World Housing Encyclopedia

A Resource on Construction in Earthquake Regions

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HOUSING REPORT

Concrete shear wall highrise buildings

Report#	79
Last Updated	
Country	Canada
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Important

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General Information

Building Type:	Concrete shear wall highrise buildings
Country:	Canada
Author(s):	John Pao Svetlana Brzev
Last Updated:	
Regions Where Found:	Buildings of this construction type can be found in major Canadian cities: Toronto, Montreal, Vancouver, etc. This type of housing construction is commonly found in urban areas.
Summary:	This concrete shear wall high-rise represents a contemporary residential and commercial construction commonly found in downtown areas of Canadian cities. This multi-family building contains 100 to 200 units and provides housing for 300 to 500 inhabitants. The height of these buildings is variable and usually ranges from 12 to 35 stories. The lateral load-resisting system consists of reinforced concrete shear walls and concrete floor slabs. The gravity load is carried mainly by concrete columns. Seismic detailing of shear walls in medium-to-high seismic regions is mandatory per the Canadian Concrete Code. Exterior walls are clad in stucco backed by cold-form steel framing or masonry veneer, steel/glazing panels, or precast panels. There is no report on the damage sustained by this building type in past earthquakes in Canada. However, because these buildings are designed according to state-of-the-art seismic codes, their seismic performance is expected to be satisfactory in an earthquake of design intensity (per the seismic design requirements of the National Building Code of Canada).
Length of time practiced:	Less than 25 years
Still Practiced:	Yes
In practice as of:	
Building Occupancy:	Residential, 50+ units
Typical number of stories:	12-35

Terrain-Flat:	Typically
Terrain-Sloped:	Typically
Comments:	This is a rather recent construction practice, resulting from the population growth in Canadian urban areas in the last few deca

