The buildings we construct reflect strongly the values, needs and aspirations of the culture that we live in. All our notable new works are built upon a firm base of past experience using current science and technology. In the Canadian construction market, cladding materials (masonry, glass, metal, stone, stucco, tile and precast concrete) compete vigorously for a share of the $35 billion (Canadian) being spent annually on building construction.

Architectural precast concrete encompasses all precast concrete units employed as elements of architectural design. Such units can be structural, loadbearing by themselves, act as permanent formwork for cast-in-place concrete or be mainly decorative.

The ability of concrete to flow and assume the contours of its mold, combined with the enormous number of finishes and textures which can be produced on the face of architectural precast concrete panels, gives a designer tremendous freedom to select the color, texture and shape he/she wishes to impart to his/her building.

High quality precast concrete produced in a plant under controlled conditions is extremely durable and resistant to weathering and abrasion. The effects of weathering, dirt accumulation and air pollution can be minimized by careful consideration of how rainwater will flow down the face of a building. The provision of drips, channels and scuppers can be used to direct this flow. Penetrating sealers are often used to repel water from absorbent surfaces, particularly where soft aggregates and a light colored matrix is used.
The adding of large amounts of insulation to new buildings following the energy crisis in the 1970s can be largely ineffective if pressures generated by wind, mechanical systems and stack effect cause air to exfiltrate and infiltrate the exterior wall. The 1985 National Building Code made air barriers mandatory on virtually all new buildings.

Systems assembled at the site are often ineffective due to poor workmanship and a lack of coordination among the trades. Starting in 1972, the development of panelized wall systems incorporating a vented exterior skin of precast concrete, brick or stone, air gap, insulation and structural precast concrete backing have been successfully used in Canada to reduce cladding costs and build a better wall (Fig. 1). Other benefits include fast enclosure of a building to shield other trades from bad weather, reduced construction time and thinner wall construction to provide more rentable space.

The precise sizing of openings and the incorporation of window fastenings and gaskets into architectural precast concrete panels will speed the installation of windows and cut glazing costs. On some projects the complete frame and window assembly is cast into panels at the factory.

**BASIC PANEL TYPES**

While there is a bewildering variety of architectural precast concrete used everywhere, most building applications can be broken down into the following categories:

(a) **Spandrel and Fascia Panels.** These panels are placed to provide horizontal bands around a structure. They may be cast flat, have returns at the top and/or bottom and be heavily sculptured.

(b) **Column Covers and Mullions.** These panels are usually narrow and run vertically up a structure. They are often used to hide the structural columns and may completely surround them at the ground level.

(c) **Window Panels.** These panels may be flat or be heavily sculptured. They may contain a single opening or a series of windows. They are either one story in height and made as wide as possible or cast narrower to span vertically for two to four floors.

(d) **Solid Panels.** These panels are used to dress up and enclose any blank wall. Properly designed, these panels can be used to support vertical loads and may be used as diaphragms to resist lateral forces on a structure.

**PANEL SIZES**

Typical panels used for a project should be drawn as large as is practicable. Since many of the manufacturing, handling and erection costs are inde-
pendent of the size of a piece, making panels larger can substantially reduce the cost. To determine the optimum size of architectural panels, a close collaboration between the designers and precast supplier is required. The trend over the past 20 years has been to increase both the size and weight of architectural precast concrete panels.

The size of the cranes in a precast plant and yard is the first constraint. Making the panel thinner will reduce the weight, but care should be taken to avoid cracking and warpage during...

