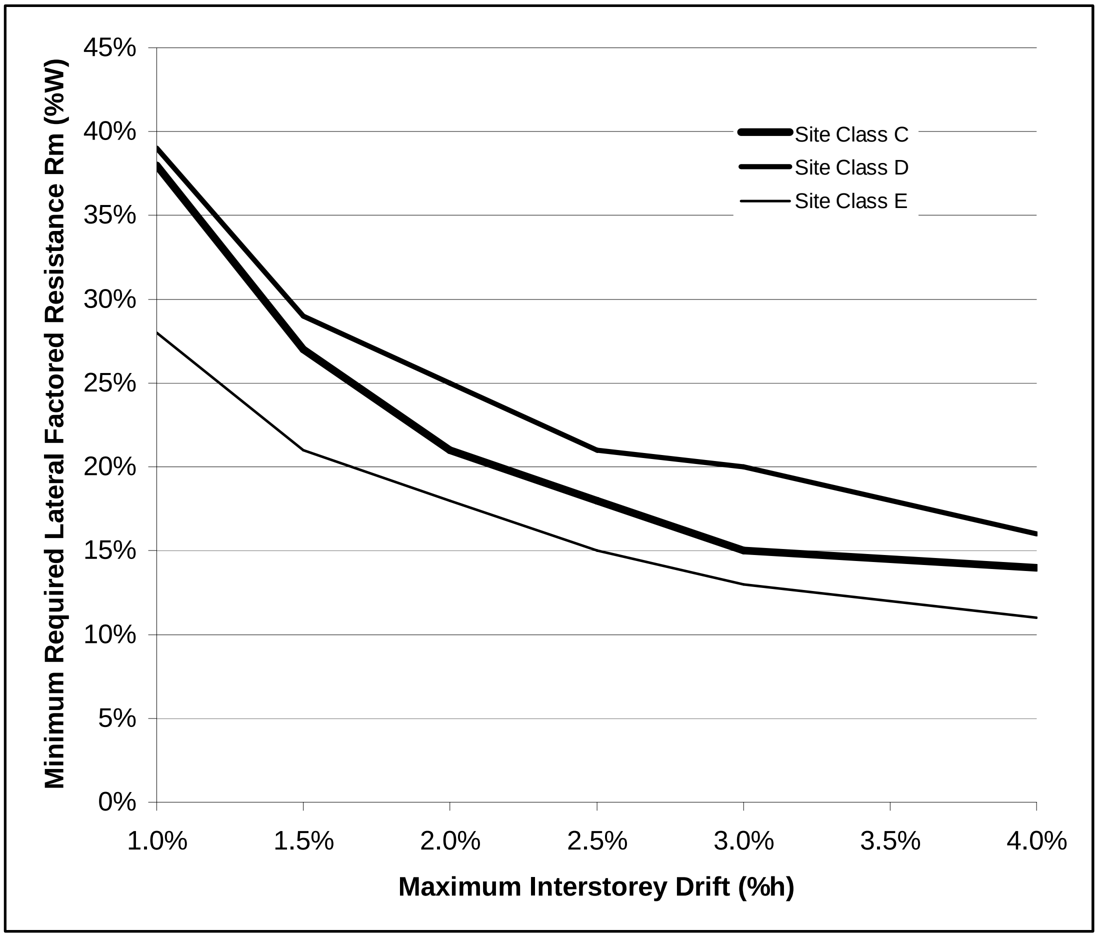
S-3 Zone 3



Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	29%	22%	18%	15%	13%	11%
D	38%	27%	22%	19%	16%	14%
E	22%	18%	16%	13%	12%	10%

Figure 4-3(b) *Minimum Required Lateral Factored Resistance R_m (%W)*
Steel Prototype S-3 Eccentric Braced Frame
Seismic Zone 3 (Chilliwack)

S-3 Zone 4

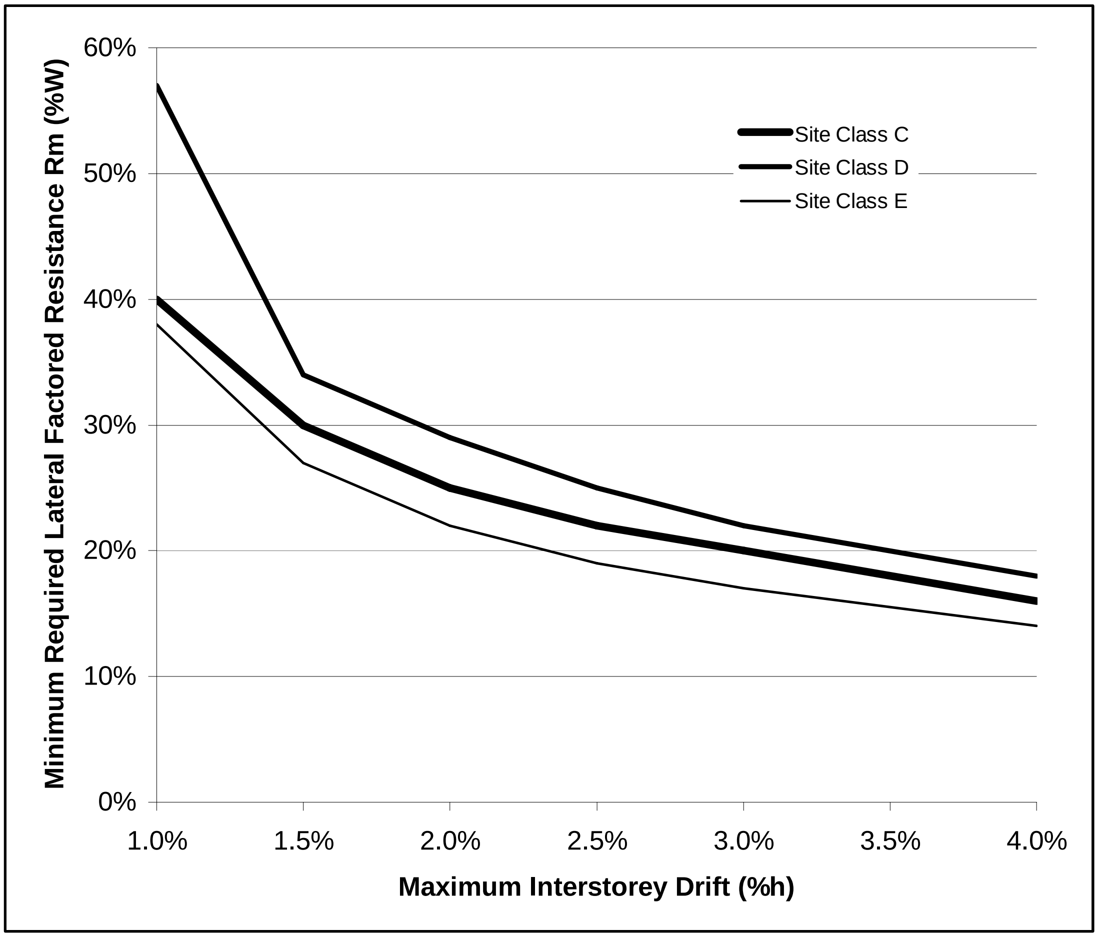


Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	38%	27%	21%	18%	15%	14%
D	39%	29%	25%	21%	20%	16%
E	28%	21%	18%	15%	13%	11%

Figure 4-3(c)

Minimum Required Lateral Factored Resistance R_m (%W)
Steel Prototype S-3 Eccentric Braced Frame
Seismic Zone 4 (Vancouver)

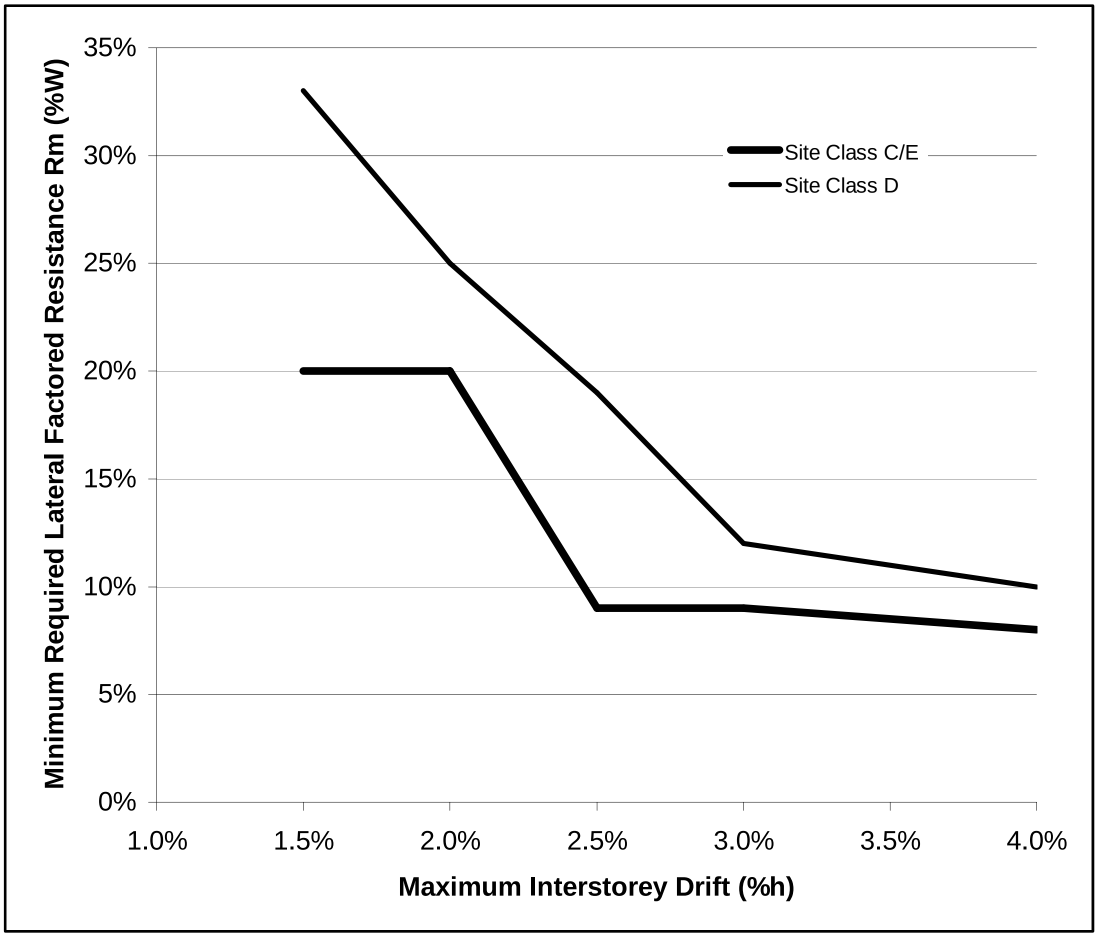
S-3 Zone 5



Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	40%	30%	25%	22%	20%	16%
D	57%	34%	29%	25%	22%	18%
E	38%	27%	22%	19%	17%	14%

Figure 4-3(d) *Minimum Required Lateral Factored Resistance R_m (%W)*
Steel Prototype S-3 Eccentric Braced Frame
Seismic Zone 5 (Victoria)

S-4 Zone 2

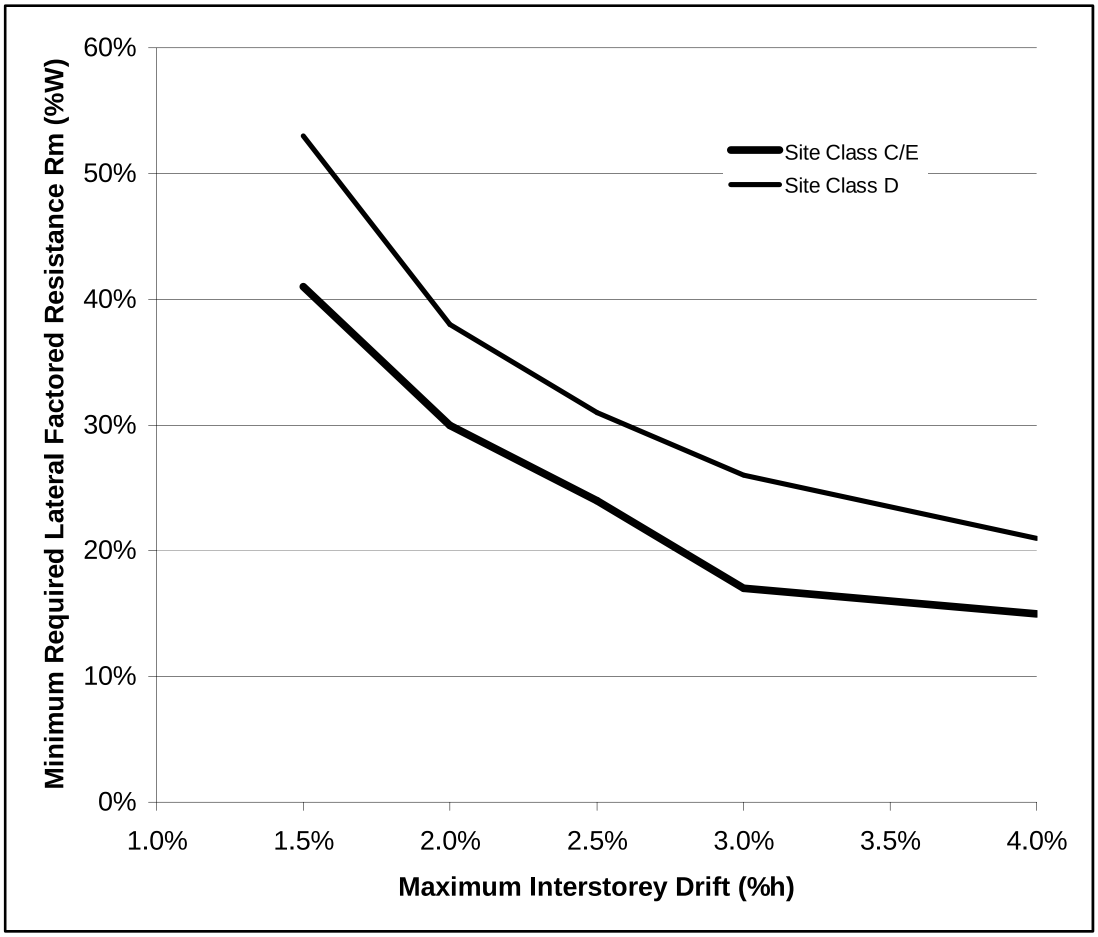


Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	NR	20%	20%	9%	9%	8%
D	NR	33%	25%	19%	12%	10%
E	NR	20%	20%	9%	9%	8%

Figure 4-4(a)

Minimum Required Lateral Factored Resistance R_m (%W)
Steel Prototype S-4 Moment Frame (Moderately Ductile)
Seismic Zone 2 (Princeton)

S-4 Zone 3

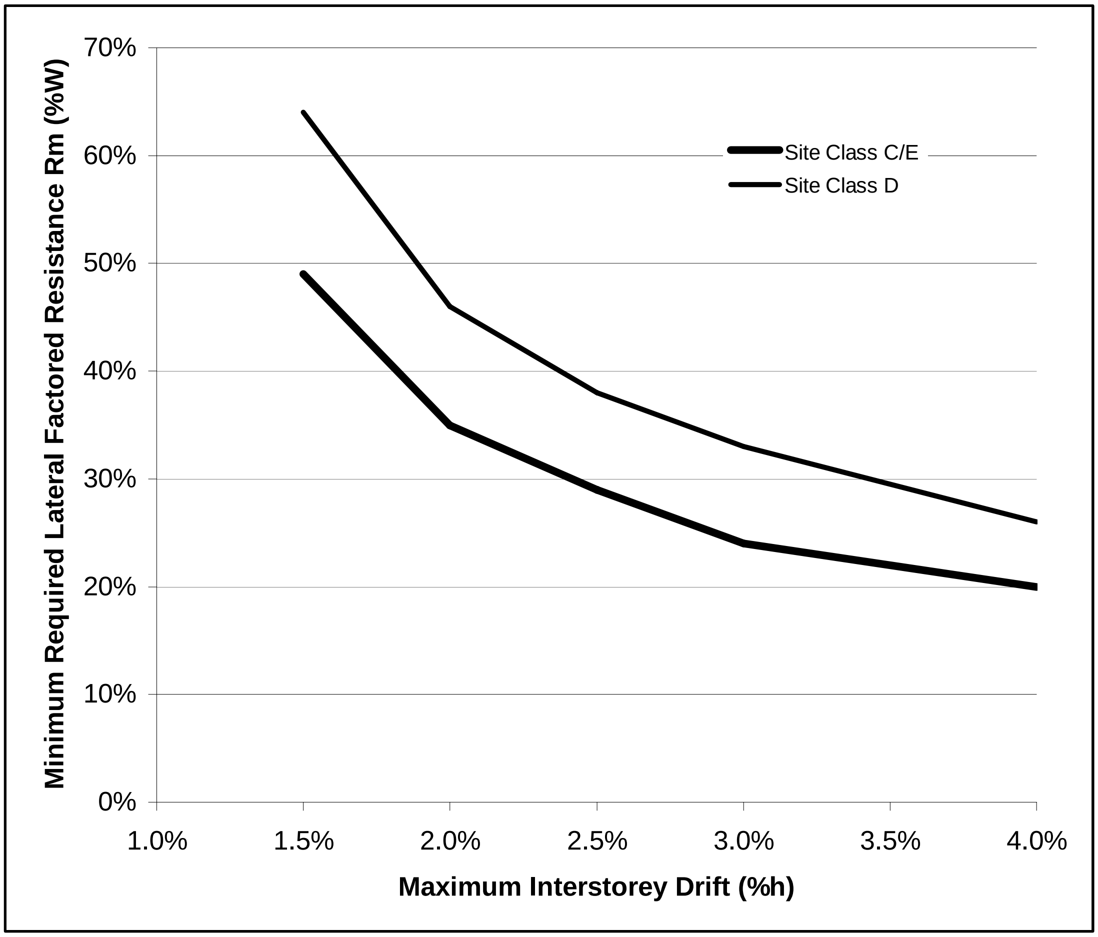


Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	NR	41%	30%	24%	17%	15%
D	NR	53%	38%	31%	26%	21%
E	NR	41%	30%	24%	17%	15%

Figure 4-4(b)

Minimum Required Lateral Factored Resistance R_m (%W)
Steel Prototype S-4 Moment Frame (Moderately Ductile)
Seismic Zone 3 (Chilliwack)

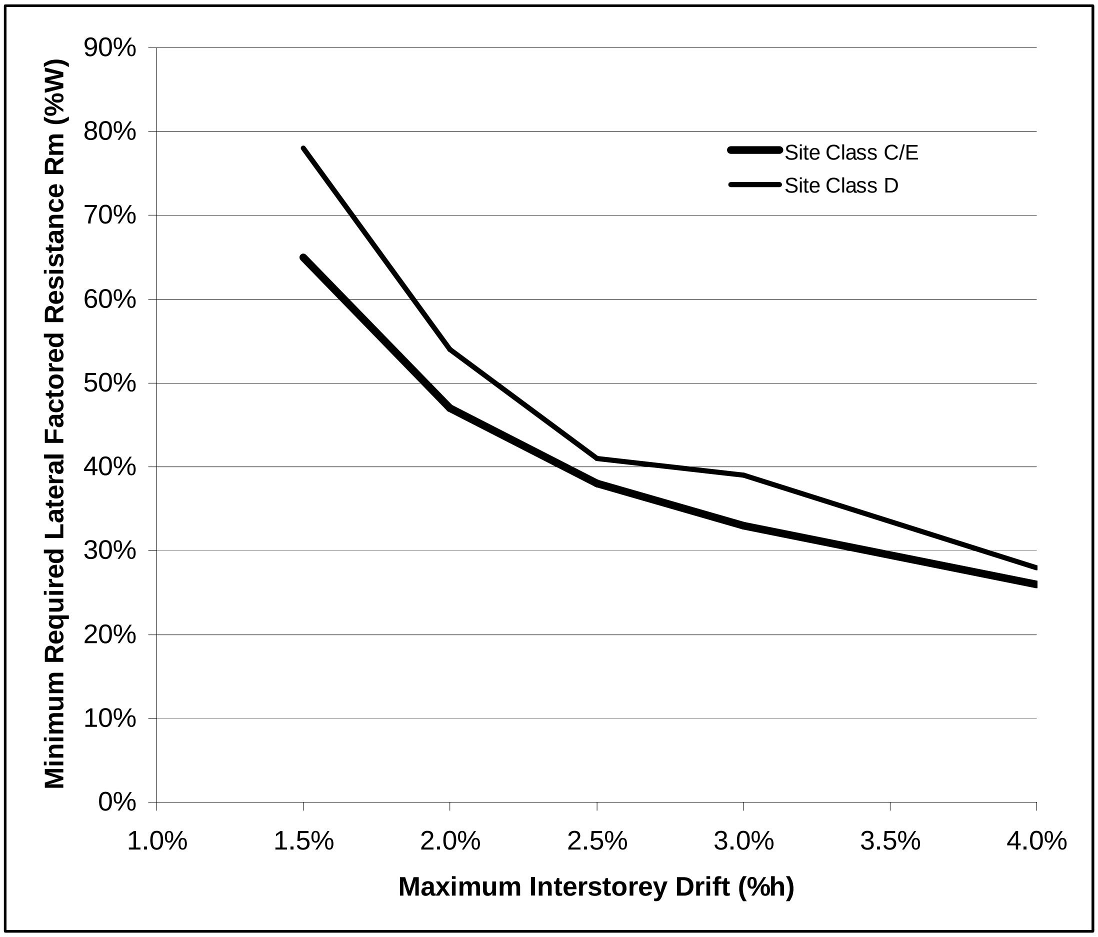
S-4 Zone 4



Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	NR	49%	35%	29%	24%	20%
D	NR	64%	46%	38%	33%	26%
E	NR	49%	35%	29%	24%	20%

Figure 4-4(c) *Minimum Required Lateral Factored Resistance R_m (%W)*
Steel Prototype S-4 Moment Frame (Moderately Ductile)
Seismic Zone 4 (Vancouver)

S-4 Zone 5



Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	NR	65%	47%	38%	33%	26%
D	NR	78%	54%	41%	39%	28%
E	NR	65%	47%	38%	33%	26%

Figure 4-4(d)

Minimum Required Lateral Factored Resistance R_m (%W)
Steel Prototype S-4 Moment Frame (Moderately Ductile)
Seismic Zone 5 (Victoria)

5.0 PERFORMANCE-BASED EARTHQUAKE RETROFIT GUIDELINES FOR LOW-RISE CONCRETE SCHOOL BUILDINGS

5.1 Prototypes

1) These guidelines include the following forms of reinforced concrete construction (prototypes) for low-rise school buildings:

   (a) Prototype C-1 for moderately ductile shearwalls
   (b) Prototype C-2 for conventional construction shearwalls
   (c) Prototype C-3 for ductile moment resisting frames
   (d) Prototype C-4 for moderately ductile moment resisting frames
   (e) Prototype C-5 for conventional construction moment resisting frames

2) Guidelines in this section for Prototype C-1 and Prototype C-2 are for shearwalls with a maximum aspect ratio of 4.0.

3) Refer to Sentence A5.1(4) of the Commentary for the choice of the moment resisting frame prototype.

4) Refer to Section 8 to check that concrete LDRSs are not governed by rocking (including footing uplift).

5) The lateral resistance of a concrete column with a clear storey height less than 50% of the inter-storey height shall not be included in the assessment or retrofit design of a concrete building if the column maximum permissible drift, calculated in accordance with Sentence 5.5(1) and prorated by h_s/h_{sc}, does not exceed 1%.

5.2 Minimum Required Lateral Factored Resistance R_m

1) Minimum required lateral factored resistance R_m for the risk assessment of a low-rise concrete building is set equal to 80% of the corresponding value obtained from Figure 5-1 to Figure 5-5.

2) Minimum required lateral factored resistance R_m for the retrofit design of a low-rise concrete building is obtained from Figure 5-1 to Figure 5-5.

3) The value of R_m, the minimum required lateral factored resistance determined from Sentence (1) or Sentence (2), can be reduced to the value R_{mr} in accordance with Equation (5-1) for clear storey heights between 3.0 metres and 4.0 metres.

$$R_{mr} = K_{mr} \cdot R_m \tag{5-1}$$

$$\text{where} \quad K_{mr} = 1.45 - \frac{h_{sc}}{6.67}$$

5.3 Calculation of Lateral Resistance

1) The calculation of the lateral resistance of concrete buildings shall comply with CSA-A23.3-04.

2) Refer to Sentence A5.3(2) of the Commentary for the lateral resistance of concrete LDRSs with insufficient lap splices.

5.4 Concrete Building Base Moments

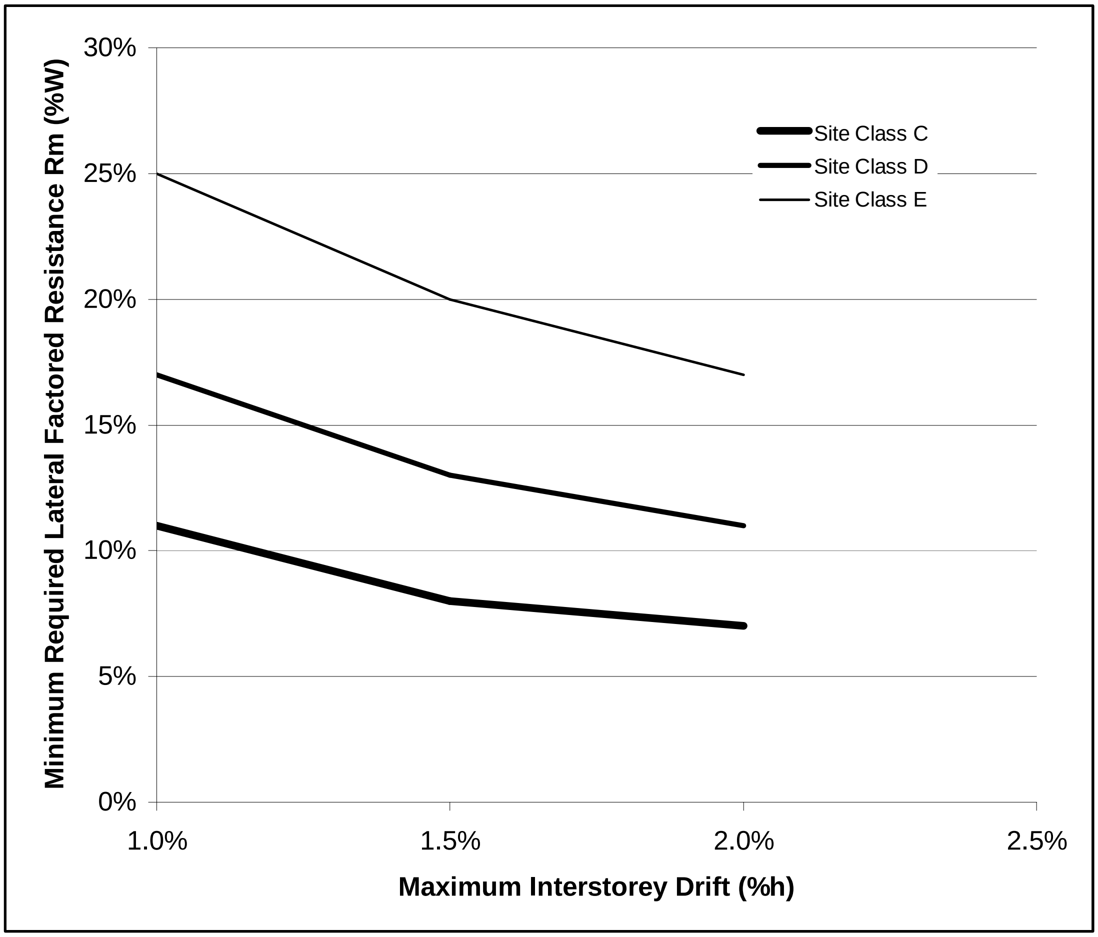
1) For Seismic Zones 3-5, the overturning moment at the base of a concrete LDRS is to be calculated in accordance with Sentence 1.11(1) using K_{bm} = 1.0 with the exception of:

   (a) K_{bm} = 0.9 for two storeys and a light roof
   (b) K_{bm} = 0.9 for three storeys with or without a light roof

5.5 Non-LDRS Drift Compatibility

1) In checking the drift compatibility of load-bearing non-LDRS elements (Sentence 1.12(2)), refer to Section A5 in the Commentary for details on calculating the maximum permissible drift for non-LDRS reinforced concrete columns.

