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Introduction

A qualified Concrete Delivery Professional (CDP) must have a good basic understanding of the product he mixes and delivers. The CDP is largely responsible for the condition and quality of the concrete in the mixer drum and delivering it per customer requirements.

The Concrete Delivery Professional routinely makes judgment calls based on product quality. Is a load too wet or dry? Is there too much sand or stone in it? Does a load of old concrete present a danger of hardening in the drum? The CDP with thorough product knowledge can make good judgments and provide better customer service for the company. Other potential benefits include reduced maintenance costs and improved overall efficiency.

The CDP also represents the concrete producer on the jobsite. Concrete that is not placed, finished, or tested properly can develop quality problems that can impact the concrete supplier and the customer. The ability to spot quality problems and report them to the company can often eliminate these problems.

The objectives of this module include:

- Provide a working knowledge of the composition of ready mixed concrete.
- Provide information on the factors that can affect concrete quality, and how the actions of the Concrete Delivery Professional can affect product quality.
- Describe the proper methods of placing, finishing and testing concrete.

To learn more about the information presented in this module, please see the list of references and recommended readings in the appendix.

Chapter 1 - Fundamentals of Concrete

Chapter Objectives

After studying this chapter, the CDP candidate should be able to:

- Describe how concrete is made and the common ingredients used in it
- Explain the basics of good concrete
- Describe the properties of plastic and hardened concrete
- Define several quality-related terms used in the ready mixed concrete and concrete construction industries.

The World's Greatest Building Material

Concrete is strong, versatile, durable, and economical. It is one of the world's most popular building materials. It is made from a variety of readily available raw materials. It can be used to build skyscrapers, dams, highways, bridges, house foundations and walkways. Concrete is simple and complex, making it a most interesting and challenging material to work with.

What is Concrete Made From?

Concrete is a mixture of cement, water, and aggregate, which is usually a combination of sand and stone or gravel. Concrete mixtures may contain other ingredients, but these are three basic ingredients common to all concrete mixtures. In its freshly mixed, or "plastic", state, concrete is a workable mixture that can be cast into any desired shape. It starts to stiffen shortly after mixing, but remains workable long enough to be placed and finished. Concrete normally sets, or hardens, within two to twelve hours after mixing, and continues to gain strength for months or even years.

Hydration: How Concrete Hardens and Gains Strength

Plastic concrete hardens as a result of hydration, the chemical reaction between cement and water. Hydrating cement particles attach themselves to the surrounding aggregate particles (See Figure 1-1).

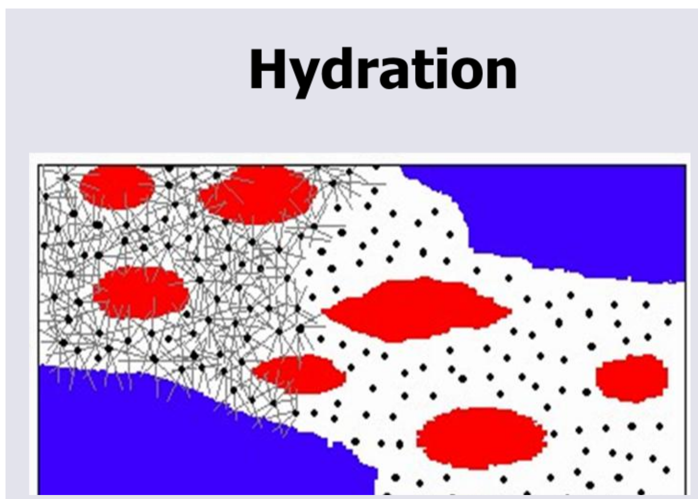


Figure 1-1: Cement hydration in concrete. This diagram of hydration looks something like a river. The "shoreline" represents coarse aggregate particles, the "islands" are sand grains, and the small dots in the river are particles of Portland cement in freshly mixed concrete. When cement mixes with water, hydration starts. Hydrating cement particles grow "fingers" that mesh together and bind the aggregates into a hardened mass as illustrated in the left side of the diagram. Over time, these bonds continue to form, filling in the voids between the particles.

Basics of Good Concrete

Concrete mixtures can be "customized" for many different types of construction. Mixture ingredients and their proportions are established to give the plastic or hardened concrete specific properties. There is no need for truck mixer drivers to be product quality and design experts, but drivers do need to be familiar with how good concrete is made.

Portland Cement: the Active Ingredient

Portland cement and water combine chemically to "glue" the other ingredients together. Supplementary cementing materials such as fly ash, and ground slag may also be used as a cementing material, but always in combination with Portland cement. Portland cement and the other cementing materials usually make up about 10% - 20% of the total volume of a concrete mix.

Water in Concrete

The amount of water added to concrete affects how strong the hardened concrete will be. Most concrete mixtures are designed with a certain cementing materials content, and enough water to make the mass workable. The required weight of water for the cementing material to completely react, or hydrate, is about 30% of the weight of cementing material. The extra water, sometimes called **water of convenience**, is added to make the product workable and easier to place. Reducing the mixing water content makes concrete stronger, while adding water dilutes the glue and makes concrete weaker.

The Ratio of Water to Cementing Material is an Important Relationship

The water to cementing materials ratio of concrete is a convenient indicator of quality. The water to cementing materials ratio describes the number of kilograms of water used for each kilogram of cementing material in a concrete mix design. For example, a concrete mix with one-half kilogram of water for one kilogram of cementing material has a water to cementing materials ratio of 0.50. When a mix contains more water than it was designed for, the concrete has less strength and durability, even if properly placed, finished and cured (See Figure 1-2). ***Adding water to a batch of fresh concrete is one of the most important product quality factors the CDP can control or influence.***

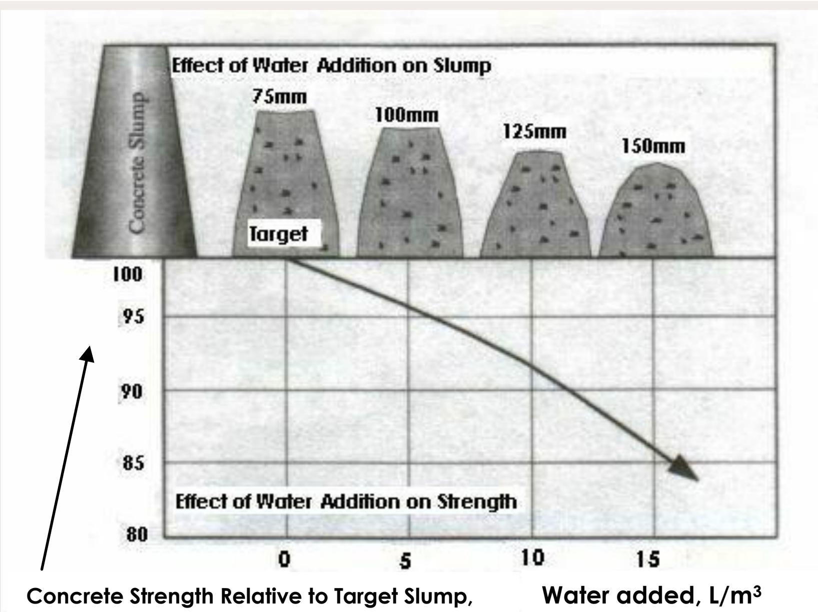


Figure 1-2: Example of the effect of water addition on slump and strength of concrete. Note that, as water is added, the slump increases and strength decreases.

Aggregates: Not Simply Rocks and Sand

Fine and coarse aggregates are added to the cement-water paste to give bulk to the concrete. The aggregates usually make up 60% to 80% of the volume of concrete mixtures and contribute significantly to the quality of the end product. If only fine aggregate (sand) is used a large amount of cement-water paste is needed to coat and bond the particles. Concrete with only fine aggregate is usually called grout or mortar.

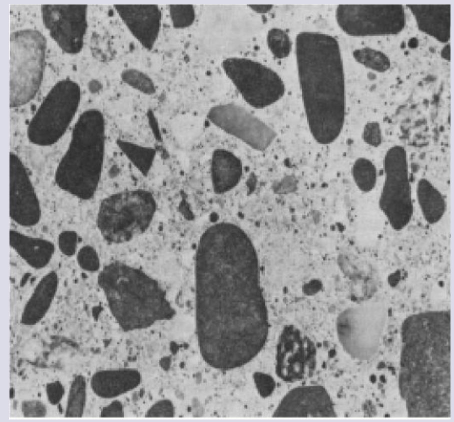
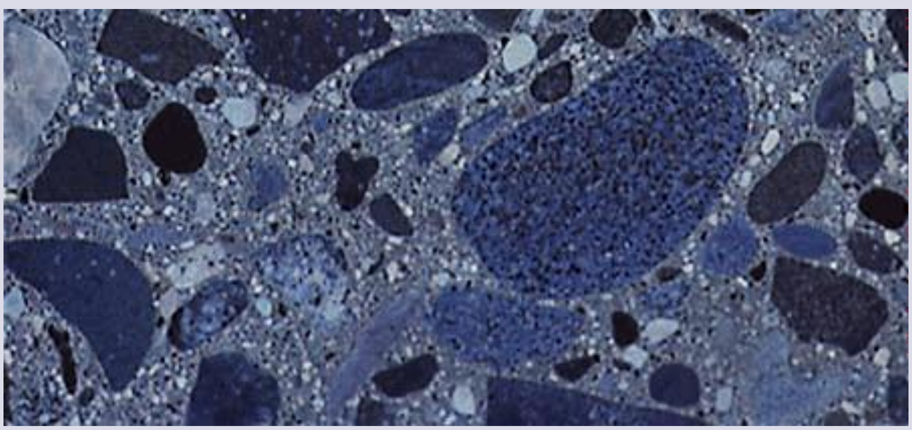


Figure 1-3: A cross-section of concrete with a good coating of cement paste on properly graded aggregates.

Coarse aggregates in concrete are usually crushed stone from a quarry or rounded gravel from a riverbed. Most concrete mixes contain more coarse aggregate than any other ingredient. Compared to an all-sand mix, coarse aggregate keeps the mixing water demand lower, increasing strength and reducing shrinkage. This produces a better quality concrete.

Fine and coarse aggregate both must be graded properly because too fine or too coarse material affects water demand and causes workability problems. Properly graded aggregates in a concrete mix allow particles with the right sizes to fill in all the spaces between sand and coarse aggregate particles (See Figure 1-3). Poorly graded aggregates result in bigger spaces that require additional cement and water paste.



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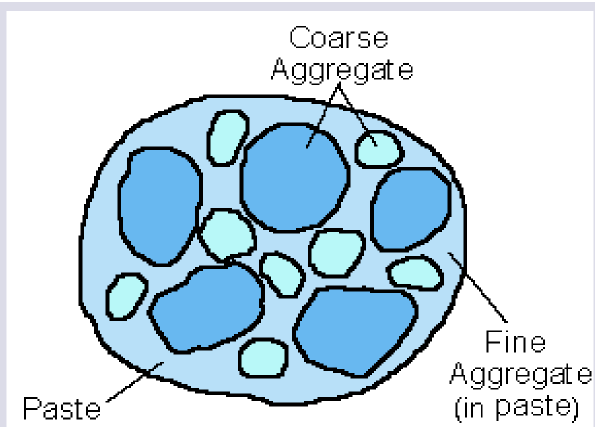

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Admixtures: Enhancing and Controlling Concrete Properties

Anything other than cementing materials, water, aggregates or fibre reinforcement added to a concrete mix is considered an admixture. Chemical admixtures in liquid form are often used to change properties of plastic concrete or to improve those of hardened concrete.

Admixtures: Enhancing and Controlling Concrete Properties

Commonly used chemical admixtures include:

- Water-reducing admixtures, used to make increase slump without adding water. Using less water will increase concrete strength.
- High Range Water Reducers (HRWR), also known as Superplasticizers, reduce concrete's water demand even further. They are generally used to produce high-strength concrete or to improve workability.
- Set retarding admixtures are used to delay concrete's setting time and are commonly used in hot weather.
- Accelerating admixtures are used to speed up the setting time of concrete, typically in cold weather.
- An air-entraining agent is often used to develop millions of tiny air bubbles in concrete. Entrained air improves concrete's freeze-thaw durability, for concrete that will be exposed to water and freezing temperatures.
- Value-added products include other liquid admixtures, plastic or metal fibres and colouring agents that are added to concrete when the customer needs a product with special properties.

Properties of Plastic Concrete

The properties of freshly mixed or plastic concrete are important because they affect the quality and in-place cost of the hardened concrete. These properties include:

- **Slump**, a measure of the consistency of concrete, or how "wet" or "dry" the mix is. The term comes from the test procedure used to measure this property of concrete.
- **Density** is the unit weight of a specified volume of concrete, usually expressed as kilograms per cubic metre. Concrete normally weighs about 2200 - 2400 kg/m^3. Lightweight concrete normally weighs 1800 – 2000 kg/m^3.
- The unit weight value can be used to calculate the **yield** of a batch of concrete. Yield is the actual volume of freshly mixed concrete, usually measured in cubic metres.
- **Air content** is a measure of the volume of entrapped and/or entrained air bubbles in concrete.
- **Temperature** of plastic concrete has a direct affect on its quality. For most applications, concrete temperatures should be in the range of 10^{o}C to 30^{o}C.
- **Workability** is the ease or difficulty of placing and consolidating the concrete. Generally, a workable mix describes concrete with aggregate and paste properties that allow it to be easily distributed, leveled, consolidated and finished.
- **Segregation** occurs when the coarse aggregate separates from the paste portion of concrete.
- **Pumpability** is the term used to describe how easily concrete can be placed with a concrete pump without segregating or clogging the pump.
- **Bleeding** is the movement of water to the surface of freshly placed concrete due to the settlement of heavier sand, stone, and cement particles shortly after placement.
- **Heat of Hydration** is the heat generated by the chemical reaction of cement with water. In thick concrete sections, heat of hydration can cause cracking.