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### Wall Systems

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<thead>
<tr>
<th>Wall System</th>
<th>Description</th>
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<tbody>
<tr>
<td><strong>(a) Conventional Wall</strong></td>
<td>INTERIOR MEMBRANE DIFFICULT TO MAINTAIN OVER THE ENTIRE WALL SURFACE</td>
</tr>
<tr>
<td></td>
<td>DEW POINT FALLS WITHIN THE INSULATION ON THE INTERIOR OF THE BUILDING</td>
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<td>AIR BARRIER DEPENDS ON THE CAULKING BETWEEN PRECAST PANELS WHICH HAS AN AVERAGE LIFE OF 5 YEARS</td>
</tr>
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<td>WALL MUST BE MAINTAINED TO BE EFFECTIVE</td>
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<tr>
<th>Wall System</th>
<th>Description</th>
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<td><strong>(b) Sandwich Wall</strong></td>
<td>WARM CONCRETE INNER WYTHE FORMS THE VAPOUR BARRIER</td>
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<td>INTERIOR AND EXTERIOR CAULKED JOINTS ARE SUBJECT TO PRESSURE DIFFERENCES AND PENETRATION BY WIND DRIVEN RAIN</td>
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<th>Wall System</th>
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<tr>
<td><strong>(c) Rain Screen Wall</strong></td>
<td>CAVITY IS VENTED TO THE OUTSIDE BY OPENINGS IN THE OUTER LAYER</td>
</tr>
<tr>
<td></td>
<td>EQUALIZED PRESSURE ACROSS THE OUTER LAYER PREVENTS WIND DRIVEN RAIN FROM ENTERING THE CAVITY</td>
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<td></td>
<td>ENTIRE WIND LOAD IS TRANSFERRED TO THE INNER WYTHE WHICH IS THE AIR BARRIER</td>
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Fig. 1. Typical wall systems incorporating architectural precast concrete wall panels.
only to resist wind loads. It is being recognized that the rigidity of the panels together with the interconnection to the building frame adds significant stiffness to the building structure. Methods of analysis to quantify this resistance and use this benefit in the overall building design are being developed.

MOLDS

General

Together with the freedom available through use of architectural precast concrete, considerable discipline must be employed by the architect to produce an economical design.

Forms to produce complex architectural shapes are extremely costly to make. However, if a large number of pieces can be produced in each mold, then the cost per square meter can be reasonable and affordable. One way to assist in this endeavor is to use the master mold technique (Fig. 2). Here, all or a large number of panels can be produced from a single mold built to accommodate the largest piece and variously subdivided to produce the other sizes required. Whenever possible, the largest pieces are produced first to avoid casting on areas worn and damaged through placing and fastening the side form bulkheads.

Details of individual panels should always be left to the precaster. Elevations, wall sections and details of each different type of wall panel should be drawn by the architect. When using large pieces, if the appearance of smaller panels is desired for aesthetic reasons, false joints (rustications) can be used to achieve this effect (see Figs. 3 and 4).

The number of forms required for a job will be determined by the time allowed to complete the job and by the facilities available. Casting can usually proceed during most of the erection process if the panels are manufactured in
the correct sequence. Keeping this in mind, a creative designer can produce an intricate design using variations of a few basic shapes (Fig. 5). As building configurations are tending to get more complex, producers are having to cope with a greater variety of shapes and sizes. Computerized drafting techniques are increasing the speed and accuracy of producing layout drawings and the individual details of each piece.

**Mold Materials**

1. **Wood** — Wood is the cheapest and most commonly used material for the manufacturing of molds. Sheets of 1200 x 2400 mm x 20 mm (4 x 8 ft x 3/4 in.) thick plywood are used for the construction of most molds and side rails, with two or more layers laminated together where added stiffness is required. The plywood can be purchased with a smooth plastic finish or a resin finish can be applied after fabrication of the form. For heavy use or complex shapes, a layer of fiberglass cloth impregnated with resin is applied to the surface of the mold. Care in sanding the form is required to avoid gouges which will show up on the surface of the panel. For large flat surfaces, a large diameter disc sander works well. Many plants have a large flat casting area set up to make assorted flat pieces using adjustable side rails. A standard wood mold will produce about 30 panels before it wears out. A stronger version, with careful stripping, can be used for 60 or 70 castings.

2. **Steel** — Steel molds are stronger, are much more expensive than wooden forms and can produce hundreds of
Fig. 3. Total envelope mold showing minimum positive draft.

Advantages:
— Accurate panel dimensions as side forms are fixed throughout production.
— Reduced labor costs as side forms are not removed and replaced each pour.

Disadvantages:
— Slightly wider joint required between panels due to draft on side forms.
— Cannot penetrate side form with lift loops.
— Must strip panel flat from mold and rotate to vertical position later.

castings. Assembling and welding thin plate sections without warpage is an art. They should be manufactured by firms who specialize in this work. Seams should be disguised and any grinding of the surface, unless extremely well executed, will show on the face of a precast panel. Steel forms can be made very accurately and are ideal for producing standardized components which will be produced on demand over a period of years, complex shapes with much repetition and deep sections which must resist a large hydraulic head of concrete. Steel forms can be made self stressing to allow prestressed reinforcement to be used through the panels.