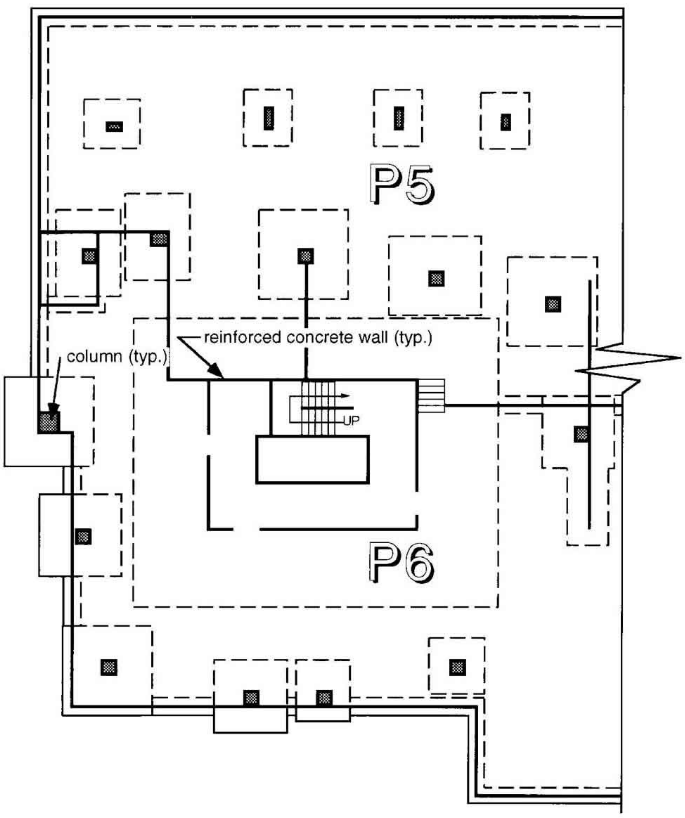
Features

Plan Shape	Other
Additional comments on plan shape	In general, buildings of this type are characterized with a regular plan. A typical building plan characteristic for residential high-rises of post-1970s construction is so-called "point block" system. Point block is characterized with a symmetrical plan (square, circular, hexagonal) with a centrally located elevator core, and the apartments are planned along all sides in a ring pattern around the core (Macsai 1976). Shear wall buildings are usually regular in elevation. However, in some buildings located in the downtown areas, lower floors are used for the commercial purposes and the buildings are characterized with larger plan dimensions; these are so-called "podium-type" buildings. In other cases, there are setbacks at higher floor levels.
Typical plan length (meters)	20
Typical plan width (meters)	20
Typical story height (meters)	2.6
Type of Structural System	Structural Concrete: Structural Wall: Moment frame with in-situ shear walls
	The main elements of gravity load-resisting system are concrete columns (which form so-called "gravity frame"). The columns are typically supported by concrete flat slab structures or two-way slabs with beams. Shear walls also carry gravity loads, according to their respective tributary areas. The main lateral load-resisting system in this scheme consists of the reinforced concrete elevator core, and additional walls located elsewhere in the building as required. Shear walls have a dual role of transferring both gravity and lateral loads. Wall thickness ranges from 500 mm at the bottom

Additional comments on structural system	gradually reducing to 350 mm at the top floors. The core houses the corridor leading to the residential units, the elevator shaft and stair wells, as well as mechanical and electrical conduits. Typical core plan dimensions are approximately 10 m by 6 m. The core is typically perforated with the openings and designed as ductile wall system according to the Canadian concrete design code. The coupling beams above the openings are designed with diagonal reinforcement provided to ensure ductile seismic response. The base of the core is designed to yield first forming a plastic hinge in this region. Shear wall structures are addressed by the National Building Code of Canada 1995 (NBC 1995) and the Canadian Concrete Code A23.3-94 Design of Concrete Structures (CSA 1994). In terms of the seismic design, NBC 1995 classifies shear wall buildings into the following two categories: nominally ductile and ductile wall systems, with the corresponding force modification factor R values of 2 and 3.5 respectively. It should be noted that R factor reflects the structural ability to perform in a ductile manner under seismic loads (elastic systems are characterized with R value of 1.0). The latest edition of the Canadian Concrete Code was published in 1994, with the previous editions in 1984, 1977, 1973 (limit state design) and 1970, 1966, and 1959 editions (working stress design). Since 1973 the concrete code includes special seismic provisions for shear wall structures. The provisions include requirements for the amount and detailing of horizontal and vertical wall reinforcement. In case of ductile shear walls (R=3.5), in addition to the distributed reinforcement (in both horizontal and vertical directions) with the required ratio of 0.25 % or higher, the code requires the use of concentrated reinforcement with minimum 4 bars at the ends of walls and coupling beams. The required area of concentrated reinforcement (at each end of the wall) is equal to 0.25% of the wall area. The philosophy of code provisions regarding ductile shear walls is based on the expected development of plastic hinges over the lower part of their height; this applies to the walls with no abrupt changes of the strength and stiffness. The provisions for coupled ductile shear walls (walls with openings) recommend the provision of diagonal reinforcement in coupling beams to ensure ductile behaviour and energy absorption capacity in the coupled wall system. The code provisions for nominally ductile shear walls (R=2.0) are less stringent, however the distributed reinforcement ratio (in vertical and horizontal

	directions) of 0.25% or higher is still required. Dynamic characteristics and seismic response of a typical Canadian shearwall highrise building were studied by Ventura (White 2001). Nondestructive dynamic ambient vibration testing of a 30-storey tower (overall height 85 m) was performed as a part of the study. The test has shown that the fundamental period of the structure was equal to 1.83 sec, whereas the periods in the second and third vibration mode were 1.55 sec and 0.78 sec. The linear damping ratios corresponding to the first three vibration modes were 8.0 %, 6.8% and 6.0 % respectively. The testing was performed while building was under construction and therefore damping ratios reflect the structural damping levels only.
Gravity load-bearing & lateral load-resisting systems	
Typical wall densities in direction 1	3-4%
Typical wall densities in direction 2	3-4%
Additional comments on typical wall densities	Variable wall density.
Wall Openings	In the buildings of this type, concrete shear walls are often perforated with openings. Interior walls are perforated with door openings, whereas elevator cores usually have openings on one or more sides (e.g. elevator doors, services etc). A typical size of door openings in the elevator core is 4'-6" (width) by 7'-4" (height).
Is it typical for buildings of this type to have common walls with adjacent buildings?	No
Modifications of buildings	Except for the removal or modification of light partition walls (usually drywalls), structural modifications in the buildings of this type are not very common. If such modifications are performed, building permit must be issued based on the advice of design professionals (architects and engineers).
Type of Foundation	Shallow Foundation: Reinforced concrete isolated footingShallow Foundation: Reinforced concrete strip footingShallow Foundation: Mat foundationDeep Foundation: Reinforced concrete bearing piles