Properties of Hardened Concrete**Hardened concrete has three important properties:**

- **Strength of Concrete**: The **compressive strength** of concrete is measured by the amount of force required to crush it. Compressive strength is important in the design of structures. **Flexural strength** is a measure of how much bending force the concrete can withstand before it breaks. In pavements and other slabs-on-grade, the design may be based on flexural strength.

The most important factors affecting compressive or flexural concrete strength are (1) the amount of cementing material in the mix, (2) the amount of water in the mix, and (3) how well the contractor protects the concrete, giving it the opportunity to cure thoroughly.

- **Concrete Durability**: Concrete used in structures and pavements are expected to have a long life and low upkeep, even under severe conditions. Exposure to **freeze/thaw cycles** when the concrete is wet in service can be very destructive to non-air-entrained concrete. Air-entrained concrete with adequate strength will withstand many cycles of freezing and thawing without showing distress. **Permeability**, the ability for water and water-born chemicals to enter concrete, also affects concrete durability.
- **Volume Changes**: All concrete shrinks as it dries. Concrete also changes volume with changes in temperature - expanding with higher temperatures and contracting as it cools. Concrete also expands and contracts with wetting and drying.

Units of Measurement in the Concrete Industry

In Canada, concrete is produced by weight (mass), in kilograms, but sold based on its volume in cubic metres. A cubic metre is the amount it would take to fill a cubical mould measuring one metre in length, width and depth. A cubic metre of concrete usually weighs close to 2400 kg.

Concrete Strength

Most concrete is sold on the basis of its **28-day design strength**. Thus, by specification, concrete must meet or exceed a particular compressive strength one-month after delivery and placement. The strength is expressed in units of stress; megapascal or MPa. At 28 days old, concrete has usually gained about 80 percent of its ultimate strength. Compressive strength is tested in a laboratory using test cylinders made when the concrete is being placed. This testing usually takes place at 7 days and 28 days after they are made. Concrete mixtures are commonly designed to achieve strengths of 20, 25, 30, 32 MPa or higher.

Chapter 2 - Components of Concrete

Chapter Objectives

After studying this chapter, the CDP candidate should be able to:

- Describe how cement works and why different types of cement are used.
- Describe aggregate types and how they affect concrete quality.
- Explain why entrained air is used in concrete and recognize how air content can be affected in concrete.
- Describe other cementing materials, why they are used, and recognize how they affect the concrete mix.
- List basic types of admixtures and their effects on concrete.
- Describe the use of "value-added" products such as fibres and colour.

History of Cement

Cement is one of the world's oldest building ingredients. The Romans combined powdered limestone and volcanic ashes to make cement to build structures that still remain. The methods used to make natural cement were largely lost or forgotten, until the British bricklayer Joseph Aspdin rediscovered the process in the early 1800's. He combined dust from his local roads where wagon wheels had pulverized limestone paving stones with lime and clay, and heated it to form "clinker." When he ground the clinker into a fine powder and mixed it with water, the mix hardened. It had a gray appearance resembling stone from the Isle of Portland in England, so he called it "Portland cement."

Many people use the word cement when they mean concrete. Cement is an ingredient in concrete. A CDP who hears someone make this error should clarify the misunderstanding by explaining the difference.

How Cement Works

When Portland cement mixes with water, a chemical reaction called **hydration** occurs. Heat, called **heat of hydration** is generated. As long as there is unhydrated cement in the concrete with access to moisture, it will continue to hydrate and gain in strength. The majority of this strength gain takes place in the first 28 days.

Types of Cement

The Canadian Standards Association (CSA), in their specification A3000, Standard Specification for Portland Cement, identifies five types of Portland cement:

Type GU (10) - **General-Purpose Cement**: This is used for most applications when no special properties of the cement are required.

Type MS (20) - **Moderate Sulfate Resistant or Moderate Heat of Hydration**: Also general-purpose cement, used when concrete is exposed to sulfate salts in water or soil that can chemically degrade concrete. Type MS cements also generate less heat of hydration. Type GU and MS together, account for more than 90% of the cement used.

Type HE (30) - **High Early Strength Portland Cement**: Used when high strengths are required one to three days after concrete placement. Type HE is often used in cold weather to accelerate strength gain, and in precast concrete.

Type LH (40) - **Low Heat Portland Cement**: Used in cases where heat of hydration must be minimized, generally only used in massive structures such as dams.

Type HS (50) - **Sulfate-Resistant Portland Cement**: Used where very high levels of sulfates are present in the water and soils.

Sometimes an air-entraining agent is ground in the cement when it is made. This type of cement will have an “A” in the description of the product, for example, Type GU-A. Air-entraining cements are rarely used for ready mixed concrete, because air-entraining admixtures allow more flexibility. There are also a variety of specialty cements and blended cements. Most cement is shipped by railway or by truck. It can be used as long as it does not come into contact with water, and remains free of lumps.

Aggregates in Concrete

Aggregates, such as sand, crushed stone and gravel, are mixed with cement and water to make concrete. Most aggregates are mined from natural sources in the earth. They generally make up 60% to 80% of concrete’s volume and weight. A typical cubic metre of concrete contains 1700 to 2000 kilograms of aggregate.

Size of Aggregates

Aggregates are typically divided into two size categories:
Fine Aggregates: Aggregates with particles smaller than 10mm, typically natural or manufactured sand (See Figure 1-4).

Coarse Aggregates: Aggregates (See Figure 1-5) ranging in size from 10mm to 40mm, typically gravel or crushed stone. Larger than 40mm coarse aggregates are used occasionally in dams or large foundations.

Figure 1-5: These laboratory samples of coarse aggregate are graded into single sizes to determine aggregate properties in the lab.

Figure 1-4: Sand (fine aggregate) makes up about 1/3rd the volume of aggregates in a typical concrete mixture.

Gradation of Aggregates

To produce concrete that is similar from batch to batch, the gradation of aggregates in the mix must be consistent. To test the gradation, a dry sample of aggregate is passed through a rack of different-sized screens, and the amount left on each screen is measured. This process is called sieve analysis. Generally, aggregates with too much or not enough of any one size of material result in problems with concrete water demand and workability.

Qualities of Concrete Aggregates

Concrete aggregates of any size must also have the following qualities:

- Clean: free from chemicals or coatings of clay and dirt
- Hard: free of soft particles that can easily break apart
- Strong: not easily fractured
- Durable: able to resist damage from freezing and thawing
- Non-porous: not able to absorb moisture easily.

The moisture content of the aggregate is also important. If aggregate is very dry when it is loaded into the concrete mix, it will absorb water from the batch, and cause the load to lose slump very quickly in the first 15 minutes. If the aggregate is very wet, it could cause the batch to exceed the desired slump if adjustments are not made to the batch water.

Other Aggregates

Figure 1-6: These lightweight aggregates were used in concrete that had a unit weight of 1800 kg/m^3

Most of the aggregates used in concrete are classified as normal weight. For special purposes, lightweight and heavyweight aggregates are used.

Lightweight aggregates are used to produce lightweight concrete, weighing less than 1600 to 2000 kg per cubic metre (See Figure 1-6). They are more porous and much lighter than normal weight aggregates. Lightweight concrete is often used on elevated slabs in steel-framed buildings.

Heavyweight aggregates are used to produce concrete for shielding against nuclear radiation. Concrete made with heavyweight aggregates can weigh from 2800 to 6000 kg per cubic metre.

Water

Water makes up about 15% to 18% of the concrete's volume. A typical cubic metre of concrete contains 140 to 180 litres. Water for concrete is often required to be "potable" or safe to drink, because chemicals or other impurities in water can affect the hydration process.

Water is required in concrete to make cement hydrate, but excess water leads to:

- Reduced strength and water-tightness
- Reduced durability
- Longer set times causing delays in finishing
- Increased shrinkage and cracking
- Weak surfaces that can dust or flake

Recycled Materials

Many concrete suppliers recycle some by-products from concrete production and equipment washing. Wash water from cleaning truck mixer drums can be re-used as batch water in fresh concrete. Water and cement slurry can be separated from the fine and coarse aggregates, and also used as a substitute for some or all of the batch water in new concrete. The reclaimed aggregates can be re-used as well.

The CDP should be aware that using recycled wash water or slurry in new concrete can affect the properties of the concrete. Special precautions must be taken to make sure that the concrete with slurry does not lose slump and set faster than plain concrete.

Air Entrained Concrete

An important property of concrete is the amount of air bubbles or voids it contains. Air in concrete can be either entrapped air, which naturally occurs in the concrete mix or entrained air, which is generated in the concrete mix by an air-entraining admixture. The total amount of entrapped and entrained air is expressed as the air content of the concrete mix.

Air Entrained Concrete *continued*

Air-entrained concrete is produced through the use of an **air-entraining agent**. It can be ground in with the cement, but is usually added to the concrete at the batch plant. The air-entraining agent generates microscopic air bubbles in the mortar of the concrete mix during the mixing cycle (See Figure 1-7). Entrained air makes concrete resistant to the effects of freezing and thawing by creating an **air-void system.** As water freezes it expands and can move into these air voids during freeze/thaw cycles, preventing damage to the concrete (See Figure 1-8).

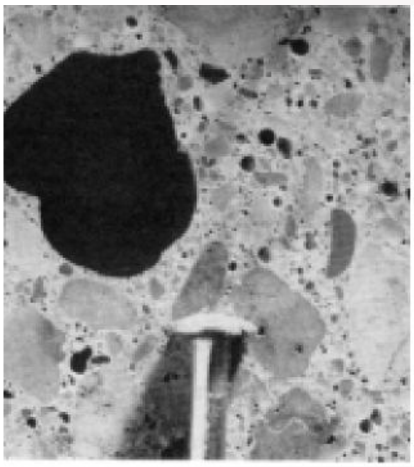
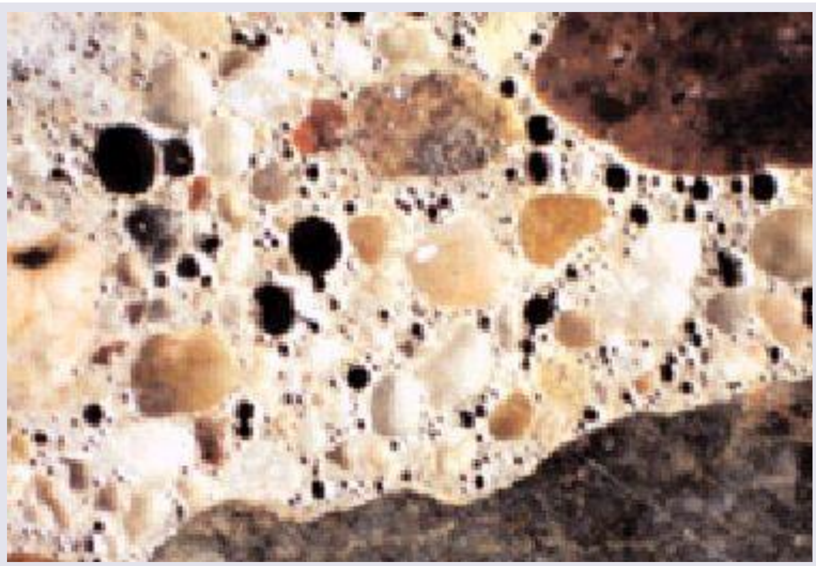


Figure 1-8: Insufficient concrete air content and spreading of deicing salt can cause scaling.

Figure 1-7: Properly entrained air will help concrete resist cycles of freezing and thawing.



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Air entrainment in concrete provides several benefits:

- Less water is required for the same slump.
- Bleeding is slowed.
- Segregation is reduced.
- Concrete holds together better during handling and placement.

However, at the same water to cementing materials ratio, air-entrained concrete will have a lower strength than one without entrained air.

Controlling Air Content Delivered to the Job

Air content can be affected by several factors, some of which can be controlled by the CDP:

- Mixing affects air content in plastic concrete. In truck mixers, the air content is reasonably stable from the completion of mixing through most normal delivery times. Under mixing prevents air bubbles from spreading evenly through the batch. Over-mixing can "beat" the air out of plastic concrete. Some entrained air is often lost during normal transport.
- The slump of the mix affects air content. It is harder to generate air bubbles at lower slumps, because there is not much water available. As slump increases by 25 mm, air content typically increases 0.5% to 1%. Air content generally increases with slump up to about 175 mm, and tends to decrease with higher slumps.
- As the temperature of concrete rises, the air content tends to decrease. Likewise, when the concrete temperature drops, air content will tend to increase.
- Air content may increase when the load in the mixer is three cubic metres or less. It may decrease when the mixer is overloaded, if the mixer is worn or has concrete buildup in the drum.
- Mixes with a higher percentage of fine aggregate or fine particles from cement have an increased air content.
- Pozzolans and mineral admixtures can decrease air content, and may require higher doses of air entraining agent.
- High air contents cause reduced concrete strength, particularly with high strength mix designs.

