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BUILDING RESILIENCE

CONCRETE PRODUCTION GUIDE FOR NEW ZEALAND

CONTENTS

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1. CONCRETE PLANT AND EQUIPMENT

PLANT TYPES

Production of concrete involves a variety of plant types that primarily consists of batch mixers, but also includes continuous mixers when smaller loads are being supplied. Three main types of mixer are used in concrete production, namely central, truck and continuous mixers. Ready-mixed concrete production in New Zealand consists primarily of truck mixers but with a growing number of central mixers.

TRUCK MIXERS

Most concrete production in New Zealand consists of a concrete batch plant where materials for concrete are weighed and loaded into concrete trucks that provide the mixing action for concrete before delivering the material to the construction site. This system is versatile and efficient since loading of concrete can be shortened using holding hoppers and mixing can occur once the truck has driven out from under the batch plant.

CENTRAL MIXERS

Mixing concrete by forced action using bowls, pans or twin-shaft mixers can be extremely efficient and reduce mixing time from 5-7 minutes to as little as 1-2 minutes. Modern central mixers also have the advantage of being able to be automated such that the final consistence level as measured by slump or spread can be machine-controlled rather than being visually estimated.

CONTINUOUS MIXERS

Concrete produced at concrete batch plant is optimised for larger volumes such that most mixers have volumes of several cubic metres. Small volumes of less than one cubic metre cannot be accurately supplied using convention concrete production systems and this is where continuous mixer have some advantage. Continuous mixers are trucks that carry the individual constituents of concrete and these are mixed in a continuous stream of concrete using a screw auger system. Calibration of feed rates of the material is done to ensure that fresh concrete is supplied in the correct proportions and having the specified fresh and hardened properties.

The technical and logistical differences between these concrete mixers are shown in Table 1 with properties given in general terms. Modern versions of each have been developed with considerable advancement in automation and overall efficiency and accuracy.

Table 1: Concrete production plant types and technical quality and logistics

Mixer type	Speed of supply	Advantage	Disadvantage
Truck	Fast	Versatile as multiple mixers	Mixing efficiency needs control
Central	Fast	Mixing time can be reduced	Breakdown production risks
Continuous	Slow	Good for small projects	Quality of supply varies

SITE VERSUS READY-MIXED BATCH PLANTS

Most concrete production is supplied by ready-mixed concrete plants that are not based at the construction site, but rather at local concrete batch plants. The advantage of this arrangement is that production can be relatively steady since supply can be optimised for many construction sites. Increased volumes of production allows ready-mixed plants to have more expertise in concrete mix design, testing and logistics. In contrast, site-based batching plant are only effective on large infrastructure projects where there is a large volume of concrete required on a regular basis. Sometimes site batching plants are also advantageous when the project is located far from existing ready-mixed batch plants.

PRODUCTION APPLICATIONS

SHUT DOWN AND START-UP OF PLANT

In terms of preparing for shut down, isolation, and start-up of machines and equipment at a ready mixed concrete plant the effects on upstream and downstream machines and equipment need to be identified, and affected personnel advised. Associated hazards (e.g. moving parts, potential energy, power source(s) must be identified and eliminated or minimised, while safety devices need to be prepared.

During the actual shut down and isolation of machines and equipment, safety devices must be used in accordance with job requirements, stored or residual energy dissipated or restrained, machine and equipment isolation verified, and all relevant personnel advised.

Prior to the start-up of machines and equipment following shut down and isolation, work areas must be inspected for hazards (e.g. obstructions, incomplete work, guards in place), which need to be eliminated or minimised. Safety devices must be removed, and affected personnel advised of machine in-service status.

Documentation must be completed for shut down, isolation, and start-up.

CONFINED SPACES

'Confined Spaces' is a term used to describe an enclosed or partially enclosed space that is not intended or designed primarily for human occupancy, within which there is a risk of one or more of the following:

- An oxygen concentration outside the safe oxygen range,
- a concentration of airborne contaminant that may cause impairment, loss of consciousness or asphyxiation,
- a concentration of flammable airborne contaminant that may cause injury from fire or explosion; or
- engulfment in a stored free-flowing solid or a rising level of liquid that may cause suffocation or drowning.

At a ready mixed concrete plant, a confined space will most likely be a concrete truck mixing bowl.

Supporting documents that outline confined space requirements and system supports should include hazard identification/risk assessment procedures and forms, entry procedures and forms, work permit procedures and forms, gas monitoring procedures and forms, emergency rescue procedures and plans, site evacuation plans.

Control measures need to be identified to eliminate, isolate, and minimise the risk of hazards in confined spaces. These hazards can be 'atmospheric' (e.g. toxic gases, flammable liquids, dust or oxygen depletion etc.), or 'other' hazards (e.g. physical falls, slips, noise, electrocution, impact, entrapment and heat stress etc.). Hazards may arise due to the changes in external conditions, such as ventilation or weather.

Monitoring and confined space testing requirements must be undertaken, and will cover the identification of continuous communication channels, environment and emergency procedures. Audio monitoring can complement visual monitoring within confined spaces, while pre-entry and periodic testing requirements must be performed.

The responsibilities and duties of personnel entering confined spaces can include ensuring safety of self and others, communication requirements, entry and exit procedures, emergency evacuation, maintenance of hazard control measures. Responsibilities and duties for a confined space entry safety 'observer' can include monitoring work and adjacent areas, remaining at post to form continual communication link and life support, maintaining and checking communication systems.

TRANSPORT OF CONCRETE

TRANSPORT AND SUPPLY OF CONCRETE (TRUCKING ISSUES)

Routine concrete truck servicing and maintenance must include checks of oil, water, tyre, fuel, ancillary equipment and truck safety systems. Waka Kotahi NZ Transport Agency (NZTA) requirements must also be met. Cleaning requirements and methods for concrete trucks and ancillary equipment must be performed to meet legislative requirements, and mechanical breakdowns managed.

Factors contributing to truck rollover (e.g. road surface, camber, corners, gradient, slosh effect, static rollover threshold, driver fatigue, speed) must be identified and avoided, while factors that impact on ready mix concrete during transportation (e.g. water, additives, speed of mixer rotation, duration in transit, weather, temperature) must be understood and managed.

Similarly, when assessing conditions for the delivery and discharge of ready mixed concrete by truck, hazards associated with site access need to be identified and controls put-in-place. Factors affecting the quality of concrete on site (e.g. duration of discharge, water added, wait time, additives and admixtures) also need to be assessed, while checks (e.g. load matches dockets, site access, location of pour) need to be performed prior to discharge of concrete.

OPERATIONS AND COMPLIANCE

MAINTENANCE OF CONCRETE PLANT AND EQUIPMENT

Routine checks and servicing must be completed on concrete batching equipment and machinery in accordance with *NZS 3104 Specification for Concrete Production.* Maintenance requirements which are beyond the expertise of the operator need to be identified and managed.

Procedures for identifying and responding to equipment failure, minimising the effect of equipment failure on the usability of concrete, and controlling hazards associated with equipment failure also need to be identified and managed.

All work operations at a ready mixed concrete plant must be safely completed; workplace and equipment appropriately cleaned, and routine maintenance performed. Associated documentation must be completed in accordance with NZS 3104.

2. LEGISLATION AND STANDARDS FOR CONCRETE PRODUCTION

All industries have legislation and standards that provide recommendations and controls for conducting business effectively, fairly and safely. Concrete production is no different and includes documentation involved with standards, health and safety, environmental control, construction, transportation and the plant audit process.

NEW ZEALAND STANDARDS

New Zealand Standards provide guidance for the minimum levels required to conduct business such as production of concrete. Design and construction of concrete structures involves several different Standards that are summarised briefly below.

NZS 3101: 2006 CONCRETE STRUCTURES DESIGN STANDARD

Design guidance for concrete structures is given in NZS 3101 that includes aspects of concrete mix design that influence strength, durability and dimensional stability. This Standard is used by civil and structural engineers for the design of concrete structures and it also refers to construction, material and testing standards given below.

NZS 3109: 1997 CONCRETE CONSTRUCTION STANDARD

Construction practice for concrete is provided in NZS 3109 which covers all types of projects from residential, commercial and infrastructure. This Standard provides guidance and recommendations for as aspects of concrete construction that includes formwork, reinforcing, concrete practice and testing. The Standard is overdue for revision being more than 20 years old.

NZS 3104: 2020 CONCRETE PRODUCTION STANDARD

NZS 3104 provides guidance on all aspects of concrete production and is the standard used by all companies involved in concrete supply. The concrete production Standard covers materials, batching, mix design and testing of concrete. This Standard has recently been revised to include modern technological developments and allows more efficient design of concrete mixes where concrete suppliers can demonstrate excellent production control.

NZS 3112: 1988 TESTING OF FRESH AND HARDENED CONCRETE

NZS 3112 is the concrete testing standard with Part 1 dealing with fresh concrete testing while Part 2 deals with hardened properties such as compressive and tensile strength. Concrete is a structural material that is primarily specified in terms of its 28-day compressive strength and it is therefore important that this property is measured accurately. The testing Standard provides details on methodology but does not provide guidance on compliance values as this is covered in NZS 3104.

NZS 3121: 2015 WATER AND AGGREGATE FOR CONCRETE

This Standard gives performance requirements for water and aggregate suitable for use as materials for making concrete to meet normal structural and durability applications. NZS 3121 provides guidance on appropriate testing regimes, frequency of testing and where appropriate limits for performance. The Standard references NZS 3111 where testing methodology for water and aggregates are given in detail.

NZS 3111: 1986 METHOD OF TEST FOR WATER AND AGGREGATE FOR CONCRETE

Establishes the requirements for methods of sampling and testing of water and aggregates used in concrete production. Test methods covered include sampling of fine and coarse aggregate, moisture content, grading, hardness, lightweight material and contaminants. This Standard is the oldest of the current concrete standards used in New Zealand.

HEALTH AND SAFETY LEGISLATION

As a construction industry manufacturing workplace a ready mixed concrete plant must observer the *Health and Safety at Work Act 2015* and *Health and Safety in Employment Regulations 1995* (plus amendments). This can cover roles and responsibilities, hazard management, accident investigation and reporting, emergency procedures, and employee participation.

Other legislation (plus amendments) relevant to safety and environmental requirements at a construction industry manufacturing workplace, must also be observed. This includes the *Resource Management Act 1991* and *Hazardous Substances and New Organisms Act 1996.*

Approved Codes of Practice, Work Exposure Standards and Guidelines, such as those produced by the Concrete NZ Readymix Sector Group, can be used to help manage hazards.

Workplace safety procedures (e.g. responsibilities, training and supervision, monitoring, and safety meetings), hazard identification and control methods (e.g. working at heights, noise, dust, and confined spaces), Personal Protective Equipment (e.g. safety footwear, hearing, eye and face protection and dust masks), and manual handling controls (e.g. correct handling technique, mechanical aids and work area layout) are all applicable to a ready mixed concrete plant.

ENVIRONMENTAL LEGISLATION

Environmental management within the concrete industry, and at a ready mixed concrete plant, falls under the *Resource Management Act 1991*, which is enforced by territorial authorities that include regional as well as city and district councils.

There are a number of activities at a concrete plant, such as wash water storage, truck movements and noise, that require consent or permit. Enforcement can include infringement or abatement notices, excessive noise direction and enforcement order. Consequences of non-compliance can include an infringement fine or cost recovery by territorial authorities for remediation work.

The concrete company must have an understanding of the impact of uncontrolled hazards (e.g. pH levels of waste product, sediment, dust, spills, noise, materials) on the environment, while procedures must be in place to control the impact of these hazards.

These environmental management procedures (and policies) should be familiar to staff, their update assigned to specific personnel, and include protocols for reporting incidents and non-compliance.

CONSTRUCTION LEGISLATION

Safe working and environmental practices at a ready mixed concrete plant must be carried out in line with the following requirements:

- The location and purpose of workplace safety procedures are explained to all staff, along with the consequences of not following them.
- Hazards are identified and controlled in accordance with workplace safety procedures.
- Plant and machinery are guarded in accordance with workplace safety procedures and manufacturer's instructions.
- Personal protective clothing and equipment is used in accordance with workplace safety procedures and manufacturer's instructions.
- Walkways, exits, thoroughfares, and platforms are kept clean and clear of obstructions.
- Barriers and signs are erected and used as required to protect the safety of site personnel and visitors.
- Hazardous materials and products are handled, stored, used, and disposed of in accordance with workplace safety procedures and manufacturer's Material Safety Data Sheets or Environmental Resource Management Authority approvals.
- Hazards, accidents, incidents, and/or near misses are reported.
- Emergency evacuation procedures are identified and rehearsed.
- Work areas are cleaned up and waste disposal arranged after each specific site operation.

TRANSPORTATION LEGISLATION

Safe transportation of fresh concrete without segregation or spillage from the production plant to the construction site. Transport of fresh concrete on site using truck, pump, wheelbarrow, conveyor skip or tremie in a safe and practical manner. All operations should be safely completed and the workplace and equipment cleaned in accordance with workplace practice and environmental safety requirements. Documentation of transport activities using log books and other records shall be undertaken in accordance with national transport legislation.

The relevant transport legislation framework as it applies to the production and supply of concrete, including:

- Driving hours and log book requirements
- Route logistics for safe transport
- Maximum weight for trucks

PLANT AUDIT SCHEME

New Zealand is unique in having the Concrete New Zealand (NZ) Plant Audit Scheme to ensure that concrete production complies with the national Standard, NZS 3104. Under the Concrete NZ banner, the scheme is operated by a group of experienced engineers who audit each of the concrete plants around New Zealand to ensure compliance with the concrete production standard. Specific aspects of this auditing process include the following activities.

INITIAL AUDITING

Before any concrete plant can be accepted as a member of the Plant Audit Scheme is must provide proof of its capability to comply with New Zealand Standards and show control of concrete production. The initial audit application is followed by an interim audit certificate usually of three months after which a 12-month audit certification may be granted. Responsible people in the following positions must also be identified for each plant, namely:

- Plant Engineer who is responsible for the performance of all concrete mix designs used at the plant
- Plant Supervisor who is responsible for daily control of concrete production
- Batcher who oversees production of each load of concrete produced by the plant
- Technician who is responsible for sampling and testing of fresh concrete at the plant

MONTHLY TESTING

The plant supervisor and engineer have a responsibility for ensuring that testing, scale checks and calibrations are undertaken at the correct frequency and that these tests have all passed. This is usually done by analysing data on a weekly basis and producing a monthly report for internal guidance to plant staff. This monthly reporting is not mandatory to comply with NZS 3104 but is recommended to provide regular guidance and to highlight areas of concern about any quality issue.

QUARTERLY REPORTING

A quarterly test frequency report is sent to the Plant Audit Committee to provide proof that all testing has been carried out by the plant. The amount of concrete testing is dependent on the type of plant and the level of concrete production while checks and calibrations have a standard frequency as given in NZS 3104 and NZS 3112. Occasionally testing frequency may be below expected levels due to low or suspended concrete production as the reasons need to be reported together with testing frequency numbers.

ANNUAL ENGINEERS REPORT

An annual report is prepared by the plant engineer that is required to be sent to the Plant Audit Committee by no later than six weeks after the end of audit year end. The engineer's report provided details on all material, scale and concrete testing and calibrations and provide evidence of the production control. Six main concrete mixes are generally reported for the purposes of demonstrating production control and statistical analysis is carried out to determine mean strength, standard deviation and coefficient of variation of each series.

BIENNIAL PLANT VISIT

Every two years a physical inspection of each concrete plant is undertaken by an auditing engineer who goes through all aspects of concrete production. A detailed checklist is used for this physical audit that includes personnel, laboratory, batching equipment, concrete batching process, fresh and hardened testing procedure, testing documentation, concrete plant condition and data reporting.

NON-COMPLIANCE

Should the concrete plant not comply with the concrete production and testing Standards, an escalation of possible actions shall be applied by the Plant Audit Committee. This may include having to increase the frequency of reporting by the plant engineer or even loss of audit status by the concrete plant.

3. CONCRETE SCIENCE AND TECHNOLOGY

CONCRETE CONSTITUENTS

Concrete is a mixture of cement, water, aggregates and chemical admixtures that are mixed and harden into a structural material. Fresh concrete needs to be workable enough for casting and compaction into formwork after which the material needs to set and harden and produce enough strength to resist the design loads expected for the structure.