Additional comments on foundation	It consists of reinforced concrete end-bearing piles.
Type of Floor System	Other floor system
Additional comments on floor system	Structural concrete: Flat slabs (cast-in-place) Floor and roof structures are of flat plate construction. Floor structures are considered in the design as rigid diaphragms.
Type of Roof System	Roof system, other
Additional comments on roof system	Structural concrete: Flat slabs (cast-in-place) Floor and roof structures are of flat plate construction.
Additional comments section 2	When separated from adjacent buildings, the typical distance from a neighboring building is 10 meters.



Typical Foundation Plan

Building Materials and Construction Process

Description of Building Materials

Structural Element	Building Material (s)	Comment (s)

Wall/Frame	Reinforced concrete	concrete compressive strength (fc')= 25-35 MPa Steel yield strength fy= 400 MPa Concrete compressive strength based on the cylinder strength
Foundations	Reinforced concrete	concrete compressive strength (fc')= 25 MPa Steel yield strength fy= 400 MPa Concrete compressive strength based on the cylinder strength
Floors	Reinforced concrete	concrete compressive strength (fc')= 40 MPa (lower floors) to 30 MPa (upper floors) Steel yield strength fy= 400 MPa Concrete compressive strength based on the cylinder strength
Roof	Reinforced concrete	concrete compressive strength (fc')= 30 MPa Steel yield strength fy= 400 MPa Concrete compressive strength based on the cylinder strength
Other		

Design Process

Who is involved with the design process?	EngineerArchitect
Roles of those involved in the design process	This is a fully engineered construction and architects and engineers are involved both in the design phase, in which they are playing a major role.
Expertise of those involved in the design process	Architectural design for buildings of this type is developed by certified architects with an university degree in architecture, who are also the members of the Architectural Institute of British Columbia (AIBC), or other similar associations elsewhere in Canada. Structural design is performed by structural engineers, who are holding a university degree in civil engineering from a recognized university and are the members of the Association

	of Professional Engineers and Geoscientists of British Columbia (APEGBC). In order to become a member of the APEGBC, it is required to practice for at least 4 years. Engineering technologists (college graduates) are also involved in the design process.

Construction Process

Who typically builds this construction type?	Contractor
Roles of those involved in the building process	Buildings of this type are typically built by developers.
Expertise of those involved in building process	This is a fully engineered construction and architects and engineers are involved both in the design phase, in which they are playing a major role, and the construction phase, in which they are performing regular inspection as per the requirements of the APEGBC and the municipalities. Construction professionals include a project manager (usually with a civil engineering degree), and construction labor - tradesmen: carpenters, rebar placers, and concrete placers.
Construction process and phasing	The main advantage of this type of "concrete core/flat plate" cast-in-place concrete high rise residential tower is it can be constructed very quickly. Typical floor-to-floor cycle is one week, however three-day cycles are often achievable. The concrete core and columns are formed by "gang forms" that can be stripped and hoisted up to the next floor and reassembled within a few hours. The flat plate floor slabs are formed by forming tables, usually called "fly forms". When the concrete is set, the "fly forms" can be loosened, lowered and "flown" to the next level. An entire floor can be "flown" in a few hours. The primary hoisting equipment required is a tower crane that is positioned within the slab floor area. As the building height increases with the construction of each floor, the tower crane would climb with the building by jacking up at the base of the crane mast. The building exterior envelope may commence the erection prior to completion of the structure (typically the construction of the exterior envelope will commence after about 10 floors of the structure are complete). The construction of this type of housing takes place in a single phase. Typically, the building is originally designed for its final constructed size.