In general, high or low air content can have a negative effect on concrete quality. High or low air can be caused by a variety of factors. Regular air content testing is an important part of the producer's quality control program.

Other Air Content Control Problems

Air loss in pumped concrete often occurs when the concrete pump boom angle is so high the supply pipe cannot be kept full of concrete. As a result, air content can be much lower at the discharge end of the pump than at the mixer and can result in a rejected load. Over-vibration can also remove entrained air, sometimes causing durability problems with in-place concrete.

Supplementary Cementing Materials

A variety of cement-like materials, widely known as supplementary cementing mateirals, or also known as pozzolans, are frequently used in concrete. These cementing materials chemically react with cement and water to improve the strength and other properties of concrete. They are stored at the plant separately and batched into the load as required, or may be blended with Portland cement when the cement is ground at the mill. The most common types of supplementary cementing materials used in concrete are fly ash, ground slag and silica fume.

Concrete with supplementary cementing materials will usually gain strength after the traditional 28-day testing period more than mixtures with only Portland cement. In many cases, however, concrete with fly ash or ground slag may have lower early-age strengths. With all supplementary cementing materials, the hardened concrete is more watertight, which makes it more resistant to weathering, corrosion or sulfate attack. Concrete with supplementary cementing materials is also resistant to alkali-silica reactivity (ASR), a reaction between certain aggregates and cements that causes deterioration of concrete.

Fly Ash

Fly ash is a by-product of burning coal in an electric power plant. As with other supplementary cementing materials, it must be used in combination with Portland cement, usually substituting for about 15 to 30 percent of the total cementing materials content (See Figure 1-9).

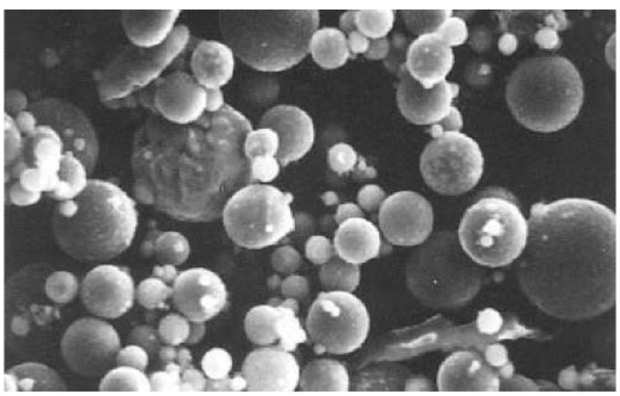


Figure 1-9: The rounded particle shape of fly ash makes concrete more workable.

The small, round shape of fly ash particles allows them to fill in the voids around the aggregates and in the cement paste.

Fly Ash Properties in Plastic Concrete

Some of the benefits of fly ash in plastic concrete include:

- Concrete containing fly ash is easier to pump, place, consolidate and finish.
- Fly ash reduces the amount of mixing water required to achieve the desired slump.
- Fly ash concrete bleeds less and have improved finishing characteristics compared to Portland cement concrete.
- Fly ash concrete can set slower and will have a reduced heat of hydration.
- Fly ash makes the concrete more economical by allowing Portland cement content to be reduced with equal strength or quality.

Fly Ash Effects on Mixing and Delivery

Fly ash in concrete has a variety of affects on the mixing and delivery process. Fly ash concrete does not lose slump or set as fast as all-Portland cement concrete. Fly ash can have a big effect on the air content of fresh concrete. Generally, fly ash concrete will require higher doses of air-entraining admixtures. The chemical composition of different loads of fly ash may cause the air content to vary quite a bit. Fly ash concrete that has been mixed excessively, or been in the mixer drum a long time, is more likely to lose entrained air than plain concrete without fly ash. Air tests should be taken frequently with fly ash concrete to verify that the air content is not high or low.

Figure 1-10: Flowable Fill (Controlled Low Strength Material) is an economic fill material

Fly Ash and Flowable Fill

A rapidly growing market for the ready mixed concrete industry is flowable fill, also known as controlled low strength material (CLSM). Flowable fill is an economical fill or backfill material produced at the ready mixed plant and delivered in truck mixers.

Flowable fill typically contains a large amount of water to make it fluid, but a small amount of Portland cement. Because the product is designed for low strength, it can include materials not used in concrete such as unclassified sand, aggregate fines, high carbon fly ash and other fill materials. In many areas, flowable fill provides power plants with a practical application for waste fly ash that would otherwise have to be buried in a landfill. The ready mixed concrete producer and the customer both benefit from the low cost of the material. The filling of utility trenches, abandoned tanks and unstable sub grades can often be done faster and using less labour with flowable fill than with loose stone or compacted earth (See Figure 1-10).

Ground Slag

Slag is a by-product from the manufacture of iron in a blast furnace. Liquid slag, which is rapidly cooled with water and ground to a fineness similar to cement has cementing properties. It can be used as a separately batched cementing material in ready mixed concrete or ground in with Portland cement at the mill. Ground slag is used at about 30% to 50% by weight of the cementing materials and can produce very strong and durable concrete. Larger quantities, up to 80% of the total cementing materials content, may be used to reduce heat generation in massive structures. Slag concrete has many of the same properties as fly ash concrete. It loses slump and sets slower than all Portland cement concrete, and it usually has lower early-age but higher ultimate strength. Ground slag is off-white in colour and usually causes plastic and hardened concrete to be noticeably paler.

Silica Fume

Silica fume is a by-product of electric furnaces in silicon metal production. Like fly ash, it has a spherical shape, although it is much finer. The average particle size is nearly 100 times smaller than a cement or fly ash particle. In fact, dry powdered silica fume is twice as fine as cigarette smoke particles.

Silica fume is very important in the production of high performance concrete. Silica fume is also used as a supplement to Portland cement in concrete, usually substituting for 10% or less of the total cementing material mass. It requires more water to produce the same slump than comparable plain concrete. Because of the high water demand, it is usually used with a superplasticizer, to maintain workability without high water content. Silica fume greatly reduces the rate of bleeding and the total amount of bleed water. Silica fume concrete is expensive to produce and place. It is frequently used for parking structures and bridges for its durability, or in tall structures requiring high strength. Concrete with silica fume (particularly dry powdered fume) will be very "sticky" and can be difficult to place and finish. Cleaning plants, trucks and finishing tools after a silica fume pour often takes extra time (See Figure 1-11).

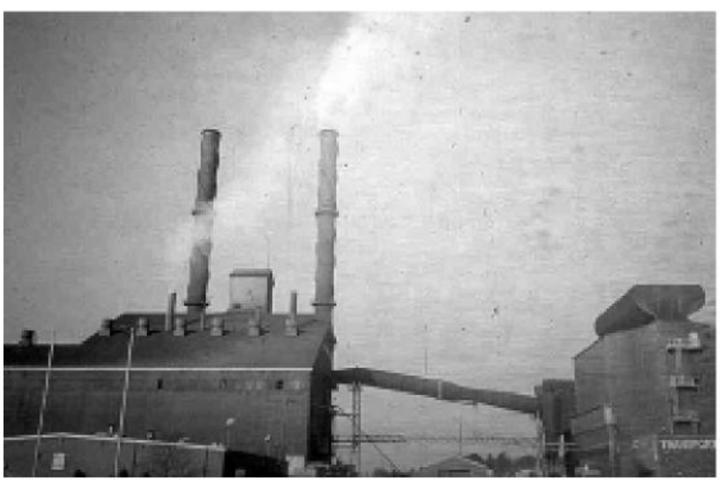


Figure 1-11: Silica fume is a byproduct of the silicon metal industry.

The Purpose of Admixtures

Admixtures improve the properties of fresh or hardened concrete. Admixtures can reduce the total in-place cost of concrete construction by reducing the time it takes to place and finish concrete, while extending the service life of concrete. Modern concrete mixtures often have a combination of admixtures in each load. Admixtures include all materials other than cementing materials, water, aggregates and fibre reinforcement added to concrete during mixing. Since these admixtures can have a strong effect on concrete properties, many are often combined with other types of admixtures to "balance" the reaction.

There are five basic types of admixtures:

- Air-entraining agents
- Water-reducing admixtures
- High-range water reducers
- Accelerating admixtures
- Retarding admixtures.

The use of air entraining admixtures and their effect on concrete has been previously discussed in this chapter.

Water Reducing Admixtures

Water reducing admixtures improve the workability of fresh concrete as well as the strength of hardened concrete. Water reducers are used to lower the mixing water content of concrete by about 5% to 10% compared to plain concrete and maintains the same slump. Concrete that contains a water reducer is more workable. It holds together better and is less likely to segregate during placement. Increased compressive strength and improved workability, using water reducers, allow the concrete producer to design concrete mixes at more economical cement factors.

What to Remember About Using Water Reducers

Water reducers can improve the pumpability of concrete. At higher dosages in the concrete, most water-reducers will retard concrete set time. Some water reducers have accelerators combined with them to offset these retarding properties. For water reducers to work properly, the load must be completely mixed and should arrive on the job with a minimum of 70 mixing revolutions.

High Range Water Reducing Admixtures (HRWR)

High range water reducing admixtures, also called superplasticizers, are used to give low slump concrete the same flowing characteristics as high slump concrete without adding extra water. Superplasticizers can also be used to produce concrete at normal slumps with low water content, but are more frequently used to make concrete flowable and easy to place. Such concrete is ideal for walls, columns, and structural concrete with a lot of reinforcing steel where strength and ease of placement are both important.

What to Remember About Using Superplasticizers *continued*

A superplasticizer is most often used to make concrete flow into tight forms or over long distances, and can be added to concrete at the plant or on the job site. To achieve the greatest benefit from a plant-added superplasticizer, the cementing materials should be wet before the superplasticizer is added. For this reason, it is often added to the batch at the end of the mixing cycle. If the cementing material is not pre-mixed with the water before the superplasticizer is added, the admixture is less effective.

Superplasticizer can also be added to concrete at the jobsite. Upon arrival at the jobsite, a technician or contractor’s representative may check the slump and determine the proper dosage of superplasticizer. After the chemical is added, mix the load for 30 revolutions at mixing speed. Generally 10 to 15 litres of superplasticizer will increase the slump of a full load of 100 mm slump concrete to 175 – 180 mm. In order to use superplasticizers effectively, the CDP **must be able to judge slumps accurately**. The load must be mixed completely, and the slump must be stable before adding the super.

Mid-Range Water Reducing Admixtures

There are admixtures that offer greater water reduction than regular water reducers, but less than a high range water reducer. The most effective use of these water-reducing admixtures is for concretes in the 125 to 200 mm slump range. Mid-range water-reducers can improve concrete workability and pumpability and do not retard set times as much as other water-reducers.

Accelerating Admixtures

Accelerating admixtures, or accelerators, reduce the set time of fresh concrete and speed up the early strength gain of hardened concrete. When the setting time is shortened, finishing operations can be completed faster, reducing labour costs. Early strength development becomes important when placing concrete in cold or freezing weather. Many accelerators include water reducing agents to produce faster setting concrete with reduced water content in cold or freezing weather. Accelerators are not designed to keep the concrete from freezing. However, they can help concrete gain strength fast enough so that exposure to freezing temperatures shortly after placement does not hurt the concrete. If the fresh concrete achieves 7 MPa or higher before it freezes, the concrete usually continues to gain strength in a normal fashion. Otherwise, the hydration process can be interrupted and the concrete may be damaged considerably.

Calcium Chloride

The most frequently used accelerator is calcium chloride. Calcium chloride is widely available, inexpensive and easy to use. The usual dosage is from 0.5% to 2%, by weight of the cementing material. Calcium chloride can be added as a water solution or in a dry, flake form. Bags of flake calcium chloride must be kept tightly closed, because it absorbs moisture causing lumps to form. These lumps do not dissolve during mixing and cause holes in the hardened concrete. **Calcium chloride causes corrosion of reinforcing steel in concrete**. As a result, most commercial job specifications forbid the use of calcium chloride in concrete. In these cases, non-chloride accelerators are often used. They have a similar effect on set times as calcium chloride, but they are more expensive.

What to Remember About Using Accelerators

Accelerators speed up the set time of concrete. Slump loss often occurs faster when accelerating admixtures are used. Delays affect the concrete's workability and strength more than with plain concrete. Proper mixing is essential. The concrete should be batched, mixed and delivered as soon as possible when accelerating admixtures are used.

Calcium chloride may be added by the CDP at the customer's request, at the plant or on the job if company policy permits. The chemical must be completely mixed through the load to be effective. Calcium chloride in excess of 2% by the weight of cement can affect concrete durability and colour.

Set Retarding Admixtures

Set retarding admixtures, or retarders, are used to offset the effects of higher temperatures on concrete. They are often used when delivery times are long. Retarders slow the rate of slump loss, allowing the concrete to remain workable longer in hot weather. Retarders delay concrete's initial set by an hour or longer, which may be useful during very large placements. Retarders can also reduce the possibility of unplanned or unnecessary "cold" joints that are caused by a delay between truckloads of fresh concrete.

What to Remember About Using Retarders

Retarders allow more time for mixing, delivery and placement in hot weather or in jobs with longer delivery times. They usually do not affect slump or air content.