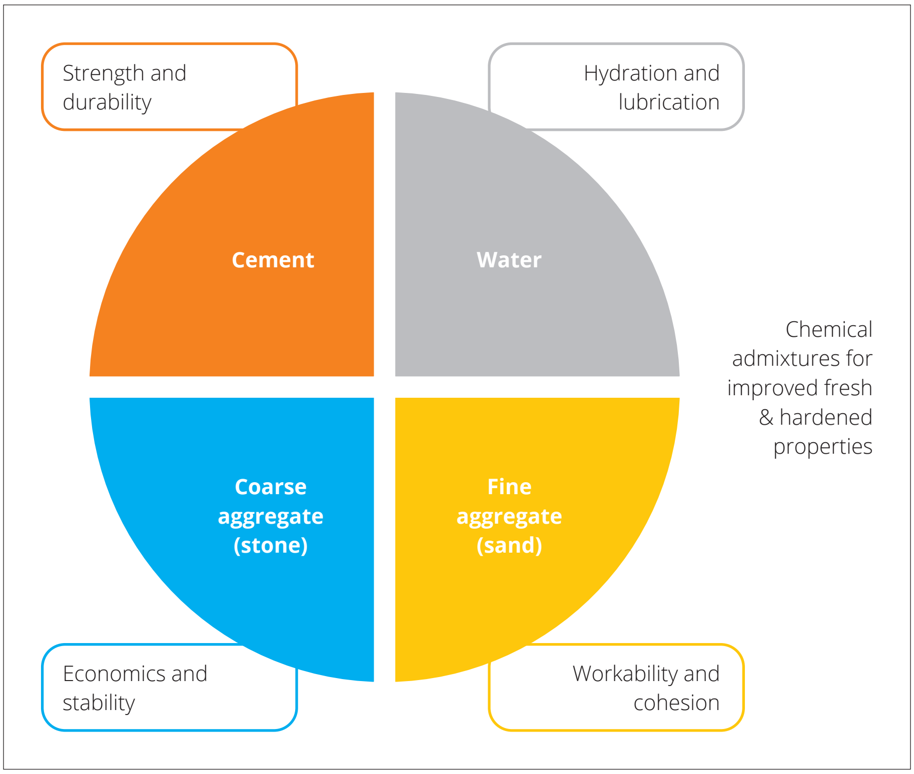


Figure 1: Constituent materials used in concrete mixes

PORTLAND CEMENT

Portland cement is a fine powder of calcium silicate anhydrite made by firing limestone (calcium source) with clay or shale (silica source). Iron is added as a fluxing agent (lowers the melting point) while gypsum is used to control setting. Fusing these materials in a kiln at 1450 ^{0}C produces clinker, which is ground to fine power to make Portland cement. In New Zealand there are two types of Portland cement commonly used:

- General Purpose (GP) used for most in situ applications
- High Early Strength (HE) cement that is used in precast concrete.

Portland cement contains calcium silicate and aluminate phases (C_3S – tricalcium silicate, C_2S – dicalcium silicate, C_3A – tricalcium silicate and C_4AF – tetracalcium aluminoferrite). Hydration is the chemical reaction between cement and water and produces a rigid network of **calcium silicate hydrate (CSH)**. Calcium hydroxide is also produced by hydration and this produces high pH that is essential for secondary cementing reactions from supplementary cementitious materials (SCMs). Continued cement hydration produces more hardened phases that increases the compressive strength of concrete. Effective curing of concrete is required to achieve full hydration of concrete.

SUPPLEMENTARY CEMENTITIOUS MATERIALS (SCMs)

These are fine powders of calcium and aluminium silicates and their reactivity depends on the reactivity and surface area of particles. Reactivity generally increases with increased fineness of powders since a greater surface area is available for reaction (shown in Figure 2). All SCMs are used in combination with Portland cement either as a blended cement such as type GB cement or the two cementitious materials are added separately into the concrete mix.

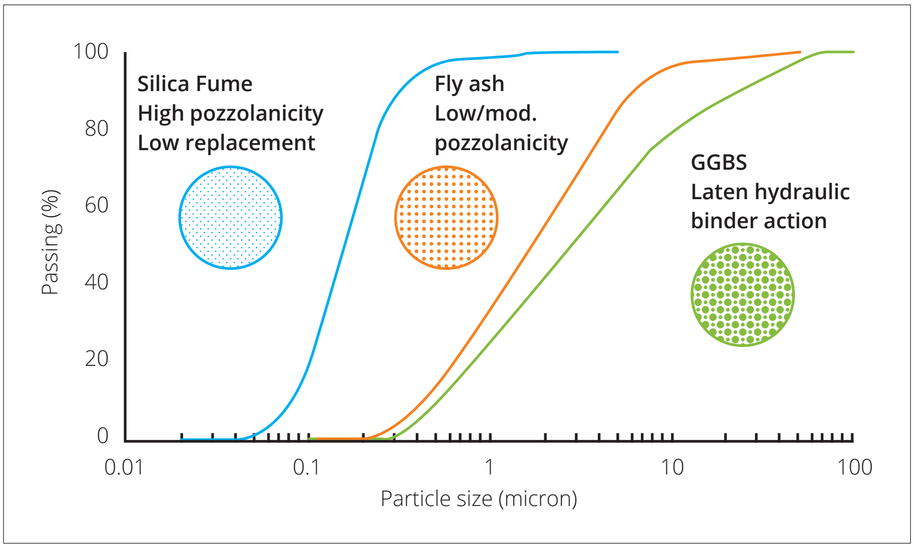


Figure 2: Typical particle size range of supplementary cementitious materials

Fly ash is the non-combustible residue from coal-fired power stations where rapid cooling forms glass composed of silica, alumina and calcium. The reactivity of fly ash in water is low due to its low calcium content but the material is pozzolanic reacting with calcium hydroxide to form similar hardened products to cement hydration. Dosage rates are typically between 25-30 percent and in some circumstances may not only improve concrete properties but also be more sustainable and save material costs.

Ground granulated blast-furnace slag (GGBS) is the non-ferrous residue from steelmaking and consists of silica and alumina glassy phases produced by rapid cooling of slag and grinding to a powder. GGBS is a latent hydraulic binder that is activated by alkalis present in concrete and forms calcium silicate and calcium aluminate hydrates. Dosage rates are typically higher at 50-65 percent as the material is more reactive than fly ash and strength development is generally good.

Silica fume is a by-product of ferro-silicon smelting, is extremely fine, glassy powder typically composed of more than 90 percent silica. It is a highly reactive pozzolan that is typically used at low cement replacement levels of less than 10 percent and due to its higher cost is mostly used in special application, such as high strength or durability applications.

Natural pozzolans are derived from glassy volcanic deposits that are ground into a fine powder to produce similar properties to other industrial SCMs such as fly ash. These natural pozzolans have the advantage of being locally available in New Zealand and are likely to be increasingly used to improve sustainability and save material costs.

AGGREGATES

Aggregates make up more than 70 percent of the volume within concrete and are used to improve economics, stability and resistance. Sourcing of aggregate is usually locally based where concrete is produced, making the material relatively cheap to produce and gives concrete a high local content. Structural concrete is composed of fine and coarse aggregate with a grading distribution for 20 microns to 20 mm. Proportioning of fine and coarse aggregate is done during the mix design process to achieve the optimum combined grading curve as shown in Figure 3.

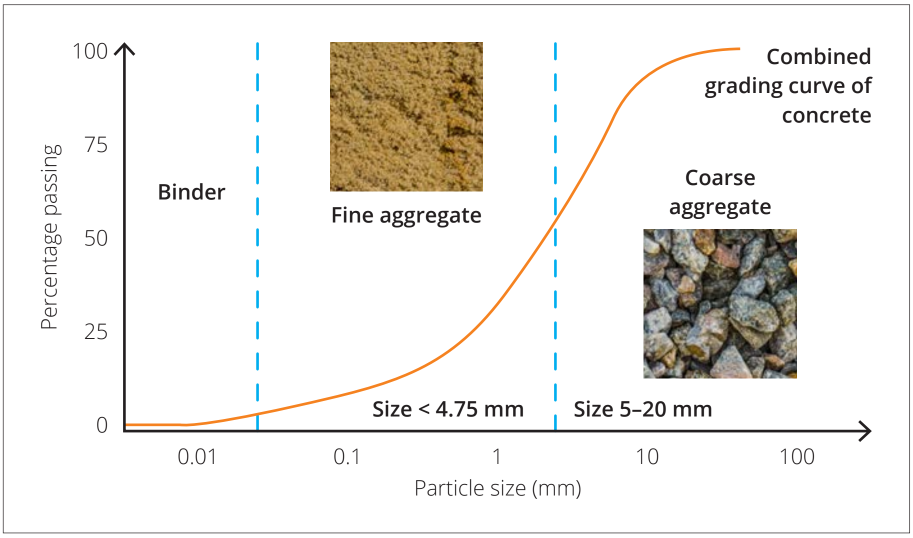


Figure 3: Typical combined grading curve of concrete

Coarse aggregate is graded with common sizes of 19 mm, 13 mm and 8 mm with stone being either crushed from hard rock quarries or being rounded from alluvial sources. Screening of course aggregate into these size fractions allows optimum blending for best particle packing and workability of concrete. Being a natural material, the properties of coarse aggregate will have a significant effect of fresh and hardened properties of concrete, most notably aggregate shape, texture, stiffness and density. Increasing the proportion of coarse aggregate in a concrete mix will reduce material costs but has a practical limit since this also reduces workability of concrete. This means the coarse aggregate content is designed according to the concrete application, such that structural concrete can cope with a higher content compared with pump concrete where higher workability is required.

Fine aggregate is commonly referred to as sand and is defined as aggregate passing the 4.75 mm sieve. The main purpose of using fine aggregate is to provide a filler material that improves workability and cohesion of fresh concrete. Grading of fine aggregate is important to ensure a continuous distribution of particle sizes, with fineness modulus (FM) is used as a simple measure of fineness or coarseness (optimum FM values are typically 2.5-2.7). Moisture content of fine aggregate are much higher than in coarse aggregates and must be allowed for when producing concrete by measurement and adjustment. Similarly, as sand is not free-draining it is important to ensure the material is not contaminated with silts, lightweight particles or other deleterious materials. Increasingly blends of fine aggregate are used for concrete using a manufactured sand (PAP7 or similar) together with a natural sand.

WATER

Water is required for hydration of Portland cement and is also required to lubricate particles to provide workability for fresh concrete. The quantity of water used in concrete has a major influence on the fresh and hardened properties of concrete. More water provides better lubrication but also dilutes the cement paste phase and this will reduce the strength of concrete. Controlling the strength of concrete is done by keeping the ratio of water to cement constant since this ratio has the greatest influence on the hardened properties of concrete. Measurement of cement during production can be accurately done to within 1 percent but keeping water contents under similar tight control is more difficult since there are several sources as shown in Figure 4.

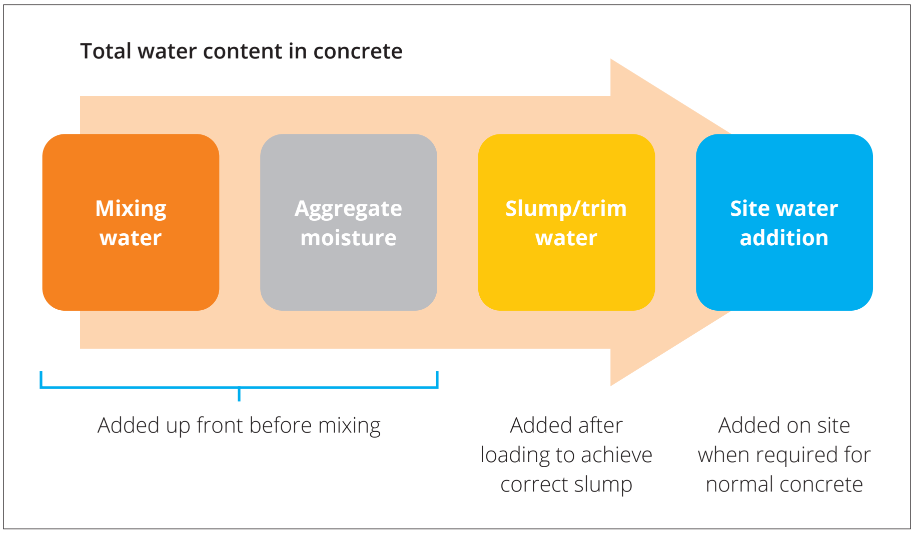


Figure 4: Components of total water content in concrete

WATER COMPONENTS IN CONCRETE MIXES

Mixing water is the main component of water added initially when batching and must be adjusted to compensate for moisture from fine and coarse aggregates. This mixing water may either be fresh potable water or recycled water from washing out of mixer bowls, which can be slurry or clear recycled water. The combination of mixing water and aggregate moisture represents more than 90 percent of the total water content required to achieve the correct slump of concrete. Care is taken when batching concrete to keep water content under design to allow for variations in material moisture and this allows final adjustment with a relatively small quantity of slump or trim water.

Site water addition can be made to concrete before discharge but clear protocols for when this is allowable as outlined in NZS 3104 and the most important aspects are as follows:

- Slump of concrete to be adjusted should be less than specified for the concrete mix
- Concrete should have been batched less than one hour before site adjustment
- Concrete to be adjusted should not be special concrete, use super-plasticisers instead

Controlling the total water content of concrete implies that there is good control on the slump of concrete being supplied, which also improves the consistency of concrete supply.

CHEMICAL ADMIXTURES

Chemical admixtures are used in virtually all concrete mixes to control fresh and hardened properties of concrete. Commonly used chemical admixtures are water-reducers (disperse fine particles and release more water for lubrication), air entrainers (produce microbubbles for freeze-thaw resistance and better workability) and set controlling admixtures (accelerators and retarders). Admixtures that are designed to enhance hardened properties include shrinkage reducers, strength enhancers and water-proofers. The wide range of chemical admixtures used in concrete are shown in Figure 5 below.

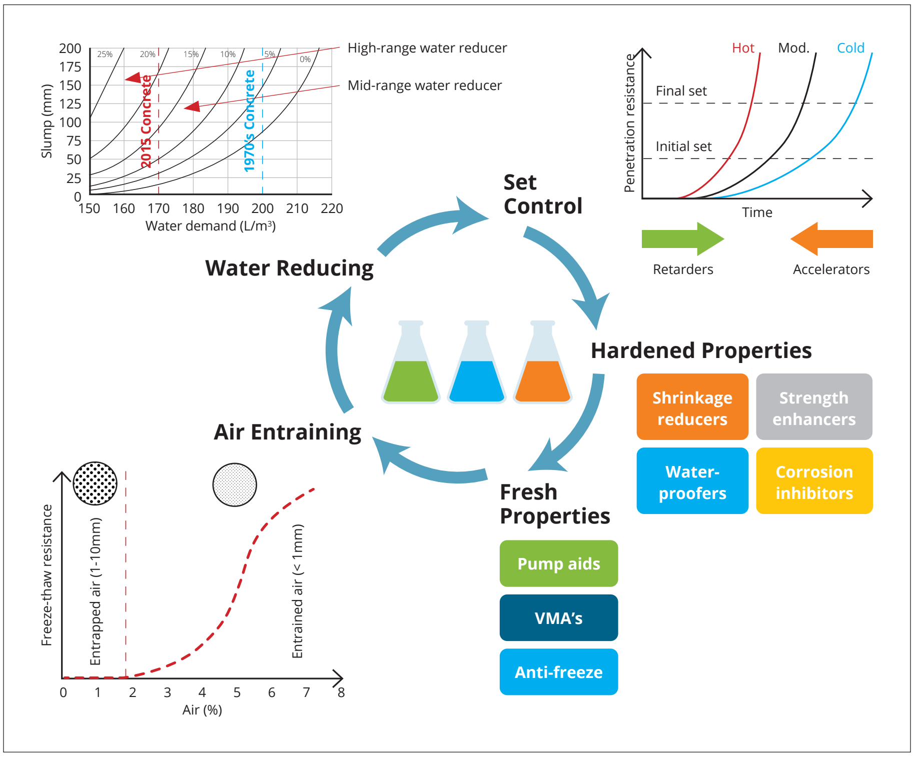


Figure 5: Main forms of chemical admixtures used in concrete

Water-reducing admixtures are used to disperse fine particles that tend to trap water and this leads to better strength and other hardened properties. Two main types of water-reducing admixtures are utilised in concrete:

- Medium-range water-reducing admixtures that are used in standard concrete mixes where only a moderate reduction in water content is required
- High-range water-reducing admixtures also called super-plasticisers that are used in special concrete mixes where a significant reduction of water is required

Air entraining admixtures are surface active chemicals that convert large-sized mix bubbles into micro-sized bubbles that improve workability, yield and durability when exposed to freeze-thaw cycles. Care is required when dosing concrete with air entraining agent as excessive air will decrease strength of the material.

Set-controlling admixtures are used to adjust the set time of concrete when exposed to either hot or cold conditions. Accelerators are used in cold weather to ensure that the cement hydration reaction is not unduly retarded and these are generally used when concrete temperatures drop below 15 ^{0}C. Retarders are used in hot weather, typically when concrete temperature exceeds 25 ^{0}C and allows placing and finishing to be undertaken in a controlled manner.

CONCRETE MIX DESIGN

Concrete mixes are proportioned to achieve the cheapest mix that will simultaneously achieve the required workability and strength while also having appropriate dimensional stability and durability for the application. Design factors for concrete mix deigns are dictated by the application and include strength grade, maximum aggregate size, target air content and consistence level defined either in terms of slump or spread. Four stages are generally undertaken when proportioning the constituents of concrete, which are listed below and illustrated in Figure 6 as well.

