

# **The World's First RPC Road Bridge at Shepherds Gully Creek, NSW**

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## **SYNOPSIS**

Reactive Powder Concrete (RPC) is a cementitious material consisting of cement, sand, silica fume, silica flour, superplastiser and water. The material was developed by Bouygues, the parent company of VSL, and is marketed under the brand name of Ductal.

It is almost self placing, and has a compressive strength of 180 MPa. The durability properties are orders of magnitude better than current high performance concrete.

In structural applications, RPC is used without any passive reinforcement. Very fine high strength steel fibres are able to withstand secondary tensile stresses. Prestressing counterbalances the main tensile stresses due to bending.

Ductal has been used worldwide for a number of structural applications, including several long span pedestrian bridges. However, the bridge over Shepherd's Gully Creek is the first bridge in the world to be constructed using Ductal for normal highway traffic.

The bridge is approximately 150km north of Sydney and replaces an existing timber bridge. It comprises four traffic lanes plus a footway. The live loading is the maximum of T44 and HLP320 truck loading.

The bridge is a single span of 15 m. It has a width of 21m, a skew of 16 degrees and is constructed in two stages. The bridge will be load tested by the Roads and Traffic Authority NSW after completion of the first half.

The superstructure comprises 16 precast pretensioned RPC beams and an in-situ reinforced concrete deck slab. The slab is placed onto thin precast RPC permanent formwork slabs that span between the beams.

The beams are of I section, with a depth of 600mm and a weight of 280 kg/m. They are spaced at 1.3m. The formwork slabs are 1.1m wide, 2.4m long, with a thickness of 25mm. The reinforced concrete slab is 170mm thick.

This paper presents the properties of Ductal and the details of the bridge. It also presents the conditions under which the use of RPC is favourable.

## **1. INTRODUCTION**

Reactive Powder Concrete (RPC) is a cementitious material consisting of cement, sand, silica fume, silica flour, superplastiser and water. The material was developed by Bouygues, the parent company of VSL, and is marketed under the brand name of Ductal. It is almost self-

placing, and has a compressive strength of 180 MPa. The durability properties are orders of magnitude better than current high performance concrete.

In structural applications, RPC is used without any passive reinforcement. Very fine high strength steel fibres are used to withstand secondary tensile stresses. Prestressing counterbalances the main tensile stresses due to bending. The use of RPC opens up opportunities for the development of new and innovative structures that can be lighter, stronger and more durable than existing structures, and with more freedom of shape.

Ductal has been used worldwide for a number of structural applications, including several long span pedestrian bridges. However, the bridge over Shepherds Gully Creek will be the first bridge in the world to be constructed using Ductal for normal highway traffic.

The construction of this bridge is considered by the Roads and Traffic Authority NSW (RTA) as an evaluation trial of the materials, design procedures and constructability of RPC.

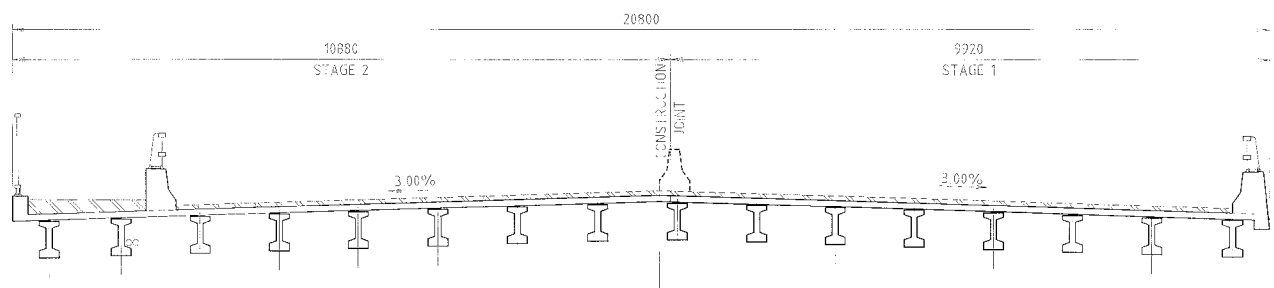
At the time of writing this paper (January 2004), the precasting of the girders was completed and the construction work on site had commenced. An update on the construction and test loading of the bridge will be available at this conference.

