AN EVALUATION OF THE MAXIMUM ACCEPTABLE CONCRETE TEMPERATURE DURING THE STEAM CURING PROCESS

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Prepared for Humes Precast

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1 INTRODUCTION

1.1 Background

Humes Precast has a long history of providing quality steam cured precast concrete girder solutions for numerous projects across Australia. The design and construction of these members is required to comply with relevant statutory requirements, including the steam curing procedure, which is the focus of this report.

For projects within the state of Queensland, the Queensland Main Roads Technical Standard MRTS70[1] for Concrete is applicable. This Standard includes the following criteria for steam curing:

- Curing is deemed to have commenced once the temperature in the enclosure has exceeded 50ºC and must be maintained for a minimum curing period. For all prestressed concrete members, curing shall continue from this commencement point until the product of the curing time and enclosure temperature exceeds 420ºC Hours.
- The application of steam shall be such that the air temperature inside the enclosure is raised at a linear rate not exceeding 24°C per hour at any time, until a minimum enclosure temperature of 50ºC is attained. This ensures gradual introduction of temperature to the immature concrete and removes the risk of thermal shock at the important early stages of strength development.
- The maximum temperature in the enclosure shall not exceed 70°C at any point in time, reducing the risk of potential deleterious Delayed Ettringite Formation (DEF) within the concrete member.
- The corresponding maximum internal temperature measured at the centre of the units largest cross section, shall not exceed 75°C.
- The manufacturer shall provide accurate instruments for recording and controlling the temperatures inside the enclosure and the maximum concrete temperature ......during the whole of the steaming operation.

Humes Precast instrument and record the temperatures inside the curing enclosure the whole of the steaming operation, including the maximum temperature over this time, with monitoring continuing from the commencement of the application of steam to the enclosure, until the moment it is turned off at 420°C Hours.

It is noted that while the temperature inside the enclosure can be controlled and recorded according to the MRTS70 requirements, the maximum concrete temperature can be recorded, but not entirely controlled. The maximum temperature reached by a concrete element during the application of steam curing would be within the core location and will depend on various factors including:

- cement type and composition
- mix design, constituent properties
- element size and shape

Historical records indicate that during the steaming operation of typical precast girders, the maximum concrete temperature within the core is maintained below the 75°C threshold. However, given the size of these common elements and the related mix design parameters, it is known that this threshold may be exceeded in some cases after the end of the steaming operation as the concrete continues to gain heat and strength and can typically reach around 85°C internally.

Concern has been expressed that such elevated core temperatures may be sufficient to risk an increased potential for deleterious expansion within the concrete matrix due to DEF.

By taking a holistic approach, this report provides guidance on the potential risk of the formation of DEF for typical girder elements with key considerations being:

- The maximum concrete temperature;
- Chemical composition of the cement;
- Overall binder combination;
- Potential for micro-cracking;
- Consideration of exposure conditions.

2 CONSTRUCTION METHOD

2.1 Concrete Mix Design

The concrete mix design typically used in the manufacture of precast girders is a Holcim supplied super workable concrete mix, denoted QS502F535 and developed in association with Main Roads Queensland, as detailed in Appendix 1. The mix contains 535kg/m^3 of binder which provides early age strength as well as the fine fillers required for high flow characteristics. The binder consists of 75% Gladstone GP Cement and 25% Gladstone fly ash from Cement Australia.

2.2 Steam Curing Procedure

Steam curing is commenced following a dedicated delay period, with low pressure steam being injected in two locations towards the bottom of the element. Steam is injected at a temperature between 50ºC and 70ºC. Steam curing is applied for 6 hours or until a specified maturity level of 420ºC hours is achieved. Test cylinders (matched cured to the temperature of the beam at a depth of 100mm from the surface) are then progressively crushed at particular time intervals to determine the compressive strength of the precast concrete element. When the cylinder strength exceeds the specified early strength, steam curing application is terminated. The elements are left to cool down until the concrete surface temperature is less than 60 degrees and within 40 degrees of ambient at which point the forms are stripped. In this way thermal shock is also avoided by allowing the heat within the member to diminish gradually.

3 LITERATURE REVIEW

3.1 DEF Deterioration

DEF is an internal chemical process which can lead to the degradation of structural concrete. It was first discovered in heat cured, precast railway ties in the early 1980's in Germany and has since been identified as a problem mainly in the USA and Europe, though it is not widespread in occurrence. No published reported cases of DEF have been issued in Australia and for that reason minimal research has been conducted in Australia on this topic.

