

Civil engineering

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1 Mortar, masonry, concrete and steel reinforcement

Mortar and concrete are essential building materials. Combined with steel and stone, they make up reinforced concrete and masonry.

The densities of different construction materials are given in Table I:

- mortar: mixture of cement/sand/water;
- concrete: mixture of cement/sand/gravel/water.

Table I: Densities of several building materials.

Sand	1 600 kg/m ³	Masonry, stone	2 500 kg/m ³
Gravel	1 800 kg/m ³	Masonry, hollow block	1 500 kg/m ³
Cement	1 440 kg/m ³	Masonry, solid block	2 150 kg/m ³
Cement mortar	2 000 kg/m ³	Masonry, hollow brick	1 400 kg/m ³
Reinforced concrete	2 500 kg/m ³		

Volumetric measurements are usually quoted in the UK and USA (a 50-kg bag of cement has a volume of 35 l) as follows:

- 1:3 mortar – 1 volume of cement per 3 volumes of sand;
- 1:2:4 concrete – 1 volume of cement per 2 volumes of sand and 4 of gravel.

The following denomination is commonly used on building sites: 1 bag of cement per 3 barrows of sand; 1 bag of cement per 2 barrows of sand and 4 of gravel. This does not correspond to the UK/US quantities quoted above.

CHOICE OF INGREDIENTS

Cement: the most common used cement is Portland. It should be dry, powdery and free of lumps. When storing cement, try to avoid all possible contact with moisture. Store away from exterior walls, off damp floors, and stacked close together to reduce air circulation.

Water: in general, water fit for drinking is suitable for mixing concrete. Impurities in the water may affect concrete setting time, strength and shrinkage, or promote corrosion of reinforcement.

Sand: sand should range in size from less than 0.25 mm to 6.3 mm. Sand from beaches, dunes or river banks is usually too fine for normal mixes.

Gravel: optimum gravel size in most situations is about 2 cm.

Note. – It is extremely important to have clean sand and gravel. Even small amounts of silt, clay or organic matter will ruin concrete. A very simple test for cleanliness is done with a clear wide-mouthed jar. Fill the jar about half full of the sand to be tested, and cover with water. Shake the mixture vigorously, and then allow it to stand for three hours. In almost every case there will be a distinct line dividing the fine sand suitable for concrete and that which is too fine. If the very fine material amounts to more than 10% of the suitable material, then the concrete made from it will be weak. This means that other fine material should be sought, or the available material should be washed. Sand and gravel can be washed by putting it in a container such as a drum. Cover the aggregate with water, stir thoroughly, let it stand for a minute, and pour off the liquid. One or two such treatments will remove most of the very fine material and organic matter.

1.1 Mortar

1.1.1 APPLICATIONS AND MIXES

- Building masonry walls
- Coatings, various small jobs in gaps, sealing
- Manufacture of cement blocks
- Different cement/sand ratios are used depending on application (Table II, Box 1).

Table II: Mixes for cement mortars.

Type of mortar	Cement (kg)	Sand (l)* 0.1 - 5 mm	UK/US denomination
Weak mortar	200 (4 bags)	1 120	1:8
Medium mortar (rough plaster, masonry mortar)	300 (6 bags)	1 260	1:6
Strong mortar (smooth plaster-bedding)	400 (8 bags)	1 120	1:4

* 1 m³ of aggregates makes up 1 100 to 1 200 l when expanded.

1.1.2 USE AND PRECAUTIONS

The mix must be homogeneous and prepared in an appropriate area (on a concrete slab, board etc.). The usual procedure is to turn the heap of sand to which the cement has been added until it is thoroughly mixed.

It is advisable to wet only the quantity of mortar to be used in the next half hour, because mortar is difficult to work after that time.

The amount of water needed depends on the cement mix and the wetness of the sand. Approximately 200 litres of water are necessary to obtain 1 m³ of mortar mixed at 300 kg cement/m³.

The correct quantity of water is chosen to obtain a plastic mortar: to check the proportions, the mortar is smoothed with a trowel: it should shine, but there must be no free water. Too much water may cause serious shrinkage and cracks (see Box 2). Mortar must be sheltered from sun and wind to avoid drying too fast.

1.2 Masonry

1.2.1 APPLICATIONS

- All major and minor jobs: foundations, walls, pillars etc.
- Advantages: use of materials sometimes available on site, and technology which is often mastered locally.
- Limitations: for large jobs (large capacity water tanks, retaining walls), it requires large quantities of materials.

1.2.2 USE AND PRECAUTIONS

- Dry stone (cut or rough), prefabricated building blocks (concrete or mortar), or clay bricks, can be used. Clean and previously wetted stones should be used:
 - about 25% of mortar for 75% of bricks or building blocks;
 - about 30% to 35% of mortar for 70 to 65% of stones.
- Medium mortar is used (300 kg of cement/m³) for joints.

1.2.3 PREFABRICATED MORTAR BLOCKS

It is very useful to manufacture blocks with a specialist team, to supply a large number of sites, and help to build a stock for future jobs. The rainy season is a good period for this work because large amounts of water are needed for watering the blocks (for curing).

Box 1

Cement.

Cement is produced by firing argillaceous limestone rocks, or a mixture of clay and limestone (5 to 25% clay, 75 to 95% limestone) at high temperatures (1 400 °C). Once calcined, the mixture is finely ground.

The addition of water to the cement causes a chemical reaction (hydration): the calcium silicates and calcium aluminates change, and become cement hydrates with the formation of crystals. This precipitate of micro-crystals is what causes the setting phenomenon: the hardening phase is simply the continuation of the crystal-formation process.

Setting and hardening are assisted by humidity and high temperatures. In normal conditions (depending on temperature and mix), approximate times are:

- 30 mins to 1 h for setting: then the concrete loses its plasticity;
- 4 hours until the setting process ends: then the concrete cannot be worked;
- finally, hardening occurs. This can take from 6 months to 1 year.

Concrete, like mortar, changes over time. Concrete becomes resistant when it hardens (Table I). Cements are characterised by their setting speed, and particularly by their compressive resistance (in bar), at 7 and 28 days of hardening.

Table I: Resistance increase during the hardening period.

Duration	Total resistance (%)
3 days	20
17 days	45
28 days	60
3 months	85
6 months	95
1 year	100

A rough general classification is:

- slow-setting cement (artificial Portland artificial cements, APC);
- ordinary cement;
- high-resistance cement;
- quick-setting cement for specific jobs (in contact with water, for sealing, etc.), which is less resistant than standard cement (80 kg/cm² at 28 days, compared with 250 kg/cm² for ordinary cement).

Generally, cement type (APC, CPJ etc.), and resistance code (35, 45 etc.) are marked on the bags (sometimes resistance at 7 and 28 days is also marked). Bags generally carry a more or less explicit designation of the type of cement and its resistance.

Most standard cements are APC or CPJ, in resistance class 35 or 45, i.e. with respective resistances of 350 and 450 kg/cm².

In theory, a specific cement is chosen depending on its use, but in practice, generally only one type of cement is available. Therefore, the mix is what varies, rather than the type of cement: for example, the quantity of cement is greater in concrete for making a cutting ring for well digging (350 to 400 kg cement/m³) than for making concrete slabs (200 to 250 kg/m³).

The way cement is stored greatly affects its properties: cement absorbs ambient humidity easily, resulting in resistance loss if stored carelessly or for too long (about 40% less resistant after 12 months of incorrect storage).

Box 2

Shrinkage.

Controlling shrinkage plays an important part in the proper utilisation of cement. Shrinkage is partly a thermal process, but primarily a hydraulic one (water evaporation), which causes cracks in mortars and concretes. This hydraulic shrinkage continues for a long time after the mortar or concrete has been laid (Table I).

Some reasons for excessive shrinkage are:

- too much water (the excess water cannot be used in the reaction and can only evaporate, causing hydraulic shrinkage);
- poor cement curing (also involving excessive evaporation);
- high cement/aggregate mix (400/500 kg cement/m³ for very rich concrete and mortars);
- irregular aggregate grain size.

Table I: Effective shrinkage period (good water proportion, temperature not too high).

Duration (days)	Shrinkage (mm/m)
2 days	0.04
7 days	0.13
28 days	0.27
3 months	0.4
1 year	0.42
3 years	0.45

A typical team for a block workshop is made up of 1 mason and 6 labourers, divided into three groups:

- 3 labourers for mixing mortar,
- 2 labourers for casting blocks,
- 1 labourer responsible for watering and storing the blocks.

Quantities of materials and output are given in Table III. Moulds are made of metal, and require a trained welder for their manufacture (Figure 1). These moulds are greased with used oil to facilitate release of the blocks. Normally two types of blocks, of different sizes (Table IV), are manufactured. An example of a block workshop is given in Figure 2.

Table III: Quantities and output for the manufacture of mortar blocks.

Bags of cement (50 kg)	Volume of sand (l)	Volume of water (m ³) (including watering)	Number of blocks
1	140	0.04	20 to 25
16	2 400	2	400
Output	400 blocks/day with a well-organised team		
Losses (broken blocks)	5 to 10%		

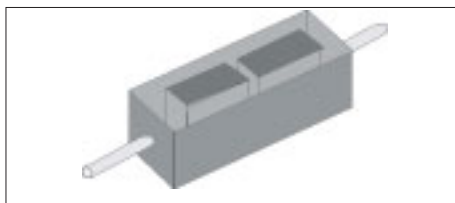


Figure 1: Mould for mortar blocks.

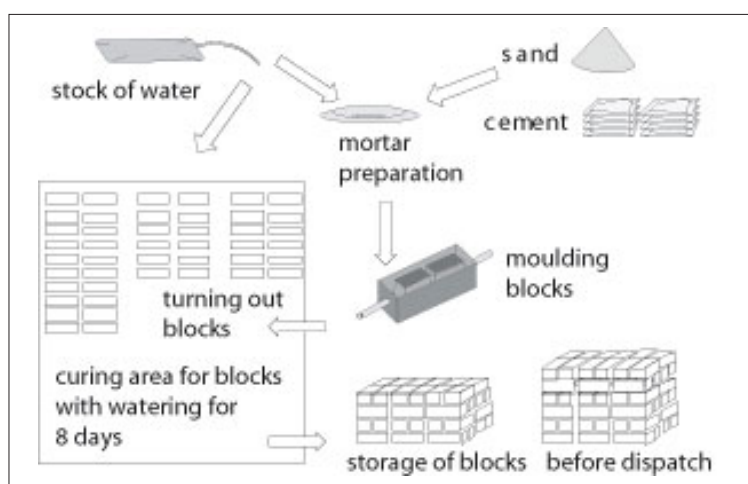


Figure 2: Plan of a mortar block workshop.

Table IV: Common measurements for mortar blocks.
W, width. H, height. L, length.

W	H	L (cm)	W	H	L (inches)	Use
15	20	40	6"	8"	16"	Load-bearing walls
10	20	40	4"	8"	16"	Partition walls

1.3 Concrete

1.3.1 APPLICATIONS

A distinction can be made between mass concrete and reinforced concrete. Mass concrete works only in compression, whereas reinforced concrete works in both compression and tension (reinforcement steel resists tensile stresses). This is why reinforced concrete is used in such a wide range of applications – foundations, retaining walls, and other structures such as platforms, slabs, pillars or beams, and special applications such as well linings, concrete rings, headwalls etc.

1.3.2 MIXES

The standard mix for concrete (Table V) is 300 kg of cement per m³ of aggregate, containing 1 volume of sand for 2 volumes of gravel, which means in practice 1 bag of cement for 1 barrow of sand and 2 of gravel. A higher cement content gives higher compressive resistance (Table VI), but shrinkage increases (see Box 2).

Table V: Mixes for concrete.

Type	Cement (kg)	Sand (l)* 0.1 - 5 mm	Gravel (l)* 6 - 25 mm	UK/US denomination
Reinforced concrete in severe conditions	400	400	800	1 : 1.5 : 3
Standard (pump bases, aprons, beams, etc.)	300 to 350	400	800	1 : 2 : 4
Foundations and pipe surrounds	200 to 250	400	800	1 : 3 : 6

* 1 m³ of aggregates make up 1 100 to 1 200 l when expanded.

Table VI: Effect of cement content on resistance at 28 days.

Mix (kg/m ³)	Resistance to compression (bars)	Resistance to tension (bars)
300	210	20
350	250	22
400	280	24

1.3.3. ESTIMATING QUANTITIES OF MATERIAL NEEDED

- Calculate the volume of concrete needed.
- Estimate the total volume of lease material needed by multiplying the required volume of concrete by 1.65 (this includes 10% extra to compensate for losses).
- Add the numbers in the volumetric proportion that you will use to get a relative total. This will allow you later to compute fractions of the total needed for each ingredient. (i.e. 1:2:4 = 7).
- Determine the required volume of cement, sand and gravel by multiplying the total volume of dry material (Step B) by each component's fraction of the total mix volume (Step C) i.e. the total amount of cement needed = volume of dry materials x 1/7.
- Calculate the number of bags of cement by dividing the required volume of cement by the unit volume per bag (0.0332 m³ per 50-kg bag of cement or 1 ft³ per 94-lb bag).

For example, for a 2 m x 2 m x 10 cm thick pump pad:

- Required volume of concrete: 0.40 m³
- Estimated volume of dry material: $0.4 \times 1.65 = 0.66 \text{ m}^3$
- Mix totals: $1 + 2 + 4 = 7$ (1:2:4 cement + sand + gravel)
- Ingredient volumes:
 - $0.66 \times 1/7 = 0.094 \text{ m}^3$ cement
 - $0.66 \times 2/7 = 0.188 \text{ m}^3$ sand
 - $0.66 \times 4/7 = 0.378 \text{ m}^3$ gravel
- Number of bags of cement: $0.094 \text{ m}^3 \text{ cement} / 0.0332 \text{ m}^3 \text{ per } 50\text{-kg bag} = 2.83 \text{ bags of cement (use three bags)}$

1.3.4 WATER CONTENT IN CONCRETE, SEPARATION

The functions of the water are to hydrate the cement, to wet the aggregate, and to ensure sufficient plasticity in mortar and concrete. Depending on the application and the quantity of cement, a certain quantity of water is added; for example, concrete is 'wetted' more to slide it into shuttering with reinforcement than to cast a footing.

The quantity of water used in the preparation of concrete also affects separation, i.e. the loss of homogeneity of the material and consequently reduced resistance. If no precautions are taken, the constituent elements of concrete (gravels, sand, cement), which have very different densities, tend to separate, the heaviest falling to the bottom and the lightest remaining at the surface.

1.3.5 USE AND PRECAUTIONS

Mixing is carried out on a well-prepared area (e.g. a concrete slab), where the procedure is to dry-mix the cement, sand, and gravel, turning over the heap regularly.

Once the dry materials are properly mixed, a crater is prepared, into which a suitable quantity of water is poured.

The water is allowed to disperse before beginning the wet mixing, which ensures the plasticity of the concrete.

The quantity of water required can be calculated from Table VII.

Table VII: Volume of water for 1 m³ of concrete at 350 kg cement/m³ (dry aggregates).

Volume of water (l)	Quality of concrete	Water/cement (l/kg)
151	Very firm	0.43
175	Firm	0.50
200	Plastic	0.57
221	Soft	0.63
231	Too soft	0.66

Some appropriate precautions to take are:

- do not add too much water, to avoid excessive shrinkage and separation of the concrete;
- protect cast concrete from sun and wind (plastic sheeting, cement bags, mats etc.), and moisten exposed surfaces, covers, and shuttering, to ensure slow drying and sufficient humidity for the chemical reaction of hardening to continue;
- stick to the correct times for removal of moulds and shuttering (Table VIII);
- allow sufficient time before putting the structure into service, e.g. generally 28 days for filling tanks with water;
- ensure correct joints between casting stages (successive stages should be cast no more than 24 hours after the previous one, casting onto a clean and roughened surface);
- vibrate the concrete well to compact it;
- work at temperatures higher than 5 °C.

Table VIII: Time required before removing shuttering at 18 °C for standard concrete.
For water tanks built in several stages, the rule is to cast one stage per day.

Tank walls, well rings etc.	24 hours
Slabs cast <i>in situ</i>	2 to 3 days
Prefabricated slabs	3 days

1.3.6 CONCRETE JOINTS

Good joints between successive concrete pours are very important for the solidity and impermeability of a structure. The conditions for a good joint are: a correct angle of joint, a well-prepared surface, and a very short delay between successive pours (Table IX).

The correct angle of joint varies depending on the type of stress undergone by the structure (Figure 3).

For a load-bearing wall or partition wall under vertical stress, joints are perpendicular, whereas for a floor or the walls of a water-tank, angled sides are preferable.

To guarantee good adhesion, it is necessary to roughen the surface of the joint to provide a key. The roughened surface is then brushed to remove rubble and dust, and the surface of the joint moistened before pouring.

Some additives, such as Sikalatex, improve adhesion (Box 3).

Table IX: Resistance of a concrete joint.

Delay between successive pours	Resistance of the joint
1 day	325 kg/cm ²
7 days	210 kg/cm ²
18 days	65 kg/cm ²

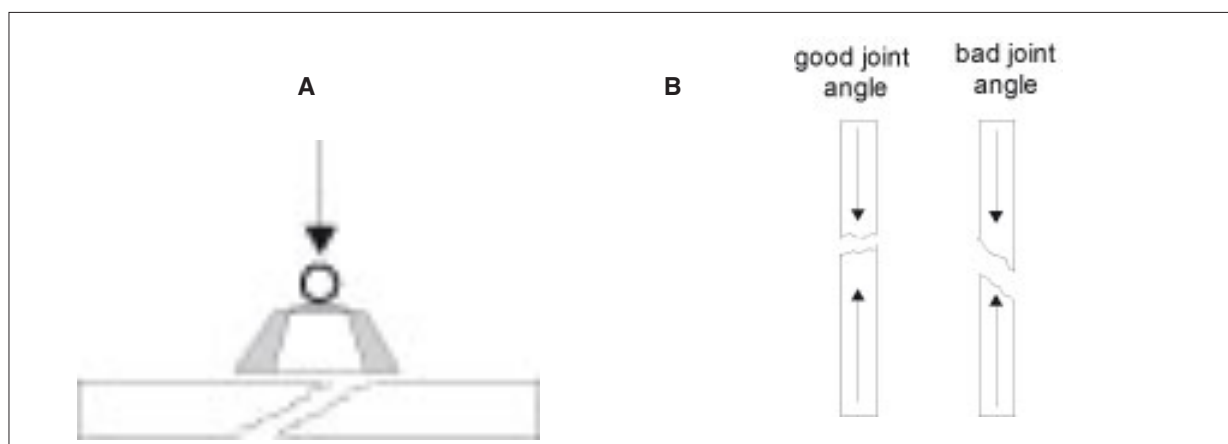


Figure 3: Concrete joints.
A: joint in a floor. B: joint in a wall under vertical load.