(3) Concrete — Concrete molds are durable and relatively inexpensive to make, particularly when a number of nearly identical forms can be cast from a single master mold. This will permit production to start sooner. Avoid concrete forms for shapes which have sharp corners. These corners get chipped and broken and can be very difficult to repair.

(4) Polyurethane — This new mold material is being used to cast some very intricate shapes. Two-part polyurethane is cast against a wooden master mold. The resulting material has a 50 to 60 durometer hardness. The forms are extremely durable and are capable of producing extremely fine detail for large numbers of casts with virtually no wear.

(5) Form Liners — Standard manufactured form liners can be purchased in a variety of textures to insert in forms to add a profile to all or part of the surface of a panel. There are two types, a rigid PVC plastic material and a soft pliable
urethane material which can be purchased loose or prebonded to a plywood backing.

**CONCRETE**

**Aggregates** — The selection of aggregates ranges from economical local river gravel and crushed limestone to very expensive dolomite, marble, quartz and granite materials. Practically any color or size anyone could ask for is available from aggregate brokers.

Manufactured sand crushed from a matching coarse aggregate is very expensive and not always available. If possible use white or gray sand at a fraction of the cost.

The aggregate supplier should determine that the aggregates and sand selected are sound, stable and free of organic impurities. In particular, avoid any aggregates containing iron pyrite which can bleed and stain the surface of panels for years.

**Face Mixes**

For materials alone, architectural concrete mixes can range from about $55/m³ ($1.56/ft³) using local aggregates and gray cement to $300/m³ ($8.49/ft³) or more when white cement, white silica sand, quartz or granite coarse aggregate and pigments are used. To reduce costs when expensive mixes are specified for flatwork, precast manufacturers place a thin layer of this face mix on the form (Fig. 6).

The face mix should not be thinner than twice the diameter of the coarse
aggregate. The face mix can be compacted with internal form vibrators or external air driven grid vibrators. The face mix is heaped up at the side form where the edge of the panel is exposed on a building. After placing the reinforcing cage, a backup mix using normal weight concrete is poured with a minimum of vibration and not later than 1½ hours after the face mix to ensure an adequate bond to the face mix.

The actual mix design used should be determined by the precaster. At least 1060 kg of coarse aggregate per cubic meter (66 lb/ft³) is required to have good distribution both on the face of a panel and on any returns that are 90 degrees to the face.

Cost Comparison (Concrete Ingredients Only)
Assumed prices (Canadian dollars):
Gray cement ..................$110/t
White cement ..................$240/t
Gray local sand .................$6/t

Fig. 5. Examples of face and back forming for deeply sculptured panels.
WELDED WIRE MESH

Fig. 6. Method for casting deep returns on panels.
Advantages:
— Saves face mix.
— Quality finish achievable as both faces of panel are cast flat in same manner.
— Back forming not required.
Disadvantage:
— Two pours are required to produce each panel.

White silica sand ..................$77/t
Local limestone coarse aggregate ..................$9/t
Local pea gravel coarse aggregate ..................$10/t
Dolomite or marble coarse aggregate ..................$35/t-$60/t
Crushed quartz or granite coarse aggregate ..................$65/t-$100/t
Pigment ..............................................$2.50/kg

Typical mix per cubic meter:
Cement ..............................................360 kg
Sand ..............................................800 kg
Coarse aggregate ........................................1100 kg
Pigment if required
2 to 5 percent of mass of cement

Note: 1 ton = 0.907 t; 1 lb = 0.454 kg.

For a 40 mm (1.6 in.) thick layer of face mix (materials only):
Basic gray mix ..................$2.20/m²
Change gray cement to white cement ..................add $1.90/m²
Change gray sand to white silica sand ..................add $2.30/m²
Change limestone coarse aggregate to medium priced quartz or granite coarse aggregate add $3.00/m²
Use 5 percent pigment in mix ..................add $1.80/m²

Note: 1 sq ft = 0.0929 m².

These figures are included to give the designer a feel for the costs involved by using different ingredients in the mix. The numbers do not include plant labor, wastage factor, handling charges, mixing charges, overhead or profit.