Ettringite is a complex calcium sulpho-aluminate hydrate that normally forms as an early hydration product in Portland cement based concrete pastes and as such is not disruptive. Delayed ettringite formation (DEF) refers to late-stage formation of ettringite in hardened, rigid concrete. Formation of delayed ettringite is accompanied by expansion and thus the development of high pressures, which may lead to cracking.

A number of factors such as curing conditions, cement composition, concrete mix constituents and proportions and exposure conditions can influence the potential for DEF. However, DEF has most commonly been evidenced in pre-cast, accelerated steam-cured elements that have been exposed to excessive temperatures during curing and have been subsequently exposed to moisture in service. It is postulated that when concrete is subjected to temperatures above approximately 70° C early in the curing process, an alteration of the early chemical reactions during cement hydration results; early formation of ettringite is suppressed and sulfates become internally trapped within the early hydrates, specifically the calcium silicate hydrate (C-S-H) which fills in the bulk of the concrete matrix and provides much of the concrete's strength. Over a period of time and given exposure to moisture, these sulfates may slowly release from the C-S-H gel into the pore solution triggering the reformation of ettringite in the hardened concrete and resulting in expansions and cracking.

According to available overseas research, an internal curing temperature of approximately 70° has been generally accepted as being the critical temperature which accelerates the C-S-H production enough to begin to trap sulfates [2,3,4]. The occurrence of DEF and the strong connection with elevated temperature curing have led to restrictions on the heat-curing process used during the manufacture of precast concrete in Australia, as indicated by Queensland Department of Main Roads, MRTS70; VicRoads 610; and New South Wales RMS B80 Specifications for concrete.

However, research has indicated that DEF is not restricted to overheated steam cured concretes[5,6,7]. Collepardi [6] states that there is experimental knowledge that cast in place concrete structures may evidence the same DEF induced damage as that of steam cured precast concrete products. Extensive studies conducted in the USA into the widespread failure of precast railway sleepers has found that many precasters have successfully used temperatures in excess of 90°C without suffering DEF related distress through careful control of cement chemistry and that the inclusion of significant amounts of fly ash virtually eliminates the potential for DEF formation. Extensive research by the Texas Department of Transport[8] has indicated that DEF can be effectively mitigated for steam cured elements even when cured up to 95°C. Thus the Texas Department of Transport and other USA agencies specify alternate methods for preventing DEF instead of imposing a limit on maximum temperature.

While there is some conjecture as to what is an excessive temperature and what maximum concrete temperature is acceptable during curing should such a limit be imposed, it is fair to say that temperature is an important influence and it has been shown that is it desirable to have lower peak temperatures to mitigate DEF. However, to accelerate formwork rotation and meet construction schedules, commercial precast concrete facilities need high strength concretes containing large quantities of heat generating cement cured at elevated temperatures, hence the dilemma.

3.2 Mitigating DEF

The exact mechanism of DEF is not completely understood nor clearly defined. The holistic approach to the assessment of risk developed by Collepardi(6) summarizes the key requirements for the development of DEF related deterioration and explains to some degree why DEF induced damage occurs in some specific circumstances when it is not anticipated, yet it is not present in other cases when it is expected to occur.

The occurrence of DEF is not simply a result of high temperature steam curing. According to the mechanism proposed by Collepardi, three conditions have to be met in the concrete for DEF to occur. They are:

- late sulfate release (due to high temperature curing or from the cement clinker)
- pre-existing micro-cracks
- exposure to water

It is postulated that in the absence of one of these elements, DEF related deterioration is unlikely to occur as depicted in Figure 1.0 below.

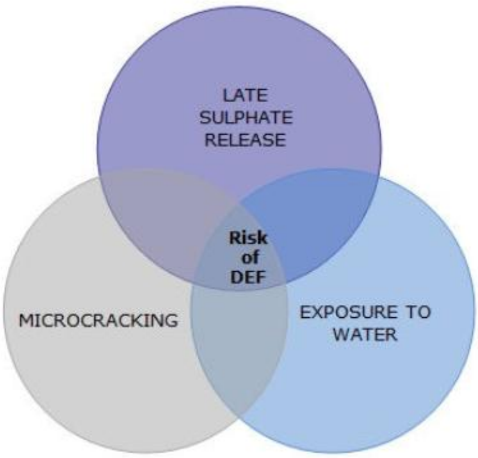

Figure 1 - The three elements required for DEF deterioration

Note: The term Sulphate is now replaced by Sulfate in many international documents and applied here.

