Practice Note 05

Low Carbon Concrete (Material)

Supplement of Engineering Design Code

Edition 1, April 2025

Summary

The Practice Note (PN) provides guidelines to the concrete mix designer to supply low- carbon concrete mix to be used in Auckland Transport concrete works.

This PN has been developed because the current standards that are in use for the Auckland Transport concrete works such as Transport Design Manual (TDM), Engineering Design Code (EDC) and AC Code of Practice for Land Development and Subdivision (AC CPLDS) do not include the Low Carbon Concrete mix requirements in sufficient detail. In addition, the PN enables compliance with AT's Sustainability Strategy 2024-2031 objectives to reduce embodied emissions attributed to infrastructure construction and maintenance by half, relative to 2021-22 (to attain the climate change goal of a low-emissions transport system).

Embodied carbon emissions refer to the total emissions caused by the extraction, manufacture and supply of construction products and materials, as well as the construction, maintenance, and end-of-life disposal processes. AT is supporting the use of low-carbon concrete where the new material achieves equal or better performance than standard concrete. AT uses the Project Emissions Estimation Tool (PEET) for quantifying and evaluating performance of embodied emissions of transport infrastructure that AT develops and maintains. AT encourages 25% minimum target reduction of CO_2 in the Low Carbon Concrete mix to satisfy the baseline Global Warming Potential (GWP), published in Building Research Association of New Zealand (BRANZ) Research Publication CO2NSTRUCT V3. AT recognises that there are different pathways to achieving the lower carbon emissions goal, including the use of renewable electricity during cement manufacture, recycled aggregates as well as Supplementary Cementitious Materials (SCM).

This Practice Note supports the use of SCM to produce Low Carbon Concrete by specifying maximum GWP performance requirement for concrete measured in $kgCO_2e/m^3$ of concrete. The SCM's included in the PN are Fly Ash (FA), Ground Granulated Blast Furnace Slag (GGBFS), Micro silica (MS) and new SCM's found based on the research. In considering the alternative binder types to achieve low carbon concrete, some concrete mixes will require longer curing regimes than currently specified in the relevant standards for cement only binder concrete. Appropriate accelerated curing process using admixtures may be employed at the discretion of the AT's nominated construction reviewer.

Furthermore, the Practice Note includes minimum concrete testing requirements, documentation requirements, certification requirements from the concrete mix supplying company, prepared in discussion with concrete industry experts. The concrete supplier shall assume responsibility of the mix designs and their properties.

An approval must be obtained from the Transport Design and Standards Manager and the Chief Scientist, in case the supplied concrete does not meet the requirements of this Practice Note.

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1. Introduction

Concrete is one of the carbon-intense materials Auckland Transport (AT) uses for the development and maintenance of the network. Approximately 80% of carbon in concrete is associated with cement. Most carbon emissions from concrete come from the manufacture of cement. One of the simplest and most impactful ways to reduce the embodied carbon is by changing the concrete material specifications, i.e., specifying low carbon concrete with low carbon cement, reduced cement or both, noting that Building Code requirements are still to be met. Reduction in cement usage in concrete can be accompanied by specifying concrete with lower up-front carbon. Low carbon concrete may result in the use of Supplementary Cementitious Materials (SCM). It is recommended that low carbon concrete is specified by performance specification, i.e., by specifying a maximum Global Warming Potential (GWP) performance requirement for concrete measured in $kgCO_2e/m^3$ of concrete. While there is a multitude of factors that contribute to the final concrete Global Warming Potential (GWP), cement is the largest factor. Branz research provides GWP (kg CO_2 e/m^3) for different concrete strengths, which will be used as the reference baseline in the PEET tool that AT adopts for quantifying and specifying the performance requirement of Low Carbon Concrete supported by testing and documentation requirements.

Specification of low carbon concrete in this Practice Note (PN) applies to Concrete works covered by:

- the Land Development Engineering Approval (EA) process (unless noted otherwise).
- any AT approved works programme or project involving upgrading and redevelopment of road infrastructure works (unless noted otherwise).
- third party developed roads and other infrastructure to be vested to AT (unless noted otherwise).
- retrofit alteration of raised safety platforms (RSP) that are considered high priority due to risk to road users (unless noted otherwise).
- any other Auckland Council (AC) or AT approval process which involves concrete.

in a manner that:

- All infrastructure complies with AT's and AC's safety requirements.
- Transport infrastructure complies with AT's Transport Design Manual requirements.
- Implementation comes into effect immediately on the signed date shown at the end of this PN.