Water demand is estimated based on the shape and grading of fine and coarse aggregate and represents the total water used to lubricate the mix together with chemical admixtures

Water/cement ratio is decided based on the required strength and the type of cementitious material being used in the mix

Proportions of aggregate phases is done based on the type of concrete being designed with higher amounts of fine aggregate being required for more workable mixes such as pump or SCC.

Select aggregate blend is done to achieve the best possible combined grading curve so that optimum particle packing is achieved in the mix.

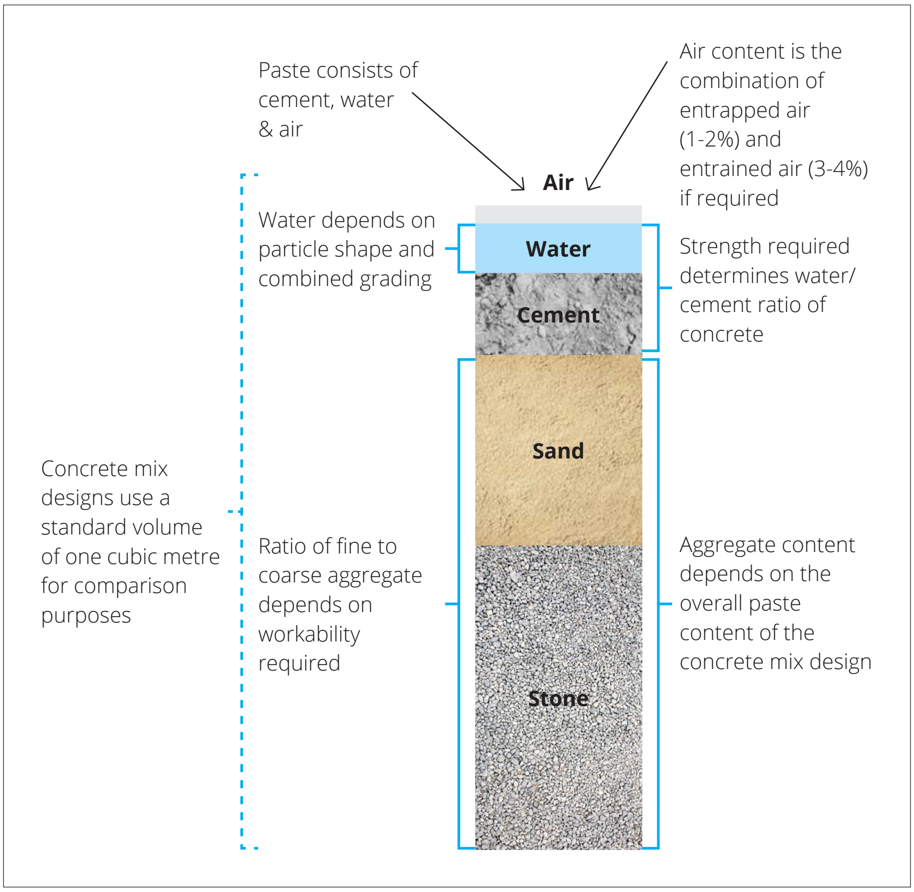


Figure 6: Simple concrete mix proportion and relevance for design

The lowest cost concrete mix is generally not achieved using the cheapest aggregates since poorer material will drive up water demand and this increases cost by having to use more cement. Good quality aggregate has the advantage of reducing the water demand of concrete that reduces costs and improves the dimensional stability of the material. While the general proportioning of concrete mixes can be done by calculation it is important when dealing with new materials and/or mix designs to run a series of trials in the laboratory to confirm performance and optimise the design.

PROPERTIES AND NATURE OF CONCRETE

Concrete is a structural material that differs from other materials such as steel that it is largely composed of natural materials and often cast on site. The versatility and low cost of concrete makes it widely used in construction with excellent long-term performance provided it is handled and protected correctly. Getting the best out of concrete can only be achieved when its properties are understood by designers, suppliers and contractors.

CEMENT HYDRATION REACTION

Portland cement mixed with water undergoes a chemical reaction that produces the strength of hardened concrete. Other cementing reactions may also occur when supplementary cementitious materials such as fly ash are used in concrete and these form similar hardened products to the hydration of cement. A by-product of cement hydration is calcium hydroxide that makes concrete alkaline (i.e. pH may be over 12). Since hardening of concrete is by chemical reaction rather than drying it is important to ensure water is not lost from the surface during construction.

NATURE OF CONCRETE

Concrete is a composite material where the different phases can be engineered to achieve a wide range of properties and performance. Despite the range of applications of concrete some common characteristics are typically found in practice:

- Concrete is strong in compression but weak in tension and needs to be reinforced with steel to transfer tensile loads
- Cracking of concrete is to be expected given its brittle nature but good design and construction practice is able to either eliminate or control cracking
- Concrete cast outdoors is initially vulnerable to damage if not protected from extreme weather conditions such that it is important that good construction practice is followed
- Concrete is composed of natural materials with over 70 percent aggregate content whose properties vary and will influence concrete properties over time
- Concrete is alkaline and care must be taken in handling and disposal of fresh concrete to reduce the risk to construction staff and the environment

ADVANTAGE OF READY-MIXED CONCRETE

Concrete construction is New Zealand is mostly supplied by ready-mixed concrete rather than relying on site batching of concrete for each project. The advantage of using ready-mixed concrete include the following:

- Concrete suppliers focus on concrete production and have specialist staff to design and test concrete mixes and source consistent materials
- Ready-mixed concrete can be supplied from plants that are audited to check compliance with the New Zealand concrete production standard (NZS 3104)
- Contractors can focus on management and construction and use ready-mixed concrete companies for delivery and testing of concrete
- Cost of readymix concrete can be kept competitive by having several suppliers and by economies of scale with more production volumes

SAMPLING AND TESTING

Thousands of concrete mixes are produced at concrete plants around NZ and it is important that output from this production is measured and controlled. Testing is undertaken at the plant and on site to assess the following concrete properties:

- Slump or spread testing to assess the consistence (stiffness or sloppiness) of fresh concrete
- Yield testing that determines the volume of concrete supplied was not short
- Air content of fresh concrete, which is particularly important for air-entrained concrete
- Compressive strength of hardened concrete that is usually measured at 7 and 28 days and used to confirm the structural grade has been achieved

PLANT VERSUS SITE TESTING

Ready-mixed concrete is mostly sampled and tested at the concrete plant where the laboratory and testing equipment are based. Site testing of concrete is sometimes requested on site, but this is more time consuming and less well controlled due to environmental and logistical issues. Two main types of testing are included in the results reported by ready-mixed concrete companies:

- Quality control testing that is mostly done randomly across production at the concrete plant and provides evidence of the production control and performance of individual concrete mixes
- Quality assurance testing that can be done at the plant or on site where tests are requested for specific concrete mixes going to projects

FREQUENCY OF TESTING

Test frequency is specified in the concrete production standard (NZS 3104). This is typically set at one test per 75 m^3 of concrete supplied but can be the frequency can be reduced for large concrete plants with annual production above 15000 m^3. This frequency of one test per 75 m^3 represents roughly one road tanker of Portland cement and one truck and trailer of each of the aggregate components used in a moderate grade concrete mix. Testing concrete more frequently than standard is costly and does not necessarily provide significantly more quality assurance.

SAMPLING OF CONCRETE

Test samples taken from a concrete mixer/truck represent an extremely small percentage of the total volume being typically less than one percent. It is important therefore that sampling is done accurately to ensure the test sample has properties similar to the bulk of the concrete supplied. Further the sampled load of concrete should be consistent with other loads of concrete supplied at the same time since only every 10-15 loads are tested. Two types of sampling of fresh concrete are routinely undertaken:

- Representative sampling usually done at the plant where three snatch samples are combined in a wheelbarrow remixing between each drop
- Snatch sampling usually done on site where a single sample is extracted using a bucket from the end of the chute or pump hose

BATCH RECORDS

The weight of materials batched in each load is recorded at the concrete plant and these records can be used confirm non-tested loads were consistent with tested loads. From these batch records the final water/cement ratio for each load can also be used to predict 28-day compressive strength.

FRESH CONCRETE TESTING

Testing of the fresh concrete properties is undertaken immediately after extracting a representative or snatch sample. Testing is done in accordance with NZS 3112 Part 1.

SLUMP TESTING

Slump testing determines the consistence of fresh concrete and is suitable for most concrete except dry mixes of less than 40 mm slump or high flow mixes where slumps in excess of 200 mm are expected. Using a clean and damp slump cone on a flat and vibration free surface, fill the cone in three equal volume layers. Each layer is tamped 25 times, spreading the blows evenly around and through the depth of each layer. After striking off the top surface and cleaning any spillage on the sides, the cone is lifted over two seconds to allow the concrete to slump. The cone is inverted, and the tamping rod used to the measure the distance to the highest point of the concrete, which is the actual slump recorded to the nearest 10 mm. Concrete that shows unusual slump pattern such as shearing needs to be retested to confirm the slump.

SPREAD TESTING

Spread testing is used to measure the flowability of high flow mixes such as blockfill, tremie and self-compacting concrete where slump testing is unreliable. The clean and damp slump cone is inverted on a flat and damp baseplate and filled by pouring in the high flow concrete without compaction. The cone is lifted slowly to a height of 50 mm to allow the concrete to flow out. Measurement is made of two diameters at right angles to each other and the average diameter reported to the nearest 10 mm. During this test and assessment can also be made of the risk of segregation (visual stability index) and the plastic viscosity (T500 time).

YIELD TESTING

Concrete is batched by weight but supplied by volume, so it is important to check that concrete mixes are not under-yielding in terms of volume. Yield testing is able to confirm this by measuring the unit weight of fresh concrete using a standard container of known volume. The clean and damp yield pot is initially weighed before being filled with concrete in three equal volumes. Each layer is fully compacted by rodding at least 25 times before tapping the sides of the container with a nylon headed hammer (typically 15-30 times depending on the workability of concrete). After carefully striking off the top surface to the level of the rim, the full container is reweighed so that the net weight of concrete can be determined. Knowing the weight and volume of concrete, the unit weight of the concrete can be calculated, and this is then used to determine the actual yield (typically greater than 1.000).

AIR TESTING

Concrete used to determine the yield is then used for the air test that measures the volume of all entrapped and entrained air in the compacted concrete. The standard method uses a pressure meter that is clamped on to the yield pot lid to form an air-tight seal. After replacement of all air above the concrete surface with water, a standard volume of pressurised air is released from the top chamber. The air gauge is calibrated to measure the change in pressure at the result of the concrete compressing and this is then read off the meter as the actual air content, which is reported to the nearest 0.2 percent. Typically air contents for non air-entrained concrete should be below 2 percent while air-entrained concrete typically have design air contents of 4-5 percent.

HARDENED CONCRETE TESTING

Tests specimens for hardened concrete testing can be taken from the same sample of fresh concrete provided this has not been contaminated with water. These test specimens need to be made within 30 minutes of sampling concrete and the fresh material should be remixed to incorporate any bleed water back into the concrete.

MAKING TEST CYLINDERS

Test cylinders are made in accordance with NZS 3112 Part 1, which stipulates the required compaction and curing to produce consistent results. Normal concrete made with a maximum aggregate size of 19 mm is typically tested using 100 mm diameter by 200 mm high steel cylinders. Concrete is compacted in three equal layers using either a minimum rodding of 25 blows and tapping the side with a nylon hammer or by mechanical vibration using a vibrating table. Once the concrete has been fully compacted, the top of the cylinder is covered to prevent drying and the temperature controlled (laboratory at 21 ± 2 ^{0}C, site at 18 ± 8 ^{0}C). Concrete cylinders need to be demoulded after 18-72 hours and placed underwater in a curing tank or fog-room with temperatures maintained at 21 ± 2 ^{0}C until strength testing at 7 and 28 days.

CYLINDER MEASUREMENT AND HARDENED DENSITY

Concrete cylinders are taken from the curing tank at either 7 or 28 days and the dimensions, tolerances and weight recorded on a standard testing sheet. The reasons for these measurements are as follows:

- Two diameters at mid-height are measured to determine the average diameter as this is used to calculate the cross-sectional area, which is used together with the crushing load to determine the compressive strength
- The height of the cylinder is measured and used together with the average diameter to determine the volume, which is need together with the weight of the cylinder to determine the hardened density
- The weight of the cylinder is measured to determine the hardened density that provides useful information especially in cases of unusual strength results
- The squareness and flatness tolerances are checked on cylinder ends as well as any defects

COMPRESSIVE STRENGTH TESTING

Cylinders are tested for compressive strength at 7 and 28 days to confirm the structural performance of concrete. Test specimens are placed centrally in the compression testing machine and if the ends are sufficiently flat and square can be loaded directed with the steel platens. In cases where the top of the cylinder is less precisely square and flat, a rubber cap restrained within a sub-platen should be used to ensure uniform loading through the specimen. Loading is done a standard rate of 10-20 MPa per minute until the cylinder has been crushed and the maximum load is recorded from which the compressive strength is calculated. Any unusual failure modes are also noted such as shearing, which could indicate incorrect test set-up or defective cylinders.

OTHER HARDENED CONCRETE TESTS

Some projects require other hardened concrete properties to be tested such as the following:

- Flexural tensile strength done in accordance with NZS 3112 Part 2 Section 7
- Splitting tensile strength done in accordance with NZS 3112 Part 2 Section 8
- Drying shrinkage testing done in accordance with AS 1012.13

CONCRETE APPLICATIONS

The versality of concrete allows mix designs to suit a wide range of applications that depend on structural form, access conditions and the rate of delivery required on site. Concrete can be delivered to small or large projects with a range of technical requirements (see Figure 7).

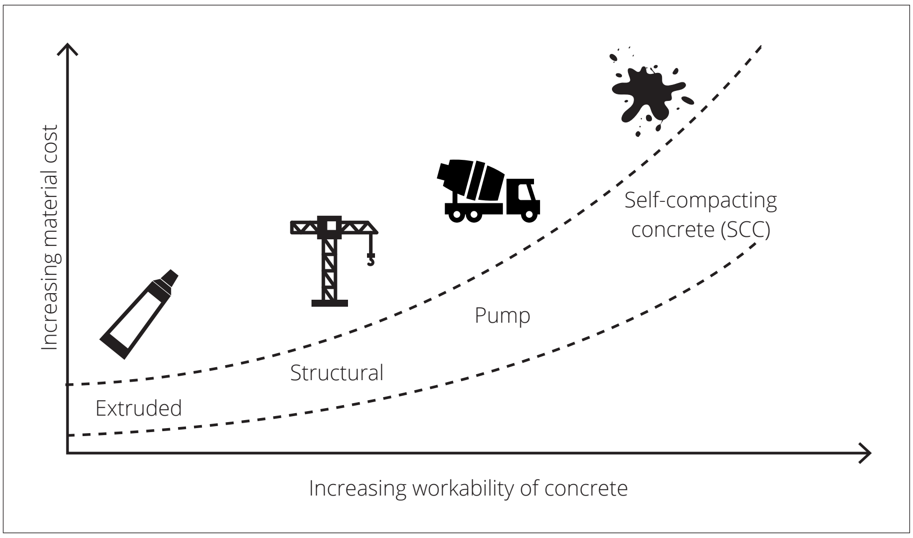


Figure 7: Different applications for concrete in terms of workability

OFF CHUTE

Concrete supplied off the concrete truck chute is the most cost-effective method of delivery to construction sites. This method of application can only be used for smaller slabs, panels or foundations and is mostly done in precast concrete factories and for residential construction. The rate of delivery in these applications is relatively slow especially if wheelbarrows are used or when extruded concrete is required such as kerbing and median barriers.

CRANE SKIPS

Moving concrete in crane skips is often used in vertical infrastructure projects where the crane boom can reach a large area of the site. The extra costs of setting up tower or mobile cranes can be off set by using standard concrete mixes that are cheaper than pump mixes. This is because standard structural concrete can be designed with lower workability requirements that generally have lower cementitious content and therefore less expensive.

PUMPED CONCRETE

Pumping concrete is a versatile and fast method of delivering concrete into formwork on construction sites. Pumping is generally done using dedicated concrete pumps with booms that can reach from 10-45 m from the truck. Concrete can be pumped longer distances through a rigid steel line in cases where closer access is not possible. Dedicated concrete mixes are often designed for pumped application to ensure a higher level of workability. Achieving appropriate workability for pumping concrete consists to increasing the proportion of fine aggregate in the concrete mix, which increases water content and therefore the cementitious content. Self-compacting concrete (SCC) is highly flowable and is sometimes pumped upwards into vertical elements such as walls and columns.

WEATHER CONDITIONS

Concrete is usually cast in situ where it is exposed to a range of weather conditions, which may affect the quality of the material. Weather conditions require special attention or precautions shown in Table 2.