Basically, free sulfate is a requirement for the expansion process, moisture must be present to dissolve and transport the sulfate and, crevices and disturbances must exist for pathways for water and transport of ions. Each of the three needed elements of the mechanism can be developed from numerous causes.

3.2.1 Late Sulfate Release

Late sulfate release can be brought about by an excessive maximum concrete temperature during curing and is also affected by the cement type, chemistry and the binder combination.

3.2.1.1 Maximum Concrete Temperature

Published overseas literature shows that peak concrete temperatures exceeding approximately 70°C during initial curing are considered a precursor to DEF related damage. The MRTS70 Specification gives a required maximum concrete temperature at the end of the steam curing cycle of 75°C. Typical temperature data for Humes Precast girder concrete is given in Figure 2.

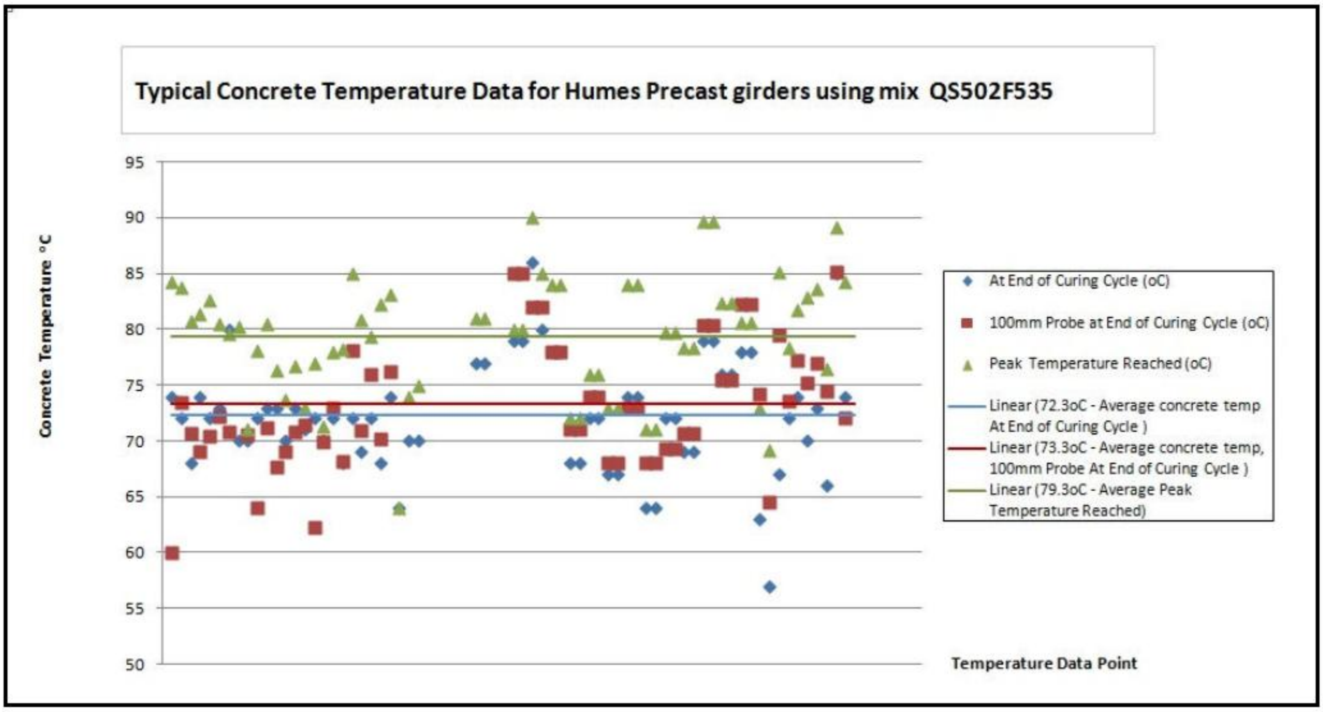

Figure 2 - Typical Curing Temperature Data for Humes Precast Girders

From the typical data, it can be deduced that:

- At <u>the end of the steam curing cycle</u>, the average typical concrete core temperature is 72.3°C. Twenty five percent (25%) of girders exceeded 75°C at the end of the curing cycle, while 1% (1 result only) exceeded 85°C.
- At <u>the end of the steam curing cycle</u>, the average typical concrete temperature <u>100mm into the concrete surfaces</u> was 73.3°C. In 31% of girders, the temperature exceeded 75°C at the end of the curing cycle

measured 100mm into the concrete surface, while 1% (1 result only) exceeded 85ºC.