Box 3

Concrete additives.

There are a large number of additives for concrete and mortar: liquefiers and plasticisers, waterproofing agents, setting accelerators, setting inhibitors, antifreeze etc. Two products widely used in water-supply structures are the liquid waterproofing Sika, and Sikalatex.

Liquid waterproofing Sika

This additive is used to make waterproof mass concrete (use for walls and floors of water tanks), as well as concretes resistant to water containing gypsum, or sea water. It comes in the form of a white liquid concentrate in 210-kg drums, which must be stored away from the sun.

Sika liquid waterproofing is added to concrete with the mixing water. The mix is 1 to 1.5% of the cement weight, i.e. about 1-1.5 litres of product for 100 kg of cement.

Sikalatex

This product dramatically improves the adhesion of mortar or concrete to all surfaces, even smooth ones (for example, joints between two pours of concrete), limits the risk of cracks, and ensures high impermeability (in the case of water-tank coatings for example). It is a milky liquid, and comes in concentrated form in 2-litre cans or 30-litre drums.

Sikalatex mortar is a bonding mortar which provides a rough surface, either for repairing concrete, or for a waterproof coat. The standard mix is approximately 0.12 l per m² of bonding layer.

1.4 Steel for reinforced concrete

Reinforced concrete benefits from the combination of the properties of its two materials: the compressive resistance of concrete, and the tensile resistance of the steel incorporated in the concrete structure (Table X).

Table X: Resistances of steel and concrete.

	Tensile resistance (kg/cm ²)	Compressive resistance (kg/cm ²)
Concrete bar	30	300
Steel bar	3 000	3 000

1.4.1 PROPERTIES OF REINFORCEMENT STEELS

The steel used for reinforced concrete is high-adhesion steel, known as HA, which has serrations in order to ensure better adhesion with the concrete.

Smooth reinforcement bars are increasingly falling out of use, and they require particular structural arrangements (greater anchorage lengths).

The correspondence between international and UK/US diameters of bars used for reinforcement are given in Table XI.

Table XI: Correspondence of diameters between international and UK/US units.

Diameter in mm	Diameter in inches
6	1/4"
8	1/3"
12	1/2"
16	2/3"
25	1"

1.4.2 PLACING, ANCHORAGE, OVERLAPS

Some typical reinforcement arrangements for various types of structural element are illustrated in Figures 4 and 5, and in Box 4.

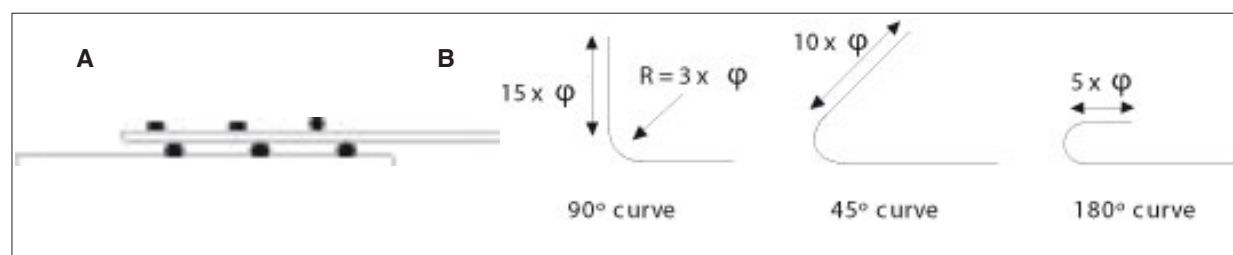


Figure 4: Arrangement of reinforcement bars.

A: welded mesh (overlapped). B: curved bar anchoring lengths.

Box 4

Welded mesh.

Welded mesh (Figure 1) is used for reinforcing slabs and partitions. It replaces standard steel reinforcement bar tied with annealed steel wire, and is easier to use. As with standard reinforcement, welded mesh is characterised by the bar diameter and the mesh size. When placing welded mesh, there should be an overlap of 3 welds in the direction of the main bars.

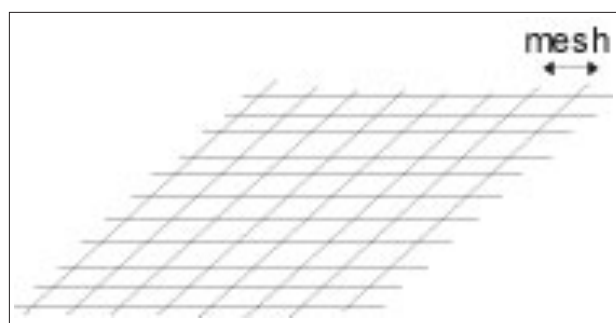


Figure 1: Welded mesh used for the reinforcement of slabs or tank sides.

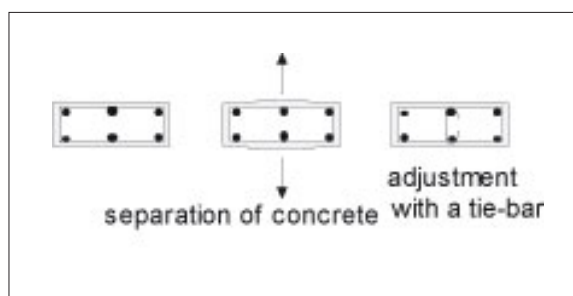


Figure 5: Reinforcement for a pillar.

The transmission of stresses from concrete to steel and vice versa occurs through adhesion. To ensure proper adhesion, it is necessary to have clean surfaces (free from organic matter, oil, rust etc.), to maintain a sufficient length of steel anchorage (Table XII), and to vibrate the concrete correctly. The reinforcement must be covered by at least 3 cm of concrete.

Table XII: Anchorage lengths.

Reinforcement	High adherence	Smooth
Curved	30 diameters	40 diameters
Straight	50 diameters	60 diameters

2 Rapid structural calculations

2.1 Load calculations

To design structures, the loads which they experience (Table XIII) must be calculated. There are two types of load:

- static loads due to the weight of structures (permanent loads);
- dynamic loads due for example to the weight of the water in a tank, or the weight of materials stored on a slab.

Table XIII: Dynamic loads on structures.

Dynamic load for slabs	
Private premises	200 kg/m ²
Public place	500 kg/m ²

Static loads are added to dynamic loads in many calculations; foundations, for example, experience the static loads of the building, plus the dynamic loads. To calculate static and dynamic loads, see Table XXIX.

2.2 Reinforced-concrete elements

The tables in this section provide indications for choosing dimensions and reinforcement arrangements standard structures. In each table, figures in *italics* are optimal from the structural and cost points of view.

2.2.1 DEFINITIONS

Slab: this term is used for suspended slabs (floors), cover slabs (on water tanks), and small structures (e.g. slabs for tapstands and washing areas).

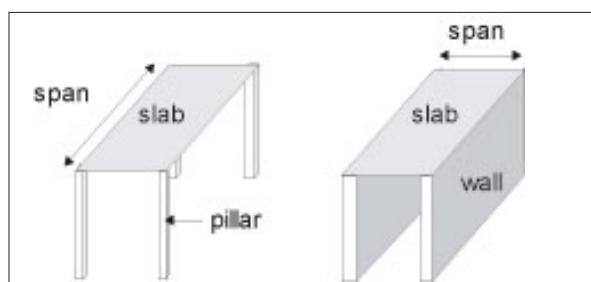


Figure 6: Span of a slab.

Base: the base is a slab on the ground serving as a foundation.

Span (of a slab or beam): the length between the supports on which the beam or slab rests (Figure 6). In the case of a slab supported by four walls, the span considered is the distance between the walls closest to one another. In the case of a slab supported by four pillars, the largest distance between supports is considered the design span.

Mesh: the spacing between the bars in a reinforcement layout. If the spacing between the transversal and longitudinal (or horizontal and vertical) bars is the same, the mesh is called square.

2.2.2 PILLARS

Sizing: the minimum cross section is equal to 1/20th of the pillar height. Pillars can support heavy loads, e.g. in the case of an elevated water tank. The reinforcement arrangements are shown in Figure 7, and the reinforcement sizing in Table XIV.

Table XIV: Reinforcement design, and permissible dynamic loads on a pillar as a function of its height. For a & b, see Figure 7.

Section (a x b, cm x cm)	Main vertical bars		Dynamic load (t) depending on height (m)					
	number	diameter (mm)	2.5	3.0	3.5	4.0	5.0	6.0
15x15	4	10	15.5	12.5	11.0	9.5		
	4	12	16.5	13.5	11.5	10.5		
	4	16	20.0	16.5	14	12.5		
15x20	4	14	21.0	18.5	16.5	13.5		
20x20	4	14			26.0	23.5	19.5	
25x25	4	14			49.5	42.5	35.5	
25x30	6	14			61.5	52.5	50.5	
30x30	4	16				70.5	53.0	48.0

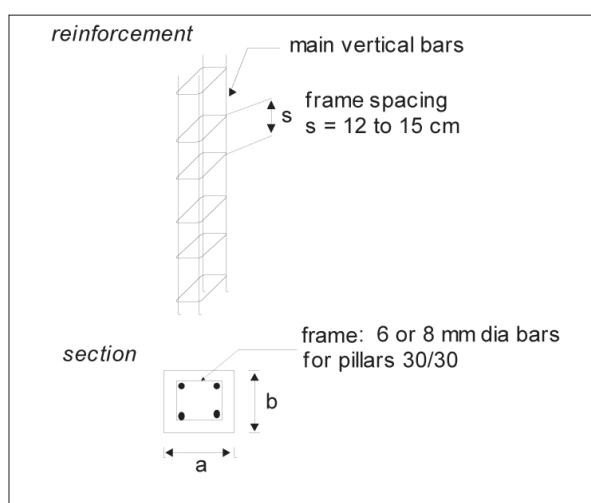


Figure 7: Reinforcement for a pillar.

2.2.3 BEAMS

Sizing: the section of the beam is equal to 0.3 times its height, which lies between 1/10th and 1/15th of its span. The reinforcement arrangements are shown in Figure 8 and Table XV.

Table XV: Reinforcement design, and acceptable dynamic load on a beam, depending on its span.

Section (a x b, cm x cm)	Main reinforcement number diameter (mm)		Dynamic load (t/m) depending on the span (m)								
			1.5	2.0	2.5	3.0	3.5	4.0	5.0	6.0	7.0
10x15	2	8	0.5								
10x20	2	10	1.0	0.5							
15x25	2	12	4.0	2.2	1.4	1.0	0.5				
15x30	2	12		2.8	1.75	1.2	1.0	0.5			
15x40	2	14			2.25	1.65	1.25	0.5			
20x30	3	12				1.8	1.3	1.0	0.5		
20x40	3	16						2.5	2.0	1.6	1.3
20x50	4	16							2.5	1.9	1.3
25x55	4	16								2.1	1.5



Figure 8: Reinforcement mesh (A) and normal dimensions (B) for a beam.

In A, frame spacing is close over the supports, and increases towards the mid-point of the beam, where s varies as a function of load and the dimensions of the beam (dynamic load 4 t, $s = 8$ cm; 2 – 3 t, $s = 12$ cm; 1 t, $s = 15 - 20$ cm).

The greater the ratio between beam height and width ($b:a$), the greater the value of s .

For thick beams (55x25) supporting loads of 1 – 2 t, $s = 40$ cm.

Nominal loads on relatively unstressed beams are 500 to 1 000 kg per m length.

2.2.4 SLABS

Sizing: minimum slab thickness 7 cm:

– slab on 2 walls:

$s = 1/20$ th to $1/30$ th of the span

– slab on 4 supports:

$s = 1/20$ th of the span

– slab on 4 walls:

$s = 1/30$ th to $1/40$ th of the span

The usual reinforcement plan for a slab is shown in Figure 9. The main bars are located towards the bottom of the slab (Figure 10), except in a base, where they are towards the top of the slab.

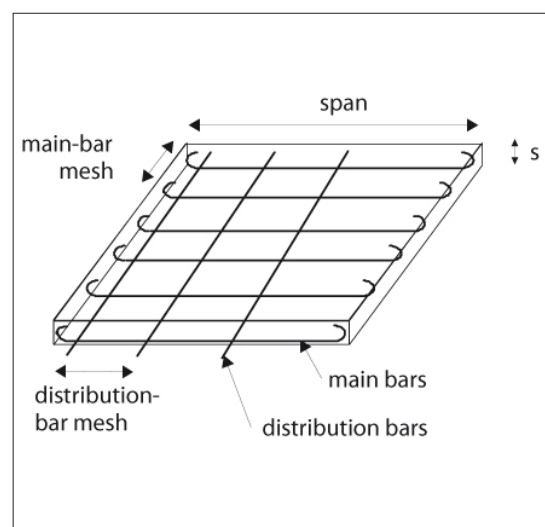


Figure 9: Reinforcement for a slab.

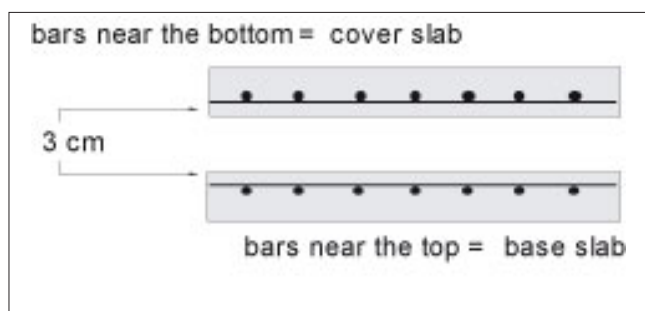


Figure 10: Location of main reinforcement bars according to type of slab (base or cover).

2.2.4.1 Rectangular slab on free supports (2 walls)

The main bars to be used for a slab on two walls, depending on the span, for a uniformly distributed load, are indicated in Table XVI.

Regarding distribution bars, diameters of 6 or 8 mm are used. The mesh is 20 cm for $L < 4$ m in 6-mm bar, and 15 cm for $L > 4$ m in 8-mm bar.

Table XVI: Main bar sizes, and acceptable dynamic load, depending on the thickness of the slab and its span.

Thickness (cm)	Reinforcements		Dynamic load (kg/m ²) depending on the span (m)							
	diameter (mm)	mesh (cm)	1.5	2.0	2.5	3	4	5	6	
7	8	14	500	250						
9	8	10	1 300	600	300	150				
12	10	11		1 500	800	450	150			
15	12	12			1 500	950	375	110		
19	12	9				1 700	800	350	100	
24	16	13					1 800	900	450	
30	16	10							1 200	650

2.2.4.2 Base (ground slab)

Generally this type of structure does not experience heavy stresses (see Table XIII) and the ground pressure provides support. A reinforcement of the same diameter for longitudinal and transverse bars, with a square mesh (Figure 11 & Table XVII), is used.

Table XVII: Mesh sizes for a base (ground slab) depending on the diameter of the bars used.

Diameter (mm)	Mesh (cm)
6	15
8	30
10	40

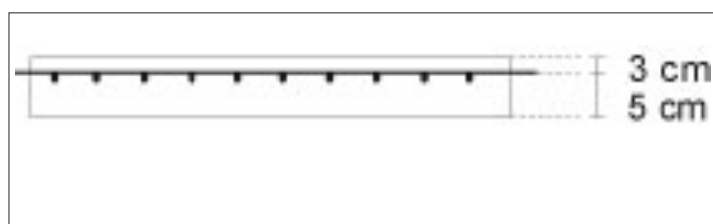


Figure 11: Layout of reinforcement for base slab.

2.2.4.3 Cover slab for water tank

Generally this type of slab is not subject to heavy dynamic loads. Therefore, a minimum thickness of 8 cm can be used. The reinforcement for a circular water-tank cover slab is shown in Table XVIII.

Table XVIII: Reinforcement for a circular water-tank cover slab.

Internal diameter of the tank (m)	Diameter of bar (mm)	Mesh (cm)
2	6	25
3	6	17
4	8	17
5	8	10
6	10	11

Semi-fixed slabs are better able to withstand stresses; reinforcement rules to be observed are illustrated in Figures 12 and 13.

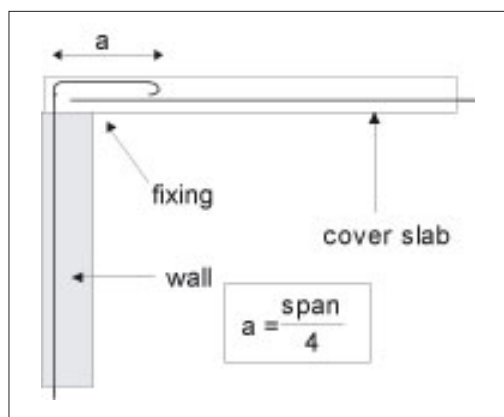


Figure 12: Reinforcement for a semi-fixed slab.

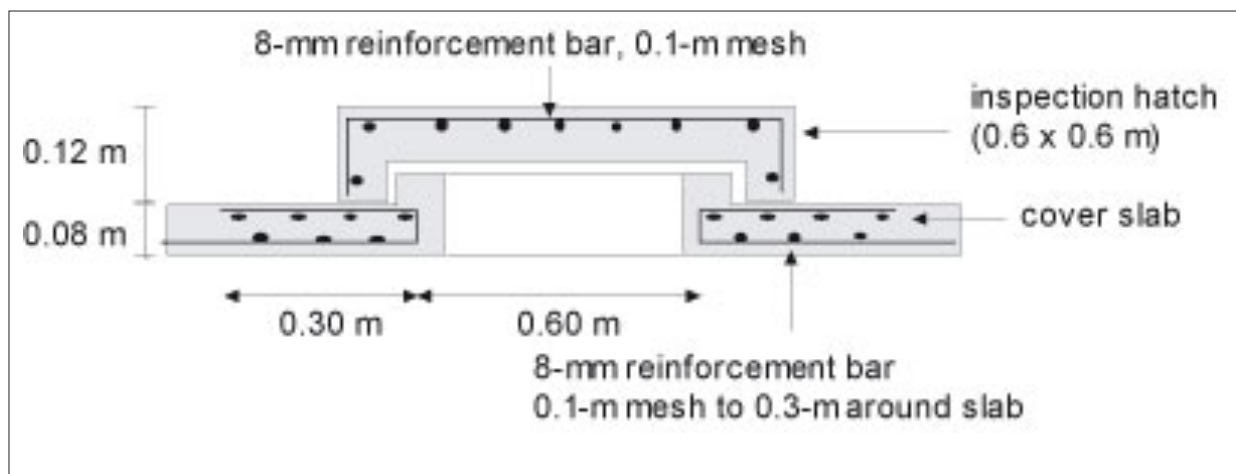


Figure 13: Dimensions and reinforcement for a water-tank cover inspection hatch.

2.2.5 RETAINING WALLS

Figure 14 and Table XIX give the dimensions and reinforcement for a reinforced-concrete retaining wall 3 m high, supporting earth (clay soil, pebbles and gravels, top soil, sandy soil).