Miscellaneous Admixtures

Chemical admixtures are constantly being developed and updated to respond to special construction needs. Some of the available specialty products include:

- Corrosion inhibitors, which are used to protect reinforcing steel in the concrete from deterioration;
- Lithium-based admixtures, which are used to counteract alkali-silica reaction (ASR);
- Gas-forming and foaming agents, which are used to produce lightweight, cellular concrete;
- Damp-proofing admixtures, which are used to reduce the tendency for moisture to travel through the concrete;
- Expansive agents, which are used to reduce the drying shrinkage of concrete.

Colouring Admixtures

Colouring admixtures are often used to create decorative or “architectural” concrete. Popular uses include decorative sidewalks and driveways, tilt-up panels, curbs, footpaths and pool decks (See Figure 1-12).

Figure 1-12: This “brick look” concrete makes a beautiful entrance.

Coloured concrete is often installed with some type of texture on the surface, making it look like stone, brick, wood, or other types of materials. Coloured concrete can be produced by adding a finely ground pigment in the plastic concrete. Coloured surfaces can also be achieved by spreading a pigment on the top of concrete and troweling it into the surface, or by staining the concrete surface after it has set. Normally, colouring admixtures or pigments added to the mix will not affect the properties of plastic concrete. With some colour admixtures a water-reducing admixture is added to the colouring agent, and changes to the mix design may be necessary.

Synthetic Fibres

Synthetic fibres made of polypropylene or nylon are used in many concrete applications. They can reduce plastic shrinkage cracking, and improve the impact resistance of concrete. A variety of synthetic fibre materials have been developed for use in concrete. Newer macro-fibres are larger in diameter and contribute to strength after the concrete cracks.

Figure 1-13: Synthetic fibres are added to concrete mixtures at a rate of about 0.3 to 1.2 kg per cubic metre.

Synthetic fibres (See Figure 1-13) are available in several forms: monofilaments - single strands of fibre, - or fibrillated fibre bundles, that look like an accordion when pulled apart. Various lengths are available as well. Monofilament fibres are less visible in the fresh and hardened concrete, but often increase concrete’s water demand more than fibrillated fibres.

Fibres and Workability

Synthetic fibres do not significantly change concrete workability, but concrete with fibre may appear to have a lower slump than it actually does. The CDP learns from experience how much water to add in fibre reinforced concrete. If higher doses are used in special mixes, the mix will look considerably stiffer and water demand will increase.

Steel Fibres

Steel fibres (See Figure 1-14) can be added to concrete as reinforcement to improve tensile strength, bending strength, and impact resistance. Steel fibres are used in amounts of 25 kg per metre or greater. Heavy industrial slab on grade applications often use steel fibres. Balling of the fibres during batching and charging operations can be a problem. Bundled steel fibres and special fibre dispensing systems are available to help overcome this problem.

Figure 1-14: The addition of steel or poly-propylene fibres has been shown to improve the flexural strength of concrete.

Chapter 3 - Batching, Mixing & Delivery

Chapter Objectives

After studying this chapter, the CDP candidate should be able to:

- Identify different types of concrete plants and their effect on loading and mixing procedures.
- Identify proper mixing techniques, effects of adding water, and mixing effects on product quality.
- Recognize the effect time and temperature has on concrete mixing and delivery.
- Describe methods used to ensure product quality in cold and hot weather.

Batching

The concrete batch plant is a small factory at the heart of the ready mixed concrete production facility. The essential function of the plant is to accurately convey, weigh, and dispense concrete ingredients into the truck or plant mixer. Concrete batch plants come in a variety of styles and configurations, designed to meet a variety of needs. Most concrete batch plants can be described as either transit mix plants or central mix plants. There are different ways of mixing concrete at these two styles of batch plants. Concrete batch plants are usually permanently installed at a supplier location, but some portable plants can be moved from job to job.

A "batch" refers to the concrete produced from one mixing cycle or operation. One truck mixer load, or one plant mixer load at a central mix plant, constitutes a batch of concrete. Concrete mixture proportions are established based on the required properties. The ingredients are batched by weight, except for water and admixtures, which may be batched by volume. Concrete is sold by volume (in cubic yards or cubic metres) as discharged from the truck mixer in a freshly mixed and unhardened (plastic) state.

Designing Concrete Mixtures

The first step in batching concrete is designing the mix. Mix designs are precisely calculated recipes, designed for specific uses such as foundation walls, bridge decks, or driveways. Most concrete is designed to reach a minimum strength, such as 20 MPa at 28 days, based on the requirements of the person ordering the concrete. Other requirements, such as water to cementing materials ratio, may also be used in designing concrete mixes. The volume of freshly mixed concrete from a known weight of the ingredients is called the "yield" of the concrete. The weight of the actual batch can be determined from the scale records at the batch plant, or will be automatically printed on a delivery ticket. The yield of the batch can be calculated using the total weight of the batch and the measured unit weight on a sample of the fresh concrete.

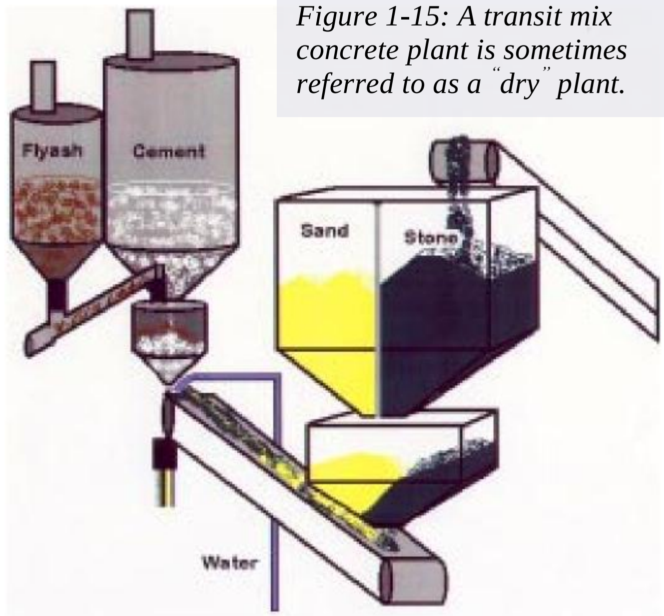
Designing Concrete Mixtures *continued*

According to CSA Standard A23.1, Concrete Materials and Methods of Concrete Construction, a fresh unit weight test is the only accepted method to determine yield, whether or not the customer's forms were filled completely. Shortages caused by things like waste, spillage, over-excavation, and spreading of forms are not the responsibility of the concrete producer and the purchaser should generally account for this when they place the order. Often, mixtures are designed to over-yield by one to two percent as a precaution against minor shortages due to small material and weight variances, or changes in air content.

Transit Mix (dry batched or truck mixed) Concrete

In transit mix concrete, all of the raw ingredients are loaded directly into the truck mixer. No plant mixer is involved. Some or all of the mixing water is usually introduced at the plant. The mixer drum is rotated at charging speed during loading.

Figure 1-15: A transit mix concrete plant is sometimes referred to as a "dry" plant.



There are three methods for mixing concrete in a truck mixer:

1. Concrete can be mixed at the jobsite. The materials are batched into the truck mixer and hauled to the job site with the drum rotating at slow, agitating speed. After arrival at the site, the concrete is then completely mixed by the CDP. This method can be used on longer delivery times, but does not allow the CDP to check the load before leaving the plant.

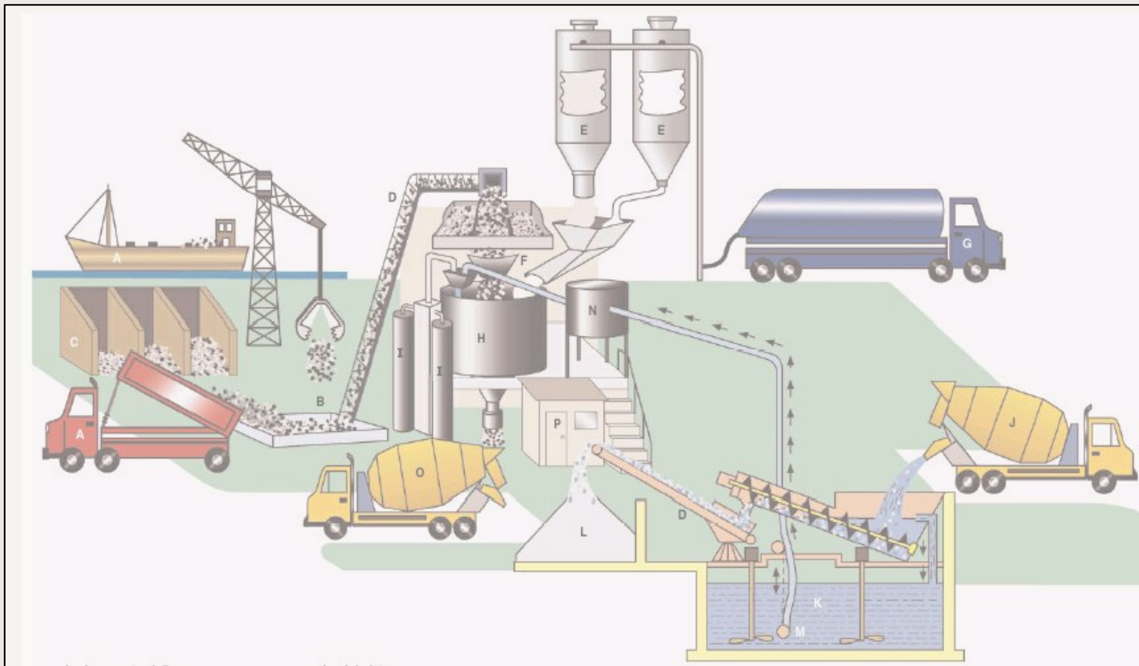
2. Concrete can be mixed in the yard. This is the most common way to mix concrete produced at a transit mix plant. The drum is turned at high speed for about 70 revolutions, at 12-18 revolutions per minute, before driving to the construction site. By completing the mixing in the yard, this procedure allows the CDP to check and adjust the water content of the batch, if required, before leaving the plant. The concrete is agitated slowly while driving to the job site.

3. Concrete can be mixed in transit. The drum is turned at medium speed while driving to the job, and then slowed to agitating speed. This saves fuel, drum wear and over-mixing of the concrete. However, it does not allow the operator to check the load completely before leaving the plant.

Central Mix Concrete

Central mix concrete plants include a stationary mixer that blends the concrete materials prior to discharge into the truck mixer (See Figure 1-16). The truck mixer is used primarily as an agitator when the concrete is centrally mixed. Non-agitating haul units such as dump trucks may be used to deliver concrete from a central mix plant. The main advantages of central mixing include faster batching and reduced wear of the truck mixer drums. However, central mix plants can be more expensive to purchase and maintain than transit mix plants.

Figure 1-16: Central mix concrete plants have the advantage of rapid batching.



A Aggregate delivery
B Aggregate receiving hopper
C Aggregate storage
D Conveyor belt
E Cementing material storage
F Weigh hopper
G Cement delivery
H Mixer
I Admixtures
J Ready mix truck with returned concrete
K Recycled water
L Reclaimed aggregates
M Pump
N Water storage
O Concrete loaded in ready-mix truck
P Control Room

Fig. 10-4. Schematic of a central mix ready mix plant.

Slurry Mix Concrete

Slurry mixers are auxiliary mixing units that can be added to a transit mix plant. Slurry is formed by mixing water and cementing materials in the slurry mixing unit. The slurry is then dispensed into the truck mixer drum along with the aggregates. Slurry mixing can improve concrete consistency, increase batching speed, and reduced dust emissions.

Shrink Mix Concrete

Shrink mix concrete is partially mixed in a central mixer and then charged into a truck mixer, where the mixing is completed. The truck mixer is turned at high speed while charging the concrete. Mixing can be completed at the plant or at the job site. The number of revolutions needed to complete the mixing of shrink mix concrete in the truck mixer varies, but generally about 30 turns of the drum produces mix uniformity throughout the load.

Figure 1-17: Nearly all new concrete plants are automated with computer controls.

Batch Plant Controls

Most modern concrete plants are fully automated with computerized systems (See Figure 1-17). Older plants may be semi-automated or operated manually. Since concrete is batched by weight, all concrete plants have some type of scales to weigh raw material before loading it into the mixer. Water can be measured by weight using scales, or by volume using meters. Admixtures are generally dispensed by volume. One cubic metre is the minimum volume that can accurately be batched from most concrete plants. Plant scales and meters must be checked for accuracy at intervals not exceeding six months.

Pre-Loading Procedures

Prior to receiving the first load of the day, the CDP should make certain there is no water in the truck mixer drum. Water from a heavy rainfall or a water valve inadvertently left open at truck startup will accumulate in the drum. This water should be discharged from the drum prior to loading. The inside of the drum should be clean and free from grease, oil and other contaminants. The CDP should be aware that it takes a small volume of concrete (essentially cementing material, sand and water) just to coat the inside surface of the drum. As a result, if the first load of the day is a one metre to three metre batch in a ten metre drum, a noticeable shortage of material can occur. Additional material should be batched in a clean mixer to compensate for coating the inner surface of the mixer. Batching procedures for the first load of the day when the drum is dry may be different than for later loads.

Pre-Loading Procedures *continued*

Sometimes fresh concrete may be batched on top of wash water and/or concrete from the previous delivery. The CDP should be aware that batching on top of old concrete can speed up set times, and cause rapid slump loss. Because small volumes of leftover concrete in the drum are hard to estimate accurately, overages or shortages are often associated with loading on top of old concrete. Ready mixed producers have varying company policies regarding loading on top of leftover concrete. The CDP needs to communicate clearly with their dispatcher when returning to the plant with surplus concrete, to help avoid problem situations with “hot” loads caused by old concrete.