This Practice Note applies to any placement of concrete for AT related works.

2. Scope

This Practice Note applies to:

- All AT projects initiated after implementation of this PN.
- All Consents or EAs lodged after implementation of this PN.

- Any AT project commenced but not yet constructed or any Consent or EA lodged with Auckland Council:
  - If the Manager – Design & Standards considers that an issue would arise if the design were not changed -where substitution of standard concrete for a low carbon alternative can achieve the same specification.
  - and if it is practicable to change the design prior to construction
  - and the cost of changing the design can be agreed to.
- Any review of the application of concrete.

3. Concrete Constituents

The main constituents of concrete are cement, aggregates and water. Concrete that can provide high durability performance is characterised by having high strength which generally means a relatively high cement content (with certain percentage of SCM) and a low water/cementitious ratio. These characteristics impart properties of low porosity and low permeability which are conducive to preventing aggressive fluids from entering concrete and reacting with components of cement paste or embedded reinforcement steel. It has been documented in the literature that use of SCM's as partial cement replacements improves durability performance, examples include:

- The use of SCM's can provide high durability performance through creating additional resistance to chloride ion penetration (chloride ions penetrating the body of the concrete build up to a concentration which initiates corrosion on embedded reinforcement and initiates corrosion).
- The use of SCM's can provide high durability performance through increasing concrete sulphate resistance (Sulphate attack causes concrete to disintegrate and concrete to crumble).
- The use of SCM's can lower the drying shrinkage of concrete.
- The use of SCM's can lower the heat of hydration.
- The use of SCM's can mitigate the likelihood of Alkali Aggregate /Alkali Silicate Reaction

The following approaches are required for selecting any new SCM as a partial replacement to the cement, to produce Low Carbon Concrete.

- Environmental Impact Assessment;
- Embodied carbon emissions (25% minimum target reduction of CO_2);
- Supply chain details;
- Recyclable/reusable opportunities;
- Trial/Testing requirements;
- Performance verification to comply with relevant standards.

In addition to or in substitution for the provisions of the relevant NZ Standards, the following requirements shall apply to the concrete constituent materials.

3.1 Cement

Portland cement is a fine powder of calcium silicate anhydrite made by firing limestone (calcium source) with clay or shale (silica source). In New Zealand there are two types of Portland cement commonly used, General Purpose (GP) cement and High Early Strength cement.

General Purpose cement is used for most in-situ applications and shall comply with NZS 3122.

The contractor shall advise the Engineer to the works in writing which brands of cement they intend to use for the various types of construction in the works. Generally, only one brand of cement shall be used for the same structure to maintain uniformity of colour and to establish undivided responsibility for cement quality. No change in the brand of cement used shall be permitted without the prior written approval of the Engineer to the works

3.2 Supplementary Cementitious Materials (SCM)

Supplementary cementitious materials (SCM) including Fly Ash (FA), Ground Granulated Blast Furnace Slag (GGBFS) and Micro Silica (MS) shall comply with the relevant part of AS/NZS 3582.

3.2.1 Fly Ash (FA)

Fly ash is a pozzolanic by-product from the combustion of coal e.g. coal-fired power plants. According to Concrete Production Guide for NZ by Concrete NZ, the dosage of FA shall be between 25-30 percent. Higher percentages of fly ash have been known to reduce carbonation resistance of concrete.

The use of fly ash as a partial cement replacement material in concrete results in significantly improved durability performance of the concrete-relative to cement-only concrete. Fly ash considerably improves the workability and pumpability of plastic concrete.

FA shall be supplied and tested in accordance with AS/NZS 3582.1.

3.2.2 Ground Granulated Blast-furnace Slag (GGBFS)

Ground Granulated Blast-Furnace Slag is a waste material separated from metals during the smelting or refining of an ore in a blast furnace. To be of value as cementitious material (iron) blast furnace slag needs to be appropriately processed to create a product with the necessary performance and consistency. Specifically, the (iron) slag must first be quenched to form slag granulate -a glassy mineral product and then the granulate is milled to cement like fineness in a cement mill creating Ground Granulated Blast Furnace Slag (GGBFS). The glass content is a significant contributor to GGBFS reactivity and is a function of the efficiency of the granulation process.

According to Concrete Production Guide for NZ by Concrete NZ, the dosage rates shall be 50-65 percent, the highest compared to the other SCMs. There is some concern related to reduced carbonation resistance at replacement levels above 50%.