Table 2: Weather conditions effects and mitigation strategies

Adverse weather	Effect on concrete	Mitigation Strategies
Cold weather	Retardation of hydration	Use accelerators in concrete
Freezing	Ice formation causing damage	Protect concrete from frost
Hot weather	Rapid stiffening and setting	Use retarders in concrete
Windy weather	High evaporation rates	Misting and anti-evaporative sprays
Variable temperature	Early thermal contraction	Insulate concrete surface overnight

COLD OR FREEZING CONDITIONS

The hydration reaction of cement and water is dependent on temperature with cold weather retarding the process. When the air temperature drops below 10 ^{0}C the hydration reaction of concrete will be retarded leading to delays in setting and strength development. Provided the air temperature does not drop below 0 ^{0}C, compensation of the concrete mix can be made using chemical admixtures that accelerate the hydration reaction. When concrete is exposed to freezing conditions the microstructure of concrete can be damaged and some form of protection is required.

HOT WEATHER

High temperatures generally occur during summer and make concrete difficult to handle unless chemically retarders are added to concrete. When concrete temperatures rise above 25 ^{0}C the cement hydration reaction accelerates leading to more rapid slump loss and stiffening of the material. If no compensation is made for temperature under these warm conditions, extra water is often used instead and this will reduce strength of concrete.

WINDY WEATHER

Evaporation of moisture off a surface such as fresh concrete is mostly depend on wind speed that often occurs at lower humidity. High levels of evaporation can occur even during cold weather provided the concrete surface is exposed to high wind speeds. Protection from rapid drying of concrete is essential for concrete after placing to avoid plastic shrinkage cracking that occurs when drying exceeds bleeding. One of the most effective methods of protecting concrete is to reduce exposure to the elements by building the structure first before casting the floor slab.

VARIABLE TEMPERATURES

Early thermal cracking of concrete is commonly found in slabs exposed to a wide range of temperatures shortly after casting when the material is green (i.e. within the first 48 hours after setting). Typically this happens when concrete slabs are cast on a sunny day with temperature peaking in the early afternoon when the material is setting. Temperatures then drops overnight such that the peak temperature may drop 15-25 ^{0}C and can lead to an excessive amount of contraction when the concrete has almost no strength.

4. BATCHING CONCRETE

STORAGE OF MATERIALS

Concrete is produced at batch plants either on site or at ready mixed concrete plants who supply to construction sites in the area. In both cases materials used to make concrete are held in silos, bins or stockpiles that must be properly maintained to ensure consistent quality without risk of contamination. Handling of each material differs depending on the properties as discussed below (see also Figure 1 for batching plant schematic).

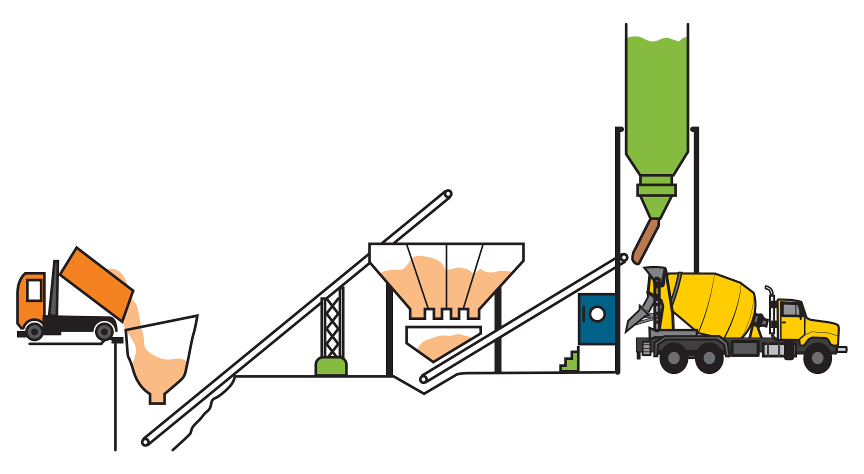


Figure 8: Concrete batching plant schematic example of truck-mixing

CEMENTITIOUS MATERIAL

These are dry powders that need to be kept dry in large silos and are moved by compressed air or screw augers. Handling of cementitious material involves multiple movements from the cement works into ships holds, regional depots and finally delivery to the concrete batch plant. This handling has the advantage of blending the material thereby reducing variations in production quality. Storage of cementitious materials at concrete plants is done in silos and pressure vessels called pods. Regular maintenance of these must be done to ensure filters and pressure valves are functioning correctly as these are essential for the safe operation of these storage facilities.

FINE AND COARSE AGGREGATE

Aggregates are held in overhead bins and/or stockpiles at the concrete plant with the material always handled in the moist state. Consistent concrete cannot be made with dry aggregate due to rapid absorption of mixing water, which means sprinklers are sometimes required to prevent the surface from drying out. With overhead bins there is little risk of contamination provide the correct material is loaded into the bin. Stockpile management to prevent contamination includes having a solid surface and ensuring no spill over between adjacent materials.

Figure 9: Aggregate storage in stockpiles at a loader-fed concrete plant

WATER

Water may come from town supply, borehole or recycled sources and handling is generally through pressured lines or tanks. Storage protocols are relatively simple with leakage and freezing being the major issues to be controlled at the concrete plant. Where production is in colder regions of New Zealand the delivery pipework needs to be either insulated, having a heating trace or have drainage valves to purge the pipework before closing overnight. Generally large water tanks either in ground or above ground will not freeze due to the large volume.

CHEMICAL ADMIXTURES

Chemical admixtures are supplied in liquid form and storage is in drums or tanks that need to be stored together in a bunded area. Each tank must be clearly labelled to prevent cross-contamination and regular checks should be made to ensure no separation of the chemical during storage. Generally concrete production is sufficient to ensure admixtures are used within a few months of production but in cases of limited or interrupted production, checks should be made that material is not older than the shelf-life.

ADDITIVES

A wide variety of additives are specified for concrete and may include steel fibres, synthetic fibres, pigments, powders, and other materials. These additives should be kept in a dry store where each material is clearly labelled for easy identification. Since these materials may having different loading requirements, any specific loading instructions should be given in poster form near either the storage area or where loading occurs. Health and safety instructions from MSDS or similar should also be available along with PPE for loading.


Steel fibers

Hooked-end · Twisted · Straight

Synthetic fibers

Polypropylene · Glass · Carbon

Figure 10: Range of structural and non-structural fibres used in concrete

MOISTURE CONTENT OF AGGREGATES

Before batching concrete can start it is important that the moisture content of aggregates, especially fine aggregates, is known. This is because concrete production uses moist aggregates and the contribution of this can be between 25-50 percent of the total water content of the concrete. Coarse aggregate is relatively free draining such that moisture contents above 1 percent are rarely possible and an estimation of the likely moisture content is generally accurate enough for concrete production. Fine aggregate can retain much higher moisture content with levels typically between 3-6 percent but may on occasions reach 10 percent. Measurement of moisture of fine aggregate can be done in the following ways shown in Figure 4.

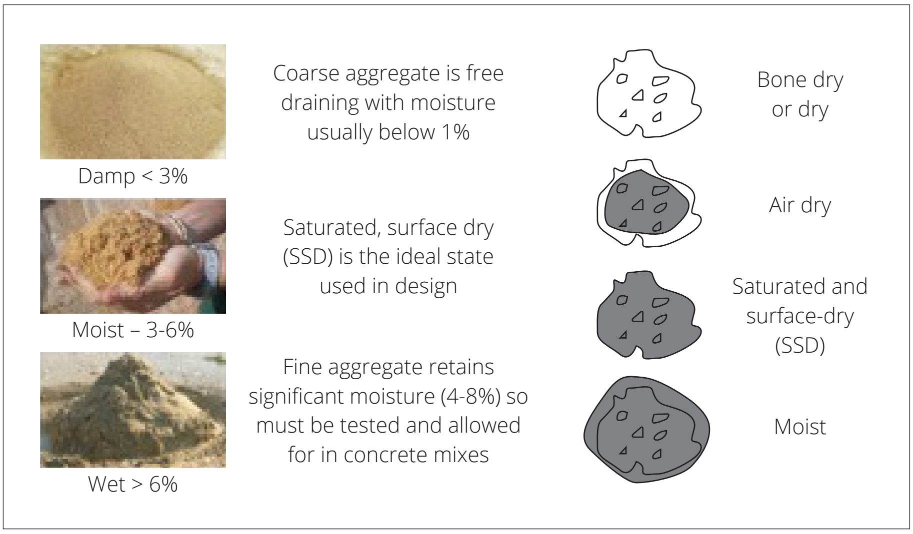


Figure 11: Moisture content and states of fine aggregates

OVEN-DRYING

The most accurate method of determining the moisture content of sand is using oven-drying in accordance with NZS 3111. This involves heating a small sample of material to 105 ^{0}C until constant weight and determining the moisture content from mass loss. The standard laboratory method involves drying for a period of 24 hours but increasingly more rapid assessment is done using hot plates and gas heating where moisture testing can be done within less than an hour. Typical sample sizes used for this testing is between 200-500 g and it is therefore important to have laboratory scales that can measure accurately with a resolution to a tenth of a gram.

MICROWAVE DRYING

Drying of sand samples can be done more rapidly by using a microwave and can be done in 5-10 minutes. Care must be taken to ensure that the material has fully dried and cooled before taking the final measurement. Regular checking during the drying process as the sand will become very hot once the moisture is driven off and this can crack the container or the glass turntable. Measurement of moist and dry weight of the sand sample is similar with that used for oven drying using a laboratory scale that can weigh to one decimal place in grams.

DISPLACEMENT

When there is no oven available for rapidly drying sand it is still possible to measure the moisture content reliably. A volumetric displacement method is used with a one litre measuring cylinder and consists of the following:

- Fill a measuring cylinder to exactly 400 ml
- Add 1000 g of moist sand to the measuring cylinder
- Wait for a minute for the water column to settle
- Remeasure the meniscus level of the combined sample
- Read off moisture content to ± 0.5 percent from the chart

MOISTURE PROBES

The most rapid method of determining moisture content of fine aggregates is using moisture probes that are able to measure every load in real-time. Modern moisture probes when well calibrated are reliable and make concrete production more accurate such that batch records can accurately predict the strength of concrete. Regular calibration and maintenance of moisture probes is essential to have confidence using these systems.

BATCHING TOLERANCES

Accuracy of weighing up materials is important when batching concrete to ensure consistency between loads and for predicting the strength of concrete. The tolerance given in NZS 3104 for weighing up materials is as follows:

- Cementitious material must be weighed to within ± 1.0 percent of the target weight
- Aggregates must be weighed to within ± 2.0 percent of the target weight
- Mixing water must be weighed or flow measured to within ± 2.5 percent of target
- Chemical admixtures need to be measured to within ± 10 percent (usually less than 1.0 percent)

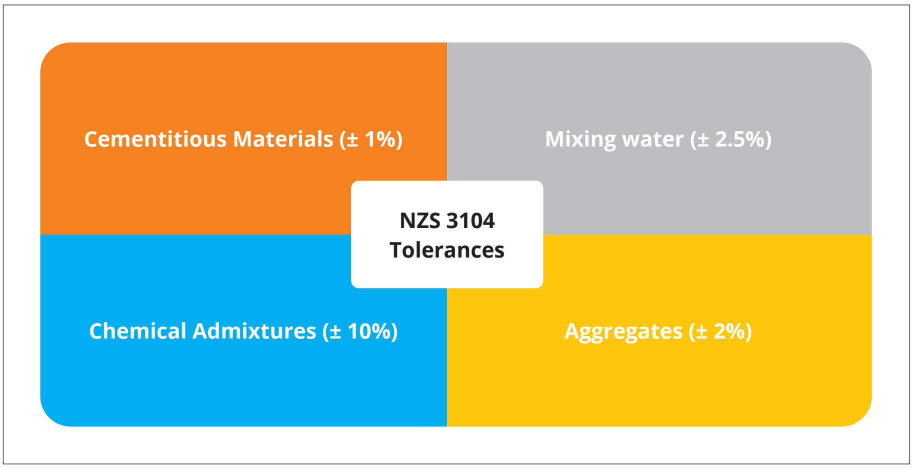


Figure 12: Tolerances for weighing materials during concrete production in accordance with NZS 3104

BATCH RECORD ANALYSIS

A record of the measured weights must be recorded after each batch of concrete has been loaded and adjusted to achieve the required slump. These batch records provide a permanent record of concrete production and are essential documentation given that testing is typically only done on every 15th load. Analysis of batch records is done to check materials are within tolerance of target weights and can also be used to predict the strength of concrete supplied. These predictions are based on determining the final water cement ratio of the batch since this is strongly linked to 28-day compressive strength of concrete. Figure 5 shows the typical relationship between water/cement ratio with 28-day compressive strength.

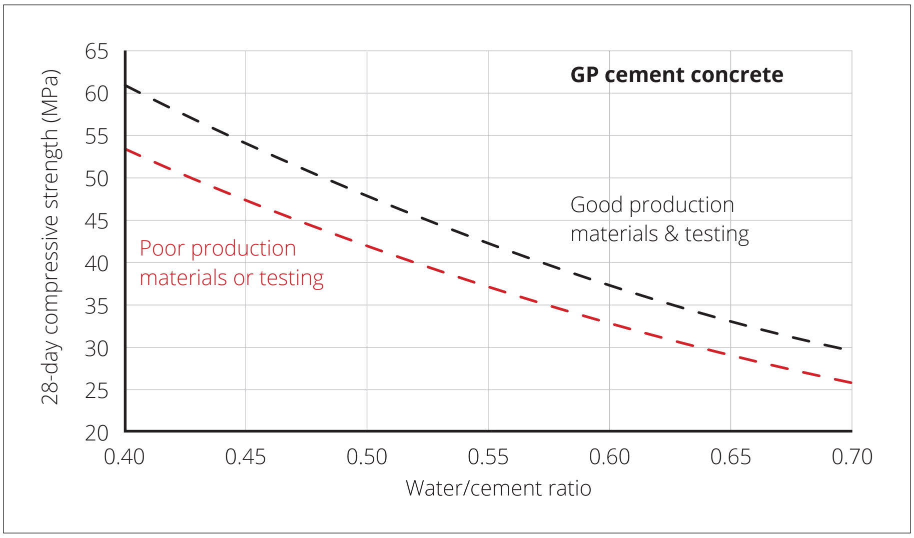


Figure 13: Predicted 28-day compressive strength from water/cement ratio of concrete

BATCHING SEQUENCE AND MIXING

Each batch of concrete needs to be loaded and mixed as efficiently as possible to achieve the best possible fresh and hardened properties. Recommended practice for the batching sequence and mixing time will depend on the type of concrete mixer and uniformity testing is done to ensure consistency of material being supplied.

BATCHING SEQUENCE

Most concrete production in New Zealand is done using truck mixers where the concrete plant measures materials loaded into each batch load and relies on the truck bowl for mixing. Under this mixing regime the following batching sequence is traditionally undertaken:

- Mixing water with chemical admixtures are loaded first into the concrete truck to ensure that dry powder does not stick to the front of the bowl
- Aggregate belt is then started with larger sized stone running into the bowl first that helps scour any loose debris sticking to the inside of the bowl and fins
- Cementitious material is started soon after aggregate belt has started so that the fine powder is blended with aggregate flow
- Fine aggregate continues to flow after cementitious material has stopped, which helps drive the powder into the mixture and reduces dust
- The bowl continues to rotate at full mixing speed of 14-16 revolutions per minute (rpm) and final trim adjustment is made with metered water at the slump stand
- Concrete truck is held at the slumping area to ensure a minimum of 70 revolutions, which at normal mixing speed should take at least five minutes
- Final measured batch quantities including the trim water used to slump concrete must be recorded on the batch records kept by the plant

Central mixing plants using either pan, large bowl or twin-shaft mixers may have a different sequence of loading and the forced action may allow shorter mixing times. The batching methodology for these central mixers needs to clear and understood by plant staff.

CONCRETE MIXING

Mixing of concrete occurs at the plant when the bowl is rotated at 14-16 rpm with no further mixing occurring when concrete is in transit since agitation speed is only 2-4 rpm. Inadequate mixing of concrete will reduce the properties of concrete, especially compressive strength. Further mixing beyond the standard 70 revolutions of the bowl needs to be undertaken in the following cases:

- When fine powders such as silica fume or CSA cement are added at the plant, especially when added after initial mixing of concrete
- When a noticeable inconsistency is noted in the mixing concrete such as a lump or cement balls that indicate that loading sequence was not optimum
- When concrete arrives on site the bowl should be spun up at mixing speed for 30 seconds as this will improve the slump of concrete
- After addition of water on site, the concrete should be mixed for two minutes at full mixing speed
- After addition of super-plasticiser on site, the concrete should be mixed for five minutes at full mixing speed

CONCRETE UNIFORMITY

Discharge of concrete on site must be uniform in terms of the properties of the material otherwise these variations could adversely affect structural performance. All mixers are tested annually to ensure that concrete properties are uniform near the start and end of discharge. Uniformity testing ensures that the following properties are consistent across the discharged load; slump, plastic density, air content and 28-day compressive strength. This testing for uniformity is also done on any new concrete mixers or after mechanical repair of the mixing bowl.