Loading Process

Concrete may also be batched on top of water and concrete that has been treated with hydration control admixtures, designed to preserve and recycle these materials. Recycled materials can be used without affecting concrete quality, when used appropriately.

When ready to load, pull or back the truck into the plant’s load lane. The truck should be spotted accurately, and the drum control put into fast charge. The outside of the drum should be kept dry when loading so dust does not adhere to it. The water tank should be filled without running over to prevent excess runoff or drainage water.

The speed and sequence by which raw materials are loaded into the truck mixer can greatly affect the quality of the product, regardless of loading into a transit mix or central mix plant. Loading into a truck mixer should take place in a specific sequence for a transit mix plant:

1. About 50% to 80% of the batch water should be loaded first to coat the drum and prevent materials from sticking or “packing” on the fins.

2. Aggregate should begin discharging into the drum. Cementing materials should then be ribboned in along with the aggregates, starting and finishing before aggregate loading is completed. Cementing materials should not be loaded by itself or along with batch water, when possible.

3. Admixtures can be added at different times during the batching cycle, but are usually loaded either with the water or fine aggregate during their discharge into the drum.

4. The remaining water is added at the end of the load, to wash down the charge hopper and fins in the rear of the mixer.

It is the responsibility of the batch plant operator to make sure the proper materials get into the concrete mixer. Different types of truck mixers accept pre-mixed concrete or raw materials at different rates. Attempting to load material faster than the drum can accept it will cause spillage and waste. Loading too quickly can prevent the cementing materials and aggregate from mixing with the water, and can cause the material to “ball” up. These balls of cementing materials and/or aggregate may not break up during the mixing cycle, and can create placing or finishing problems. Extremely dry fine aggregates may also cause lumps in the fresh concrete to form.

Mixing

Many concrete quality problems can be traced back to poor mixing. Proper mixing techniques must be followed immediately after loading and after adding water or other products to a load. Company policies on mixing procedure vary, depending on the types of equipment and mix designs involved. Here are some basic guidelines:

1. CSA Standard A23.1 requires truck mixers to produce uniformly mixed concrete in 70 - 100 revolutions at mixing speed. It takes most truck mixers about five minutes to mix a load to 70 revolutions at high speed.

2. Normally, 300 revolutions are the maximum number of turns (mixing and agitating) permitted before project inspectors can reject a load.

3. Charging and mixing speed is normally considered 12 - 18 revolutions per minute (rpm). Higher rpms are not always better, since the concrete may be worked too violently, causing the materials in the batch to breakdown or segregate.

4. Agitating speed once the load is properly loaded and mixed is 2 - 4 rpm.

5. Central mixers can generally produce uniform concrete with about 60 to 90 seconds of mixing.

6. Buildup of concrete inside the truck drum or worn-out fins will affect mixing. The CDP must be aware of the condition of the drum, and make adjustments in mixing time or speed as necessary to properly mix the load.

7. The CDP should watch for signs indicating that the mixer is not doing its job. There are a series of tests, discussed in CSA Standard A23.1, which can be performed on concrete from the initial and final part of discharge. A quick series of slump tests, or a visual check, will indicate that the mixer is producing uniformly mixed concrete. Tracking empty truck weight and watching for shortages can be indicators of buildup in the drum.

Truck mixer drums rotate at different speeds. Most mixers have a rating plate from the mixer manufacturer attached to the mixer frame, specifying mixing speeds and other mixing information. Since the mixer speed is controlled by the speed of the truck engine, many trucks have to run at full throttle to reach proper mixing speed. Newer, more efficient trucks can effectively mix concrete at lower engine speeds. The CDP should know the engine speed required to mix and agitate properly for each truck operated.

Judging the Load

During the mixing process, the load must be checked periodically. One of the most important qualities to check is the desired slump, which should be printed on the delivery ticket.

The following chart and pictures describe the characteristics of high and low concrete slumps:

Observed Condition	Approximate Slump	Discharge Characteristics
Very Stiff	Less than 50 mm	Not flowable, crumbly consistency
Stiff	50 mm to 75 mm	Barely flows; "needs help" down chute
Medium	100 mm to 125 mm	Flows sluggishly, piles up in mound
Wet	150 mm to 175 mm	Flows well; piles slightly
Very Wet	175 mm or more	Very fluid; over 200 mm, almost self-leveling

One of the most important skills that the CDP must develop is the ability to judge the slump of concrete in the drum. This ability is difficult to master and takes practice. The speed that the drum is turning will affect the way the concrete looks. A visual check on every load should always be made with the drum at agitating speed before leaving the yard. The CDP should be able to visually judge the slump of the concrete within about 25 mm. This can be particularly difficult on smaller loads or when weather conditions and inadequate lighting make it hard to see inside the drum. Some mixers have hydraulic slump meters that measure the resistance of the drum as it turns the concrete. Slump meters should be calibrated periodically against a properly performed slump test. Very stiff concrete has a high resistance to turning, while wet concrete rolls with less resistance, causing different readings on the slump meter.

The CDP should not place too much emphasis on any one technique of estimating slump. Different mix designs, aggregates, additives, load sizes, and the type of truck mixer can greatly affect the apparent versus actual slump. Ultimately, experience is the best tool to use for judging slump.
Besides slump, the CDP should look at the appearance of the load. CDPs who are accustomed

Judging the Load *continued*

to the materials available at their plant can often see or smell if a certain product is in a load. The CDP should check the consistency of the load to see if it is too stony or too sandy, as well as the colour and uniformity of the mix. If gates in the plant stick during loading, or if coarse and fine aggregates get mixed together before going into the plant, the load may not have the correct proportions of raw material.

A good method to check the slump and quality of the mix, especially on small loads, is to reverse the drum so that the concrete is brought to the mouth of the drum where it can be easily seen. The CDP should also verify as closely as possible that the concrete is the right volume and type of material indicated on the ticket. If the batch plant operator mistakenly puts the wrong load on the wrong truck, the CDP can often catch the error before the truck leaves the yard.

Adding Water at the Plant

If there is any kind of problem with the load, it must be reported immediately to the batch plant operator, or other personnel as indicated by company policy. Concrete batch plant operators often withhold some water from each batch, allowing for minor slump adjustment at the plant or at the job site. The CDP should understand the job requirements for adding water, because some projects have strict specifications that will limit the total amount of water to be added.

For operations where all mixing is done in the trucks – that is, the plant itself has no central mixer - the load must be completely mixed by turning the drum at least 70 revolutions at mixing speed before leaving the yard. If slump is low at the project site, additional water may be authorized by the Contractor of your company's quality control (QC) people. The CDP should not make the decision themselves. A rule of thumb is that 5 litres of water will increase the slump of one cubic metre of concrete by 25 mm. To increase the slump of 10 cubic metres of concrete from 50 to 125 mm would require 150 litres. Low-slump concrete at high temperature may require more water and air-entrained concrete in cool weather may not need as much water. Adding water to air-entrained concrete may also increase air content, which in turn increases slump.

The CDPs should always check the slump **before** starting to wash down the charge hopper and fins! If the load is properly mixed and water is still required to bring the load up to the required slump, the necessary water can then be added. Concrete should be mixed at 12 to 17 rpm for 30 revolutions, or about two minutes, after water is added. If the load still does not meet the target slump, the batch plant operator or quality control technician should be notified.

Delivery

CDPs are expected to mix and deliver concrete in the shortest time possible. Concrete is a perishable product that needs to be placed and finished before it starts setting and hardening. Once the cementing material combines with water in a load, the hydration process that causes concrete to set up begins. Many specifications and CSA Standard A23.1 have a limit of **120 minutes** from the time the load is batched until it is discharged. On some placements, the time limit is only 60 minutes! Delays affect product quality, cause problems with scheduling, and lead to unhappy customers.

Delivery *continued*

The CDP must plan ahead to minimize delays.

- CDPs in line at the plant should stay with their trucks and should be ready to load immediately when called by the batch plant operator.
- Delivery tickets should always be reviewed for the following: load size, desired slump, mix design, and special aggregates, cementing materials, admixtures or additions such as reinforcing fibres.
- The CDP should make sure they know the location of the job site and the best route to get there. If the dispatcher provides a specific route to the job, the CDP should follow it unless granted specific permission to do otherwise.
- Each load must be mixed thoroughly and checked for slump and consistency. If additional water is required to raise the slump, the load should be re-mixed and checked again. The drum should then be slowed to agitating speed.
- Water tanks should be filled prior to leaving the yard with each delivery. In most cases, the truck water tank is depressurized before leaving the yard to conserve air for the truck's braking system and prevent accidental introduction of water into the load.
- The vehicle must be free from debris that may fall off truck and damage property. Any items carried on outside of truck must be secured.

Jobsite Addition of Water

Sometimes after arrival on the jobsite, the CDP finds that the load has lost slump. The customer may also want the load wetter than specified on the delivery ticket. Slump adjustment and water-adding policies are sensitive issues and must be handled according to company policy and project-specific restrictions.

Before adding any water on the job site, the load should be re-mixed at mixing speed for about 10 seconds, in case any segregation of the mix has occurred in transit. The slump of the load should be checked and the customer notified of the approximate slump. Often the customer's representative and/ or the project technician may want to check the load before authorizing the addition of water to the load.

Adding water to the concrete after initial mixing is known as **re-tempering** the load. If possible, slump tests should be taken before concrete is re-tempered. To make field adjustments, CSA Standard A23.1 permits a single addition of water and air entrainment admixture to the load at the jobsite prior to discharge. Any such adjustment to the mixture at the jobsite should be documented on the delivery ticket, especially if the customer requests excessive water since the customer then is taking on the legal and technical responsibilities of the batcher.

Jobsite Addition of Water *continued*

Alternatively, concrete slump can be increased at the jobsite by adding a water-reducing admixture or superplasticizer. The CDP should be aware that adding water to air-entrained concrete could increase the air content, which in turn will increase slump.

CSA Standard A23.1 requires that these guidelines be followed when adding water to concrete on the job site:

1. Water additions should not cause the design or specified water to cementing materials ratio to be exceeded.

2. The amount of water added should be only what is required to increase the concrete slump to the specified level.

3. Any water addition must be done before discharge of the load into the forms.

4. Water can be added only once to each load within 60 minutes of the batch time. Never add water to a partial load.

The CDP should be aware that samples for testing concrete should be taken only after all the adjustments such as an addition of water or admixtures are made and the concrete is properly mixed.

After water is added to the concrete, the load must be mixed for an additional 30 revolutions at mixing speed. Water added at the request of the customer should be recorded on the delivery ticket, and signed by the customer or customer-authorized personnel. This is an important legal precaution. If your company's quality control representative directs that water be added, record this as well. This information must be documented in case future problems with the concrete occur.

Temperature

The temperature of the plastic concrete directly affects quality. Generally, concrete should be maintained between 10° and 35°C. There are some parts of the country where maintaining concrete temperature within these limits is not possible, but the purchasers will accept this condition. The rate at which concrete sets and hardens depends on the concrete and ambient temperature.

Concrete temperatures below 10°C can cause set time to slow down drastically, often leading to finishing and form removal problems. Strength and durability can be compromised if the concrete does not achieve initial set before exposure to freezing conditions. Likewise, concrete temperatures above 35°C can result in increased water demand, more slump loss, faster set time, making air entrainment harder to control, and cause placing and finishing problems. Hot concrete also leads to reduced ultimate strength. Low 28-day concrete strength problems are much more common in hot weather.

The temperature of raw materials affects the temperature of the concrete. Water and aggregates can be heated or cooled to control the temperature of plastic concrete. Ice may be needed as a part of the mixing water in hot weather.

Cold Weather

Cold weather is not necessarily freezing weather. CSA Standard A23.1 defines cold weather as "when air temperature is at or below 5°C or when there is a probability of its falling below 5°C within 24 hours of placing.

There are a number of methods to maintain concrete temperatures in cold weather:

- Use of heated materials will increase concrete temperature. Warm water is the most commonly used method to increase concrete temperature. In severe cold weather, aggregates will also need to be heated. Caution must be used when adding cold water from the tank or another source because it will reduce the concrete temperature. Care should be taken to prevent extremely hot water from direct contact with cement, as this will cause rapid setting.
- Use of an accelerating admixture helps maintain setting time and rate of hardening within desirable limits. Type HE (30) high-early cement may also be used although most plants do not have this extra silo for this special cement.
- Concrete containing fly ash or slag may have a slower setting time in cold weather. Frequently, the amount of these materials in the mix are reduced or eliminated in cold weather to facilitate speeding up the finishing operations.
- Over-mixing concrete creates heat. Once concrete is mixed, the mixer should be slowed to low speed.
- Increasing cement content of mixes may help speed finishing operations in the wintertime.

Hot Weather

In many areas of the country, high temperatures can make concrete difficult to mix and deliver. Again, since concrete temperature has a direct affect on its quality, these steps can be taken to minimize hot weather effects on concrete.

- Use a low heat of hydration cement (Type LH) cement and/or a pozzolan to slow down concrete set time.
- Use cold water for batching concrete. In severe hot weather, ice can be substituted for water or liquid nitrogen can be used to cool concrete.
- Prevent delays in driving time to the jobsite whenever possible.
- Use a set-retarding admixture to slow concrete set time and help with placing and finishing.
- Park trucks in shaded areas when possible, if unloading is delayed.
- Fill the truck water tank with cold water, when available.
- Add water on the job at the last minute prior to unloading, so the customer can get the full benefit of the increased slump.

