WEDC Developing knowledge and capacity in water and sanitation

GUIDE 32

How to make concrete

Concrete is a complex material that requires care during the preparation, mixing, placing and curing (hardening) for the final product to be of acceptable quality for construction. This guide describes the main components of concrete, how to combine them and how to use the final mix. It also considers the special difficulties of using concrete in hot and cold climates and mixing concrete by hand.

Contents

Note: Cement is a hazardous chemical substance and should be handled with extreme care. Despite the apparent simplicity of concrete, it is a complex material and requires careful attention if the final product is to be strong, hard and durable.

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Concrete constituents

Concrete is a mixture of cement, fine aggregate (sand less than 5 mm diameter) and coarse aggregate (gravel 6 – 20mm diameter). When mixed together in the correct proportions they produce a dense material. Water is added to the mix to react chemically with the cement to make it harden and to make the complete mixture easy to move and place where required. The fine and coarse aggregates provide most of the bulk and strength of concrete, the cement 'glues' the individual particles together. Despite the apparent simplicity of concrete, it is a complex material and requires careful attention if the final product is to be strong, hard and durable.

Cement

Cement is made from a mixture of clay and limestone which, when heated together, form a new substance. Once cooled this substance is ground to a fine powder and gypsum is added to produce cement.

When water is added to cement a chemical reaction begins which causes the individual particles of cement to bind together. As the particles bind together, the concrete mix gradually becomes stiffer and harder to manipulate. Eventually the chemical bond becomes so strong that the concrete appears as a hard solid mass. It is said to have 'set'. At this stage the chemical bonding is very weak and is easily broken if the mixture is disturbed.

The time taken for the cement to set depends on the temperature and the way the cement is used. In cold climates total setting can take five to six hours but in hot weather it can take less than one hour.

The chemical reaction continues after the cement has set and, as it does so, it becomes steadily harder and stronger. Most of the reaction and strength development takes place over the first month but it continues at a gradually decreasing rate over many years.

As the cement reacts with the water, heat is produced. In small quantities this is not a problem as increased temperature increases the rate of the chemical reaction. However, if the temperature rises too much it will drive water out of the mix which will prevent the cement from fully hardening. It can also cause

Figure 1. Laying cement and bricks

the cement to crack, reducing the final strength of the mixture.

There are many different types of cement but by far the most common (and the one most likely to be present on the local market) is usually known as 'Ordinary Portland Cement'. This cement is suitable for most general uses such as concrete for small buildings and mortar for brick and block laying.

Storing and handling cement

Cement is a hazardous chemical and should be handled with care. Cement dust can damage skin and eyes. In theory, people working with cement should be provided with protective clothing, including overalls, goggles and gloves, and helmets where work extends above head height. In practice, especially during emergencies, it is unlikely that protective clothing will be available or worn.

Cement in small quantities is usually supplied in 25kg or 50kg bags. These bags are often made of paper and are not waterproof and must therefore be protected from water. Some water will gradually be absorbed from the atmosphere and will react with the cement to start the hardening process.

Cement bags should preferably be stored inside a building, off the floor (Figure 2). If that is not possible, store the bags on pallets laid on flat ground and covered with plastic sheeting. Do not store more than four bags high as compressing the cement will assist the hardening process.

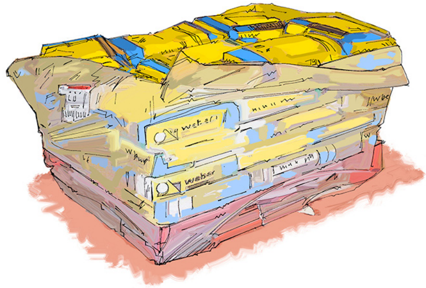


Figure 2. Packets of cement wraped in plastic and stored off the ground

Even under good storage conditions, cement loses significant strength if stored for more than four to six weeks. Cement stocks should be rotated so that the oldest is used first and bags are regularly checked for damage.

