Development of Geopolymer Precast Floor panels for the Global Change Institute at University of Queensland

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Abstract: Wagners EFC (Earth Friendly Concrete) has been successfully utilised for construction of 11m span precast panels in what is believed to be an Australia first use of suspended geopolymer concrete in the building industry. The design team (including Bligh Tanner Consulting Engineers, Lead Consultant Hassell Architects and Arup Sustainability) with the support of University of Qld worked closely with Wagners to fast track the testing and certification phase of EFC to enable use on this exemplar sustainability project.

Adoption of geopolymer to minimize the carbon footprint of this 6 star Greenstar rated project necessitated precasting of the floor panels to ensure quality control of the concrete placement. Use of precast provides opportunities for shaping a vaulted soffit, which improves the efficiency of the cooling systems incorporated in the panels as well as enhancing the space architecturally.

The project necessitated close collaboration between the design team, Wagners, the precast fabricator, Precast Concrete, and the builder, McNab, to achieve high quality panels, which are an important visual element in the project. The concrete mix has performed very well with low shrinkage, no visible cracking and good performance in relation to testing of cylinders and load testing of the full panels.

The project is very significant in the following Conference categories – Design, Sustainability, Precast/geopolymer, Architecture, Project case study

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Fig 1. Architectural rendering of completed project
Image courtesy HASSELL Architects

1. Introduction

This paper is written from a design process perspective to demonstrate how recent innovations in material technology can be incorporated into a construction project. The chief author is a Director of Bligh Tanner, a medium sized civil, structural and environmental consulting engineering business that has always sought to develop and utilise new technologies, particularly in relation to positive environmental outcomes.

The Global Change Institute (GCI) is a University of Queensland organisation researching global sustainability issues including resource security, ecosystem health, population growth and climate change. The conceptual design of a new building to house the institute was undertaken by the project architects, Hassell and Arup Sustainability commencing in 2009. At this time the University of Qld was undertaking a number of new building projects utilising principles of sustainable design. The GCI building was to be the exemplar project being benchmarked using the Green Building Council Greenstar rating (at 6 Greenstar level) as well achieving an Australia first Living Building Challenge compliance. The Living Building Challenge is an international rating system based in North America that looks to go a broader basis of sustainability, assessing the seven performance areas of site, water, energy, health, materials, equity and beauty. Further design parameters set for the project were zero net carbon emission for building operation, carbon neutral with carbon offset. The building is designed to use only 40% of the benchmark Green building Council energy benchmark for an educational building.

At the commencement of the schematic design phase of the project, a study tour of recent leading sustainable construction projects in Sydney and Melbourne was undertaken. Buildings visited included University of Sydney Law School, Surry Hills library, Green Building Council and the Macquarie Bank building in Sydney and CH2, The Gauge, Vic Urban in Melbourne. One interesting finding was that success of the building passive and low energy thermal systems was greatly influenced by the engagement of the building occupants in the operation of the systems. With the Global Change Institute occupying this key University building, the potential for pushing boundaries in the building design from materials to passive energy systems seemed high. The building aims to be in natural ventilation mode for 88% of the year and this goal can only be achieved if the building occupants embrace the opportunities that are afforded by the built-in operational systems.

2. Design process

Use of geopolymer concrete was one of many potential ideas mooted in the preliminary concept study by Arup Sustainability, although the nature of its use was not conceived. The material was put forward due to its substitution of Portland cement, which has a high carbon/energy footprint in its production. The general feeling at that early stage was that its development was too immature and that the most likely uses would be in the manufacture of concrete blocks or for landscaping pavements and the like. We were aware that geopolymer had been trialed by some local council engineers for pavements and that some bridge girders had been manufactured for the purposes of testing. Our initial discussions with industry experts indicated that although it was recognised that geopolymer concrete had a number of potential benefits such as low shrinkage, the required testing for compliance with AS3600 and the ability to control quality of batches had a long way to go. One significant question about substituting 100% of OPC was whether the product was even concrete within the intent of AS3600. It was recognised that the material compliance aspects of AS3600 were largely performance requirements and as such could potentially be applied to geopolymer concrete.