## 2. DESCRIPTION OF THE BRIDGE

The Shepherd's Gully Creek bridge is approximately 150km north of Sydney and replaces an existing timber bridge. It comprises four traffic lanes plus a footway. The live loading is the maximum of T44 and HLP320 truck loading.

The bridge is a single span of 15m length. It has a width of 21m and is on a skew of 16 degrees. It will be constructed in two stages. The bridge is to be load-tested by the RTA after completion of the first half.

The substructure comprises driven steel piles with a cast-in-place capping beam. The superstructure (Figure 1) comprises 16 precast pretensioned RPC beams and an in-situ reinforced concrete deck slab. The slab is placed onto thin precast RPC permanent formwork slabs that span between the beams. The beams are of I-section, with a depth of 600mm and a weight of 280 kg/m (Figure 3). They are spaced at 1.3m. The formwork slabs are 1.1m wide, 2.4m long, with a thickness of 25mm. The reinforced concrete slab is 170mm thick.



**Fig. 1: Cross Section of the Shepherds Gully Creek Bridge**

### 3. PROPERTIES OF RPC FOR DESIGN

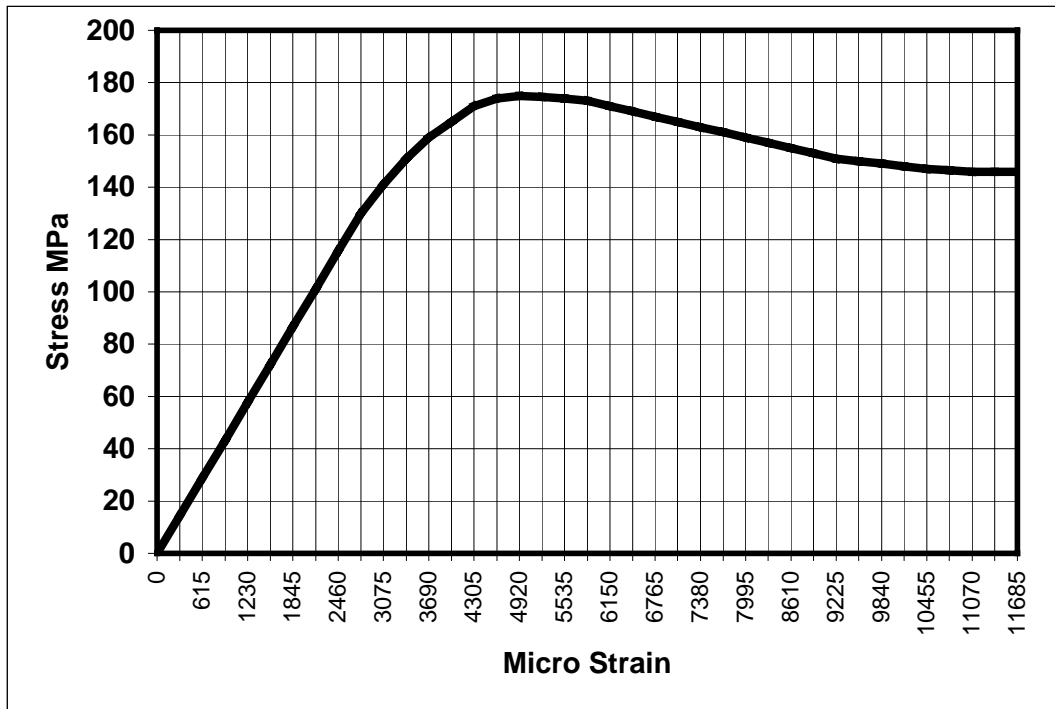
The development and testing of the production mix for the bridge were performed at the University of New South Wales (UNSW), and are reported in detail in the literature (2).

The properties used in the design are summarised in Table 1. The stress/strain plot from a typical compression test is shown in Figure 2 and the stress/deflection plot for a typical flexure test is shown in Figure 3.