SURFACE FINISHES

(a) Smooth Formed — Not all producers will attempt this finish. The quality and maintenance of the formwork must be outstanding. The use of white cement will give better color uniformity
than gray cement. This finish is subject to visible crazing, a network of tiny non-structural surface cracks that penetrate only as deep as the thin layer of cement paste at the surface of a panel. To reduce the possibility of crazing, use a minimum amount of cement and water in the mix and consolidate well.

(b) Acid Etched — This finish is achieved by using a muriatic acid solution to dissolve away the surface cement paste to reveal the sand and, with further etching, the coarse aggregate. The harder materials (granite, quartz, silica, etc.) will not react with the acid and will look bright and sparkle when exposed. The finish is best suited to the production of small pieces because of the difficulty in maintaining uniformity on large flat areas. Concentrations of cement paste and under and over etching of different parts of a panel can cause streaking. Panels are normally finished by placing them face up in the yard, wetting the surface, applying the acid with stiff bristle brushes, rinsing and removing to storage racks. Other methods of dipping the panels in large acid baths and of spraying the acid on the panels using specially designed stainless steel pumps, tanks and nozzles have been successfully used.

c) Sandblasted — Sandblasting is the most popular and normally the least expensive way to add a texture to precast concrete panels. The depth of a light sandblast made with a single pass of the jet stream is extremely difficult to control, particularly when the panels are sculptured. A medium sandblast which removes about 3 mm (⅛ in.) of the surface will mainly reveal the sand and cement paste. When the coarse aggregate is exposed by deeper sandblasting, the surface of the stone will be permanently frosted by the action of the abrasive. This dulling action will lighten the color of dark aggregates and will vary in degree depending on the hardness of the stone. Portions of a panel can be left unblasted by making a shield of wood or sheet metal to fit over the panel and cover those areas.

(d) Surface Retarded — This is a non-abrasive process which is very effective in bringing out the full color and texture of the coarse aggregate. After the forms have been coated with a mold release, one or two coats of a chemical retarder are painted or sprayed on to the form surfaces where the aggregate is to be exposed. The strength of the retarder is selected to vary the depth of exposure, normally one-third to one-half the diameter of the coarse aggregate. After stripping the retarded cement paste covering, the stone is removed using a high pressure water spray. It is advisable to match the color or tone of the matrix to that of the stone so minor segregation of the aggregate will not be noticeable. This finish, when used with closely packed, hard, stable aggregates, is highly resistant to staining from dirt and air pollution. It is also the easiest finish to repair when damaged.

e) Water Washed — Water washing normally refers to exposing the aggregate by brushing away the surface cement paste on unformed surfaces or to surfaces where the mold has been removed prior to the hardening of the concrete. When an exposed aggregate finish must return on the cast up face of a panel, the top surface may be seeded with coarse aggregate which is worked into the concrete with a trowel. Retarder sprayed on to the fresh concrete is often used to assist in removing the cement paste.

(f) Other Finishes — While the above described finishes are the most popular, many other finishes can be applied to the surfaces of architectural precast panels. Panels may be bushhammered using electric or pneumatic hammers to fracture the surface of the concrete. Ribs formed on the surface of panels can be randomly broken to give a very appealing effect. Some companies have the equipment and capability to hone and polish the surfaces of flat concrete panels
to various degrees. The entire panel can be done or the finish applied only to certain raised flat areas of a piece.

(g) Veneer Facings — Precast concrete units faced with brick, tile and natural stone such as marble, granite and limestone have recently become extremely popular with architects. The panel can be completely covered or bands or strips of brick or stone can be embedded in a panel to form feature strips. Design values and procedures for manufacturing veneer faced precast concrete panels are given in Chapter 6, CPCI Metric Design Manual, Second Edition.

(h) Combined Finishes — Combinations of finishes using the same concrete mix are often produced. Some of the combinations are smooth and sandblasted, smooth and retarded, retarded and sandblasted, and retarded and acid etched. When a retarded texture is combined with another finish, the area to be retarded should be outlined with a raised demarcation strip placed in the form to prevent the retarder from spreading to the other part of the form. It is virtually impossible to selectively acid wash only a portion of a panel. This treatment should be superimposed over other finished areas.

Using two different facing mixes in the same panel is an expensive procedure. The first mix is poured within an area bounded by a raised wood strip the thickness of the face mix. Within 1 1/2 hours the form surface around the first pour is carefully mopped clean and the second mix is poured and vibrated.