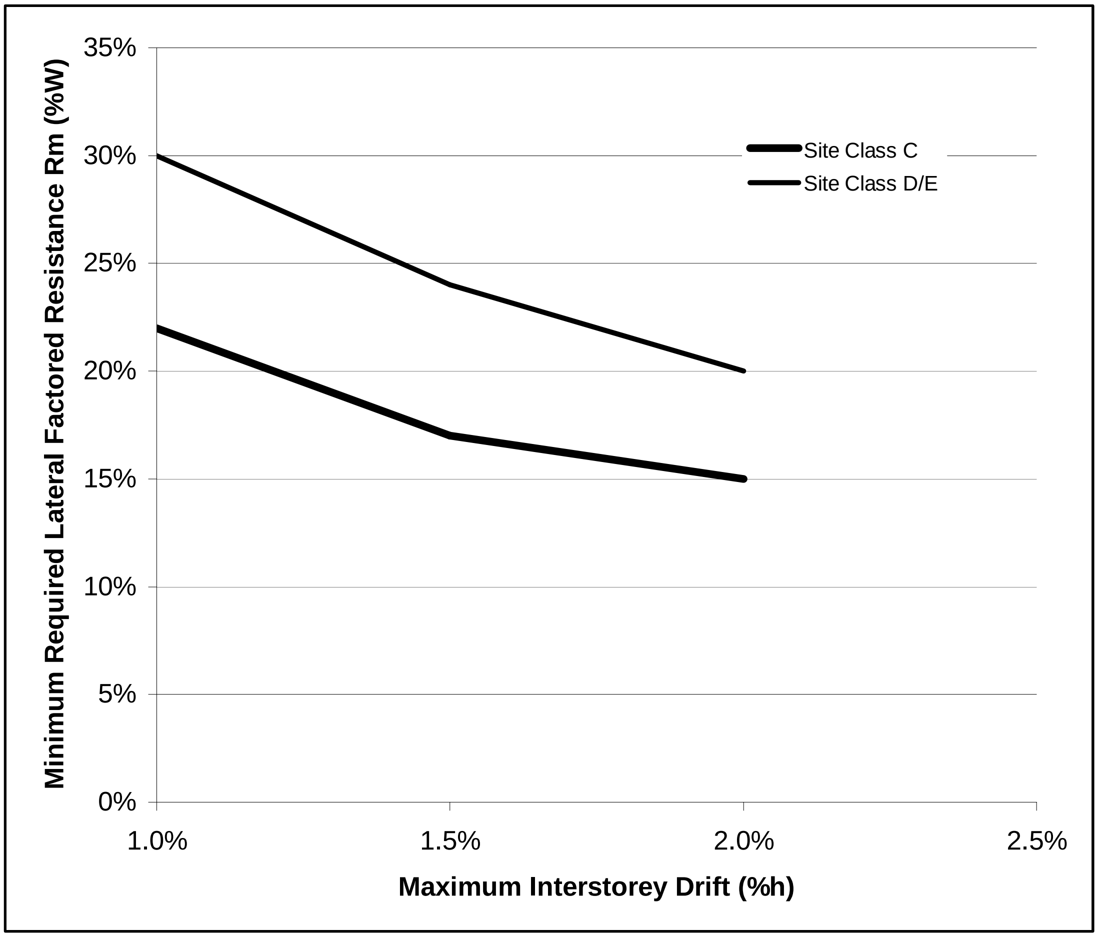
C-1 Zone 2



Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	11%	8%	7%	NP	NP	NP
D	17%	13%	11%	NP	NP	NP
E	25%	20%	17%	NP	NP	NP

Figure 5-1(a)
Minimum Required Lateral Factored Resistance R_m (%W)
Concrete Prototype C-1 Shearwall (Moderately Ductile)
Seismic Zone 2 (Princeton)

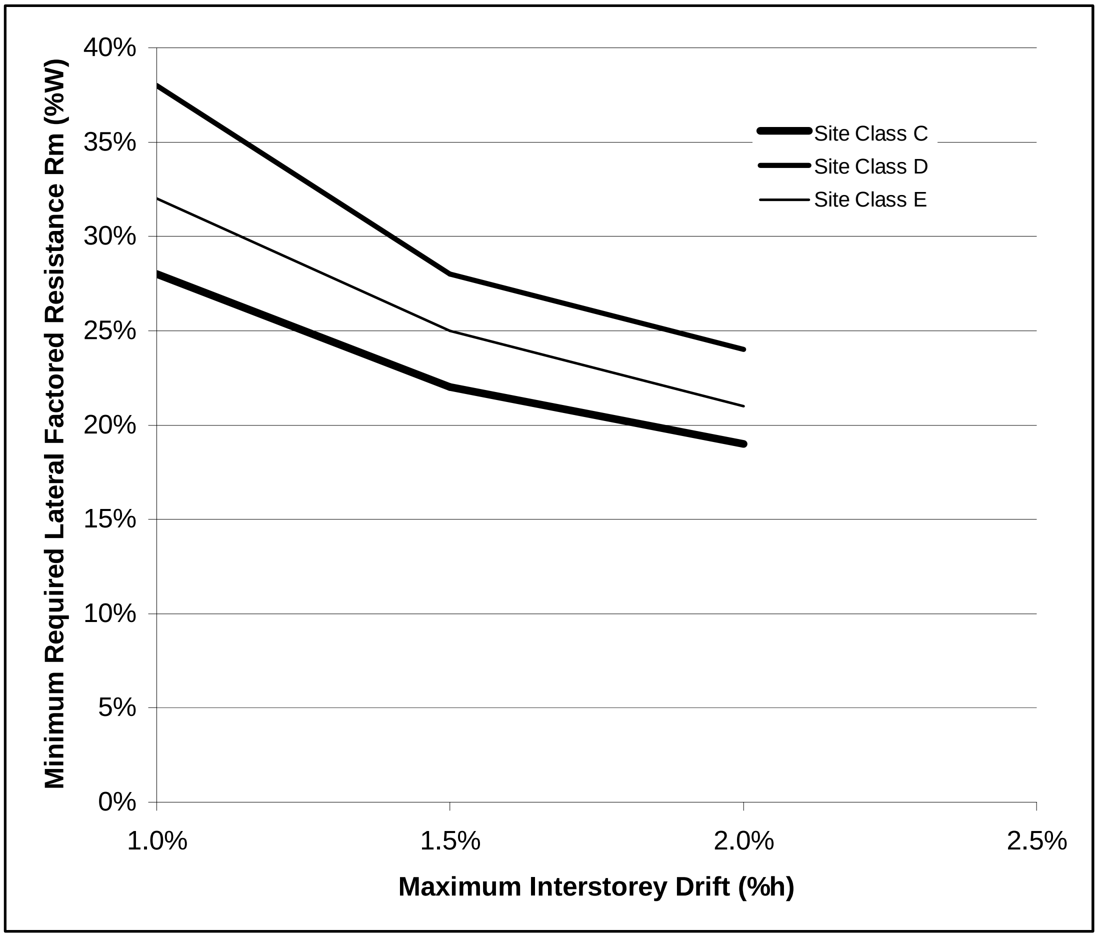
C-1 Zone 3



Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	22%	17%	15%	NP	NP	NP
D	30%	24%	20%	NP	NP	NP
E	30%	24%	20%	NP	NP	NP

Figure 5-1(b) *Minimum Required Lateral Factored Resistance R_m (%W)*
Concrete Prototype C-1 Shearwall (Moderately Ductile)
Seismic Zone 3 (Chilliwack)

C-1 Zone 4

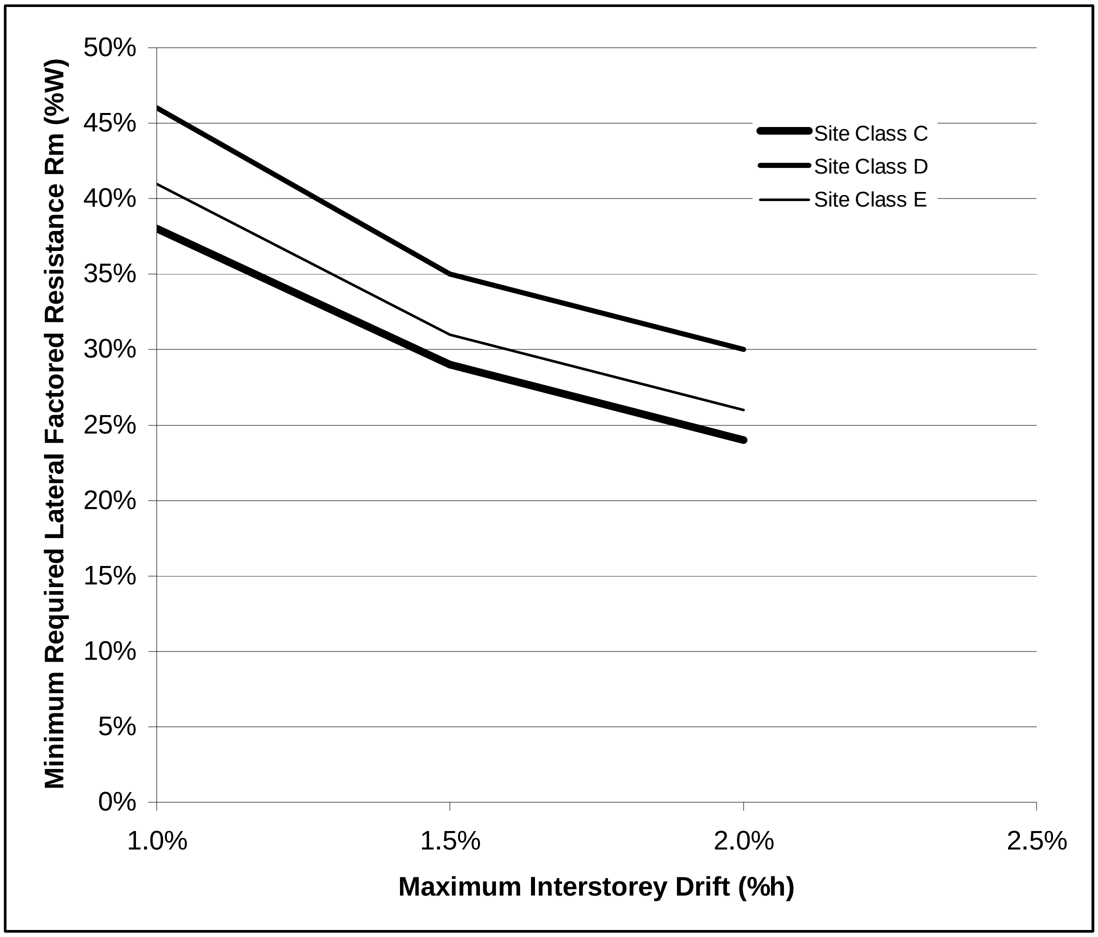


Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	28%	22%	19%	NP	NP	NP
D	38%	28%	24%	NP	NP	NP
E	32%	25%	21%	NP	NP	NP

Figure 5-1(c)

Minimum Required Lateral Factored Resistance R_m (%W)
Concrete Prototype C-1 Shearwall (Moderately Ductile)
Seismic Zone 4 (Vancouver)

C-1 Zone 5

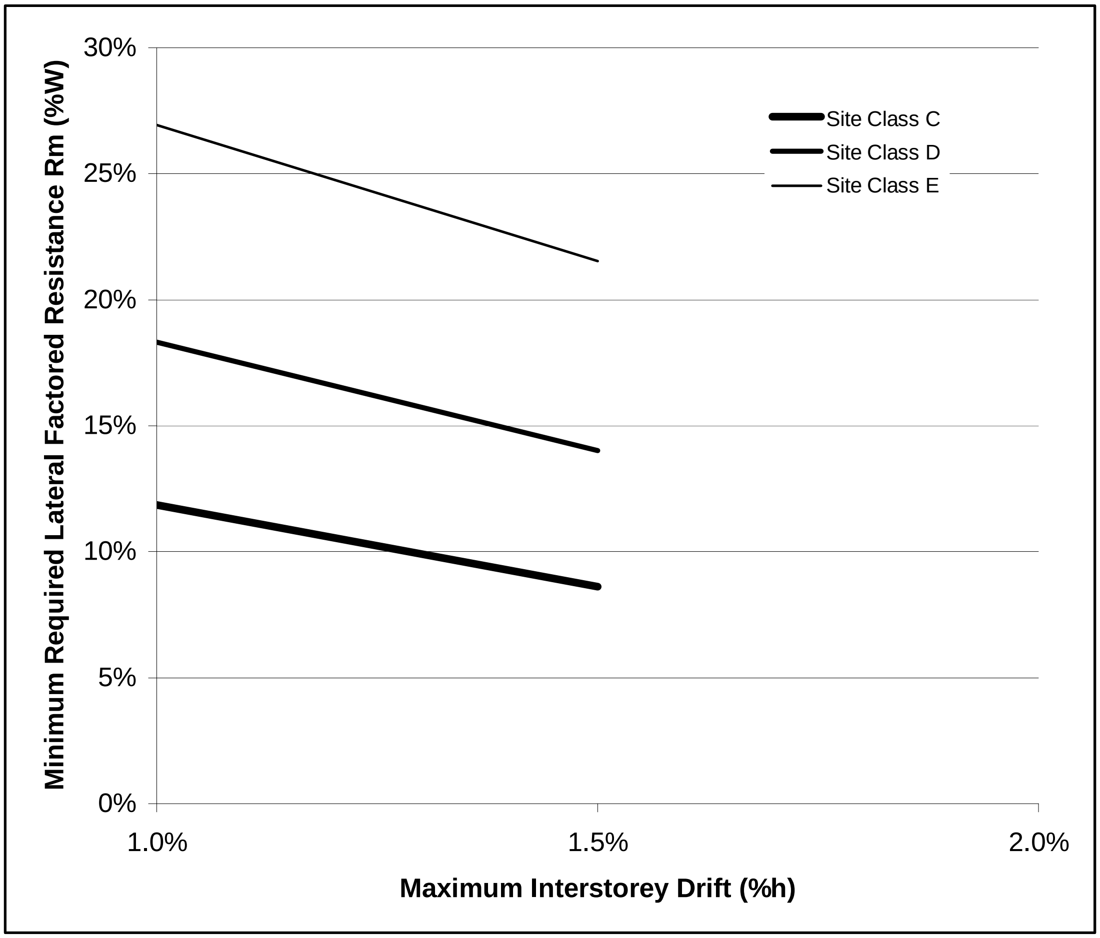


Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	38%	29%	24%	NP	NP	NP
D	46%	35%	30%	NP	NP	NP
E	41%	31%	26%	NP	NP	NP

Figure 5-1(d)

Minimum Required Lateral Factored Resistance R_m (%W)
Concrete Prototype C-1 Shearwall (Moderately Ductile)
Seismic Zone 5 (Victoria)

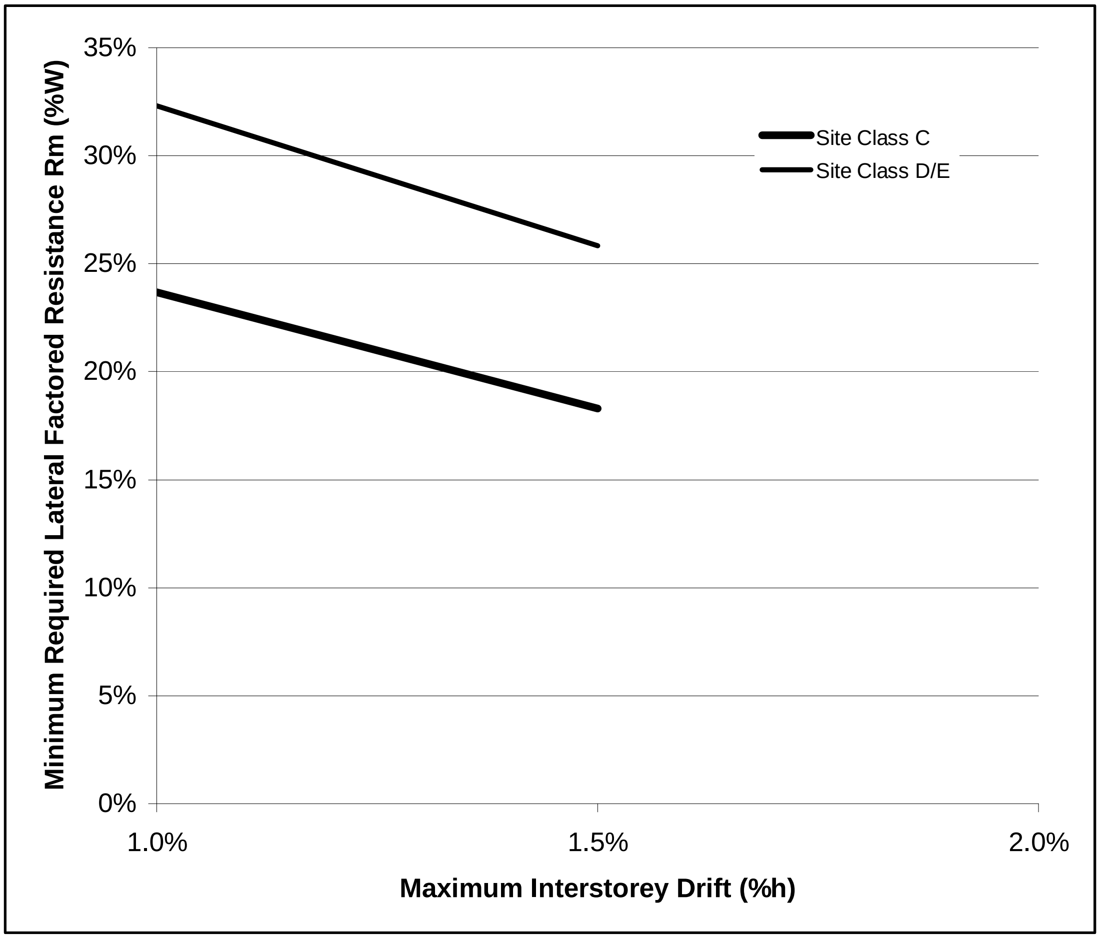
C-2 Zone 2



Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	12%	9%	NP	NP	NP	NP
D	18%	14%	NP	NP	NP	NP
E	27%	22%	NP	NP	NP	NP

Figure 5-2(a) *Minimum Required Lateral Factored Resistance R_m (%W)*
Concrete Prototype C-2 Shearwall (Conv. Construction)
Seismic Zone 2 (Princeton)

C-2 Zone 3

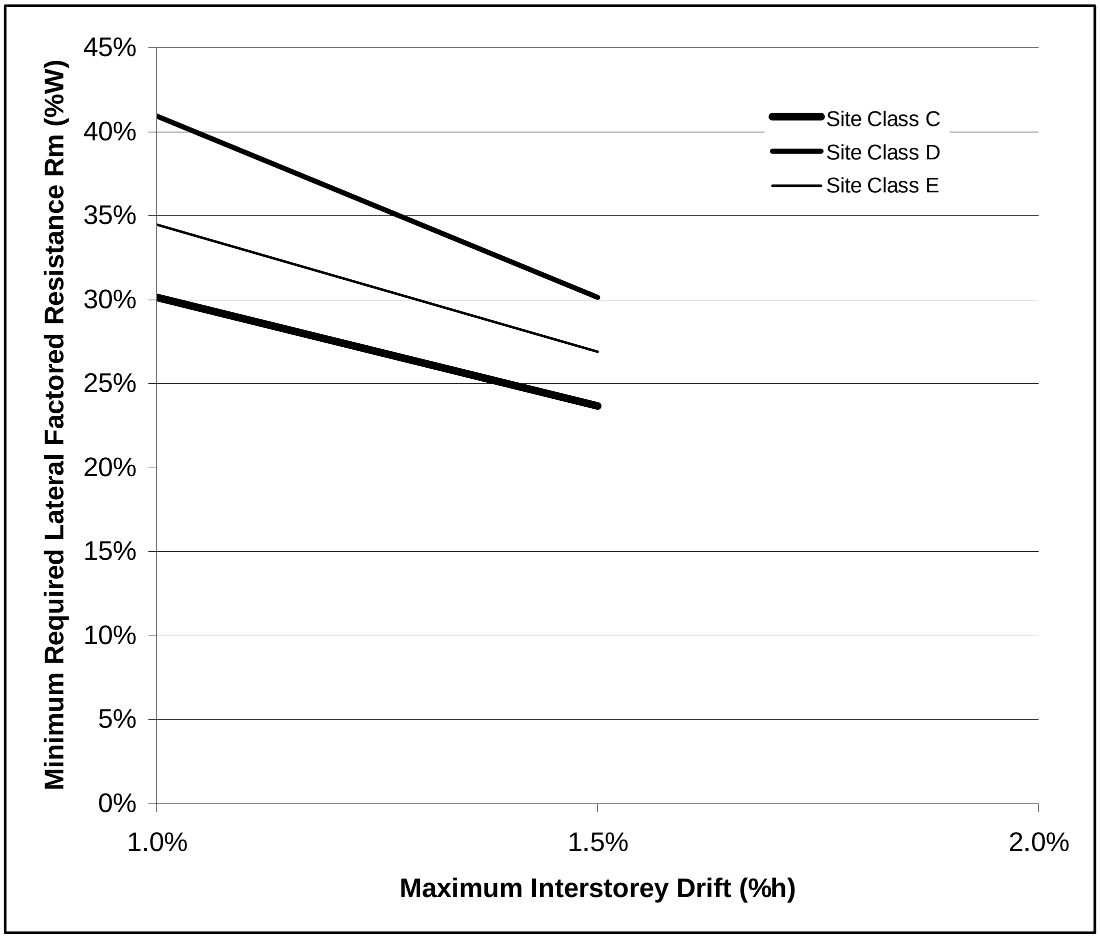


Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	24%	18%	NP	NP	NP	NP
D	32%	26%	NP	NP	NP	NP
E	32%	26%	NP	NP	NP	NP

Figure 5-2(b)

Minimum Required Lateral Factored Resistance R_m (%W)
Concrete Prototype C-2 Shearwall (Conv. Construction)
Seismic Zone 3 (Chilliwack)

C-2 Zone 4

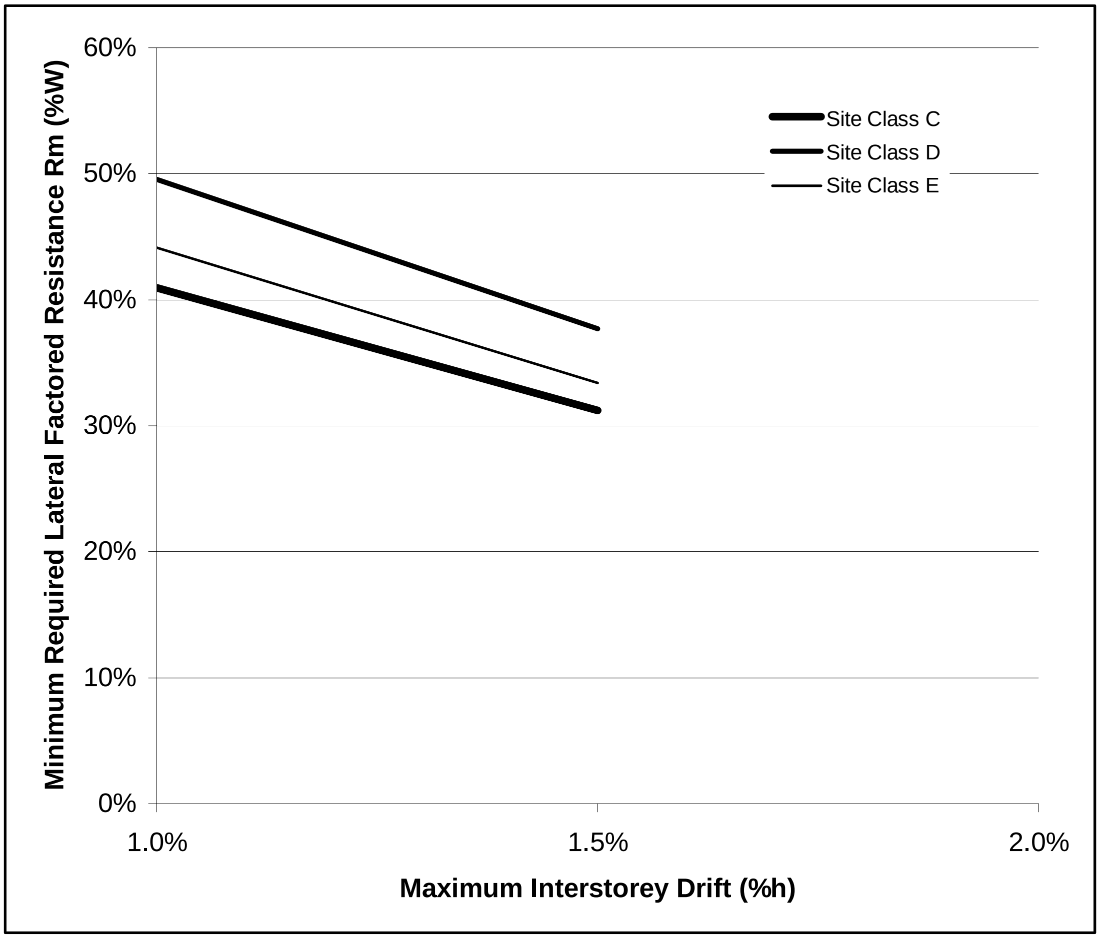


Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	30%	24%	NP	NP	NP	NP
D	41%	30%	NP	NP	NP	NP
E	34%	27%	NP	NP	NP	NP

