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CPCI Technical Information Bulletin: Total Precast Concrete High-Rise Construction and Provincial Building Codes

Canadian Precast /Prestressed Concrete Institute

Contents

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Background

Multi-storey precast concrete buildings have been used throughout Canada for more than fifty years. In a total precast building, the precast concrete floor and roof components are connected to act as diaphragms, and precast concrete shear walls are commonly used as the lateral load resisting system. Precast concrete construction is a prefabricated modular system, where building components are fabricated at certified manufacturing facilities, transported to the construction site, installed into position and connected to form the completed structure.

Is a precast concrete building structure considered a new structural system?

A precast concrete building structure is not a new structural system. Precast concrete multi-storey structures have been constructed for more than fifty years and Chapter 1 of the Fifth Edition CPCI Design Manual (2017) provides a short history of precast concrete in Canada, including multi-storey precast buildings built since the 1960s. Engineering firms across Canada have designed numerous total precast buildings and structures using precast concrete diaphragms and shear walls. Some examples can be found on the CPCI website in the Project of the Month listings http://www.cpci.ca/en/about_us/project_month/

Case Studies of Total Precast Concrete Buildings:

King and Lyle
London, Ontario - September 2019

The King and Lyle Apartments is a 21-storey total precast concrete apartment building in London, ON consisting of 298 one-, two- and three-bedroom units ranging from 32 to 130 square metres for a total building area of 30,100 square metres.

The City of London requested a three-storey high podium that would resemble town houses at street level finished with brick and masonry units of different colours. As double-wythe insulated precast concrete walls are used on the exterior, the effect was achieved with form liners during the casting of the panels. To further reduce the scale at street level, the 21-storey tower was set back on the podium at the third and tenth floors. Click here for more information.

Riverbank Lofts

Cambridge, Ontario

Riverbank Lofts is a 10-storey total precast luxury apartment building located in historic downtown Hespeler.

This total precast building contains large balconies supported off of wing walls and wrapped balconies on the corners supported on columns to act as an extension from the interior suite to the outdoor space and surrounding views. Connections were required to be hidden from the balconies so the wing walls extend to the interior of the building while still providing a thermal break to the interior shear walls. This provides continuity of the thermal barrier for an improved functionality of the building while maintaining a clean finish on the exterior.

Click here for more information.

Maple Avenue Condo

Barrie, Ontario

Maple Avenue Tower is a 17-storey Condo (with a 4-storey precast concrete parking garage and a composite transfer slabs at the 5th floor) and Mixed Retail (Total Precast Building) in Barrie, Ontario. The building features 169 residential units and 247 parking spaces. Precast construction's added value comprises engineering design and detailing of the precast components, as well as forming, reinforcing, casting, transportation and erection.

For this project the precast concrete panel system also provides the exterior architectural finish, creating a subtle stained colour palette look with flat accent areas. An innovative framing method created by the design team allows the wall system to be staggered, providing a look that breaks up the mass of the structure and incorporates the aboveground parking structure into the overall design. The precast concrete erection took only 8 months to complete which accelerated the whole construction schedule.

Click here for more information.

The Belmont Trio

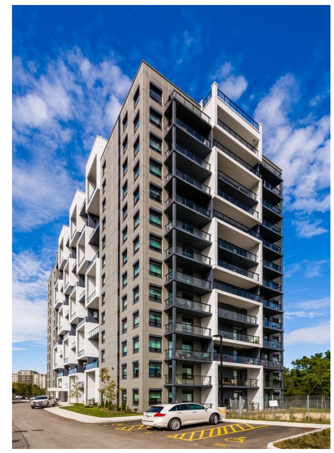
Kitchener, Ontario

The Trio project consists of three apartment buildings with a shared above-ground parking garage in Kitchener, ON.

Building A as a total precast concrete structure was among the first total precast concrete residential apartment towers to feature a perimeter bearing alignment [structural walls aligned parallel to the length of the building slab, exterior walls and one corridor wall].