Chapter 4 - Handling, Placing & Finishing

Chapter Objectives

After studying this chapter, the CDP candidate should be able to:

- Describe methods of placing concrete and the advantages & disadvantages of each.
- Identify how placing methods can affect concrete quality, and understand the "dos and don'ts" of handling, placing and finishing concrete.
- Describe concrete curing and how it affects concrete properties.
- Briefly describe concrete cracking and means to control it.

Handling and Placing

The unloading, or placing, and finishing process begins when the concrete reaches the jobsite. There are many different methods of discharging and placing concrete into forms, with advantages and disadvantages to each method. No matter how the concrete is unloaded, care must be taken so quality of in-place concrete is not affected.

There are two ways concrete can be affected during handling and unloading:

- Delays on the jobsite in the unloading process can cause slump loss, especially during hot weather. This will force addition of water to the mix so the concrete stays workable, but will reduce strength.

- Segregation can occur if the handling and unloading methods do not move the concrete in a uniform way. Coarse aggregate can separate from the mortar paste and the mix will lose its full strength potential or result in other durability problems. One such problem is the appearance of pockets of coarse aggregate separated from the mortar in hardened concrete, called **honeycombing** (See Figure 1-18).

Figure 1-18: Honeycombing occurs when coarse aggregate separates from the mortar portion of the concrete.

Placement Methods

The following chart lists types of placement methods, the normal use, advantages, and what the CDP should watch out for.

READY MIXED CONCRETE PLACEMENT METHODS

Equipment	Normal Use	Advantages	Points to Watch For
Belt conveyors	Conveying concrete horizontally, or to a higher or lower level	Adjustable reach and variable speeds. Can move large volumes of concrete quickly where access is limited.	Care must be taken to make sure segregation does not take place when concrete leaves belt going into forms.
Belt conveyor-mixer mounted	Conveying concrete horizontally to a higher or lower level	Conveyor arrives with the concrete, more efficient for the customer. Adjustable reach and variable speed.	Care must be taken to make sure segregation does not take place when concrete leaves belt going into forms.
Buckets	Mostly used with cranes	Makes more efficient use of equipment normally on site. Clean discharge and wide range of placing capabilities.	Bucket size should match the load size and crane capacity or delays can occur. Discharge should be controllable.
Chutes	Conveying concrete to a lower level	Low cost and easy to maneuver. No power required, gravity does most of work.	Chute must be properly supported as longer sections are used. Watch for segregation at chute end.
Cranes	Often used when concrete placed above ground level	Versatile, can lift other building materials on site.	Can only handle one task at a time, needs careful scheduling for best use.
Drop-chutes or "elephant trunks"	Placing concrete in vertical forms	Can direct concrete into forms without segregation. Avoids spillage of concrete on side of form.	Must have large enough opening at top to handle speed of placement or spillage can occur.
Power buggies	Short, flat hauls on all types of construction	Very versatile and faster than using just labour to unload.	Must have enough units on job to support constant unloading rate.
Pumps - mobile or stationary	Placing concrete either horizontally or vertically through pipes or hoses	Pipes or hoses take up little space. Concrete delivered in constant stream, less problems with consolidation. Mobile pumps can be moved during pour - more efficient.	Need constant supply of proper slump concrete in system or pump may plug up. Distance and bends in hose or pipe can slow efficiency. Mixes need to be designed for pumping to account for some loss of slump and air. Watch for constant changes in boom configuration during placement.
Screw spreaders	Used for spreading concrete on flat surfaces, typically pavements	Works well with low-slump concrete. Spreads concrete over wide area more efficiently at uniform depth.	Usually part of a paving train, should not be used as vibrating device for consolidation.
Slip-form machines	Used to form continuous curbs, gutters, road barriers or containment tanks	Cost-effective way to form and place higher volume of horizontal or vertical special shapes.	Requires special mix design and extremely low slump concrete. Mixer must be capable of discharging at required rate and usually controlled from cab of truck.
Tremie	Placing concrete underwater	Can be used to funnel concrete through water into foundation or other structure.	End of tremie must always be buried in fresh concrete to preserve seal against water. Concrete mixture must be rich in cement and at higher slumps.
Wheelbarrow	Short, flat hauls on general construction	Simple, economical and maneuverable, not a mechanical device that can break down.	Slow and labour intensive.

Placement methods *continued*

Figure 1-19: The mobile concrete pump is a very popular placement method

Proper Placement

Proper concrete placement is a critical step in good quality concrete work (See Figure 1-19).

The following is a checklist of proper placement practices:

- Forms are the moulds in which concrete is placed. Forms should be clean, straight and properly braced to prevent movement, deformations, or blowouts. Formwork that bulges or deflects when concrete is placed will cause shortages. Formwork should not leak and form faces should be treated with a release agent to aid in the form removal process.
- Reinforcing steel should be clean and free of loose rust or other materials.
- The condition of the subgrade over which concrete is placed is very important. The subgrade should be well and uniformly compacted at optimum moister content for the soil and evenly graded to prevent shortages. It must be free of grass and other organics or other construction debris, and free from ice or snow in cold weather and not frozen.
- Moisten the subgrade only in dry, hot or windy conditions, which can cause cracking of the concrete after it is placed. There should be no standing water on the subgrade before concrete placement (See Figure 1-20).
- If concrete is being placed over a vapor barrier such as plastic sheeting, an 80 to 100 mm layer of damp compacted crushed stone should be over the plastic. This will help absorb water from the mix, allow quicker finishing and prevent potential cracking.
- Take precautions against weather conditions that can affect placing and finishing operations, such as wind, sun and rain.

Proper Placement *continued*

- Grades should be set up so that surface water drains away from the main structure. In some cases drain tiles should be set up to carry water away from the area.
- Concrete should be discharged as close as possible to its final position, with each batch placed against previously placed concrete. The material should not be dumped in separate piles and then leveled or worked together or moved significant distances from where it is discharged. Vibrators should not be used to move concrete.
- Concrete should be placed in layers of equal thickness. This is particularly important in walls, columns or other vertical forms. Each layer should be consolidated and the next layer blended in. This will prevent flow lines, seams or cold joints.
- If vibrators are used to consolidate the concrete or combine layers, 5 to 15 seconds is adequate time for the vibrator to be used each time it is placed in the concrete. Under vibrating will not consolidate the concrete properly, and over vibrating will drive the entrained air out of the plastic concrete and can cause segregation. Vibrator insertions should be made so the visible consolidated areas overlap.
- If placed by hand, concrete should be spread using a short-handled, square-end shovel or a concrete rake. Never use a garden rake, which can cause segregation.

Figure 1-20: Subgrade should be slightly moistened in dry conditions. There should be no standing water on the subgrade before concrete placement. (Courtesy of Portland Cement Association).

Concrete Finishing

Now that the concrete has been placed, it has to be finished properly. Here are some finishing guidelines:

- Tamp the concrete with a spade or shovel along the edges of the forms, or tap the forms lightly with a hammer. This consolidates the concrete and creates a flat and even surface at the formed edge. It also releases large air voids, which if left in the concrete can form surface defects called "bug holes".
- Use a lumber or metal straightedge, called a screed, to level the concrete at the top of the form. Rest the screed on edge on top of the forms and draw it across the concrete with only a slight sawing motion. Keep an excess of concrete in front of the screed to fill in any low spots.

Concrete Finishing *continued*

- If a vibrating screed is used, it must be moved at the proper speed and operating frequency to prevent an excessive amount of mortar on the surface.
- Smooth the concrete as soon as it has been screeded with a wood or metal tool, called a bull float or a darby. This flattens the surface of the concrete, and should be done before bleed water becomes visible on the surface. Do not over finish the concrete and close off the surface at this stage.
- Wait for bleed water on the surface to disappear and there is no more water sheen before starting the final finishing operations. Any finishing operations done while bleed water is still on the surface will trap moisture in the top layers of the concrete and can cause severe surface defects.
- The waiting period can be different for every job depending on the concrete mixture and weather conditions.
- Never sprinkle cement on standing water at the concrete surface to dry it up, or spray water on the surface to help finishing. These practices can weaken the concrete surface and cause surface defects. If the presence of bleed water delays finishing, drag a hose over the surface to remove some of the bleed water. A very fine water fog misted on the concrete surface or a chemical finishing aid can be used to help in finishing during hot weather.
- Use an edging tool around the top of the forms to make a clean, rounded edge at the surface.
- Concrete shrinks when it hardens and dries out, and “contraction joints” are cut in the slab to provide a weak section so that the crack occurs at these planned locations and looks neat. Contraction joints can be prepared by scoring the slab with a grooving tool, cutting with a saw, or by placing joint strips to the required depth before finishing. Spacing and depth of the joints should be done to industry standards or job specifications. Edging and jointing should be done between 4 to 12 hours after the concrete is finished. The surface should be hard enough to cut but not old enough so that it starts cracking.
- Floating is performed after initial edging and jointing. Floating by hand or machine should never be done with any bleed water on the surface of the concrete. Floating embeds large aggregates beneath a layer of mortar, removes slight humps and imperfections, and further compacts the surface of the concrete for subsequent finishing operations (See Figure 1-21). For most exterior concrete floating may be followed by a broom or burlap drag to provide texture for slip resistance.
- Troweling is a final finishing step for basements and other floors to obtain a smooth surface. For commercial or industrial use the concrete may be troweled with power equipment. **Exterior concrete that will be exposed to freezing and thawing with deicing salts should never be steel troweled!** Excessive troweling can remove air entrainment from the surface and make it more likely to peel or scale.

Concrete Finishing *continued*

Figure 1-21: Proper timing and sequence of finishing operations is essential for quality flatwork.

Curing Concrete Slabs

All newly placed and finished concrete slabs should be "cured." Curing is a process where concrete is provided with sufficient moisture and kept at the proper temperature, so the cementing materials will continue to hydrate and gain strength. If the concrete dries out too quickly, ultimate strength gain will be greatly reduced. Improper or inadequate curing can reduce the strength of concrete by as much as 50 percent. Proper curing will improve durability, give the surface a better appearance and be more wear resistant. The curing process should begin as soon as possible after finishing (See Figure 1-22).

Figure 1-22: Proper curing is essential for concrete to reach its maximum potential for durability and strength.

There are several methods of curing concrete. The concrete can be kept continually moist over at least seven days using water hoses with burlap or straw to retain moisture at the surface. Another method is applying a curing compound on the concrete surface immediately after finishing is done. The curing compound forms a layer on the surface and keeps moisture in the concrete. Some products can also act as a surface sealer, which keeps water and chemicals from getting into the surface pores of the slab.

In cold weather, water curing should not be used and the concrete should be covered with blankets or protected by some means from freezing until it gains sufficient strength.

Cracking

As concrete dries it shrinks, and this causes it to crack. Concrete can crack before it sets and hardens within about 4 to 8 hours after placement, and this is called plastic shrinkage cracking (See Figure 1-23). Plastic shrinkage cracking is most likely to occur on hot, dry and windy days, when the concrete surface dries out before the concrete has set and hardened. Use a set retarding admixture to slow concrete set time and help with placing and finishing. Air entrained concrete and rich mixes, especially those containing silica fume are more susceptible to plastic shrinkage cracking. It can also occur if the concrete setting is retarded on cold and dry days. The contractor should take precautions to reduce rapid evaporation of water from the concrete surface by using windbreaks, fog sprays or chemical finishing agents.

Figure 1-23: Plastic shrinkage cracking can occur if the surface of the concrete is allowed to dry out before the concrete sets. (Courtesy of Portland Cement Association).

After the concrete has hardened, it continues to dry out and shrink and this can also cause **drying shrinkage cracking** (See Figure 1-24). Long stretches of concrete, without joints, will crack at relatively equally spaced locations. Contraction joints will keep these cracks in planned locations, as discussed above. Further, concrete slabs should not be allowed to stick or bond to existing building elements, such as columns or walls. To prevent this bonding, isolation joints through the entire depth of a slab are used to separate newly placed concrete from bonding to existing structures. Concrete can also crack if the subgrade settles under loads or for various other reasons.

Figure 1-24: Improper jointing can cause unsightly cracking due to drying shrinkage. (Courtesy of Portland Cement Association

It is not the responsibility of the concrete delivery professional to know all the reasons for concrete cracking. However, the CDP should observe placing and finishing practices and document and report practices that may cause problems with the finished product.

Chapter 5 - Testing

Chapter Objectives

After studying this chapter, the CDP candidate should be able to:

- Describe proper procedures for sampling concrete to conduct tests.
- Recognize proper procedures for testing fresh concrete, including measuring temperature, slump, density, air content and making test specimens for strength tests.
- Explain the effect improper testing can have on the company and the customer.

Concrete Testing

Concrete producers routinely test ready mixed concrete to evaluate product quality and to detect quality defects before they cause problems. All concrete testing shall be done in accordance with CSA Standards A23.1 and A23.2. Customers also do their own testing of ready mixed concrete, usually by hiring a third party testing laboratory whose employees' function as job inspectors. Based on test results, concrete loads are either accepted or rejected and a part or all of the payment, as established in the job contract, may be withheld.