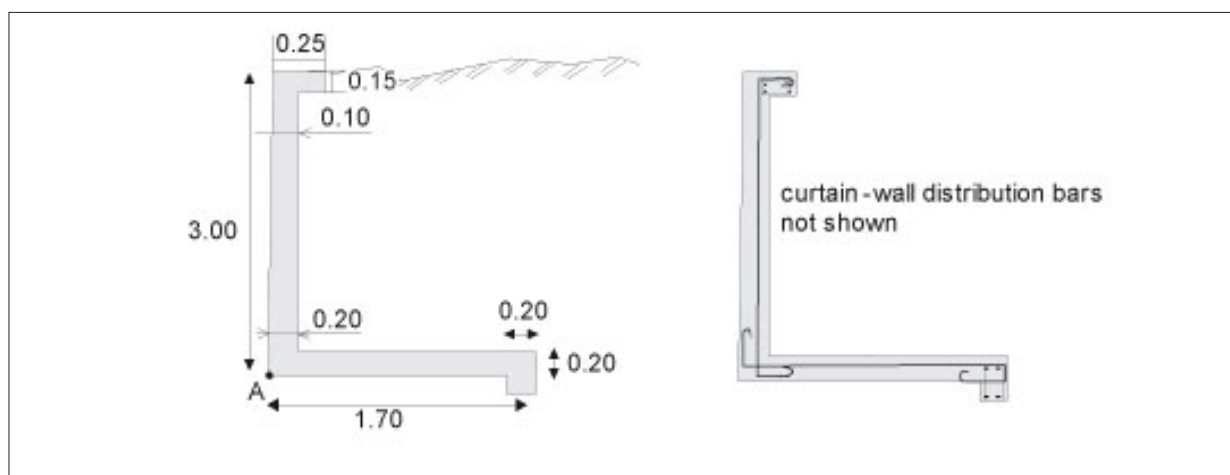


Figure 14: Dimensions and arrangement of reinforcement of a reinforced-concrete retaining wall 3 m high.

Table XIX: Reinforcement dimensions for a reinforced-concrete retaining wall 3 m high.

Reinforcement bars of the curtain wall	10-mm bar / mesh 11.5 cm
Distribution reinforcement bars	Every second bar is stopped at mid-height
	8-mm bar / mesh 20 cm for lower part
	6-mm bar / mesh 20 cm for upper part
Base reinforcement bars (footing)	Same reinforcement as for curtain wall
	10-mm bar / mesh 11.5 cm main bars
	8-mm bar / mesh 20 cm distribution bars

2.2.6 FOUNDATIONS

Generally, foundations are 30 cm deep, in concrete mixed at 350 kg cement/m³ in which large stones are placed (Figures 15 to 17). This concrete is commonly used in foundations because it requires a relatively small volume of concrete and is therefore less expensive. A finishing screed of concrete evens out differences in level due to large stones and at the same time provides a flat surface for erecting walls or pouring concrete for a tank wall.

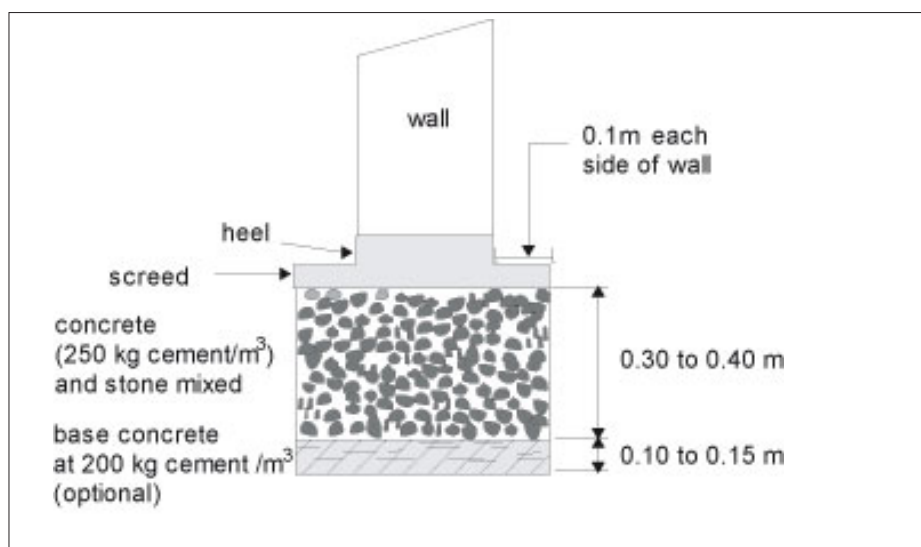


Figure 15: Section through a foundation.

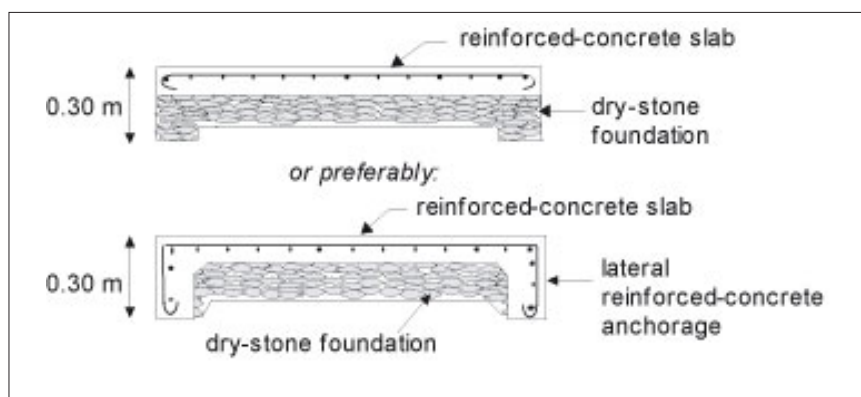


Figure 16: Foundation under slab.

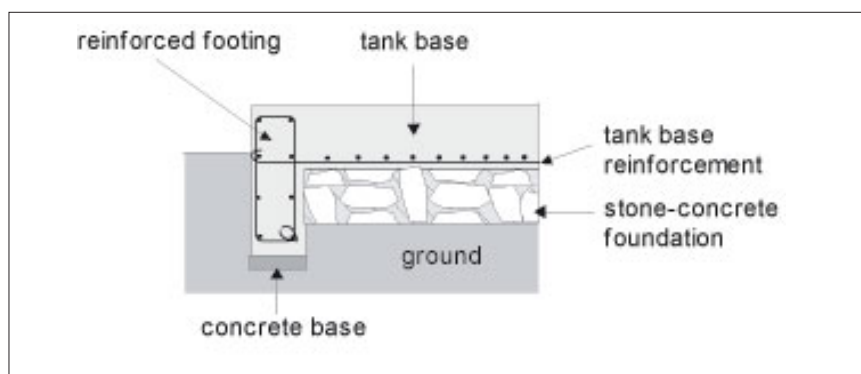


Figure 17: Example of foundation for a medium-sized water tank. Total height of footing is 40 cm (including slab thickness); width of footing is 15 cm.

The best tank shape is circular (Table XX); rectangular tanks have a great number of disadvantages.

Table XX: Examples of the capacity of standard circular water tanks.

Height (m)	1	1.45	1.7	2.65	3.25
Diameter (m)	1.75	2.25	2.75	4.75	6
Capacity (m ³)	2	5	10	45	90

2.2.7 WATER TANKS

2.2.7.1 Circular water tanks

Horizontal reinforcement (in circles) is essential to withstand the stress on the circumference of a circular tank (Table XXI to XXIII). At the top of the tank, the force is very weak, and reinforcement is hardly necessary; however, the space between the circular reinforcement bars should not be more than three times the thickness of the tank wall.

Table XXI: Horizontal reinforcement, in 1-m sections starting from the top. Preferred sizes are shown in italics.

Wall thickness (cm)	10	10	10	10	10
Diameter (m)	1.5 to 2	2 to 2.5	2.5 to 3	4.5 to 5	6
Height (m)	Diameter of the bars (mm) and mesh (cm) used				
0-1	8 / 25	8 / 25	8 / 25	8 / 25	8 / 25
1-2	8 / 25	8 / 25	8 / 25	8 / 15	10 / 17.5
2-3		8 / 15	8 / 15	10 / 12.5	12 / 15
3-4			10 / 15	12 / 12.5	12 / 10

Table XXII: Vertical reinforcement (distribution bars).
In practice, it is sufficient to stop every second bar at mid-height.

Diameter (mm) and mesh (cm) of bars used	
Bottom of tank up to mid-height	8 / 10
Mid-height up to top of tank	8 / 20

Table XXIII: Base reinforcement.

Diameter of the bars used (mm)	Mesh size
6	15 cm – square mesh
8	30 cm – square mesh

An example of reinforcement of a circular tank is shown in Figure 18. The spacing of the horizontal bars increases the nearer they are to the top of the tank, moving away from the heavily-stressed area:

- the procedure is to divide the tank into 1-m sections;
- the spacing is increased to a maximum of three times the thickness of the wall above it.

This configuration is generally modified for large-capacity tanks.

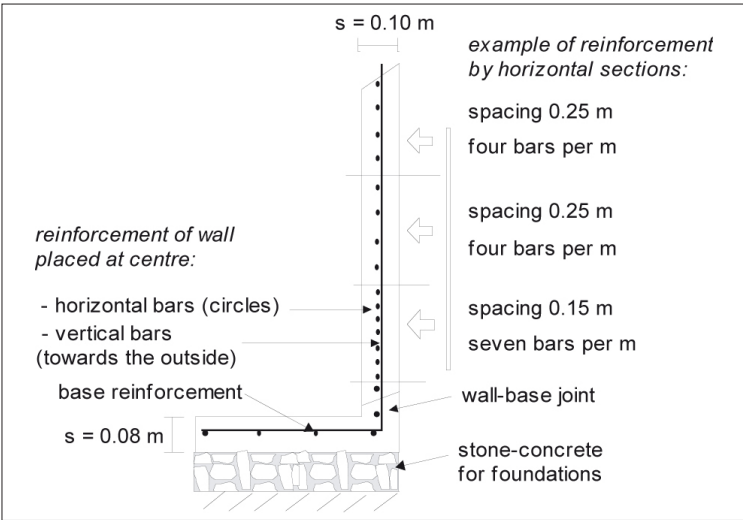


Figure 18: Example of reinforcement for a circular tank.

2.2.7.2 Rectangular tanks

The configuration of an example of reinforcement for a rectangular tank is shown in Table XXIV and Figs 19 to 21.

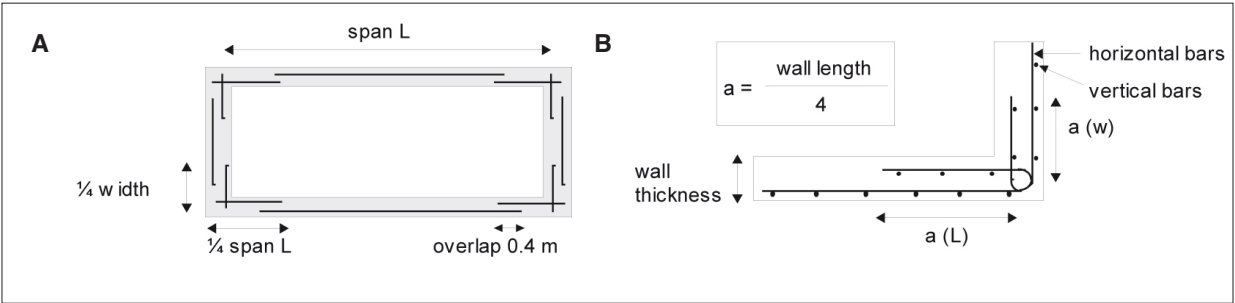


Figure 19: Reinforcement for a rectangular tank.
A: horizontal section through wall reinforcement. B: vertical section through wall and base reinforcement.

Table XXIV: Dimensions and reinforcement of a rectangular water tank.

Capacity (m ³)	3	5	10	20	45	70
Height (m)	1.5	2	2	2.5	3	3
Width/length (m)	1.5 / 1.5	2 / 2	2 / 3	2 / 4	4 / 4	4 / 6
Partition-wall thickness (cm)	10	10	11	11	14	14
Vertical-wall reinforcement						
diameter (mm) / mesh (cm)	12 / 15	12 / 10	12 / 10	16 / 12	16 / 9	16 / 9
Horizontal-wall reinforcement						
diameter (mm) / mesh (cm)	8 / 17	8 / 13	8 / 13	12 / 19	12 / 15	12 / 15
Base reinforcement						
diameter (mm) / mesh (cm)	6 / 15	6 / 15	6 / 15	6 / 15	6 / 15	6 / 15
optional	8 / 30	8 / 30	8 / 30	8 / 30	8 / 30	8 / 30

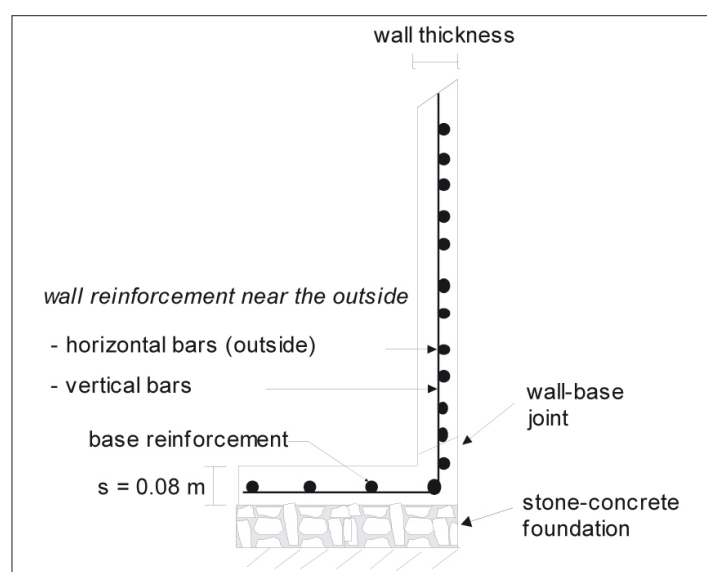


Figure 20: Wall reinforcement for a small rectangular tank: wall length less than 2 m, with overlap ('a' in Figure 19) 40 cm minimum.

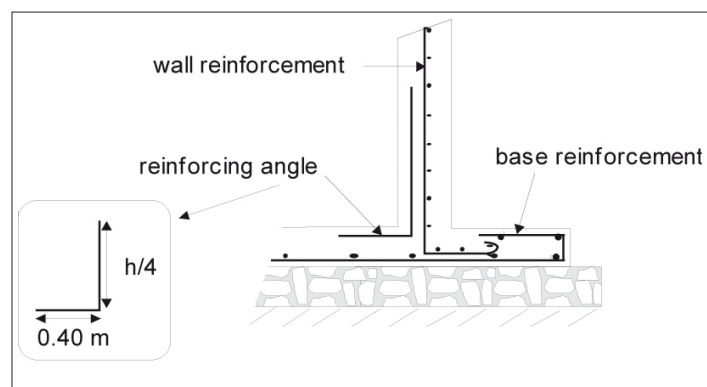


Figure 21: Wall reinforcement for a high-capacity rectangular tank.

2.3 Standard jobs in masonry

It is possible to build retaining walls and small tanks in masonry provided that sufficient stone and enough workers are available.

As the strength of the structure depends on the weight of the masonry resisting the thrust of the water, it is usually necessary to build walls very thick at the base. Table XXV indicates adequate dimensions for an earth-retaining wall (Figure 22), and of a water-retaining wall (tank or dam – Figure 23), calculated to avoid overturning (see Section 3.2.3.7). These calculations correspond to retaining firm earth without dynamic loads.

Table XXV: Dimensions of a masonry retaining wall, and dam wall or tank wall, depending on the thickness at the base, for a thickness of 20 cm at the top.

Retaining wall		Dam wall or tank wall	
Height of the wall (m)	Thickness at the base (m)	Height of water (m)	Thickness at the base (m)
1.0	0.40	1.0	0.65
1.5	0.65	1.5	1.00
2.0	0.85	2.0	1.35
2.5	1.10	2.5	1.72
3.0	1.35	3.0	2.10
3.5	1.60	3.5	2.50
4.0	1.80	4.0	2.80

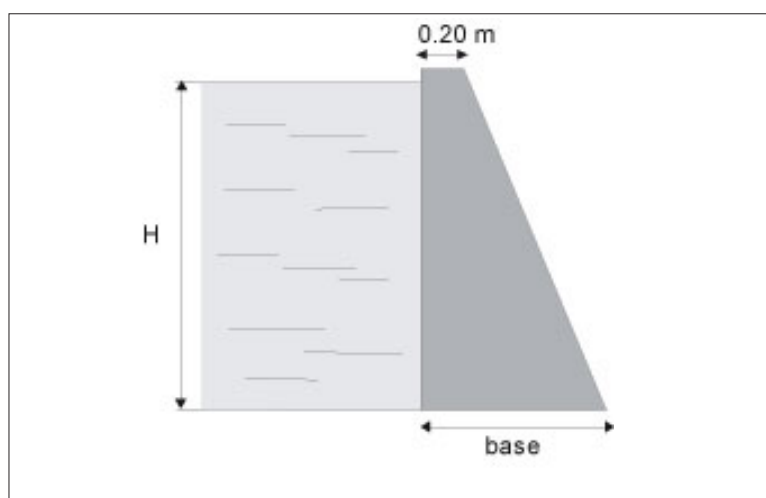


Figure 22: Retaining wall.

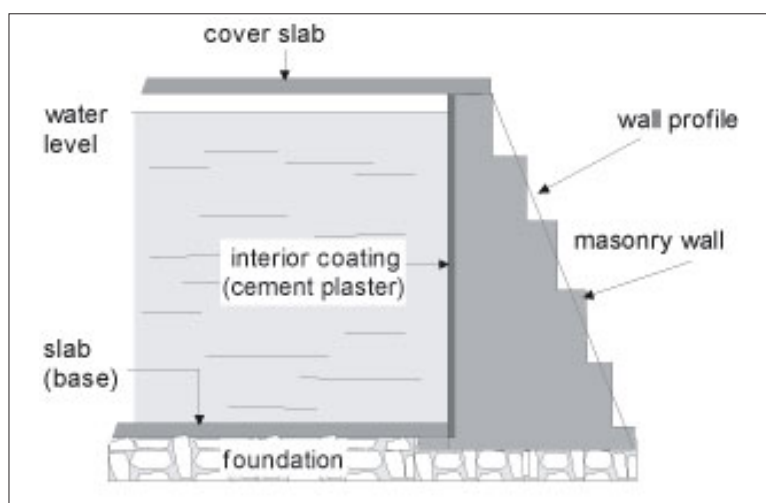


Figure 23: Tank side wall.