Figure 5-2(c)

Minimum Required Lateral Factored Resistance R_m (%W)
Concrete Prototype C-2 Shearwall (Conv. Construction)
Seismic Zone 4 (Vancouver)

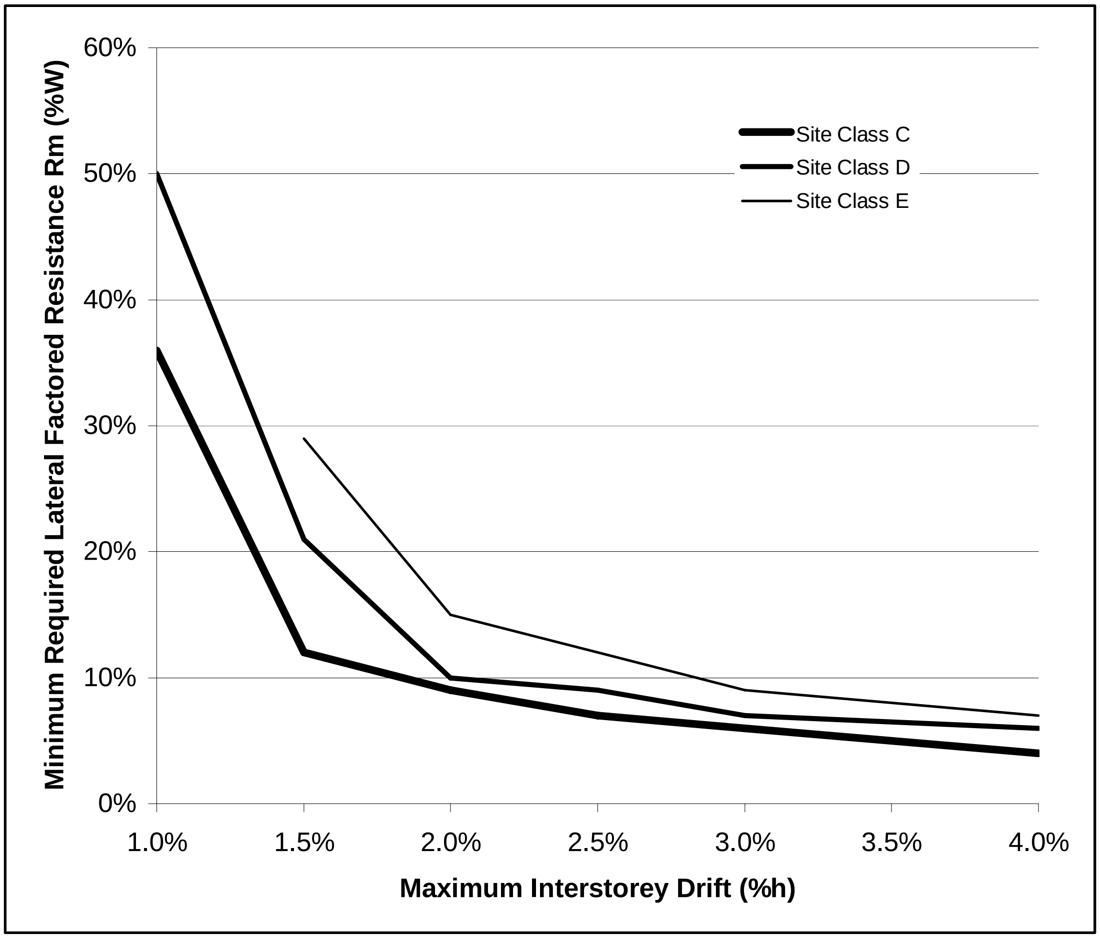
C-2 Zone 5



Site Class	1.0%	1.5%	2.0%	2.5%	3.0%	4.0%
C	41%	31%	NP	NP	NP	NP
D	50%	38%	NP	NP	NP	NP
E	44%	33%	NP	NP	NP	NP

Figure 5-2(d)
Minimum Required Lateral Factored Resistance R_m (%W)
Concrete Prototype C-2 Shearwall (Conv. Construction)
Seismic Zone 5 (Victoria)

C-3 Zone 2

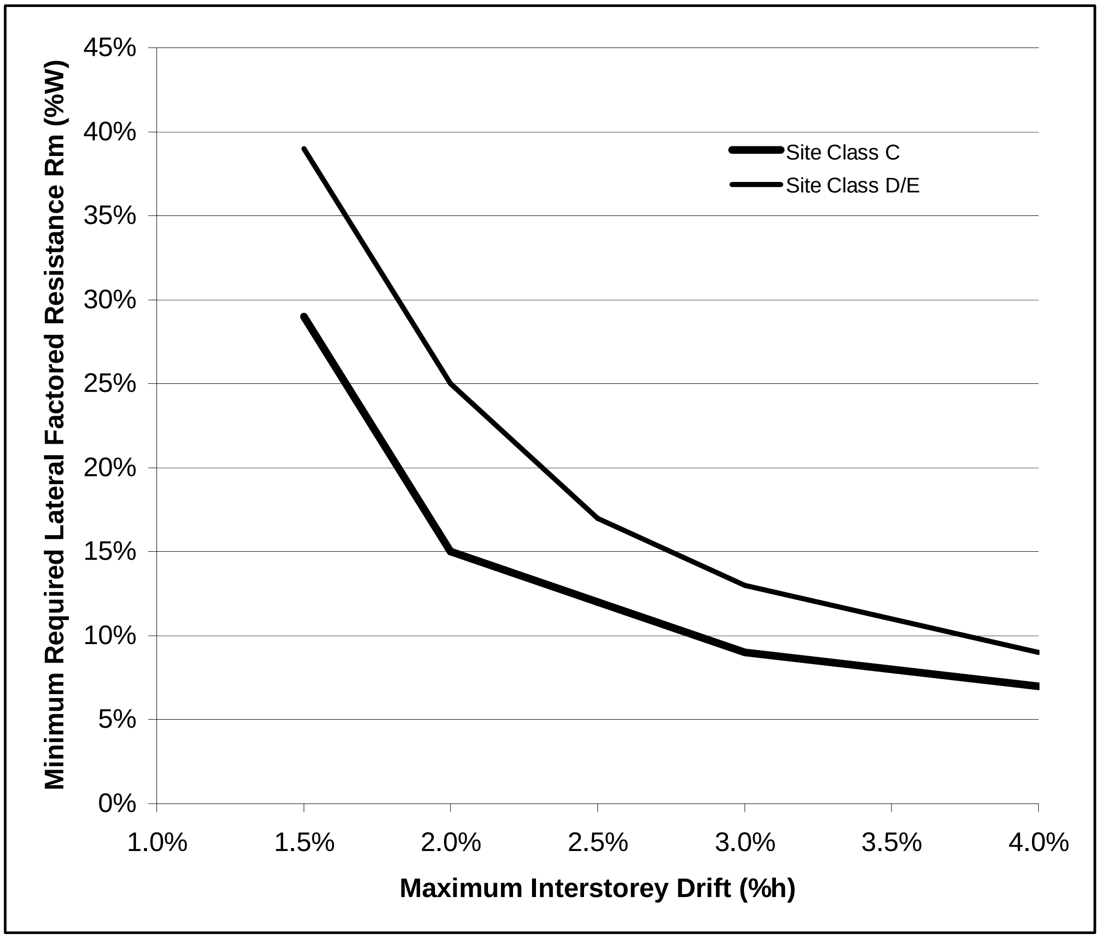


Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	36%	12%	9%	7%	6%	4%
D	50%	21%	10%	9%	7%	6%
E	NR	29%	15%	12%	9%	7%

Figure 5-3(a)

Minimum Required Lateral Factored Resistance R_m (%W)
Concrete Prototype C-3 Moment Frame (Ductile)
Seismic Zone 2 (Princeton)

C-3 Zone 3

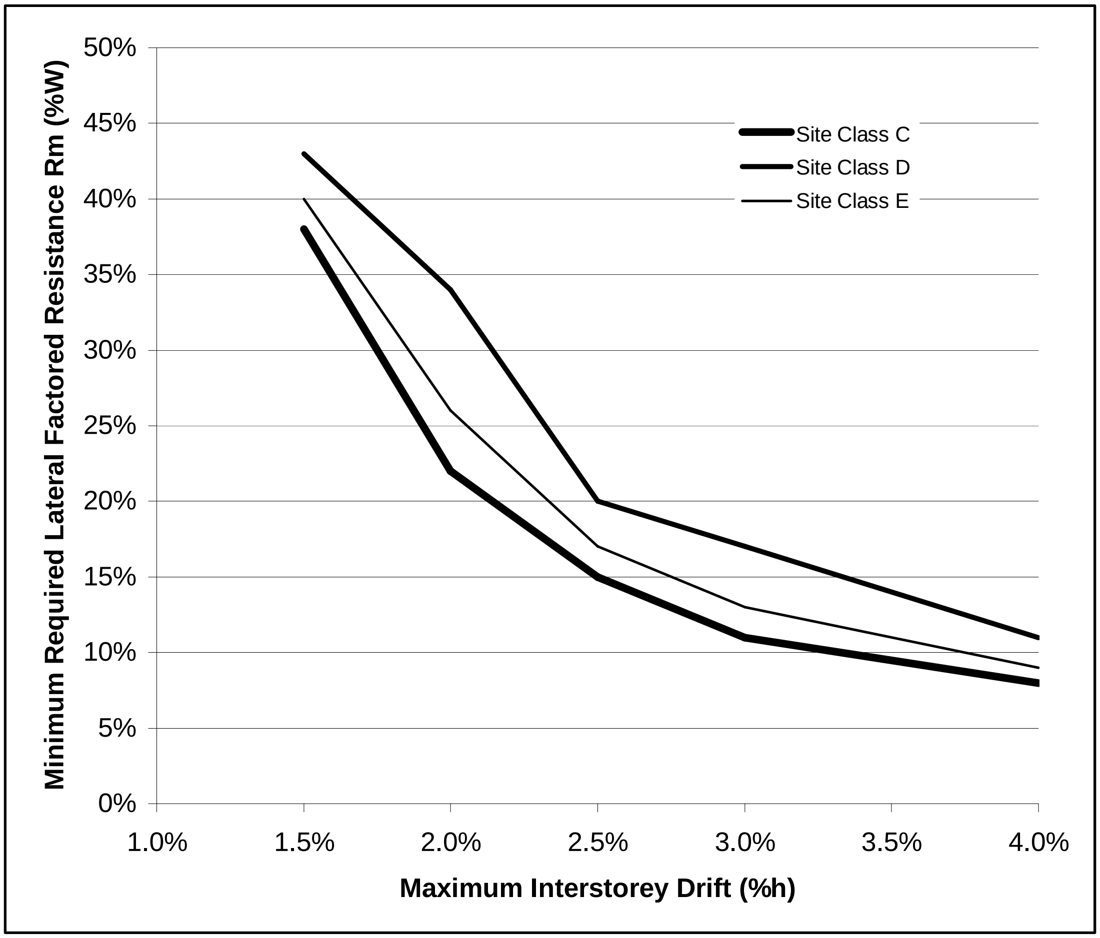


Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	NR	29%	15%	12%	9%	7%
D	NR	39%	25%	17%	13%	9%
E	NR	39%	25%	17%	13%	9%

<u>Figure 5-3(b)</u>

Minimum Required Lateral Factored Resistance R_m (%W)
Concrete Prototype C-3 Moment Frame (Ductile)
Seismic Zone 3 (Chilliwack)

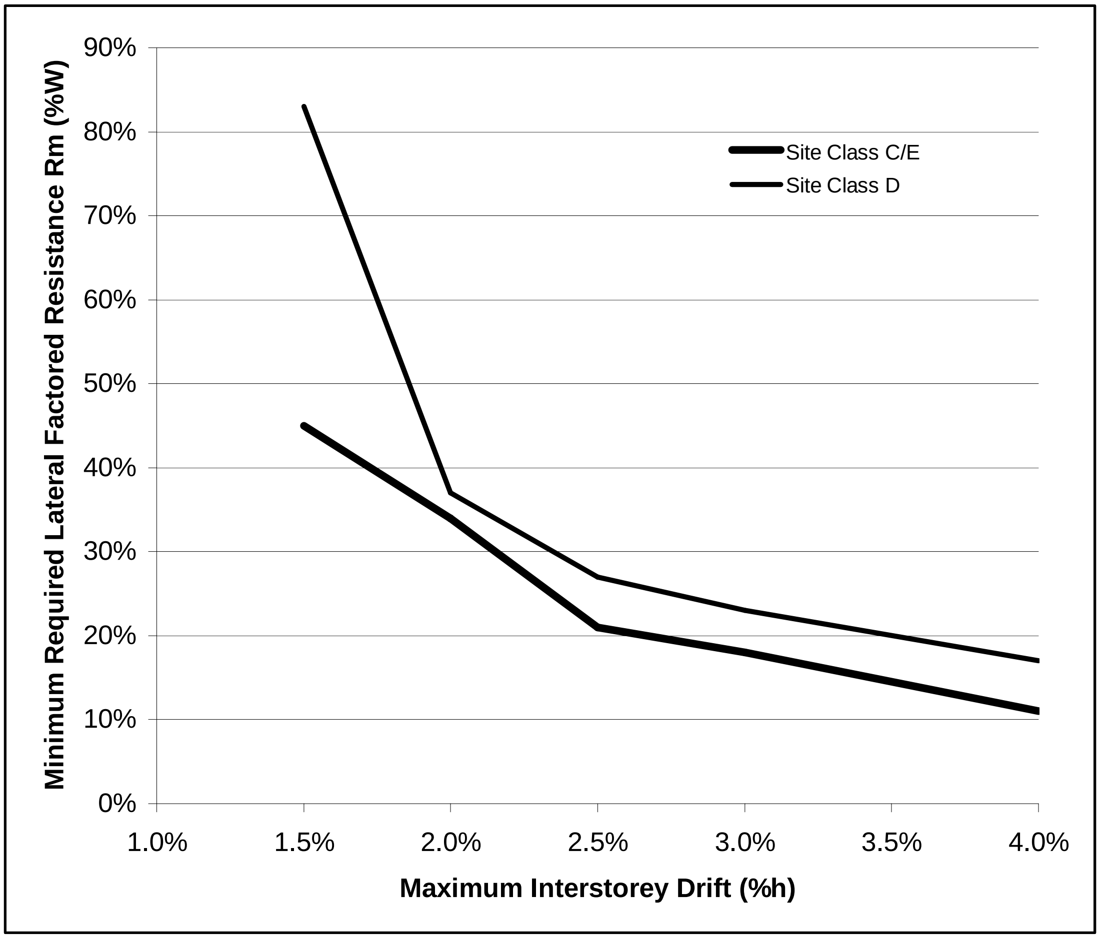
C-3 Zone 4



Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	NR	38%	22%	15%	11%	8%
D	NR	43%	34%	20%	17%	11%
E	NR	40%	26%	17%	13%	9%

Figure 5-3(c)
Minimum Required Lateral Factored Resistance R_m (%W)
Concrete Prototype C-3 Moment Frame (Ductile)
Seismic Zone 4 (Vancouver)

C-3 Zone 5

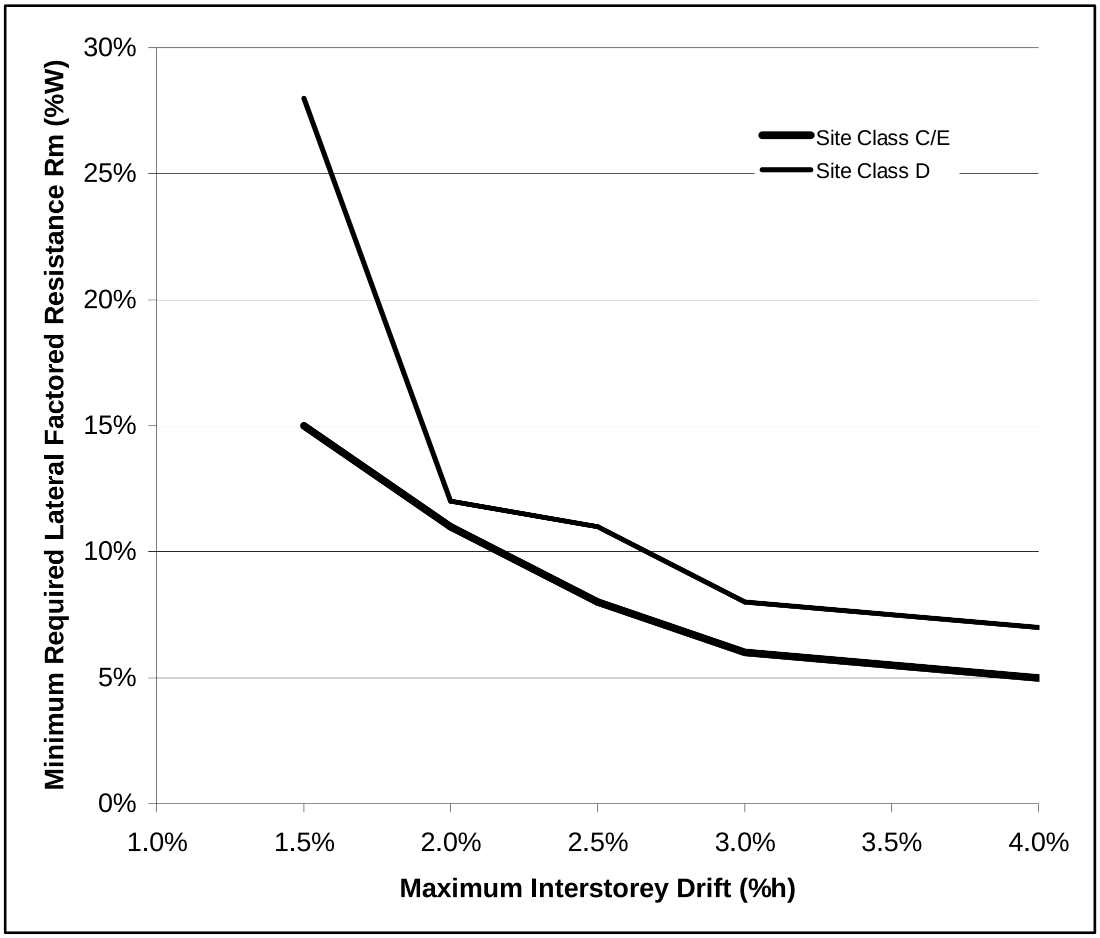


Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	NR	45%	34%	21%	18%	11%
D	NR	83%	37%	27%	23%	17%
E	NR	45%	34%	21%	18%	11%

Figure 5-3(d)

Minimum Required Lateral Factored Resistance R_m (%W)
Concrete Prototype C-3 Moment Frame (Ductile)
Seismic Zone 5 (Victoria)

C-4 Zone 2

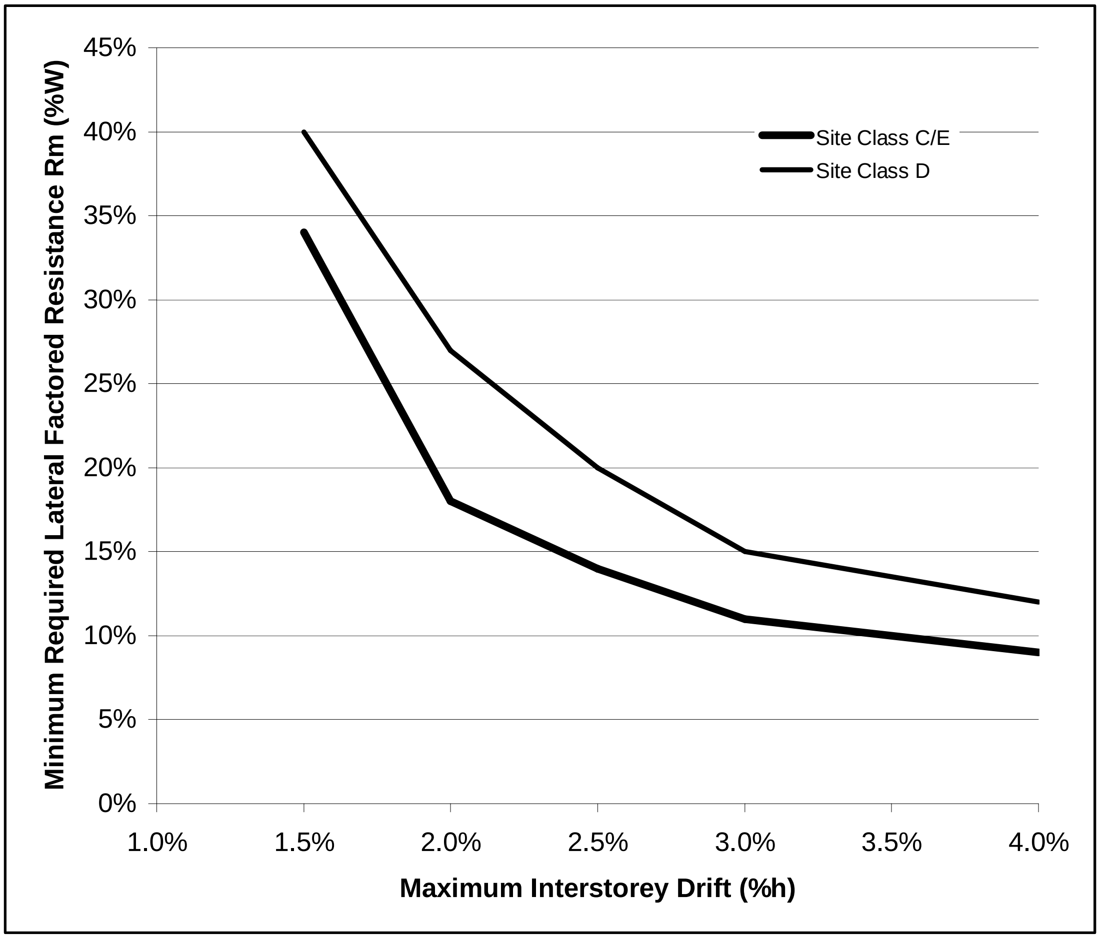


Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	NR	15%	11%	8%	6%	5%
D	NR	28%	12%	11%	8%	7%
E	NR	15%	11%	8%	6%	5%

Figure 5-4(a)

Minimum Required Lateral Factored Resistance R_m (%W)
Concrete Prototype C-4 Moment Frame (Moderately Ductile)
Seismic Zone 2 (Princeton)

C-4 Zone 3

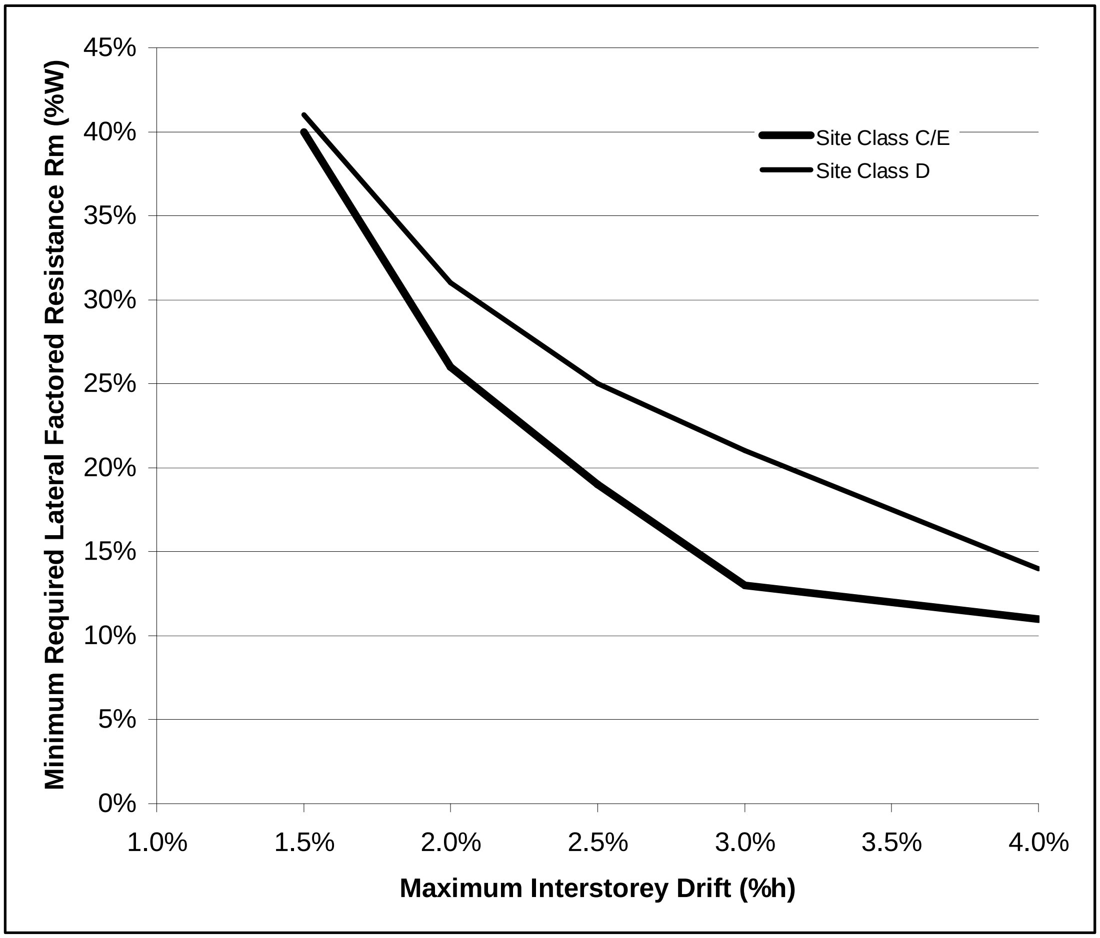


Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	NR	34%	18%	14%	11%	9%
D	NR	40%	27%	20%	15%	12%
E	NR	34%	18%	14%	11%	9%

Figure 5-4(b)

Minimum Required Lateral Factored Resistance R_m (%W)
Concrete Prototype C-4 Moment Frame (Moderately Ductile)
Seismic Zone 3 (Chilliwack)