Damaged cement

Cement that contains lumps of hardened cement that cannot be broken by hand will have lost strength (Figure 3). If better quality cement is available, those bags containing hard lumps should be discarded. If cement containing lumps is all that is available, the lumps should be discarded. The remaining cement will have lost some strength, and should be used with caution. The quality of the remaining cement cannot be assessed from visual inspection. As a guide, the proportion of such cement added to concrete should be increased by between 10 and 20%.

Figure 3. Damaged bag of cement

Aggregates

Coarse aggregate

Aggregates must be clean and strong (this will depend on the rock from which they originated). They should be free of organic material, fine sand and impurities such as salt.

Fine particles of dust, soil or organic material will prevent the concrete mix bonding together to make a solid material. It will produce planes of weakness in the mixture that will allow water to enter or the concrete to crack.

As a rough guide to cleanliness, rub some of the aggregate between both hands. If the hands stay clean then the aggregate is probably ok. If the hands are stained, consider washing the aggregate to clean it (Figure 4).

If your hand is stained with aggregate, consider washing it again

Both the size and shape of the aggregate affects concreting. Large aggregate (20mm) is generally easier to work with and requires less water in the mix but should not be used if the concrete is to include steel reinforcement or only thin sections of concrete are to be laid. Similarly, rounded aggregate (such as river gravel) requres less water to make

Figure 4. If your hand is stained with aggregate, consider washing it again

the concrete workable than crushed or angular shaped aggregate.

Sometimes natural large aggregate is not readily available and, in some societies, it has been replaced by crushed bricks. This approach is highly energy intensive and the strength of the aggregate can be very variable, depending on how well the bricks were made in the first place.

Fine aggregate

Fine aggregates by which we usually mean sand, are normally naturally occurring, often from local river beds. As with coarse aggregates the cleanliness of the sand can be checked by rubbing the sand between both hands. Sand should preferably be washed or sieved to remove very fine particles, but it is unlikely that this will be possible in an emergency. If the sand is found to be dirty, consider whether other sources of cleaner sand are available.

Storing aggregates

Aggregate should be stored on a hard, dry patch of ground. Piles of different aggregate sizes should be separated by a space or a physical barrier to prevent mixing. Set up a stock rotation system so that newly delivered aggregate is not placed on top of existing stock. As the aggregate is used, fine materials will gradually fall to the bottom of the pile. If the same pile is used continuously, the bottom layer will become contaminated with excess fine materials and produce poor concrete.

The moisture content of the aggregate is important because it affects the quantity of water that must be added to the concrete mix. Large aggregate will tend to quickly drain any excess water but high temperatures may lead to drying out. Try to keep stored aggregates at a constant moisture content, possibly by spraying the pile with water regularly.

The moisture content of fine aggregate is more problematic. Freshly delivered sand is often very wet and should be allowed to stand for a day before use. Try not to use the bottom 300 – 600mm of a sand pile as this is likely to be saturated. In hot weather, fine aggregate will also have a significant difference in moisture content between the inside and outside of the pile so try to mix the aggregate as it is used.

Hot weather brings other problems. If the aggregate is hot it will contribute to the temperature of the concrete mix as it hardens. This can lead to excessively high temperatures in the mix which will reduce the final strength of the concrete. Try to store aggregates under shade and, if possible, regularly spray with water.

Water

Wherever possible use drinking quality water for mixing concrete. Impurities in the water can affect the final strength of the concrete. In hot climates, keep the water as cool as possible. If possible use water from a borehole or piped water supply. If you must store water for concrete mixing, store it in containers protected from the sun. Paint them white to reflect sunlight.

Concrete mixes

Mix ratios

Different mix ratios are used for different applications. In general, the stronger the concrete required, the larger the proportion of cement in the mix.

Mixing

The concrete mix is the proportion of each constituent (cement: sand: aggregate). Mixes can be prepared by weight or by volume. Of the two, mixing by weight is more accurate. (This is usually called 'weigh batching'). If large weighing scales are not available, then mixing by volume is usually the only practical option.

When mixing by volume, use containers of known volume to measure the proportions. A bucket levelled off with a straight edge or a prefabricated gauge box is best.