It is important not to forget to install weep-holes through earth-retaining walls to let out infiltration water, otherwise the thrust of the soil added to that of the water may cause the wall to collapse.

2.4 Water-point surface works

The surface works of water points can be built in masonry or reinforced concrete. The plans for the different parts and the main building arrangements are shown in Figures 24 to 26 (surface works of a borehole), 27 to 28 (surface works of a well) and 29 to 30 (tapstand and apron).



Figure 24: Important features of surface works for a borehole.

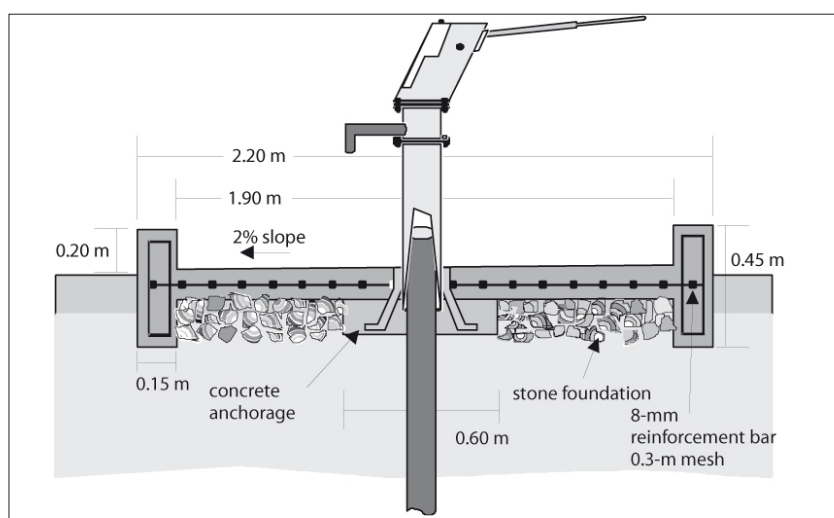


Figure 25: Construction details for typical surface works for a borehole.

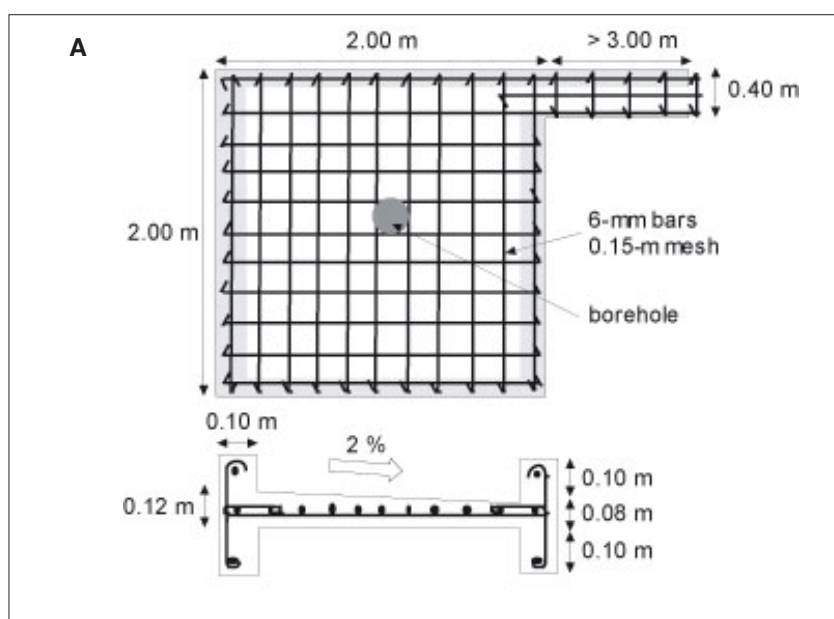


Figure 26: Reinforcement. A: slab.

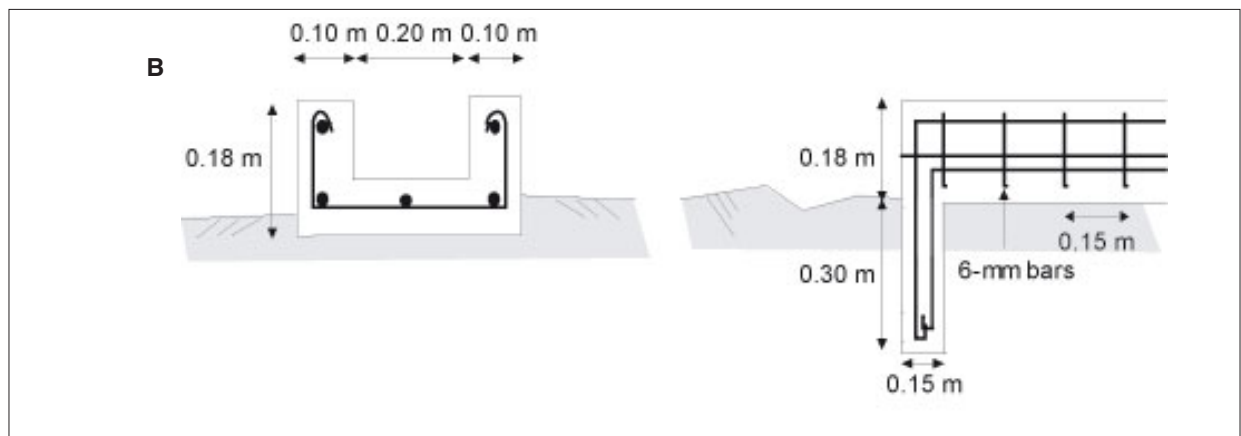


Figure 26: Reinforcement.
B: drainage channel.

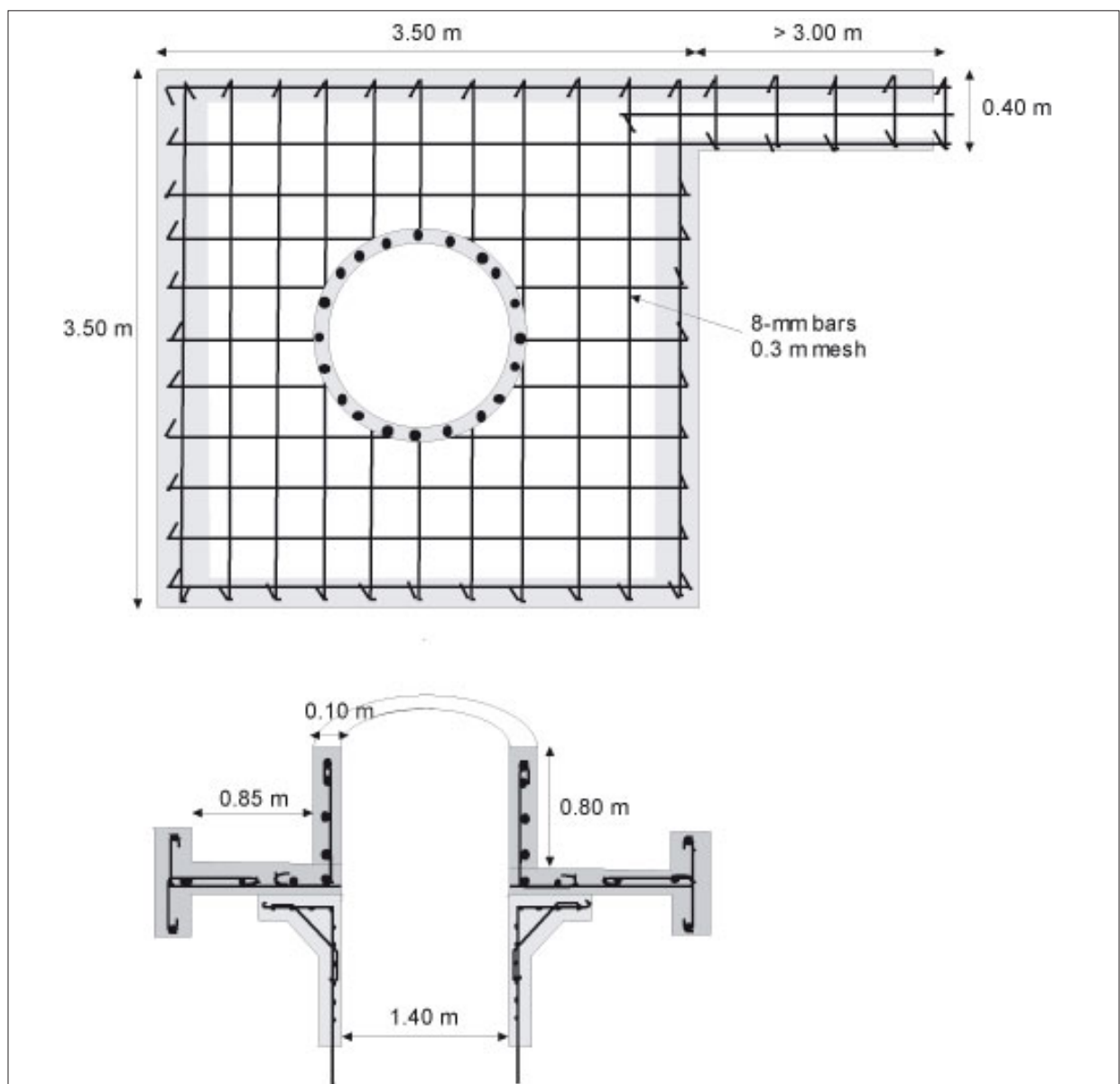


Figure 27: Plan and section of surface works for a well.

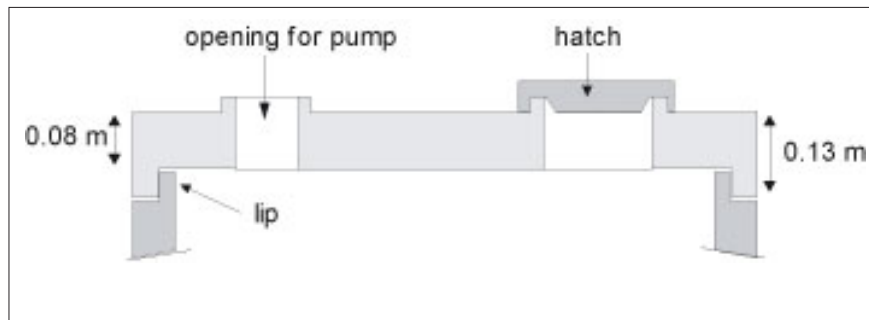


Figure 28: Well cover and inspection hatch.

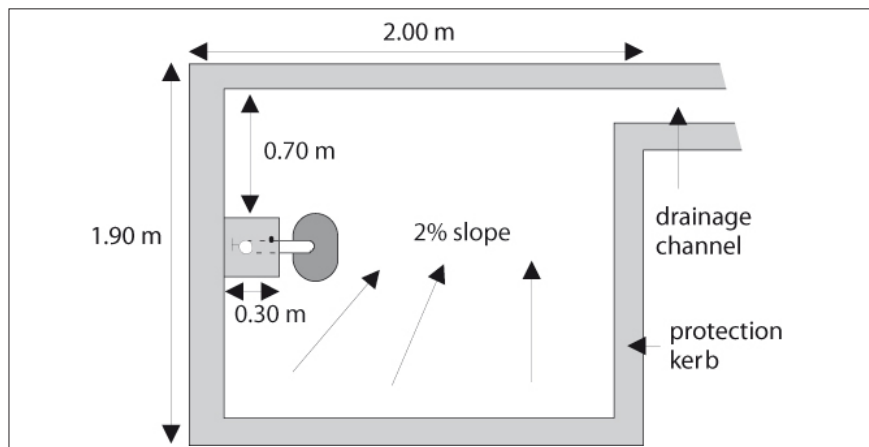


Figure 29: General plan of tapstand and apron.

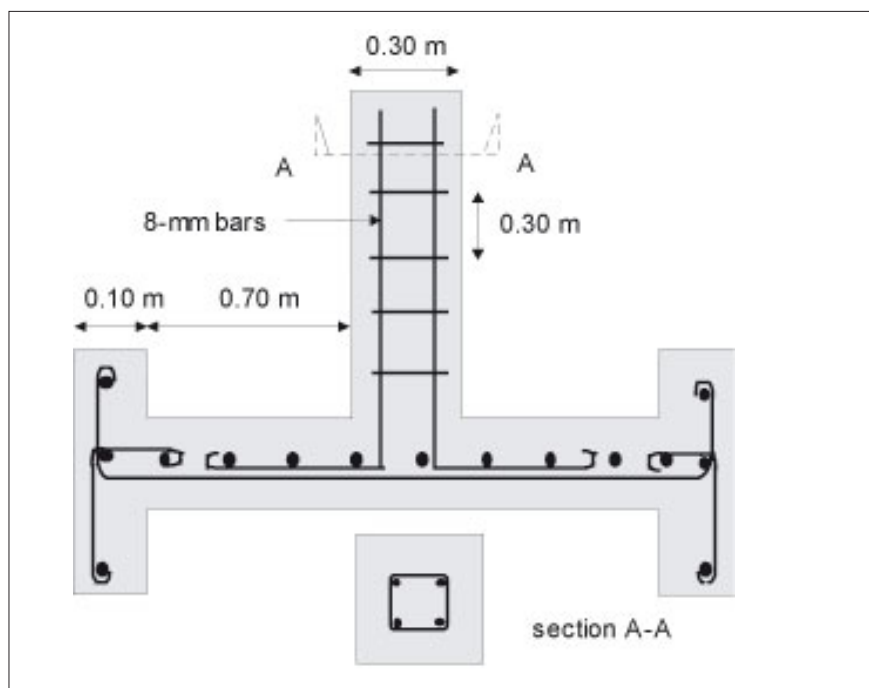


Figure 30: Reinforcement for tapstand and apron.

3 Further information

3.1 Stresses in structures and type of reinforcement

To make proper use of reinforced concrete, it is essential to carry out a precise determination of the loads borne by structures, and how they affect the positioning of reinforcement bars. Two simple examples are given here to facilitate rapid understanding of the procedures to be adopted.

3.1.1 BEAMS AND SLABS ON FREE SUPPORTS

A uniformly-distributed load is applied on the beam (its own weight, to which the dynamic loads to be supported are added – Figure 31A). The beam is distorted under the load, and the following can be observed:

- compressive stress: the load creates a distortion which tends to compress the concrete;
- tensile stress: an area in tension, generally symmetrical in relation to the compression area, appears under the load;
- shear stress (the reaction of the supports causes a force opposing the applied force, which tends to shear the beam).

Without reinforcement, fractures occur due to the tensile and shear stresses (Figure 31B).

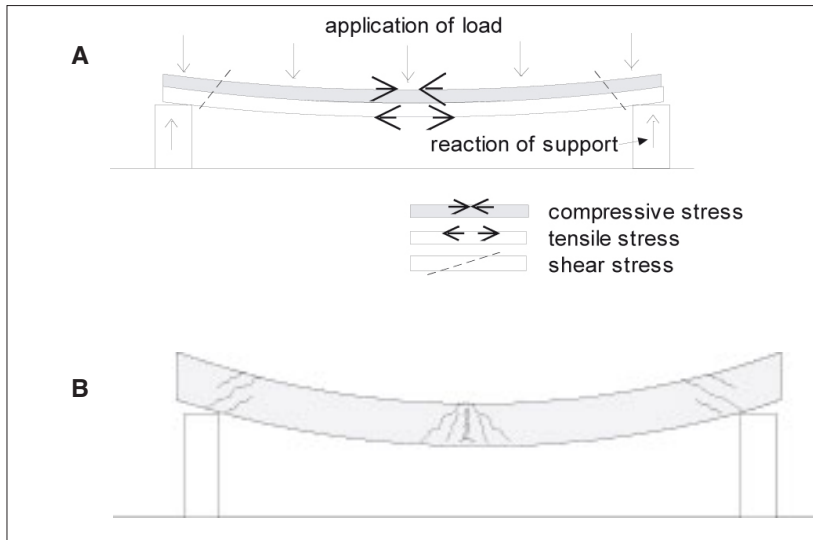


Figure 31: Unreinforced beam on two simple supports under a uniformly-distributed load. A: stresses. B: cracking and fracture under the effect of loading.

3.1.1.1 Positioning of the reinforcement depending on the stresses

Specific reinforcement elements are used, depending on the stresses:

- the main bars (Figure 32A) are placed in areas under tension (tensile stress);
 - frames and stirrups (Figure 32B) are placed in areas where shearing occurs, i.e. mainly next to supports (the support reaction causes shear stress). Frames are then spaced progressively wider towards the mid-point of the beam (where shear stress is zero);
- the distribution and/or installation bars (Figure 32C) facilitate the assembly of the main bars with frames, and distribute the stresses.

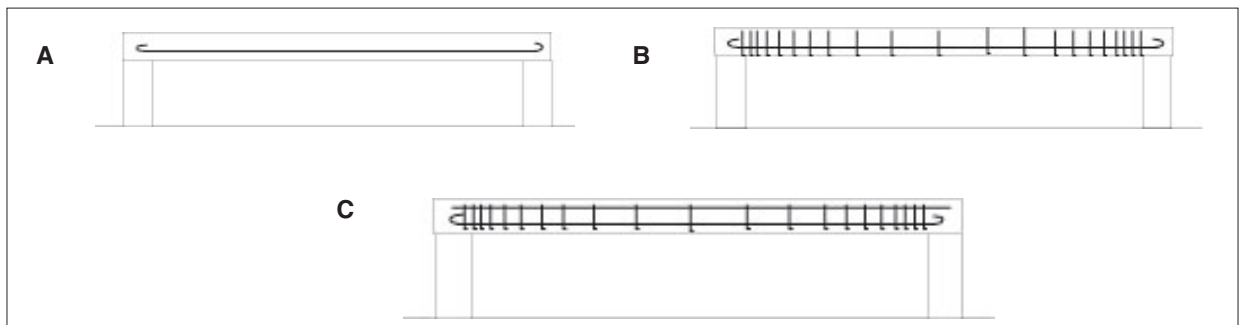


Figure 32: Reinforcement of a beam on free supports.

A: location of main bars in the lower part of the beam (tensile area). B: location of frames close together near the supports and gradually more spaced out towards the mid-point of the beam. C: location of installation bars to permit assembly of frames and main bars.

3.1.1.2 Extension to the case of a full slab supported by 2 walls (cover)

From a mechanical point of view, a slab is similar to a set of beams attached to one another, supporting a uniformly distributed load. Shear stresses are much lower than in a beam (geometric effect), and frames are not necessary. However, distribution bars, placed perpendicular to the main bars (tied with steel wire), are necessary to distribute the load over the whole surface of the slab, to avoid large cracks (Figure 33).