- The average peak core temperature reached within the concrete during the steaming process was 79.3°C. In 77% of girders, the temperature exceeded 75ºC and in 8% of girders, the temperature exceeded 85ºC.

Given the particular mix design used and related characteristics, it can be expected that at some point, due to high heat generation through cement hydration, the MRTS specified temperature for control of DEF (75°C) will be exceeded within the concrete core and within 100mm of the surface of the girder members in a significant number of cases. This is despite the fact that a proportion of the mixing water for the concrete consists of ice in an effort to control temperature rise.

The number of precast concrete units with internal temperatures exceeding the specified 75°C will vary from member to member, due to a number of factors including member geometry etc, as will the magnitude of generated internal temperature. The temperature of the external surface of the girders will settle into an equilibrium with that of the curing enclosure (50ºC to 55ºC) well below the maximum specified temperature.

Where the internal concrete core is deemed to be susceptible to DEF following MRTS70, the risk of damage due to DEF is alleviated by unaffected concrete in the vicinity of the external surface of the members coupled with the use of a high strength, very low porosity and virtually impermeable concrete mix which will protect against potential moisture penetration needed for DEF formation.

3.2.1.2 Cement Type and Chemistry

DEF has been found to be dependent on the type and composition of the cement used. The extensive research program conducted by the Texas Department of Transportation [(8)] using various cement types, aggregates and steam curing temperatures found that the use of sulfate resisting (Type V) cement showed very little, if any, DEF induced expansion for any of the aggregates used or for any of the curing temperatures evaluated.

Humes Precast use Cement Australia's Type GP cement from Gladstone, QLD. This Type GP cement also comfortably conforms to the requirements for Type SR (sulfate resisting) cement as specified in the Australian Standard for the manufacture of Portland and Blended Cements, AS3972 -2010 [(9)]. Given the cement used contains a low sulfate content, the risk of DEF damage is significantly reduced.

With respect to cement chemistry, Kelham conducted a series of experiments with more than 70 cement compositions and evaluated expansion data for curing temperatures of 23°C, 70°C, 75°C, and 90°C[(2)]. Based on this series of trials, Kelham concluded that expansions tend to increase with increasing cement fineness, alkali content, C_3A content, C_3S content, and MgO content. He proposed the following empirical equation that would estimate expansion with a known cement composition where a negative value means that no expansion would be expected.

$$\text{Expansion at } 90°C = 0.00474*SSA + 0.0768*MgO + 0.217*C_3A + 0.0942*C_3S + 1.267*Na_2Oeq - 0.737*abs(SO_3 - 3.7 - 1.02*Na_2Oeq) - 10.1$$

Where:

SSA	Fineness Index (m^2/kg)
MgO	Magnesium Oxide percentage
C_3A	Tricalcium Aluminate percentage determined using Bogue's Equation
C_3S	Tricalcium sulfate percentage determined using Bogue's Equation
SO_3	Sulphur trioxide
Na_2O eq	Potassium and Sodium oxides expressed as an equivalent value of sodium oxide

A standard Cement Certificate provided by Cement Australia (Appendix 2) contains the following information on the chemistry of the cement being used:

SSA	385 m^2/kg
CaO	63.8%
MgO	1.1%
SiO_2	19.1%
Al_2O^3	5.2%
Fe_2O^3	3.4
SO_3	2.3%
Na_2O eq	0.4

Using Bogue's equation C_3A and C_3S can be calculated and the likely expansion at $90^{O}C$ is calculated using the Kelham Equation as being a negative value (-0.87). Therefore according to the work by Kelham, Cement Australia's Gladstone cement is considered non-expansive at $90^{O}C$. Though importantly also, it is noted that Australian Standard AS3972 (9) does not reference Bogue compositions for cement as there are errors in determining values particularly with the incorporation of mineral additions and minor additional constituents.