Construction issues	

Building Codes and Standards

Is this construction type address by codes/standards?	Yes
Applicable codes or standards	CSA A23.3-94 Design of Concrete Structures 1959 National Building Code of Canada 1995 (seismic provisions for buildings are included in Section 4) CSA A23.3-94 Design of Concrete Structures (seismic provisions for shear wall structures included in Section 21) The most recent code/standard addressing this construction type issued was 1994.
Process for building code enforcement	Building design in Canada must be performed according to the local building bylaws, which are different for different municipalities. These bylaws usually refer to provincial building codes (e.g. British Columbia Building Code), or (if provincial codes are not available) to the National Building Code of Canada. After the construction documents have been prepared, construction drawings are submitted for the approval to the municipality in which the building is located. The drawings are reviewed for compliance with the BC Building Code, as well as City Zoning and Development and Building regulations. For large and complex buildings, plumbing and mechanical systems are also reviewed. During the construction, building inspectors (employees of the municipality) are responsible for inspecting the various stages of building construction to ensure compliance with all applicable codes and bylaws. Once the construction is completed, building occupancy permit is issued (provided that the construction was completed in a satisfactory way).

Building Permits and Development Control Rules

Are building permits required?	Yes
Is this typically informal construction?	No
Is this construction typically authorized as per development control rules?	Yes

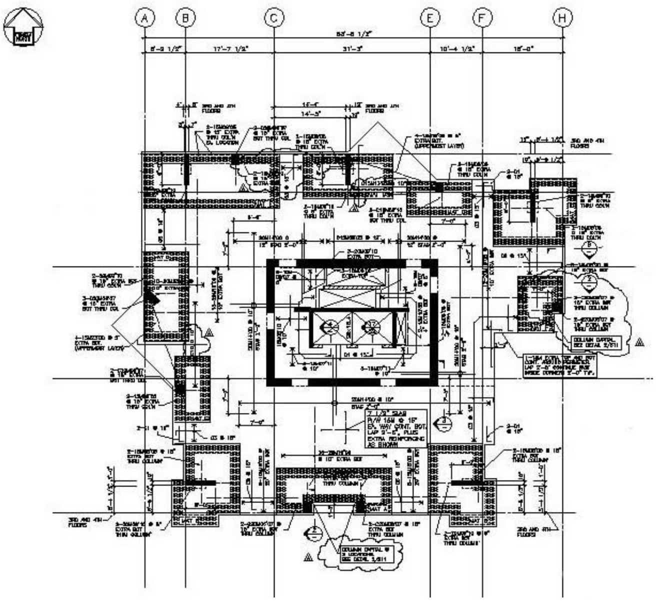
Additional comments on building permits and development control rules	

Building Maintenance and Condition

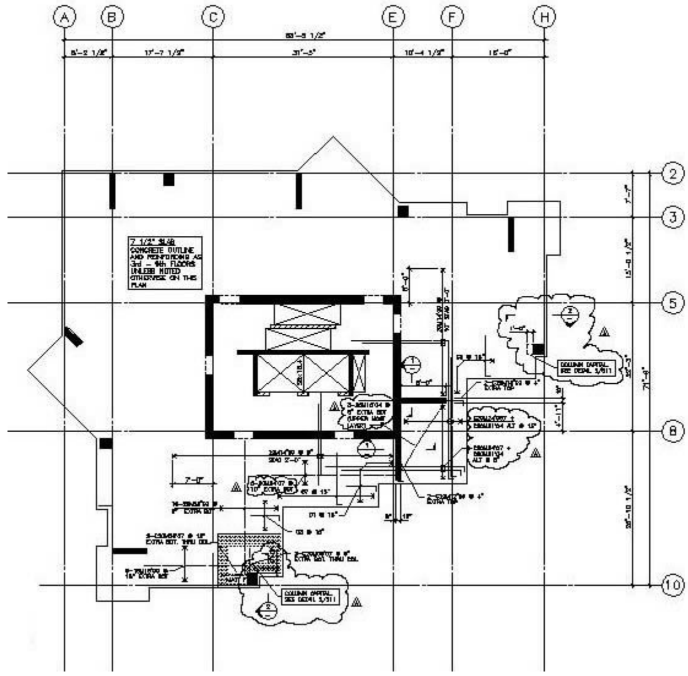
Typical problems associated with this type of construction	In some cases there are problems associated with the slab construction. Slabs are relatively thin and there is a problem associated with the perforation through the slab (ducts, etc.).
Who typically maintains buildings of this type?	Owner(s)Renter(s)
Additional comments on maintenance and building condition	