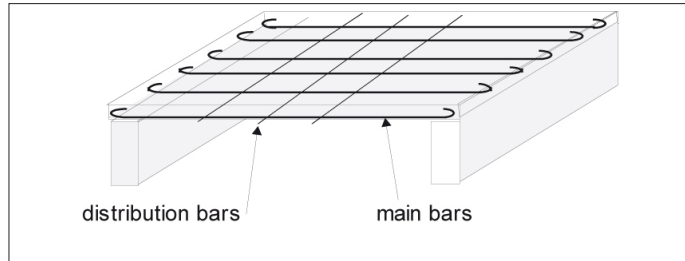


Figure 33: Reinforcement of a full slab supported on two walls.

3.1.2 PILLARS AND WALLS

These elements are subject to vertical forces which result in compressive stresses. However, if these elements are very high, other stresses can act in all directions. Reinforcement is then used (Figure 34) to reabsorb all these stresses (to avoid buckling and bulging of the pillar due to the application of a large load).

The buckling height determines the reinforcement required in a pillar. If the slenderness (real height of the pillar in relation to the shortest side) is less than 15, then the pillar is considered to act only in compression, and there is no risk of buckling.

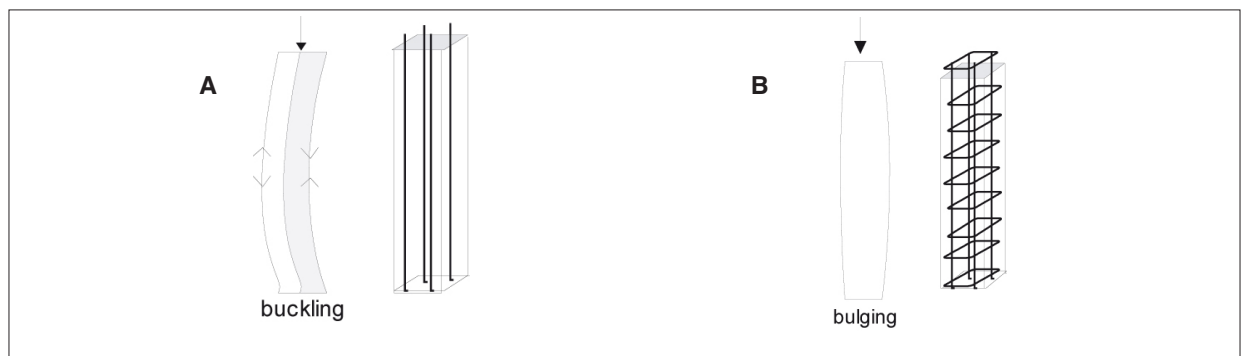


Figure 34: Reinforcement of a pillar to reabsorb all the stresses acting on the structure..

A: to avoid buckling, which deforms the pillar and leads to tensile strain, longitudinal reinforcement is used. **B:** bulging of a section is restricted by the placing of transverse frames, which also facilitate the location of longitudinal bars.

3.2 Calculation of structures and common jobs in reinforced concrete

3.2.1 INTRODUCTION AND METHODOLOGY

The following methodology is used to calculate common concrete structures:

- choice of assumed stresses (τ) on the materials (concrete and steel);
- sizing of the reinforced-concrete element: beam height/width, pillar section, slab thickness and span;
- identification of forces: structural weight, water pressure in a tank, thrust of the soil (and water) on a retaining wall, weight of a vehicle on a culvert;

Box 5**Table for selection of reinforcement bars.**

In practice, the calculations for reinforced-concrete structures give sections of bars which depend on the stresses experienced by one element (beam, slab, pillar etc.).

Table I determines the diameter and the number of steel bars per metre, depending on the calculated bar section.

Table I: Characteristics of steel reinforcements.

Diameter (mm)	Weight (kg/m)	Section of 1 bar (cm ²)	Mesh (cm) / number of bars per m								
			50 2/m	35 3/m	25 4/m	20 5/m	17 6/m	15 7/m	12.5 8/m	11 9/m	10 10/m
5	0.15	0.2	0.39	0.59	0.79	0.98	1.18	1.37	1.57	1.77	1.96
6	0.21	0.28	0.57	0.85	1.13	1.41	1.7	1.98	2.26	2.54	2.83
8	0.38	0.5	1.01	1.51	2.01	2.51	3.02	3.52	4.02	4.52	5.03
10	0.59	0.79	1.57	2.36	3.14	3.93	4.71	5.5	6.28	<u>7.07</u>	7.85
12	0.85	1.13	2.26	3.39	4.52	5.65	<u>6.79</u>	7.92	9.05	10.18	11.31
14	1.16	1.54	3.08	4.62	6.16	<u>7.7</u>	9.24	10.78	12.32	13.85	15.39
16	1.51	2.01	4.02	6.03	8.04	10.05	12.06	14.07	16.08	18.1	20.11
20	2.36	3.14	6.28	9.42	12.57	15.71	18.85	21.99	25.13	28.27	31.42
25	3.68	4.91	9.82	14.73	19.64	24.54	29.45	34.36	39.27	44.18	49.09
32	6.03	8.04	16.08	24.13	32.17	40.21	48.25	56.3	64.34	72.38	80.42
40	9.43	12.57	25.13	37.7	50.27	62.83	75.4	87.96	100.5	113.1	125.6

Example of use of the table

- In bold: 12-mm bars at 25-cm centres (= 5 bars per m) must be used; the corresponding section is 4.52 cm². If only 8-mm bars are available, it is necessary to use 9 bars per m (11-cm centres).
- Underlined: the calculation of a structure in reinforced concrete gives a bar section of 6.5 cm². The reinforcement of the structure (slab) will be therefore be 5 bars per metre of 14 mm, or 6 bars of 12 mm, or 9 bars of 10 mm, depending on availability.

- identification of stresses acting on these elements: simple compression, shearing (reaction of the supports on which the structure rests), bending (tension and compression in the structure), peripheral forces (circular tanks);
- calculation of reinforcement-bar sections and spacing required to withstand these stresses (Box 5). The following simplified method is proposed: only the section of the main bars is calculated; then a ratio in relation to this is applied to obtain the section of distribution bars to be used.

3.2.2 EXAMPLES OF APPLICATION**3.2.2.1 Assumed stress limits for materials**

The assumed stress limits for concrete and steel are shown in Tables XXVI and XXVII.

Table XXVI: Stress limits for concretes which are not of high quality (aggregate size and quantities of water and cement are not carefully controlled).

Concrete mix (kg of cement/m ³)	Stress (kg/cm ²)
250	46
300	58.5
350	68.5
400	76.5

Table XXVII: Stress limits for steels.

For water-supply applications, HA bars with a resistance of 1 650 kg/cm² are recommended, to avoid any cracks which could be particularly damaging to the waterproofing of the material (corrosion of these steels). The elastic limit is the stress above which the bar material does not return to its initial state after being stressed.

	Elastic limit (kg/cm ²)	Stress limit (kg/cm ²)
Smooth bars	2200-3400	1470-2270
High adhesion bars (HA)	4200-5000	2700-3300

3.2.2.2 Sizing of concrete sections

The geometrical characteristics of the structure allow empirical determination of its concrete section (Table XXVIII), except for rectangular tanks (see Section 2).

Table XXVIII: Rapid calculation of concrete sections for common structures.

Type of structure	Parameter to be sized	Parameter sizing (cm)
Square section pillar	Height (minimum 15 cm)	1/14.4 buckling height of the pillar ($h_{\text{buckling}} = 0.7 h_{\text{real}}$)
Beam	Height (minimum 15 cm) Width (minimum 10 cm)	1/10th to 1/15th span of the beam Width = 0.3 height
Slab on 4 supports	Thickness (minimum 8 cm)	1/20th span
Slab on 2 walls		1/30th span
Slab on 4 walls		1/40th span
Wall of a circular tank	Thickness (minimum 8 cm)	$s = 0.22 \times D \times H$
Wall of a rectangular tank	Thickness (minimum 8 cm)	See Section 2.2.7.2

3.2.2.3 Forces applied to structures and resulting stresses (moments)

There are two types of loading, static loads G (weight of structure, water in a tank), and dynamic loads P (Table XXIX). Total stress S is therefore:

$$S = G + 1.2 P$$

For water-supply structures (subject to water pressure) such as tank walls and tank bottoms:

$$S = 1.2 G$$

Table XXIX: Calculation of static and dynamic loads.

<i>Permanent loads on structures</i>	
Stone masonry	2 500 kg/m ³
Hollow load-bearing blocks	1 500 kg/m ³
Concrete – reinforced concrete	2 400 - 2 500 kg/m ³
Slab in reinforced concrete	25 kg/m ² /cm of thickness
<i>Dynamic loads for slabs in use</i>	
Private premises	200 kg/m ²
Structures open to the public	500 kg/m ²

3.2.2.4 Stresses in structures, bending moments

The stresses experienced by structures when loads (or forces) are applied to them are characterised by moments. Calculation of moments depends on the loads supported (uniform or point loads, point and direction of application of the force), and the type of structure (whether or not fixed to other reinforced-concrete elements). Moments differ in all points of the structure. For example, the moment at the centre of a slab on free supports is maximum, whereas it at the supports it is zero. It is the maximum moment that should be determined when designing a structure.

Bending-moment diagrams

The most common case is the simple bending moment, incorporating tension and compression. These bending stresses can be represented in diagrams that are useful for understanding stresses on structures and for locating reinforcement. Two examples of bending moment diagrams feature a beam (or slab) subject to a uniformly distributed load, and the walls of a rectangular tank subject to water pressure.

– Beam or a slab

Moments in three standard configurations – free, semi-fixed, and fixed supports – are shown in Figure 35. Stresses (and the calculation of moments, Table XXX) experienced by these three types of beam are different. The maximum bending moment is located at the centre of the beam.

Table XXX: Calculation of maximum bending moment for a uniformly-distributed load in three standard configurations of beam.

P: weight of the load (kg). L: span of the beam (m). BM: bending moment (kg/m).

Beam on free supports	Maximum moment at the centre Next to the support	$BM = -P \times L^2/8$ $= 0$
Semi-fixed beam	Maximum moment at the centre Next to the support	$BM = -P \times L^2/10$ $= + P \times L^2/24$
Fixed beam	Maximum moment at the centre Next to the support	$BM = -P \times L^2/12$ $= + P \times L^2/12$

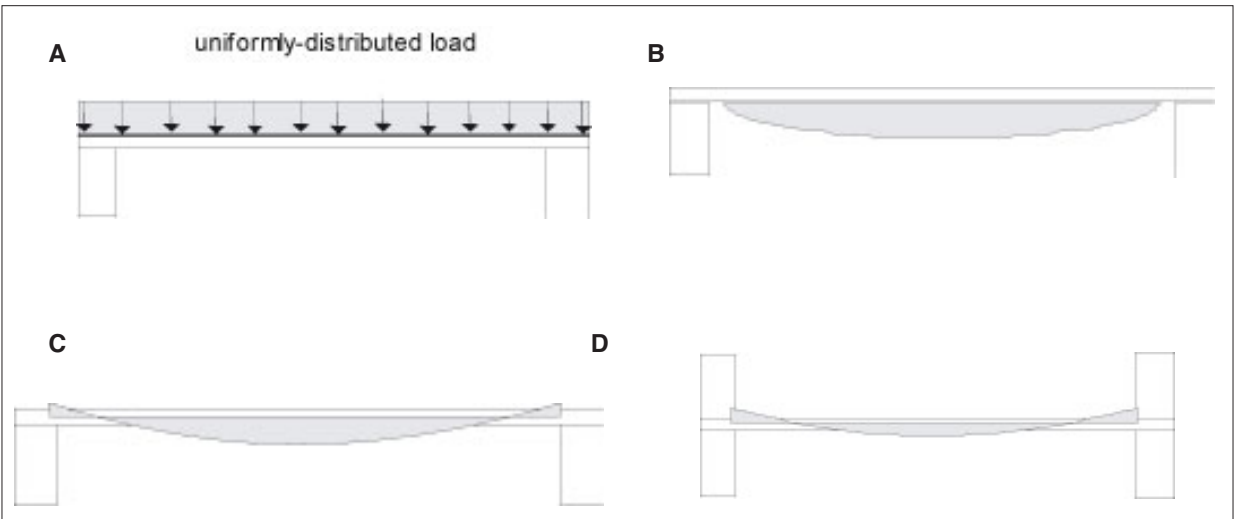


Figure 35: Stresses in a beam.

A: uniformly-distributed load. B: moment on 2 supports. C: moments on 2 semi-fixed supports. D: moments on 2 fixed supports.

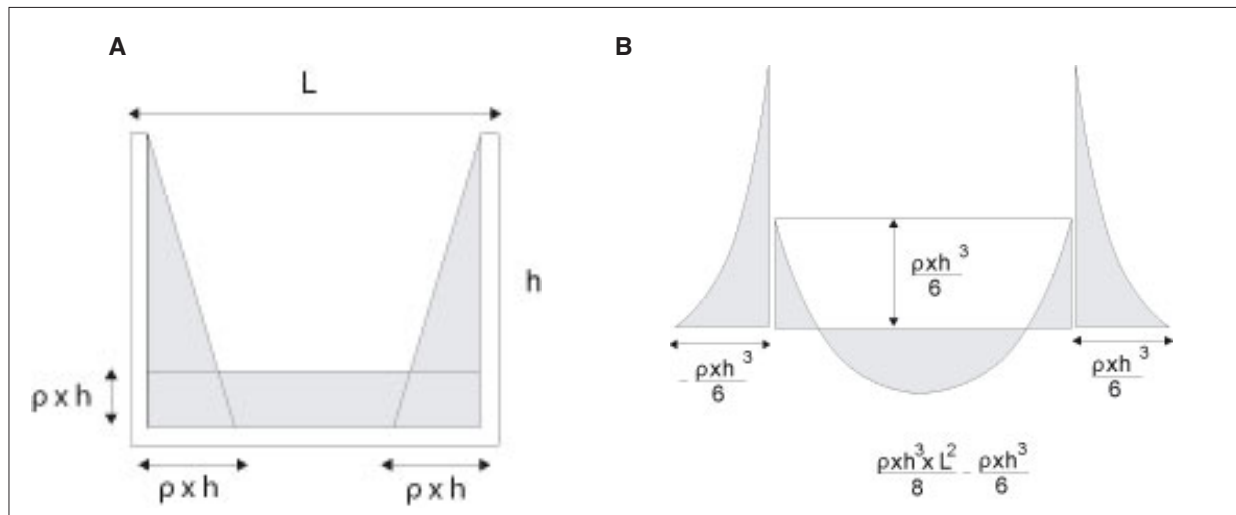


Figure 36: Rectangular tank subject to water pressure.

A: diagram of forces (pressure) resulting from weight of water in the tank.

B: bending moment diagram in a vertical section of the wall.

h: depth of water (m). ρ : density (kg/m^3).

Bending moments opposite to the direction of application of the load appear when the beam is semi-fixed or completely fixed. The tensile area then reduces considerably, down to almost 50% for a fixed beam. As far as possible, semi-fixed beams and slabs (with pillar reinforcement and beam reinforcement linked) are therefore preferred.

– *Elevated rectangular tank subject to water pressure*

A bending moment diagram for the walls of an elevated rectangular tank subject to water pressure is shown in Figure 36. The walls are fixed (linked to one another) and moments resulting from this linkage can be noted at the angles, which require reinforcements (see Section 2).

3.2.3 DESIGN CALCULATION EXAMPLES

3.2.3.1 Pillars

In the example of a pillar acting only in compression, i.e. without buckling, the non-buckling condition allows the determination of the section of the pillar as a function of its height.

Dimensions

$$a = \frac{l_f}{14.4}$$

where a is the smallest dimension and l_f the buckling length. This length depends on the actual length of the pillar l_0 and the type of pillar (fixed or otherwise). Buckling length l_f is determined by:

$$l_f = 0.7 \times l_0$$

The concrete section of the pillar is therefore given by:

$$A_{\text{concrete}} = a^2$$

Calculation of permissible load

The pillar is not loaded above 50 kg/cm^2 , so that:

$$\text{permissible load (kg)} = 50 \times a^2$$

This calculation does not take account of the section of the pillar reinforcement bars. In the case of small pillars, for which the section (A_{steel}) is significant relative to the concrete section (A_{concrete} , already defined), an equivalent section (A_{eq}) can be calculated from:

$$A_{\text{eq}} = A_{\text{concrete}} + (15 \times A_{\text{steel}})$$

Thereby obtaining: permissible load (kg) = 50 x A_{eq}

This calculation also helps verify the dimensions of a pillar and the non-buckling condition (Table XXXI).

Table XXXI: Example of calculation of a pillar in reinforced concrete loaded to 50 kg/cm².

CALCULATION

Data

Actual pillar height required	4 m
Diameter of vertical reinforcement bars	12 mm

Calculation of dimensions

Buckling height	2.8 m
Dimension of smallest side	20 cm
Permissible total load on the pillar ¹	20 t
Permissible total load on the pillar ²	24 t

VERIFICATION OF A PILLAR ALREADY DESIGNED

Data

Actual pillar height	4 m
Dimension of smallest side	15 cm
Diameter of vertical reinforcement bars	12 mm
Total load on the pillar	20 t

Stress on pillar and buckling ratio³

Stress in reinforced rate of pillar	69 kg/cm ²
Buckling ratio	19

1. Calculation without taking account of reinforcement bars.
2. Calculation taking account of reinforcement bars in compression.
3. This example demonstrates that if the stress is greater than 50 kg/cm², the pillar is under-sized. In the same way, if the buckling ratio is greater than 14.4, the stress must be much lower than 50 kg/cm².

Note. – When designing a pillar, the reinforcement (A_{steel}) is not calculated (the pillar is calculated in simple compression). On the other hand, the pillar is always reinforced (see Section 2) and A_{steel} is taken into account when the permissible load on the pillar is verified later.

3.2.3.2 Slabs in simple flexion

- Design of the concrete section (Section 2).
- Calculation of total weight per m² of slab (static + dynamic loading).
- Calculation of maximum moment in the slab (Table XXXII).
- Calculation of the reinforcement section in flexion by the approximate formula:

$$A_{\text{steel}} = \frac{M}{\tau_{\text{steel}} \times Z}$$

where M is the moment (kg.m), τ the stress limit of the reinforcement bars (kg/cm²) and z the leverage in the structure (cm), calculated by: $z = 7/8 \times t$, where t is the thickness of the slab.

The calculations and design details are summarised in Table XXXIII.

Table XXXII: Maximum moment in a slab.