Early in the design, we explored the potential for incorporation of structural timber. The work at UTS developing and testing Timber-Concrete Composite (TCC) floors was of interest and was proposed as a potential floor system that combined the benefits of timber (LVL) framing with the acoustic, fire separation and wearing properties of concrete. It was at this stage that we identified the strong potential for use of geopolymer concrete in the system, as the structural topping would be working at low stress and precasting of the TCC panels would enable quality control in a factory environment. Use of precast was also recognised as advantageous considering very limited site access off Staff House Road and a site bounded by existing buildings on 3 sides.

Fig 2. Timber concrete composite floor panel

The design of the passive and low energy thermal control systems was developing at the same stage and this was pushing the floor systems toward high thermal mass with active heat exchange through pumping of air or water through a concrete slab system. The next logical iteration of the design was to precast geopolymer concrete floor panels with hydronic pipes coils incorporated. To maximise the effectiveness of the radiant heat transfer from the concrete, the soffit needs to be exposed with maximum surface area. This then led to the development of vaulted soffit panels, which were both visually appealing, of high thermal efficiency and reflected light down on to functional spaces. Suspended ceiling panels below the panels contain lighting, comms and sprinklers. Various forms of the 11m span panels were explored, which allowed for air distribution in a plenum/services void above the panels. The exposed concrete frame, which supports the precast geopolymer concrete panels, was designed to incorporate the air distribution system, which supplies the plenum.

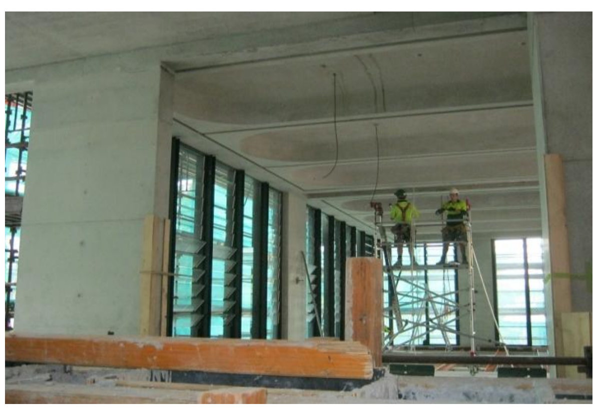

Fig 3. Global Change Institute – vaulted panel soffit

By this stage we had made contact with Wagners, based in Toowoomba who were developing a geopolymer concrete product branded Earth Friendly Cement (EFC). Wagners had undertaken some preliminary testing and had engaged Dr James Aldred who worked for GHD, Sydney Office at the time to produce an initial summary engineering report that would ultimately lead to further verification testing for compliance with AS3600. Wagners were extremely interested to be involved with the GCI, which was to be a leading sustainability driven project. Although the use of geopolymer was so novel that it would not gain any additional Greenstar points in the Material category, UQ as the client understood the significance of the innovation which went beyond Greenstar rating. Wagners were asked to fast track the reporting and testing with a critical cut off date for the interim research report to be delivered to give confidence that use of geopolymer concrete on the project was viable. The Greenstar submission which is currently being assessed does include up to 4 points for the use of the geopolymer concrete on the basis of being a world first innovation and exceeding the Greenstar benchmarks. To us, a critical factor was the acceptance by Dr Aldred of GHD who would ultimately be certifying that the EFC could be considered as concrete in accordance with the design rules of AS3600 and the associated material properties that they are based on. A positive interim report was delivered during the design period and indicative supply costs were entered into the project cost plan. The only issue that was identified as potential concern relative to normal concrete was carbonation resistance however this was not considered to be of significance for our case with internal use only. Subsequent testing has shown that rate of carbonation for the mix design adopted is similar to normal concrete incorporating blended cement. At this point the project consultants accepted EFC geopolymer concrete as the preferred option for the precast floor beams used in the three suspended floors.

A further critical consideration was the ability to supply the EFC concrete to the precast fabricator and also for the precast fabricator to be willing to take on the risk of working with a new product. The design team and Wagners worked closely with Precast Concrete at this stage of the project to ensure that the process was feasible. Bligh Tanner stipulated that a full-scale load test (up to maximum working load) could be undertaken on a panel to confirm the strength and deflection were as predicted. This was a considered prudent considering the world first application of modern geopolymer concrete for suspended construction.