C-4 Zone 4

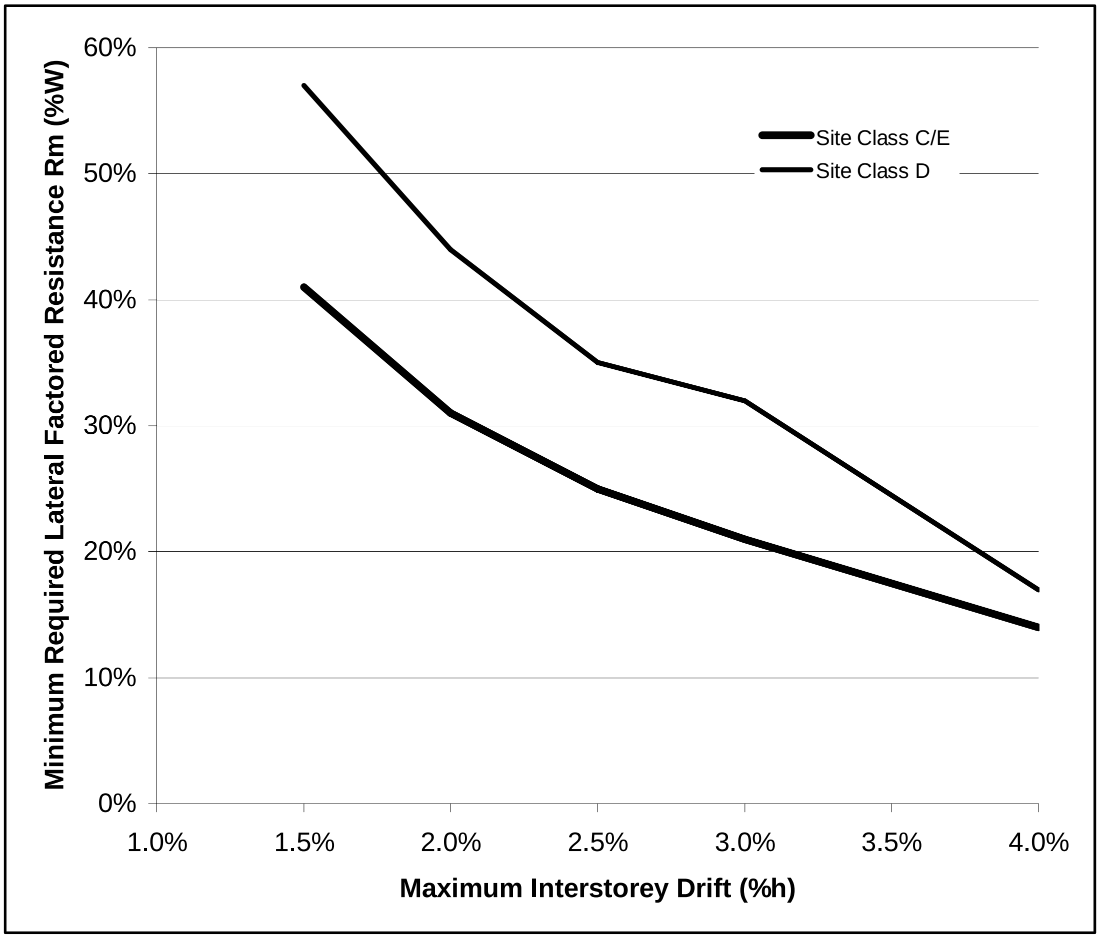


Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	NR	40%	26%	19%	13%	11%
D	NR	41%	31%	25%	21%	14%
E	NR	40%	26%	19%	13%	11%

Figure 5-4(c)

Minimum Required Lateral Factored Resistance R_m (%W)
Concrete Prototype C-4 Moment Frame (Moderately Ductile)
Seismic Zone 4 (Vancouver)

C-4 Zone 5

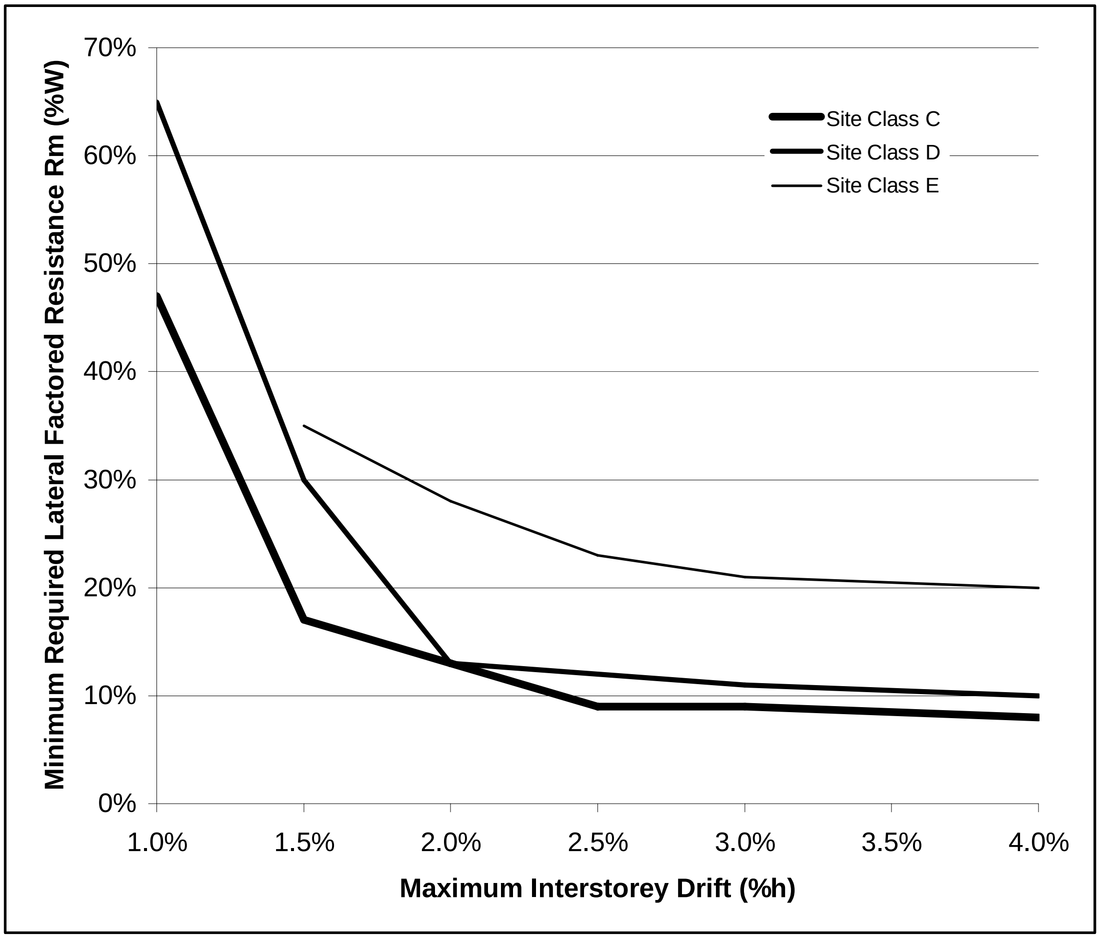


Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	NR	41%	31%	25%	21%	14%
D	NR	57%	44%	35%	32%	17%
E	NR	41%	31%	25%	21%	14%

Figure 5-4(d)

Minimum Required Lateral Factored Resistance R_m (%W)
Concrete Prototype C-4 Moment Frame (Moderately Ductile)
Seismic Zone 5 (Victoria)

C-5 Zone 2

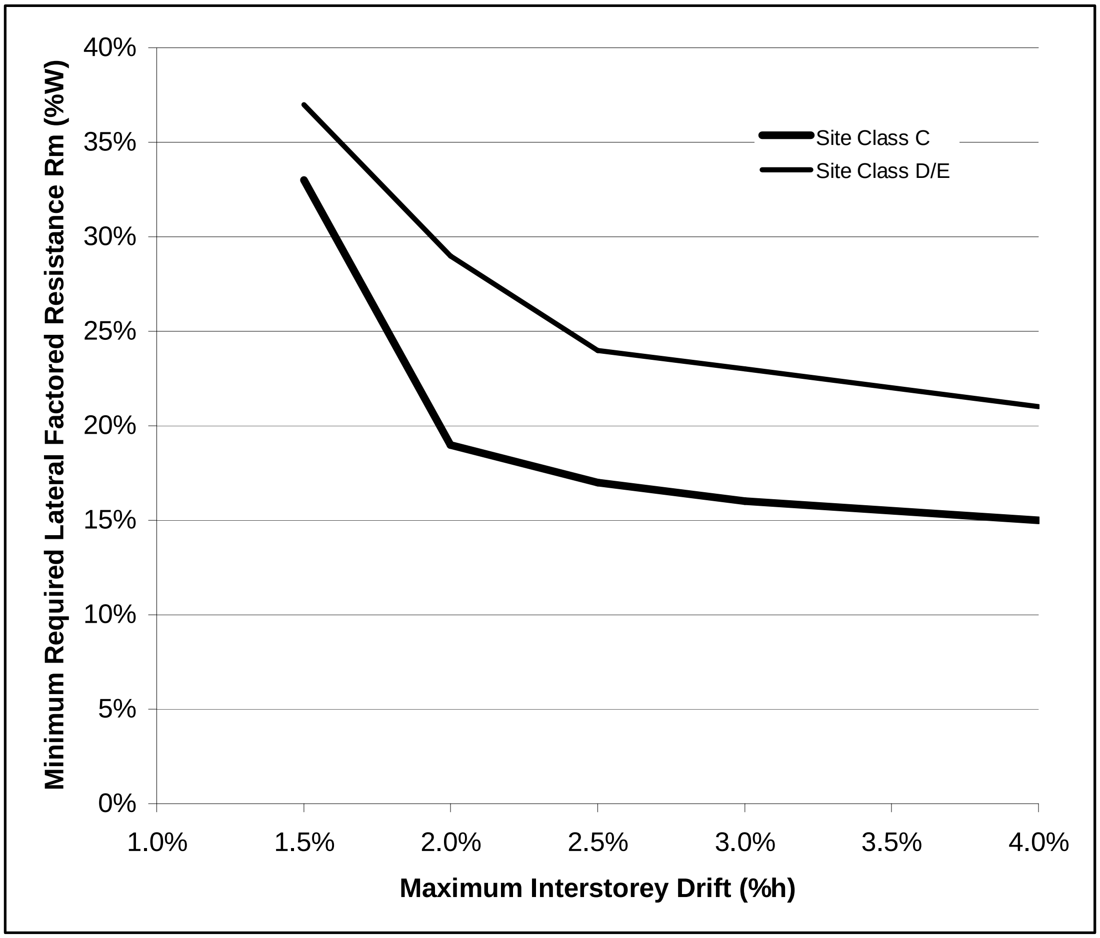


Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	47%	17%	13%	9%	9%	8%
D	65%	30%	13%	12%	11%	10%
E	NR	35%	28%	23%	21%	20%

Figure 5-5(a)

Minimum Required Lateral Factored Resistance R_m (%W)
Concrete Prototype C-5 Moment Frame (Conv. Construction)
Seismic Zone 2 (Princeton)

C-5 Zone 3

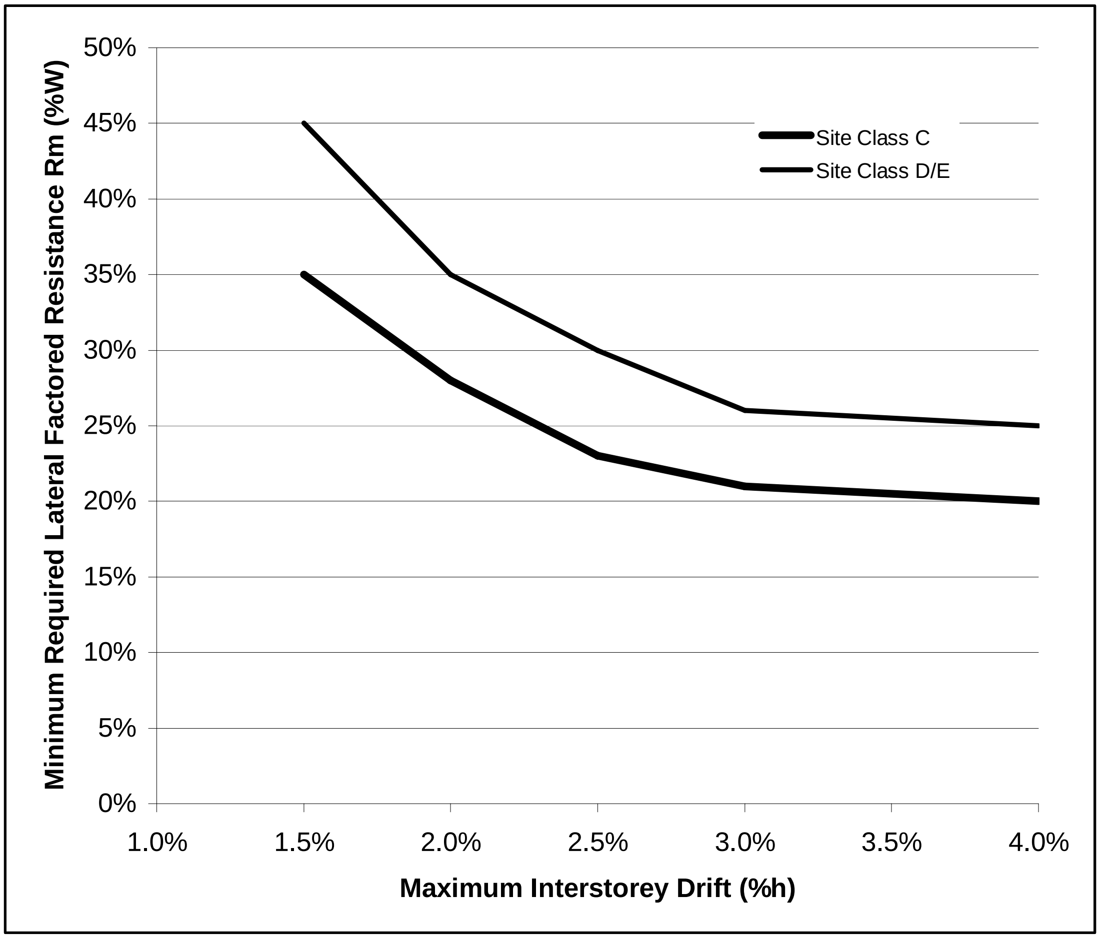


Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	NR	33%	19%	17%	16%	15%
D	NR	37%	29%	24%	23%	21%
E	NR	37%	29%	24%	23%	21%

Figure 5-5(b)

Minimum Required Lateral Factored Resistance R_m (%W)
Concrete Prototype C-5 Moment Frame (Conv. Construction)
Seismic Zone 3 (Chilliwack)

C-5 Zone 4

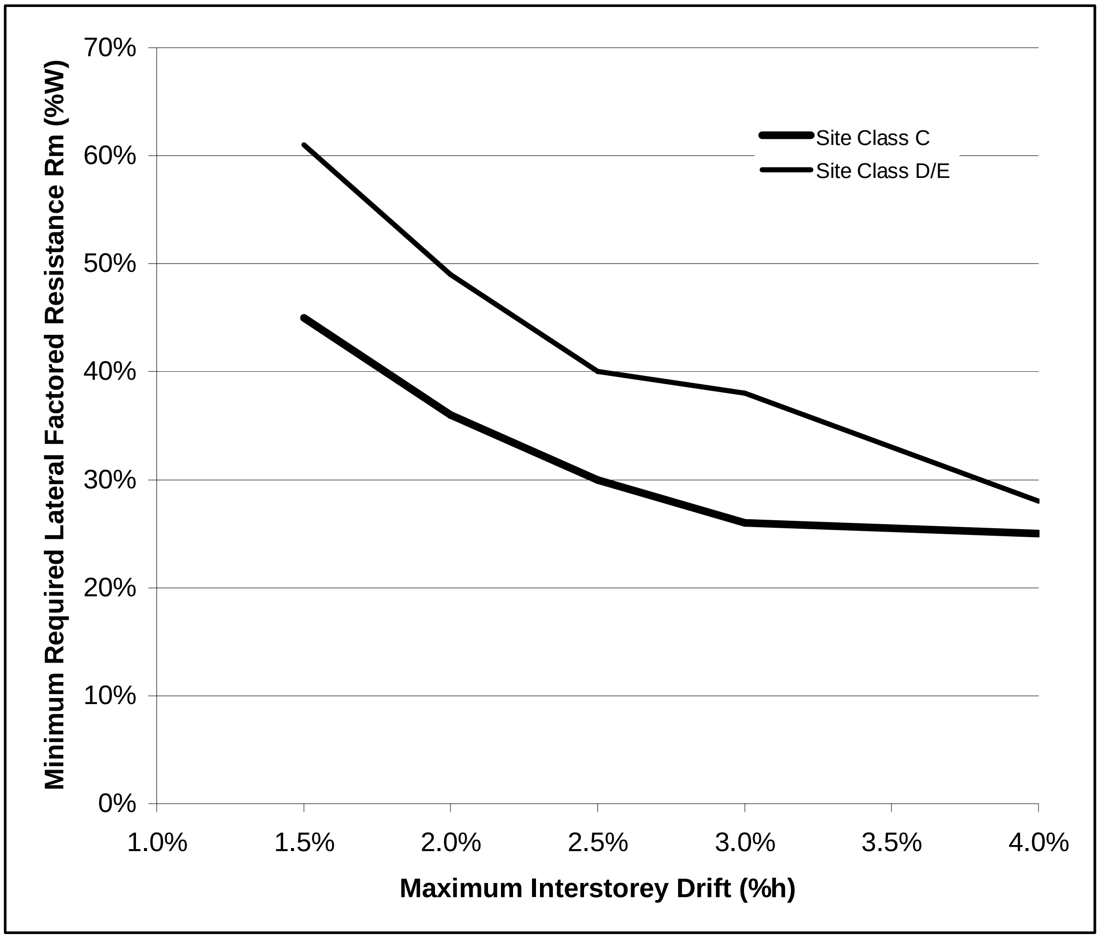


Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	NR	35%	28%	23%	21%	20%
D	NR	45%	35%	30%	26%	25%
E	NR	45%	35%	30%	26%	25%

Figure 5-5(c)

Minimum Required Lateral Factored Resistance R_m (%W)
Concrete Prototype C-5 Moment Frame (Conv. Construction)
Seismic Zone 4 (Vancouver)

C-5 Zone 5



Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	NR	45%	36%	30%	26%	25%
D	NR	61%	49%	40%	38%	28%
E	NR	45%	36%	30%	26%	25%

Figure 5-5(d)

Minimum Required Lateral Factored Resistance R_m (%W)
Concrete Prototype C-5 Moment Frame (Conv. Construction)
Seismic Zone 5 (Victoria)

6.0 PERFORMANCE-BASED EARTHQUAKE RETROFIT GUIDELINES FOR LOW-RISE CONCRETE MASONRY SCHOOL BUILDINGS

6.1 Prototypes

1) These guidelines include the following forms of concrete masonry construction (prototypes) for low-rise school buildings:

   (a) Prototype M-1 for sliding masonry
   (b) Prototype M-2 for reinforced masonry in flexure/shear

2) Refer to Section 8 to check that concrete masonry LDRSs are not governed by rocking (including footing uplift).

6.2 Minimum Required Lateral Factored Resistance R_m

1) Minimum required lateral factored resistance R_m for the risk assessment of a low-rise concrete masonry building is set equal to 80% of the corresponding value obtained from Figure 6-1 to Figure 6-2.

2) Minimum required lateral factored resistance R_m for the retrofit design of a low-rise concrete masonry building is obtained from Figure 6-1 to Figure 6-2.

3) The value of R_m, the minimum required lateral factored resistance determined from Sentence (1) or Sentence (2), can be reduced to the value R_{mr} in accordance with Equation (4-1) for clear storey heights between 3.0 metres and 4.0 metres.

$$R_{mr} = K_{mr} \cdot R_m \qquad (6\text{-}1)$$

where $K_{mr} = 1.45 - \dfrac{h_{sc}}{6.67}$

6.3 Calculation of Lateral Resistance

1) The calculation of the lateral resistance of concrete masonry buildings shall comply with CSA-S304.1-04.

2) Sliding (shear friction) in-plane factored resistance, V_{rs}, of an unreinforced masonry wall with openings is calculated as below:

$$V_{rs} = \phi_m \times W_2 \tag{6-2}$$

6.4 Masonry Building Base Moments

1) For Seismic Zones 3-5, the overturning moment at the base of a concrete masonry LDRS is to be calculated in accordance with Sentence 1.11(1) using K_{bm} = 1.0 with the exception of:

   (a) K_{bm} = 0.9 for two storeys and a light roof
   (b) K_{bm} = 0.9 for three storeys with or without a light roof

6.5 Out-of-Plane Requirements

1) Out-of-plane requirements given in this section apply to both exterior and interior concrete masonry walls (including heavy partition walls).

2) Concrete masonry walls shall meet the minimum vertical reinforcement requirements of CSA-S304.1-04 except as noted in Sentence (3).

3) Concrete masonry walls do not require vertical reinforcement if the following requirements are met:

   (a) Site Class C/D soils
   (b) Walls are either fully confined in accordance with requirements of Sentence (4) or walls are laterally braced in accordance with Sentence (5).

4) Concrete masonry walls are fully confined as noted in Sentence (3)(b) if the following requirements are met:

   (a) Walls fully confirmed top and bottom by stiff concrete frames or walls with the top of the wall having a minimum surcharge of 50% of the weight of the wall
   (b) Wall height not greater than 3.5 metres
   (c) Minimum wall thickness is 140 mm

5) Lateral bracing of concrete masonry walls shall meet the following requirements:

(a) Full-height vertical bracing elements with maximum horizontal spacing of 50% of the wall height (2.4 metre maximum spacing).
(b) Minimum required factored moment resistance of vertical bracing element R_{mb} conforming to Equation (6-3)
(c) Minimum required factored resistance R_{mc} of connections between vertical bracing element and concrete masonry wall conforming to Equation (6-4)

$$R_{mb} = \frac{W_b t}{4} \quad (6\text{-}3)$$

$$R_{mc} = \frac{12 R_{eb} R_o}{h_w n_b} \quad (6\text{-}4)$$

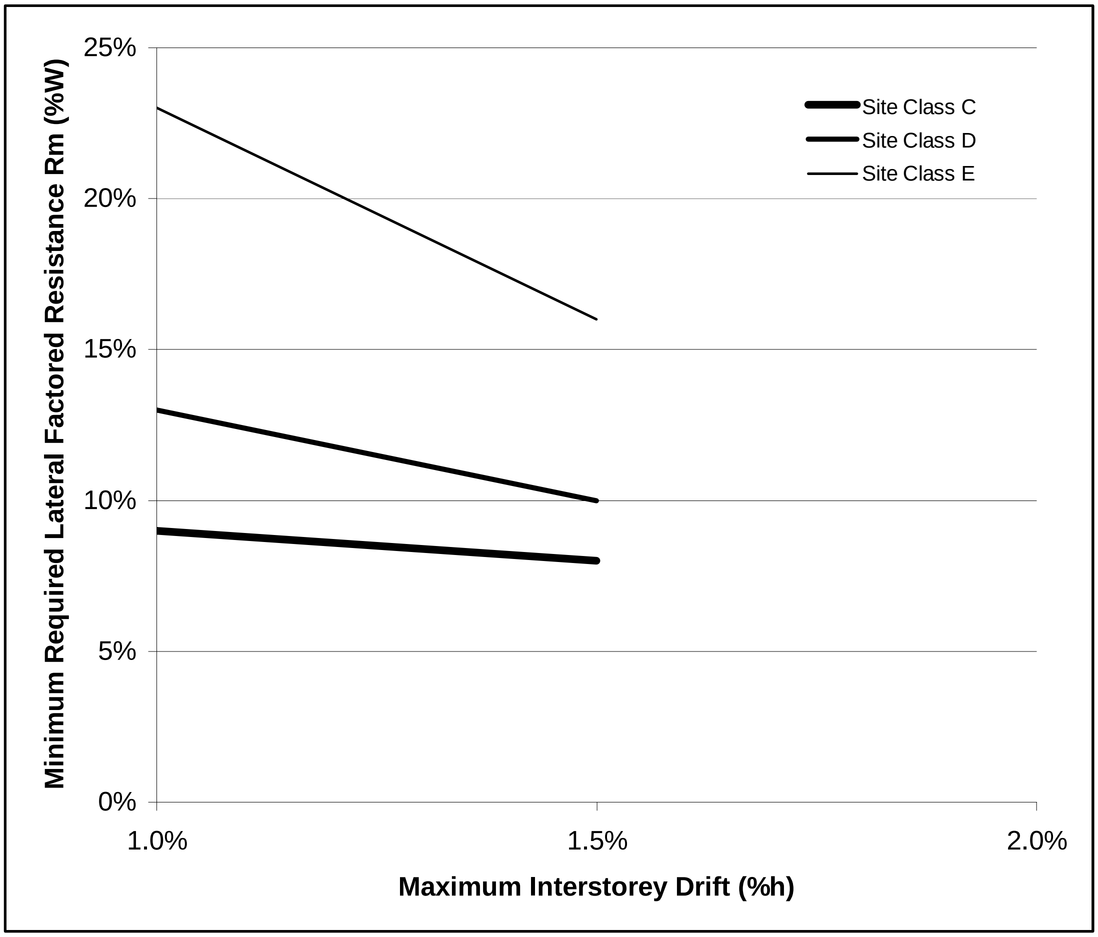
6) Concrete masonry walls subject to both in-plane and out-of-plane loading shall be reinforced to meet the greater requirements of the in-plane and out-of-plane loading.

6.6 In-fill Walls

1) Unreinforced concrete in-fill walls must meet the out-of-plane requirements of Section 6.5.

2) Concrete blocks in the top corners of in-fill walls require hazard abatement measures to prevent the falling of significant portions of the concrete blocks during development of in-plane resistance.