Type of slab	Maximum moment at centre
Rectangular slab on two free supports (2 walls)	$\frac{P \times L^2}{8}$
Semi-fixed rectangular slab (on 2 walls)	$\frac{P \times L^2}{10}$
Circular slab supported at its periphery	$\frac{P \times L^2}{20}$

Table XXXIII: Calculations for the construction of a rectangular slab in flexion on two supports (walls).**DATA***Geometric characteristics*

Slab span	4 m
Type of slab ¹	Semi-fixed
Dynamic load	500 kg/m ²

Bars available in the field

Main-bar diameter	12 mm
Distribution-bar diameter	8 mm

RESULTS OF CALCULATIONS*Dimensions*

Slab thickness ²	14 cm
Total load ³	850 kg/m ²
Maximum moment in the slab	1 360 kg.m

Wall reinforcement⁴

Calculated section of main bars	9 cm ²
Actual diameter of main bars	12 mm
Actual mesh of main bars	13 cm
Calculated section of distribution bars	3 cm ²
Actual diameter of distribution bars	8 mm
Actual mesh of distribution bars	17 cm

1. The slab can be semi-fixed or on free supports and supported by 2 continuous walls, on pillars or on its four sides.
2. For a slab supported by 2 walls.
3. Total load = static load + dynamic load.
4. The reinforcement mesh must be between 10 and 30 cm: if more or less steel is required, it is necessary to change the diameter of bars used, rather than go outside these limits.

3.2.3.3 Economic design of reinforced-concrete tanks

The dimensions given in Table XXXIV do not apply to large-capacity tanks, because the height must be lower than 4 m. Octagonal or hexagonal tanks come closer to the most favourable shape, the circle.

Table XXXIV: Optimum dimensions from an economic viewpoint for the construction of a tank in reinforced concrete.

Cylindrical tank	Covered (slab)	Diameter = height
	Open	Diameter = 2 x height
Square-base tank	Covered	Side = height
	Open	Side = 1/2 height

3.2.3.4 Circular tank

In circular tanks, the force acting on the circumference is critical. It is therefore considered that the horizontal circular bars (these are the main bars), withstand the stress in the circumference while the vertical bars (known as distribution bars) resist the pressure on the walls.

The bars of the base resist the weight of the depth of water above them.

– Calculation of wall thickness (t - minimum 10 cm):

$$t = 0.22 \times D \times H$$

– Calculation of the horizontal-bar sections by horizontal sections through the tank every 1 m of height:

$$A_{\text{steel}} = \frac{P \times R}{\tau_{\text{steel}}}$$

where A is the bar section (cm²) per metre of height, H the water depth (m), and R the tank radius (m). The value of P is 1 200 H (kg/m), and $\tau_{\text{steel}} = 1\,650$ kg/cm².

Water density is taken as equal to 1.2 to take account of the effect of filling and emptying of tanks.

– Calculation of vertical distribution bar section per metre length of wall:

$$A_{\text{vertical}} = 1/3 \times A_{\text{horizontal}}$$

– Reinforcement of base, see Section 2.2.4.2.

All these calculated sections (cm²) can be converted into real sections (bar diameter and mesh) using Table XXXV.

Table XXXV: Simplified calculation for a small-capacity covered circular tank (< 200 m³).

DATA

Geometrical characteristics

Depth of water in the tank	4 m
Internal diameter of the tank	6 m
Capacity of the tank	113 m ³

Bars available in the field

Diameter of main bars	12 mm
Diameter of distribution bars	8 mm

RESULT OF THE CALCULATIONS

Dimensions

Thickness of vertical walls	10 cm
Actual height of tank	4.3 m
External diameter of tank	6.2 m

Reinforcement with horizontal sections of 1 m¹ (A = bar section in cm²)

Section	PR (kg)	A _{horizontal} calculated (cm ²)	A _{horizontal} actual (12-mm bar) mesh (cm)	A _{vertical} calculated (cm ²)	A _{vertical} actual (8-mm bar) mesh (cm)
0-1 m	1 800	2	57	1	30
1-2 m	5 400	4	29	2	30
2-3 m	9 000	6	19	2	15
3-4 m	12 600	8	15	3	15

1. The mesh must be between 10 and 30 cm: if more or less steel is required, it is necessary to change the diameter of bars used, rather than go outside these limits.

3.2.3.5 Rectangular tank

For tanks of a capacity lower than 100 m³, that are covered and with a link between the walls and the slab, simplified reinforcement calculations are applicable (Table XXXVI). The main bars are the vertical bars which resist the water pressure on the walls, and the horizontal bars are the distribution bars.

Table XXXVI: Simplified calculation of a covered rectangular tank of a capacity less than 100 m³.

DATA

Geometrical characteristics

Depth of water in tank	3 m
Internal width of tank	6 m
Internal length of tank	4 m
Capacity of tank	72 m ³

Bars available in the field

Diameter of main bars	16 mm
Diameter of distribution bars	12 mm

RESULT OF THE CALCULATIONS

Dimensions

Maximum bending moment	4 500 kg.m
Thickness of vertical walls	14 cm
Actual height of tank	3.3 m
External width of tank	6.28 m
External length of tank	4.28 m

Wall reinforcement¹

Calculated section of main bars per m length	23 cm ²
Actual diameter of main bars	16 mm
Actual mesh of main bars	9 cm
Calculated section of distribution bars per m height	8 cm ²
Actual diameter of distribution bars	12 mm
Actual mesh of distribution bars	15 cm

1. The mesh must not be greater than 30 cm; if less steel is required, the diameter of the bars must be reduced, rather than exceeding this mesh size.

Maximum bending moment due to thrust of water on the vertical wall:

$$M_{\max} = \frac{\rho \times H^3}{6}$$

where $M_{\max}$ is in kg.m, ρ is the density (kg/m³), and H the water height (m).

Thickness of the wall as a function of $M_{\max}$

$$t = 2 \times \sqrt{\frac{M_{\max}}{100}}$$

where $M_{\max}$ is in kg.m and t is in cm.

Section of the vertical bars for 1 metre length of wall:

$$A_{\text{bar}} = \frac{M}{\tau_{\text{steel}} \times Z}$$

where A is bar section (cm²), $M = M_{\max}$ (kg.cm), $z = 7/8 \times t$ (cm) and $\tau_{\text{steel}} = 1\,650$ kg/cm².

Section of horizontal bars per metre height of wall:

$$A_{\text{horizontal}} = \frac{1}{3} \times A_{\text{vertical bar}}$$

Reinforcement of the base, see Section 2.2.4.2.

3.2.3.6 Elevated rectangular tank

The calculation is identical to that given above (see Section 3.2.3.5), except for the base slab of the tank and the pillars (for quick determination tables, see Section 2). Static loads correspond to the sum of the weight of water, the walls, and the reinforced-concrete slabs (cover and base).

The example given in Figure 37 and Table XXXVII is a tank made up of 5m³ modules which are added to one another to increase the capacity (5, 10, 15 m³). During construction it is imperative to build suitable foundations (there is a heavy loading on each pillar), as well as a belt linking the pillars to the base.

It is also necessary to ensure that the pillars are perfectly perpendicular. This is facilitated by intermediate chaining every 2 m for structures higher than 3 m.

Table XXXVII: Simplified calculations for a small-capacity elevated rectangular tank (5 m³ module).

DATA

Geometrical characteristics of a module (supported tank)

Height of bearing structure	3 m
Height of tank	2 m
Width	1.5 m
Length	2 m
Capacity	5 m ³

TANK DIMENSIONS

Walls

Thickness	10 cm
Vertical reinforcement	12 mm dia / 10-cm mesh
Horizontal reinforcement	8 mm dia / 13-cm mesh

Base slab

Thickness	10 cm
Main reinforcement	12 mm dia / 10-cm mesh
Distribution reinforcement	8 mm dia / 13-cm mesh

Cover slab

Thickness	8 cm
Main reinforcement	8 mm dia / 15-cm mesh
Distribution reinforcement	8 mm dia / 30-cm mesh

DIMENSIONING OF SUPPORT STRUCTURE

Beams

Span	1.5 m
Section	15 x 30 cm
Main reinforcement	2 bars of 12 mm dia

Pillars

Height	3 m
Section	15 x 15 cm
Main reinforcement	4 bars of 12 mm dia

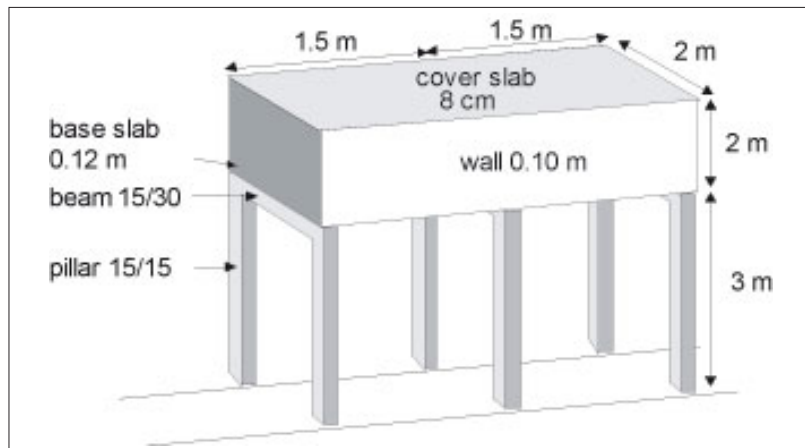


Figure 37: Elevated rectangular tank.

3.2.3.7 Reinforced-concrete retaining walls

Features of the slope to be retained, to be considered in designing a retaining wall, are as follows (Figure 38 & Table XXXVIII):

- θ , the natural angle of the soil embankment before construction of the wall. The smaller the value of θ , the less stable the soil and the more difficult it will be to retain;
- A , the thrust coefficient, which takes account of the soil type, and therefore θ and τ_{soil} ;
- f , the coefficient of friction, which characterises the resistance to motion of the concrete relative to the soil (the smaller the value of f , the greater the tendency of the base of the wall to slip because of the ground thrust);

Table XXXVIII: Soil characteristics to be included in the design of an embankment retaining wall.

Type of soil	ρ_{soil} (kg/m ³)	θ original slope	A coefficient of thrust	f coefficient of friction
Humus-rich soil	1 450	45	0.171	
Clay soil	1 800	45	0.171	
Brick earth	1 900	55	< 0.130	
Fine sand	1 420	30	0.333	
Sandy soil	1 700	35	0.270	
Clay and mud	1 850	20	0.490	
Stones, gravels	1 550	45	0.171	
Wet clay				0.3
Dry clay				0.5
Sand				0.4
Gravel				0.6

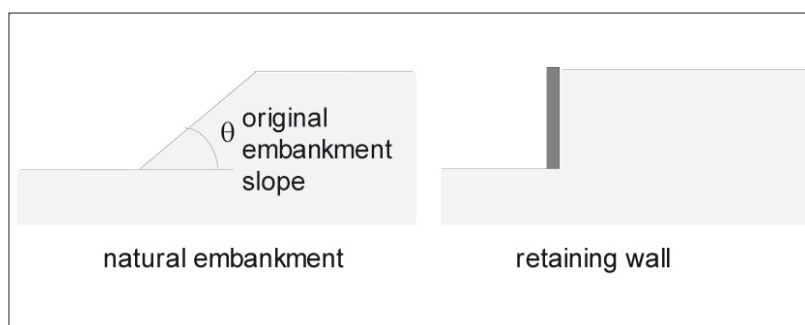


Figure 38: Retaining wall for an embankment.

– Q, the of ground thrust, calculated by:

$$Q = A \times \rho_{\text{soil}} \times \frac{h^2}{2}$$

where the non-dimensional coefficient A is a function of the original earth slope angle, ρ_{soil} is the specific weight of the soil, and h is the height of the wall (Figure 39). The forces acting on the wall are P (static weight of the wall, weight of the earth on the sole, plus any extra loading from the embankment) and Q (ground thrust).

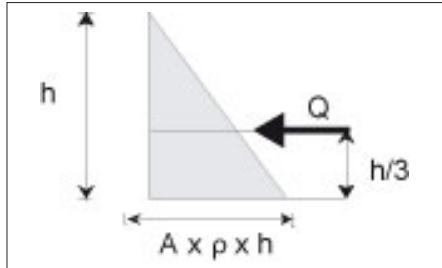


Figure 39: Ground thrust on a retaining wall.

Moments to be considered are:

- overturning moment (M_r), a function of thrust Q and the lever arm in relation to the overturning point ($M_r = Q \times z_r$);
- stabilising moment (M_s), a function of weight P and the lever arm in relation to the overturning point ($M_s = P \times z_s$).

For the calculation of retaining walls, the conditions of non-overturning and non-sliding should be fulfilled (Figures 40 & 41).

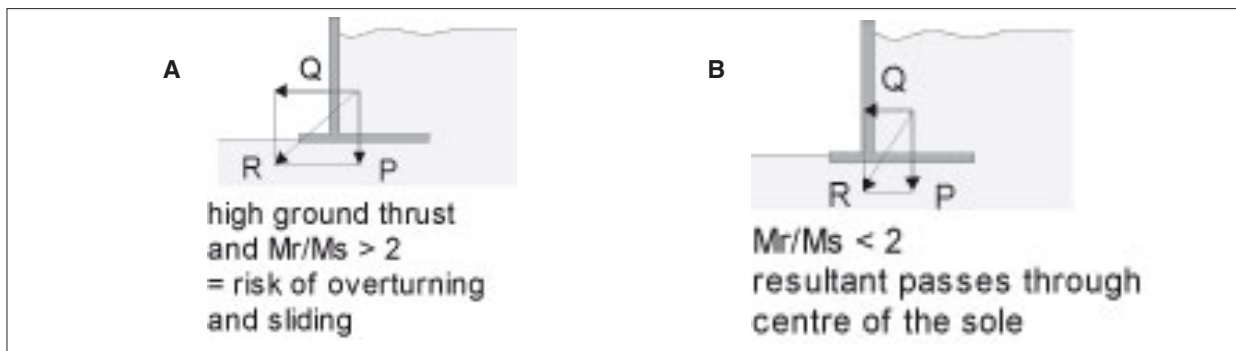


Figure 40: Conditions of non-overturning and non-sliding.

A: non-overturning ($M_r/M_s < 2$). B: non-sliding ($Q/P < f$).

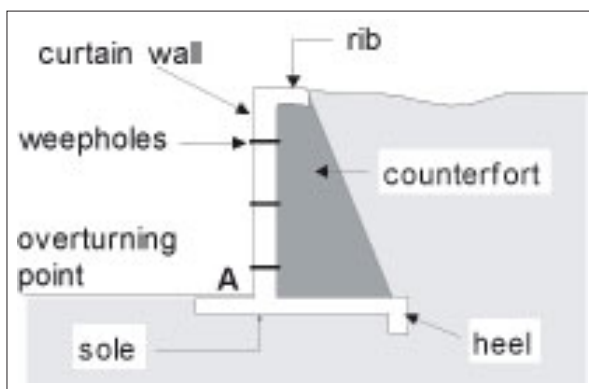


Figure 41: Standard configuration of reinforced-concrete retaining walls.

Weephole made every 2 – 3 m² to avoid accumulation of water (which adds to ground thrust); heel, an anchorage opposing sliding caused by ground thrust; counterfort, an element ensuring rigidity and providing lateral anchorage; sole, foundation stretching in front of the curtain wall to ensure better distribution of pressure on the ground.

3.2.3.8 Simplified calculation of a retaining wall in reinforced concrete

This wall is shown in Figure 42.

– Assumptions:

- $\rho_{\text{soil}} = 1\,600 \text{ kg/m}^3$
- $\theta = 35^\circ$
- coefficient of friction $f = 0.35$
- overturning point A, (lever arms Z_r and Z_s are calculated in relation to this point)

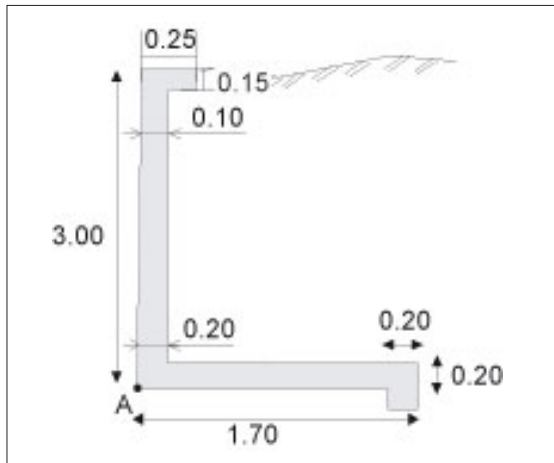


Figure 42: Reinforced-concrete retaining wall.

– Vertical load calculation:

- curtain wall: $P_{\text{curtain}} = (0.1 + 0.2)/2 \times 2.8 \times 2\,500 = 1\,050 \text{ kg/m}$
- earth: $P_t = 2.8 \times 1.5 \times 1\,600 = 6\,720 \text{ kg/m}$
- sole: $P_s = 1.7 \times 0.2 \times 2\,500 = 850 \text{ kg/m}$
- total vertical loads: $P = 8\,620 \text{ kg/m}$

– Calculation of stabilisation moment:

$$\text{moment} = \text{force} \times Z$$

where the moment is in kg.m, force in kg/m length, and lever arm Z between the line of action of the force and the overturning point A. Here, for 1 metre length of wall:

- curtain wall: $M_{\text{curtain}} = 1\,050 \times 0.12 = 126 \text{ kg.m}$
- earth: $M_{\text{earth}} = 6\,720 \times (1.50/2 + 0.20) = 6\,384 \text{ kg.m}$
- sole: $M_{\text{sole}} = 850 \times (1.70/2) = 722.5 \text{ kg.m}$
- stabilisation moment: $M_s = 7\,232.5 \text{ kg.m}$

– Calculation of thrust - horizontal forces:

- $Q = 0.27 \times 1\,600 \times (3^2/2) = 1\,944 \text{ kg/m}$ length of wall

– Calculation of overturning moment:

The thrust applies to $h/3$, i.e. 1 m above A:

- thrust: $M_r = 1\,944 \times 1 = 1\,944 \text{ kg.m}$
- overturning moment: $M_r = 1\,944 \text{ kg.m}$

– Verification of the two main criteria:

- non-overturning condition: ratio between stabilisation and overturning moments ($M_{\text{stab}}/M_{\text{overt}}$) must be greater than 2. This condition is clearly fulfilled here:

$$\frac{M_{\text{stab}}}{M_{\text{overt}}} = \frac{7\,232.5}{1\,944} = 3.7$$

- non-sliding condition: the ratio of vertical to horizontal forces must be less than the coefficient of friction, as here:

$$\frac{Q}{P} = \frac{1\,944}{8\,620} = 0.23$$

which is less than that of f (0.35).