Following receipt of the interim GHD report which was generally positive, Bligh Tanner developed a detailed list of testing that was required to enable our final recommendation of acceptance for use of geopolymer concrete on the GCI project. This recommendation was required regardless of the 3rd party Certification in accordance with AS3600 which Wagners were required to provide in support of the EFC mix design.

3. Compliance Testing

Wagners EFC geopolymer concrete was included in the design for the 33 no. precast floor beams (volume 320m^3) that formed three suspended floors in the building. Bligh Tanner built a specification for the geopolymer concrete in these beams that relied on:

- Testing key material properties referenced in the Australian Standard for Concrete Structures, AS 3600
- Having independent engineering verification that the tested properties showed that the structural performance properties were complimentary to the design basis for design reinforced concrete enshrined in AS 3600.

All tests were undertaken by Wagners Technical services, in some cases using external laboratories. The results were independently assessed by Dr James Aldred of AECOM who Wagners commissioned to provide the independent certification on the EFC geopolymer concrete as supplied. At the end of the supply period Dr Aldred provided certification to the effect that all EFC supplied was in compliance with the project specification, the details of which are presented by Dr Aldred in a separate paper at this conference.

The range of compliance tests covering structural performance included:

- 28 day Compressive strength
- density
- 28 day flexural strength
- 28 day indirect tensile strength

- Modulus of elasticity
- Stress strain curve
- Poissons ratio
- 56 day drying shrinkage
- Creep
- Tensile development lengths for reinforcement bar, bond
- Chloride content
- Sulfate content
- Alkali aggregate reaction
- Load testing of a proto-type beam
- Fire testing of a loaded floor element

All of the test samples, with the exception of creep and the fire and load tests, were cast and made from EFC geopolymer concrete supplied during the supply phase of the project. The relevant Australian Standard test method was used in all cases.

Creep was assessed via full scale prestressed beams which were made in 2010 and have been monitored under load via the use of internal vibrating wire strain gauges.

A fire test was conducted at the CSIRO fire testing station at North Ryde, Sydney prior to project commencement.

The first floor beam panel produced, acted as the proto-type to be load tested. Figure 6 shows the test undertaken where the measured deflection under an equally distributed 10 tonne load was 2.85 mm, slightly less than the predicted 3 mm using an uncracked section analysis.

The testing program revealed a number of beneficial properties of the geopolymer concrete compared to normal GP based concrete, most notably:

- Half the typical 56 day drying shrinkage, at an average value of 320 microstrains
- 30% higher flexural tensile strength than a comparison standard concrete
- Extremely low heat of reaction

These properties would indicate that an improved level of performance would be achieved in a range of typical structural applications.


Figure 4 & 5

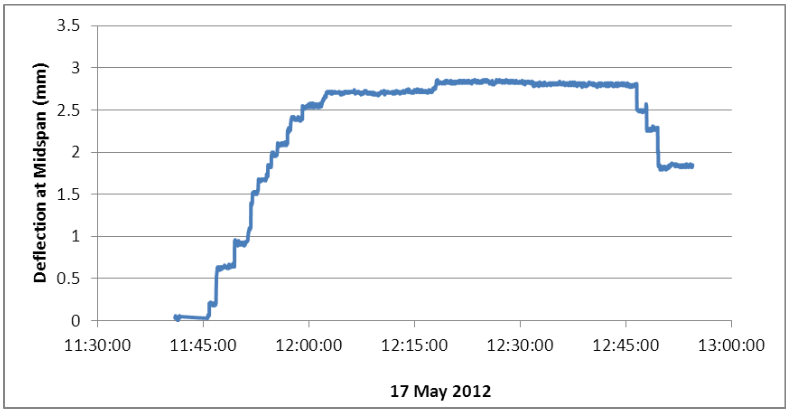

Figure 6. Proto-Type EFC Geopolymer Beam Load Test

4. Practical Aspects

Apart from the design and specification details, the geopolymer concrete was required to meet all of the usual handling requirements involved in batching and delivering concrete. This project had the added complication of dealing with a 2 – 3 hour travel time from a Toowoomba batching facility to a Brisbane precast factory. At the time, the only Wagners batch plant set up to produce EFC was located in Toowoomba. While EFC can be produced in normal concrete batching facilities, it is a requirement that no GP cement contaminate the mix because it causes rapid setting, particularly at higher temperatures. If weigh bins and the like are shared with normal concrete production in a batch plant then it is possible that the fines of GP cement dust will enter the EFC geopolymer mix in enough quantity to cause variable set times.