The use of GGBFS as a partial cement replacement material in concrete results in significantly improved durability performance of the concrete relative to cement only concrete.

GGBFS shall be supplied and tested in accordance with AS/NZS 3582.2.

3.2.3 Micro (Amorphous) Silica (MS)

Silica is a very fine pozzolanic material comprised mostly of amorphous silica produced by electric arc furnaces; a by-product derived from the processing of silicon metal or ferro-silicon alloys. According to Concrete Production Guide for NZ by Concrete NZ, the dosage rates shall be about 5-8 percent. Micro Silica (MS) imparts high strength and improves durability characteristics. Mixes with MS are very sensitive to curing regime and higher dosages might lead to shrinkage issues.

Australian Standard AS/NZS 3852.3 defines the various amorphous silica SCM's as Amorphous Silica and Pumice.

Typically, MS is used for the primary purposes of obtaining high strength and superior durability performance in concrete, including where low heat concrete is required.

MS shall be supplied and tested in accordance with AS/NZS 3582.3.

3.2.4 Other SCMs

As the market grows, there will be more opportunities around other SCMs as a substitute for cement. Use of potential new SCMs (for example, Natural pozzolans) should be considered after rigorous scientific, laboratory and field performance evaluation in accordance with the standard SCM and concrete testing methodology as generally adopted in NZ. The process of considering new SCMs should follow the approach mentioned in Section 3 of this PN and must be approved by Manager-Transport Design and Standards, and Chief Scientist.

3.3 Aggregates

Aggregates make up more than 70 percent of the volume within concrete. Coarse aggregate is graded with common sizes of 19mm, 13mm and 8mm with stone being either crushed from hard rock quarries or being rounded from alluvial sources. Fine aggregate, commonly referred to as sand, 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. As sand is not free draining, it is important to ensure the material is not contaminated with silts, lightweight particles, or other deleterious materials. Proportioning of fine and coarse aggregate is done during the mix design process to achieve the optimum combined grading.

Fine and coarse aggregate shall conform to the requirements of NZS 3121. Aggregates shall contain no organic impurities when tested in accordance with NZS 3111, Section 17.

If the aggregates used have a potential to react expansively with cement alkalis, the reactive alkali in the concrete mix shall not exceed 2.8 kg/m^3. Determination of total reactive alkali content shall be in accordance with Concrete NZ *Technical Report 3 (TR3) Alkali Silica Reaction: Minimising the Risk of Damage to Concrete: Guidance Notes and Recommended Practice*.

The Contractors mix design shall state if the aggregates used have a potential to react expansively with cement alkalis.

No change in the source of supply of aggregate shall be permitted without prior approval of the Engineer to the works. The Engineer to the works may order sampling and testing of aggregate to be carried out by an independent testing laboratory. In the event of unsatisfactory performance, the cost of testing shall be borne by the Contractor.

Furthermore, it needs to consider the unintended environmental consequences (e.g. use of plastic as an aggregate substitute will not likely be supported by AT), origin and end of life of the material.

3.4 Water

Water is required for hydration of 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. 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.

Water used for making concrete shall be free from visible contamination like oil or organic matter and shall comply with the requirements of NZS 3121.

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 be fresh potable water or recycled water from washing out of mixer bowls, which can be slurry or clear recycled water. Where it is intended to use recycled water from within the batching plant to produce concrete, its use and quantity of use shall be identified in the mix design.
Site water addition can be made to concrete before discharge but clear protocols for when this is allowable as outlined in NZS 3109 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.

3.5 Admixtures

Admixtures added to concrete can enhance performance and meet the specific needs of different construction projects. Provisions on Admixtures shall apply as per NZS 3109 and NZS 3104. Where admixtures are accepted, they shall comply with AS 1478 and shall be used in accordance with the manufacturer's instructions.

In considering the alternative binder types to achieve low carbon concrete, some concrete mixes will require longer curing regimes than currently specified in the standards for cement only binder concretes. Appropriate accelerated curing process by use of admixture may be employed at the discretion of AT's nominated construction reviewer. Nevertheless, the concrete producer shall assume responsibility of the suitability, quantity and performance of any admixture used in the mix.

3.6 Chlorides

Provisions on Chlorides shall apply as per NZS 3109**.** The use of calcium chloride in any concrete shall not be permitted. The use of unwashed beach sand shall not be permitted.

3.7 Sulphate

Provisions on Sulphate shall apply as per NZS 3109.