**PANEL REINFORCEMENT**

To facilitate casting panels on a daily cycle, most precasters prefabricate cages in a steel assembly area from one to several days before casting. Welded wire fabric is usually chosen as the main reinforcement with reinforcing bars added by the designer to suit loading conditions or to strengthen the panel around openings. Mesh can be custom ordered and made to the exact size needed for large jobs with much repetition. Otherwise, flat sheets of two standard sizes are kept on hand and cut and bent to suit.

A single layer of mesh is placed at the center of panels below 150 mm (5.9 in.) thick and two layers, one in each face, are placed at the center of panels 150 mm (5.9 in.) and thicker. For mesh and bars No. 30 and smaller, clear concrete cover to reinforcement should not be less than 20 mm (0.79 in.) [30 mm (1.18 in.) where panels are exposed to deicing salts].

In thin panels where this cover cannot be maintained, the reinforcement should be galvanized. Galvanized mesh is available as a stock item from manufacturers (currently at a 36 percent premium over regular mesh). Galvanized rebar is double the price of ordinary reinforcing bars.

The detailed design of architectural panels is covered in Chapters 3 and 6 of the CPCI Metric Design Manual, Second Edition.

**CONNECTIONS**

It is the practice of Canadian manufacturers of architectural precast concrete to install their own products and systems at the jobsite. They, therefore, realize that connection design is critical to the economical and safe use of their products. Poorly designed connections can reduce the normal rate of installation to half. The gap between the back of a panel and the supporting structure should be 25 to 40 mm (1 to 1.6 in.) to allow for construction tolerances.

To simplify analysis, employ only two load support connections for each panel. In addition, supply enough lateral support connections in each piece to prevent panel rotation and to resist wind pressure, wind suction and panel bowing. For non-loadbearing panels the connections should allow for thermal
movements without affecting adjacent panels.

Connections should be of simple construction, be placed in an accessible location and allow for an adjustment of 25 mm (1 in.) in three dimensions from the design location. Standardize designs and, when panel weights are within a tonne of each other, size the connections for the heaviest panel and use the same one for all similar conditions.

Many producers favor the use of levelling bolts for loadbearing connections and threaded rods for lateral connections to permit fast temporary fixing to the building (Fig. 7). The final adjustment can be made without the use of the erection crane.

Detailed procedures for the design of connections are presented in Chapter 4 of the CPCI Metric Design Manual, Second Edition.

Fig. 7. Examples of connections — Connections such as these allow three-way adjustment and fast release of the erection crane.
TRANSPORTATION

Most precast units are transported on standard 2.4 m wide x 12.2 m (8 x 40 ft) flat deck trailers with drop deck trailers used for some taller units. Standard A-frames and finger racks are used to support panels vertically during shipping. Special custom frames are fabricated to transport sculptured panels. Panels are chained tight to the trailers. Special care must be taken to prevent the cracking of panels by selecting the correct blocking points and to prevent marring of the concrete surfaces through the use of nonstaining softening material and corner protectors.

ERECTIOIN

Safe and efficient erection procedures are the key to the economical use of precast concrete architectural panels. It is strongly recommended that the precast manufacturer take contractual responsibility for the installation of the precast concrete work either by use of his own forces or by an independent erector hired and controlled by him. This will help to insure a quality job, better adherence to schedules and a minimum of disputes over split responsibilities.

The expense of an idle crane and crew can run from $4000 to $5000 per working day. It is imperative, therefore, that the erector perform a field check prior to starting the installation of the precast units. This will determine whether the location, line and grade of the supports for the panels is within the given tolerances and that adequate clearance between the building structure and panels has been maintained. Also, a field survey to establish an offset line of the building face, elevation marks and panel joint locations should be marked at each floor using the contractor's control points, bench marks and centerlines. Erection should not proceed until the

Fig. 8. Industrial Life Tower, Montreal. Architect: Tolchinsky and Goodz. This insulated rain screen double window panel contains 39 pieces of granite veneer fastened to the concrete backing by stainless steel anchor clips.
contractor has corrected any deficiencies in the work.