Gauge boxes

A simple wooden box fitted with handles can be fabricated of known volume. For example a box 300mm high x 400mm wide x 540 mm long has a volume of 65 litres. Two boxes full of aggregate will be sufficient to mix with a 50kg bag of cement when making 1:2:4 mix concrete.

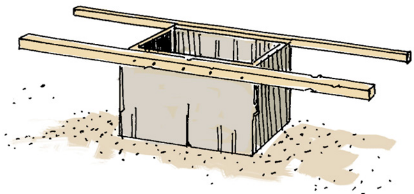


Figure 5. A gauge box

Water content

The amount of water in a mix is critical to the final strength of the concrete. If not enough is added the chemical hardening of the cement will be incomplete and the mix will be very difficult to manipulate. If too much is added the water will replace the aggregates in the mix and lead to a weak concrete. Concrete achieves its maximum strength with a water:cement ratio of 0.3 but this is not achievable when mixing by hand (the mix would be too dry to mix it properly). For hand mixed concrete the minimum water cement ratio is usually considered to be 0.55 by weight. This is equivalent to 27.5 litres of water to every 50 kg bag of cement.

Don't forget that the water : cement ratio includes water retained in the aggregate. The amount of water recommended assumes aggregates are damp. The amount of water added should be adjusted up or down depending on the actual wetness of the aggregate.

Water : cement ratio

The water cement ratio is calculated by dividing the mass of the water in the mix by the mass of the cement.

Table 1. Concrete mixes for various applications

Mixes	Use	'One bag mixes'			Batch volumes
Nearest traditional mix for comparison		**Aggregate volumes (litres) per 50kg bag of cement**	**Approx. yield, m^3**	**Number of mixes per m^3**	**For 1m^3 (approx.) Cement – bags** **Aggregate - litres**
1:3:6 or 1:8 all-in	Foundations, pipe surrounds	Fine 130 Coarse 180	0.24	4.2	Cement 4.2 Fine 560 Coarse 780
1:2.5:5 or 1:6 all-in	Foundations where ground conditions are poor or where it is difficult to keep excavations dry	Fine 110 Coarse 160	0.21	4.8	Cement 4.8 Fine 540 Coarse 790
-	General mass concrete. Minimum for structural unreinforced concrete	Fine 90 Coarse 150	0.19	5.4	Cement 5.4 Fine 510 Coarse 800

1:2:4	As above but where greater durability is required, such as solid floors, pump bases. Minimum recommended for reinforced concrete in mild conditions*	Fine 80 Coarse 130	0.17	6.0	Cement 6.0 Fine 490 Coarse 800
1:1.5:3	Reinforced concrete in severe conditions (exposed to sea water, acidic water, driving rain, alternate wetting and drying, or to freezing when wet).	Fine 65 Coarse 95	0.13	7.7	Cement 7.7 Fine 500 Coarse 730

Notes:

* Mild conditions – completely protected against weather or aggressive conditions, except for a brief period of exposure to normal weather during construction.

The information in these tables are based upon the use of a BS 12 cement with a standard strength class of 42.5. If cements of lower strength class are used (i.e. those containing pulverized fuel ash, ground blast furnace slag or limestone) the proportions of aggregate should be reduced by 10 per cent. The yield will be reduced accordingly.

Adapted from the Cement and Concrete Association construction guide.

Mechanical mixing

The best way to mix concrete is in a concrete mixer. Mechanical mixers need less water to ensure complete mixing and produce a more consistent concrete. If possible use a mixer that will hold enough material to use a full bag of cement. As a rough guide a 200 litre mixer will hold the aggregates needed to mix with a 50 kg bag of cement.

To mix concrete:

- Start the mixer drum turning
- Load half the coarse aggregate and anticipated water volume into the mixer
- Add most of the cement and fine aggregate
- Gradually add the remaining materials, avoiding a build up of dry or hardened material on the blades and drum.
- Mix for two minutes to obtain a uniform consistency and colour.

Figure 6. A mechanical mixer

Hand mixing

Figure 7 shows the materials required for hand mixing.