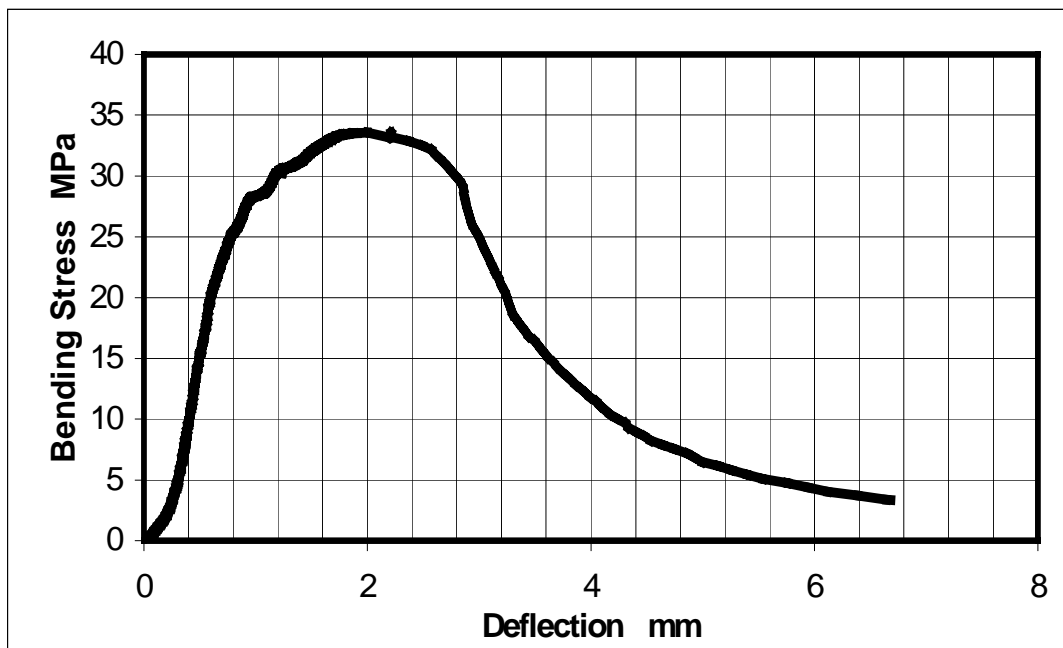
**Table 1: Design Properties**

Property	Standard	Heat Treated Ductal	Non Heat Treated Ductal
Fluidity	ASTM C230	Between 190mm and 250mm after 20 drops	Between 190mm and 250mm after 20 drops
Compressive strength	AS 1012.9	$f'_c \text{ min} = 160 \text{ MPa}$	$f'_c \text{ min} = 140 \text{ MPa}$
Flexural Tension Modulus of Rupture	AS 1012.11	$F_{cf} \text{ min} = 24 \text{ MPa}$	$F_{cf} \text{ min} = 20 \text{ MPa}$
Flexural Tension first cracking	AS 1012.11	$F_{ct} \text{ min} = 20 \text{ MPa}$	$F_{ct} \text{ min} = 16 \text{ MPa}$
Modulus of Elasticity	AS 1012.17	47 GPa	45 GPa
Shrinkage	AS 1012.13	< 500 microstrain after heat treatment	< 500 microstrain after 56 days
Density		2,450 kg/cu m	2,450 kg/cu m

The heat treatment consists of curing in steam at a temperature of 90°C for a period of 48 hours, resulting in rapid strength gain and substantially reduced creep, and causes almost all the shrinkage to occur during the period of heat treatment.



*Fig. 2: Typical Compression Test - Stress/Strain*



*Fig 3: Typical Flexural Test - Load/Deflection (Prism cross-section 100x100mm; Span 300mm)*

## 4. DURABILITY PROPERTIES

The extremely high resistance of RPC to the penetration of aggressive agents, due to the absence of capillary porosity, corresponds to excellent durability characteristics (Table 2).

**Table 2: Durability Properties**

Durability Indicator	Value	Ductal compared to High Performance Concrete
Total porosity	2% - 6%	1/4 to 1/5 of HPC
Microporosity (>10µm)	< 1%	1/10 to 1/30 of HPC
Permeability (air)	$2.5 \times 10^{-18}$ sqm	1/50 of HPC
Water absorption	< 0.2 kg/sqm	1/50 of HPC
Chloride ions diffusion	$0.02 \times 10^{-12}$ sqm/s	1/50 of HPC
Electrical resistance (excl. fibre)	$1.13 \times 10^3$ kΩ.cm	12 to 17 times HPC
Electrical resistance (incl. fibre)	137 kΩ.cm	1.5 to 2 times HPC
Abrasion resistance coefficient	1.3	2 to 3 times HPC
Fatigue, impact and blast resistance	-	Far superior to HPC

## 5 DESIGN

### 5.1 General

While the ultra-high strength of RPC puts it outside the direct provisions of Austroads and AS3600, a Design Guide has been prepared by UNSW to be in accordance with the intent of the Australian standards. This Guide is based on extensive testing in France as well as at UNSW. The design approach was presented at the November 2000 Austroads Conference (1). A prestressed beam made from RPC has about 40% to 50% of the volume of a conventional prestressed beam. The depth is approximately the same as a conventional prestressed beam in order to provide stiffness for deflection control.

