

BC CARPENTER APPRENTICESHIP PROGRAM **LEVEL 4**

Line G: Concrete Formwork

Competency G-8: Install Specialized Formwork

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Symbol Legend



Electric shock: This icon is a reminder for potential electric shock.



Explosive: This icon is a reminder for a possibly explosive situation.



Flammable: This icon is a reminder for a potentially flammable situation.



Important: This icon highlights important information.



Poisonous: This icon is a reminder for a potentially toxic/poisonous situation.



Resources: The resource icon highlights any required or optional resources.



Safety gear: The safety gear icon is an important reminder to use protective equipment.



Self-Test: This icon reminds you to complete a Self-Test.

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Program Outline

Line B – Documentation and Organizational Skills

B-2 Use Construction Drawings and Specifications

B-3 Interpret Building Codes and Bylaws

B-4 Plan and Organize Work

Line D – Survey Instruments and Equipment

D-2 Use Site Layout Equipment

Line F – Site Layout

F-2 Prepare Building Site

Line G – Concrete Formwork

G-8 Install Specialized Formwork

Line H – Wood Frame Construction

H-5 Build Stair Systems

H-6 Build Roof Systems

H-7 Build Specialized Framing Systems

H-8 Perform Renovations and Additions

H-9 Build Timber and Engineered Wood Construction

H-10 Build Decks and Exterior Structures

Line I – Finishing Materials

I-1 Install Roofing Materials

I-5 Install Interior Finishes

I-7 Install Interior Floor, Ceiling and Wall Systems

Line J – Building Science

J-1 Control the Forces Acting on a Building

Competency G-8: Install Specialized Formwork

Innovations in technology have provided the construction industry with many methods for constructing concrete buildings. Many of these new methods require specialized formwork.

Carpenters must keep up to date with changes in technology and safety regulations for these specialized formwork methods.

Learning Objectives

When you have completed the Learning Tasks in this Competency, you should be able to:

- identify the requirements for architectural formwork
- build architectural formwork

Competencies

Written: “Install specialized formwork”

You will be tested on your knowledge of terminology, construction methods, and uses of specialized formwork.

Practical: You will construct specialized formwork such as frustums and curved walls.

LEARNING TASK 1

Describe Architectural Formwork

Because concrete can be formed into almost any shape, some of the most beautiful buildings in the world are made from concrete. *Architectural concrete* is concrete that is left exposed to view after the building is finished (Figure 1). Most commercial buildings have some architectural concrete. Architectural concrete requires special attention to the design and construction of the formwork. Residential concrete is usually buried below the ground. The appearance of residential concrete is not as important as the concrete's strength and position.

Architectural concrete can be plain or feature decorative finishes such as texture, colour or stamping. These finishes are created using special forming material, form liners, exposed aggregate, tooling, sandblasting or grinding.



Figure 1 — Examples of textured concrete and decorative precast architectural concrete

Since the concrete surface is also the finished surface, architectural concrete can be an economical choice. Most concrete surfaces require very little maintenance, meaning maintenance costs are usually low as well.

Architectural Formwork

The requirements for the formwork for architectural concrete are quite stringent. The formwork must be carefully built to produce flat and true surfaces. Even the slightest defect in the formwork will be reproduced on the surface of the finished concrete.

Some of the architectural requirements are:

- smooth, flat surfaces
- uniform colour and texture of finished concrete
- clean, straight lines
- tie holes spaced evenly
- no honeycomb or bug holes

Maintaining flat, smooth surfaces for cast-in-place concrete is difficult due to the flexibility of standard 19 mm ($\frac{3}{4}$ ") thick plywood form sheathing. The sheathing spans from one stud, or support, to another. The spacing of these supports and the pressure of the fresh concrete will determine the amount of deflection.

In Canada, architectural concrete is usually designed based on CSA standard CAN/CSA A23.1, which allows for a maximum deflection in formwork of 1/400. This requires narrow stud spacing and low rates of placement of concrete. In the United States, the American Concrete Institute (ACI) uses 1/360 as a ratio for deflection. Some architects require the contractor to cast a sample panel or test block of concrete that, after the architect approves it, will be used as a standard finish that all of the concrete for the job must meet.

Form Sheathing and Liners

Specialty form plywood is normally used for forming smooth-surfaced architectural concrete. Form plywood has a paper-coated overlay facing covered with plastic or resin to give a blemish-free surface to the concrete. Typically it's made with seven plies and is about 20% stronger than standard plywood of the same thickness. Edges of the sheets are sealed to guard against water absorption that would cause swelling.

Steel forms or liners are very strong and can be used to minimize the number of joints and to give a smooth surface. Most forms used in precasting operations are made from metal in order to give a uniform surface and to stand up to many reuses. Fibreglass-reinforced plastic (FRP) is used for forms when unusual shapes are desired. FRP gives concrete a very smooth surface.

Form liners are used inside the wall forms on the exposed side of the concrete (Figure 2) to produce smooth surfaces or to create textures or designs. Form liners are available with a variety of stock textures. Custom form liners can be made on-site from a variety of materials. Many of these materials require a bond-breaking coating so that they can be removed after casting.

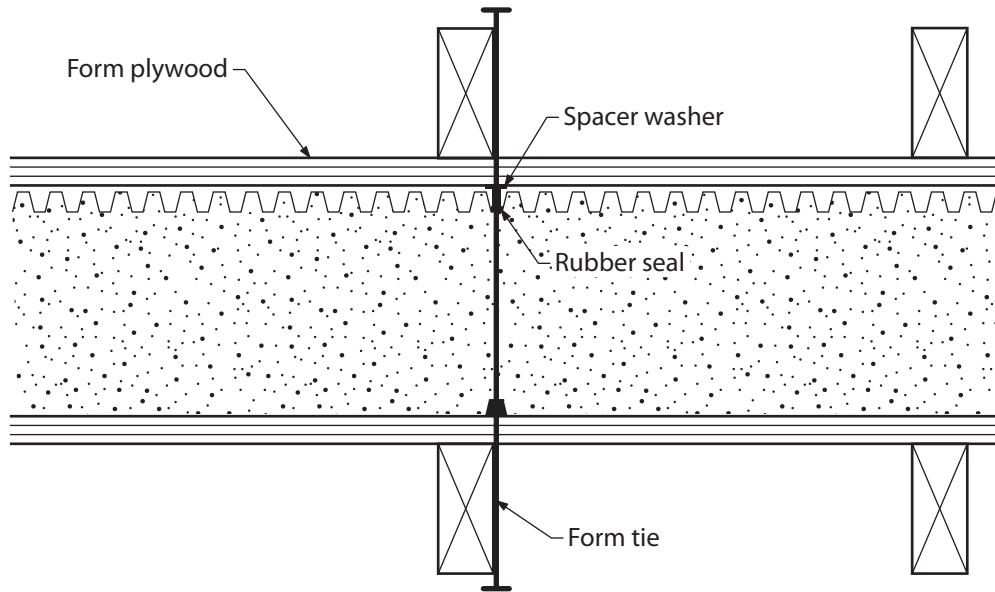


Figure 2 — Plan view detail of a wall form liner

Photo engraving by a computer numerical control (CNC) cutting machine can create engraved panels for use as form liners (Figure 3).



Figure 3 — Finishes achieved with form liners

Exposed Aggregate, Tooling, Sandblasting and Grinding

Architectural concrete finishes can be created using several other methods besides specialized forming. Vertical or horizontal exposed aggregate finishes can be achieved using gap-graded aggregate and a retarder. After the concrete is sufficiently strong to support itself, the surface is washed to remove fines and cement paste, leaving an exposed aggregate finish (Figure 4). Horizontal exposed aggregate finishes can also be created by seeding the surface with aggregate.



Figure 4 — Exposed aggregate vertical finish

Tooling with a bush hammer will give a rough texture and can be used to hide form seam lines and other minor defects. Sandblasting will give an etched look. A broken (fractured) fin finish can be achieved with a form liner and then by hammering (tooling) to create the look of broken fins (Figure 5).



Figure 5 — Broken fin (fractured) finish

Grinding will smooth the surface and can be followed up with polishing (Figure 6). This can give a cut-stone look and a mirror-like finish when a sealer is applied.