Heinz and Ludwig (10) have postulated that the ratio of $(SO3)^2/Al_2O_3$ is an important measure of the potential for future expansion under the effects of DEF with a safe value being 2, with cements with a ratio less than 2 not being susceptible to DEF. Based on the information provided by Cement Australia the ratio of $(SO3)^2/Al_2O_3$ for Gladstone GP cement is typically 1.02 and therefore the cement would not be considered to be susceptible to DEF.

Day (3) has proposed a limit of 0.67 for the ratio of SO_3/Al_2O_3 to minimise the risk of DEF. For Gladstone GP cement this ratio is typically 0.44 and thus the risk of DEF is considered to be minimal.

Based on work conducted by researchers such as Kelham, Heinz and Ludwig and Day, it appears that the Gladstone GP cement is unlikely to suffer DEF related expansion even when cured at temperatures greater than the normally recommended values of 75ºC.

3.2.1.3 Binder Combination and the Use of Supplementary Cementitious Materials

The work by the Texas Department of Transport (and numerous other researchers) has shown by the introduction of fly ash as a cement replacement within concrete the effects on DEF related expansion are mitigated. Trials conducted by the Texas Department of Transport have shown that 20% replacement of Type 1 cement with fly ash eliminated expansions irrespective of aggregate type or cement source.

These finding has been confirmed by other investigators such as Hime[11], Collepardi [6] and Thomas [12].

The typical precast girder mix design used by Humes is included in Appendix 1. Based on the cement chemistry and use of high levels of fly ash replacement (25%) in this mix it is highly unlikely that late sulfate release will occur irrespective of the peak curing temperature.

3.2.2 Control of Micro-cracks

Concrete micro-cracking can be promoted by one or more of the following causes:

- the occurrence of Alkali Silica Reaction (ASR) with micro-cracks initiated due to the formation of expansive compounds around individual aggregate particles
- curing at high temperature, with internal and external temperature differences establishing thermal stresses
- excessive heating/cooling rate, introducing thermal shock as the concrete member is heated or cooled too quickly
- too short a preset period where steam is applied to immature concrete before cement hydration has developed sufficiently to allow strength gain.
- weathering effects due to environmental exposure of the concrete units
- dynamic loads in service causing stress concentrations
- freeze-thaw cycles created localised stress concentrations on concrete pore spaces.
- localised high stress in pre-stressed elements due to design, erection etc

Humes Precast effectively manages these potential causes and reduces the likelihood of micro-cracking from occurring by the following methods:

- ASR is mitigated within the concrete by the use of 25% fly ash in conjunction with the Type GP cement component. Accelerated mortar bar tests undertaken using this cementitious binder combination have shown that the aggregates currently being used are non reactive, in this case, therefore ASR is not deemed to be of concern as regards the MRTS70 specification.
- Use of high strength, high quality concrete consisting of a high binder content, low-water cement ratio and the use of a high range water reducer to reduce water content, resulting in a highly impervious concrete. The use of fly ash has also been extensively shown to reduce permeability [13].
- By ensuring the required preset period is completed, prior to the addition of steam, the specified heating of the units is controlled, the required 420ºC hours of maturity is achieved and the controlled cooling of the unit is completed, prior to striping of the forms, reducing the potential for thermal stresses or shock.

- In addition the transfer of prestress is not applied to the concrete units, until compressive strength can be confirmed via dedicated test cylinders cast and cured under the same conditions as the concrete within the unit.

3.2.3 Exposure to Moisture

DEF requires moisture or frequent wetting/drying cycles in order to form. In the absence of water, sulfates cannot diffuse through the pore aqueous phase and migrate towards the existing micro-cracks to form ettringite. Field investigations conducted by Collepardi (6) on precast concrete ties clearly revealed that ties not exposed to rain did not exhibit DEF deterioration.

The exposure to moisture experienced by individual girder members will depend on the insitu conditions, their location within the structure and the presence or otherwise of a protective waterproof membrane. While this would need to be assessed for each project independently, it is noted that the concrete within the Humes precast members is of high quality and relatively impervious, such that moisture may not be able to penetrate beyond the concrete surface. Subsequently where moisture is unable to reach the inner section of the girder elements that experience higher temperatures, the formation of DEF is less likely.