### 5.2 Flexure

Prestressing together with the high compressive strength of the RPC provides the flexural strength of the beams. The pretensioning consists of 20 No.15.2mm prestressing strands, giving at transfer a P/A of 30MPa and compression in the bottom flange of 40MPa. The beams are designed to work compositely with the reinforced concrete deck slab. Reinforcement is provided to connect the concrete slab to the RPC beams. The beam details are shown in Figure 4.

### 5.3 Shear

The shear strength is provided by the tensile strength of the RPC. No additional shear reinforcement is required. The compression due to the prestress is added to the material tensile strength to counter the tensile shear stresses.

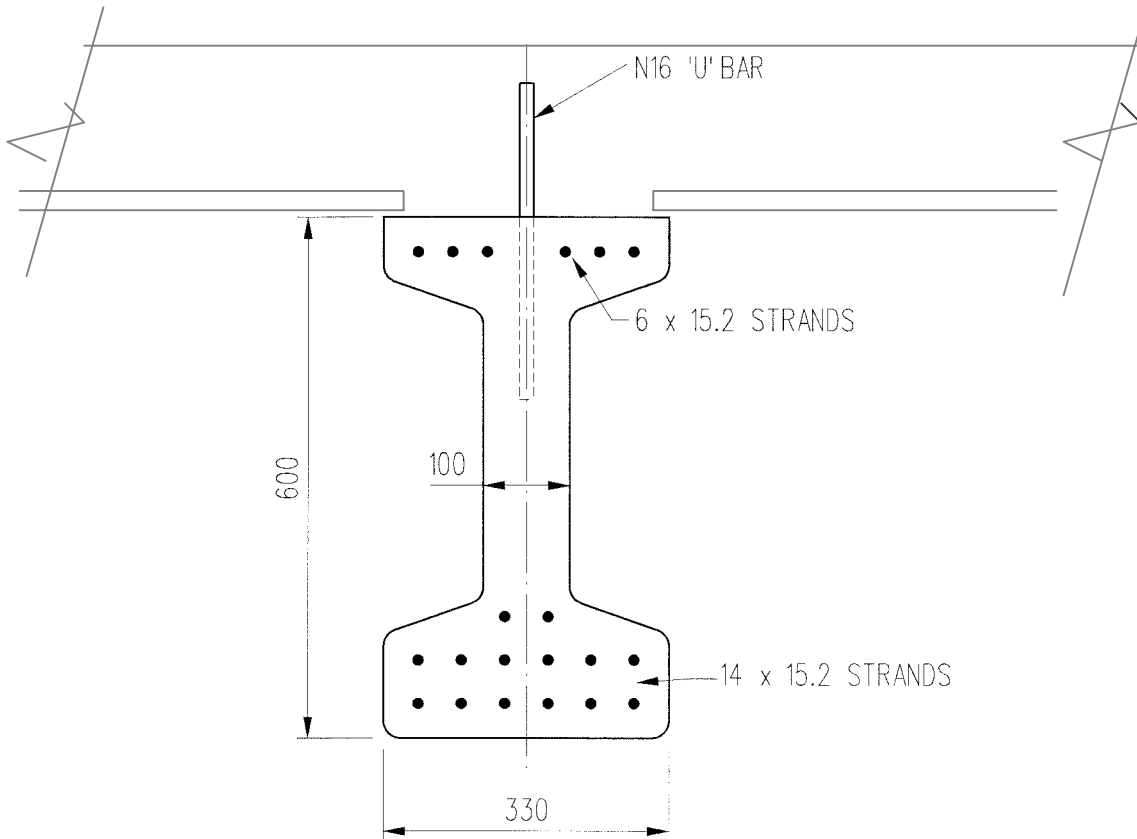
### 5.4 Hog and Deflection

The hog due to the pretensioning is basically stable after the heat treating. Deflection is calculated based on the E of 47GPa obtained after heat treating. The hog of the beams was

22mm before heat treating and 35mm after heat treating. The maximum live load deflection expected is 23mm under the HLP320 load.