A perimeter bearing scenario also presents some challenges with structured underground parking, as the internal corridor bearing line usually runs right through the middle of the drive aisle. ABA and the client, HIP Developments Inc., worked around this by designing and constructing a separate total precast concrete above-grade parking structure to serve all of the Trio buildings.

Click here for more information.



Bromley Place

Calgary, AB

Bromley Place, Calgary, AB was the site for a 31-storey apartment building, built in 1977. At the time it was (and remains) the tallest total precast concrete building in Canada.

The ambitious project goals were met principally by the flexibility and reliability of precast concrete production and finishing techniques, creating a strikingly bold design with architectural precast panels. A wide variety of other precast products - including precast beams, columns, covers, stairs and elevator shafts were all incorporated into this virtual showplace for the precast design in 1977. After 43 years the building remains in excellent condition and famously recognized in the Calgary Skyline.

The Paramount Building

San Francisco, United States

Built in 2001 a 39 storey and 128 m high the Paramount building is the tallest precast prestressed concrete framed structure in San Francisco. The building incorporates a novel precast concrete moment resisting frame designed specifically to withstand the severest seismic regions in the United States. The precast concrete components were post-tensioned onsite to provide a very effective seismic resisting frame. The building is an apartment complex, with the lower floors accommodating retail spaces, parking and recreational amenities.

Precast Concrete – CPCQA *Certification Program*

As the benefits of using modular construction are becoming more well-known, the use of multi-storey precast concrete buildings is increasing. Precast/prestressed concrete is a high-performance material and total precast buildings utilize the benefits of this high strength, durable, non-combustible material. Precast concrete buildings also provide a long service life with excellent thermal and acoustical control.

Precast concrete construction offers the benefits of all-weather construction, and site safety is improved with just-in-time delivery and fewer trades on site that reduces risk as compared to other building systems.
During fabrication, precast concrete materials are used efficiently with less waste, and precast manufacturing offers the advantages of plant-fabrication quality control. Precast concrete is produced by manufacturers certified to CSA A23.4 Precast Concrete – Materials and Construction ("CSA A23.4") with more stringent quality control requirements and tolerances as compared to cast-in-place ("CIP") concrete.

Members of the Canadian Precast/Prestressed Concrete Institute (CPCI) are required to be certified by the Canadian Precast Concrete Quality Assurance (CPCQA) Certification Program. CPCI only recognizes the CPCQA certification program as the most stringent certification program in Canada for precast concrete. Visit www.precastcertification.ca for more information.

Precast Concrete Design in Accordance with Provincial Building Codes and CSA A23.3 Design of Concrete Structures

The benefits of precast concrete's prefabrication quality are recognized in CSA A23.3 Design of concrete structures. In fact, CSA A23.3 acknowledges an increased material resistance factor for precast concrete produced in a facility certified in accordance with CSA A23.4 Precast concrete – Materials and construction. The material resistance factor is increased from 0.65 to 0.70.

Do provincial Building Codes and CSA A23.3 specify requirements for a precast concrete building's lateral load resisting system and do these requirements apply to the Provincial or National Building Code seismic ductility-related force modification R_d factors?

Provincial building codes and CSA A23.3 have requirements to design a precast concrete building's lateral load resisting system and the associated seismic force resisting system ("SFRS"). Links to each provincial building code are provided here: [https://canadabusiness.ca/government/regulations/regulated-business-activities/building-codes-regulations-and-related-standards/.](https://canadabusiness.ca/government/regulations/regulated-business-activities/building-codes-regulations-and-related-standards/)

The CSA A23.3 Standard provides requirements for a precast concrete SFRS. A few of the relevant clauses related to precast concrete lateral load resisting systems are noted below:

i. Clause 1.1 indicates the scope of CSA A23.3-19 is to specify requirements for the design and strength evaluation of reinforced and prestressed concrete. Precast concrete elements and structures conform to these categories.