SITE WATER ADDITION

Site water addition to concrete is sometimes permitted provided this is controlled and complies with:

- Requested by the purchaser or engineer due to slump being below that requested
- The concrete being adjusted is normal and not special concrete (use super-plasticiser)
- Concrete was batched less than 60 minutes before site water addition
- Water addition does not exceed 10 L/m^3 and the amount is recorded on the delivery docket

Placing concrete at lower than the design slump is not just extra work but can lead to poor hardened properties as concrete is more difficult to compact and finish. Controlled addition of water to concrete is generally relatively safe and will not adversely affect the quality of concrete.

Uncontrolled water addition on site should be reported since this practice can severely compromise the structural integrity of concrete. The following practices are examples of uncontrolled water addition:

- Adding water to concrete to increase the slump beyond that stated on delivery docket
- Adding excess water to concrete i.e. above 10 L/m^3
- Adding unmetered water from another source other than truck hose

RETURNED CONCRETE

Concrete less than 90 minutes old can be returned to the concrete plant and reused as part of other loads provided the following limitations are adhered to:

- Returned concrete must be of the same or higher strength to that being supplied
- Air entrained concrete cannot be used when non-air entrained concrete is being supplied
- Returned concrete should not be used in special concrete or decorative concrete mixes

In many cases returned concrete cannot be reused due to concerns about the quality of the material when returned to the plant (e.g. concrete too old, slump of concrete too low or uncontrolled water addition on site). This returned concrete can be dumped at the plant and recycled in the following ways:

- Dumped into recycling ponds where the solids can be reclaimed and used as washed recycled aggregate
- Poured on the ground as a “snail trail” to allow easy crushing into a recycled aggregate
- Pouring into interlocking “Lego” block moulds which can then be sold for retaining walls and flood protection systems
- Used for plant improvements such as floors for new stockpile areas or bunding of site to prevent run-off

5. CALIBRATING BATCH EQUIPMENT

Batching of concrete is done by weighing materials, which is the most accurate and efficient method of checking quantities in each load. The accuracy of all weighing equipment used at the concrete batch plant must be regularly checked with the frequency and allowable tolerance being dependent on each material and the type of weigh scale system being used.

WEIGH SCALES

Three types of weigh scales are used that are listed in order of typical age; full load cell, mechanical/load cell or mechanical systems. Details on each of these weigh scale systems are given below:

- Scales using full load cell weighing have four of these electronic devices with the combined weight being recorded on the scale
- Scales using a combination of mechanical and load cells usually have a knife edge on one side with two load cells on the other side that record the applied weight
- Scales using mechanical systems rely on older generation technology such as springs and balances to measure the applied weight and are not electronic

Modern weigh scales using full load cell systems are the most reliable and are less prone to gradual creep in accuracy that is found in older mechanical systems. This is why calibration frequency differs between these different types, which also provides an incentive to modernise weigh scale equipment. Note that no materials can be volume-batched except for water where flow meters can be used.

FREQUENCY OF SCALE CHECKS AND CALIBRATIONS

The frequency of these depends on whether this is a routine scale check done by the plant supervisor or an independent calibration done by a scale testing specialist. The required frequency of these checks and calibrations are given in NZS 3104 and summarised in Table 3.

Table 3: Frequency and tolerance of tests of batch plant weighing equipment

Material type	Routine check Full load cell scale	Routine check Mechanical/Load cell	Independent Calibration
Cementitious	Quarterly – 0.4%	Monthly – 0.4%	Every two years – 0.2%
Aggregate	Every 6 months – 0.4%	Quarterly – 0.4%	Every two years – 0.2%
Water	Every 6 months – 2.0%		Every two years – 2.0%
Admixture	Not required		Annually – 10.0%
Laboratory scales	Monthly		Annually – 0.2%

These test frequencies are required regardless on the level of concrete production and can only be suspended if there is no concrete production at the concrete plant for an extended period. Most of these tests require concrete to be produced as part of the weight used in scale checks and calibration is so called make weight rather than test weights (i.e. used the material itself as part of the applied load on the scale).

SCALE CHECKING AND CALIBRATION METHODOLOGY

Testing of weigh scales uses calibrated test weights that are either made from steel (typically 20 – 30 kg) or concrete (typically 200 – 1000 kg). These test weights need to be calibrated by independent weigh scale specialist at the following frequency:

- Concrete blocks if not sealed in steel must be tested every two years as weight can change
- Concrete blocks if sealed in steel and kept undercover require only an initial calibration
- Steel test weight each with a unique identification number require only an initial calibration

Testing methodology of scale checking or calibration generally requires a combination of test and make weights since the amount of test weight is not enough to load the scale to its full capacity (e.g. cement scale may be 2-3 tonne while aggregate scale may be 12-15 kg). The large capacity of most weigh scale is because the volume of concrete in each batch is typically between 5.0 and 6.5 m^3. It is important to check for error across the full working range of each weigh scale, and the procedure is as follows:

- Test readings for older mechanical/load cell systems must include at least 10 steps that are even spaced up to the full operating range of the scale
- Test readings for modern load cell systems can be done in three steps at roughly 10 percent, 50 percent and 100 percent of the full operating range of the scale
- Make weight when testing cement scales cannot exceed test weight and in the case of aggregate scales the make weight cannot exceed twice the test weight
- At each step in the testing process the applied weight, observed scale reading and difference must be recorded on a standard scale test sheet
- At each step, the difference between applied weight and scale reading (incremental error) shall be carried across as the cumulative error, which is used to check variation (best done on a spreadsheet)
- Main water meters need only be checked to 200 litres while trim water meters are tested to 50 litres

Examples of a routine scale check for a typical cement scales are shown in Table 4 below that was done in 10 steps as maximum test weight was limited to 250 kg.

Table 4: Typical routine scale check of cement weigh scale at plant having 10 test weights of 25.0 kg

Make Weight Scale reading	Certified Test Weights	Total weight (Make + Test)	Scale Reading (kg)	Incremental Error (kg)	Cumulative Error (kg)
0	250	250	250	0	0
248	250	498	498	0	0
499	250	749	750	1	1
749	250	999	1000	1	2
1000	250	1250	1250	0	2
1249	250	1499	1500	1	3
1500	250	1750	1750	0	3
1748	250	1998	1999	1	4
2001	250	2251	2250	-1	3
2248	250	2498	2499	1	4
				Max. Variance	0.20%

The maximum variance is calculated from the percentage of the cumulative error divided by the total certified weight at any step (worst case of 0.20 percent variance was after step 4 and step 8 where total certified weight was 1000 kg and 2000 kg respectively). A similar procedure is undertaken on aggregate scales except that test weight tend to be considerably heavier and make weights may be twice that of test weights.

Independent calibrations are done every two years and have lower tolerance on the maximum variance since during the test adjustments can be made to improve accuracy. Some professional scale test specialists carry large test weights of several tonnes and can undertake weigh scale calibrations in three steps without having to use make weights. This has the advantage that testing can be done after concrete production has finished for the day and does not interfere with plant operations.

LABORATORY EQUIPMENT

Testing of concrete involves a wide range of equipment that needs to be checked and calibrated regularly by plant staff or independent calibration specialists. This checking and calibration consist of monthly checks, quarterly and annual calibrations.

MONTHLY EQUIPMENT CHECKS

The technician responsible for testing equipment and is required to check and fill out the monthly from that includes the following:

- Visual inspection of thermometer, slump cone, tamping rod, measuring rule, yield pot and air meter
- Check electronic balances using test weights and recording scale reading

QUARTERLY CALIBRATIONS

The air meter needs to be calibrated at quarterly intervals where the gauge is checked at three different content levels. Given the typical range of air contents found in concrete, air contents are usually checked at 2 percent, 4 percent and 6 percent using air canisters placed into water. Air contents measured during this test need to be within 0.2 percent of the actual air content up to 5.0 percent and within 0.5 percent for air contents above that value.

ANNUAL CALIBRATIONS

These calibrations can be done by plant staff unless otherwise noted and should be recorded in the annual calibration sheet. The list of laboratory equipment that needs to be calibrated annually includes:

- Compression testing machine (independent calibration required by specialist)
- Electronic balances for laboratory weighing (independent weigh scale specialist)
- Thermometers used for fresh concrete and curing tanks
- Slump concrete and tamping rod measurements
- Volume of yield pot using water and glass plate
- Vernier calliper accuracy and checking of set squares
- Sieve used for grading analysis of fine and coarse aggregate

Table 5: Monthly equipment checks and quarterly and annual calibrations

Number	Monthly checks	Quarterly calibration	Annual calibration
1	Slump cone	Air meter	Compression machine
2	Tamping rod		Electronic balance
3	Measuring ruler		Thermometers
4	Yield and air equipment		Slump concrete and rod
5	Thermometer		Vernier and square
6	Electronic balances		Yield and air equipment
7			Aggregate sieves

There are several other important piece of laboratory equipment that should be inspected at least annual to ensure quality testing. These other pieces of equipment include the following:

- Cylinder moulds should be in good condition with smooth internal surfaces, square base and easy release mechanism so concrete cylinders are not damaged
- Hot box or temperature-controlled room where cylinders are stored overnight in steel moulds before demoulding samples
- Sub-platen that restrains the rubber cap should be in good condition with square and flat surfaces to ensure direct transfer of load from the testing machine to the concrete cylinder

6. ORDERING AND DISPATCH OF CONCRETE

ORDERING CONCRETE

Fresh concrete is supplied by volume but batched by weight by ready-mixed concrete suppliers. All concrete mixes are designed to yield slightly more than the ordered volume (roughly 1 percent extra). This is done to ensure the concrete supplied is not short of the ordered quantity.

LOGISTICS

Before concrete can be supplied to site the contractor needs to consider the following logistical issues:

- Site access constraints in term of weight restrictions, road clearances, local by-laws, etc.
- Time of delivery and special conditions that might apply in some areas
- Method of concrete placement such as crane, pump, off chute or wheelbarrow
- Rate of supply required to keep up with placement of concrete
- Washout facilities on site for cleaning chutes on concrete trucks
- Retempering options for concrete on site
- What site testing requirements apply to the project if any?

SPECIFYING CONCRETE

Concrete can be supplied in an infinite number of types, so it is important that the appropriate mix is ordered. Key aspects to consider when selecting concrete include strength grade, workability, maximum aggregate size and special properties if required.

Strength grade of concrete is defined in terms of megapascals (MPa) with structural grades ranging from 17.5 and 50 MPa for Normal concrete. Concrete supplied with strengths above 50 MPa is classified as being Special concrete:

- Grade 17.5–25 MPa – residential construction such as foundations and house slabs
- Grade 30 MPa – commercial construction where loading is relatively light
- Grade 35–40 MPa – industrial and some infrastructure projects
- Grade 45–50 MPa – large infrastructure or when exposed to severe exposure conditions
- Grade 55–65 MPa – large infrastructure that involves precast concrete

Workability is the amount of energy required to move concrete and is measured indirectly with consistence tests such as slump and spread. Slump is often specified by the engineer with following guidance in other cases:

- Slumps less than 40 mm – extruded or slipform concrete that needs to be very stiff with low workability
- Slumps of 50–100 mm – used when relatively stiff concrete is required such as casting on slopes
- Slumps of 100–140 mm – normal structural concrete used in slabs and beams
- Slumps of 140–180 mm – higher slump concrete for columns and walls or for improved pumpability
- Slumps above 180 mm – flowing concrete that is usually measured using the spread test
- Spreads of 500–700 mm – high flow concrete using for blockfill, tremie or self-compacting concrete

Aggregate size needs to be considered since larger stone sizes provide economic and technical benefits but there is a practical limit in most applications. The following guidelines apply when selecting the maximum aggregate size to be used in a concrete mix:

- Mortar mixes do not use coarse aggregate such that the maximum aggregate size in 5mm
- Micro-concrete used in specialist application and pumping down narrow lines use 8mm
- Many pump and self-compacting concrete mixes use 13 mm to improve workability

- Structural concrete mixes cast in open forms with low to moderate reinforcement use 19 mm
- Special applications like large mass concrete application using 25 mm or 37.5 mm aggregate

PRODUCTION AND DELIVERY

Once concrete has been ordered by the contractor, the required concrete must be produced at the ready-mixed concrete plant and delivered to site. Several protocols apply concrete production and delivery to ensure the supplied material is fit for purpose, consistent and can be safely handled.

CONCRETE PRODUCTION

Control of concrete production is undertaken by the Concrete NZ Plant Audit Scheme who ensure that procedures given in the concrete production standard are followed. Important processes that are monitored include the following:

- All material used to make concrete such as cementitious material, aggregates, water and chemical admixtures is regularly tested to ensure consistent properties
- Weigh scales and other measuring devices used in batching and testing concrete is routinely checked and calibrated for accuracy
- Batching of concrete is done to the required accuracy and a record of loaded weights is kept as evidence of compliance, which is referred to as the batch record
- Concrete is fully mixed at the plant to ensure optimum performance with mixing times for truck mixing being at least 70 revolutions at full mixing speed of 14-16 revolutions per minute
- Testing of concrete is undertaken at the plant for quality assurance purposes with test frequency being every 75 m^3 except for large plants when frequency can be reduced
- Concrete is dispatched with a delivery docket that provided details of the load being carried in the concrete in terms of volume and mix design details

DELIVERY REQUIREMENTS

To ensure everyone is free from harm and the environment is not affected by construction, the following delivery requirements need to be considered before delivery of concrete:

- Traffic management to ensure concrete trucks have a safe and legal area to park and discharge concrete
- Appropriate traffic management to avoid conflict with all road users that includes pedestrians using sidewalks passing the construction site
- Environmental management policy to prevent contamination on site or concrete trucks dragging contaminants off site when leaving
- Checking of approach distances from potential hazards such as power lines, towers, cranes or open trenches and foundations
- Reversing of trucks on to concrete pumps must be done using a spotter who is trained in the standard hand signals and there is good lighting for this to be seen
- Pumping of concrete is done safely and no blowback into concrete trucks is done unless using approved methodology

DOCUMENTATION

The delivery docket brought to site by the driver provides documentation for both the contractor and the ready-mixed concrete supplier:

- Contractor receives details about what was loaded into the truck, which may also include a running total of concrete supplied up to that delivery when dealing with large pours
- Ready-mixed concrete supplier returns with a copy of the delivery docket, which can provide useful additional information added by the driver such as any additional water added on site and the estimated final slump value

MIXING WATER

Using extra water over that designed to increase the slump of concrete is the most common problem affecting the quality of concrete. Extra water added on site may exceed the mix design and this will dilute the cement paste and reduce strength and durability of concrete.

PLANNING AND LOGISTICS

Planning plant operations involves coordination of logistics and technical issues that all affect performance that can be monitored and tracked. Details of these issues are given in Table 6.

Table 6: Planning plant operations and performance effects

Activity	Requirement	Planning & organisation	Performance Indication
Materials	Consistent supply within specification and good agg. moisture control	Regular sampling and testing of materials and fresh concrete	Consistent concrete supply in terms of low variability of slump and strength
Trucks	Enough trucks and drivers that are well maintained and correctly trained	Regular maintenance, driver training and good ordering & dispatch	Deliveries optimised to arrive on time with consistent concrete
Plant	Concrete plant well resourced, maintained to efficient production	Scheduled maintenance and scale checks and calibration on time	Reduction in production stoppages and limited material wastage
Testing	Accurate and honest representation of concrete production	Training of technicians, correct equipment and regular calibration	Lower cement contents, low CoVs and WTCoVs
Batching	Batches in consistently within tolerance of target quantities	Batcher training, good resources and good plant maintenance	Batch records controlled with low tolerances and fewer rejected loads
Slumping	Trucks released from the plant at the correct slump level	Slumping done by trained staff who receive feedback from testing staff	Site slumps are consistent with test slumps close to target values
Records	Clear batching, testing and delivering docket records are maintained	Staff understand the importance of maintaining good plant records	Batch records should be able to predict tested strength results

DOCUMENTATION

Concrete production involves a range of activities that when well documented can confirm concrete supply was done in accordance with the standard, NZS 3104. The following documentation is usually kept at the plant:

- Plant diary with weather conditions, any unusual issues from site or changes in materials such as moisture content of aggregates
- Orders and dispatch information is generally kept using electronic database systems, which provides evidence when there is a dispute about what concrete mix was ordered, volume and supply rate or special requirements such as testing
- Batch records for each load to confirm that concrete was supplied in tolerance of NZS 3104 and can be used to predict strength when there is an issue
- Delivery dockets stored at the plant with any additional information from the driver about site water addition or other concerns
- Test records of quality assurance and control of aggregates and concrete that were done at the plant or on site are retained and entered in a database for inspection by the plant engineer
- Scales check and calibration data for batching and testing equipment is kept in a file at the plant for easy inspection by the plant and auditing engineer

Understanding the importance of these records is crucial as many queries about the quality of concrete supply can be quickly addressed using this information. Electronic databases also allow better management of this data but much of the documentation is still paper-based.