Mix on a clean smooth surface such as a large piece of packing case plywood or a concrete slab. Measure out the fine and coarse aggregates into a compact pile. Form a crater in the top and add the measured quantity of cement. Turn over the mix at least three times to fully combine the different materials. Form a second crater in the top of the pile and add some of the water. Bring the dry material from the edge of the pile to the water and keep mixing. Add extra water as necessary until a uniform consistency is achieved. Try not to add more water than is necessary for complete mixing and to achieve a workable mix. (See Figure 8 Steps 1 to 12).

A workable mix is when the concrete is neither too dry nor too wet. Knowing when a mix is workable comes with experience. A workable concrete is slightly liquid, so that it can be encouraged to fill formwork or moulds, but is not so liquid that it can be formed into a low cone without collapsing completely. A workable mix therefore behaves partly as a solid and partly as a liquid.

Placement and compaction

Concrete in its wet state will not keep to a specific shape. Construct a framework of timber walls (shuttering) to keep the concrete in place until it has set. The timber that comes into contact with concrete is often coated with a thin film of oil to make it easier to remove the timber when the concrete has set. Pour the concrete into the shuttering and push it so that it fills the space. It is important to remove air voids from the concrete so compact the mixture either using a vibrating poker or by vigorously moving a piece of reinforcing rod up and down in the mix. Don't over compact the mix as this will cause the materials in the concrete to separate.

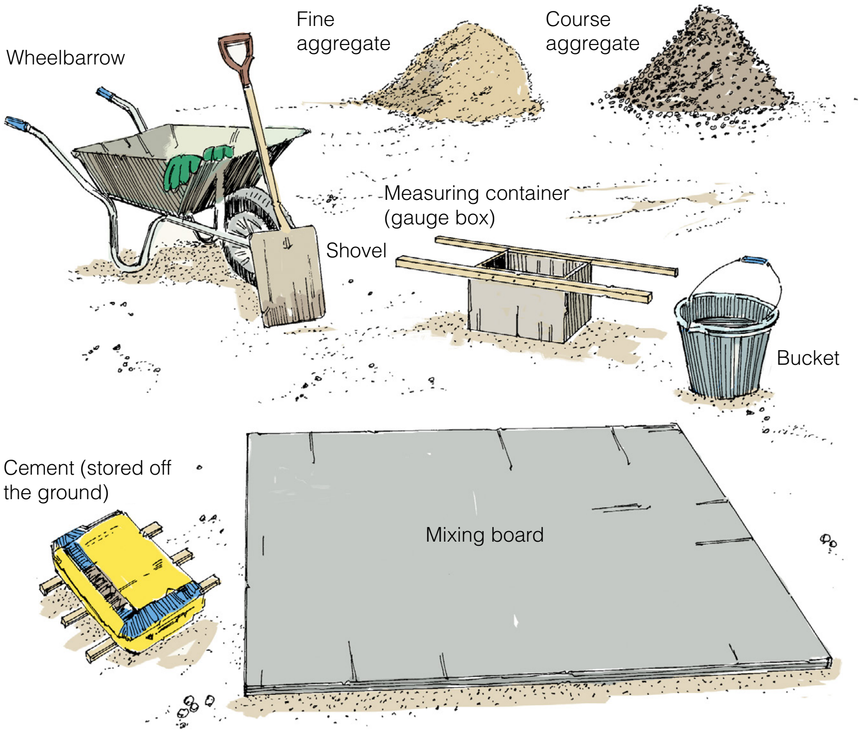
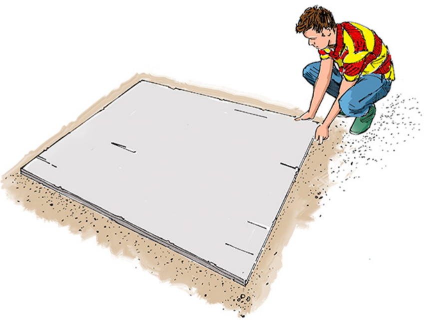