ii. Clause 16.4.2.2 has requirements for in-plane force transfer for both precast floor and wall systems. Precast concrete members and connections for diaphragms and shear walls are to comply with these requirements, so clearly precast shear walls, diaphragms and connections are to be designed to CSA A23.3.

iii. Clause 16.5.2.3 specifies requirements for precast floor and roof diaphragm connections.

iv. R_d is defined in CSA A23.3 as the ductility-related force modification factor, as specified in the National Building Code of Canada. CSA A23.3 Chapter 21 has specific seismic design requirements for structural systems having various R_d values, including precast systems with specific values of R_d, so it is implicit that the R_d values from the Building Code can be applicable to precast concrete systems. If a precast SFRS is designed for the higher seismic loads associated with a R_d = 1.5 structure, the specific requirements for ductility and detailing for higher Rd values (and resultant lower seismic loads) in Chapter 21 do not apply.

Unless Building Code seismicity parameters dictate otherwise, designing the SFRS of a precast concrete building for the higher loads associated with R_d = 1.5 is common in the precast industry. If this is the case, the additional design and detailing requirements of Chapter 21 for higher ductility systems with larger R_d values, and correspondingly smaller seismic loads, do not apply.

v. The specific seismic provisions for ductile and moderately ductile precast concrete structures and their SFRS are provided in Clause 21.8. This clause has specific additional seismic design requirements for ductile and energy dissipating precast concrete lateral load resisting systems (shear walls and frames designed for R_d = 2 and higher). Structures designed to lower R_d values need not comply with these requirements for and Clause 21.6 has the seismic requirements for conventional construction (R_d = 1.5)

vi. For structures having R_d = 2 and higher, Clause 21.9 has specific additional seismic design requirements for precast concrete diaphragms. Structures designed to lower R_d values need not comply with these specific requirements but would still have to satisfy other CSA 23.3 provisions related to diaphragms including the requirements in Chapters 14 and 16.

What is the standard of practice with respect to a precast concrete building and the scope of the precast concrete design services provided by the Primary Structural Engineer (“PSE”) and the Specialty Structural Engineer (“SSE”) undertaking the specialty precast component and connection design?

For precast concrete buildings, generally, the prime consultant and/or Primary Structural Engineer (PSE) is responsible for determining the project’s design loads, designating the primary structural system, undertaking the overall lateral load analysis, and has design responsibility for the cast-in-place (CIP) substructure and foundations.

Drawings and specifications prepared by the PSE provide the required design loads for the precast system, and these drawings typically indicate generic precast concrete connection types and connection locations to provide the design intent.

Typically, the PSE structural drawings are issued for the Building Permit and do not include all of the element reinforcing, bar lists and connection designs of the manufactured precast components and connections. Like structural steel connections that are generally the steel fabricator’s responsibility on steel building projects, the precast manufacturer is typically responsible for the precast concrete connections, including precast connections to CIP substructures or foundations.

Detailed member and connection design are typically not within the scope of the PSE, similar to a pre-engineered steel building. Various precast manufacturers use different types of reinforcing details and connections, and once the project's precast manufacturer is selected, the precast concrete design engineer acting as a Specialty Structural Engineer (SSE) takes responsibility for the specialty precast member and connection design. Connection designs, especially at precast to CIP interfaces are coordinated between the PSE and SSE, and precast connection design is generally undertaken by the SSE. The PSE does not design or detail all the individual connections that are the responsibility of the precast manufacturer and the SSE.

Depending on the roles and responsibilities of the PSE and SSE for a specific project, the SSE may also undertake a lateral load analysis based on design loads provided by the PSE and the specific precast system being designed. Building loads and foundation loads would then typically be coordinated with the PSE.