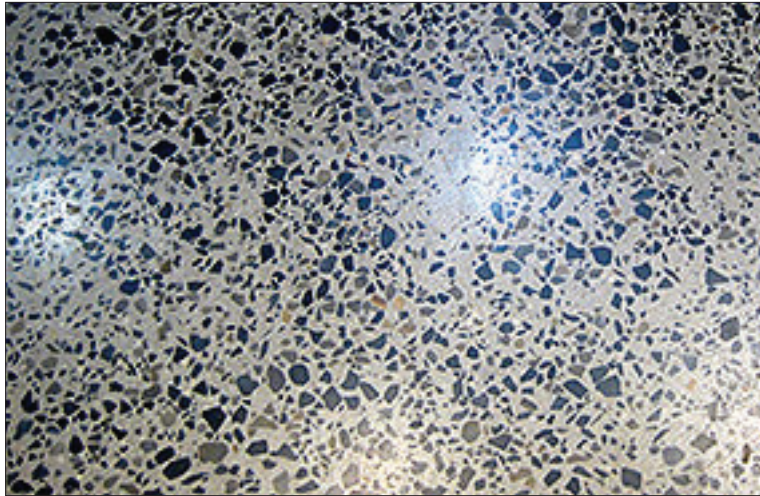


Figure 6 — Ground and polished concrete finish

Colour

Architectural concrete is sometimes coloured. This can be accomplished by adding a pigment to the mix, by acid etching, by using coloured aggregate or by adding a dry-shake colour/hardener during finishing. As Portland cement is normally grey, special white cement is sometimes used instead in order to achieve lighter colours. White cement and white sand are used to produce white concrete.

Types of Exposed Concrete Surfaces

Walls

Walls can be left flat and featureless, but architectural concrete walls usually have a pattern created by rustication strips (Figure 7). The exposed wall surface should be relatively free of blemishes, such as bug holes, sanding and honeycomb.



Figure 7 — Wall with rustication strips used to hide both sheathing joints and construction joints

Walls may be curved, may contain arches and may be textured to improve aesthetics. Retaining walls used in landscaping may be cast on-site, precast or made from unit masonry.



Figure 8 — Decorative retaining wall

Columns

Although spiral cardboard tubes are often used for forming columns, most architectural concrete columns have a smooth finish without spiral seam lines. This is achieved by using a form liner or other types of forms instead of spiral cardboard. Columns may have an enlarged base, be tapered or have a capital head or unusual shape (Figure 9).



Figure 9— Decorative columns

Ceilings

Architectural concrete ceilings may be textured by using a form liner or other material, or they may be shaped using dome pans or other methods (Figure 10).



Figure 10— Concrete ceiling created with dome pans



Now complete Self-Test 1 and check your answers.

Self-Test 1

1. What is architectural concrete?

2. Why is architectural concrete considered to be an economical choice?

3. What is the normal maximum allowable deflection allowed for architectural concrete?

4. What is FRP and why is it used?

5. What are form liners used for?

6. What look does a ground and polished concrete surface give when coated with a sealer?

LEARNING TASK 2

Plan Architectural Formwork

Careful planning is needed before constructing architectural formwork. Forming systems must be chosen that will give the required finished look. Forms should produce the desired surface, which could be smooth, textured, lined or exposed aggregate. Concrete surfaces should have a uniform colour and texture. Patterns in the concrete should have clean, straight lines. Tie holes should be spaced evenly, and there should be no honeycomb or bug holes.

Proper planning includes following the drawings and specifications, selecting the correct concrete mix, choosing appropriate forming materials and hardware and carefully placing embedded metals.

Drawings and Specifications

Drawings and specifications will specify the desired surface. The contractor can use a form liner or sheathing that they are familiar with along with their choice of forming system. The final finish is the end product, not the forming method.

The architect will sometimes specify that a test block or panel of concrete be cast to show the quality of the finished surface of the concrete (Figure 1). All of the different textures and finishes should be demonstrated in the test block, including a sample of rustication and control joints.

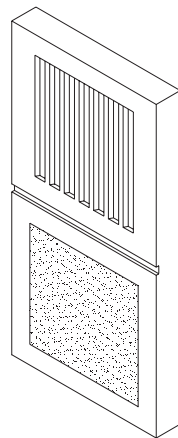


Figure 1 — Test casting of concrete

In most cases WorkSafeBC requires the contractor to have formwork plans approved by a professional engineer.

Location and Details

The architectural and structural drawings will normally include the location and details for all construction joints, control joints, expansion joints, chamfered edges, rustication strips, reveals and other special design features (Figure 2). Plans should also include the locations and details of all metal embeds.

When planning the layout of form sheathing, the locations of the joints and ties can be critical. The formwork must be designed to be strong enough to support the concrete and to leave a balanced, pleasing appearance.

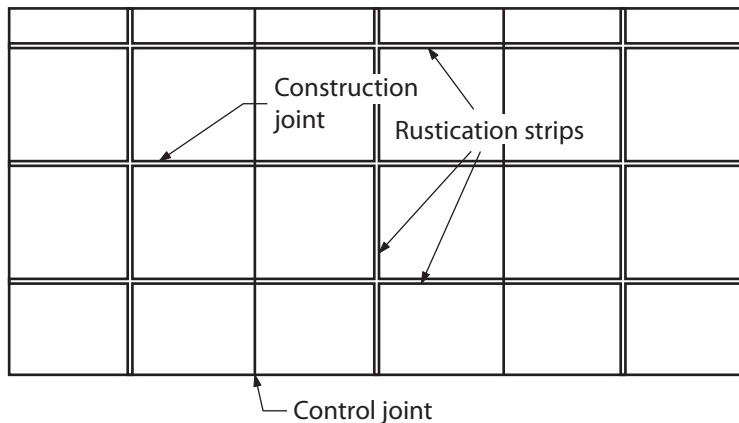


Figure 2 — Locations for construction joints, control joints and rustication strips

Tolerances

Plans and specifications will usually include allowable tolerances for construction. These can include tolerance for variation in plumb, level, position, true (straightness), dimension and allowable deflection. For example, the architect may specify that walls be plumb to within 5 mm ($\frac{1}{4}$ ") over a height of 3 m (10 ft.). Typically, more deflection is allowed for rough surfaces than for smooth concrete surfaces, as deflection is more noticeable on smooth surfaces.

Materials

Materials such as concrete mix, form sheathing and hardware are especially important when it comes to planning formwork for architectural concrete.

Concrete Mix Design

To achieve a high-quality surface, it is important for the concrete to consolidate well. To achieve this, the concrete mix design can include increased amounts of cement and plasticizer. This will give a more uniform surface that has no bug holes or other defects. Most ready-mix concrete manufacturers have suggested mixes designed specifically for architectural concrete.

Specialty Form Sheathing

The choice of form sheathing will depend on a number of factors. These can include the desired finished look for the concrete, whether or not form liners are being used, requirements for curved walls and ability to withstand high concrete pressures.

Sheathing for architectural concrete forms is normally a high-end resin-coated paper-faced plywood, but it may also be steel, aluminum, hardboard, insulating board, fibreboard, cardboard, fibre-reinforced plastic or thin precast concrete panels.

Hardware

Most large-scale forming is done with proprietary formwork systems. Hardware is part of the system and is specified by the formwork designer. The choice of ties will depend on the system used, the required strength and whether the tie holes will be patched, plugged or left as an architectural feature.

Tie holes may be plugged with a precast concrete plug (Figure 3) or filled and patched to a smooth surface. When tie holes are left unfilled to form an architectural design, the placement of the ties in the formwork is critical.

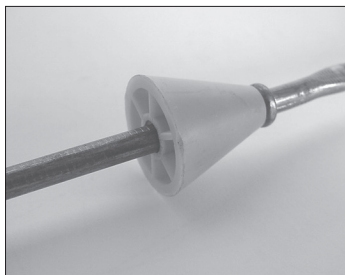


Figure 3 — Tie with cone to facilitate plugging or leaving open as an architectural feature

Sequencing

WorkSafeBC requires that the formwork design for most architectural concrete projects be approved by a professional engineer. The formwork design needs to show the sequencing of forming, concrete placement, curing, stripping, reshoring and any surface treatments. This sequencing may be repeated time after time for multi-storey buildings. Even when a professional engineer is not required by WorkSafeBC, the careful planning of the sequencing is important for both safety and the final look of the concrete.

Embedded Metals

In many concrete placements, metal components must be incorporated into the concrete to give protection and support or to provide a welding surface. The metal embeds shown in Figure 4 and Figure 5 serve quite different purposes, but the way the inserts are installed is similar. The pieces must be precisely located and securely supported so they do not move during concrete placement. They must also be positioned such that they will not interfere with the removal of the formwork.