7. CONTROL TESTING OF CONCRETE

TESTING PROCEDURES

Thousands of concrete mixes are produced at concrete plants around New Zealand and it is important that output from this production is measured and controlled. Testing is undertaken at the plant and on site to assess the following concrete properties:

- Slump or spread testing to assess the consistence (stiffness or sloppiness) of fresh concrete
- Yield testing that determines the volume of concrete supplied was not short
- Air content of fresh concrete, which is particularly important for air-entrained concrete
- Compressive strength of hardened concrete that is usually measured at 7 and 28 days and used to confirm the structural grade has been achieved

PLANT VERSUS SITE TESTING

Ready-mixed concrete is mostly sampled and tested at the concrete plant where the laboratory and testing equipment are based. Site testing of concrete is sometimes requested on site but this is more time consuming and less well controlled due to environmental and logistical issues. Two main types of testing are included in the results reported by ready-mixed concrete companies:

- Quality control testing that is mostly done randomly across production at the concrete plant and provides evidence of the production control and performance of individual concrete mixes
- Quality assurance testing that can be done at the plant or on site where tests are requested for specific concrete mixes going to projects

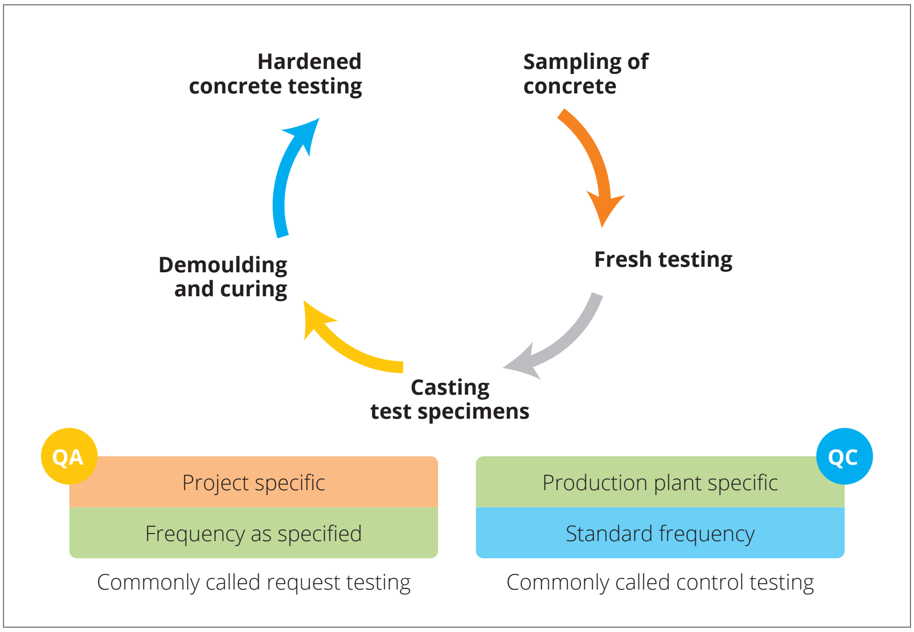


Figure 14: Quality assurance and quality control testing in practice

FREQUENCY OF TESTING

Test frequency is specified in the concrete production standard (NZS 3104). This is typically set at one test per 75 m^3 of concrete supplied but can be the frequency can be reduced for large concrete plants with annual production above 15000 m^3. This frequency of one test per 75 m^3 represents roughly one road tanker of Portland cement and one truck and trailer of each of the aggregate components used in a moderate grade concrete mix. Testing concrete more frequently than standard is costly and does not necessarily provide significantly more quality assurance.

SAMPLING OF CONCRETE

Test samples taken from a concrete mixer/truck represent an extremely small percentage of the total volume being typically less than one percent. It is important therefore that sampling is done accurately to ensure the test sample has properties similar with the bulk of the concrete supplied. Further the sampled load of concrete should be consistent with other loads of concrete supplied at the same time since only every 10-15 loads are tested. Two types of sampling of fresh concrete are routinely undertaken:

- Representative sampling usually done at the plant where three snatch samples are combined together in a wheelbarrow (see Figure 15 below)
- Snatch sampling usually done on site where a single sample is extracted using a bucket from the end of the chute or pump hose

Three different portions of the load are taken and combined together in a wheelbarrow

Procedure:

1. Discard any water contamination
2. Take first portion (roughly 9 L)
3. Remix concrete for 30 seconds
4. Repeat to get two more portions
5. Remix portions in the wheelbarrow

Alternatively, portions may be taken from different parts of discharge on site or using a scoop our of the truck.

First portion in wheelbarrow

Figure 15: Representative sampling of concrete

BATCH RECORDS

The weight of materials batched in each load is recorded at the concrete plant and these records can be used to confirm non-tested loads were consistent with tested loads. From these batch records the final water/cement ratio for each load can also be used to predict 28-day compressive strength.

FRESH CONCRETE TESTING

Testing of the fresh concrete properties is undertaken immediately after extracting a representative or snatch sample. Testing is done in accordance with NZS 3112 Part 1.

SLUMP TESTING

Slump testing determines the consistence of fresh concrete and is suitable for most concrete except dry mixes of less than 50 mm slump or high flow mixes where slumps in excess of 200 mm are expected. Using a clean and damp slump cone on a flat and vibration free surface, fill the cone in three equal volume layers. Each layer is tamped 25 times, spreading the blows evenly around and through the depth of each layer. After striking off the top surface and cleaning any spillage on the sides, the cone is lifted over two seconds to allow the concrete to slump. The cone is inverted, and the tamping rod used to the measure the distance to the highest point of the concrete, which is the actual slump recorded to the nearest 10 mm as shown in Figure 16. Concrete that shows unusual slump pattern such as shearing needs to be retested to confirm the slump.

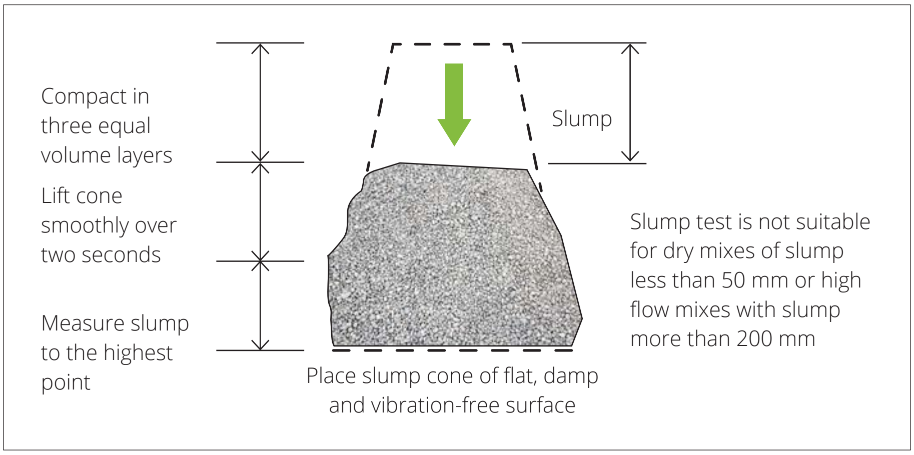


Figure 16: Slump testing of concrete

SPREAD TESTING

Spread testing is used to measure the flowability of high flow mixes such as blockfill, tremie and self-compacting concrete where slump testing is unreliable. The clean and damp slump cone is inverted on a flat and damp baseplate and filled by pouring in the high flow concrete without compaction. The cone is lifted slowly to a height of 50 mm to allow the concrete to flow out (see Figure 17). Measurement is made of two diameters at right angles to each other and the average diameter reported to the nearest 10 mm. During this test and assessment can also be made of the risk of segregation (visual stability index) and the plastic viscosity (T500 time).

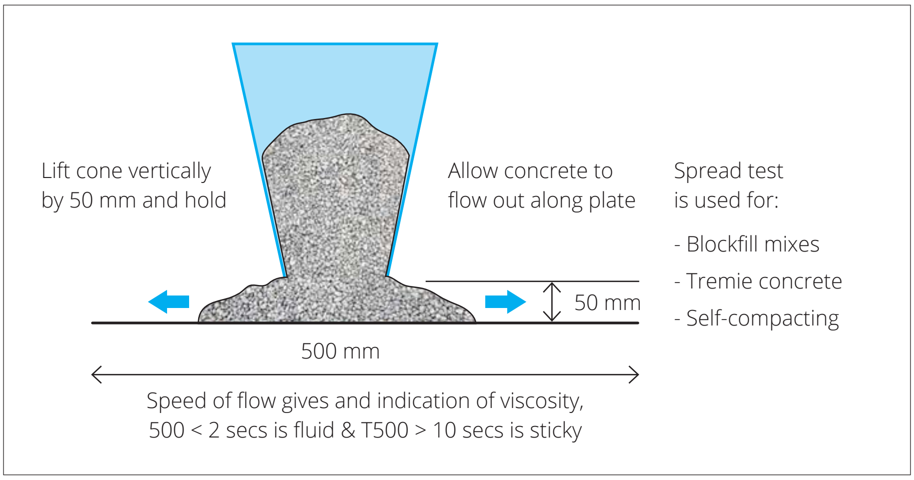


Figure 17: Spread testing of concrete

YIELD TESTING

Concrete is batched by weight but supplied by volume and so it is important to check that concrete mixes are not under-yielding in terms of volume. Yield testing confirms this by measuring the unit weight of fresh concrete using a standard container of known volume (shown in Figure 18). The clean and damp yield pot is initially weighed before being filled with concrete in three equal volumes. Each layer is fully compacted by rodding at least 25 times before tapping the sides of the container with a nylon headed hammer (typically 15-30 times depending on the workability of concrete). After carefully striking off the top surface to the level of the rim, the full container is reweighed so that the net weight of concrete can be determined. Knowing the weight and volume of concrete, the unit weight of the concrete is calculated and used to determine the actual yield (typically greater than 1.000).

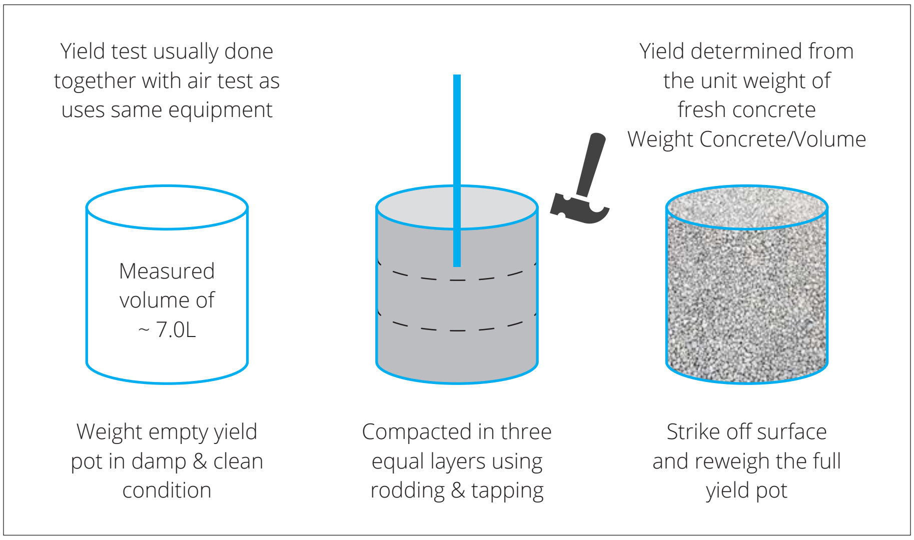


Figure 18: Yield testing of fresh concrete

AIR TESTING

Concrete used to determine the yield is then used for the air test that measures the volume of all entrapped and entrained air in a compacted sample of fresh concrete (shown in Figure 19). The standard method uses a pressure meter that is clamped on to the yield pot lid to form an air-tight seal. After replacement of all air above the concrete surface with water, a standard volume of pressurised air is released from the top chamber. The air gauge is calibrated to measure the change in pressure at the result of the concrete compressing and this is then read off the meter as the actual air content, which is reported to the nearest 0.2%.

Typically, air contents for non air-entrained concrete should be below 2% while air-entrained concrete typically have design air contents of 4-5%. Excessive air in concrete will reduce compressive strength with the rule of thumb being 1% excess air reduces strength by 5%.

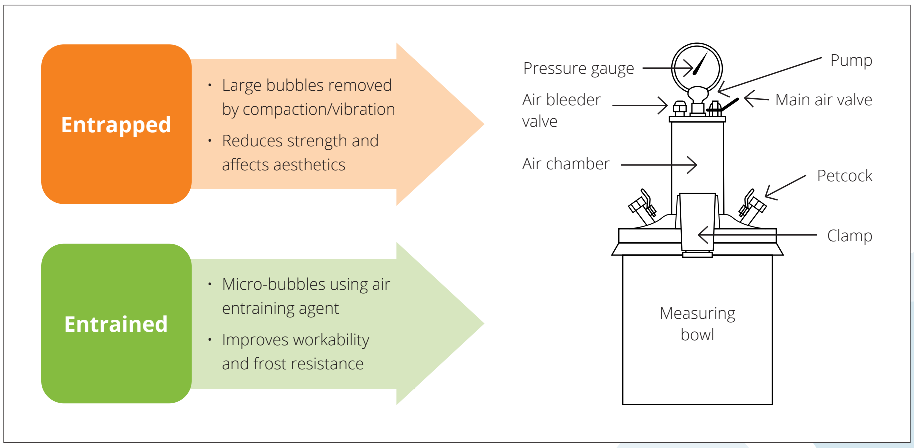


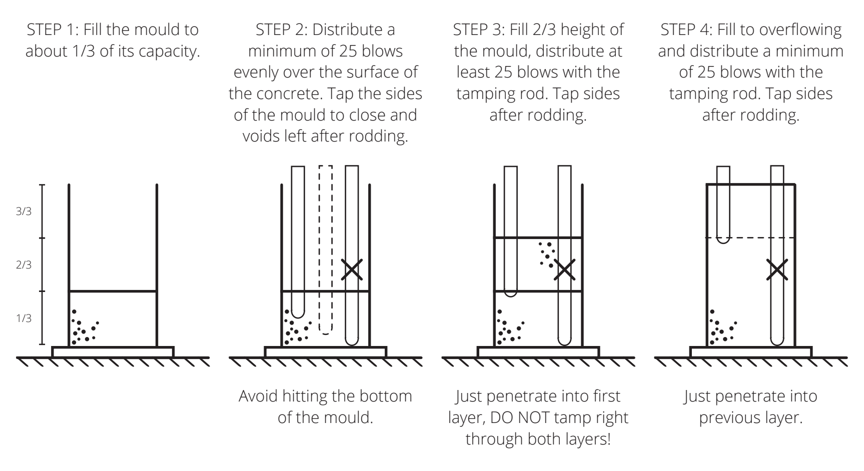
Figure 19: Air content testing of fresh concrete

HARDENED CONCRETE TESTING

Tests specimens for hardened concrete testing are taken from the sample of fresh concrete within 30 minutes. Remix the concrete sample before sampling to ensure no bleed water is on the surface.

MAKING TEST CYLINDERS

Test cylinders are made in accordance with NZS 3112 Part 1, which stipulates the required compaction and curing to produce consistent results. Normal concrete made with a maximum aggregate size of 19 mm is typically tested using 100 mm diameter by 200 mm high steel cylinders. Concrete is compacted in three equal layers using either a minimum rodding of 25 blows and tapping the side with a nylon hammer or by mechanical vibration using a vibrating table (Figure 7). Once the concrete has been fully compacted, the top of the cylinder is covered to prevent drying and the temperature controlled (laboratory at 21 ± 2 ^{0}C, site at 18 ± 8 ^{0}C). Concrete cylinders need to be demoulded after 18-72 hours and placed underwater in a curing tank or fog-room with temperatures maintained at 21 ± 2 ^{0}C until strength testing at 7 and 28 days.



STEP 1: Fill the mould to about 1/3 of its capacity.

STEP 2: Distribute a minimum of 25 blows evenly over the surface of the concrete. Tap the sides of the mould to close and voids left after rodding.

STEP 3: Fill 2/3 height of the mould, distribute at least 25 blows with the tamping rod. Tap sides after rodding.

STEP 4: Fill to overflowing and distribute a minimum of 25 blows with the tamping rod. Tap sides after rodding.

Avoid hitting the bottom of the mould.

Just penetrate into first layer, DO NOT tamp right through both layers!

Just penetrate into previous layer.