- Determination of curtain-wall reinforcement:

- calculation of the maximum moment in the curtain wall:

$$\text{moment}_{\max} = \frac{Q \times h}{3}$$

- calculation of the main bar section:

$$A_{\text{steel}} = Q \times h/3 / \tau_{\text{steel}} \times z$$

where Q is the ground thrust (kg/m length), h wall height (m), z lever arm in wall (20 cm thick) and τ_{steel} stress limit of the reinforcement bars (kg/cm²):

$$A_{\text{steel}} = \frac{Q \times h/3}{\tau_{\text{steel}} \times z} = \frac{1\,944 \times 2.8/3}{1\,650 \times 17.5} \approx 7 \text{ cm}^2$$

- conversion to an actual reinforcement section

main bars: 10 mm dia / 11.5 cm mesh

every other bar interrupted at mid-height

distribution bars: 8 mm dia / 20 cm mesh for lower part

6 mm dia / 20 cm mesh for upper part

sole reinforcement: as for curtain wall

4 Shuttering

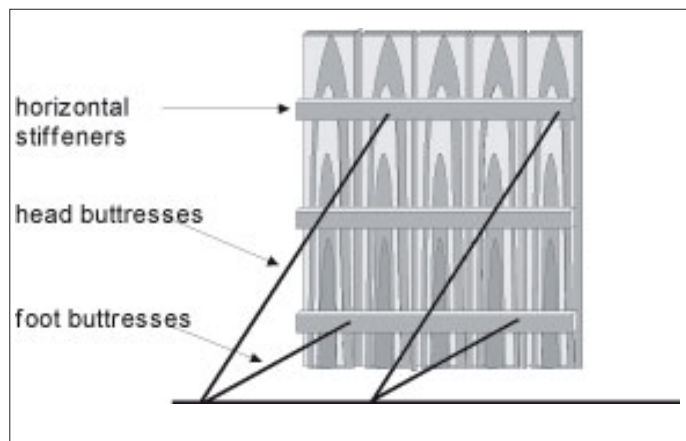
The dimensions of the shuttering are determined by the structure to be built and the type of shuttering to be used (sliding shuttering, tank wall shuttering etc.). Shuttering has to take high static loads as well as significant dynamic loads due to vibration of the concrete. At the time of the design and use of the shuttering, it is therefore necessary to consider:

- stresses during casting of the concrete;
- sealing;
- ease of vibration of the concrete (internal and external vibration);
- surface finish required;
- ease of removal and re-use.

4.1 Wooden shuttering

This type of shuttering is cheap, easy to use and easy to modify (Figures 43, 44, and Box 6). It allows the concrete to dry slowly, and produces a rough surface finish which provides a key for a surface coating. The tools required for putting up and taking down the shuttering are stays, (generally wood), clamps and builder's hooks.

Figure 43: Wooden shuttering with buttressing and vertical and horizontal stiffeners to prevent deformation under the weight of concrete.



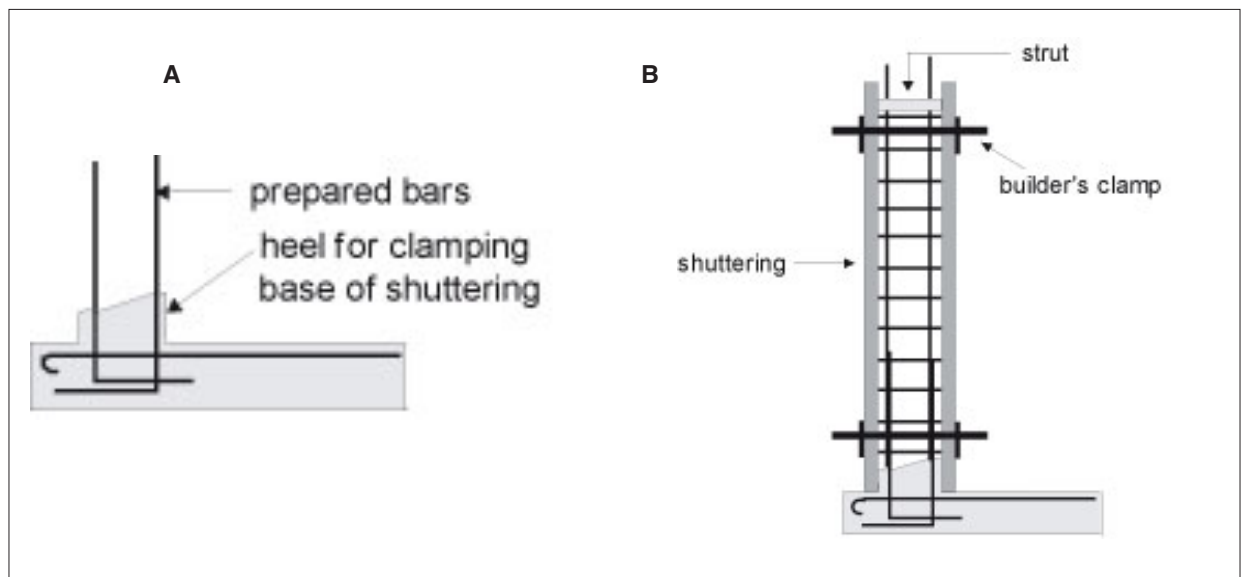


Figure 44: Shuttering for a pillar or curtain wall.

A: awaiting shuttering and reinforcement. B: shuttering and reinforcement in place.

4.2 Metal shuttering, well moulds

This type of shuttering is commonly used for jobs requiring precision, a smooth surface finish, and multiple re-use of the shuttering. Examples of applications are for producing concrete rings, (Figure 45), cutting rings (Figure 46), well linings (Figure 47) or headwalls (Figure 48). They must be stored upright to prevent deformation.

5 Estimation of work time

Work times calculated for different jobs are shown in Table XXXIX.

Table XXXIX: Work times for standard jobs.

Excavation	
Plain soil	1.8 m ³ /person/day
Gritty soil	1.3 m ³ /person/day
Soft rock	0.6 m ³ /person/day
Hard rock	0.4 m ³ /person/day
Rock crushing (production of gravel)	14 men/m ³ /day
Mixing and handling concrete	1 mason and 4 labourers/m ³ /day
Blockwork masonry	1.4 masons and 3.2 labourers/m ³ /day

Box 6

Calculations for circular shuttering in 16 elements.

For a circular tank in 16 elements (Figure 1), the geometric features of one shuttering element are determined initially (Figure 2). Here, the angle of a shuttering element $\theta = 2\pi / 16 = 23.75^\circ$.

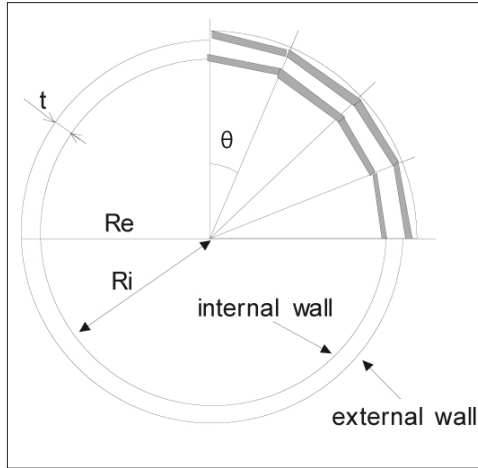


Figure 1: Shuttering for a 16-element circular tank.

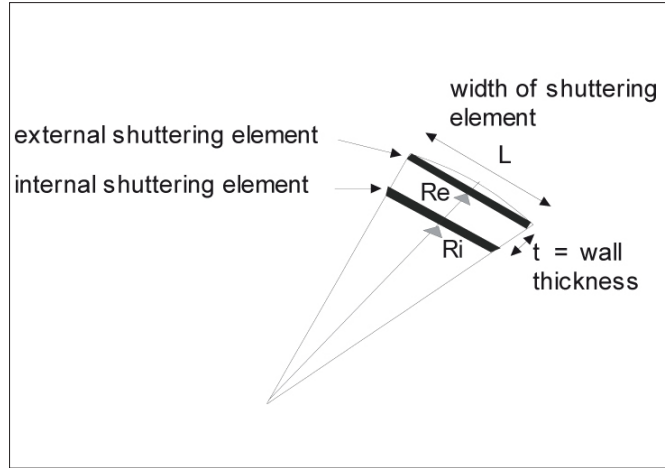


Figure 2: Geometric projection of a shuttering element.

The width of the interior shuttering element is $L_i = 2R_i \tan \alpha$. The width of the outside shuttering element is $L_e = 2R_e \tan \alpha$, with angle α equal to $\theta/2$, and R_e and R_i the external and internal radii such that $R_e = R_i + t$.

Example for a tank of 3 m diameter and 3.5 m height (Figures 3 & 4) :

$$\theta = 2 \times \pi / 16 = 23.75^\circ$$

$$\alpha = \theta / 2 = 11.8^\circ$$

$$L_i = 2 \times 1.5 \times \tan 11.8 = 0.626 \text{ m}$$

$$L_e = 2 \times (1.5 + 0.1) \times \tan 11.8 = 0.668 \text{ m}$$

$$t = 10 \text{ cm}$$

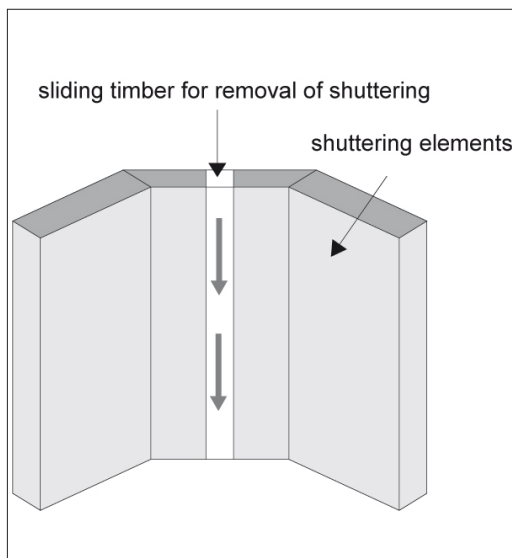


Figure 3: Interior shuttering, either to the full height of the tank, or sliding (several passes).

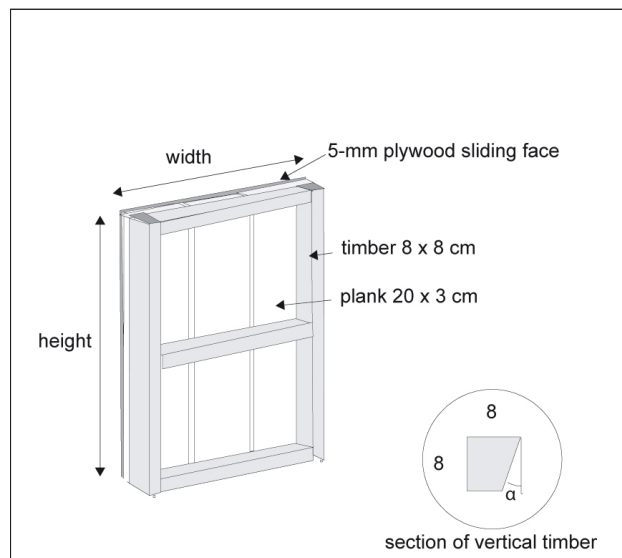


Figure 4: Sliding timber in one element for the removal of shuttering (probably several will be needed).

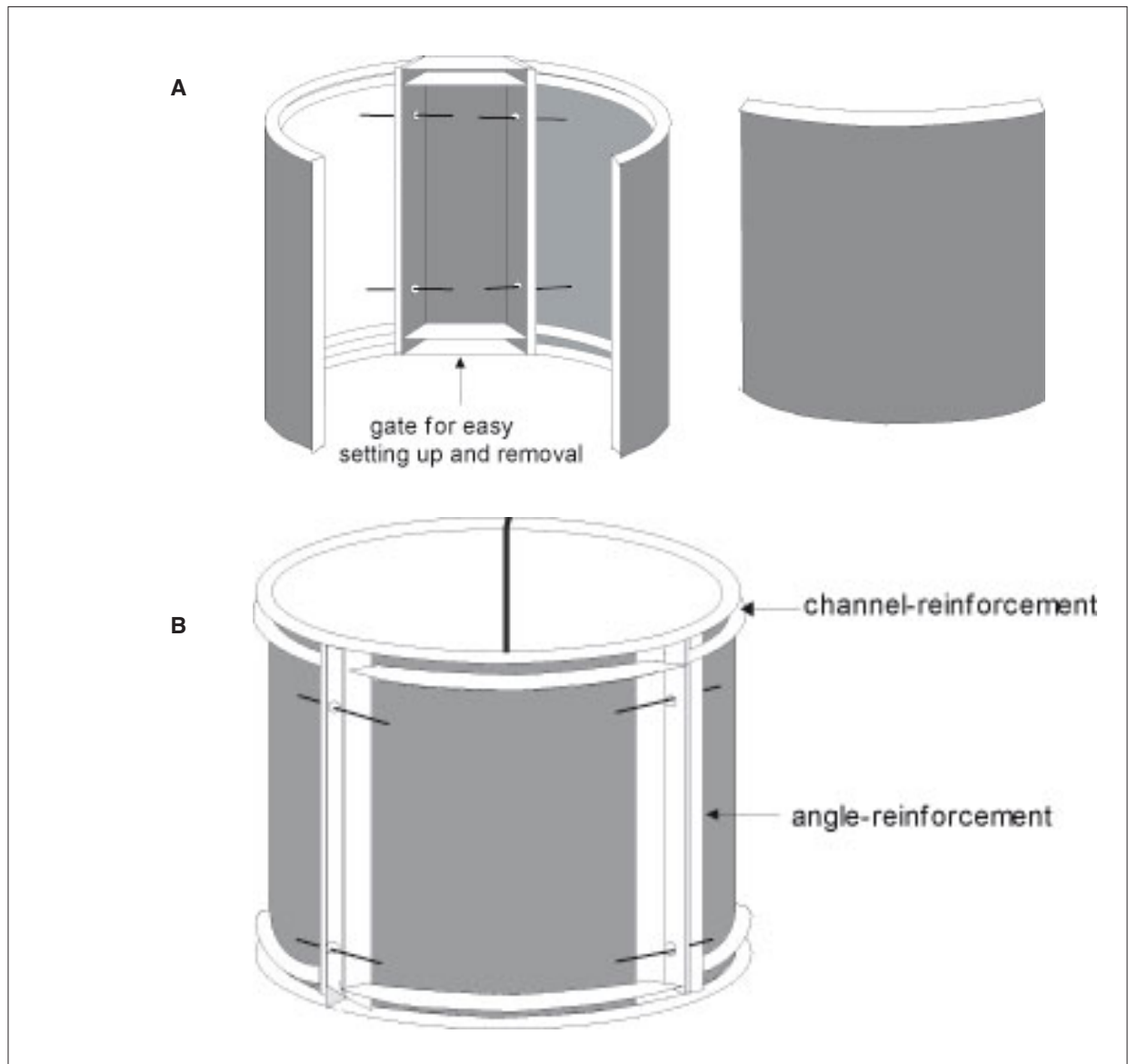


Figure 45: Metal shuttering for a concrete-ring mould.
A: internal mould. B: external mould.

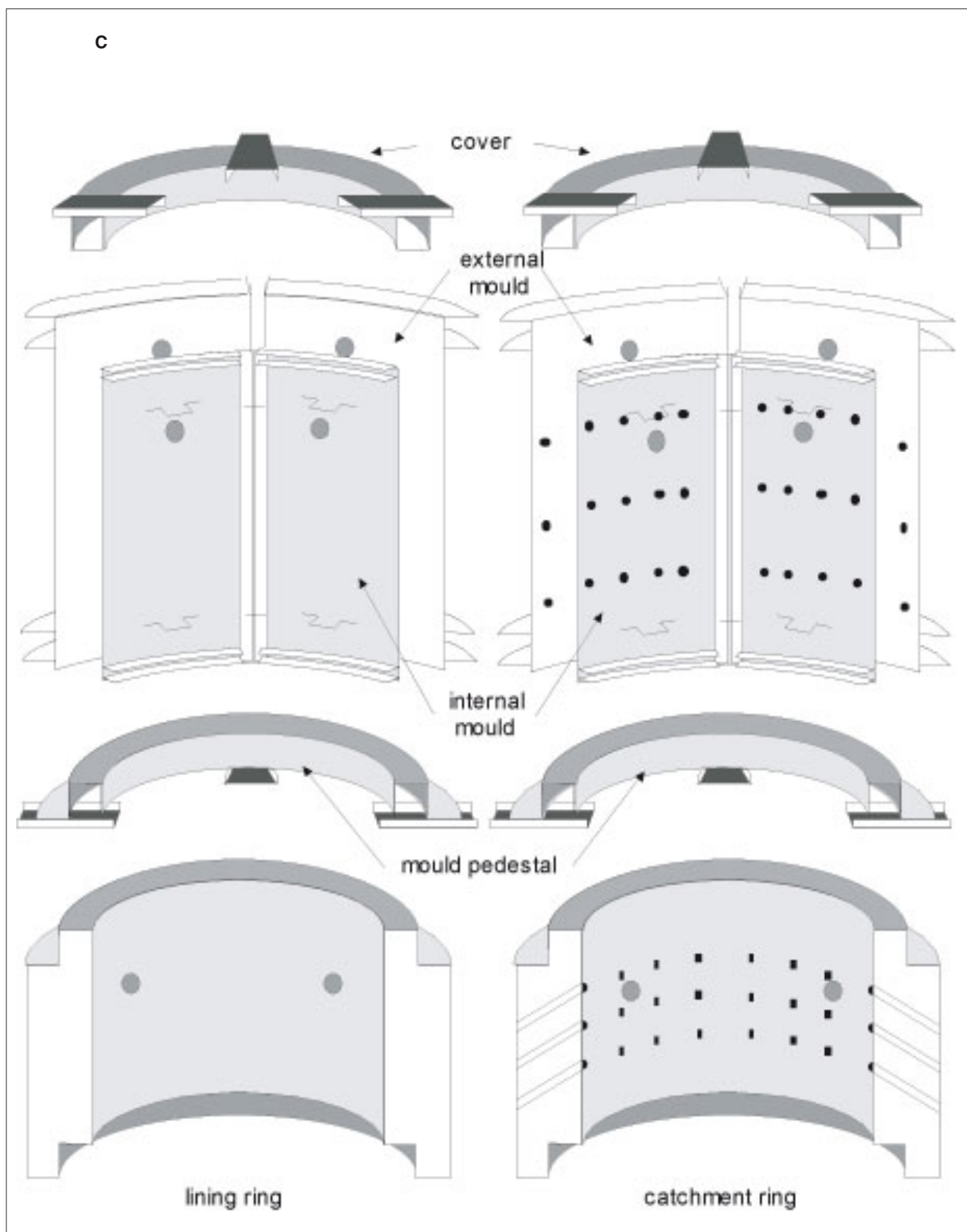
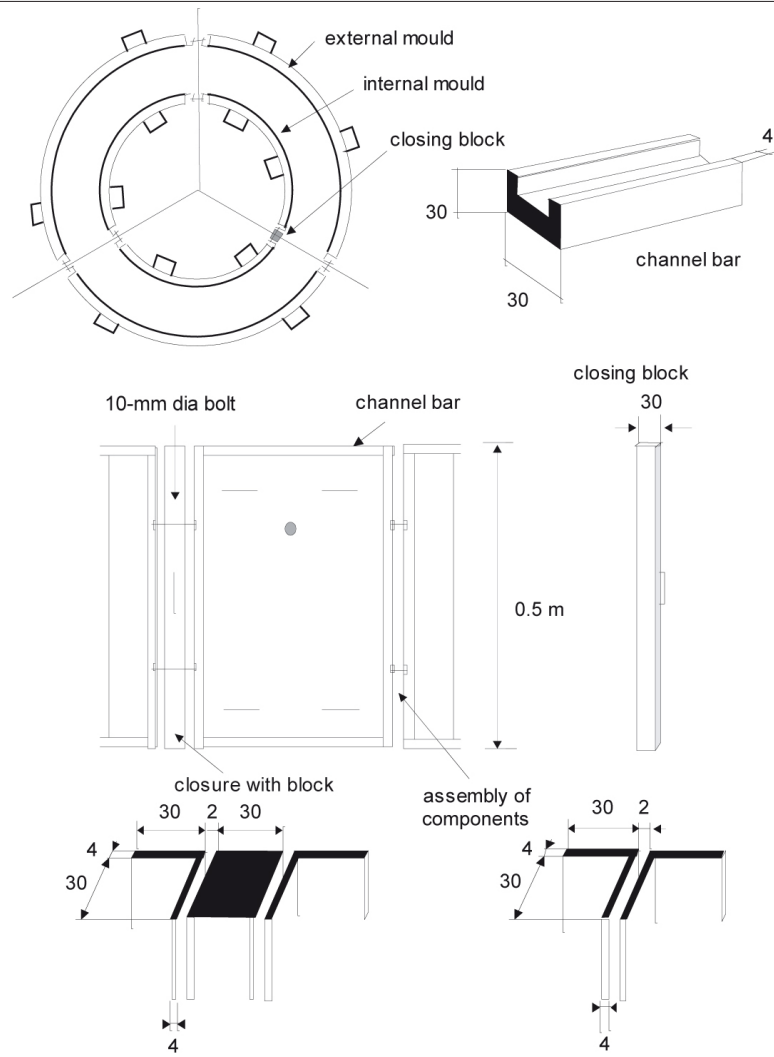