### 5.5 Shrinkage and Creep

The total shrinkage and shortening due to creep is taken up during the heat treating. The shrinkage measured was less than 500 microstrain.



**Fig. 4: Typical Precast Pretensioned Ductal Beam**

## 6. PRECASTING

The plant for the mixing of the RPC and the forms for the precasting were set-up by VSL in the Heavy Structural Engineering Laboratory of UNSW at Randwick in Sydney. The material is basically self-placing. External vibration is used to give the final compaction. The beams were demoulded two days after casting and were then heat treated.



***Fig. 5: Mixer for Ductal***

The mixer is shown in Figure 5, the forms and pretensioning frame in Figure 6, and a demoulded beam in Figure 7. A demonstration load test of a 25mm thick formwork slab is shown in Figure 8.



***Fig. 6: Forms and pretensioning frame***



***Fig. 7: Typical beam***



*Fig. 8: 25mm thick permanent formwork slab, span 1.3m load 18 kPa*

## **7. CONSTRUCTION**

The construction is the same as the construction using conventional concrete beams and slabs. The beams have the significant advantage that they only weigh 4.2 tonnes for a length of 15.1m. This compares to about 9 tonnes for a conventional prestressed beam. The permanent formwork slabs have the advantage of being only 25mm thick, together with their light weight.

## **8. TESTING OF THE BRIDGE**

The bridge is to be load tested at up to three stages:

1. On completion of the first stage of construction, comprising the eastbound carriageway;
2. One year after completion of the bridge;
3. Five years after completion of the bridge.

The load tests will be carried out by RTA using its purpose built load test rig (Figure 9). The test load will induce effects into the bridge equivalent to 1.5 times the T44 serviceability load (ie the equivalent of effects of a 650 kN truck). The tests should confirm that the behaviour of the bridge conforms to the design.



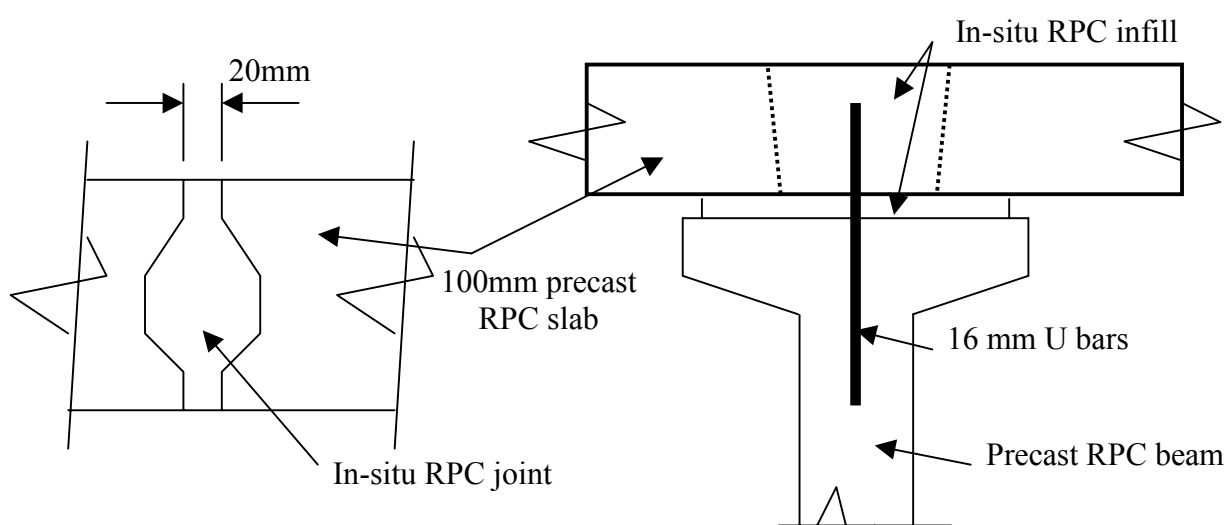


***Fig. 9: RTA Load Test Rig***

## **9. ALTERNATIVE SLAB SOLUTION**

During the design of the bridge an alternative solution was developed for the deck slab using a 110mm precast pretensioned RPC slab instead of the 170mm reinforced concrete slab. This system uses in-situ RPC at individual connections between the slabs and beams, and at the joints between slabs. Use of the RPC beams and slabs results in a very low weight bridge superstructure. The precast slab can also be used as the deck on steel or conventional concrete beams. As the Shepherds Gully Creek bridge is the first use of this new material for a road bridge, it was decided to use RPC for the beams and permanent formwork only, together with a conventional reinforced concrete slab.