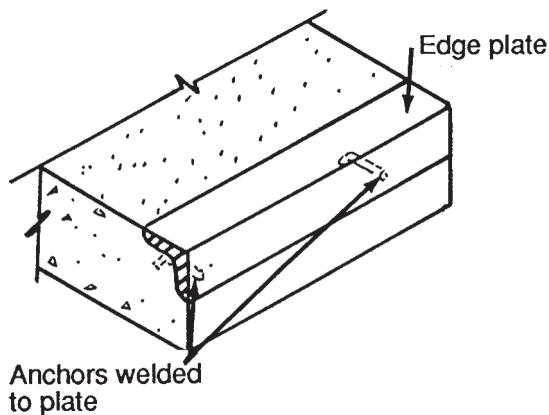


Figure 4 — Protective edge plate

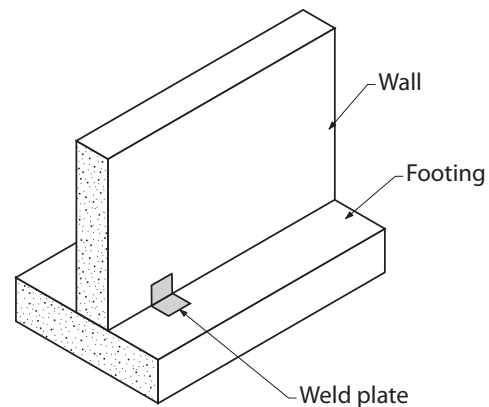


Figure 5 — Weld plates and joist seats

Anchorage

Embedded metals are anchored to the concrete by deformed rods, bolts, studs or bent bars. These anchors are welded to the back of the metal components before they are delivered to the job site. Small weld plates may have only one anchor, while protective edge plates (angle iron) may have anchors welded every 300 mm (12") along their entire length.

Edge Protection

Angled metal plates are used to protect the edges of loading docks, doorways and the exposed corners of columns or walls in high-traffic areas. Before the concrete is placed, the protective angle edge plate (Figure 4) is attached to the form using nails, bolts or wire.

If bolts are used, attach them so that the nuts are on the concrete side of the metal. Once the concrete has set, the bolts may be withdrawn, leaving the nuts embedded in the concrete. If nails or wires are used, cut them flush with the exposed face of the metal after form removal.

Weld Plates

In precast concrete construction, weld plates are used to connect sections. Figure 5 shows a weld plate embedded in the footing so that a precast wall may be connected to it. A corresponding weld plate is cast into the wall. After the wall and footing are in place, the two plates are welded together. Concrete stairs and walkways often have embedded welding plates to which railings can be attached.



Now complete Self-Test 2 and check your answers.

Self-Test 2

1. A good forming system will produce what type of architectural concrete surface?

2. Who is responsible for designing the forms?

- a. architect
- b. professional engineer
- c. contractor
- d. formwork manufacturer

3. What is a test block or panel used for?

4. The architectural and structural plans will show the locations and details for _____.

5. What are allowable tolerances?

6. Concrete mixes for architectural concrete usually have elevated levels of what two ingredients?

7. Why is tie spacing important?

8. What are the purposes of embedding metals?

LEARNING TASK 3

Calculate Architectural Formwork

Projects that include large amounts of architectural concrete can often be built more economically and quickly by using patented forming systems such as those created by Peri™ and Doka™. When the architectural and structural drawings are done in CAD, the form manufacturing company's software can automatically do a take-off of all form components needed for the project, down to the last nut and bolt.

For projects where the contractor constructs their own forms, a detailed list of forming materials will need to be calculated.

Wall forms may be built in place (loose forming) or constructed as larger components (gang forming). Slab and ceiling forming may be done with fly tables, scaffolding or other methods. Girder and beam forming is usually built in place, and column forms can be built in place or manufactured using various types of material, such as fibre tubes, metal or fibreglass-reinforced plastic.

Centreline Perimeter and Contact Area

Finding the centreline perimeter and the contact area will help with calculating the wall formwork and labour costs. A detailed take-off may be needed due to the architectural concrete aesthetic requirements, but many experienced contractors can calculate wall-forming materials based on the contact area.

Centreline Perimeter

The centreline perimeter is the distance around the foundation measured at the centreline of the foundation wall. It is the average of the inside perimeter and the outside perimeter. Centreline perimeter is used to calculate concrete volumes and virtually all the forming materials necessary to form the footing and wall.

Finding the centreline perimeter is the first calculation to be made when determining required concrete volumes or formwork for foundations. The centreline perimeter is equal to the perimeter of the outside of the building minus 4 times the wall thickness:

$$\text{Centreline perimeter} = [(\text{length of building} + \text{width of building}) \times 2] - (4 \times \text{wall thickness})$$

The outside perimeter is reduced by 4 times the wall thickness to allow for the overlap at each outside corner of the building, so that the corners don't get included twice in the calculations (Figure 1).

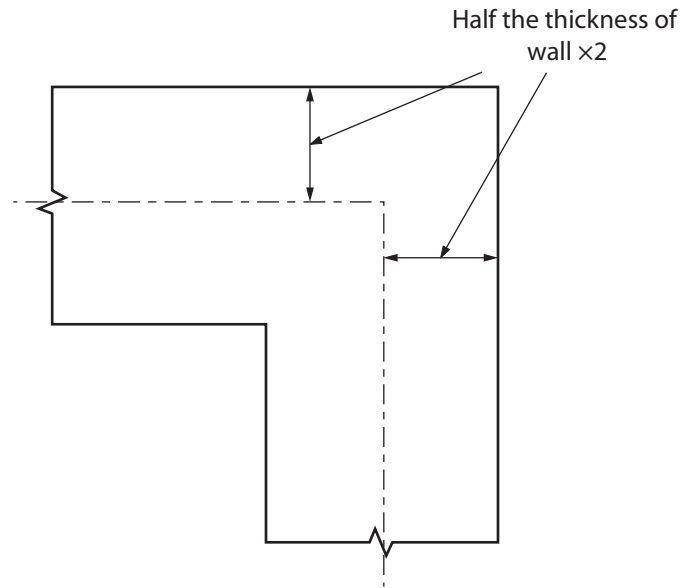


Figure 1 — Plan view of centreline at corner

The perimeter of the outside of a rectangular building can be calculated by using the overall length of the building and the overall width of the building. Jogs at the corners (Figure 2) do not have to be considered (imagine the inside corner flipped outwards).

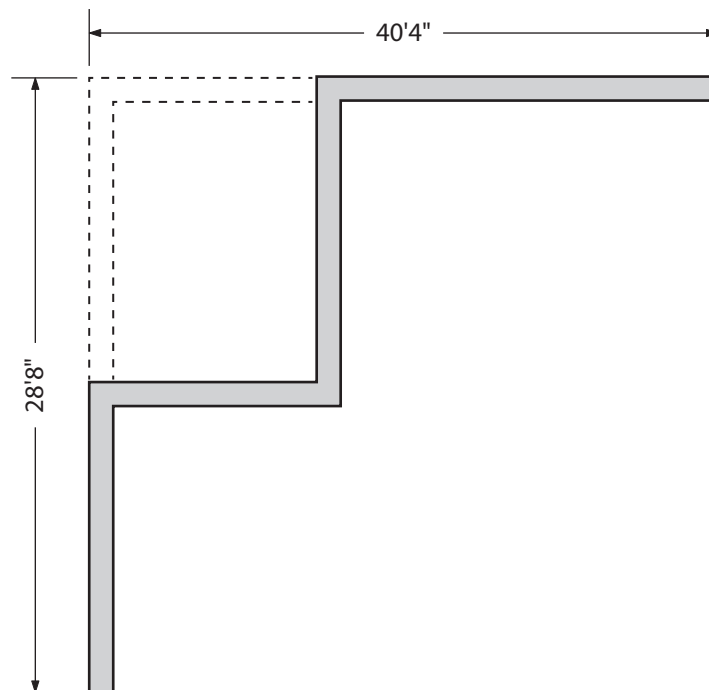


Figure 2 — Wall with corner jog measures the same as a wall without a jog

Sample Problem 1

Figure 3 shows a simple plan view and section view for a footing and foundation wall with a uniform wall height.

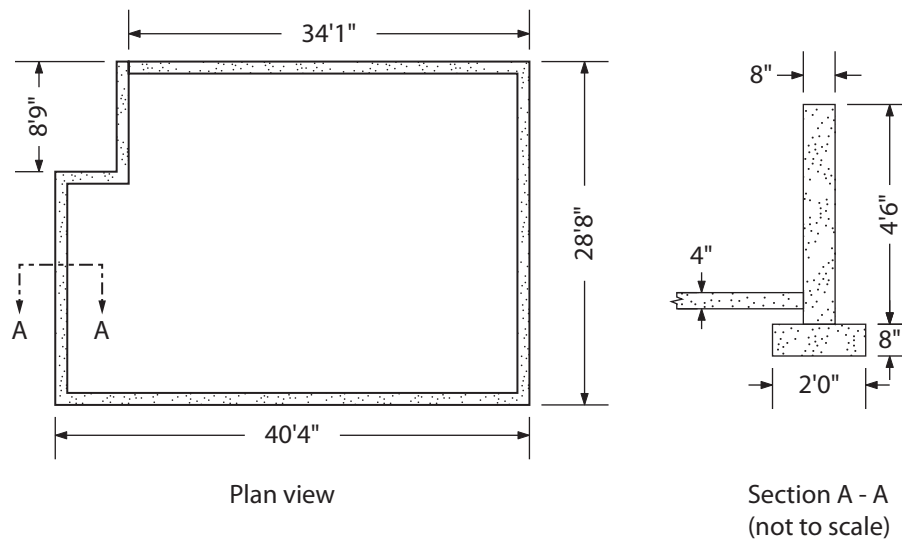


Figure 3 — Simple foundation drawings

Using the dimensions from Figure 3, the length of the centreline perimeter is:

$$\begin{aligned}
 \text{Centreline perimeter} &= [(\text{length of building} + \text{width of building}) \times 2] - (4 \times \text{wall thickness}) \\
 &= ((40.33 \text{ ft.} + 28.67 \text{ ft.}) \times 2) - (4 \times 0.67 \text{ ft.}) \\
 &= 138 \text{ ft.} - 2.68 \text{ ft.} \\
 &= 135.32 \text{ ft.}
 \end{aligned}$$

Sample Problem 2

This foundation includes an internal jog to allow for an entrance alcove (Figure 4). The depth of this jog is 6'9", and it must be added to the centreline perimeter twice to include the jog. Note that the length of the jog (8'7") is already included in the overall length of the wall.