Construction Economics

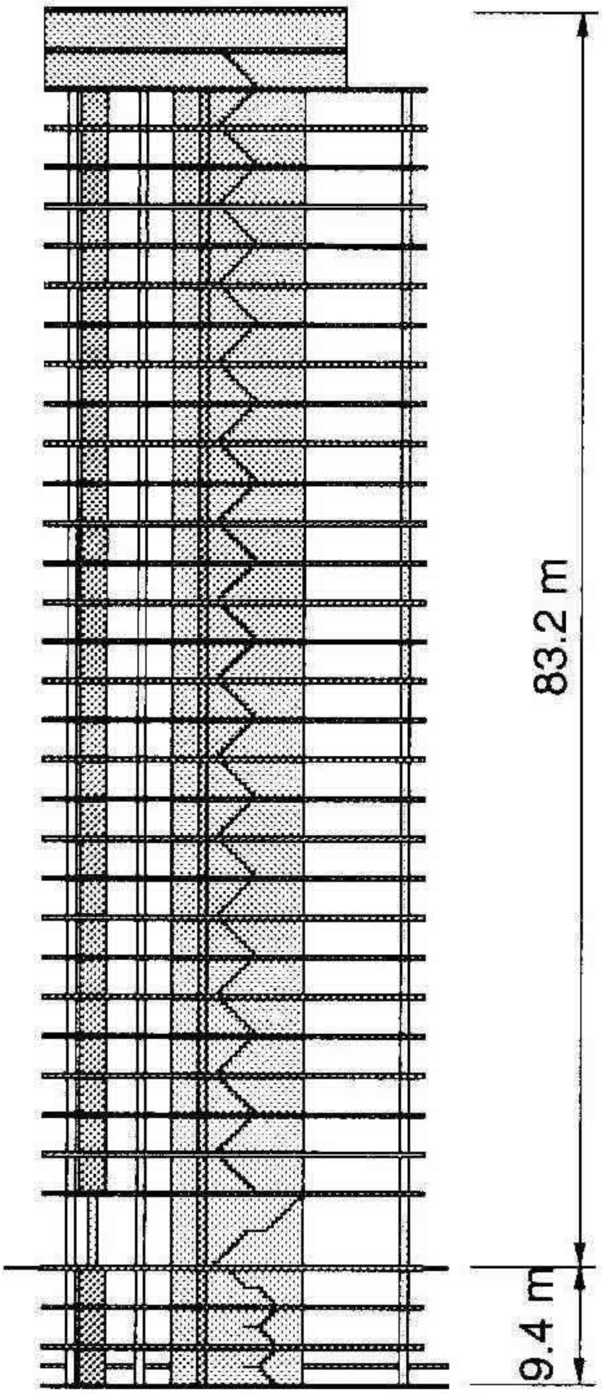
Unit construction cost	Unit cost for the structural part only is around CAN$ 220/m# ($US 140/m#), and the cost of the competed building with finishes (excluding the underground parking) is approximately CAN$ 880/m# ($US 560/m#).
Labor requirements	The construction progresses at a pace of approx. 1 floor/week (in some cases it may be 1 floor/4 days). The construction crew (for concrete part) includes 20 people.
Additional comments section 3	