M-1 Zone 2

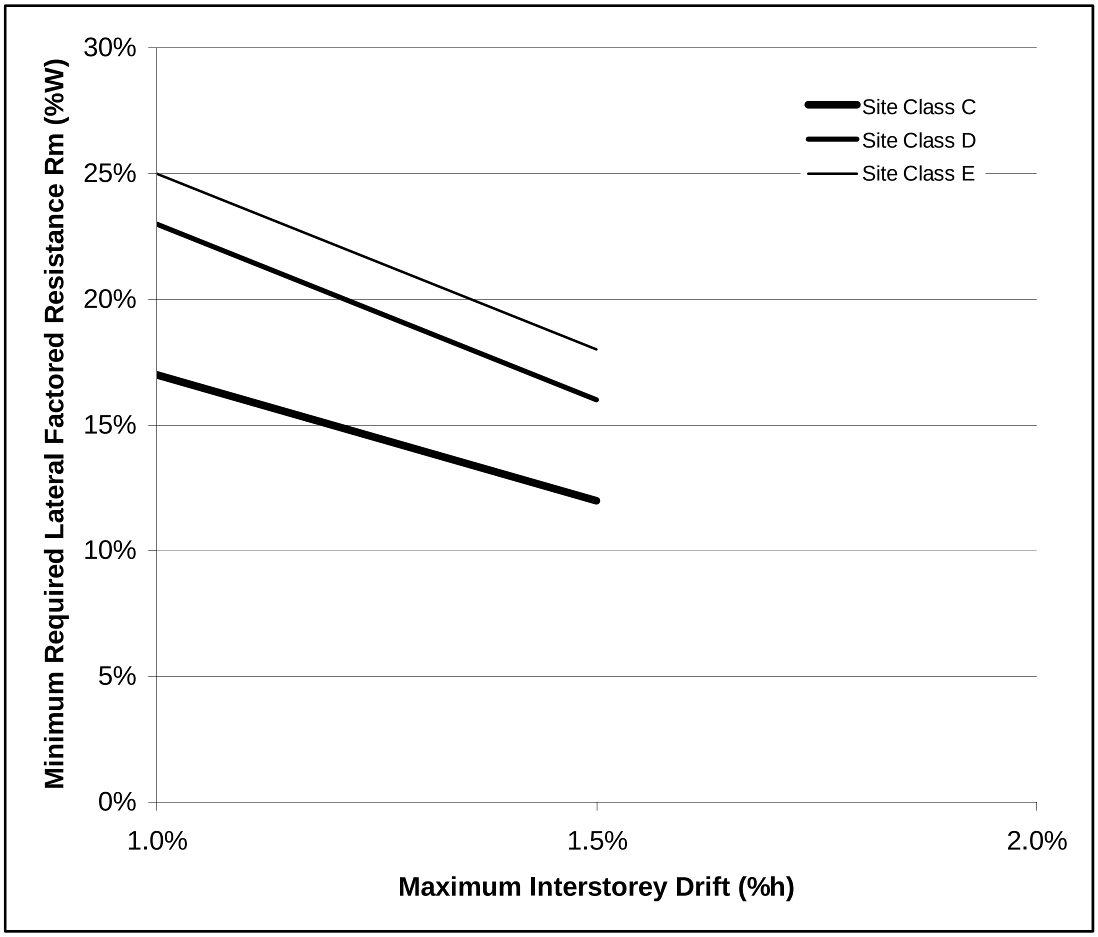


Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	9%	8%	NP	NP	NP	NP
D	13%	10%	NP	NP	NP	NP
E	23%	16%	NP	NP	NP	NP

Figure 6-1(a)

Minimum Required Lateral Factored Resistance R_m (%W)
Concrete Masonry Prototype M-1 Unreinforced Shearwall
Seismic Zone 2 (Princeton)

M-1 Zone 3

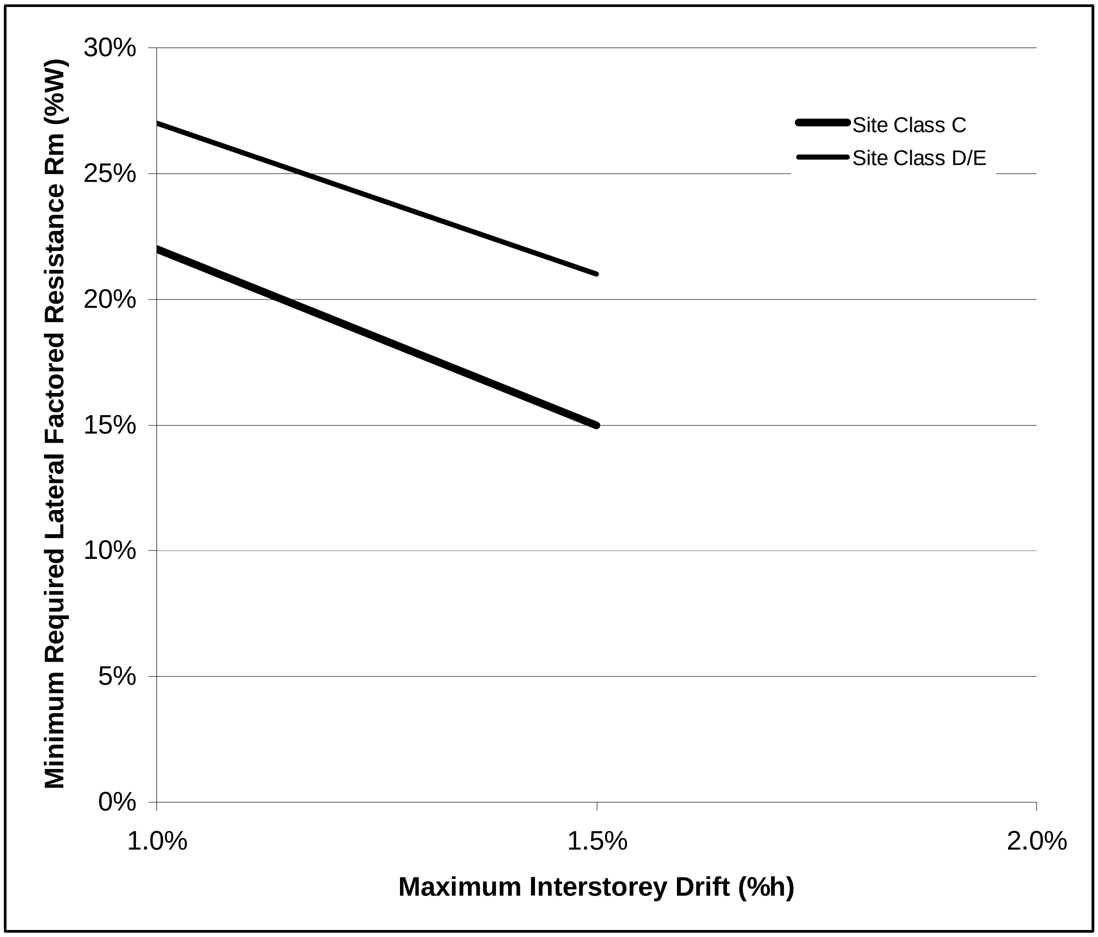


Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	17%	12%	NP	NP	NP	NP
D	23%	16%	NP	NP	NP	NP
E	25%	18%	NP	NP	NP	NP

Figure 6-1(b)

Minimum Required Lateral Factored Resistance R_m (%W)
Concrete Masonry Prototype M-1 Unreinforced Shearwall
Seismic Zone 3 (Chilliwack)

M-1 Zone 4

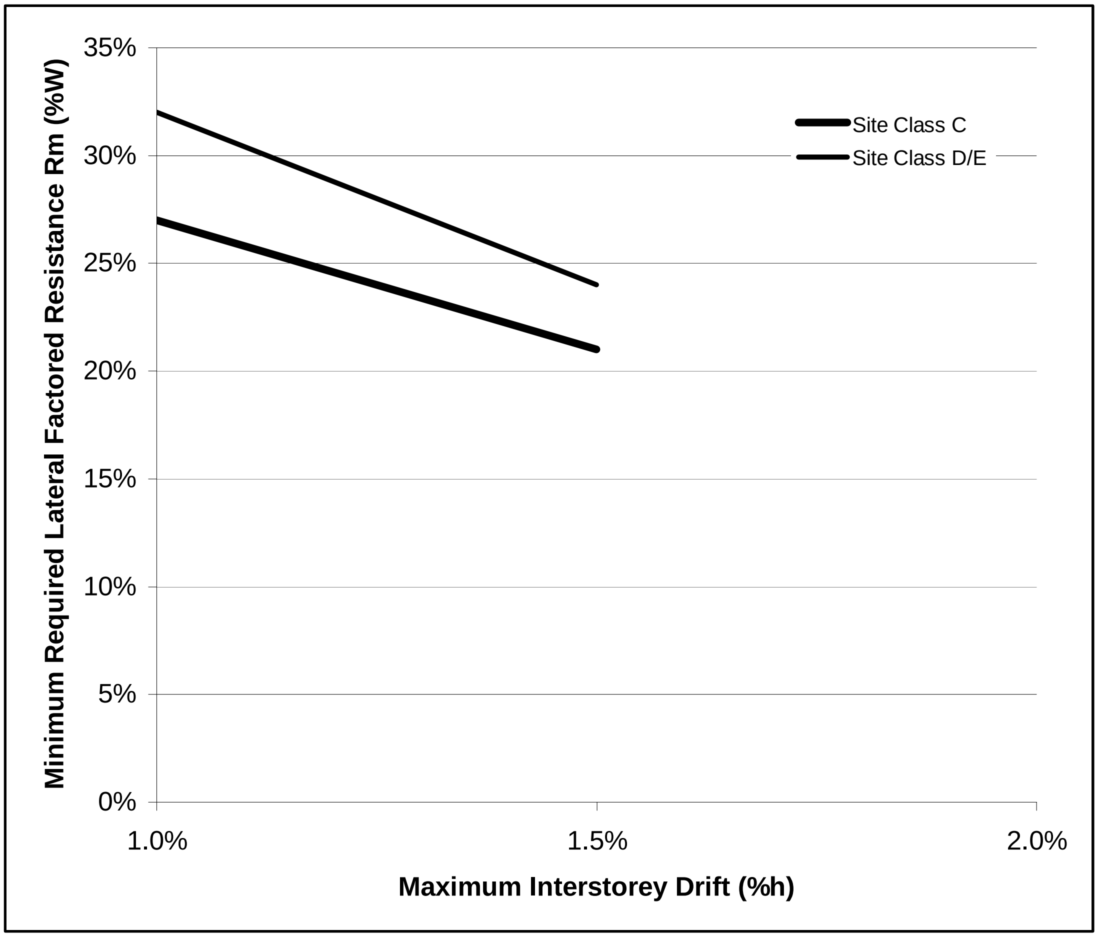


Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	22%	15%	NP	NP	NP	NP
D	27%	21%	NP	NP	NP	NP
E	27%	21%	NP	NP	NP	NP

Figure 6-1(c)

Minimum Required Lateral Factored Resistance R_m (%W)
Concrete Masonry Prototype M-1 Unreinforced Shearwall
Seismic Zone 4 (Vancouver)

M-1 Zone 5

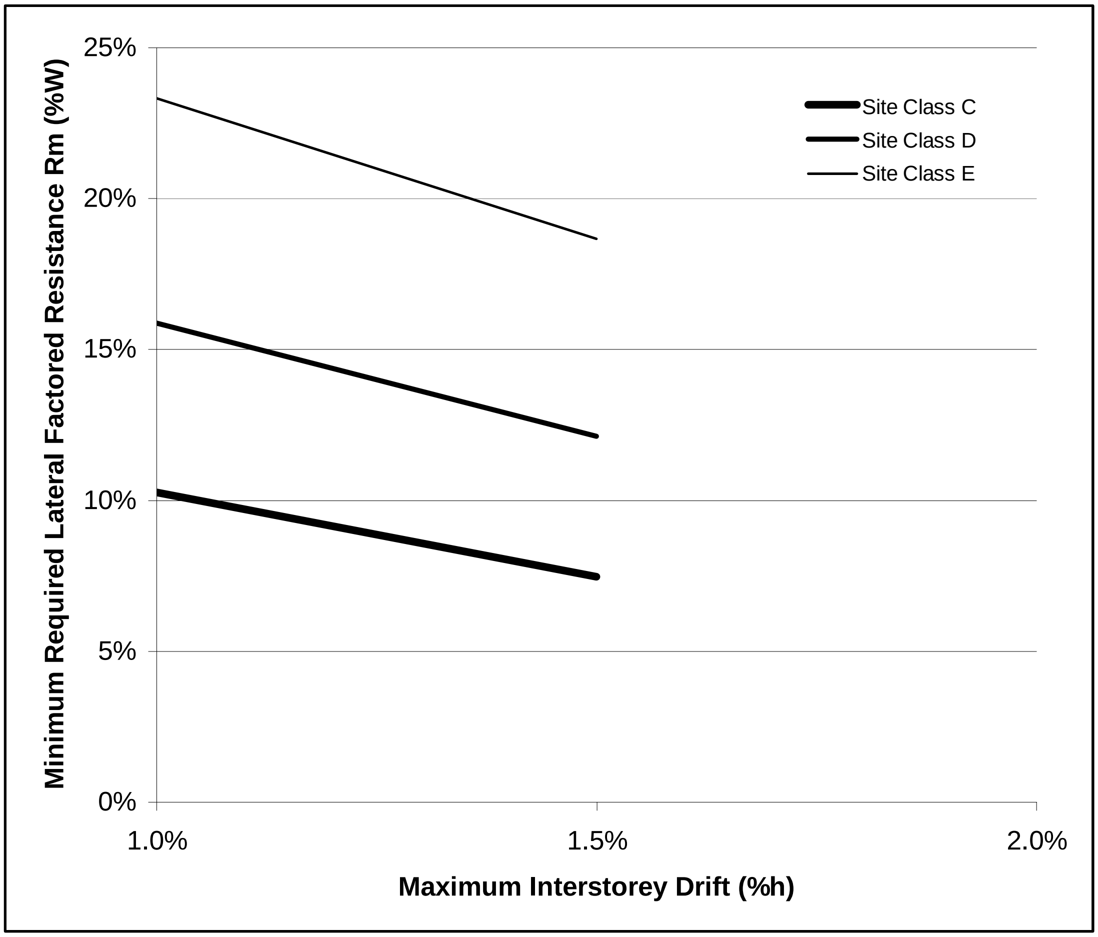


Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	27%	21%	NP	NP	NP	NP
D	32%	24%	NP	NP	NP	NP
E	32%	24%	NP	NP	NP	NP

Figure 6-1(d)

Minimum Required Lateral Factored Resistance R_m (%W)
Concrete Masonry Prototype M-1 Unreinforced Shearwall
Seismic Zone 5 (Victoria)

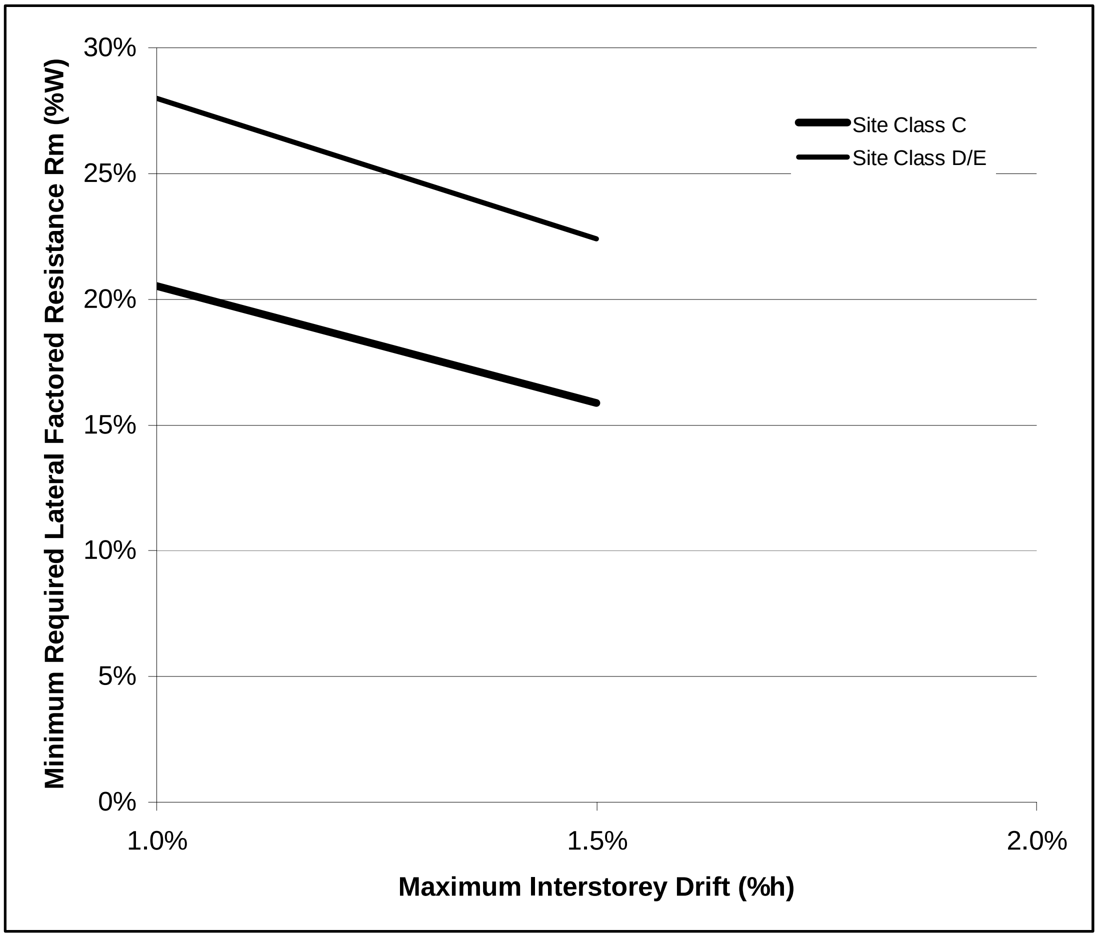
M-2 Zone 2



Site Class	1.0%	1.5%	2.0%	2.5%	3.0%	4.0%
C	10%	7%	NP	NP	NP	NP
D	16%	12%	NP	NP	NP	NP
E	23%	19%	NP	NP	NP	NP

Figure 6-2(a) *Minimum Required Lateral Factored Resistance R_m (%W)*
Concrete Masonry Prototype M-2 Reinforced Shearwall
Seismic Zone 2 (Princeton)

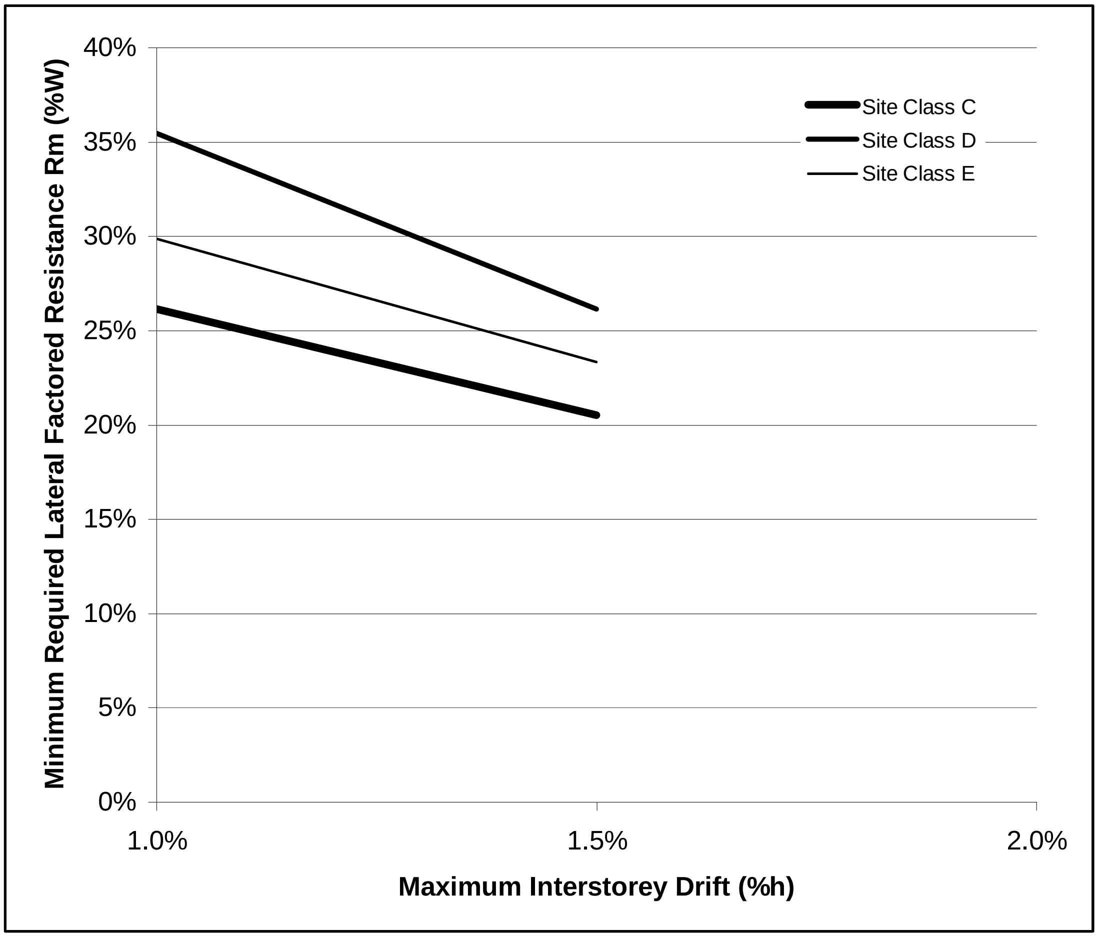
M-2 Zone 3



Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	21%	16%	NP	NP	NP	NP
D	28%	22%	NP	NP	NP	NP
E	28%	22%	NP	NP	NP	NP

Figure 6-2(b)
Minimum Required Lateral Factored Resistance R_m (%W)
Concrete Masonry Prototype M-2 Reinforced Shearwall
Seismic Zone 3 (Chilliwack)

M-2 Zone 4

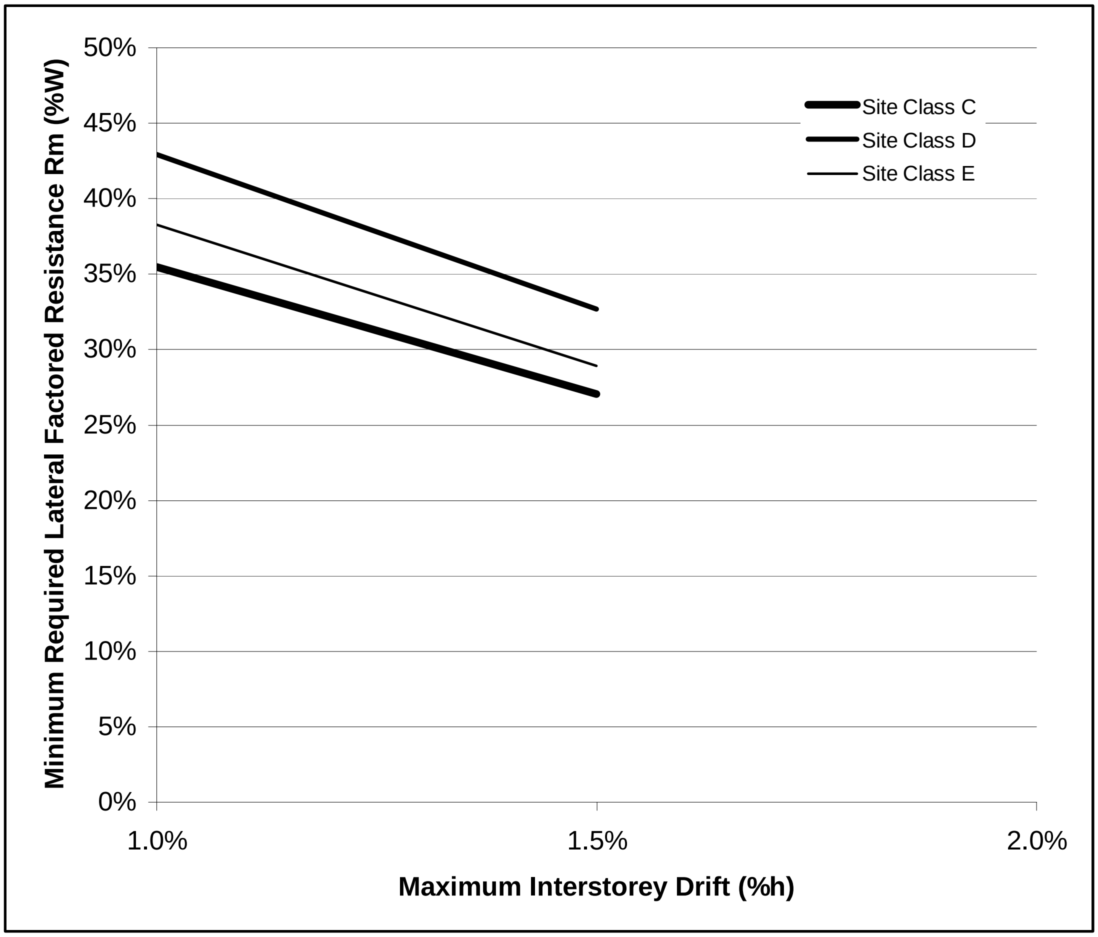


Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	26%	21%	NP	NP	NP	NP
D	35%	26%	NP	NP	NP	NP
E	30%	23%	NP	NP	NP	NP

Figure 6-2(c)

Minimum Required Lateral Factored Resistance R_m (%W)
Concrete Masonry Prototype M-2 Reinforced Shearwall
Seismic Zone 4 (Vancouver)

M-2 Zone 5



Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	35%	27%	NP	NP	NP	NP
D	43%	33%	NP	NP	NP	NP
E	38%	29%	NP	NP	NP	NP

Figure 6-2(d)

Minimum Required Lateral Factored Resistance R_m (%W)
Concrete Masonry Prototype M-2 Reinforced Shearwall
Seismic Zone 5 (Victoria)

7.0 PERFORMANCE-BASED EARTHQUAKE RETROFIT GUIDELINES FOR LOW-RISE CLAY BRICK MASONRY SCHOOL BUILDINGS

7.1 Prototypes

1) These guidelines include the following forms of clay brick masonry construction (prototypes) for low-rise school buildings:

   (a) Prototype B-1 for sliding masonry

2) Refer to Section 8 to check that the clay brick masonry prototype is not governed by rocking (including footing uplift).

7.2 Minimum Required Lateral Factored Resistance R_m

1) Minimum required lateral factored resistance R_m for the risk assessment of a low-rise clay brick masonry building is set equal to 80% of the corresponding value obtained from Figure 7-1.

2) Minimum required lateral factored resistance R_m for the retrofit design of a low-rise clay brick masonry building is obtained from Figure 7-1.

3) The value of R_m, the minimum required lateral factored resistance determined from Sentence (1) or Sentence (2), can be reduced to the value R_{mr} in accordance with Equation (7-1) for clear storey heights between 3.0 metres and 4.0 metres.

$$R_{mr} = K_{mr} \cdot R_m \qquad (7\text{-}1)$$

where $K_{mr} = 1.45 - \dfrac{h_{sc}}{6.67}$

7.3 Calculation of Lateral Resistance

1) Factored sliding (shear friction) resistance, V_r, of a clay brick masonry wall is calculated as below:

$$V_r = \phi_m \times W_2 \qquad (7\text{-}2)$$

7.4 Out-of-Plane Performance Requirements

1) The out-of-plane performance of a clay brick masonry wall is acceptable if the following requirements are met:

   (a) Wall height/thickness ratio does not exceed the values given in Table 7.1.
   (b) Wall thickness is not less than three wythes
   (c) Bonding courses are no further apart than six courses
   (d) Diaphragm conforming to Section 10 is provided at top of wall for restraining out-of-plane movement

2) Clay brick masonry walls that do not meet the requirements of Sentence (1) have an acceptable out-of-plane performance if full-height vertical bracing elements are installed in accordance with Sentence 6.5(5).

3) The two options for clay brick masonry walls in a building founded on Site Class E soils are (a) conformance with the requirements of Sentence (2) or (b) determination of design criteria by UBC based on the results of a site response analysis.