Mobile cranes are usually selected to install architectural precast panels on low or medium-sized buildings which have adequate access around the site at the ground level. Cranes with dual hoist drums allow panels shipped on their side to be rotated in the air and placed directly on the building. Telescoping boom hydraulic cranes are useful for installing panels under overhanging structural elements. Often the employment of a large crane will justify its additional expense by reducing crane movement about the site and allowing the panels to be erected at each floor before moving to the next level. This
Fig. 10. Rowes Wharf, Boston. Architect: Skidmore Owings and Merrill. A wood form is used to cast these complex curved window units. Eight stripping points connected to rolling blocks on the spreader beams are used to gently remove each panel from the mold. Note the cast in inserts for attaching the window frames.

Fig. 11. Rowes Wharf, Boston. Architect: Skidmore Owings and Merrill. The finished panels are chained to the truck, ready for shipment. The raised ribs are lightly sandblasted. Urethane molds were used to achieve the fine detail on the inserts on the lower panel face.
Fig. 12. John H. Winters Headquarters Building, Austin. Architect: J. P. J. Architects. Custom-made steel stands were used to safely transport spandrel panels back to back on flat deck trailers. A spreader beam with C-hooks bolted to diaphragms cast on the back of the panels is used to lift the panels into position. After an initial learning period, panels were erected at a rate of 24 per day using an eight man crew and a 160 megagramme crane.

avoids moving men, materials and equipment up and down the building.

Figs. 8-20 show various applications of architectural precast concrete in Canada.

CONCLUSION

The fabrication and installation of custom architectural precast concrete panels is a thriving industry in Canada. Forty plants spread across the country produce these products. These companies routinely combine high levels of craftsmanship with amazing ingenuity to transmit a designer’s wishes into concrete. At the same time, the marketplace insists that they give due regard to economy and close adherence to project schedules.
Fig. 13. Hyatt Hotel, Greenwich. Architect: Kohn Pederson Fox Associates. These ornate columns were produced by casting the various cylinders vertically in plastic lined molds. After stripping and acid washing, the cylinders were placed in a horizontal form and the joining blocks were cast in a separate pour. Prior to stripping, the columns were post-tensioned over their full length using deformed prestressing bars.

Fig. 14. Hyatt Hotel, Greenwich. Architect: Kohn Pederson Fox Associates. Forty-two 14.6 m (48 ft) tall columns support a glass roof which encloses the atrium. This area serves as the interior focal point for the design.

Fig. 15. Hyatt Hotel, Greenwich. Architect: Kohn Pederson Fox Associates. This photograph shows the panel reinforcing and back forming for the production of six Tuscan arches for the project. The pieces are so complex it took five weeks and 600 man hours for the carpenters to build this wooden mold.
Fig. 16. Hyatt Hotel, Greenwich. Architect: Kohn Pederson Fox Associates. A finished Tuscan arch is ready for shipping. Notice the extremely fine detail reproduced from the formwork.

Fig. 17. Hyatt Hotel, Greenwich. Architect: Kohn Pederson Fox Associates. The exterior of the hotel was designed to have the appearance of an English manor house. The buff-colored precast units were acid etched to closely resemble Indiana limestone.
Fig. 18. Walter McKenzie Hospital, University of Alberta Health Sciences Centre, Edmonton. Architects: V.H.S.C. Architects Group. This trailer is specially equipped to transport two 18 t (20 tons) 3.8 m (12.5 ft) high, 4 m (13.1 ft) long spandrel panels. The center of the panel is faced with red brick. The sculptured top and bottom sections have a lightly retarded surface finish. Panels are a full rain screen design with a 12 mm (0.5 in.) air gap, 64 mm (2.5 in.) rigid insulation and a 100 mm (4 in.) concrete backing.

Fig. 19. Walter McKenzie Hospital, University of Alberta Health Sciences Centre, Edmonton. Architects: V.H.S.C. Architects Group. Brick faced spandrel panels provide a striking exterior facade for this hospital building. A mechanical space with walkways behind the panels and above the ceiling is used to deliver heating, air conditioning, electrical power and gases to all parts of the hospital.
Fig. 20. Regina City Hall. Architect: Joseph Pettick. This beautiful 17 story office structure uses sculptured panels faced with a white quartz exposed aggregate. The exterior panels are loadbearing window units which support prestressed beams and double tee floor and roof slabs. The vertical look is achieved by facing the panels with opaque glass between the windows.

REFERENCES

3. Precast Concrete - Materials and Construction - CAN3-A23.4-M78, Canadian Standards Association, Ottawa, Canada.