4 SUMMARY

In light of the findings presented in this report, it can be concluded that if the concrete temperature during steam curing exceeds 75ºC, it does not necessarily increase the risk of DEF as other factors also contribute to its formation. By applying a holistic approach other influential factors may be considered, and a temperature in excess of 75ºC noted as only one indicator of potential DEF risk.

The report authors believe that an internal maximum concrete temperature up to 85°C generated from a controlled steam curing process may be considered acceptable for the typical Humes Precast girder elements where conditions do not support the other effects required for formation of DEF. Should this temperature be exceeded, remediation measures in the form of a dedicated water-proof coating is recommended for added protection against the possibility of moisture ingress that could activate DEF in the future.

It was identified that according to the holistic model proposed by Collepardi, the risk for DEF related distress is very low, in the Humes precast units, due to the following:

- the presence of ideal cement chemistry resisting DEF
- use of 25% fly ash to mitigate ASR and reduce permeability
- management of the potential causes of micro-cracking through controlling steam curing profiles and limiting temperature gradients
- protection from moisture ingress due to impermeable surface layer of high quality, non heat affected concrete

Therefore, despite the likelihood that peak concrete temperatures may exceed the MRTS70 recommended level in some instances, particularly beyond the end of the steaming operation, the review of current literature and findings presented within this report have demonstrated that DEF within the Humes precast units is regarded as low considering all other contributing factors and mitigation methods currently employed.

5 FURTHER WORK

Humes Precast is undertaking further work on the issue of DEF and its influence on durability of concrete. A research program has commenced at an Australian University where a range of cements and supplementary cementitious materials are to be investigated. A four stage study is currently under way on specific properties of Humes concrete and this is the first study where local Australian materials will be evaluated for DEF potential.

5.1 STAGE 1 - MATERIAL CHARACTERISATION

Study the chemistry and mineralogy of component materials used in the manufacture of precast products referencing overseas sourced high DEF potential cements. Materials will cover:-

- Imported high DEF potential cement
- Gladstone cement (SR cement to AS3972)
- Gladstone fly ash
- Superplasticiser and other admixtures
- Aggregates and sand specific to precast product manufacture (considering ASR potential) and other relevant components of concrete

5.2 STAGE 2 - STUDIES ON CEMENT (BINDER) PASTES

Set up experiments that force the formation of ettringite by accelerated means and study the influence of temperature on DEF using reference overseas high DEF potential cements and local materials. Issues for study would include:-

- Control temperature of 75ºC - establish what happens
- Look at temperature of 90ºC - what are the changes in DEF formation
- Look at influence of period of temperature application
- Look at influence of superplasticiser and other admixtures on DEF potential

5.3 STAGE 3 - STUDIES ON MORTARS SPECIMENS

To refine studies on mortar specimens to further validate outcomes derived from material characterisation and paste studies. Cover the following:-

- Standard suite of tests mainly to AS2350 (strength, shrinkage etc) to establish benchmark for high DEF potential cement and for local materials used for precast product manufacture
- Mortar expansion testing to validate actual DEF potential

5.4 STAGE 4 - STUDIES ON CONCRETE

Limited studies on concrete using two binder system (high DEF reference cement and precast concrete mix) to validate mortar results covering:-

- Standard tests (strength development, shrinkage etc)
- Consider scanning electron microscope studies depending on findings of earlier work
- Possible longer term study as concrete might take time to develop DEF in quantities significant enough to validate risk

6 APPENDIX 1: TYPICAL MIX DESIGN

Holcim (Australia) Pty Ltd
18 Little Cribb St,
Milton Qld 4064

ABN 87 099 732 297
Phone +61 7 3364 2733
Fax +61 7 3866 7101
www.humes.com.au

Concrete Mix Design 6EFC06 QS502F535 Townsville Mix Design Certificate 110411

Customer:	Humes Townsville	**Date:**	11-Apr-11
Attention:	Safar Kesari	**From:**	Brett Beaver
Email/Fax:	safar.kesari@humes.com.au	**Ph:**	0419 475 825
Project:	All	**Acc Mngr:**	
Specification:	TMR	**Copies:**	Yianto Charles
Primary Plant:	Holcim Townsville	**Backup Plant/s:**[2]	Humes Townsville