Table 7.1 Maximum h/t Ratios for Out-of-Plane Performance of Unreinforced Clay Brick Masonry Walls

Wall Category	**Seismic Zone**	**Maximum h/t Ratio**	
		Class C	*Class D*
One-storey building	3	16	16
	4	16	13
	5	13	13
First storey of multi-storey building	3	18	18
	4	18	15
	5	15	15
Top storey of multi-storey building	3	14	14
	4	14	9
	5	9	9
Intermediate storey of multi-storey building	3	16	16
	4	16	13
	5	13	13

B-1 Zone 2						
Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	9%	NP	NP	NP	NP	NP
D	13%	NP	NP	NP	NP	NP
E	23%	NP	NP	NP	NP	NP

Figure 7-1(a)

Minimum Required Lateral Factored Resistance R_m (%W)
Clay Brick Masonry Prototype B-1 Unreinforced Shearwall
Seismic Zone 2 (Princeton)

B-1 Zone 3						
Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	17%	NP	NP	NP	NP	NP
D	23%	NP	NP	NP	NP	NP
E	25%	NP	NP	NP	NP	NP

Figure 7-1(b)

Minimum Required Lateral Factored Resistance R_m (%W)
Clay Brick Masonry Prototype B-1 Unreinforced Shearwall
Seismic Zone 3 (Chilliwack)

B-1 Zone 4						
Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	22%	NP	NP	NP	NP	NP
D	27%	NP	NP	NP	NP	NP
E	27%	NP	NP	NP	NP	NP

Figure 7-1(c)

Minimum Required Lateral Factored Resistance R_m (%W)
Clay Brick Masonry Prototype B-1 Unreinforced Shearwall
Seismic Zone 4 (Vancouver)

B-1 Zone 5						
Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	27%	NP	NP	NP	NP	NP
D	32%	NP	NP	NP	NP	NP
E	32%	NP	NP	NP	NP	NP

Figure 7-1(d)

Minimum Required Lateral Factored Resistance R_m (%W)
Clay Brick Masonry Prototype B-1 Unreinforced Shearwall
Seismic Zone 5 (Victoria)

8.0 PERFORMANCE-BASED EARTHQUAKE RETROFIT GUIDELINES FOR ROCKING ELEMENTS IN LOW-RISE SCHOOL BUILDINGS

8.1 Prototypes

1) These guidelines include the following form of construction (prototypes) for low-rise school wood frame, steel, concrete or masonry buildings:

   (a) Prototype R-1 for low aspect ratio rocking element
   (b) Prototype R-2 for moderate aspect ratio rocking element
   (c) Prototype R-3 for high aspect ratio rocking element

2) Prototype R-1 has a maximum aspect ratio of 1 for cantilevers and 2 for piers. Prototype R-2 has a maximum aspect ratio of 2.5 for cantilevers and 5 for piers. Prototype R-3 has a maximum aspect ratio of 4 for cantilevers and 8 for piers.

3) Refer to the definition of aspect ratio in Section 1.3. For rocking cantilevers, the height is measured to the centre of mass.

8.2 Minimum Required Lateral Factored Resistance R_m

1) Minimum required lateral factored resistance R_m for the risk assessment of a rocking LDRS in a low-rise building is set equal to 80% of the corresponding value obtained from Figure 8-1 to Figure 8-3.

2) Minimum required lateral factored resistance R_m for the retrofit design of a rocking LDRS in a low-rise building is obtained from Figure 8-1 to Figure 8-3.

3) The value of R_m, the minimum required lateral factored resistance determined from Sentence (1) or Sentence (2), can be reduced to the value R_{mr} in accordance with Equation (8-1) for values of H, the height of the building centre of mass above the underside of the rocking footing, between 3.0 metres and 6.0 metres.

$$R_{mr} = K_{mr} \cdot R_m \qquad (8\text{-}1)$$

where $K_{mr} = 1.33 - \frac{H}{9}$

4) The value of R_m, the minimum required lateral factored resistance determined from Sentence (1) or Sentence (2), increases in accordance with Equation (8-2) for values of H, the height of the building centre of mass above the underside of the rocking footing, between 1.5 metres and 3.0 metres.

$$R_{mr} = K_{mr} \cdot R_m \qquad (8\text{-}2)$$

where $K_{mr} = 1.8 - \dfrac{H}{3.75}$

8.3 Calculation of Lateral Resistance

1) Factored resistance, V_{rr} of a rocking element above its foundation is calculated as below:

$$V_{rr} = \phi_r \times \frac{(W_3 \times L) + (W_4 \times \frac{L}{2})}{h} \qquad (8\text{-}3)$$

2) Factored resistance, V_{rr} of a rocking foundation is calculated as below:

$$V_{rr} = \frac{\phi_r \cdot W_r \cdot L}{2 \cdot H} \qquad (8\text{-}4)$$

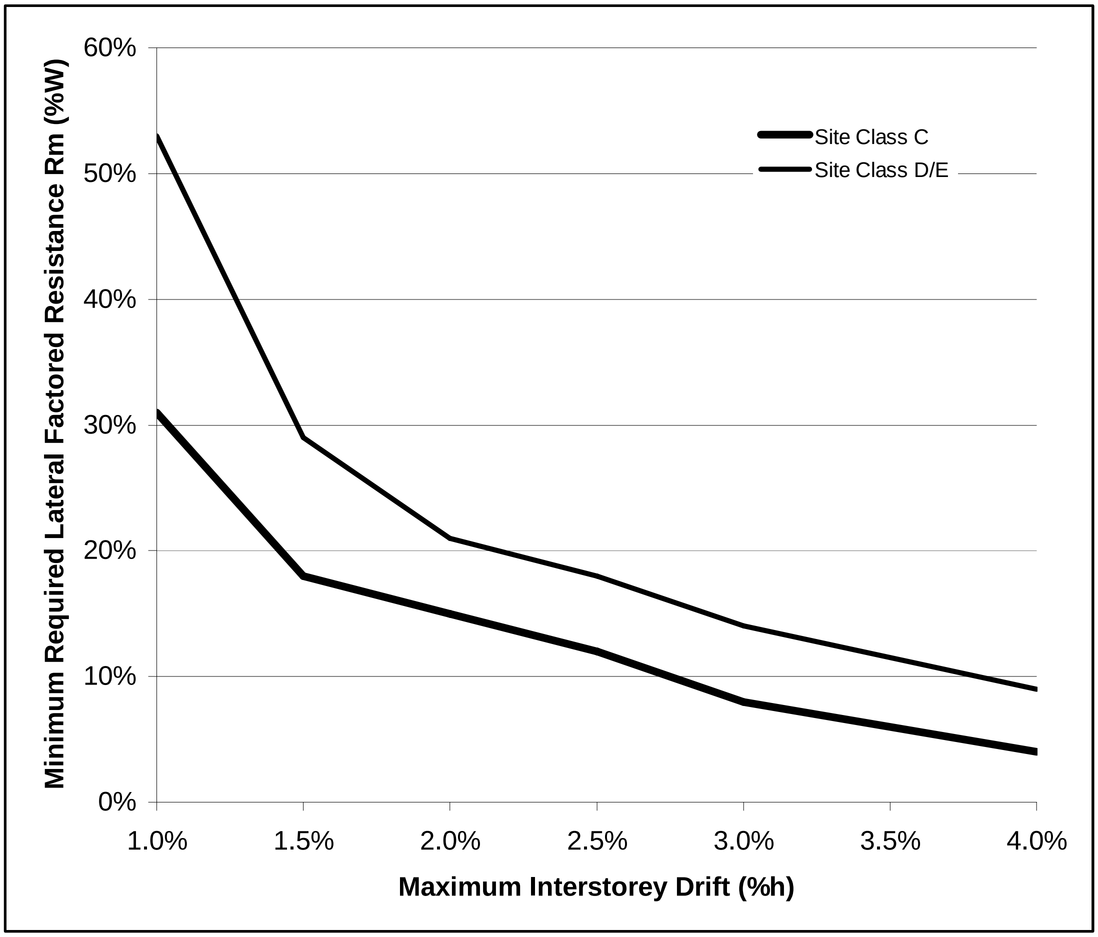
8.4 Rocking Check

1) All building elements that are capable of rocking in resisting lateral deformation, including uplift and rocking of foundations, must be checked to determine if rocking is the governing form of lateral resistance. Rocking is the governing form of lateral resistance if its unfactored overturning moment is greater than its unfactored restoring moment.

2) For concrete or masonry shearwalls whose lateral resistance is governed by flexure rather than shear, lateral resistance is provided by a combination of flexure and rocking.

3) Refer to Section A8.4 in the Commentary for rocking check details on each LDRS.

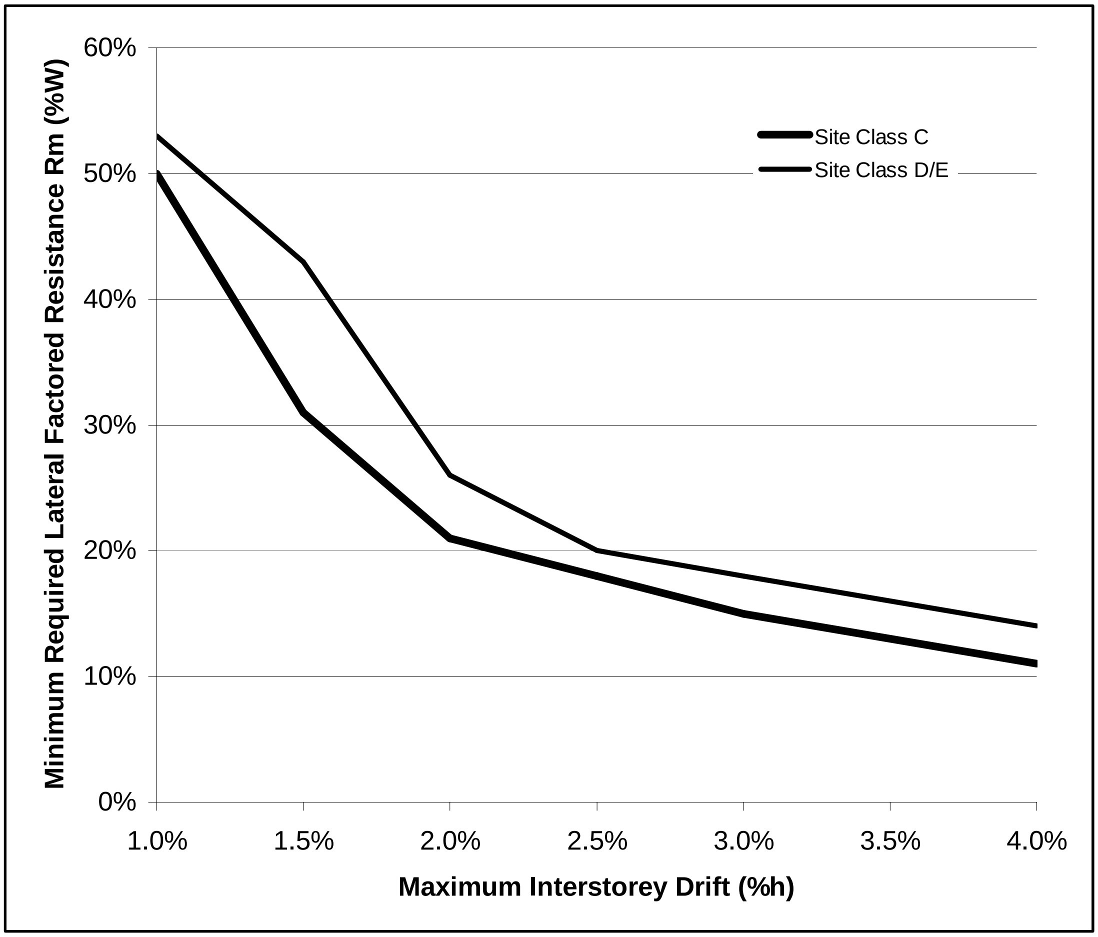
R-1 Zone 2



Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	31%	18%	15%	12%	8%	4%
D	53%	29%	21%	18%	14%	9%
E	53%	29%	21%	18%	14%	9%

Figure 8-1(a) *Minimum Required Lateral Factored Resistance R_m (%W)*
Rocking Prototype R-1 Low Aspect Ratio Elements
Seismic Zone 2 (Princeton)

R-1 Zone 3

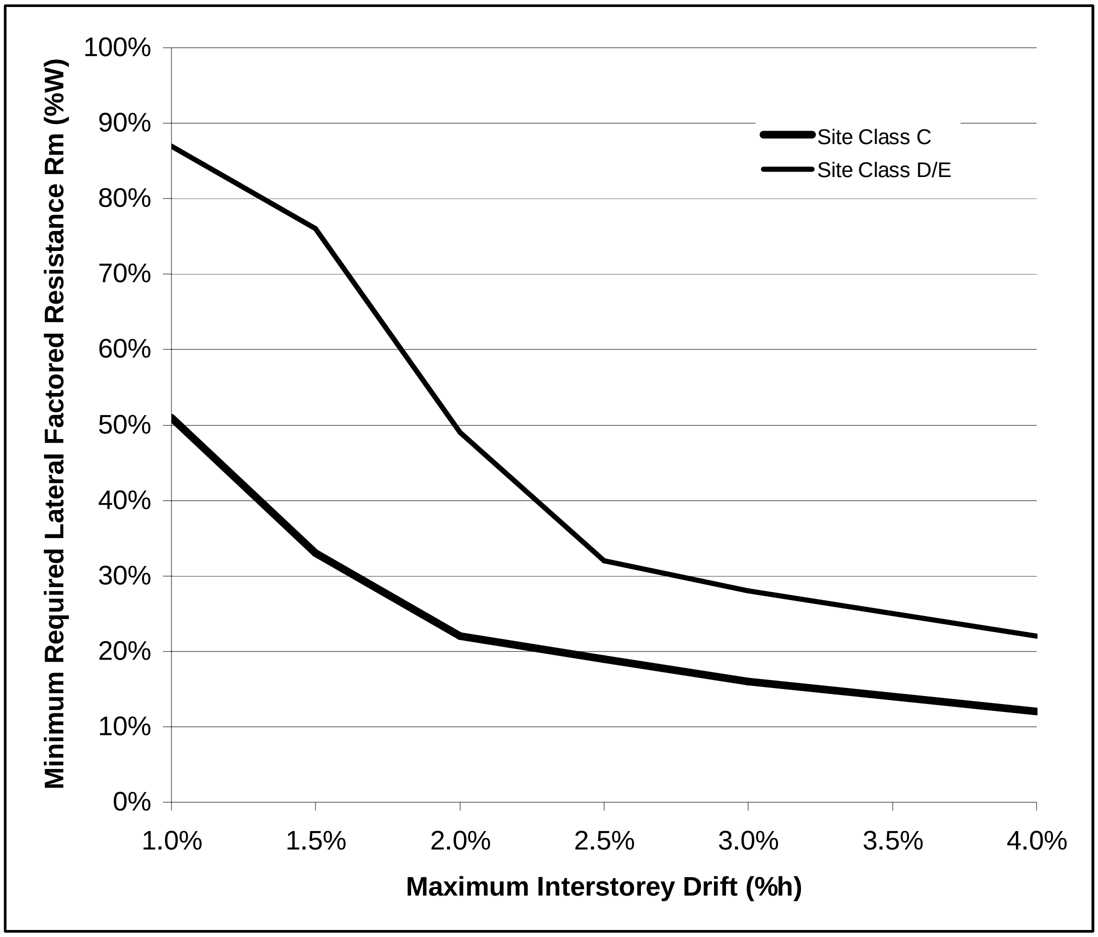


Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	50%	31%	21%	18%	15%	11%
D	53%	43%	26%	20%	18%	14%
E	53%	43%	26%	20%	18%	14%

Figure 8-1(b)

Minimum Required Lateral Factored Resistance R_m (%W)
Rocking Prototype R-1 Low Aspect Ratio Elements
Seismic Zone 3 (Chilliwack)

R-1 Zone 4

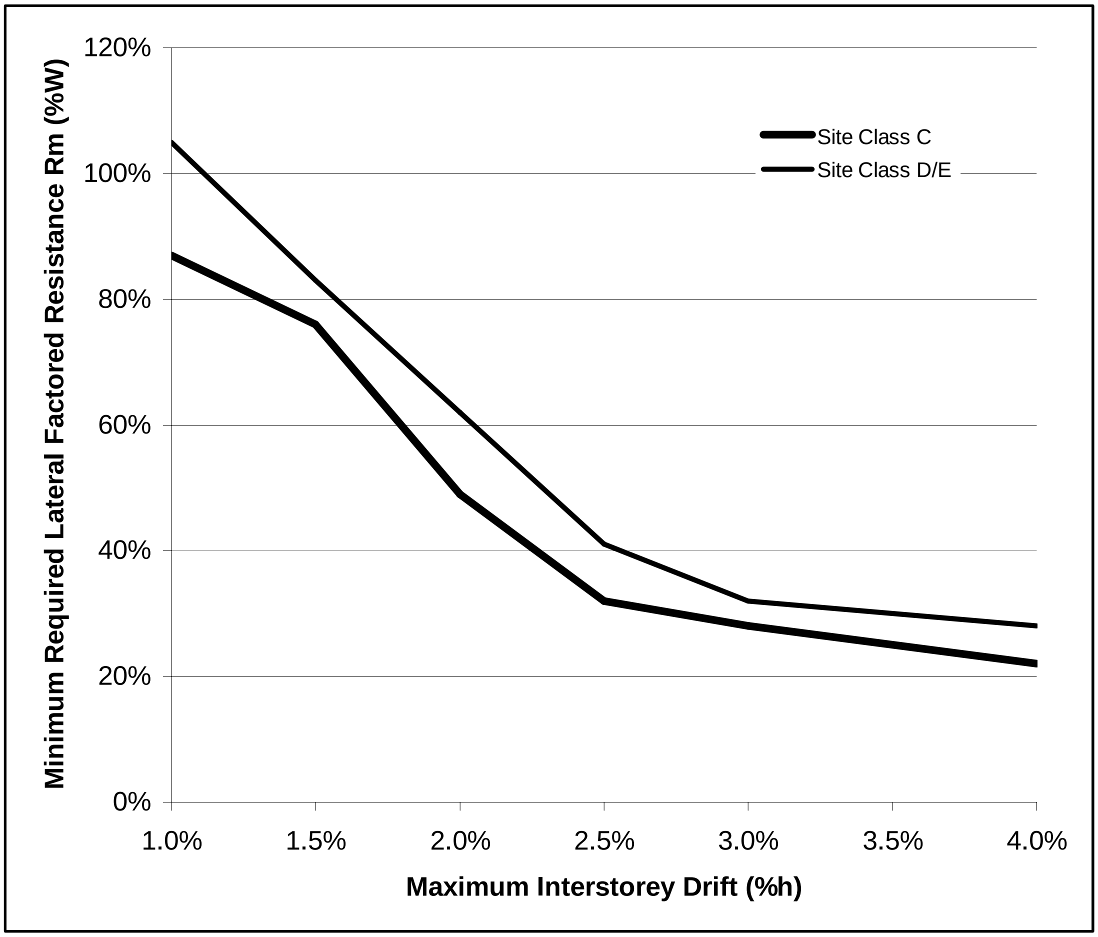


Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	51%	33%	22%	19%	16%	12%
D	87%	76%	49%	32%	28%	22%
E	87%	76%	49%	32%	28%	22%

Figure 8-1(c)

Minimum Required Lateral Factored Resistance R_m (%W)
Rocking Prototype R-1 Low Aspect Ratio Elements
Seismic Zone 4 (Vancouver)

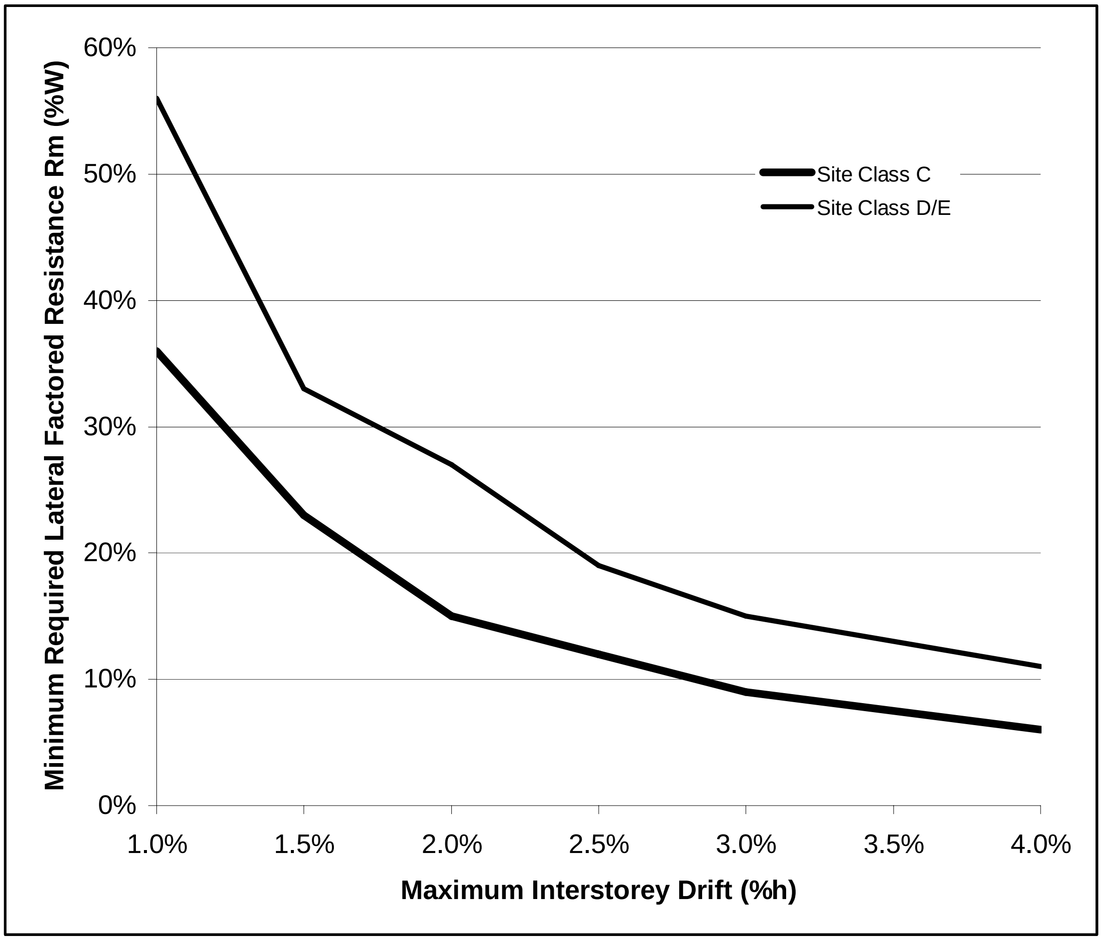
R-1 Zone 5



Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	87%	76%	49%	32%	28%	22%
D	105%	83%	62%	41%	32%	28%
E	105%	83%	62%	41%	32%	28%

Figure 8-1(d) *Minimum Required Lateral Factored Resistance R_m (%W)*
Rocking Prototype R-1 Low Aspect Ratio Elements
Seismic Zone 5 (Victoria)

R-2 Zone 2

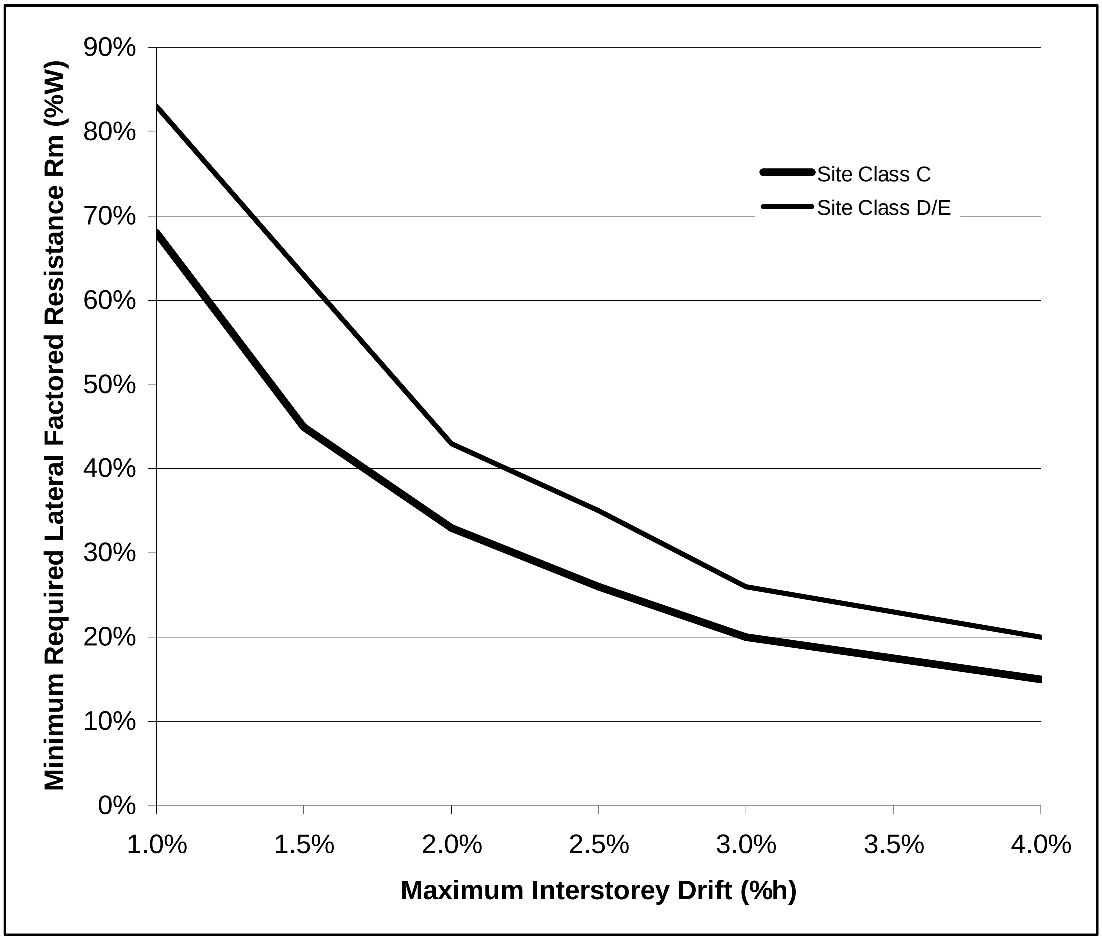


Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	36%	23%	15%	12%	9%	6%
D	56%	33%	27%	19%	15%	11%
E	56%	33%	27%	19%	15%	11%

Figure 8-2(a)

Minimum Required Lateral Factored Resistance R_m (%W)
Rocking Prototype R-2 Medium Aspect Ratio Elements
Seismic Zone 2 (Princeton)