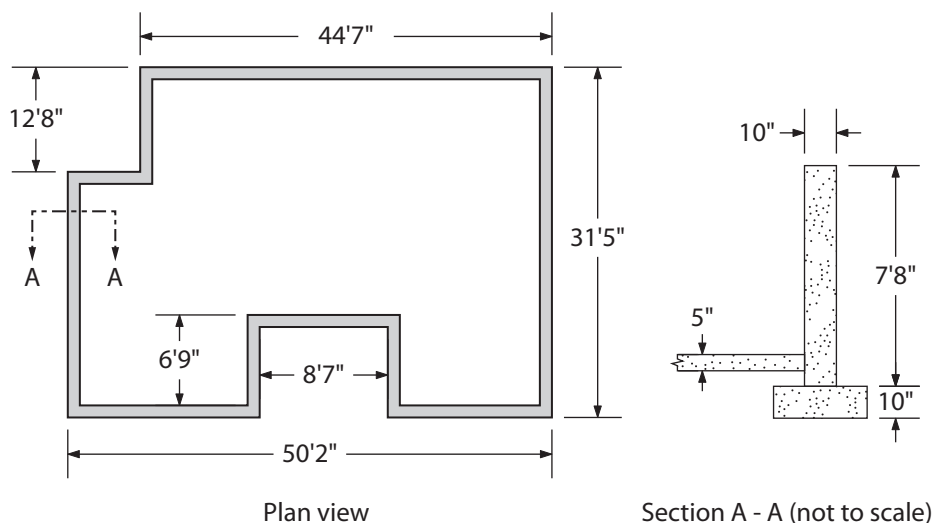


Figure 4 — Plan and section drawings for sample problem 2

$$\begin{aligned}\text{Centreline perimeter} &= [(50.17 + 31.42 + 6.75) \times 2] - (4 \times 0.83) \\ &= 173.36 \text{ ft.}\end{aligned}$$

Contact Area

The contact area of the wall forms is equal to the centreline perimeter $\times$ the height of the concrete wall $\times 2$ (multiplied by 2 to get the area for both sides). Using the dimensions given in Figure 4, the wall contact area for sample problem 2 would be:

$$\begin{aligned}\text{Wall contact area} &= 173.36 \text{ ft.} \times 7.67 \text{ ft.} \times 2 \\ &= 2659.34 \text{ sq. ft.}\end{aligned}$$

If stud, waler and tie spacings were known, the contact area could be used to calculate all the forming materials required and the volume of concrete needed for both footings and walls.

Concrete Volume

Most concrete calculations involve finding the volumes of rectangular solids. To find the volume of concrete in a rectangular solid, use the following formula:

$$\text{length} \times \text{width} \times \text{height} = \text{volume}$$

Since $\text{length} \times \text{width} = \text{area}$, the formula can also be written as:

$$\text{area} \times \text{height} = \text{volume}$$

The following are examples for finding volumes of non-rectangular shapes.

Bridge Pier

Bridge piers are built in various shapes. The example shown in Figure 5 has two semi-cylindrical shapes at each end of a rectangle. All measurement units are in millimetres.

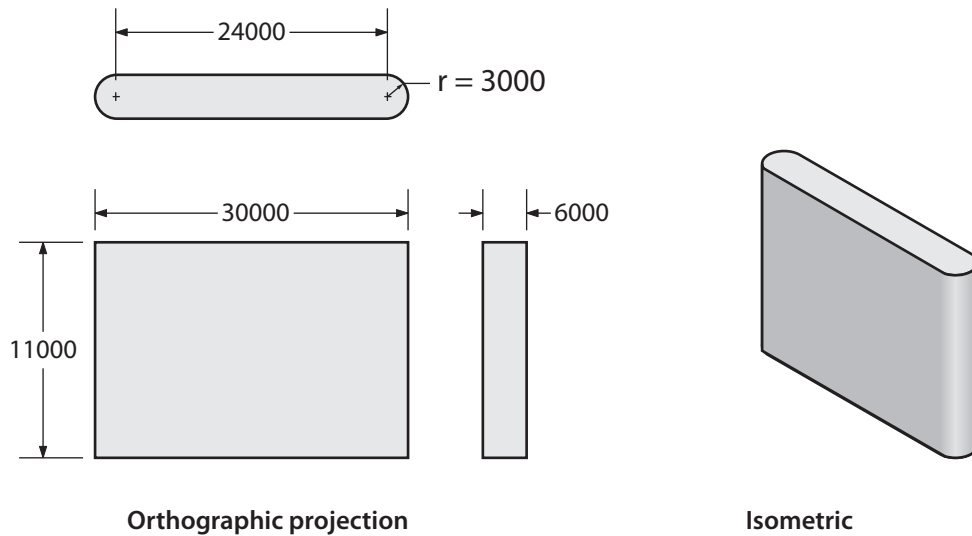


Figure 5 — Bridge pier

Example

The volume of concrete in a pier equals the area of the top of the pier multiplied by the height of the pier. The two semi-cylinders constitute one cylinder. We want to have our final result in cubic metres, so we'll use dimensions in metres in the calculations.

Referring to Figure 5, the area of the top is calculated as follows:

$$\begin{aligned}
 \text{Area of the top of the cylinder} &= \pi r^2 \\
 &= 3.1416 \times (3 \text{ m})^2 \\
 &= 28.274 \text{ m}^2
 \end{aligned}$$

$$\begin{aligned}
 \text{Area of the top of the rectangle} &= \text{width} \times \text{length} \\
 &= 24 \text{ m} \times 6 \text{ m} \\
 &= 144 \text{ m}^2
 \end{aligned}$$

$$\begin{aligned}
 \text{Total area of top} &= 28.274 \text{ m}^2 + 144 \text{ m}^2 \\
 &= 172.274 \text{ m}^2
 \end{aligned}$$

$$\begin{aligned}
 \text{Volume of concrete in pier} &= \text{area of top} \times \text{height} \\
 &= 172.274 \text{ m}^2 \times 11 \text{ m} \\
 &= 1895.01 \text{ m}^3
 \end{aligned}$$

Complex Angular Shapes

To calculate the concrete volume for the footing, wall and corbel in Figure 6, the structure needs to be broken down into five shapes. All measurement units are in millimetres.

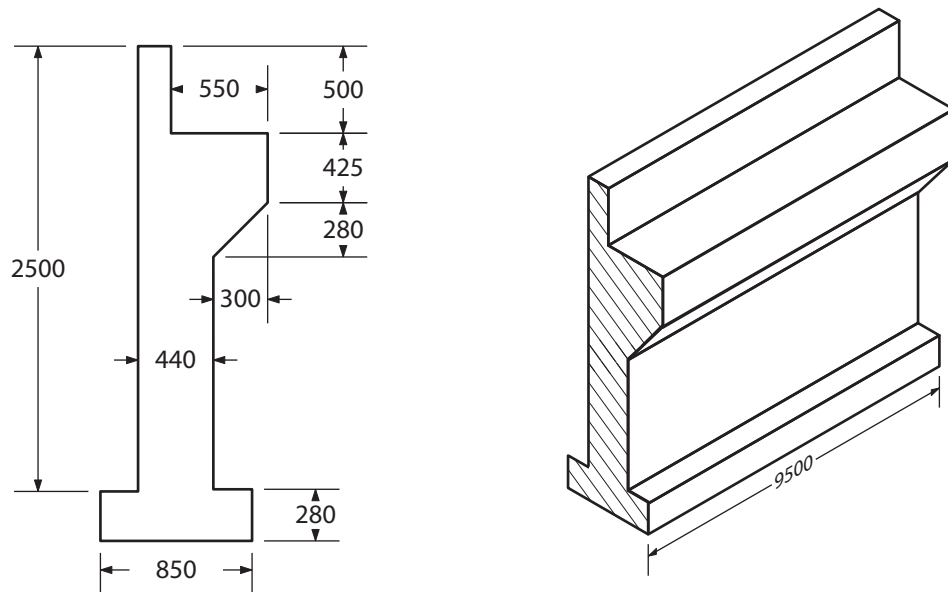


Figure 6 — Corbel in a concrete wall

Example

The cross section of the wall can be broken down into four rectangles and one triangle as shown in Figure 7. Once the cross section area is found, it is multiplied by the length of the concrete member.