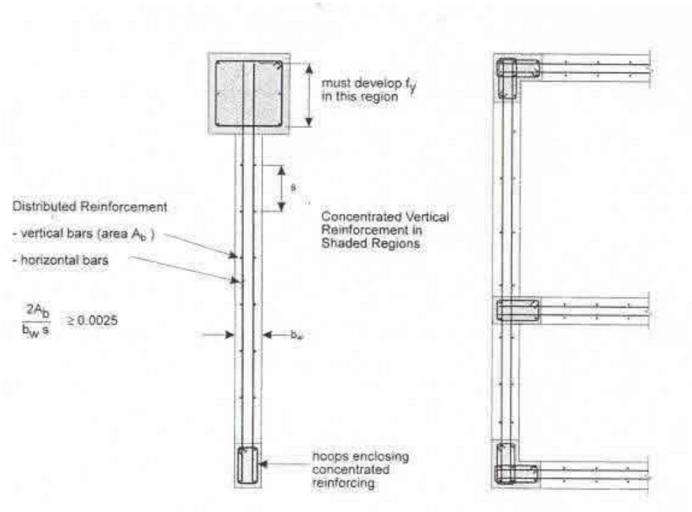
Plan of a Typical Building - Lower Floor Levels



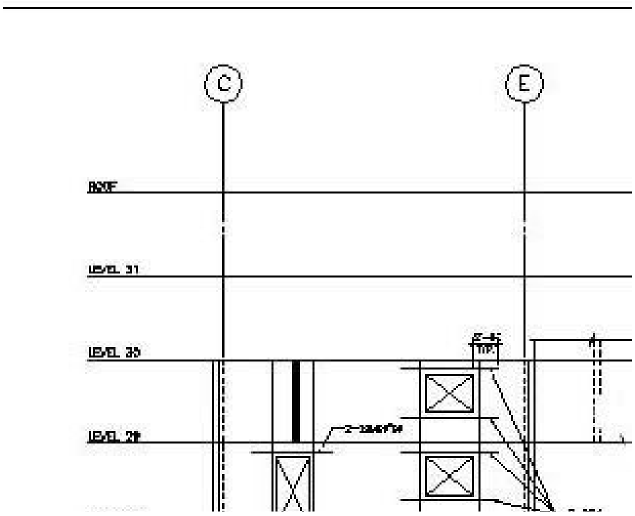
Typical Building Plan - Upper Storey Levels