			Product Identification					
Concrete Product Code[6]			QS502F535					
Concrete Mix Description			50/10/700					
Location in Structure			ALL					
			Specified Requirements					
Strength Grade (f'c) (MPa @ 28 days)			50					
Maximum Aggregate Size (mm)			20					
Nominal Slump (mm)			180 ± 40					
Slump Flow (Spread Test mm)								
J-Ring (jr mm)			N/A					
T500 (seconds)			N/A					
Specified Minimum Cement Content (kg/m^3)			450					
Specified Maximum W/C Ratio			0.40					
Material	**Source / QAC No.**	**Ref Std**	**Mix Design Proportions (as per notes)**[2,3]					
GP Cement[7]	GP - Gladstone CA -	AS3972	400					
Flyash[7]	FA - Gladstone CA -	AS3582	135					
Aggregates		AS2758.1						
20mm Agg	Bohle 2009-58	AS2758.1	715					
10mm Agg	Bohle 2009-58	AS2758.1	385					
Coarse Sand	Burdekin Rapisarda 2010-2	AS2758.1	360					
		AS2758.1						
Fine Sand	Cleveland N166	AS2758.1	192					
Admixtures		AS2758.1						
HRWR (litres)	Grace ADVA 620	AS1478	2.0-3.0					
Design Total Free Water (L/m^3)[5]			180					
Typical W/C ratio			0.34					

7 APPENDIX 2: CEMENT CERTIFICATE

STANDARD CEMENT CERTIFICATE

FINAL

Prior Reports: None

Certificate Number: CERT120074

Issued: 02, February 2012

Cement Australia
PO Box 1328
Milton QLD 4064
Australia
Telephone: +61 7 3335 3000
Fax: +61 7 3335 3222

Product being certified:	Townsville GP
Product sample date:	28-Dec-2011
Sample Identification:	Sample Code: 11120686
Description:	Grab Sample from Despatch Silo - Townsville Despatch
Testing Conditions:	As received at Cement Australia Darra Laboratory, 12 Station Avenue, Darra Queensland 4076 Australia. Testing commenced on 03-Jan-12

Test Results

Test	Fineness Index	Residue 45µm Sieve	Normal Consistency	Setting Time Initial	Setting Time Final	Soundness[1]	Loss on Ignition
	m^2/kg	%	%	min	min	mm	%
Result	385	6.5	27.6	90	165	1	4.2
Standard	AS/NZS 2350.8:2006	AS/NZ 2350.9-2006	AS/NZS 2350.3:2006	AS/NZS 2350.4:2006	AS/NZS 2350.4:2006	AS/NZS 2350.5:2006	AS/NZS 2350.2-2006
AS 3972:2010 Limit	None	None	None	45min Minimum	360min Maximum	5mm Maximum	None

Test	CaO by XRF	SiO_2 by XRF	Al_2O_3 by XRF	Fe_2O_3 by XRF	SO_3 by XRF	MgO by XRF	Na_2O Equivalent
	%	%	%	%	%	%	%
Result	63.8	19.1	5.2	3.4	2.3	1.1	0.4
Standard	AS/NZ 2350.2-2006	AS/NZ 2350.2-2006	AS/NZ 2350.2-2006	AS/NZ 2350.2-2006	AS/NZ 2350.2-2006	AS/NZ 2350.2-2006	AS/NZ 2350.2-2006
AS 3972:2010 Limit	None	None	None	None	3.5% Maximum	None	None

Test	Mortar Compressive Strength			Shrinkage	Peak Temp Rise		16 wk Sulfate Resistance	Total Chloride by XRF 2
	3 Days	7 Days	28 Days	28 Days				
	MPa	MPa	MPa	µStrain	°C	hrs	µStrain	%
Result	36.3	49.6	61.5	Not Tested	Not	Tested	Not Tested	0.021
Standard	AS/NZS2350.11:2006			AS/NZ 2350.13-2006	AS2350.7-2006		AS2350.14-2006	AS/NZS 2350.2:2006
AS 3972:2010 Limit	Not Tested	35MPa Minimum	45MPa Minimum	Not Tested	Not Tested		Not Tested	0.1% Maximum

This sample conforms to the following requirements of AS 3972:2010

Type GP	Type GB	Type HE	Type LH	Type SL	Type SR
✔					

Mineral Additions: May Contain up to 7.5% Limestone mineral addition

Minor Additional Constituents: Nil

Approved Signatory

V Connell
Chemical Testing
Construction Materials Testing

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NATA Accredited Laboratory Numbers
187 188

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