R-2 Zone 3

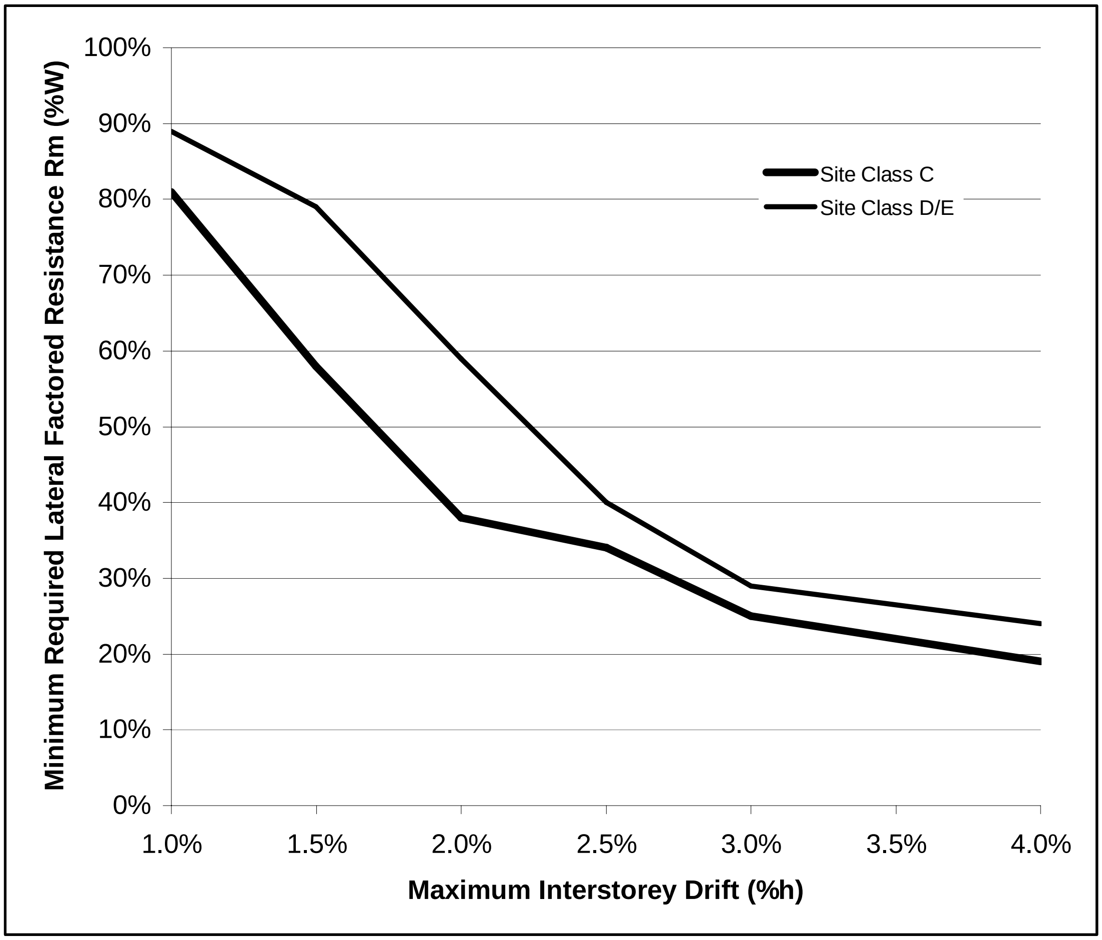


Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	68%	45%	33%	26%	20%	15%
D	83%	63%	43%	35%	26%	20%
E	83%	63%	43%	35%	26%	20%

Figure 8-2(b)

Minimum Required Lateral Factored Resistance R_m (%W)
Rocking Prototype R-2 Medium Aspect Ratio Elements
Seismic Zone 3 (Chilliwack)

R-2 Zone 4

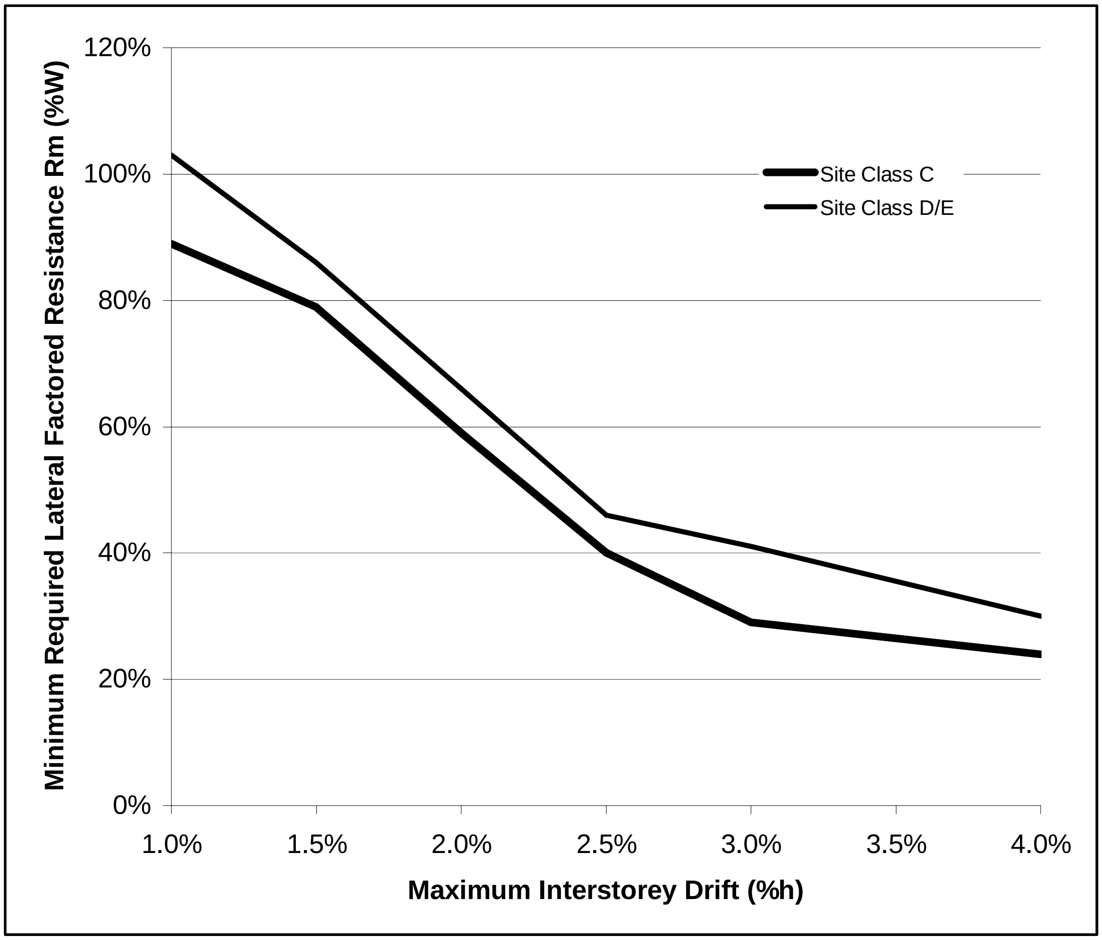


Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	81%	58%	38%	34%	25%	19%
D	89%	79%	59%	40%	29%	24%
E	89%	79%	59%	40%	29%	24%

Figure 8-2(c)

Minimum Required Lateral Factored Resistance R_m (%W)
Rocking Prototype R-2 Medium Aspect Ratio Elements
Seismic Zone 4 (Vancouver)

R-2 Zone 5

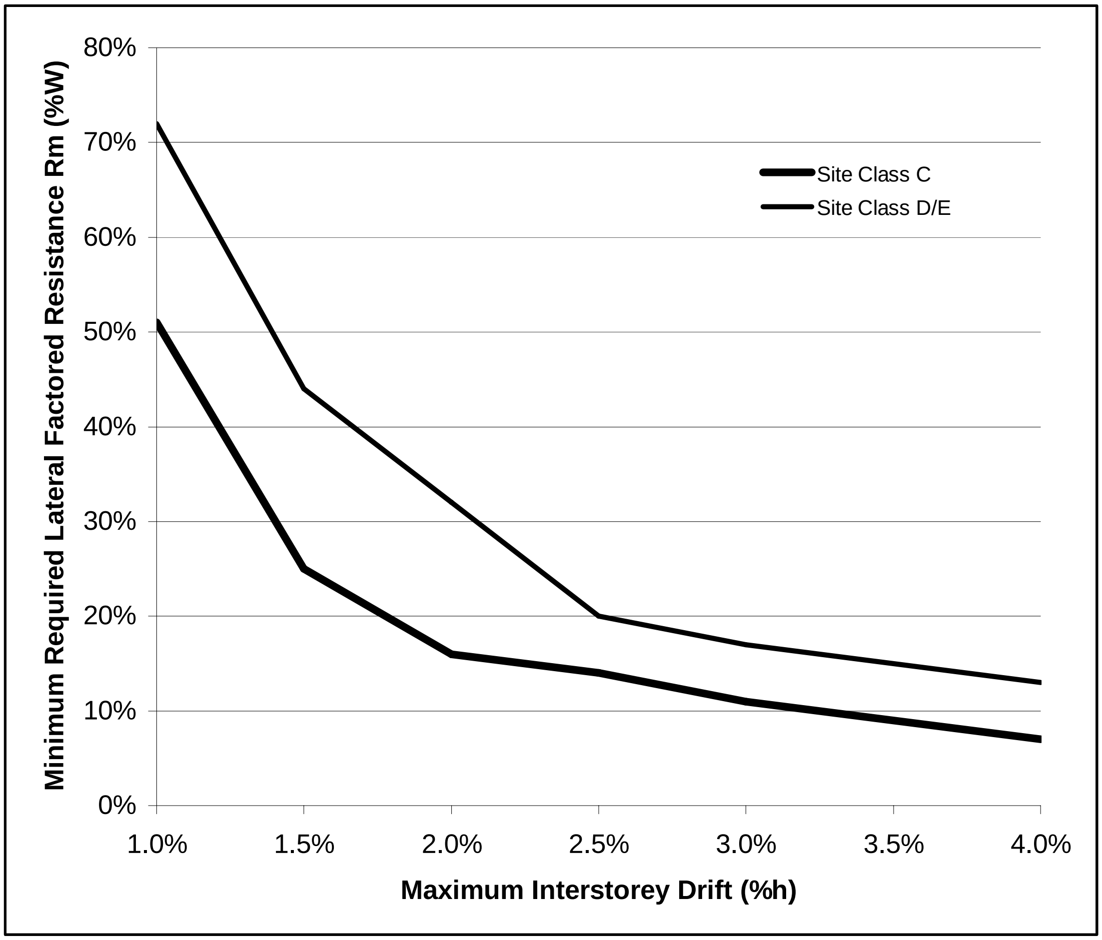


Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	89%	79%	59%	40%	29%	24%
D	103%	86%	66%	46%	41%	30%
E	103%	86%	66%	46%	41%	30%

Figure 8-2(d)

Minimum Required Lateral Factored Resistance R_m (%W)
Rocking Prototype R-2 Medium Aspect Ratio Elements
Seismic Zone 5 (Victoria)

R-3 Zone 2

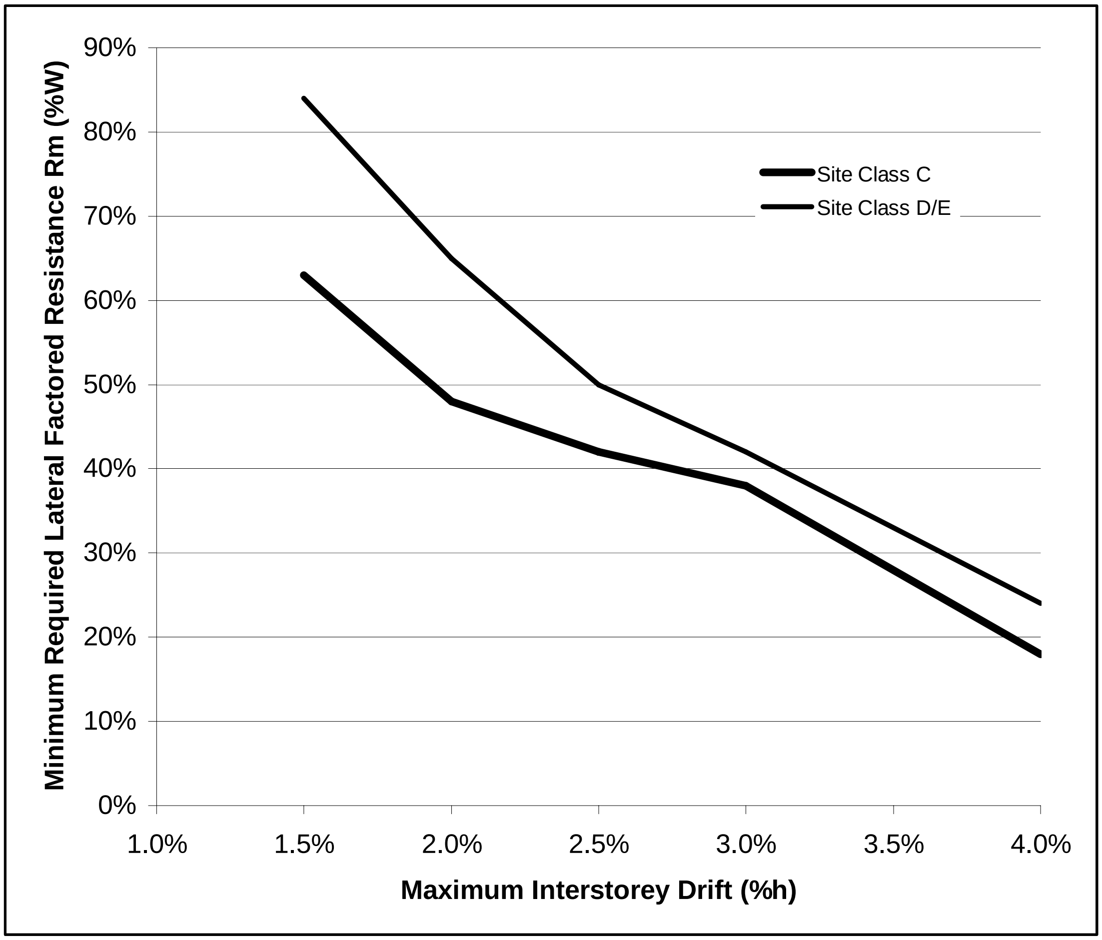


Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	51%	25%	16%	14%	11%	7%
D	72%	44%	32%	20%	17%	13%
E	72%	44%	32%	20%	17%	13%

Figure 8-3(a)

Minimum Required Lateral Factored Resistance R_m (%W)
Rocking Prototype R-3 High Aspect Ratio Elements
Seismic Zone 2 (Princeton)

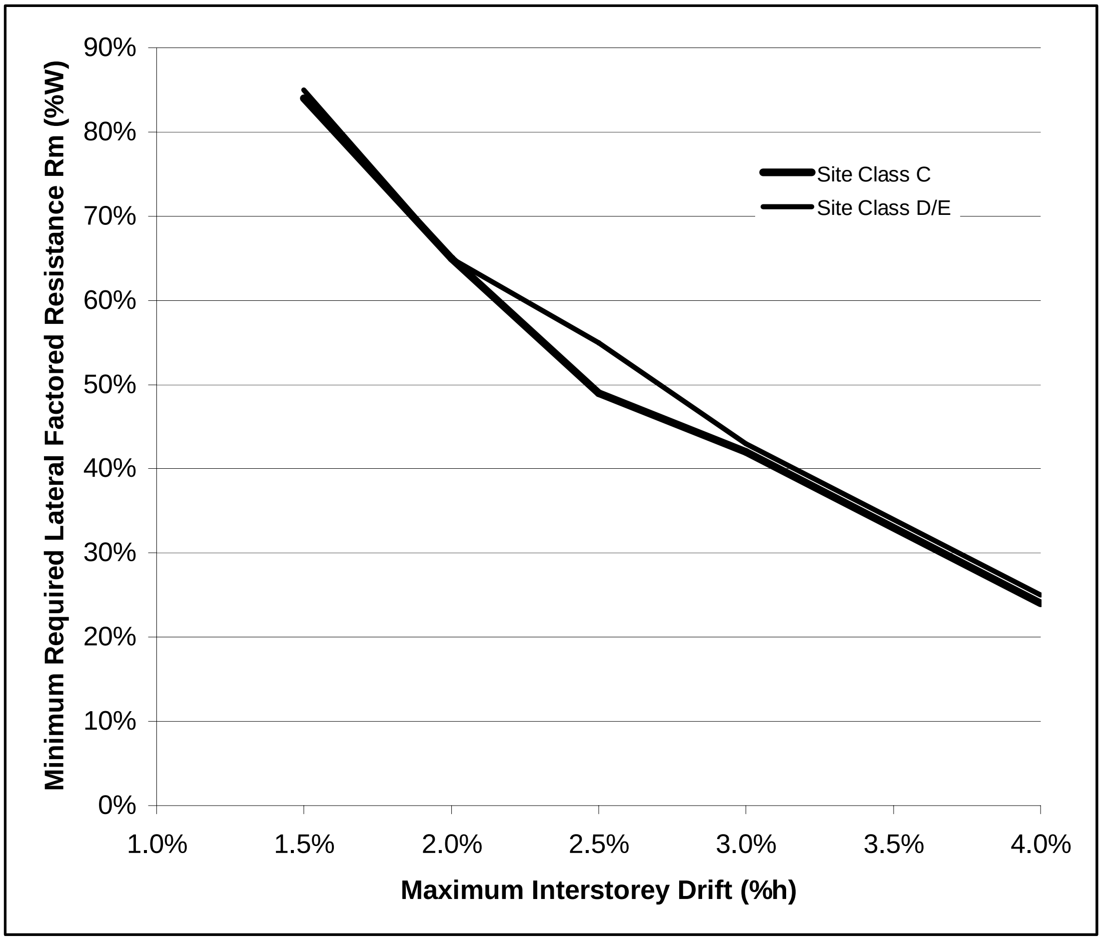
R-3 Zone 3



Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	NR	63%	48%	42%	38%	18%
D	NR	84%	65%	50%	42%	24%
E	NR	84%	65%	50%	42%	24%

Figure 8-3(b) *Minimum Required Lateral Factored Resistance R_m (%W)*
Rocking Prototype R-3 High Aspect Ratio Elements
Seismic Zone 3 (Chilliwack)

R-3 Zone 4

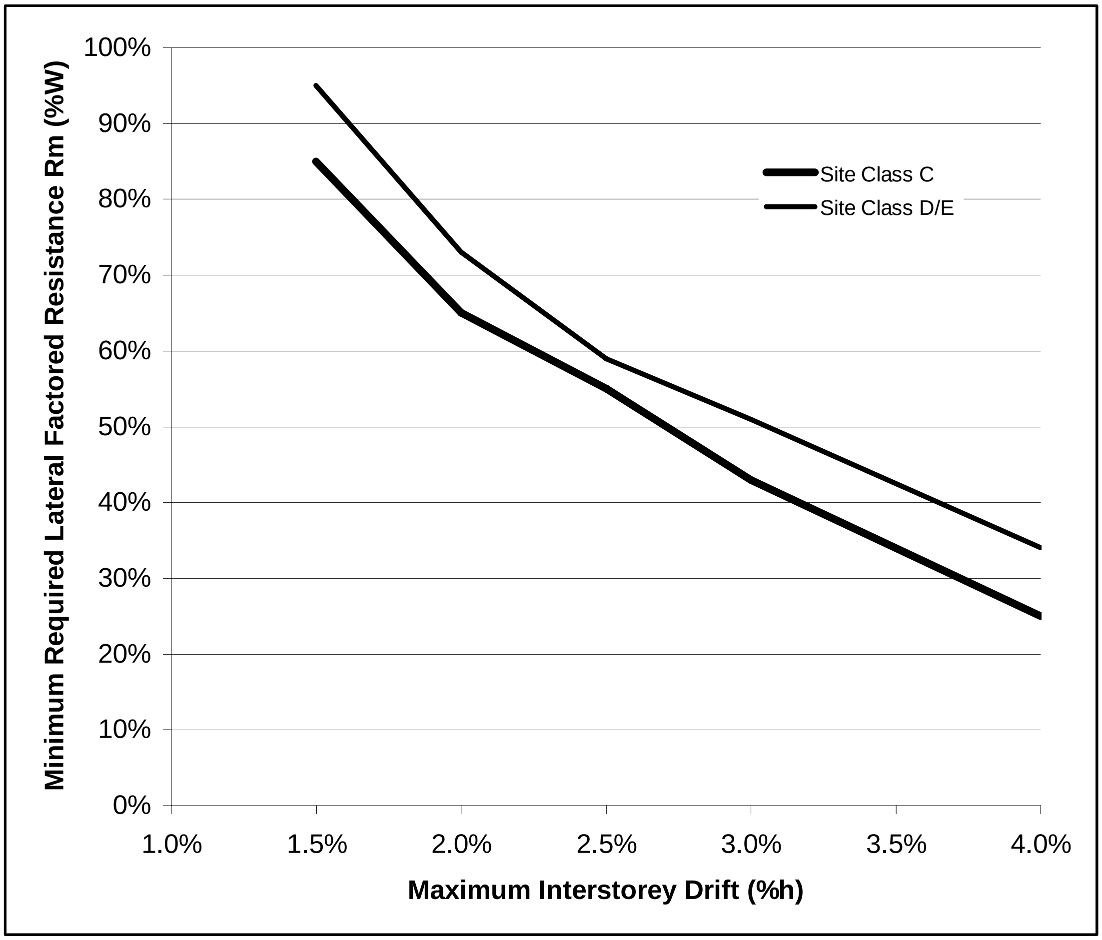


Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	NR	84%	65%	49%	42%	24%
D	NR	85%	65%	55%	43%	25%
E	NR	85%	65%	55%	43%	25%

Figure 8-3(c)

Minimum Required Lateral Factored Resistance R_m (%W)
Rocking Prototype R-3 High Aspect Ratio Elements
Seismic Zone 4 (Vancouver)

R-3 Zone 5



Site Class	*1.0%*	*1.5%*	*2.0%*	*2.5%*	*3.0%*	*4.0%*
C	NR	85%	65%	55%	43%	25%
D	NR	95%	73%	59%	51%	34%
E	NR	95%	73%	59%	51%	34%

Figure 8-3(d)

Minimum Required Lateral Factored Resistance R_m (%W)
Rocking Prototype R-3 High Aspect Ratio Elements
Seismic Zone 5 (Victoria)

9.0 PERFORMANCE-BASED EARTHQUAKE RETROFIT GUIDELINES FOR HEAVY PARTITION WALLS IN LOW-RISE SCHOOL BUILDINGS

9.1 Scope of Heavy Partition Walls Guidelines

1) The scope of this Section of the Bridging Guidelines includes the following forms of construction that have a significant influence on the seismic performance of potentially high risk heavy partition walls:

   (a) Hollow concrete block construction
   (b) Clay brick masonry
   (c) Clay tile
   (d) Pumice block
   (e) Glass block

2) All heavy partition walls are to be removed or retrofitted to provide an acceptable seismic performance.

9.2 In-Plane Requirements

1) Unreinforced heavy partition walls constructed of clay tile, pumice block or glass block are to be considered as having either insignificant or unreliable in-plane resistance and shall not be considered part of any LDRS.

9.3 Out-of-Plane Requirements

1) Removal and replacement, rather than retrofitting, is the recommended method of hazard mitigation for clay tile, pumice block and glass block heavy partition walls.

2) All clay brick masonry walls shall conform to the out-of-plane requirements of Section 7.4.

3) All concrete masonry walls shall conform to the out-of-plane requirements of Section 6.5 and to the requirements of Section 6.6 where applicable.

10.0 PERFORMANCE-BASED EARTHQUAKE RETROFIT GUIDELINES FOR DIAPHRAGMS IN LOW-RISE SCHOOL BUILDINGS

10.1 Prototypes

1) These guidelines include the following forms of diaphragm construction (prototypes) for low-rise school buildings:

   (a) Prototype D-1 for blocked plywood diaphragm

   (b) Prototype D-2 for unblocked plywood diaphragm

   (c) Prototype D-3 for steel deck Type A diaphragm

   (d) Prototype D-4 for steel deck Type B diaphragm

   (e) Prototype D-5 for horizontal plane of steel frame with tension only bracing

   (f) Prototype D-6 for horizontal plane of steel frame with tension/compression bracing

2) Steel deck Type A diaphragms have screwed side lap fasteners and nailed or welded-with-washer deck-to-frame connectors. Steel deck Type B diaphragms have button-punched or welded side lap fasteners and welded-without-washers deck-to-frame connectors.

3) Concrete diaphragms must meet the requirements of Section 10.6 and are to be assessed and retrofitted, where required, using best current practice and in accordance with the building code.

10.2 Notations

1) The definition of W_d in Section 1.4 is for the weight of the complete diaphragm (including 25% of snow loading for roof diaphragm) and the weight of the total length of walls supported by the diaphragm along the edges of the diaphragm perpendicular to the direction of shaking. The height of the supported wall is to the mid-height of the wall for each storey above and below the diaphragm. For a roof diaphragm, the height of the supported wall is from the mid-height of the top storey wall to the top of the wall or parapet.

10.3 Minimum Required Lateral Factored Resistance R_{md}

1) Minimum required lateral factored resistance R_{md} for the risk assessment of a diaphragm in a low-rise building is set equal to 80% of the corresponding value obtained from Figure 10-1 to Figure 10-6.

2) Minimum required lateral factored resistance R_{md} for the retrofit design of a diaphragm in a low-rise building is given in Figure 10-1 to Figure 10-6.

10.4 Calculation of Lateral Resistance

1) The calculation of the lateral resistance of a wood diaphragm shall comply with CAN/CSA-086-01.

2) The calculation of the lateral resistance of a diaphragm comprising a horizontal plane of steel bracing shall comply with CAN/CSA-S16-01.

3) The calculation of the lateral resistance of a steel deck diaphragm shall comply with the latest edition of the Steel Deck Institute (SDI) or alternate reference given in the commentary.

10.5 Chord Force and Strength

1) Chord force, F_c for a wood or horizontal steel frame diaphragm is calculated as below:

$$F_c = \frac{R_{md} W_d L_d}{200s} \tag{10-1}$$

2) Chord force, F_c for a steel deck diaphragm is calculated as below:

$$F_c = \frac{R_{md} W_d L_d}{400s} \tag{10-2}$$

10.6 Diaphragm Redistribution of Inertia Mass

1) Subject to meeting the requirements of Section 10.1(3), concrete diaphragms (rigid diaphragms) can be assumed to effectively redistribute inertia mass between interconnected LDRSs if the plan eccentricity complies with Sentence (2).

2) Maximum plan eccentricities for buildings with concrete diaphragms are as below:

   (a) 20% in one direction and 10% in the other orthogonal direction subject to the qualification of Sentence (2)(b).

   (b) 10% in one direction and 10% in the other orthogonal direction when the total factored resistance ratio R_r contributions from wood frame and/or steel LDRS prototype S-1 equal or exceed 25% of R_{rt}, the sum of R_r values for all LDRSs.