Volume = end area × length

$$\text{Area 1} = 0.500 \times 0.190 = 0.095 \text{ m}^2$$

$$\text{Area 2} = 0.425 \times 0.740 = 0.315 \text{ m}^2$$

$$\text{Area 3} = 0.300 \times 0.280 / 2 = 0.042 \text{ m}^2$$

$$\text{Area 4} = 0.440 \times 1.575 = 0.693 \text{ m}^2$$

$$\text{Area 5} = 0.850 \times 0.280 = 0.238 \text{ m}^2$$

$$\text{Total area} = 1.383 \text{ m}^2$$

$$\text{Volume} = 1.383 \text{ m}^2 \times 9.5 \text{ m} = 13.14 \text{ m}^3$$

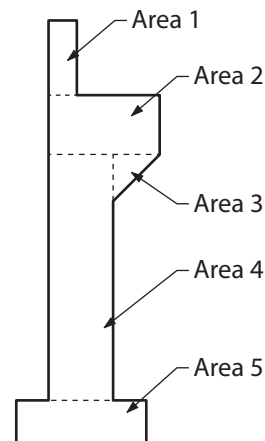


Figure 7 — End area subdivisions

Volume Calculations for Irregular Shapes

Volume for irregular shapes (Figure 8) can be calculated as follows:

$$V = \frac{H}{6}(ab + 4am + at)$$

where H = height

a_b = area at bottom

a_t = area at top

a_m = area at middle (by measurement, not by average)

The height must be measured at right angles to the top and bottom.

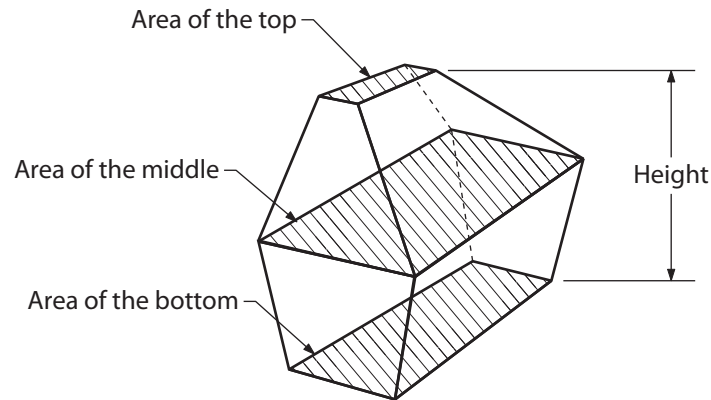


Figure 8 — End area subdivisions

Conical and Pyramid Shapes

The volumes of conical and pyramid shapes are calculated by multiplying $1/3$ of the area of the base times the height (Figure 9).

$$\text{Volume} = \frac{1}{3} \times \text{area of the base} \times \text{height}$$

The height must be measured at right angles to the base.

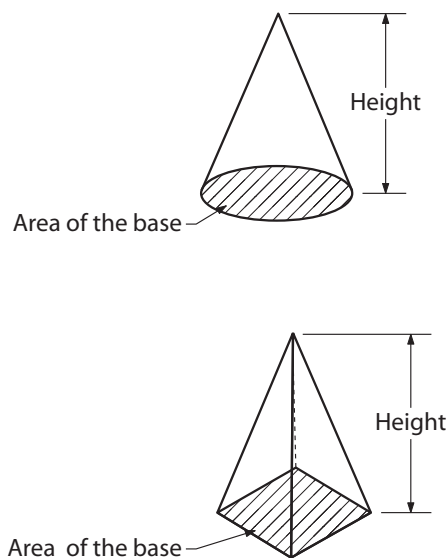


Figure 9 — Cone and pyramid

Frustum of a Cone or Pyramid

Frustums of cones or pyramids are cones or pyramids with the top (peak) removed. A conical column capital is a frustum of a cone.

The cone is cut off at a right angle to the height, making the second surface parallel to the base of the cone. Figure 10 shows a frustum of a cone.

The volume of a frustum of a cone or pyramid is calculated in three steps:

1. Calculate the volume of the tall cone (Figure 11).
2. Calculate the volume of the small cone.
3. Subtract the volume of the small cone from the volume of the tall cone.

The tall cone height minus the small cone height is the height of the column capital.

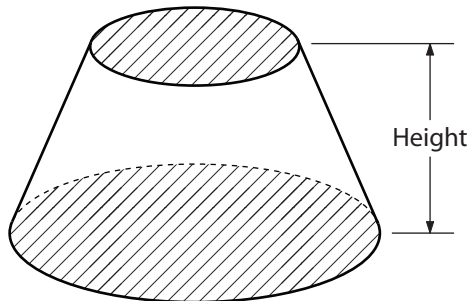


Figure 10 — Frustum of a cone

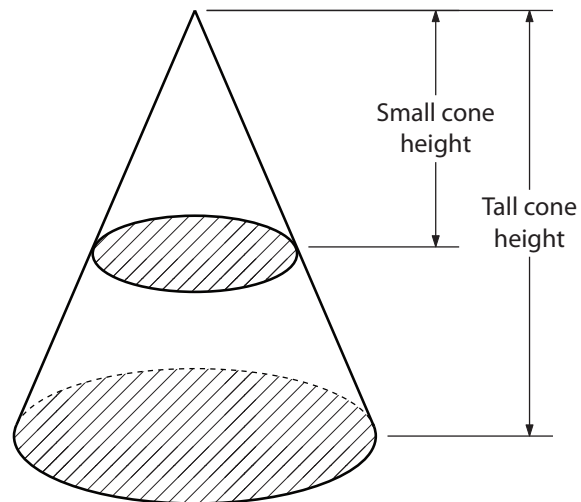


Figure 11 — Column capital volume



Now complete Self-Test 3 and check your answers.

Self-Test 3

All measurements are in millimetres.

1. Find the volume of the concrete shape shown in Figure 1.

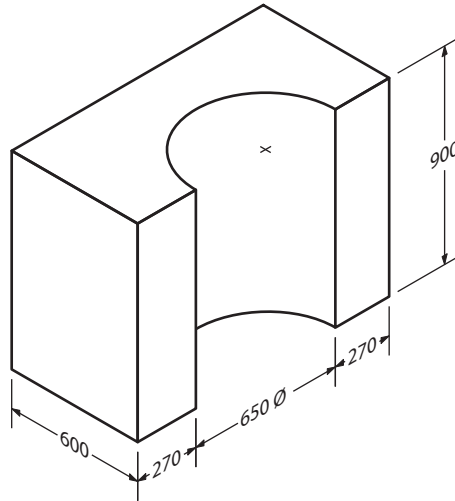


Figure 1 — Concrete block

2. Find the volume of the concrete shape shown in Figure 2.

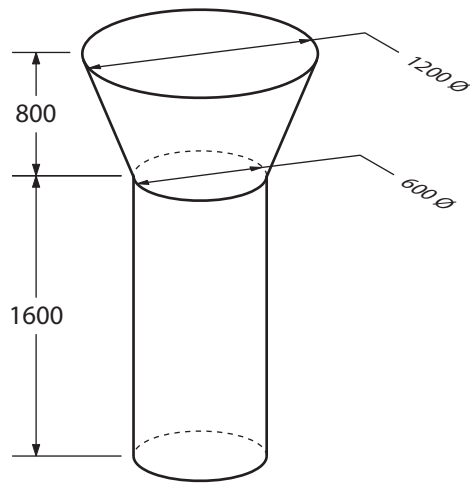


Figure 2 — Column capital

LEARNING TASK 4

Build Architectural Formwork

Some of the factors to consider when forming for architectural concrete include:

- the layout of the form sheathing, tie locations and spacing
- inlays such as rustication strips and reveals
- form assembly, support and bracing
- concrete placement
- stripping
- surface treatments

Formwork and Layout

Creating a flat wall surface that is smooth and uniform is difficult. In multi-storey projects formwork often gets reused in the same location on each floor level. New form materials may be required to create a surface that is smooth and uniform. In order to maintain a high level of quality, the formply must be handled carefully from erection through stripping.

Plans often require the formwork panels to be laid out in a certain symmetrical pattern when seams are to be left visible. Figure 1 shows an example of tight, properly aligned seams.



Figure 1 — The result of tight, properly aligned seams

Figure 2 shows a noticeable misalignment of new concrete formed on top of existing concrete.



Figure 2 — The result of improperly aligned seams

To prevent leakage of the cement paste, the formwork for architectural concrete must be watertight, with all corners locked together. When a smooth surface is specified, the joints between the sheathing panels will need to be filled with patching material, caulked or covered.