Figure 20: Casting and compacting test cylinders for compressive strength

CYLINDER MEASUREMENT AND HARDENED DENSITY

Concrete cylinders are taken from the curing tank at either 7 or 28 days and the dimensions, tolerances and weight recorded on a standard testing sheet. Cylinder measurements are as follows:

- Two diameters at mid-height are measured to determine the average diameter used to calculate the cross-sectional area
- The height of the cylinder is measured and used together with the average diameter to determine the volume, which is need together with the weight of the cylinder to determine the hardened density
- The weight of the cylinder is measured to determine the hardened density that provides useful information especially in cases of unusual strength results
- The squareness and flatness tolerances are checked on cylinder ends as well as any defects that should be less than 10 mm

Hardened density is always reported on test certificate since this provide valuable information that complements strength data as shown in Figure 8. The following information can be inferred when analysing hardened density data:

- Compaction and curing have been done correctly without excessive voidage that will reduce the density of concrete
- Water content of concrete is close to target as excess water will not only reduce strength but will also reduce density

- Correct concrete mix has been tested as each type of concrete has a unique density, which can be checked in cases where samples were accidentally switched
- Hardened density can provide evidence in cases where air entrainment is well above target levels and will complement visual evidence of excess air bubbles

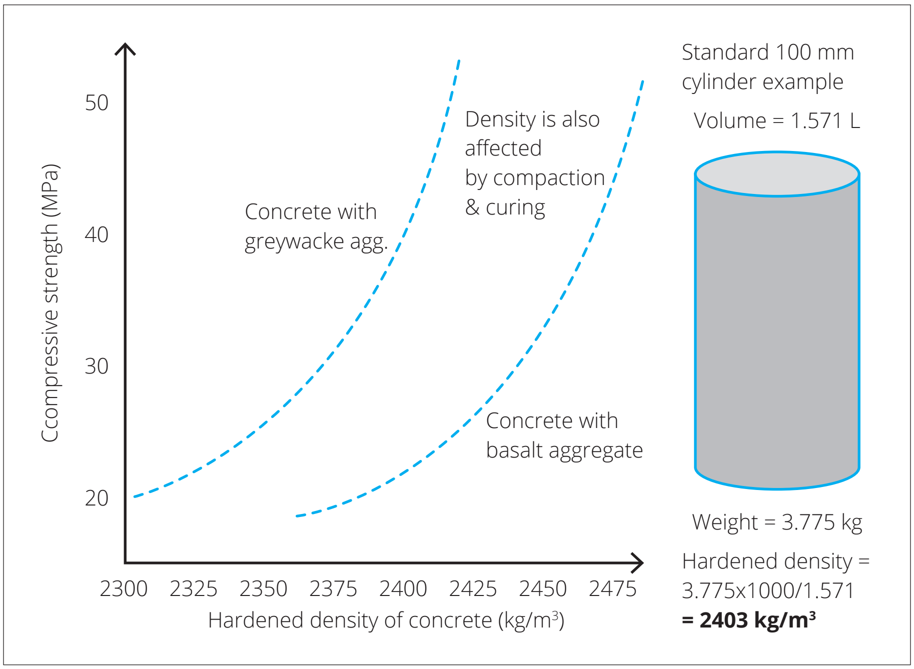


Figure 21: Hardened density of concrete and its relationship with compressive strength

COMPRESSIVE STRENGTH TESTING

Cylinders are tested for compressive strength at 7 and 28 days to confirm the structural performance of concrete. Test specimens are placed centrally in the compression testing machine and if the ends are sufficiently flat and square can be loaded directed with the steel platens (shown in Figure 9). In cases where the top of the cylinder is less precisely square and flat, a rubber cap restrained within a sub-platen should be used to ensure uniform loading through the specimen. Loading is done a standard rate of 10-20 MPa per minute until the cylinder has been crushed and the maximum load is recorded from which the compressive strength is calculated. Any unusual failure modes are also noted such as shearing, which could indicate incorrect test set-up or defective cylinders.

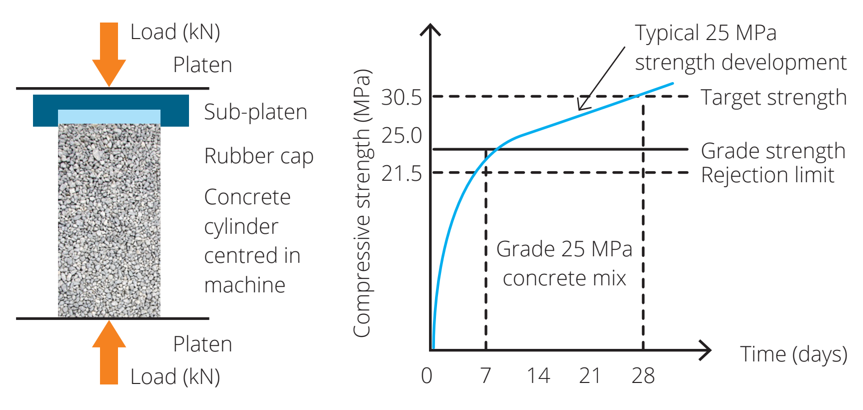


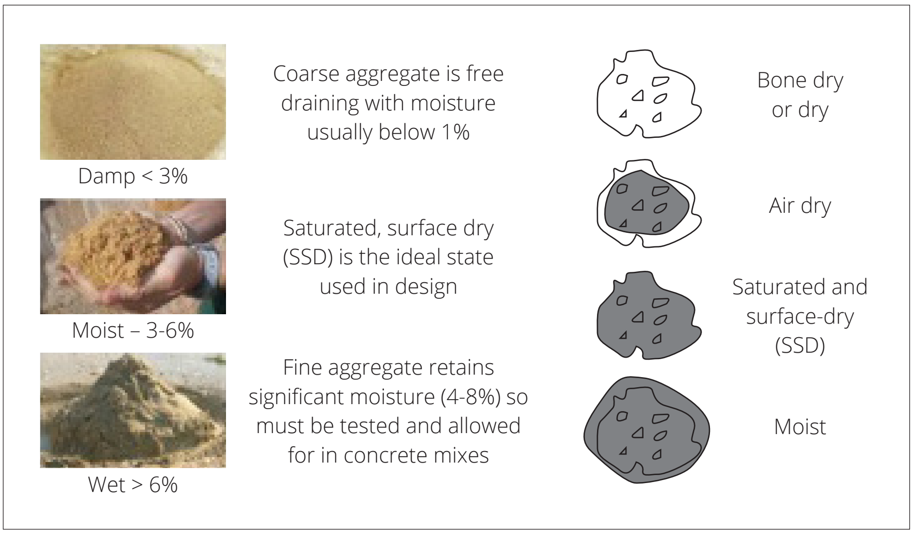
Figure 22: Compressive strength testing of concrete

Analysis of compressive strength is done by plant engineers responsible to each readymix concrete plant. The following checks are made when analysing compressive strength values that are reported weekly by the concrete technician:

- 7-day strengths are checked as an early warning of the likely 28-day compressive strength as typically this is approximately 75 percent of 28-day strength
- 28-day compressive strength is checked to confirm that it is above the grade strength and to take appropriate action should this be lower, especially if below the rejection limit, which is generally a very rare event in practice
- The variation of strengths within major series (e.g. 25 MPa 19 mm concrete) is assessed by calculating the standard deviation and from this the coefficient of variation can be determined (COV less than 10 percent generally indicated good production control)
- Testing control can also be checked by assessing the within test coefficient of variation calculated from the difference in strength between the high and low values used to calculate each average strength measured at 28-days

MOISTURE CONTENT OF AGGREGATES

Coarse aggregate is relatively free draining such that moisture contents generally below 1 percent and an estimation of the likely moisture content is generally accurate enough for concrete production. Fine aggregate retains more moisture with levels typically between 3-6 percent but may on occasions reach 10 percent. Measurement of moisture of fine aggregate can be done in the following ways shown in Figure 23.



Coarse aggregate is free draining with moisture usually below 1%

Saturated, surface dry (SSD) is the ideal state used in design

Fine aggregate retains significant moisture (4-8%) so must be tested and allowed for in concrete mixes

Figure 23: Moisture content and states of fine aggregates

OVEN-DRYING

The most accurate method of determining the moisture content of sand is using oven-drying in accordance with NZS 3111. This involves heating a small sample of material to 105 ^{0}C until constant weight and determining the moisture content from mass loss. The standard laboratory method involves drying for a period of 24 hours but increasingly more rapid assessment is done using hot plates and gas heating where moisture testing can be done within less than an hour. Typical sample sizes used for this testing is between 200-500 g and it is therefore important to have laboratory scales that can measure accurately with a resolution to a tenth of a gram.

MICROWAVE DRYING

Drying of sand samples can be done more rapidly by using a microwave in 5-10 minutes. Regular checking during the drying process as the sand will become very hot once the moisture is driven off and this can crack the container or the glass turntable. Recording moist and dry weight of the sand sample is similar with that used for oven drying using a laboratory scale that can weigh to one decimal place in grams.

DISPLACEMENT

When there is no oven available it is still possible to measure sand moisture content reliably. A volumetric displacement method is used with a one litre measuring cylinder and consists of the following:

- Fill a measuring cylinder to exactly 400 ml
- Add 1000 g of moist sand to the measuring cylinder
- Wait for a minute for the water column to settle
- Remeasure the meniscus level of the combined sample
- Read off moisture content to ± 0.5 percent from the chart

8. SPECIAL TESTING OF CONCRETE

Special testing covers other tests that are sometimes undertaken in concrete laboratories such as sieve analysis of aggregates, tensile strength testing and drying shrinkage.

SIEVE ANALYSIS OF AGGREGATES

Grading of fine and coarse aggregate is an important part of assessing the quality and consistency of material used in the production of concrete. Concrete mix designs require blending of fine and coarse aggregate components to produce a combined grading curve that has an even distribution of sizes to ensure good particle packing. This is shown in Figure 24 where a typical concrete mix with a maximum aggregate size of 19 mm is designed with two fine aggregate types (e.g. dune sand and PAP7 manufactured sand) together with two coarse aggregate sizes (e.g. 13 mm and 19 mm stone).

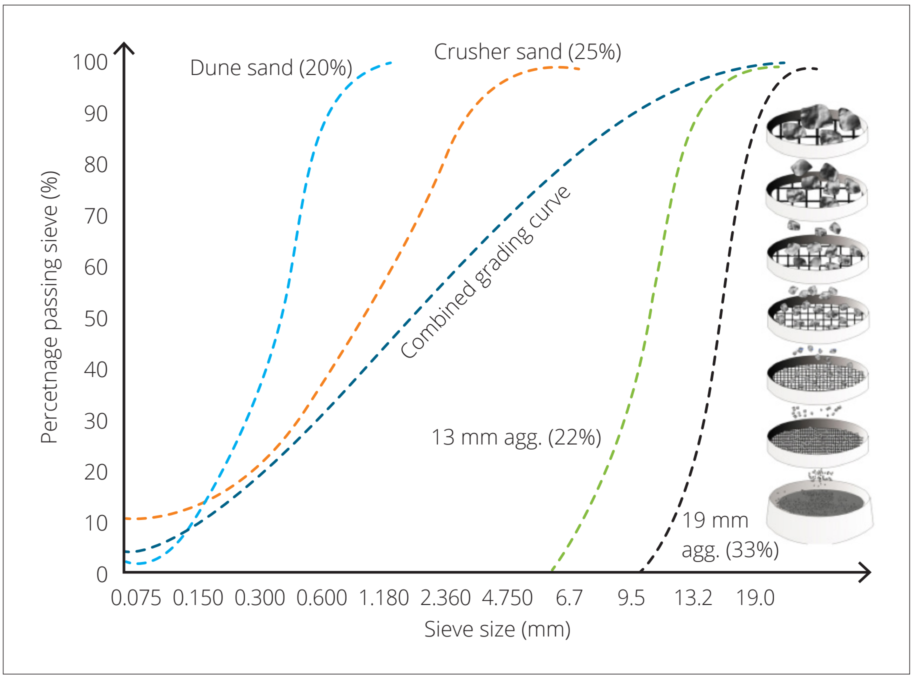


Figure 24: Aggregate and combined grading curve for typical 19 mm concrete mix

Each of these aggregate components needs to be supplied to an agreed grading, which then is tested during production at the quarry and during concrete production. This is done for quality control by the aggregate supplier and quality assurance by the concrete producer.

COARSE AGGREGATE GRADING

Testing of coarse aggregate grading is done in the following way (see also Figure 2):

- Sampling from stockpiles or conveyor belts in a representative manner, which typically means taking a reasonable sized sample of 4-10 kg
- The initial sample is then reduced by quartering or using a riffle box to produce a test sample with the maximum weight depending on sieve size (sieves are made with a diameter that range from 200-450 mm)
- Drying of the coarse aggregate is then done to ensure all particles are surface dry (this is done either in an oven or by air drying in the laboratory)
- The test sample is then loaded into the nest of sieves and shaken for a period of five minute either using a mechanical shaker or by hand. Standard coarse aggregate sieve sizes are as follows; 25.5mm, 19.0 mm, 13.2 mm, 9.5 mm, 6.7 mm and 4.75 mm with sizes is red being optional intermediate sieve sizes.

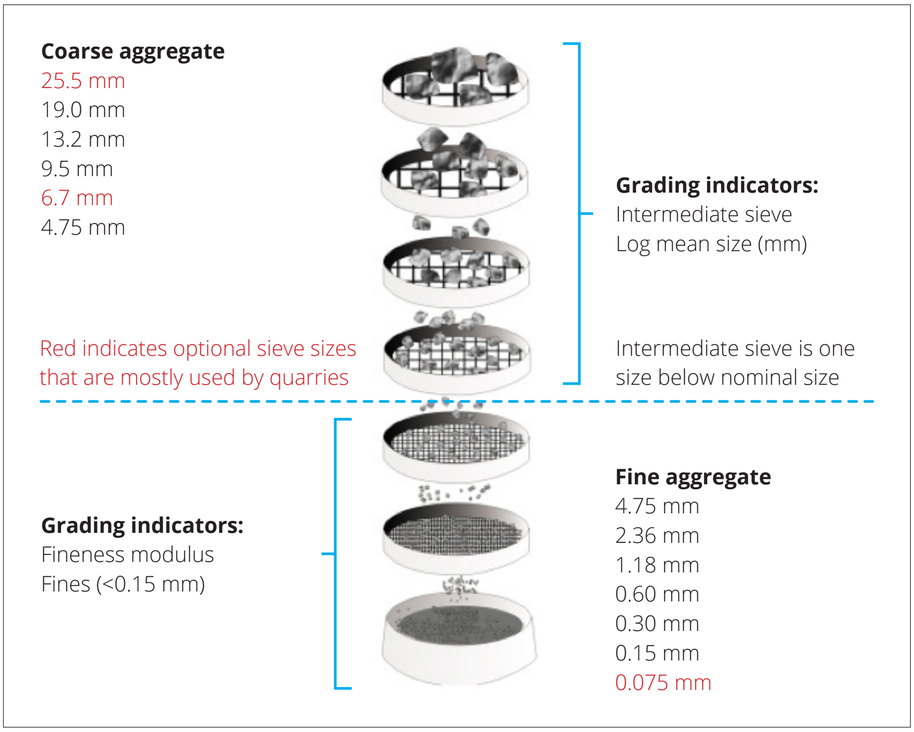


Figure 25: Grading of fine and coarse aggregates and analysis of results

FINE AGGREGATE GRADING

Testing of fine aggregate grading is done in the following way (see also Figure 2 above):

- Sampling from stockpiles or conveyor belts in a representative manner and is usually done with a sampling tube that extracts multiple small samples to produce a total sample of approximately 1 kg
- The damp sample is then reduced to 200-250 g by quartering the initial sample to produce a test sample that is generally tested with 200 mm diameter sieves
- The damp sample is then dried in an oven and the moisture content can be recorded and reported as part of the grading analysis
- The dry test sample is then loaded into the nest of sieves and shaken for 10 minutes using a mechanical shaker. Standard fine aggregate sieve sizes are as follows; 4.75, 2.36, 1.18, 0.60, 0.30 and 0.15 mm and sometime the 0.075 mm sieve is added to check the proportion of fine particles

ANALYSIS OF AGGREGATE GRADING RESULTS

Once the aggregate sample has been graded the results of each individual test can be compared against previous results and with the target range that is either given in NZS 3121 or specified in the supply agreement. Grading of aggregate can also be analysed by determining the following indicators of grading:

- Fineness modulus (FM) is determined from the percentage passing the six sieves used for grading fine aggregate and is a measure of the fineness or coarseness of sand (e.g. FM less than 2.0 is fine while FM of greater than 3.0 is coarse)
- Fines content of sand is defined as the proportion passing the 0.15 mm sieve and typically this should be between 5-10 percent on the blend of fine aggregate
- Percentage passing the intermediate sieve size is used by auditing engineers to determine the consistency of supply of coarse aggregate (e.g. for 19mm aggregate this would be the 13.2 mm sieve)
- Log mean size (LMS) is a statistical index that is used for coarse aggregate and is equivalent to FM used for fine aggregate and provides an indication of average size (e.g. 19 mm aggregate has a target LMS of 16 mm while 13 mm aggregate has a target LMS of 10 mm)

TENSILE SPLITTING STRENGTH

Tensile strength testing of concrete is undertaken in specific cases where unreinforced concrete is required to provide resistance to bending that produces tension within the material. Tensile splitting strength is a relatively simple method of indirectly determining the tensile strength of concrete, which is typically only 10 percent of its compressive strength (e.g. 30 MPa concrete may have a tensile splitting strength of 3.0 MPa). The testing set-up for this test is shown in Figure 3.