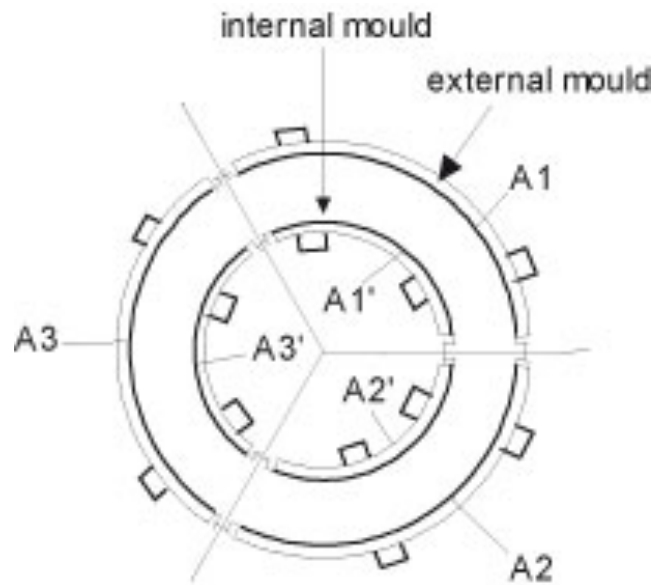
Figure 45: Metal shuttering for a concrete-ring mould.

C: various parts of the mould. D: assembly details. E: numbering of various parts of the mould.

D



E



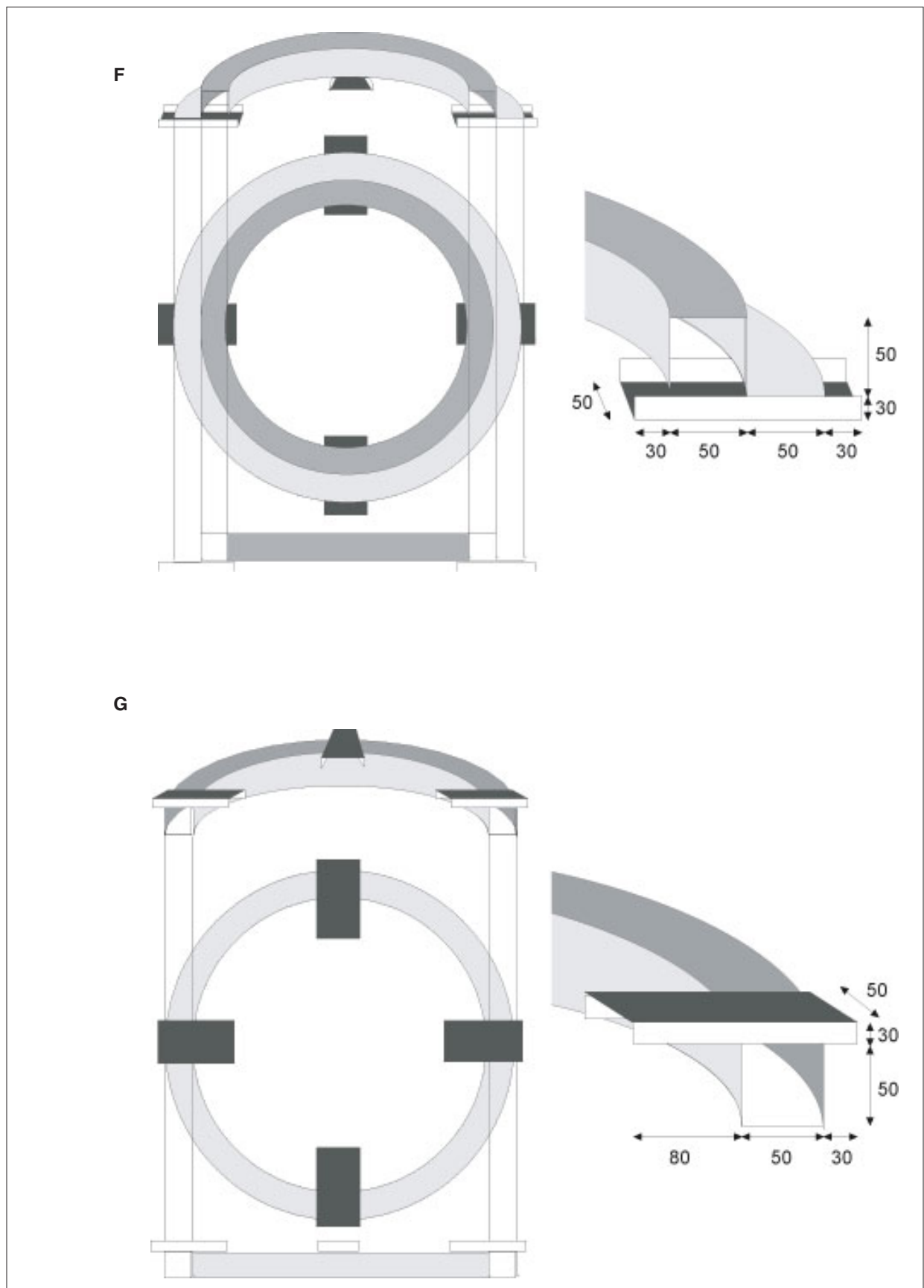


Figure 45: Metal shuttering for a concrete-ring mould.
F: pedestal. G: cover.

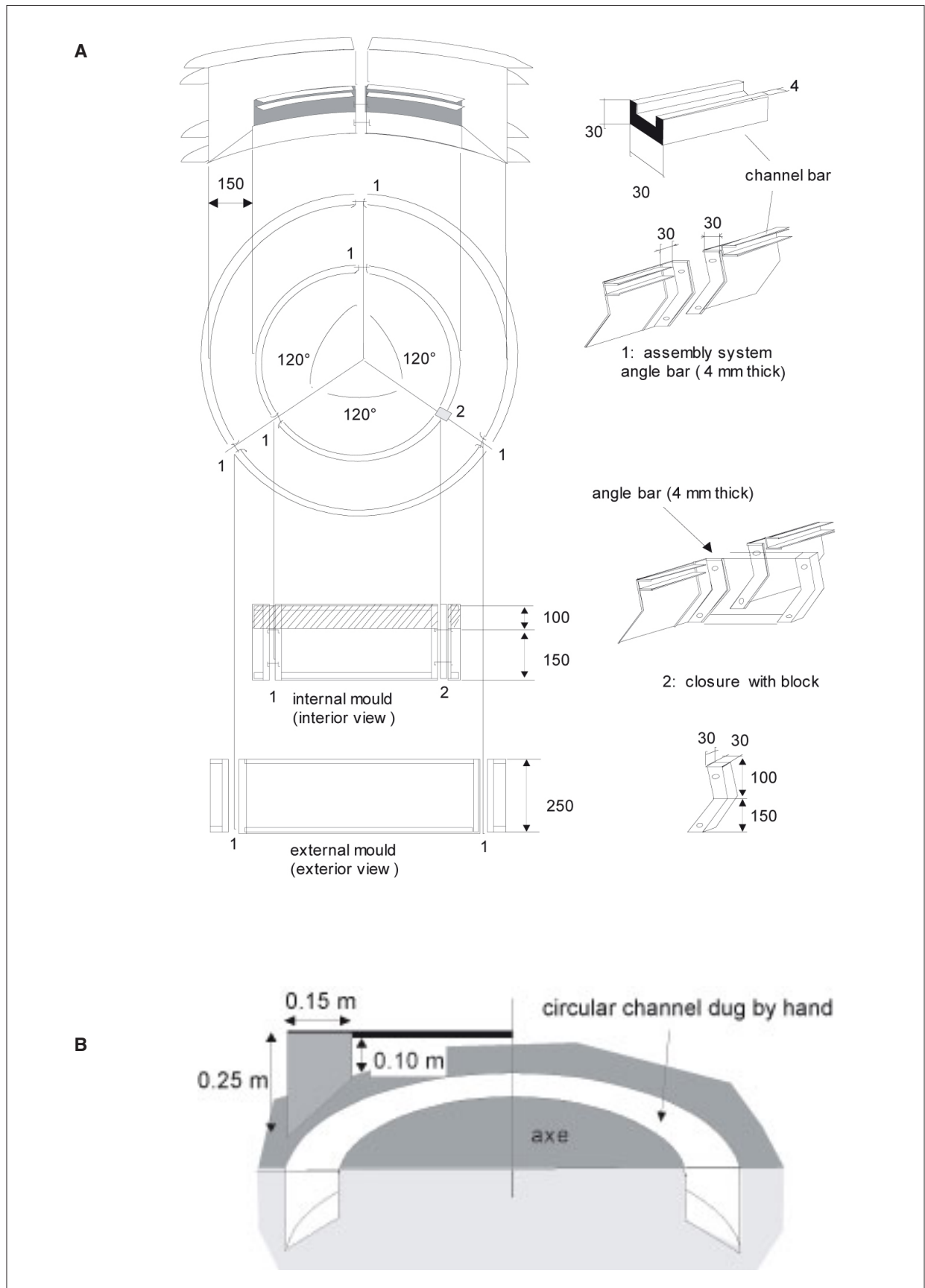


Figure 46: Shuttering for cutting ring.
A: metal. B: mould made directly in the ground

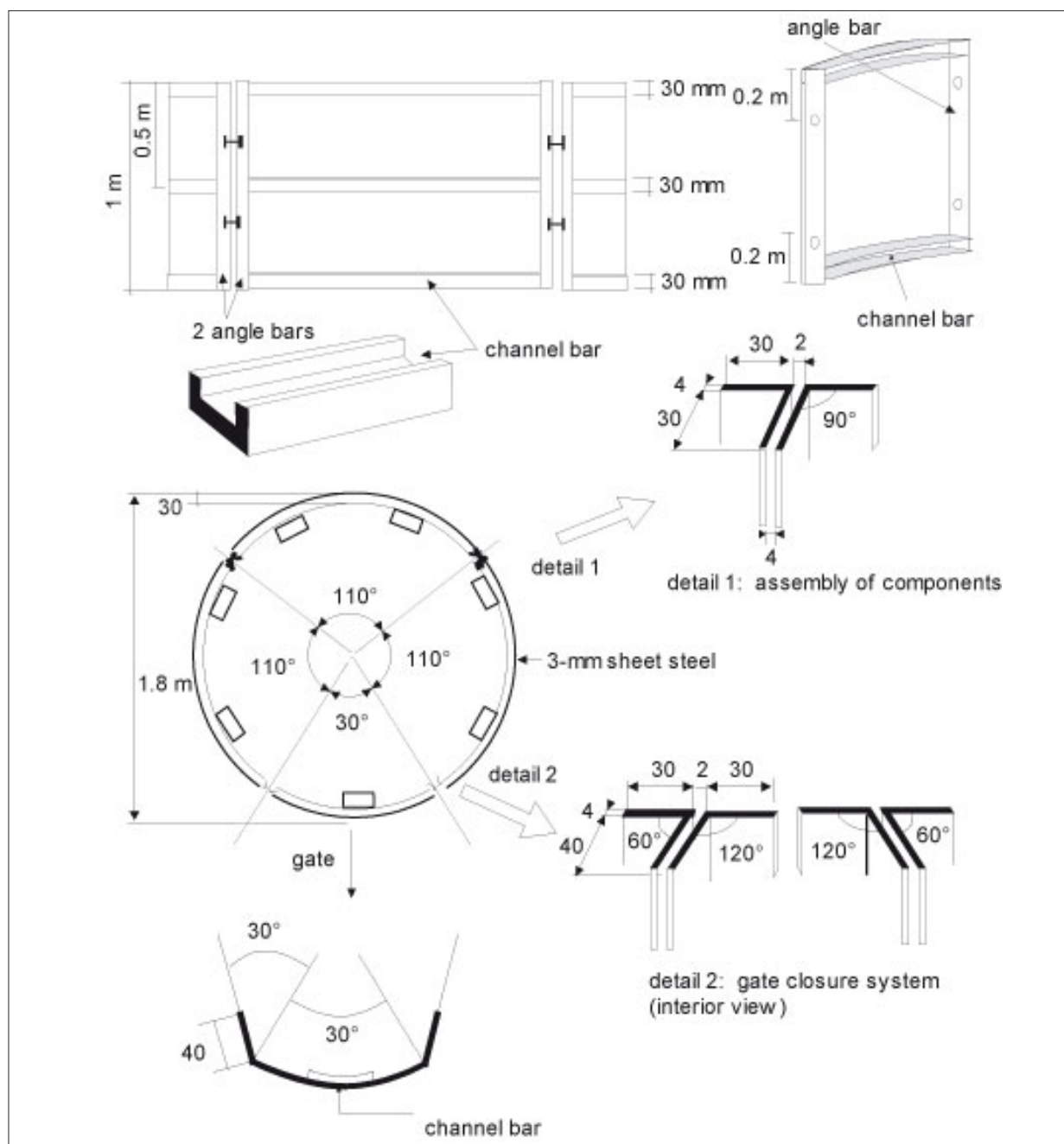


Figure 47: Sliding shuttering for a 1.8-m diameter well.

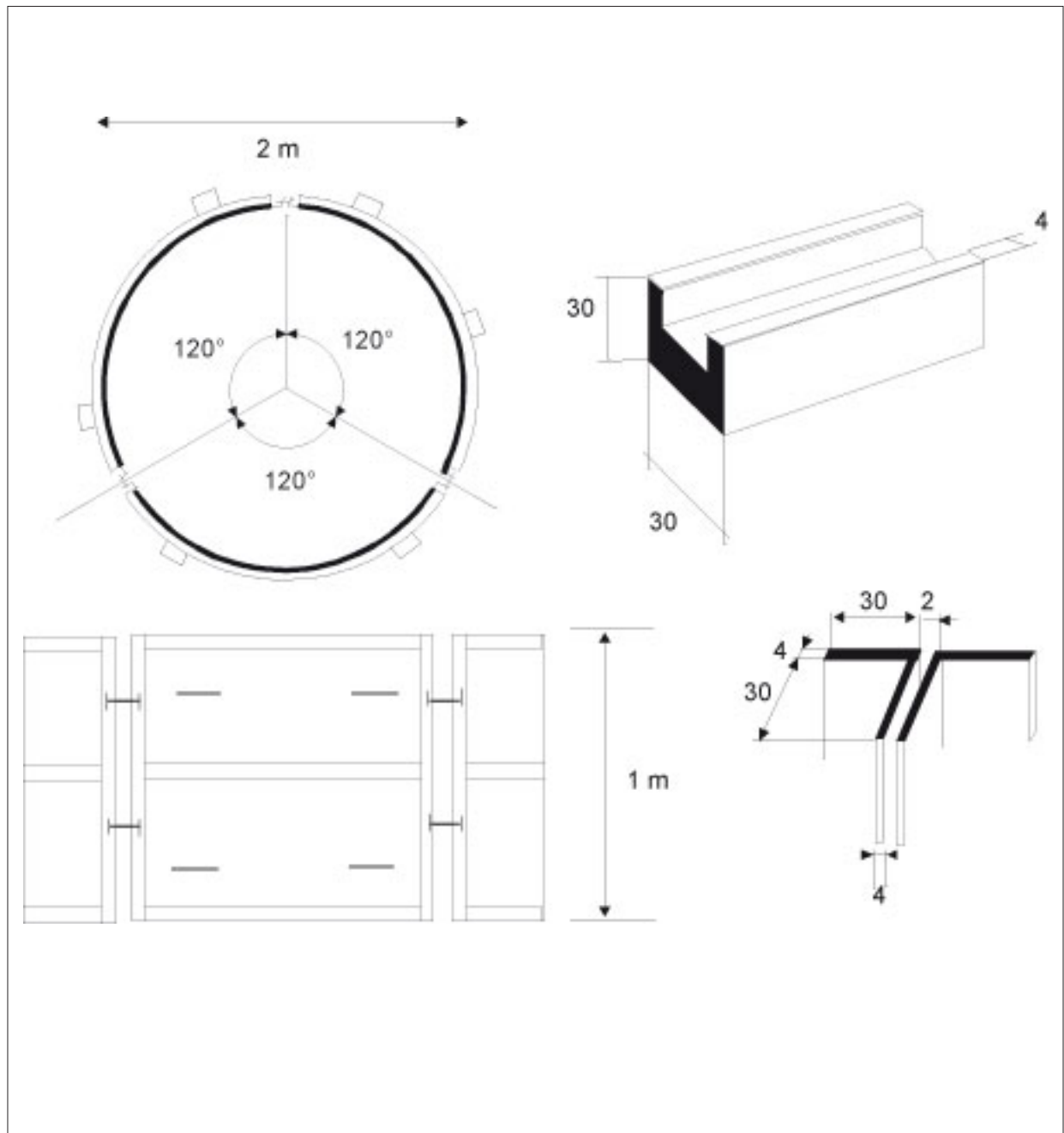


Figure 48: Shuttering for a headwall (2 m external diameter)