Nailing should be minimal and done with smooth-faced hammers to avoid marring the forms. Any patching of form defects needs to be done in a manner that won't telegraph to the concrete surface (Figure 3).



Figure 3 — The result of improper patching of forms

Form release agents must be of a non-staining type. Control joints must be installed perfectly plumb and level and secured to the formwork at intervals small enough to eliminate movement during the placement of the concrete.

Waste Moulds

Disposable formwork is used for some concrete shapes. The forms are built from materials such as lath and plaster that allow complicated details to be formed. The formwork is usually destroyed by the stripping process. Waste moulds are used when there are compound curves and intricate details. The compound curve of the soffit of a curved stair is often formed as a waste mould.

Form Liners

Form liners can be purchased in a selection of stock textures, or custom form liners can be made on-site from a variety of different materials. Site-built form liners are often rough-sawn boards or sandblasted plywood that is incorporated into the form design to give a wood-grain surface to the finished concrete. Many materials require a bond-breaking coating (release agent) so that they can be removed after casting.

Dense foam rubber, which is very flexible, is used to make manufactured form liners. The flexibility of the liner allows intricate patterns to be cast in the concrete and enables the liner to be stripped from the concrete without damaging the form liner or the concrete.

Other form liners are made from expanded polystyrene (EPS) foam. The pattern in the EPS foam is cut out with a hot wire that is bent to the shape of the pattern. These liners are usually destroyed by the stripping process.

The form liners are used inside the wall forms on the exposed side of the concrete, as shown in Figure 4.

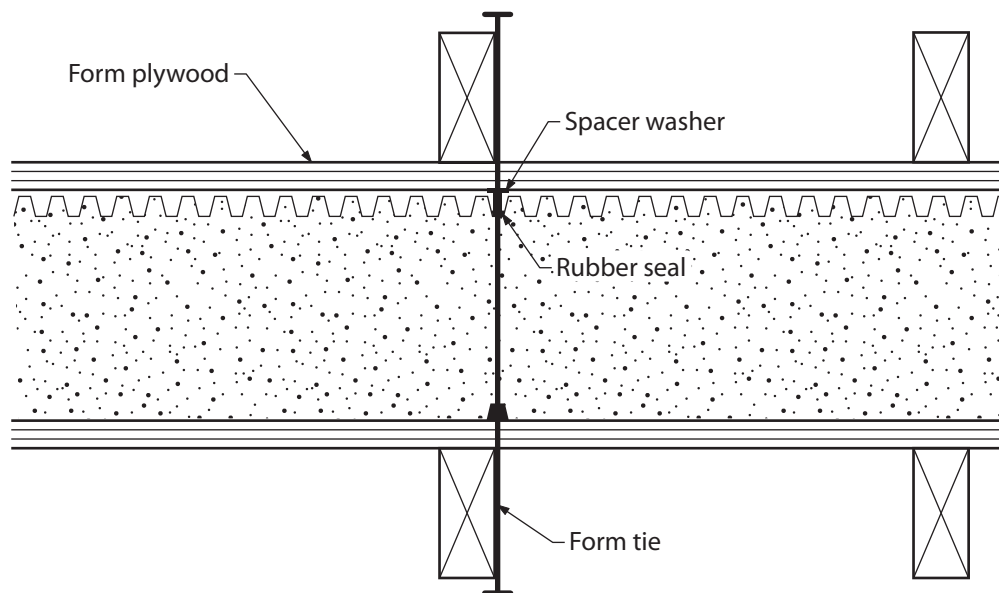


Figure 4 — Plan view detail of a form liner

Rubber washers seal the form liner to the tie so that the paste in the concrete doesn't leak out. The effective wall thickness is measured from the high points of the rubber form liner, so the ties must be longer than for a wall without the form liner.

Tie Location

The ties have to be laid out carefully, following the architect's drawings. The holes may be plugged with a precast concrete plug (Figure 5) or filled and patched to a smooth surface. In some situations the tie holes are left unfilled as part of the architectural design (Figure 1), in which case the placement of the ties in the formwork is critical (Figure 6).



Figure 5 — Plugged tie holes



Figure 6 — Improper tie spacing with one cone left in place

Figure 7 shows two typical tie spacing layouts. These layouts are popular because they provide a repeatable pattern that will produce a pleasing final appearance while providing sufficient structural support to the forms during the placement of the concrete.

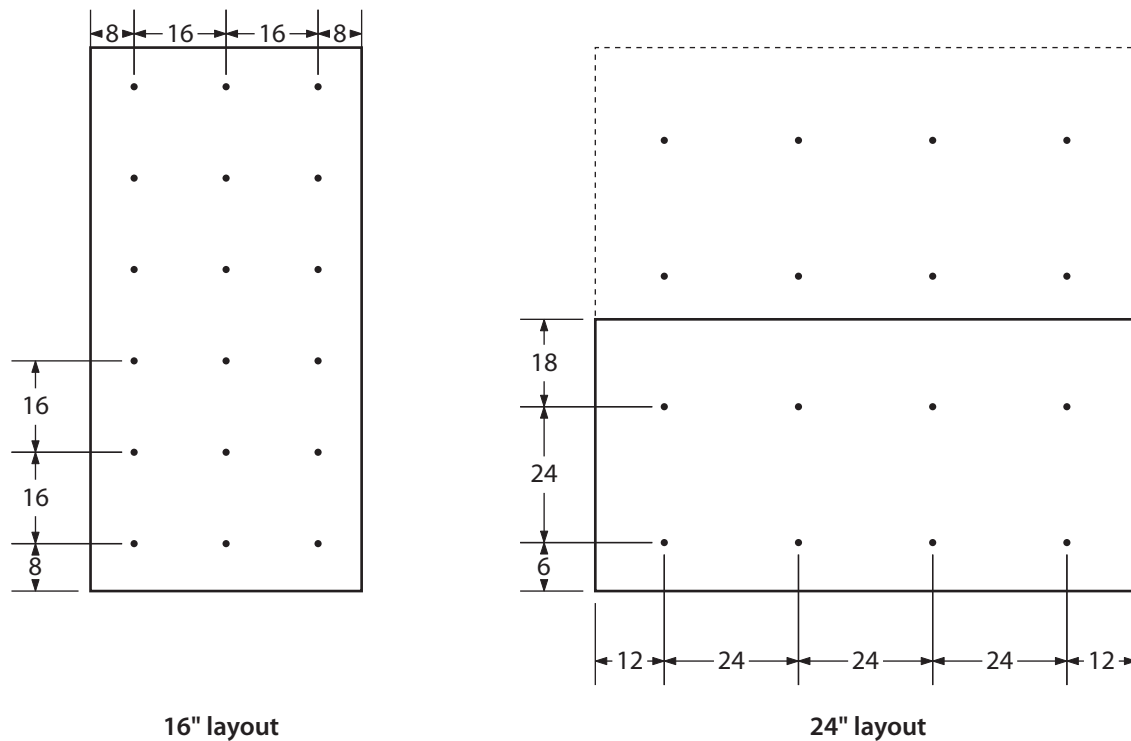


Figure 7 — Tie spacing layouts

Architectural Inlays

Architectural inlays, such as rustication, may be used to create a pleasing pattern and to hide formwork joints, control joints and construction joints.

Rustication

Rustication is used to form lines or grooves in the surface. Figure 2 in Learning Task 2 is an elevation view of a finished concrete wall showing the placement of rustication strips, some of which also act as control joints and to hide construction joints.

Figure 8 shows an example of a wall where rustication provides a decorative pattern and hides formwork seams, control joints and construction joints. Two construction joints are visible at the building's corner.



Figure 8 — Rustication

Rustication Strips

Rustication strips are most often made at the job site from wood (Figure 9). The wood should be free of knots and able to be ripped easily. The size of the rustication strip is specified on the drawings, and the sides must be sloped to allow removal of the wooden strips.

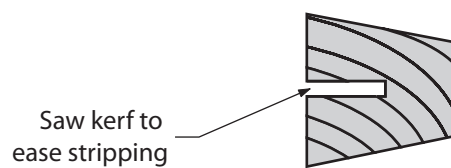


Figure 9 — Section view of rustication strip

Site-cut rustication should be made carefully, as it shapes the finished detail on the building. Defects in the rustication will affect the finished look of the building and may require the whole concrete wall to be re-cast. Cutting a saw kerf in the formwork side of the rustication strip will help make the removal of the wooden strips easier. Soaking the wooden strips in form oil for a few days is a good method of ensuring ease of stripping. To resist spalling of the concrete at the edges of rustication strips, only remove them after the concrete has sufficient strength to resist damage.

Manufactured rustication strips can be purchased in many different profiles. Manufacturing allows for much more sophisticated profiles than site-made strips. They are usually made of wood or sheet metal that is covered with plastic. When using plastic products, be careful to store them on a flat surface and out of the sun. The smooth surface of the manufactured strips makes them easier to strip than site-made strips.