Figure 7. Materials and equipment required for handmixing concrete

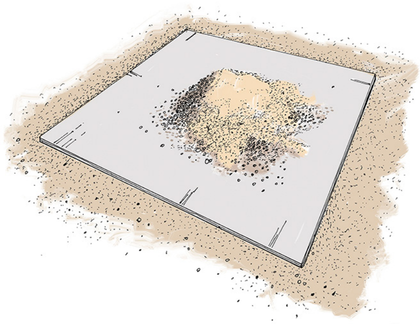


Step 1. Laying out the board

Step 3. Levelling the contents of the container

Step 2. Filling the container with aggregate

Step 4. Emptying the contents of the container



Step 5. Aggregates and cement ready for mixing

Step 6. Mixing the aggregates and cement together

Step 7. Making a crater in the mixture

Step 8. Pouring water into the crater

Step 9. Mixing the pile again

Step 10. Pouring more water into the crater

Step 11. Continuing to mix

Step 12. Testing the mix

Curing

Curing is the term used to describe the chemical hardening of the concrete. It will only fully take place if the concrete is kept moist and the temperature controlled. There is usually enough water added to the mix to enable curing to take place provided none is lost through drying out and the temperature of the mix is not allowed to rise too high. The concrete can be protected by:

- Leaving the shuttering in place for a week
- Covering or wrapping in plastic sheets
- Covering with wet sacking which are kept damp
- Regular spraying with water.
- Horizontal slabs can also be cured by:
- Covering in wet sand
- Flooding with water held within a low clay dam (Figure 8).

Curing should be started as soon as the concrete has hardened and continued for at least seven days.

Concreting in extreme temperatures

Cold weather

Do not concrete in freezing weather. The hardening process stops and the water expands as it freezes, leaving cracks in the concrete. At low temperatures try to retain as much heat as possible in the concrete by:

- using warm water;
- adding extra cement to the mix; and
- insulating the concrete with straw or fabric.

It may be possible to construct some concrete components indoors, or to erect a shelter so that the area to be concreted can be heated. Chemicals can be added to the concrete mix to prevent the water from freezing but these are only effective over limited temperature ranges.

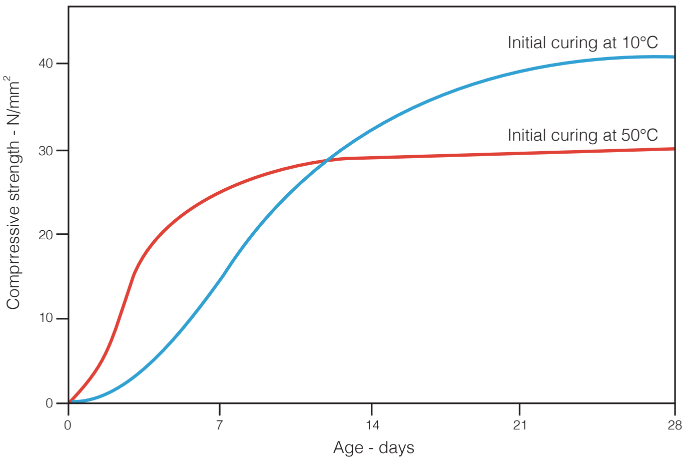
Figure 8. Constructing a clay dam

Hot weather

The main problems with concreting in hot climates are the rapid hardening of the mix and high temperatures affecting the hardening process. Concretes cured in high temperatures gain strength quicker than in cold temperatures but do not achieve as high a long term strength In emergencies, this is not normally a problem as most concreting only requires a fairly low strength.

The main techniques for working in hot climates are:

- Include admixtures (special chemicals) such as hardening retarders and water reducing admixtures to increase the time between mixing and hardening. This is unlikely to be possible during an emergency.
- Shade aggregates from the sun and spray regularly with water.
- Store water in insulated containers or ones painted to reflect sunlight.
- Mix concrete for the minimum amount of time before placing.
- Mix concrete as close as possible to the place where it will be used.
- Cover wet concrete with plastic sheeting as soon as possible after laying.



The higher the concrete temperature during mixing and the first 24 hours of curing, the greater the early rate of strength development but the lower the ultimate strength. Extremes of temperature have been chosen to emphasize a typical effect.

Figure 9. Variation in concrete strength with ambient temperature dam

Source: C&CQ (1980)

Notes

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