3) Buildings with concrete diaphragms that do not meet the requirements of Sentence (2) must be upgraded to meet the requirements of Sentence (2).

4) Wood, steel decking and horizontal steel frame diaphragms are to be considered ineffective in redistributing inertia mass between interconnected LDRSs that are spaced more than 5m apart. For such diaphragms, inertia mass is distributed between interconnected LDRSs on the basis of the tributary plan area of the diaphragm. Inertia mass distributed by tributary plan area can be effectively redistributed between LDRSs that are within 5 metres of each other as measured perpendicular to the direction of shaking (refer to commentary for details).

10.7 Steel Deck Diaphragms

1) In Seismic Zones 3-6, Type B steel deck is not to be introduced as new material in the retrofit of diaphragms. In Seismic Zones 3-6, part or all of an existing Type B steel deck can be retained in a retrofitted building if it is demonstrated that the lateral resistance of the Type B steel deck meets the requirements of Section 10.3.

10.8 Wood Diaphragms in Wood Frame Buildings

1) With the exception of Sentence (2), existing roof and floor wood diaphragms in a wood frame building are considered to have acceptable strength and connections to resist inertia forces in a life-safe manner if the following requirements are met:

   (a) Building founded on underlying Site Class C/D soils.

   (b) Four sides of diaphragm have LDRSs that meet the requirements of these guidelines.

(c) Maximum diaphragm span is 15 metres between LDRSs that are connected to the diaphragm in compliance with the requirements of Section 11.

2) With one exception, roof diaphragms with shiplap perpendicular to the joists or roof diaphragms with tongue-and-groove decking must be upgraded. Diaphragms with tongue-and-groove decking do not require upgrading if all of the following requirements are met:

(a) All requirements of Sentence (1)

(b) Decking at least 64 mm thick

(c) Deck side spikes confirmed at 1000 mm maximum spacing

3) Timing of the diaphragm retrofits required in Sentence (2) can be delayed to coincide with replacement of the roof membrane if the diaphragm upgrading can then be upgraded in a more cost-effective manner.

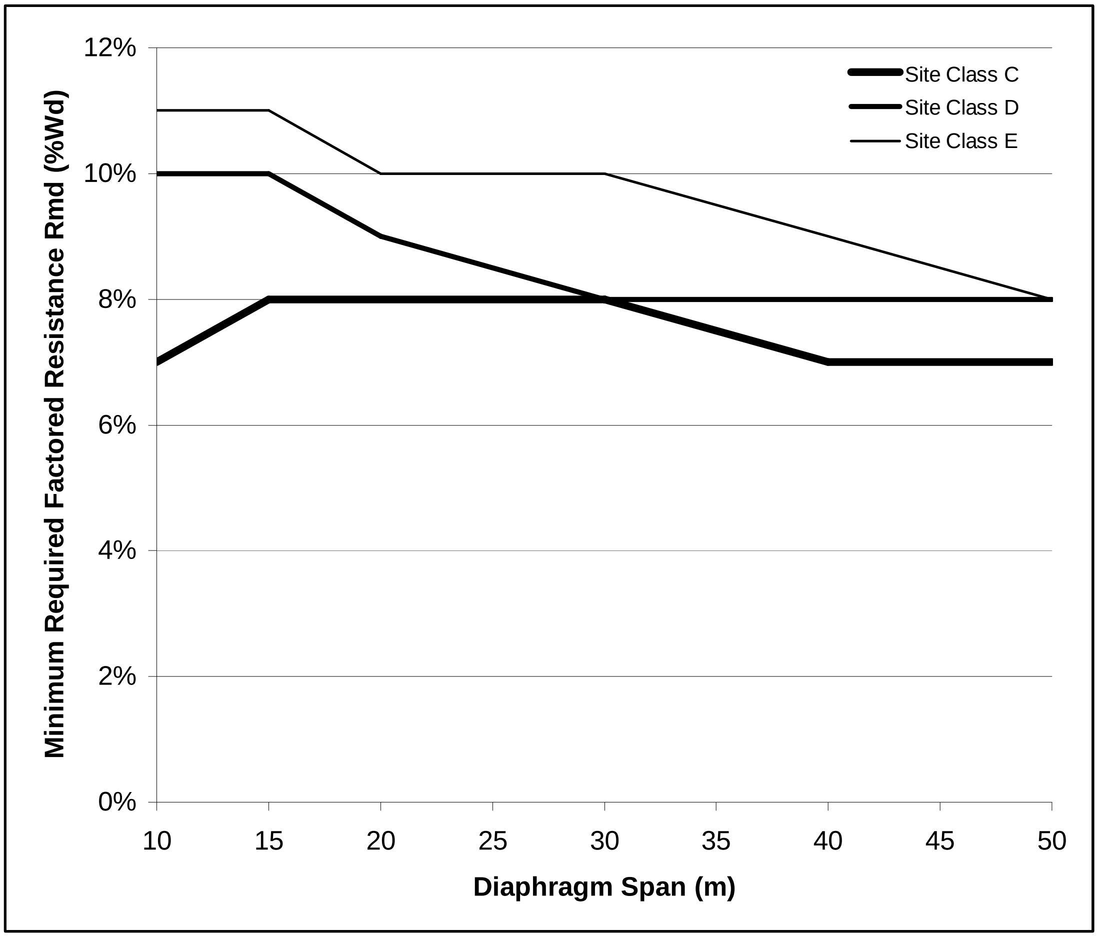
10.9 Inelastic Strain Limitation

1) The inelastic strain in wood diaphragms shall not exceed 1.0% when all connected LDRSs are assumed to have deformed to their ISDL.

2) The inelastic strain in steel deck diaphragms shall not exceed 0.5% for Type A steel deck and 0.25% for Type B steel deck when all connected LDRSs are assumed to have deformed to their ISDL.

3) The inelastic strain in the horizontal steel frames shall not exceed 0.5% when all connected LDRSs are assumed to have deformed to their ISDL.

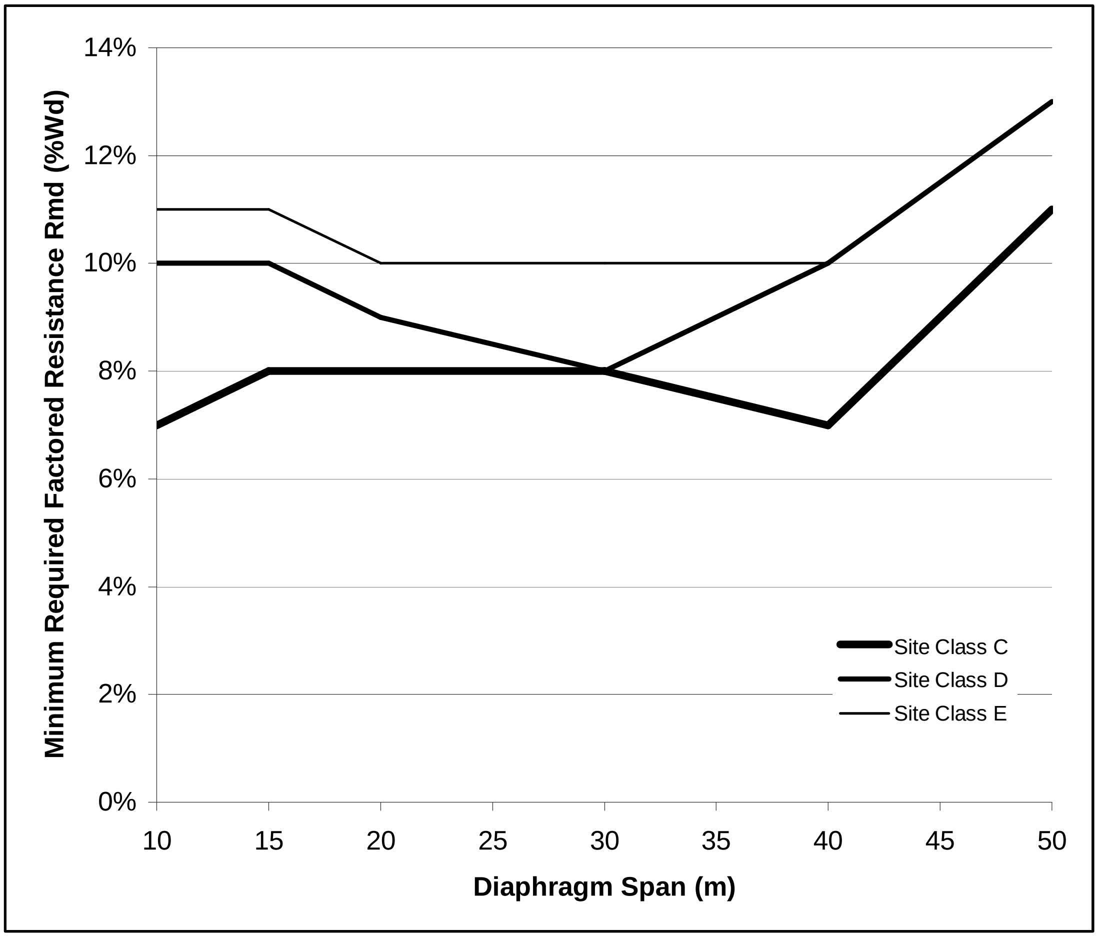
D-1 Zone 4



Site Class	10m	15m	20m	30m	40m	50m
C	7%	8%	8%	8%	7%	7%
D	10%	10%	9%	8%	8%	8%
E	11%	11%	10%	10%	9%	8%

Figure 10-1(c) *Minimum Required Retrofit Factored Resistance R_{md} (%W_d)*
Diaphragm Prototype D-1 Blocked Plywood/OSB
Seismic Zone 4 (Vancouver)

D-2 Zone 4

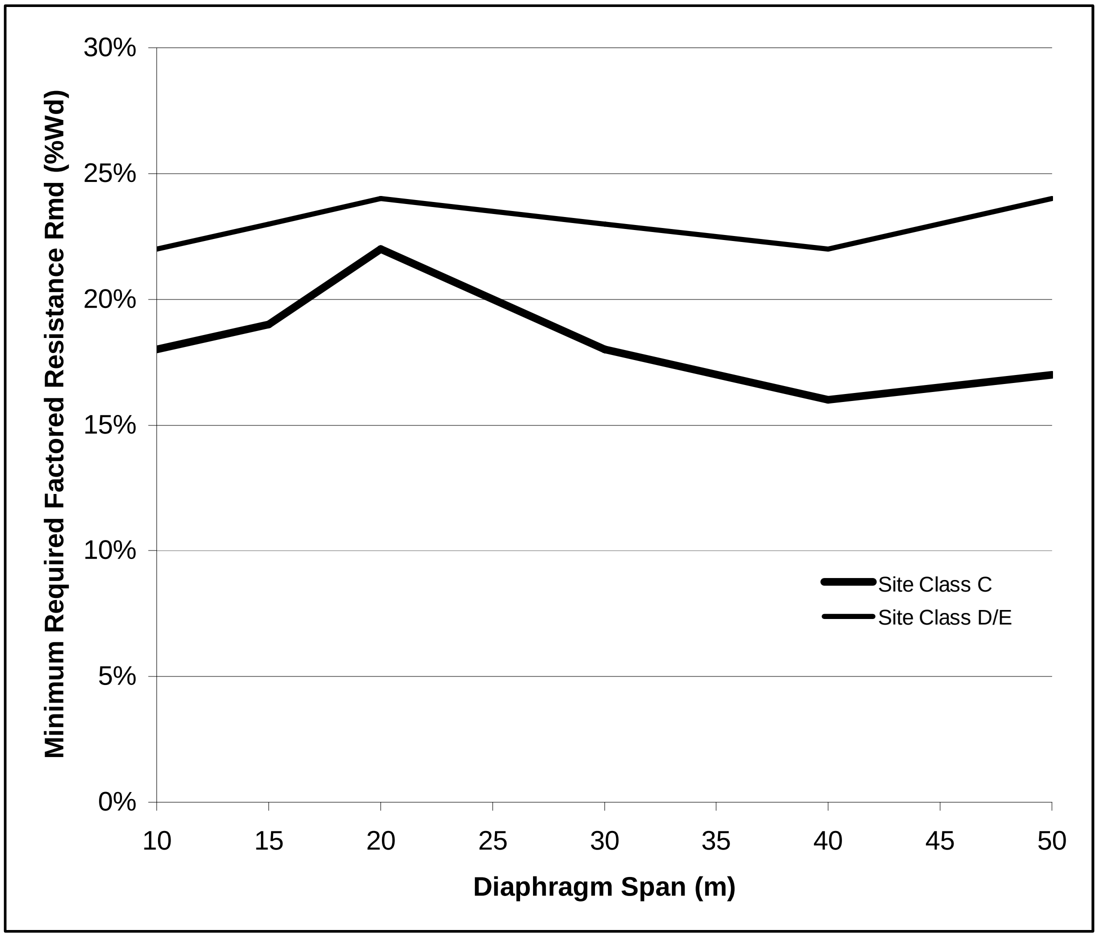


Site Class	*10m*	*15m*	*20m*	*30m*	*40m*	*50m*
C	7%	8%	8%	8%	7%	11%
D	10%	10%	9%	8%	10%	13%
E	11%	11%	10%	10%	10%	13%

Figure 10-2(c)

Minimum Required Retrofit Factored Resistance R_{md} (%W_d)
Diaphragm Prototype D-2 Unblocked Plywood/OSB
Seismic Zone 4 (Vancouver)

D-3 Zone 4

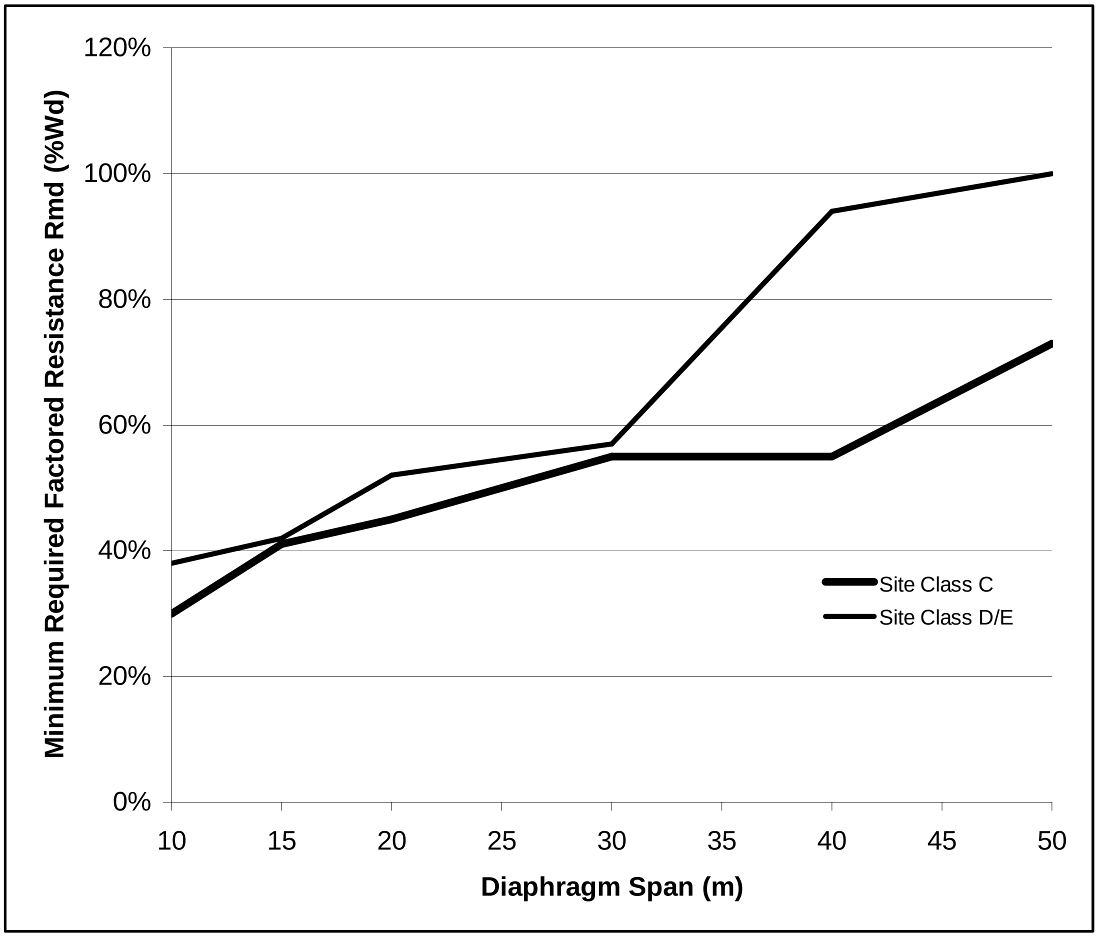


Site Class	*10m*	*15m*	*20m*	*30m*	*40m*	*50m*
C	18%	19%	22%	18%	16%	17%
D	22%	23%	24%	23%	22%	24%
E	22%	23%	24%	23%	22%	24%

Figure 10-3(c)

Minimum Required Retrofit Factored Resistance R_{md} (%W_d)
Diaphragm Prototype D-3 Steel Deck Type A
Seismic Zone 4 (Vancouver)

D-4 Zone 4

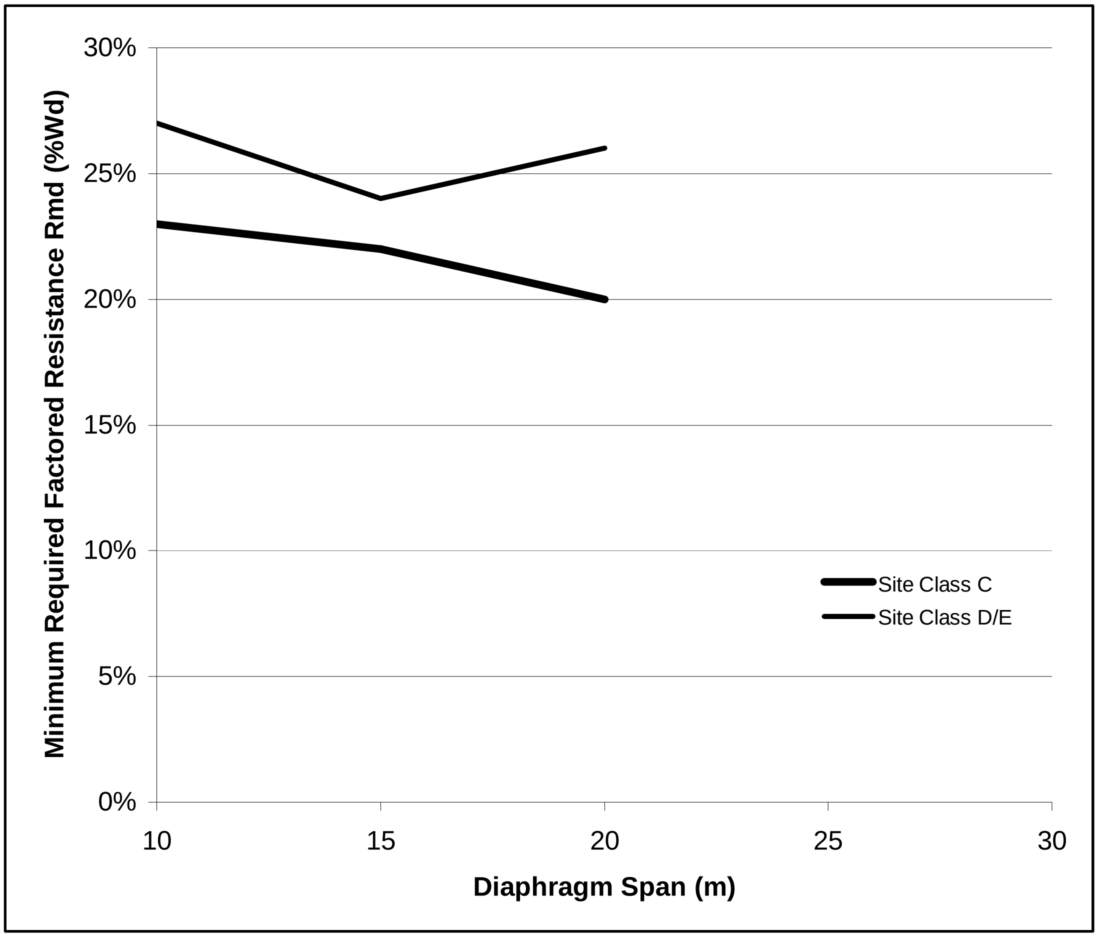


Site Class	*10m*	*15m*	*20m*	*30m*	*40m*	*50m*
C	30%	41%	45%	55%	55%	73%
D	38%	42%	52%	57%	94%	100%
E	38%	42%	52%	57%	94%	100%

Figure 10-4(c)

Minimum Required Retrofit Factored Resistance R_{md} (%W_d)
Diaphragm Prototype D-4 Steel Deck Type B
Seismic Zone 4 (Vancouver)

D-5 Zone 4

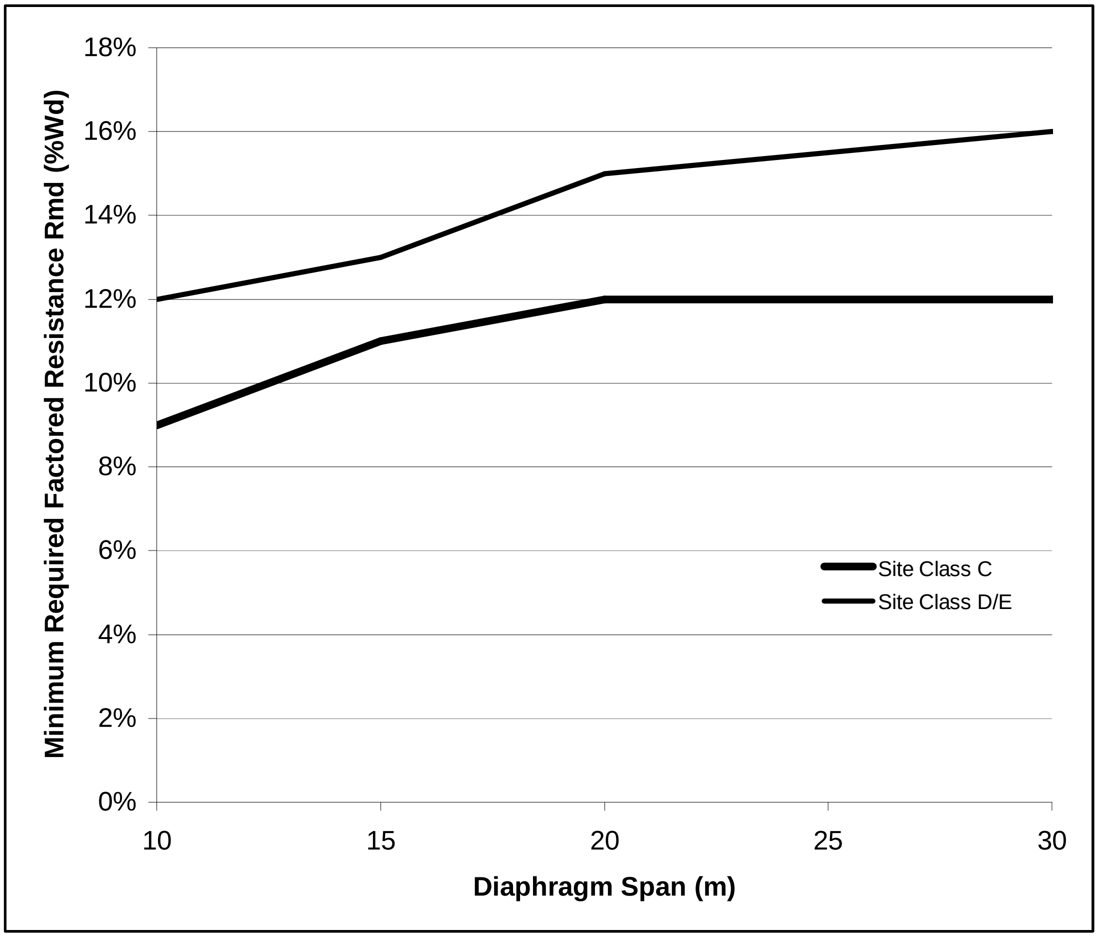


Site Class	*10m*	*15m*	*20m*	*30m*	*40m*	*50m*
C	23%	22%	20%	NP	NP	NP
D	27%	24%	26%	NP	NP	NP
E	27%	24%	26%	NP	NP	NP

Figure 10-5(c)

Minimum Required Retrofit Factored Resistance R_{md} (%W_d)
Diaphragm Prototype D-5 Steel Bracing (Tension Only)
Seismic Zone 4 (Vancouver)

D-6 Zone 4



Site Class	*10m*	*15m*	*20m*	*30m*	*40m*	*50m*
C	9%	11%	12%	12%	12%	11%
D	12%	13%	15%	16%	14%	14%
E	12%	13%	15%	16%	14%	14%

Figure 10-6(c)

Minimum Required Retrofit Factored Resistance R_{md} (%W_d)
Diaphragm Prototype D-6 Steel Bracing (Tens./Comp.)
Seismic Zone 4 (Vancouver)

11.0 PERFORMANCE-BASED EARTHQUAKE RETROFIT GUIDELINES FOR CONNECTIONS IN LOW-RISE SCHOOL BUILDINGS

11.1 Types of Connections

1) The guidelines in this section are for the following categories of connections:

   (a) Diaphragm connections
   (b) Member connections
   (c) Attachment connections

2) Diaphragm connections are the connections between the types of diaphragms addressed in Section 10 and the walls to which the diaphragm is connected.

3) Member connections provide a shop or field splice within a member or connect a member to a frame or foundation. The centreline of the member connections must coincide with the member centreline.

4) Attachment connections are connections that secure non-structural elements within the structural system (e.g. cladding connections, parapet brace connections).

11.2 Level of Risk

1) A connection requires seismic upgrading if its factored resistance R_c is less than the minimum factored resistance R_{mc} as calculated in accordance with Section 11.3, Section 11.4 and section 11.5.

11.3 Minimum Factored Resistance - Diaphragm Connections

1) The minimum factored resistance R_{mc} of a connection loaded in shear or tension in a wood, steel deck or horizontal braced steel frame diaphragm is calculated as below:

$$R_{mc} = 1.5 \frac{R_{ed} R_o}{n_c} \qquad (11\text{-}1)$$

2) Refer to the commentary for clarification of the number of connections to be used in Equation (11-1).

3) Concrete diaphragm connections are to be compliant with the requirements of the building code.

11.4 Minimum Factored Resistance - Member Connections

1) The minimum factored resistance of a timber or steel member connection shall be calculated in accordance with the CSA standard referenced in Sections 3-4.

11.5 Minimum Factored Resistance - Attachment Connections

1) The minimum factored resistance R_{mc} of an attachment connection is calculated in accordance with Section 4.1.8.17 of the building code.

11.6 Calculation of Connection Resistance

1) The factored resistance of a connection is to be calculated in accordance with the manufacturer's recommendations and best current practice.