Responsibilities of the professional structural engineers providing services on a project need to comply with the project's requirements and consider relevant provincial engineering professional guidelines and any requirements of the Authority Having Jurisdiction. The structural information to be shown on the PSE and SSE drawings needs to comply with the project requirements, applicable codes, Standards, and regulations, including CSA A23.3 and CSA A23.4. This is supported by the following clauses in each:

i) CSA A23.3 Clause 5 has specific requirements for information to be provided on drawings and documents for concrete structures, including CIP and precast, prestressed concrete.

ii) CSA A23.3 Clause 16.3 has specific requirements for information that is to be provided in PSE drawings and documents so sufficient information is provided to the SSE for the design and detailing of the precast concrete, and to coordinate the design between the PSE and SSE.

iii) For precast concrete, CSA A23.4 Annex A3.4 has additional requirements for precast shop and installation drawings related to the SSE's scope, which is generally not within the PSE's scope.

iv) CSA A23.4 Annex A and Table A.1 outlines responsibilities of the SSE and PSE for various options of design responsibility as applicable for a specific project contract, and it is not a requirement that the SSE provides complete drawings of the precast member designs and connections unless the project owner is specifically providing this information to the precast concrete manufacturer to directly fabricate, which is not common in buildings.

What are the typical structural analysis methodologies and structural design/analysis software normally used to design precast concrete buildings?

It is common practice to use industry standard structural methodologies and analysis software to design precast concrete buildings, considering the particulars of precast concrete elements and connections. Load effects and member and connection resistances are determined in accordance with the applicable Building Code and Standards.

The method of analysis of a precast concrete building, including computation of deflections and stiffness assumptions, is the responsibility of the professional engineer undertaking the design, and the Provincial Codes and CSA A23.3 provide some guidance and requirements. This is supported by the following:

i) Engineering professionals are expected to design in accordance with good engineering practice, and -in conformance to the provincial code and all other applicable standards such as CSA A23.3. For ultimate limit states the Building Code safety criteria requires the factored resistance equal to or exceed the effect of factored loads. The standard of practice of a reasonably prudent and competent structural engineer performing precast concrete design services is expected to apply the relevant requirements of the provincial codes and CSA A23.3 to accurately calculate imposed axial, shear, torsional and flexural loads on precast concrete building elements, including the lateral load resisting system.

ii) CSA A23.3-19 Clause 1.3, Chapter 9 and Chapter 21 indicate requirements related to structural analysis methods that can be applied to both CIP and precast concrete, as applicable.

iii) Using various analysis methods, professional engineers can consider all loads imposed on a precast concrete structure under the applicable building codes, including loads imposed on the structure by seismic events. Professional engineers can calculate imposed axial, shear, torsional and flexural loads on the precast elements and connections, the CIP substructure and foundation, and anticipated deflections. Like cast-in-place structures, multi-storey precast concrete buildings can be analyzed structurally to determine the effects of the applied loads, including any potentially large shear wall or diaphragm load effects that can occur at lower podium levels. Building deflections can also be calculated based on the precast concrete system being analyzed.

iv) As with any type of structural system, the professional engineer responsible for the structural analysis, including the PSE and SSE as related to their specific scope of work, each take professional responsibility for their specific design responsibilities, including the analysis methods used, and are fully accountable for the correctness, suitability, and appropriateness of their engineering designs to be in compliance with provincial codes and CSA A23.3.

Do provincial building codes require a precast concrete building utilizing conventional concrete shear walls to be limited to a certain height?

For concrete structures such as precast concrete, designed and detailed in accordance with CSA A23.3, the precast building height is not necessarily restricted, depending on the R_d and R_o factors and the seismic parameter $IEF_aS_a(0.2)$. For conventional concrete shear walls with $R_d = 1.5$, $R_o = 1.3$ and a suitable value of $IEF_aS_a(0.2)$, there are no height limit restrictions specified for a multi-storey precast concrete building.