4. Concrete Mix design

The concrete supplier shall be responsible for the design of all concrete mixes and shall undertake acceptance testing and on-going compliance testing to comply with the requirements of NZS 3104 and this Practice Note.

The concrete mix design details shall be submitted to the designer appointed by Auckland Transport for review and make sure that requirements of Practice Note are met at least two weeks before concrete supply commences.

The following mix details shall be supplied in writing:

- Specified compressive strength of concrete and grade.
- Nominated slump.
- Batch weights of cement and aggregates.
- Total amount of water in mix.
- Water/cement ratio by weight.
- Name and quantity of any admixture.
- Source and type of cement and aggregates including sands.
- Where appropriate, either for ready mix concrete plant: current grading certificate from the NZ mix concrete association; or for other concrete-the supporting data as required by NZS 3104 to show the concrete production facility grading.
- Total alkali content and total chloride content in kg/m^3, and sulphate content expressed as a percentage by mass of acid soluble $S0_3$ to mass of cement.

The Low Carbon Concrete is specified by specifying the maximum Global Warming Potential (GWP) performance requirement for concrete measured in $KgCO_2e/m^3$ of concrete. Specifying a requirement for suppliers to demonstrate the GWP via Quality Assurance documentation.

AT adopts the Project Emission Estimation Tool (PEET) to evaluate embodied carbon performance. The PEET tool uses updated values of GWP from different sources of emissions. The PEET tool uses the following (embodied Carbon $kgCO_2e/m^3$) for different concrete strengths as per Branz's research.

The typical baseline Global Warming Potential (GWP) values for the in-situ no reinforcement concrete mix, as published in the BRANZ Research Publication are included in Table 4.1.

The GWP values with CO_2 reduced by 25% of the baseline GWP as target reduction for AT projects are included in Table 4.1.

Table 4.1 Baseline GWP and AT Target GWP

Concrete Strength	20MPa	25MPa	30MPa	35MPa	40MPa	45MPa	50MPa
Baseline GWP $kgCO_2e/m^3$	265	291	321	361	417	441	494
AT Target-GWP $kgCO_2e/m^3$	198	218	240	270	312	330	370

AT promotes efficient equipment/ technology for the production and supply of concrete. Concrete mixer trucks and equipment based on electrical energy have already been introduced in the concrete industry. To further reduce emissions associated with concrete, the construction industry should prefer electrical energy instead of fossil fuel-based equipment for the production and supply of concrete to AT's projects.

5. Concrete Testing Requirements

Testing of ready mixed concrete shall be carried out to assess the following:

- Slump to assess the consistency of concrete.
- Compressive strength of hardened concrete that is usually measured at 7 and 28 days (NZS 3112 part 1).
- Quality control testing (provides evidence of the production control and performance of individual concrete mixes).
- Flexural tensile strength test (modulus of rupture test) done in accordance with NZS 3112 part 2 of section 7
- Splitting tensile strength test (required for unreinforced concrete to assess resistance to bending) done in accordance with NZS 3112 part 2 of section 8
- Drying shrinkage testing done in accordance with AS 1012.13.
- Hardened concrete density testing.
- Aggregate grading to comply with target range given in NZS 3121.

Frequency of testing is specified in the concrete production standard NZS 3104. Concrete mix design confirmatory tests, control tests and their evaluation shall comply with the requirements stated in NZS 3104.

6. Documentation Requirements

Concrete production involves a range of activities that when well documented can confirm concrete supply was done in accordance with the standard NZS 3104. Understanding the importance of these records is crucial as many queries about the quality of concrete supply can be quickly addressed using this information.

The documentation includes the following:

- Concrete batching plant dairy with record of moisture content of aggregates.
- Orders and dispatch information of the concrete mix
- Batch records for each load
- Delivery dockets
- Test records of quality assurance
- Scales check and calibration data

7. Certification Requirements

The concrete supplied to the project works shall be from an approved Ready-Mix plant that has a current audit certificate from Concrete New Zealand Audit Scheme. In addition to the above documentations, AT requires a certificate from the ready-mix plant for the specific mix with an independently verified carbon calculation tool. The concrete company should have an Environmental Product Declaration (EPD), but it can be used to demonstrate the accuracy of the carbon calculation tool.

Ideally the QA documentation would take the form of an independently certified (EPD), or third party verified carbon calculator, compliant with the principles, procedures and product category rules set out in ISO 14025 and EN 15804.

The concrete supplier must provide the mix GWP with supporting calculation showing breakdown of components and third-party verification.