The CDP is an important part of every concrete producer's quality program, because the CDP has a large degree of responsibility for product quality through the mixing and delivery process. The CDP can make the difference between an acceptable load and one that is unacceptable which could be rejected. Rejected loads cause job and delivery schedule delays, financial liability for the concrete producer, and unhappy customers. However, ensuring that a quality product is delivered to the customer is only a part of the quality process. Testing the concrete to ensure it meets the job requirements is the other part and is usually the responsibility of an independent party, like a testing laboratory.

Following proper testing procedures is critical to measuring the properties of concrete as delivered and ensuring that it meets the job specifications. If testing is not done according to standard procedures, concrete that is perfectly acceptable may be rejected or penalties applied, which can add up to significant costs and delays to the project. These problems often result in disputes over who was responsible.

The CDP is the eyes and ears of the concrete producer on the jobsite. Therefore, the CDP needs to know how concrete testing should be performed, and be able to recognize when testing procedures are incorrect. The CDP should document the problem and notify the company.

Qualifications to Test Concrete

Standard procedures for testing concrete at the jobsite are outlined by CSA and other agencies. Most specifications and CSA Standard A23.1 require the technician conducting the tests to be certified by the Canadian Council of Independent Laboratories (CCIL), American Concrete Institute (ACI), or an equivalent program. This certification requires the technician to pass a written exam and demonstrate skill in common field-testing procedures, such as slump and air content as well as making test specimens. CSA Standard A23.1 also states that test results will not be acceptable and concrete cannot be rejected if the standard test procedures are not followed. For this reason the CDP should recognize and document improper testing practices.

Sampling for Tests

Obtaining a proper sample of fresh concrete is the first step in the testing process. The quality of the concrete load is judged on the basis of this sample. Thus, it is very important that the sample accurately represents the concrete load and sampling is performed in accordance with CSA Test Method A23.2-1C, Sampling Plastic Concrete.

Here are the proper steps to obtain the sample:

- When three strength test cylinders are made, the minimum sample size must be AT LEAST 20 litres of concrete, which is about one-half a wheelbarrow. Smaller samples may be taken if only temperature, slump and air tests are performed.

- Concrete samples for testing should be obtained after all the adjustments are made to the load. A truck should not be sampled if a significant portion is discharged into the forms and an adjustment, such as water or admixture addition, is made to a partial load.

- The sample should be taken at one interval during discharge between 10 and 90 % of the load.

- The sample should be obtained by diverting the entire flow of concrete from the truck chute into a wheelbarrow or other sample container or the technician can pass the sample receptacle through the discharge stream. The CDP may need to reduce the rate of discharge during sampling. Do not permit the technician to take intermittent shovelfuls from the stream; the entire discharge stream cross-section must be sampled. Concrete should never be directly discharged into a test container such as a cylinder mould or air content test bucket but must always be discharged into a larger receptacle such as a wheelbarrow (See Figure 1-25).

- The concrete sample must be protected from evaporation, due to sun, wind or extreme temperatures. Cover the sample with plastic or wet burlap between sampling and testing operations if necessary.

- The sample should be moved to the testing location and remixed with a shovel or scoop before starting the tests. Tests for slump and air must be completed within 10 minutes of taking the sample. If test cylinders are also being made, molding of the cylinders must start within 20 minutes of obtaining the sample.

Sampling for Tests *continued*

Temperature

Many project specifications may require the inspector to determine whether the temperature of the fresh concrete is within specified limits. Typical requirements for fresh concrete temperature range from 10°C to 35°C. For proper testing techniques, see CSA Test Method A23.2-17C, Temperature of freshly mixed hydraulic cement concrete.

These procedures should be followed:

Figure 1-26: The thermometer must be inserted into the concrete at least 75 mm when the temperature is measured.

- Use an approved, calibrated thermometer that can read to the nearest 1°C. Concrete temperature may be measured in the sample obtained or on the concrete in place.
- Insert the stem of the thermometer into the concrete. The temperature probe must be covered by at least 75 mm of concrete around it (See Figure 1-26).
- Read the temperature after the thermometer has been in place for at least two minutes, to be sure the temperature reading has stabilized.
- Record the temperature to the nearest 0.5°C.

Density

The density test is used to determine the weight of one cubic metre of concrete, and the result is used to calculate the yield of the concrete load. It is also useful as an indicator whether the correct amounts of materials are batched and if there is a problem with the air content. Density is measured in kilograms per cubic metre. The unit weight of normal weight concrete is between 2200 to 2400 kg/m^3. Refer to CSA Test Method A23-6C, Density, Yield and Cementing Materials Factor of Plastic Concrete. The density test is not mandatory and is typically conducted on request when a check on the yield of the concrete is desired.

Follow these procedures to determine the Density of fresh concrete:

- A sample of concrete must be obtained (see sampling procedure above).
- Use a 7, 15 or 30 litre cylindrical container. The container used for checking air with a pressure metre can also be used, if the maximum size of the aggregates in the concrete is less than 28 mm. Record the weight of the container, and dampen the inside of it.

- Place the container on a flat surface. Fill the container in three equal layers. Each layer of concrete must be rodded 25 times. A standard rod with a diameter of 16 mm and a rounded end should be used. A vibrator can be used, and measure filled in two equal layers. The sides of the container should be tapped with a rubber mallet after rodding each layer to close the rod holes. The concrete should then be leveled off even with the top of the container using a strike off bar.
- Clean the top edge and sides of the container. Weigh the container with concrete in it. The unit weight of concrete can then be calculated.

Figure 1-27: Concrete is sold by volume. Concrete yield is calculated from the density.

If these procedures are not followed, results may be incorrect and cause rejection of the concrete. The technician is required to run a second test before making any decisions regarding rejecting the load. If the container is not completely full and level with the surface, a low density result may suggest that the concrete has excessive water or high air content. If the exterior of the container is not cleaned properly, a high density result will result in a lower calculated yield. For these reasons, the correct procedure for compacting the concrete in the container and cleaning the container is very important. If a CDP observes problems with density testing, the problem should be documented and reported to the dispatcher or company quality control representative (See Figure 1-27).

Slump

The slump test measures the consistency or stiffness of the fresh concrete. The slump that the customer desires depends, to some extent, on where the concrete will be used and the method of placement. Slump does not measure the water content of the mix, because water reducers and superplasticizers can be used to increase slump while keeping the water content low. However, if the slump is changing for the same mix design, it can indicate the relative amount of water is varying in different loads. Adding more water to concrete over the designed amount will affect the water/cement ratio, the strength and durability of the in-place concrete, and the test sample. The slump test is performed in accordance with CSA Test Method A23.2-5C.

This is the proper testing procedure for slump:

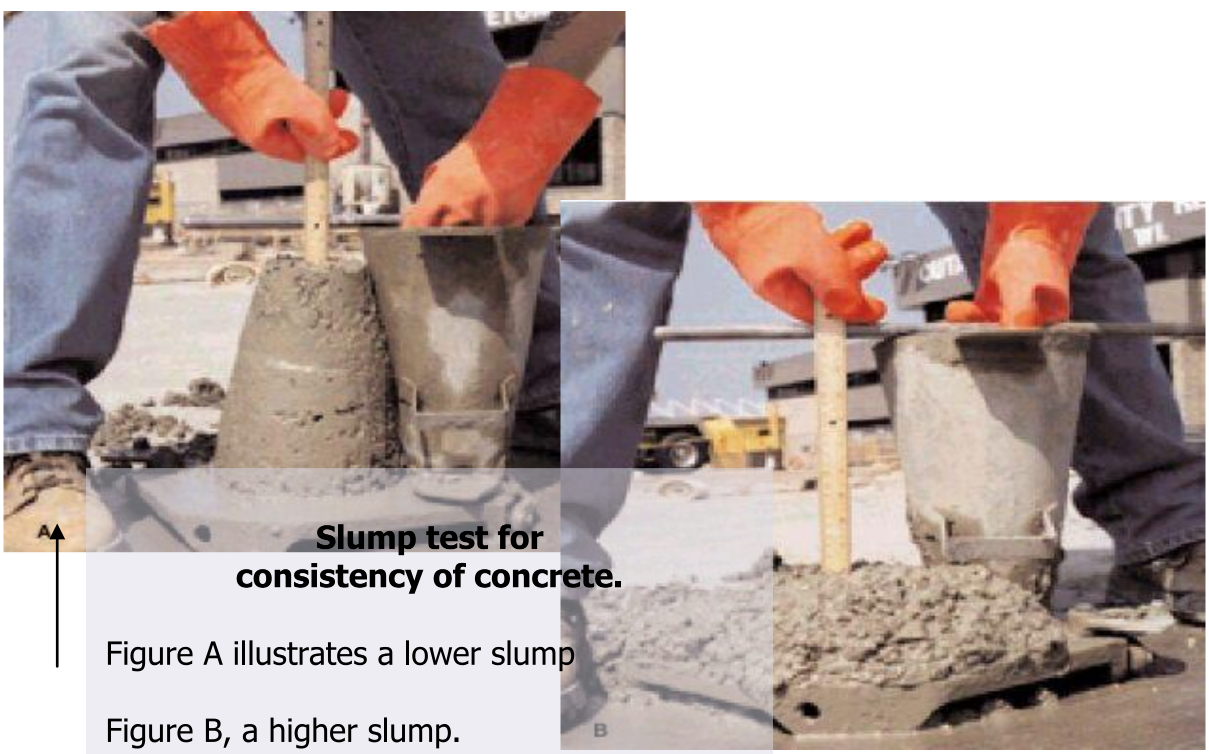
- A sample of concrete must be obtained (see sampling procedure above). The slump test must be done on a flat, level surface. The technician must hold the cone firmly in place (by standing on the foot pieces) during the test, so it does not lift or move out of place (See Figure 1-28).
- The slump cone must be clean and damp, but not soaking wet. The cone is filled in three layers of equal volume. Each layer is rodded 25 times with a standard rod. Rod each layer so the strokes just push the rod into the top of the previous layer. The rod should not strike the base that the slump cone is resting on.
- The top layer should have a small amount of concrete showing above the top of the slump cone. After rodding is complete, level off the concrete from the top of the cone with the rod. The cone should not be tapped or struck in any way as it is being filled or after filling. Concrete that spills around the base of the cone should be cleaned away.

- The cone shall be raised slowly and lifted from the concrete in 5 seconds with a steady, even vertical motion. The entire operation of conducting the slump test from start to finish should take 2 minutes or less.
- The slump is the distance that the concrete has fallen (slumped) from the original 300 mm height of the slump cone. The slump cone is placed beside the slumped concrete on a flat surface and the slump is measured from the top of the slump cone and the average height of the slumped concrete sample. Slump is measured and recorded to the nearest 5 mm (See Figure 1-29).
- After the slump cone is pulled away, any portion of concrete that greatly falls away or shears off and comes apart is not acceptable, and the test must be redone.

If this procedure is not followed, results may be incorrect, and a load can be rejected even though the slump may actually meet job requirements. The CDP should watch for the tests being conducted on a smooth and flat surface and not on dirt, the consolidation procedure followed correctly, the slump cone not tapped with a mallet, and the cone lifted from the concrete in a steady motion in five seconds.

If a CDP observes problems with slump testing, the problem should be documented or reported to the concrete supplier.

Figure 1-29: The slump of the concrete should be measured to the nearest 5 mm.



Slump test for consistency of concrete.

Figure A illustrates a lower slump

Figure B, a higher slump.

Air content

Due to the many factors affecting entrained air, it is important to regularly check concrete's air content. Remember that entrained air in concrete is needed for durability in freezing exposures. The pressure meter and the volumetric air meter, also known as the roll-a-meter, are most commonly used. The pressure meter cannot be used for concrete made with lightweight aggregates, and a volumetric air meter must be used (See Figure 1-30).

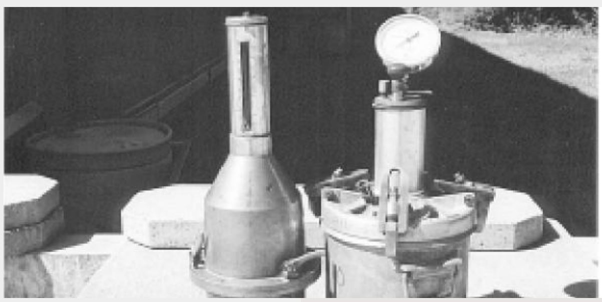


Figure 1-30: Air content is generally measured using a pressure meter (right). The volumetric air meter (left) must be used for concrete with lightweight aggregate.

Figure 1-31: Make sure all the space between the sample and the lid of the pressure meter has been filled with water, then pump the meter to its initial starting point.

Using a Pressure Meter

Follow these procedures to test air content with the pressure meter:

- A sample of concrete must be obtained (see sampling procedure above).
- Dampen the pressure meter bowl, and fill it with concrete as was done for the density test. Strike-off the concrete with a flat bar, and attach the top of the meter.
- Fill the sample chamber of the pressure meter slowly with water through one of the petcocks, using a bulb syringe, until water comes out the other petcock. Make sure the sample chamber is completely filled with water.
- Pump up the pressure chamber such that the gauge needle falls on the starting line. Make sure the needle has stabilized. Close both petcocks on the sample chamber cover (See Figure 1-31).
- Open the air valve between the sample chamber and the pressure chamber. Tap the pressure gage by hand to stabilize the needle.
- Read the gage and determine the air content to the nearest 0.1%.