Do provincial building codes or CSA A23.3 require a precast concrete shear wall to emulate a cast-in-place shear wall?

Provincial codes and CSA A23.3 do not generally require precast concrete shear walls emulate cast-in-place shear walls. This is supported by the following:

i) Precast concrete shear walls are typically constructed as individual stacked wall panels, connected together to provide the required lateral load resistance. For typical building structures designed to $R_d = 1.5$, it is common to use horizontal grouted joints, with welded connections or grouted rebar connections joining the panels. CSA A23.3 Clause 21.9 provides requirements for precast shear walls having R_d values 2 or greater. There are no requirements that precast concrete shear walls emulate cast-in-place concrete shear walls. Specific design provisions are provided for R_d values of the structure being designed. Similarly, for $R_d = 1.5$ structures, there are no requirements in Chapter 21 that precast concrete shear walls emulate CIP.

ii) It is not a requirement in CSA A23.3 that a precast shear wall emulate a CIP shear wall, and a precast concrete shear wall with connections can be designed to comply with all the necessary provisions of the Provincial Codes, CSA A23.3, and other applicable Standards.

iii) The 2014 edition of CSA A23.3 added additional requirements for precast concrete SFRS in Clause 21.8, including provisions for ductile shear walls having R_d =3.5 or 4.0. For these higher ductility systems the precast concrete SFRS must comply with Clause 21.5, and this may require precast concrete emulate CIP shear walls in some situations, particularly in plastic hinge regions. However, these requirements do not apply to precast shear walls designed to R_d=1.5.

iv) Precast concrete shear wall joints must be designed to resist the intended loads, similar to horizontal construction joints that occur in CIP shear walls. Precast concrete shear wall panels can utilize vertical rebar and rebar grouted couplers, similar to projecting vertical rebar in CIP wall construction joints, except with the precast panels all bars are coupled at the same joint location. In the United States, some American seismic Code provisions (that are not Code requirements in Canada) may require precast concrete emulate monolithic CIP construction, and rebar coupler manufacturers were able to demonstrate proprietary rebar grouted couplers can perform satisfactorily as noted in ACI 550.1R "Guide to Emulating Cast-in-Place Detailing for Seismic Design of Precast Concrete Structures". This US document can provide justification for detailing precast concrete jointed structures with mechanical rebar splices in order to achieve monolithic construction and emulate CIP in order to potentially satisfy the US Code requirements. However, it is not a requirement in Provincial codes or CSA A23.3 that precast concrete shear walls emulate CIP shear walls, especially for R_d=1.5 structures.

Does CSA A23.3 require precast concrete buildings be designed to provide structural integrity, including precast-to-precast connections and connections between the precast structure and CIP?

Precast concrete buildings designed to CSA A23.3 are to be designed to provide structural integrity, including precast-to-precast connections and connections between the precast structure and CIP. This opinion is based on the following reasons:

i) Precast concrete components and connections must be designed to resist the intended loads in accordance with the provincial codes and CSA A23.3.

ii) As a minimum, precast concrete building component must be connected for structural integrity to effectively tie precast structural elements together in accordance with CSA A23.3 Clause 16.5. Clause 16.5 has specific requirements for structural integrity in precast concrete structures. Clause 16.5.3.1 has specific requirements for multi-storey precast concrete structures more than three-storeys in height.

Summary
Multi-storey precast concrete buildings are not a new structural system, and precast concrete buildings can be designed to comply with the Provincial codes and CSA A23.3 requirements. Professional engineers are to hold paramount the safety, health and welfare of the public and it is expected a professional practice would ensure the precast concrete design comply with the applicable codes, standards and regulations.

Disclaimer: This report provides a brief summary on the use of precast structural systems for buildings and is not intended to replace professional expertise. This report should be used as information only and the structural systems and the overall design of the building must be in accordance with local building codes, standards, and bylaws. The design must be reviewed and approved by professional engineers knowledgeable with precast concrete systems.

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