Rustication strips need to be placed carefully. In Figure 10, the rustication strip was misaligned, causing it to be out of level, which allowed the construction joint to show.



Figure 10 — Out-of-level rustication strip

Reveals

A *reveal* is a small groove in the soffit of a concrete member such as a slab, used to create a drip line (Figure 11). It should be tapered for ease of stripping and resembles a scaled-down rustication strip. Rustication strips are sometimes also known as *reveal strips*.



Figure 11 — Reveal acting as a drip

Chamfers

Normally all outside architectural concrete corners are chamfered. This prevents spalling when stripping and helps guard against damage later on. Chamfers can be triangular or cove-shaped and may be site-made or manufactured.

Alignment, Support and Bracing

Proper form construction, alignment, support and bracing are all required to result in a finished product that has very little deflection with straight, true lines and accurate dimensions.

Columns

Columns require the strongest forms because they are often tall and the concrete is all placed in one lift. The pressures from the fresh concrete require the column clamps to be spaced closer together at the bottom than at the top.

If cardboard tubes are used, they should be lined. Metal and FRP forms give smooth finishes, but care should be taken to align the seams for all columns in the same direction and to locate the seams where they are least visible. Figure 12 and Figure 13 illustrate the results produced by using an unlined cardboard form compared to a two-piece metal form.



Figure 12 — Column formed with unlined cardboard



Figure 13 — Column formed with two-piece metal form

Care needs to be taken to ensure proper alignment of multiple columns when they are placed in rows.

Beams and Girders

The pressures exerted on the sides and bottoms of beams and girders are not as great as those on walls and columns. The most important concern for beams and girders is the falsework that supports and braces the soffit of the beam form. The falsework must be able to carry the load of the fresh concrete and the equipment used to place the concrete.

Suspended Slabs

The sideways pressures on the edge forms for suspended slabs are low. Often 2×6 lumber is used as the edge form. As with beams and girders, the main concern is the falsework used to support and brace the slab form. The formwork for suspended slab construction is often a prefabricated slab table that can be quickly set up and removed.

Curved Walls

Curved walls (Figure 15 and Figure 16) require specially made top and bottom plates. These are often made from two layers of 19 mm ($\frac{3}{4}$ ") thick plywood laminated together. The sheathing is made of layers of thin plywood. Plywood grain direction and thickness depend on the radius of the curve. Figure 14 lists the minimum bend radii for dry plywood. Soaking the plywood in water or cutting in many saw kerfs can allow for tighter bending.

Plywood Thickness	Across Grain	Parallel to Grain
$\frac{1}{4}$ "	2 ft.	5 ft.
$\frac{5}{16}$ "	2 ft.	6 ft.
$\frac{5}{8}$ "	3 ft.	8 ft.
$\frac{1}{2}$ "	6 ft.	12 ft.
$\frac{5}{8}$ "	8 ft.	16 ft.
$\frac{3}{4}$ "	12 ft.	20 ft.

Figure 14 — Minimum bending radii for dry plywood without saw kerfs



Figure 15 — 60-foot-radius curved wall



Figure 16 — 5-foot-radius curved wall

Concrete Placement

To minimize deflection of the formwork, the rate of placement should be moderate and the stud spacing close. Vibrating one layer of placement well into the previous layer will help to keep the placement lines hidden. The mix design for the concrete will have to be carefully followed to keep the colour of the finished concrete uniform.

Adequate vibration is required to consolidate the concrete fully. Use the vibrator to consolidate and level concrete but not to move concrete, as this can cause sanding streaks and segregation.

An extension hose, or elephant trunk, is needed on the pump to allow the concrete to exit

the hose as close as possible to where it is being placed. This minimizes the separation of the aggregates from the paste.

The formwork must be designed to allow full vibration because inadequately vibrated concrete will leave honeycomb and bug holes. Patching and repairing honeycomb and bug holes is only an option for concrete that is not going to be seen. Patching architectural concrete is not generally acceptable to the architect (Figure 17).



Figure 17 — Poorly patched architectural concrete

Metal embeds must be placed carefully in the correct location and at the correct elevation. They may be fixed to the formwork or handset as shown in Figure 18.



Figure 18 — Embed for handrail attachment

Stripping and Cleaning Forms

The design of the formwork should include a form removal process that allows the formwork to be stripped safely and efficiently. To avoid damage to the concrete, the materials should be removed carefully even if they are not going to be reused as formwork.

Worker safety is increased if the formwork removal is done in a systematic manner, completing one section at a time. As each section is completed, the materials should be cleaned, oiled and carefully stacked in a dry location.

Concrete test samples, taken at the time of placement, will be used to determine the strength of the concrete. Architectural concrete should generally reach at least 10 MPa of compressive strength before stripping takes place; however the minimum strength will be specified by the engineer who helped design the structure. Depending upon the curing conditions and the concrete mix design, the forms may be removed in only a few days. In all cases, it is the engineer who will decide when the concrete is strong enough to allow the forms to be removed.

When stripping gang form panels, adequate bracing and support must be maintained until the panel is connected to and fully supported by the lifting crane. Overhead formwork should be removed from the top down and from the outside inward.

The engineer's re-shore schedule must be followed carefully and the re-shored concrete must be inspected prior to adding an additional load.

The photos in Figure 19 show the result of carelessly stripping a form at the first floor level. The photos were taken on the second floor level, and all the floor levels above had the same defects in the same locations.



Figure 19 — Telegraphed form damage

Protection of the Concrete Surfaces

Stripping should not begin until the concrete has gained sufficient strength to resist the stresses of form removal. If the weather has been cool, the curing of the concrete will be slower, and stripping of the formwork may have to be delayed.

Figure 20 shows spalling caused by premature stripping of the formwork. The attachment of wooden rustication strips to the formwork should be done in such a way that the rustication strip is left behind in the concrete as the form is stripped away. The rustication strips can then be left in the concrete until they shrink and can be easily removed.

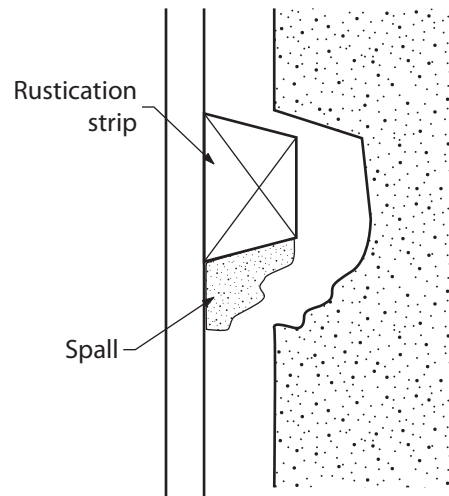


Figure 20 — Spalling

Use Wooden Pry Bars and Wedges

Never use metal pry bars directly against the concrete surface. Use wooden wedges or wooden pry bars to protect the surface of the concrete. Figure 21 shows the correct ways to lever formwork away from the concrete.

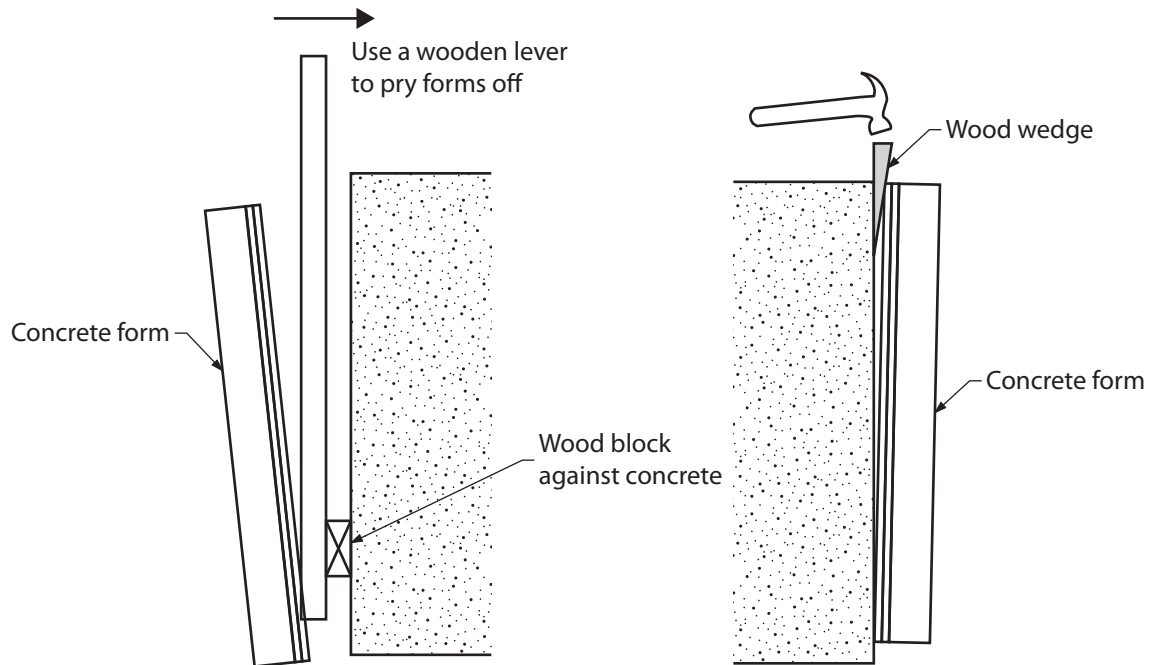


Figure 21 — Proper stripping techniques

Cleaning of Formwork

Forms must be properly scraped and cleaned before reuse. Figure 22 shows a column on the fifth floor in which a seam has enlarged due to poor scraping of a two-piece metal form that had been used twice on each of the five floor levels.