Based on several years of EFC supply to a range of external projects and trials, Wagners were able to demonstrate that the geopolymer concrete could be handled and finished similarly to normal concrete. In the case of filling and compacting precast moulds the methods are the same.

Curing is required to be carried out for a period of 7 days under ambient curing conditions in order to ensure full strength development as well as produce a sound durable surface. Methods for curing include :

- Leaving the forms in place,
- Covering the hardened surface with plastic sheet,
- Misting with water, or
- Chemical curing compound of not less than 90% efficiency for a minimum period of 7 days. Insufficiently cured geopolymer surfaces will display a weak dusting surface.

On unformed surfaces that are hand placed an initial mist with water should precede covering with the chosen curing method to ensure there is sufficient available moisture for the ongoing geopolymer binder reaction.

During placing operations up until final set, exposed surfaces should not be allowed to dry out. EFC geopolymer has very little bleed, which means on exposed surfaces there will typically be required the application of an evaporative retardant spray during placing operations to ensure the surface does not dry out. Care needs to be taken to ensure any sprays applied to the surface are not subsequently worked into the concrete and increase water content of the geopolymer paste at the surface.

Under ambient temperature conditions of 22 – 33 ^{0}C EFC has a similar set time to normal GP based concrete. Accelerated strength development can be achieved by the application of low heat, keeping the EFC at 38 ^{0}C.

The GCI beams were specified by the project architects to have an off-white colour. The natural colour of EFC after it has fully cured and achieved full strength is off-white, an attribute given by the amount of slag powder contained in the mix as one of the alumino-silicate source powders. In the days immediately following setting and stripping the surface colour of EFC will appear a strong greenish hue, which is due to the slag based geopolymer reaction. After several days exposure to the atmosphere the EFC colour becomes a consistent off-white. This aspect will be a cost effective benefit on architecturally themed work requiring off-white colour.

A practical beneficial aspect of geopolymer concrete in relation to travel time, is that loads can be batched with all ingredients except the activating chemicals and transported up to 12 hours or more to a remote destination in a completely dormant non-reactive state. At the destination the chemicals are added in a dry powder form directly into the Agitator bowl and mixed on site. Using this method the geopolymer concrete was transported from Toowoomba to Brisbane, and activated when the precast factory was ready for casting.

Figure 7. EFC geopolymer concrete being vibrated into the beam moulds at Precast Concrete Pty Ltd factory, Brisbane

The finished precast geopolymer beams were installed into the building structure during the period August to October 2012.

Figure 8 Precast geopolymer beams installation

Following installation, sealing of the precast EFC geopolymer beams was undertaken on site. Several patch trials were carried out to ensure compatibility between the geopolymer concrete and proprietary sealers.

In regards to proprietary sealer products that have a dust inhibiting or surface repair characteristic, it should be noted that they may not have that effect on geopolymer concrete due to its different chemistry. Proprietary dust inhibiting sealers are generally designed to penetrate and react with leftover by-products from the Portland cement hydration reaction which occurs in normal concrete. Trials should be conducted to establish the compatibility of sealers with any particular geopolymer concrete prior to application.

5. Conclusion

Geopolymer concrete has now moved beyond an emerging technology into the space of a structural concrete that can be designed and used in structures and other applications, as long as the necessary verification and testing is undertaken. The term geopolymer is very broad and encompasses a range of different concretes which may have quite different structural properties. The proprietary geopolymer concrete used in the GCI building proved to be fully compliant with the structural performance parameters that AS 3600 is based on.

The use of geopolymer concrete in the multi-storey GCI building provides an example of how a medium sized engineering consultancy went about assessing a new technology's 'fit for purpose' suitability. It is hoped that this example may provide a path for others to explore new and innovative approaches to building that improve the sustainability of our built environment. In association with a range of other sustainability innovations utilised in this building, the geopolymer concrete floor beams help make the GCI building project be an outward communication of its inner purpose.