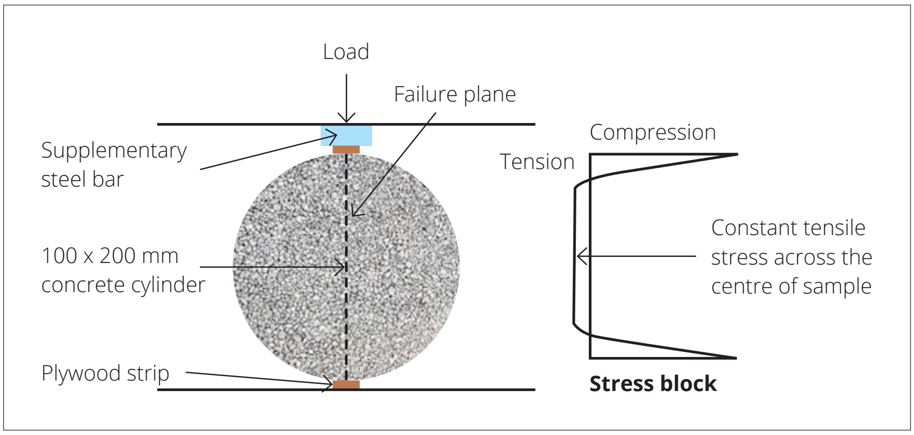


Figure 26: Testing set-up for tensile splitting strength measurement

Testing methodology for tensile splitting strength is as follows:

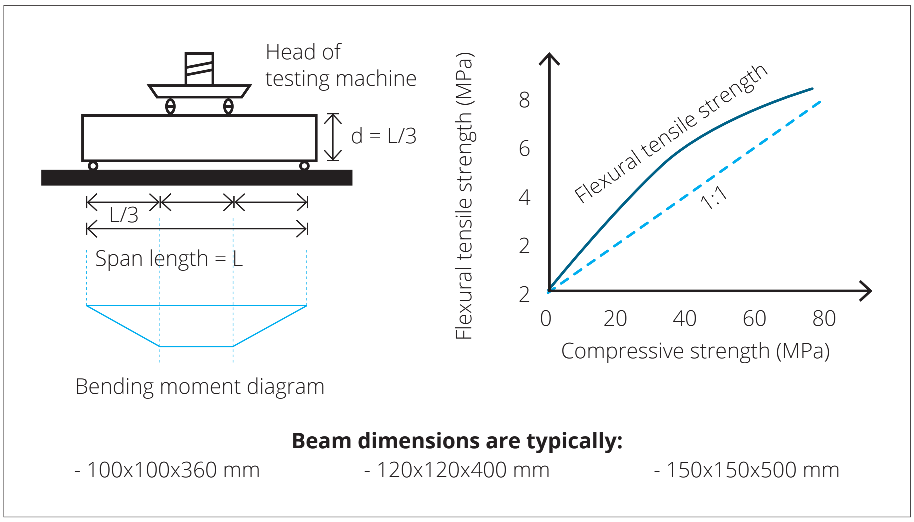
- Standard concrete cylinders of 100 mm diameter are extracted from the curing tank and weighed and measured as per compressive strength testing
- Testing should be done on smooth sides of the cylinder and it is important to avoid seam lines or ridges left from the steel mould
- Test cylinders are placed in a testing jig that allows the specimen to be held in position lying along its length while timber strips are placed on the top of bottom together with the supplementary steel bar
- The test set-up as shown in Figure 3 is centred in the compression testing machine and the top platen lowered carefully until in contact with the steel bar
- The test cylinder is then loaded at the standard load rate of 1-2 MPa per minute, which equates to 32-64 kN per minute until the sample splits and the maximum load is recorded
- Splitting of the concrete cylinder should be directly through the centre to produce two halves with only some minor crushing at the surface
- The tensile splitting strength is calculated from the maximum load and for 100 mm cylinders equates to 0.0318 times the load

Testing of tensile splitting strength is done in accordance with NZS 3112 Part 2 Section 8, which provides details of all aspects of the testing and analysis.

Note that tensile splitting strength produces lower strength values than tensile flexural strength testing where beam samples are used. The size of the test sample also has a slight effect with 100 mm diameter samples producing higher strength values than 150 mm diameter samples. Tensile strength also develops at a different rate to compressive strength such that 7-day strengths are typically above 80 percent of the 28-day strength whereas for compressive strength the ratio is lower at approximately 75 percent.

FLEXURAL TENSILE STRENGTH

Many projects specify flexural tensile strength testing also referred to as modulus of rupture testing where unreinforced concrete beams are tested in flexure. The test consists of a rig with two sets of steel rollers on the top and bottom of the beam that induces third point loading along the length of the beam. The testing set-up for measuring flexural tensile strength is shown in Figure 27 below.



Beam dimensions are typically:
- 100x100x360 mm
- 120x120x400 mm
- 150x150x500 mm

Figure 27: Testing set-up for flexural tensile strength

Testing procedure for determining the flexural tensile strength of concrete is as follows:

- Beams used for this testing are cast, compacted and cured in the same manner as cylinders used to test compressive strength
- Typically, the test specimens are 100x100x360 mm beams that are placed into a testing rig with the bottom rollers set at 300 mm apart while the top rollers are 100 mm apart
- Once the beam is centred within the testing machine the top platen is lowered until contact is made with the testing rig
- Loading of the beam is undertaken at 1-2 MPa per minute and this is maintained until the beam breaks and the maximum load is recorded
- The flexural tensile strength is then calculated from the maximum load that was applied to the beam (formula is given here)
- Failure should occur within the central third of the beam where the maximum bending moment is applied to the material and a correction must be applied if this is not the case

Testing of flexural tensile strength is done in accordance with NZS 3112 Part 2 Section 7 which provide details of all aspects of the testing and analysis. What is not emphasized but has a major influence of the quality of this testing is the following:

- Beam samples need to be cast in rigid and dimensionally accurate mould to ensure all surfaces are square and flat to allow good load transfer when under testing
- Handling of beams during the first few days as concrete may be easily damaged that can adversely affect the measured tensile strength

DRYING SHRINKAGE OF CONCRETE

Testing for drying shrinkage of concrete is done in accordance with AS 1012.13, which involves specialist equipment in material testing laboratories. The testing procedure consists of cast concrete prisms that are initially cured in water for 7-days before being exposed to a standard drying regime for 56-days during which time regular measurements are made of shrinkage. This requires precise measurement of shrinkage down to one micron that requires expertise in undertaking these readings. A summary of drying shrinkage equipment and typical test results are shown in Figure 5.

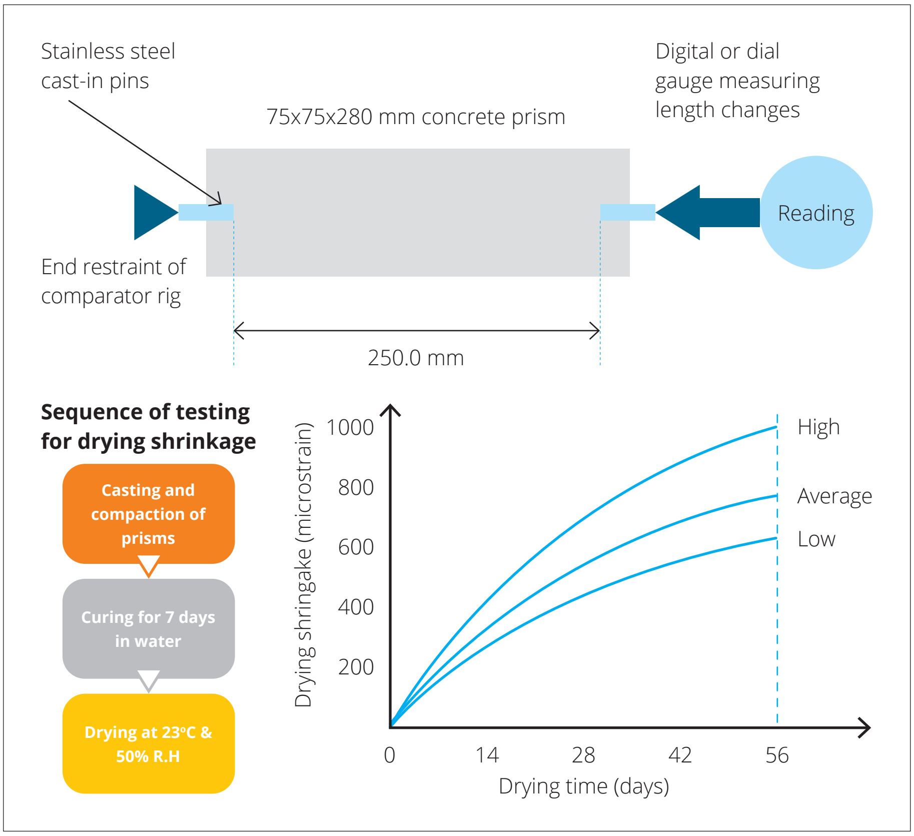


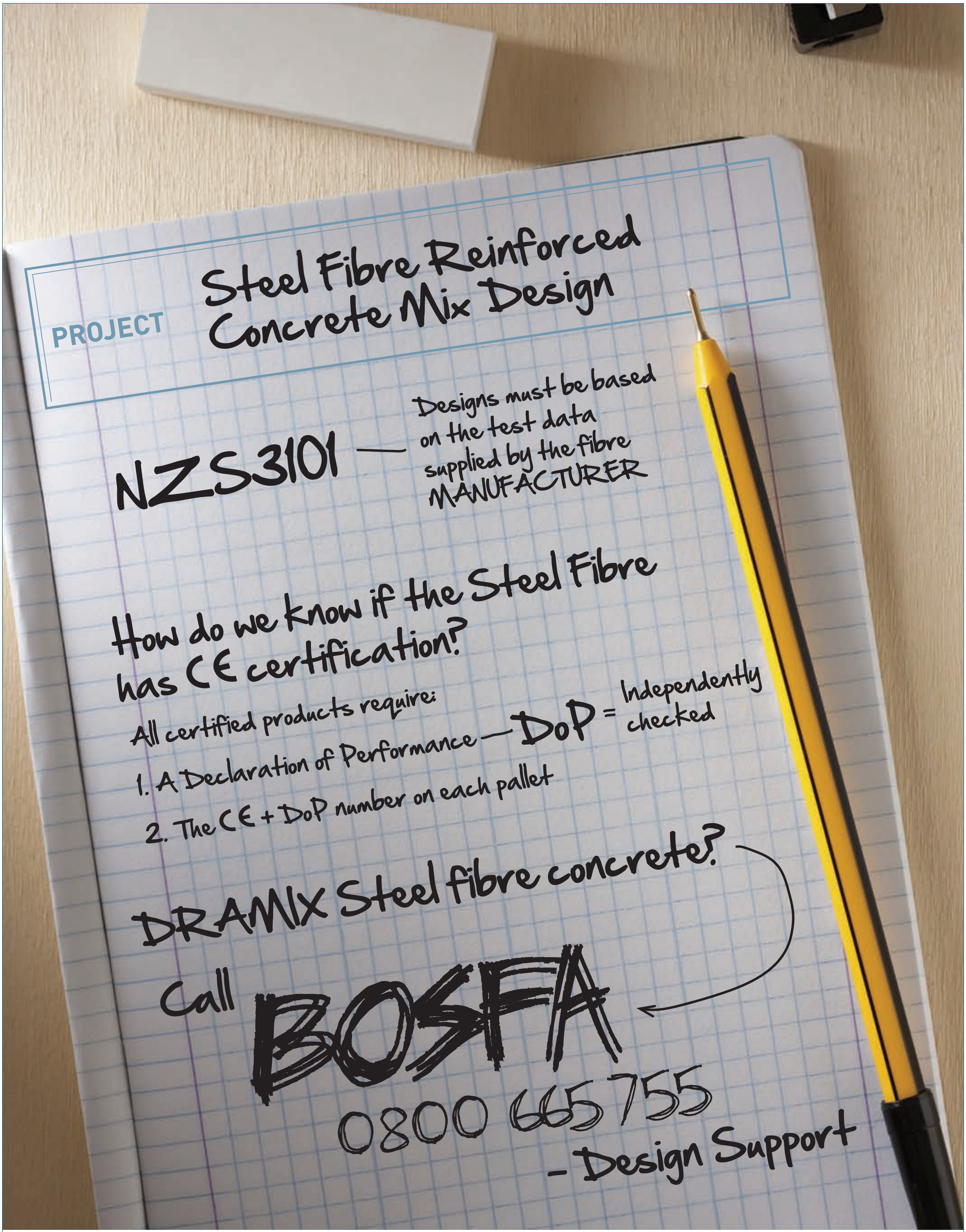
Figure 28: Testing methodology for measuring drying shrinkage of concrete

Drying shrinkage testing of concrete is done as follows:

- Dedicated moulds are used to cast three concrete prisms per concrete sample with stainless steel pins cast into the concrete to ensure an exact gauge length of 250 mm
- Concrete to be tested is cast into an oiled mould and compacted as per cylinders before being stored overnight at a constant temperature of 21 ± 2 ^{0}C
- After 24 hours the concrete prisms are demoulded carefully and stored in water at 21 ^{0}C to gain strength before exposure to drying
- Before drying starts the concrete prism is removed from the curing tank, surface dried and the initial length measurement is made on the comparator at a constant temperature of 23 ^{0}C
- Concrete prisms are then placed in a drying cabinet where the environment is controlled at a temperature of 23 ^{0}C and humidity of 50 percent R.H.
- At weekly intervals, the concrete prisms are removed from the drying cabinet and length readings are made at a constant temperature of 23 ^{0}C
- Drying shrinkage is calculated by subtracting the reading at each drying time from the initial reading before drying started and reporting this as micro-strain (change in length over gauge length multiplied by 1000)

The most important drying shrinkage value is that recorded after 56-days with average values being approximately 750 micro-strain. It should be noted that drying shrinkage of concrete measured with this test is significantly higher than that found in typical structures since the drying rate is more severe than ambient and the size of prisms is smaller with a cross-section of 75 mm by 75 mm.

NOTES



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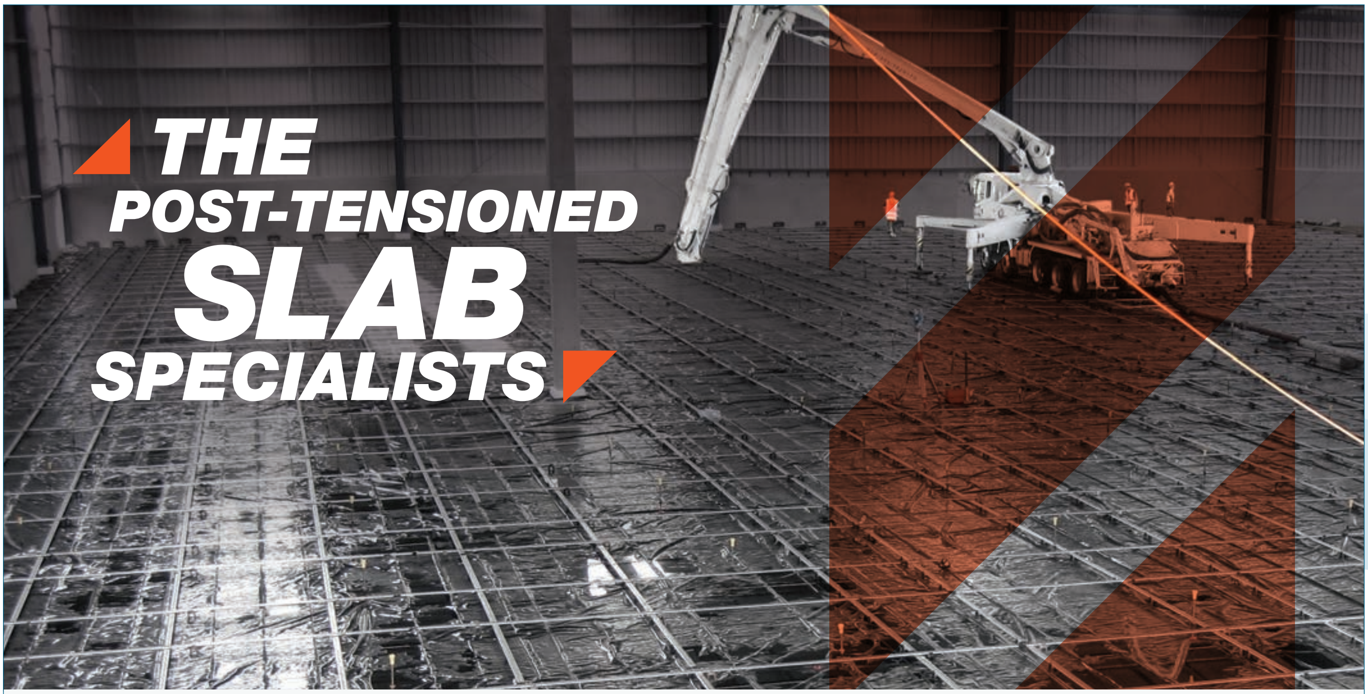
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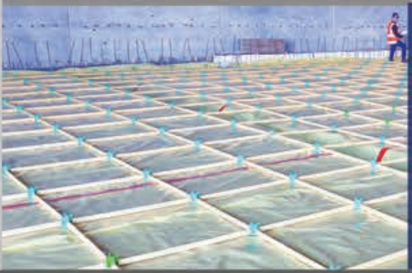

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