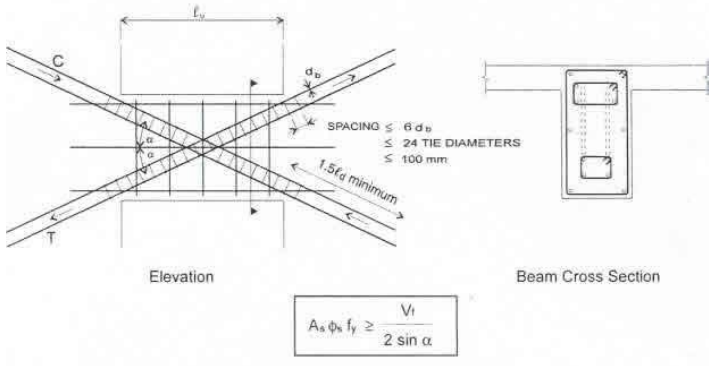


Building Elevation

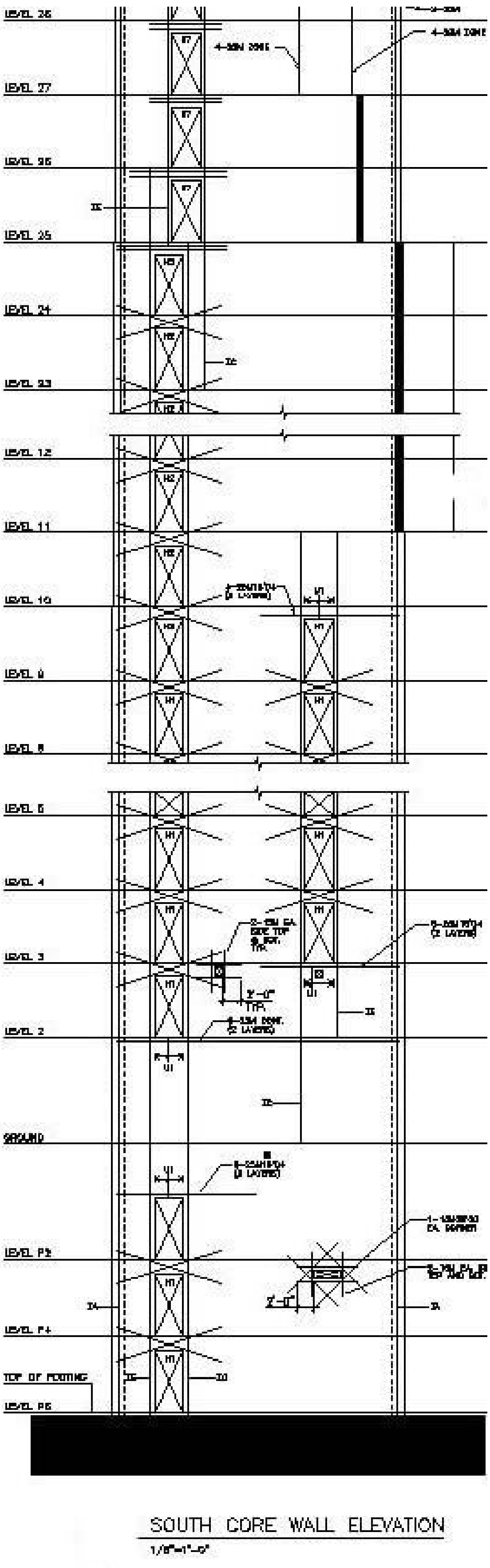


Wall Seismic Detailing (Source: CSA 1994)





Header Reinforcement Detailing (Source: CSA1994)



Elevator Core Reinforcement Details

A Typical Building Under Construction

Socio-Economic Issues

Patterns of occupancy	One family typically occupies one housing unit i.e. apartment. In case of smaller housing units, one person occupies one housing unit. Each building typically has more than 100 housing unit(s). 100-200 units in each building. The number of housing units depends on the size of the building (plan dimensions, number of stories, etc.)
Number of inhabitants in a typical building of this construction type during the day	>20
Number of inhabitants in a typical building of this construction type during the evening/night	>20

Additional comments on number of inhabitants	In general, 300 to 500 inhabitants occupy one building.
Economic level of inhabitants	Middle-income classHigh-income class (rich)
Additional comments on economic level of inhabitants	The two main categories of inhabitants in buildings of this type are: families with lower income who cannot afford to own a single-family house (this is mainly the case with rental buildings) and younger professionals/couples who desire to live in an urban area (this applies both to the case of rental buildings and condominiums). Economic Level: The ratio of Housing Price Unit to middle class annual Income is 3:1.
Typical Source of Financing	Personal savingsCommercial banks/mortgages
Additional comments on financing	
Type of Ownership	RentOwn with debt (mortgage or other)Units owned individually (condominium)
Additional comments on ownership	
Is earthquake insurance for this construction type typically available?	Yes
What does earthquake insurance typically cover/cost	In case of apartment buildings, insurance covers the insured contents. The deductible is usually 5 to 6% of the inured value (depending on the insurance agency), irrespective of the type of the building and the location.
Are premium discounts or higher coverages available for seismically strengthened buildings or new buildings built to incorporate seismically resistant features?	No
Additional comments on premium discounts	
Additional comments section 4	

Earthquakes

Past Earthquakes in the country which affected buildings of this type

Year	Earthquake Epicenter

Past Earthquakes

Damage patterns observed in past earthquakes for this construction type	Buildings of this type have not been subjected to the effects of damaging earthquakes in Canada so far.
Additional comments on earthquake damage patterns	-Shear failures corresponding to diagonal tension, web crushing, or sliding shear (if shear strength is less than flexural strength); - Shear cracking around wall openings; - Buckling of longitudinal bars in boundary regions of plastic hinge zones (in cas

Structural and Architectural Features for Seismic Resistance

The main reference publication used in developing the statements used in this table is FEMA 310 “Handbook for the Seismic Evaluation of Buildings-A Pre-standard”, Federal Emergency Management Agency, Washington, D.C., 1998.