Using a Volumetric Meter

Follow these procedures to test air content with the volumetric meter:

- Fill the meter bowl the same way as described for the density test. Strike-off the concrete with a flat bar. Attach the top of the meter. Fill the meter slowly with water using the funnel. Remove the funnel, adjust the water to the zero mark, and attach the cap.

Figure 1-32: The volumetric air meter does take significant effort to obtain an accurate air content measurement.

- Invert and agitate the meter. Place the meter inclined on the ground and roll it repeatedly. Let it stand still several minutes until the water level stops dropping.

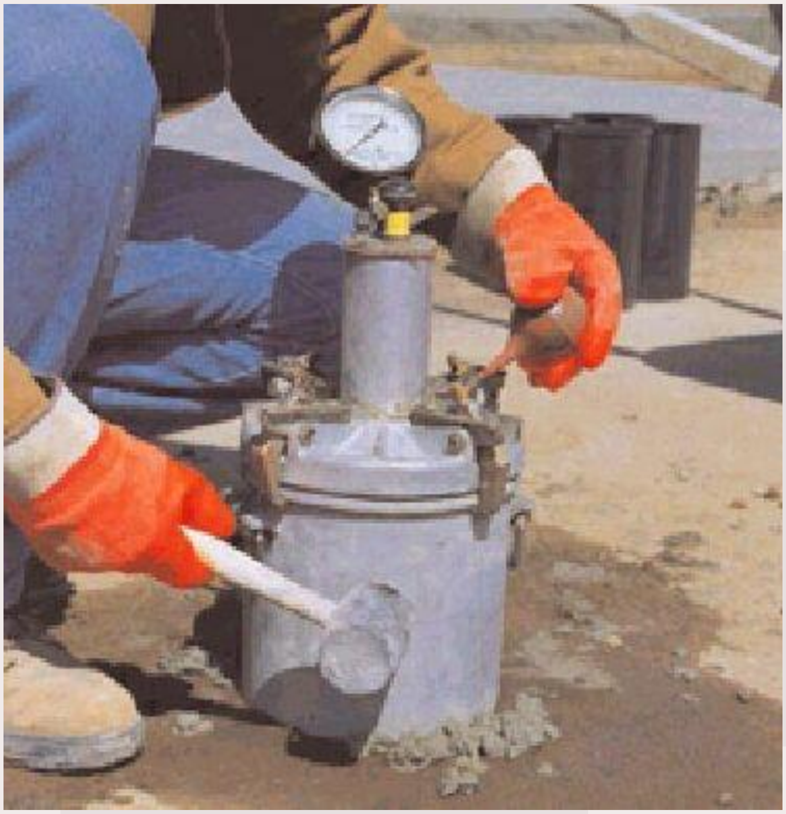
- Repeat the rolling procedure again until two readings do not change. This may take 5 to 10 minutes or more. Remove the lid and remove the foam (if any) by using calibrated cups of isopropyl (rubbing) alcohol.

- Read the water level to the nearest 0.25%. Add the number of cups of alcohol added to the final water level reading on the meter to get the air content. For example, a reading of 3.5 after adding two cups of alcohol indicates an air content of 5.5%.

If this procedure is not followed, results may be incorrect, and a load can be rejected, even though the air content may actually meet job requirements. The test should be run on a flat surface. The proper consolidation procedure should be followed and the concrete should fill the container.

If the measured air is not within specifications, the technician should conduct a retest before making any decisions. Proper effort should be applied with the roll-a-meter to ensure that all the concrete is dislodged from the container and thoroughly mixed with the added water. Improper operation of the roll-a-meter will provide a low air content reading. It can take a long time to determine the air content with the roll-a-meter with concrete mixtures having high cement content (See Figure 1-32). If a concrete delivery professional observes problems with air testing, the problem should be documented or reported to the concrete supplier.

Air Content *continued*



Pressure Method (CSA Test Method A23.2-4C, *Air Content of Plastic Concrete by the Pressure Method*) - practical for field testing all concretes except those made with highly porous and low- density aggregates. Volumetric Method (CSA Test Method A23.2-7C, *Air Content of Plastic Concrete by the Volumetric Method*) - practical for field testing of all concretes containing any type of aggregate.

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Chase Indicators

Sometimes a Chase indicator is used to check air content (See Figure 1-33). This device should only be used as a relative indicator and cannot be used to reject a load. However, it can be used as a quick and easy method to indicate approximate air content. It should not be used to accept or reject a load, based on its results.

Figure 1-33: The Chase air indicator is a quick but unofficial method to check the approximate air content.

Test Specimens - Cylinders

Test cylinders are made on the job, taken to a laboratory, cured and put into a testing machine that breaks them to measure compressive strength. Normally cylinders are broken at 28 days to check whether the concrete meets the job requirements. At least two cylinders should be prepared from the same concrete sample for the 28-day test. These are called "acceptance" cylinders because they are made to determine whether the concrete is acceptable and conforms to job specifications for compressive strength (See Figure 1-34).

Figure 1-34: Generally, concrete test cylinders are broken in the lab after 28 days to ensure that concrete meets the job requirements, or for quality control.

Follow these procedures when making concrete test cylinders:

- Cylinder moulds used to make test specimens should be clean, dry and not used for any other purpose before being filled with concrete.
- A sample of concrete must be obtained (see sampling procedure above).
- The cylinder moulds should be filled in three equal layers and each layer should be rodded 20 times with a standard rod (See Figure 1-35) for 100 X 200 mm moulds and concretes with normal slumps.

Cylinders *continued*

- The sides of the mould should be tapped between each layer to close the voids from

Figure 1-36: Improper storage of cylinders (as shown here) will make test results invalid.
Overnight storage must be moist and in a temperature range between 15 and 25°C

rodding. The tapping may be with a light mallet or the palm of your hand.

- The concrete shall be struck off even with the top of the mould with a float or trowel to level off the top or the cylinder. A smooth finished top surface should be obtained.
- To prevent evaporation of water from the top surface, cover the top of each cylinder with a plastic bag or plastic cylinder cover. Air, slump, and temperature tests should be made whenever cylinder tests are made, and the results recorded by the technician.
- If the cylinders are made for acceptance testing, they should be moved to a curing location on the jobsite. This location should be away from any traffic that could disturb the cylinders while they cure. These cylinders are maintained in the curing containers for a maximum of 76 hours for specified compressive strengths of less than 35 MPa, whereupon the specimens are returned to the laboratory. For specified compressive strengths of 35 MPa and higher, the specimens must be returned to the laboratory within 24 hours. (See Figure 1-36).
- Acceptance cylinders must be shielded from direct sun and maintained at a temperature from 15 to 25°C. On many commercial jobs, special curing boxes with the ability to maintain a controlled temperature are used to store test specimens. The specimens can also be immersed in water at a controlled temperature (See Figure 1-37).
- Cylinders must be carefully transported to the laboratory so that they are not damaged during the movement. Cylinders must be at least 20 hours old before they can be transported to the laboratory.

Cylinders *continued*

Cylinders may give incorrect results if these procedures are not followed. Exposing acceptance cylinders to sunlight and extreme temperatures or allowing the cylinders to dry out can significantly affect their strength, and cause perfectly acceptable concrete to fail the requirements of the specification. This can result in project delays, payment delays, and significant expense to the concrete supplier. Cylinders should be prepared according to the standard practice described above. They should be protected from extreme temperatures and evaporation of water from the surface during the time they are at the job site. The cylinders should be properly padded and protected when they are transported to the laboratory.

In some cases cylinders are used to determine the strength development of concrete in the structure to schedule removal of formwork, to continue construction or to allow traffic on a road or bridge. These cylinders are placed beside the structure and exposed to the same environment and are called **field-cured cylinders**. Field-cured cylinders **should not** be used for acceptance of concrete quality as delivered by the concrete producer. Field cured cylinders should not be disturbed by construction activity during this field cure, and should not be sent to the laboratory until it is time for them to be tested.

If the CDP observes cylinders improperly stored, or acceptance cylinders left at the jobsite for more than two days, the problem should be documented or reported to the concrete supplier.
Refer to CSA Test Method A23.2-3C, Making and Curing Concrete Compression and Flexural Test Specimens.

Test Specimens - Beams

Concrete strength, especially for pavements and airport runways, is sometimes evaluated by testing concrete beam specimens. These beam specimens are typically 150 x 150 x 500 mm and with the moulds are very heavy and difficult to handle. Other beam sizes are also used. Beams are made by consolidating concrete in two layers either with a rod or a vibrator. Concrete beams should be stored in standard curing conditions similar to acceptance cylinders, carefully protected during the initial curing period, and transported to the laboratory for testing within 48 hours. Beam strengths can be affected more than cylinders by improper curing, handling and transporting.

Review Workbook

Introduction

Each module contains a short set of review questions that is designed to help you study for the CDP certification exam. You can use these to learn key concepts that will be on the exam, and then as your study guide for the exam itself.

We have organized each Module's set of review questions in chronological order by section. The section title on the left refers to the section in the Module where this information is covered. Fill in the blank for each question and then check your answers at the end of each Module's Review.

Key concepts in these questions may be on the test. If you can't answer a fill-in-the-blank question, read that section in the chapter again. Not all the material on the CDP certification exam is in the review questions so remember to read all five Study Guide Modules carefully for additional important topics you might find on the exam.

Good Luck!

Module I - Chapter 1: Fundamentals of Concrete

SECTION TITLE	QUESTION
Hydration: How Concrete Hardens and Gains Strength	1. When cement chemically reacts with water the process is called ________________________.
The Ratio of Water to Cementing Materials Is an Important Relationship	2. When a concrete mixture has more water than it was designed for, the concrete will have ______________________ strength.
Properties of Plastic Concrete	3. _______________________ is a measure of concrete consistency.
Properties of Plastic Concrete	4. The yield, or volume of the concrete in the truck can be calculated from the ________________.
Properties of Plastic Concrete	5. Normal weight concrete usually weighs between _______________ to _____________ kg/m^3

Module I - Chapter 2: Components of Concrete

SECTION TITLE	QUESTION
Types of Cement	1. Type _________________ cement can be used when accelerated strength gain is needed.
Qualities of Concrete Aggregate	2. Concrete aggregates should be _____________, ________________, __________________ and ______________________.
Air Entrained Concrete	3. Entrained air makes concrete resistant to the effects of _____________ and _____________.
Controlling Air Content Delivered to the Job	4. ______________ mixing or ________________ mixing can affect air content in concrete.

Module I - Chapter 2: Components of Concrete *continued*

SECTION TITLE	QUESTION
Fly Ash Properties in Plastic Concrete	5. Fly ash ____________________ the amount of mixing water needed in order to get the desired slump.
Calcium Chloride	6. Calcium chloride is usually not allowed in concrete construction with __________________ __________________.

Module I - Chapter 3: Batching, Mixing and Delivery

SECTION TITLE	QUESTION
Transit Mix Concrete	1. At a _____________________ plant, concrete ingredients are loaded into the truck and completely mixed in the truck mixer.
Mixing	2. The maximum number of drum revolutions normally allowed is _________ revolutions.
Mixing	3. Normal agitating speed is between __________ and _______________ revolutions per minute after the concrete has been mixed.
Delivery	4. Most specifications only allow a total of _______ minutes from the time the load is batched until discharge is complete.
Jobsite Addition of Water	5. After adding water on the job, the load should be mixed for __________ revolutions at normal mixing speed.
Cold Weather	6. Colder temperature concrete will set more ___________________ than hotter concrete.
Hot Weather	7. Concrete with temperatures above 32°C can result in more ________________________.

Module I - Chapter 4: Handling, Placing and Finishing

SECTION TITLE	QUESTION
Placement Methods	1. A ____________________ machine places extremely low slump concrete and usually needs a special mix design.
Placement Methods	2. When _____________________ concrete, air content is often lower at the discharge end than when it went into the pump.
Proper Placement	3. When placing walls or columns, each layer of concrete should be blended into the previous layer to prevent __________ or __________.
Curing Concrete Slabs	4. ___________ is the process of maintaining the proper amount of moisture and temperature.
Cracking	5. ____________________ cracking can occur on hot, dry and windy days if the surface dries out before hardening.

Module I - Chapter 5: Testing

SECTION TITLE	QUESTION
Sampling for Tests	1. The concrete sample should not be discharged into a ________________________like a cylinder mould or air bucket.
Slump	2. A _________________ test is not valid if the sample shears away or falls off after the slump cone is lifted.
Slump	3. The _________________ should never be tapped with a rubber mallet or other device during the test procedure.
Air Content	4. A _____________________ meter must be used whenever the air content of lightweight concrete is checked.
Cylinders	5. When filling cylinder moulds, each layer should be rodded _____________ times with a steel rod.
Cylinders	6. The normal time that concrete cylinders are cured before testing for acceptance, is _______ days.

Review Workbook - Answers

Chapter 1

1. hydration
2. less
3. Slump
4. unit weight
5. 2200 - 2400

Chapter 2

1. Type HE (30) high-early
2. clean, hard, strong, durable, non-porous
3. freezing, thawing
4. Too much, too little
5. reduces
6. reinforcing steel

Chapter 3

1. transit mix
2. 300
3. 2, 4
4. 120
5. 30
6. slowly
7. slump loss

Chapter 4

1. slip form
2. pumping
3. flow lines, cold joints
4. curing
5. Plastic shrinkage

Chapter 5

1. test container
2. slump
3. slump cone
4. volumetric
5. 20
6. 28