Figure 22 — Seam enlarged due to poor scraping and cleaning

Surface Treatments

There is a variety of rough and smooth surface treatments that can be performed on architectural concrete.

Rough Surface Treatments

Rough surface finishes may just require patching or plugging of tie holes and defects, unless tie holes are being left open as an architectural feature. Sandblasting or tooling can be done to create an even rougher surface.

Sandblasting

Sandblasting is a very common finish used for architectural concrete. It produces a fine texture but will not fix imperfections left by the formwork. Unlevel surfaces and deflections in the form surfaces will “telegraph” to the surface and still show up after sandblasting.

The batching of architectural concrete must be carefully controlled, but even so, maintaining a consistent colour is difficult. Sandblasting will reduce slight differences in the colour of different loads of concrete.

Sandblasting can be done in various weights. Using a test block as the definition of the type of finish desired will simplify the instructions to the worker doing the sandblasting.

Tooling

Tooling the surface of the concrete with a bush hammer can make a rougher texture than sandblasting. The bush hammer chips off the surface of the concrete, exposing the aggregate beneath. Bush hammering is rarely done because of the amount of labour that is required.

Exposed Aggregate

Exposed aggregate finish is used extensively for exterior concrete work. The special concrete mix design for this purpose uses gap-graded aggregate. A gap-graded aggregate mixture is a mixture of different sizes of rocks, with some of the sizes missing so that there is a gap in the sizes.

Most exposed aggregate concrete is made with coarse aggregate that is all $\frac{3}{8}$ " in diameter; the rest of the aggregate is sand. Using gap-graded aggregate makes it easy to leave the surface with an even, pebbled look. Exposed aggregate is expensive because more cement paste is needed to fill the gaps between the large aggregate.

A retarder is used to keep the surface of the concrete from setting. The retarder is sprayed on the surface of the finished slab or on the formwork for walls. After the forms are stripped or the slab is at least 12 hours old, the surface of the concrete is hosed off or pressure-washed to reveal the aggregate.

The wash-off from exposed aggregate concrete cannot be flushed into the storm drain. The Department of Fisheries and Oceans monitors outfalls and can trace water flow to the source. Steps must be taken to control and filter the wash-off. By diverting the wash-off to a flat area on the site, the water will be filtered through the soil. Large-capacity wet-dry vacuums are sometimes used to collect the wash water, which can then be filtered and disposed of. Municipalities often have guidelines for this work.

The exposed aggregate finish is washed repeatedly to remove the cement paste. The concrete slabs and walls should be sprayed with curing compound immediately after the washing process is finished. A sealer can be applied to the surface of the concrete to brighten the aggregate's appearance. If a bright finish is desired, the sealer will have to be applied as often as twice a year.

Smooth Surface Treatments

Rubbed Finish

A rubbed finish is done after any patching has been completed and as soon after form removal as practical (no later than 24 hours). The entire surface is wetted and rubbed with an abrasive, such as a carborundum brick, until a uniform colour and texture are achieved.

Sand Floated Finish

Sand floating must be done within six hours of form stripping. The surface is wetted, and sand is worked into the surface using a wooden hand float in a circular motion to produce a uniform colour and texture.

Sack-Rubbed Finish

For a sack-rubbed finish (also known as a *grout cleandown finish*), timing is not as critical as with the rubbed or sand floated finishes. Patching of larger holes needs to be complete and set, and then the concrete surface is wetted for at least one hour prior to sacking. The mix is 1 part cement, 1.5 to 2 parts fine sand and enough water to create the consistency of thick paint.

The mix is applied to the surface with a brush, trowel or rubber float and vigorously rubbed into the surface with burlap fabric (sacking) or a wooden or rubber float until the small air holes (bug holes) are filled. Extra surface grouting material should be removed using a rubber float in a sawing motion.

The last step is to use a sack or rubber float to work a dry mix of the same proportions onto the concrete surface, which should still be damp. The end result is a finish that has a uniform colour and texture.

Grinding and Polishing

Grinding and polishing concrete is a process that is similar to sanding a hardwood floor. A power grinder and edger are used with diamond disks ranging from 16 to 3000 grit. A hardener (densifier) is sprayed on the concrete surface each time a new grit size is used.

When grinding is complete, the last grinding disk is replaced with a burnishing pad for polishing. A sealer is applied to the concrete before the last pass with a burnishing pad. The result is a stone-like surface that shines.



Now complete Self-Test 4 and check your answers.

Self-Test 4

1. What type of hammer should be used for nailing form sheathing?

2. What type of release agent is normally used on architectural concrete forms?

3. What is the advantage of a rubber-type form liner?

4. What precaution should be taken if tie holes are to be left exposed?

5. What three things are rustication strips normally used for?

6. When should rustication strips be removed from the concrete?

7. What are chamfer strips used for?

8. If the plywood is being bent across the grain and the radius is 5 feet, what is the thickest plywood that can be dry bent for this purpose?

9. When can formwork for architectural concrete be stripped?

10. Why are wooden wedges and wooden pry bars used to help strip forms?

11. How is a sand floated finish created?

Answer Key

Self-Test 1

1. Architectural concrete is concrete that is left exposed to view after the building is finished.
2. Because the concrete surface is also the finished surface, it saves cladding costs. Maintenance costs are reduced, since most concrete surfaces require very little maintenance.
3. 1/400 in Canada and 1/360 in the United States
4. Fibreglass-reinforced plastic – it is used for forms when a smooth surface and/or unusual shapes are desired.
5. to create textures from very smooth to quite rough, or to create decorative designs
6. a mirrored cut-stone look

Self-Test 2

1. A smooth, flat surface (unless a rough-textured surface is required) with a uniform colour and texture. Patterns in the concrete should have clean, straight lines. Tie holes should be spaced evenly, and there should be no honeycomb or bug holes.
2. c. The contractor is responsible for the formwork design, but normally it must be approved by a professional engineer.
3. to show an example of the quality and texture of the finished surface of the concrete
4. All construction joints, control joints, expansion joints, chamfers, rustication strips, reveals and other special design features. Plans should also include locations and details of all metal embeds.
5. The amount the construction is allowed to deviate from plumb, level, positioning, dimension, etc.
6. cement and plasticizer
7. to ensure sufficient strength and to give a pleasing appearance (unless tie holes are patched)
8. to give protection or support or to provide a welding surface

Self-Test 3

1. Rectangular solid $= 0.600 \times (0.270 + 0.650 + 0.270) \times 0.900$
 $= 0.643 \text{ m}^3$
 Half cylinder $= (3.1416 \times (0.650/2)^2 \times 0.900)/2$
 $= 0.149 \text{ m}^3$
 Total volume $= 0.643 \text{ m}^3 - 0.149 \text{ m}^3$
 $= 0.494 \text{ m}^3$
2. Cylinder volume $= 3.1416 \times (0.600/2)^2 \times 1.600$
 $= 0.452 \text{ m}^3$
 Capital head $= \text{Large cone volume minus small cone volume}$
 $= (1.600 \times [\frac{1}{3} \times (3.1416 \times 0.600^2)]) - (0.800 \times [\frac{1}{3} \times (3.1416 \times 0.300^2)])$
 $= 0.603 - 0.075$
 $= 0.528 \text{ m}^3$
 Total volume $= 0.452 + 0.528$
 $= 0.980 \text{ m}^3$

Self-Test 4

1. a smooth faced hammer
2. a non-staining type
3. strips easily and can be reused
4. Ties will have to be laid out very carefully following the architect's drawings.
5. to hide formwork seams, control joints and construction joints
6. after the concrete has sufficient strength to resist damage and the strips have had sufficient time to shrink
7. to bevel or round outside concrete corners, making them more resistant to mechanical damage
8. $\frac{3}{8}$ "
9. when the okay is given by the professional engineer based on concrete strength
10. to avoid marring the fresh concrete surfaces
11. Sand floating must be done within 6 hours of form stripping. The surface is wetted and, using a wooden hand float in a circular motion, sand is worked into the surface to produce a uniform colour and texture.