The slab to slab joint is a keyed joint that uses RPC infill and does not require any reinforcement (Figure 10). The slab to beam connection uses 16mm U-bars at 300mm spacing and an RPC infill (Figure 11).



***Fig. 10 Slab to Slab Joint***

***Fig. 11 Slab to Beam Joint***

Prototypes of the slab to slab joint and the slab to beam connection were made (Figure 12 ) and test loaded to failure. The arrangement of the slab joint test is shown in Figure 13. The slab to slab joint was loaded by a simulated wheel load adjacent to the joint (Figure 14). The first crack appeared at 2.11 times an 80kN wheel serviceability load, and the failure load was 1.82 times an 80kN wheel ultimate load. Figure 15 shows the slab at 80% of its final load, at which point the dial gauges were removed. The results of the tests demonstrated excellent performance of the connections. In particular, the slab behaved as if the non-reinforced slab to slab joint did not exist.

The slab to beam joints were loaded in direct shear. They failed in a ductile manner due to progressive yielding of the U-bars. The load exceeded the theoretical ultimate capacity.



***Fig. 12 : Slabs prior to casting of slab to slab joint and slab to beam connections***



***Fig. 13: Test loading of slab to slab joint***



*Fig. 14: Prototype slab to slab joint with simulated wheel load adjacent to joint*



*Fig. 15 : Test slab at a simulated wheel load of 250kN*

## **10. WHEN SHOULD RPC BE CONSIDERED**

RPC is a ductile material that possesses ultra high compressive strength, high tensile strength and high durability together with high fatigue performance. It also has excellent impact, blast and abrasion resistance.

The properties of RPC make it the ideal material for bridge applications. It is particularly beneficial :

- when the bridge is in an aggressive environment
- when weight in the final structure is an issue
- when weight during construction is an issue
- when fatigue or impact are major concerns
- when architectural considerations are the priority

## **11. COST**

The Shepherds Creek Bridge site was selected by the RTA to be the first trial of RPC due to it being a single span, being constructed in 2 stages which assists in programming of load testing, and is close to Sydney. The reason for using RPC was to evaluate its performance, and the beneficial conditions listed above did not apply. The total cost of the bridge is approximately 10% above the cost of a conventional bridge.

For a typical beam, the RPC solution has less than 40% of the volume of a conventional beam and does not contain any reinforcement, however this does not completely offset the higher cost of the materials. Savings in the cost of the RPC solution can come from the significantly lower weight reducing the substructure costs and reducing the erection costs. Consideration of life cycle costs also favours an RPC solution. For example, a Ductal member in an aggressive marine environment will have a design life of several hundreds of years.

## **12. CONCLUSIONS**

The design, construction and testing of the Shepherds Creek Bridge demonstrate the practical use of RPC for road bridges.

The current cost of RPC means that it is more likely to be economical for particular rather than general applications. Examples of this are bridges in aggressive environments, widening of existing bridges, and superstructure replacement on existing substructure. It is expected that the cost will reduce as economies of scale are introduced.

## **13. DISCLAIMER**

The opinions expressed in this paper are those of the authors and do not necessarily reflect the policies and practices of the Roads and Traffic Authority of NSW.

## **14. REFERENCES**

1. I.GILBERT, N.GOWRIPALAN AND B.CAVILL, "On the Design of Precast, Prestressed Reactive Powder Concrete (Ductal) Girders", *Austroads 4<sup>th</sup> Bridge Conference, Adelaide, November 2000*.
2. N.GOWRIPALAN, R.WATTERS, I.GILBERT AND B.CAVILL, "Reactive Powder Concrete (Ductal) for Precast Structural Concrete – Research and Development in Australia", *21<sup>st</sup> Biennial Conference of the CIA, Brisbane, July 2003*.