The total width of door and window openings in a wall is: For brick masonry construction in cement mortar : less than ½ of the distance between the adjacent cross walls; For adobe masonry, stone masonry and brick masonry in mud mortar: less than 1/3 of the distance between the adjacent cross walls; For precast concrete wall structures: less than 3/4 of the length of a perimeter wall.

Structural/Architectural Feature	Statement	Seismic Resistance
Lateral load path	The structure contains a complete load path for seismic force effects from any horizontal direction that serves to transfer inertial forces from the building to the foundation.	TRUE
Building Configuration-Vertical	The building is regular with regards to the elevation. (Specify in	TRUE

	5.4.1)	
Building Configuration-Horizontal	The building is regular with regards to the plan. (Specify in 5.4.2)	TRUE
Roof Construction	The roof diaphragm is considered to be rigid and it is expected that the roof structure will maintain its integrity, i.e. shape and form, during an earthquake of intensity expected in this area.	TRUE
Floor Construction	The floor diaphragm(s) are considered to be rigid and it is expected that the floor structure(s) will maintain its integrity during an earthquake of intensity expected in this area.	TRUE
Foundation Performance	There is no evidence of excessive foundation movement (e.g. settlement) that would affect the integrity or performance of the structure in an earthquake.	TRUE
Wall and Frame Structures-Redundancy	The number of lines of walls or frames in each principal direction is greater than or equal to 2.	TRUE
Wall Proportions	Height-to-thickness ratio of the shear walls at each floor level is: Less than 25 (concrete walls); Less than 30 (reinforced masonry walls); Less than 13 (unreinforced masonry walls);	TRUE
Foundation-Wall Connection	Vertical load-bearing elements (columns, walls) are attached to the foundations; concrete columns and walls are doweled into	TRUE

	the foundation.	
Wall-Roof Connections	Exterior walls are anchored for out-of-plane seismic effects at each diaphragm level with metal anchors or straps.	TRUE
Wall Openings		N/A
Quality of Building Materials	Quality of building materials is considered to be adequate per the requirements of national codes and standards (an estimate).	TRUE
Quality of Workmanship	Quality of workmanship (based on visual inspection of a few typical buildings) is considered to be good (per local construction standards).	TRUE
Maintenance	Buildings of this type are generally well maintained and there are no visible signs of deterioration of building elements (concrete, steel, timber).	TRUE

Building Irregularities

Additional comments on structural and architectural features for seismic resistance	
Vertical irregularities typically found in this construction type	Other
Horizontal irregularities typically found in this construction type	Other
Seismic deficiency in walls	- Inadequate amount of vertical reinforcement in the wall end zones (boundary elements); - Inadequate lap splices causing non-ductile flexural failure

Earthquake-resilient features in walls	#NAME?
Seismic deficiency in frames	
Earthquake-resilient features in frame	
Seismic deficiency in roof and floors	
Earthquake resilient features in roof and floors	
Seismic deficiency in foundation	
Earthquake-resilient features in foundation	

Seismic Vulnerability Rating

For information about how seismic vulnerability ratings were selected see the Seismic Vulnerability Guidelines

	High vulnerability		**Medium vulnerability**		**Low vulnerability**	
	A	B	C	D	E	F
Seismic vulnerability class					o	-|

Retrofit Information

Description of Seismic Strengthening Provisions

Structural Deficiency	**Seismic Strengthening**

Additional comments on seismic strengthening provisions	Seismic strengthening of newer buildings of this type had not been performed in practice, as it is considered that these buildings meet the code requirements and would be able to resist the effects of possible earthquakes.
Has seismic strengthening described	

strengthening described in the above table been performed?	No.
Was the work done as a mitigation effort on an undamaged building or as a repair following earthquake damages?	Not applicable
Was the construction inspected in the same manner as new construction?	Not applicable
Who performed the construction: a contractor or owner/user? Was an architect or engineer involved?	Not applicable
What has been the performance of retrofitted buildings of this type in subsequent earthquakes?	Not applicable
Additional comments section 6	

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