8. Non-Compliance with the requirements

Any proposal to produce low carbon concrete that is not in accordance with this Practice Note will require the approval from Transport Design and Standards Manager and Chief Scientist.

9. Abbreviations

AC	Auckland Council
AC-CPLDS	Auckland Council – Code of Practice for Land Development and Subdivision
AT	Auckland Transport
BRANZ	Building Research Association of New Zealand
EA	Engineering approval
EDC	Engineering Design Code

FA	Fly Ash (AS 3582 Part 1 SCM (for use with Portland and Blended cement) (FA is high in silica and alumina and low in calcium)
GB	General purpose blended cement- NZS 3122
GGBFS	Ground Granulated Blast-furnace Slag- AS 3582 Part 2 (High in calcium and silica with moderate alumina)
GP	General purpose Portland cement- NZS 3122 (High in calcium and silica)
GWP	Global Warming Potential
HE	High early strength cement- NZS 3122
ISC	Infrastructure Sustainability Council
MS	Micro (Amorphous) Silica- AS/NZS 3582: Part 3 (High in silica, low in calcium and other elements)
NDE	Non-Destructive Examination
PEET	Project Emission Estimation Tool
PN	Practice Note
RSP	Raised safety Platforms
SCM	Supplementary Cementitious Materials
TDM	Transport Design Manual
UNO	Unless noted otherwise

10. Definitions

Term	Definition
Admixture	A material other than cement, aggregate or water added to concrete to modify its properties.
Batching plant	A plant capable of weighing, in the required quantities and to the required degree of accuracy, the materials constituting a batch of concrete. A batching plant may also have a concrete mixer mounted integrally with it.
Concrete mixer	A rotating drum, tube, trough, or pan fitted with fins or paddles which can combine all the ingredients of a concrete batch into a uniform mass in not more than 70 revolutions at mixing speed and of discharging the concrete with the required uniformity.
Embodied carbon	Embodied carbon refers to the total emissions caused by the extraction, manufacture and supply of construction products and materials and the construction, maintenance, and end of life disposal processes.
Ready mixed concrete	Concrete made from a mixture of cement, coarse aggregates, sand, and water with or without admixtures. Concrete is batched at a batching plant and mixed in a concrete mixer incorporated in the plant or in truck mixers held stationary at the plant until mixing is completed. The Ready-Mixed Concrete is then delivered to the site in a suitably plastic state for placing.
Upfront carbon	Upfront carbon refers to those embodied carbon that happen before the asset is in use.

11. Supporting Information

11.1 Design Manuals

- Auckland Transport – Transport Design Manual
- Auckland Council Code of Practice for Land Development and Subdivision Chapter 3: Transport

11.2 Related documents

Work shall comply with the relevant requirements of the following standard specifications together with further provisions herein.

NZS 3101	Concrete Structures Standard
NZS 3104	Specification for concrete production
NZS 3109	Concrete Construction
NZS 3111	Methods of test for water and aggregate for concrete
NZS 3112	Methods of test for concrete- Part 1: Tests relating to fresh concrete. Part 2: Tests relating to the determination of strength of concrete.
NZS 3114	Specification for concrete surface finishes
NZS 3121	Water and aggregate for concrete
NZS 3122	Specification for Portland and Blended Cements
NZS 3124	Specification for concrete construction for Minor Works
AS 1478	Chemical admixtures for concrete, mortar and grout
AS/NZS 3582	Supplementary Cementitious Materials (SCM)
AS/NZS 3582	Part 1: Fly ash
AS/NZS 3582	Part 2: Ground Granulated blast furnace slag
AS/NZS 3582	Part 3: Micro (Amorphous) silica
AS 3583	Test methods for supplementary cementitious materials (series of Standards)
AS/NZS 4671	Steel bars reinforcement
AS 1012.13	Methods of testing concrete-Determination of the drying shrinkage of concrete for samples prepared in the field or in the laboratory.
ISO 14025	International Standard for Environmental Labels and Declarations.
EN 15804	Sustainability of construction works.

Neville, A.M. “Properties of Concrete” (4th Edition) (1995), Longman Group Ltd, ISBN 0 582 23070 5

Concrete Production Guide For New Zealand, Concrete NZ, ISBN 978 0 908956 80 7

BRANZ Research Publication CO2NSTRUCT Version 3

12. Approval

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AT reserves the right to review, amend or add to this Practice Note at any time upon reasonable notice to users of the Transport Design Manual and related documents.