Analysis and Testing of the 275 Dincel Wall System for Stiffness, Shear & Flexural Capacities

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- Mr Mehdi Habibaghahi and Mr Sepehr Faridmarandi for Finite Element Analyses and design of supporting structures
- Mr Peter Brown and Mr Rami Haddad for overseeing and conducting the tests
- Tech Lab and the Structures Laboratory for the fabrication of test specimens and supporting structures

Executive Summary

The Dincel Structural Walling system comprises of permanent polymer formwork that uniquely snaps together to build all types of structural walling in an efficient manner. When filled with ready mix concrete, the polymer shell provides a strong and durable protective barrier for the concrete infill of residential, commercial and civil walling applications. Dincel walling, which is offered in varying thicknesses, has been used in Australia since the year 2000. The 200 Dincel Wall has been tested during the years 2009-2011 at UTS, where it was demonstrated that the concrete filled polymer encapsulation provides additional flexural capacity and confinement when compared with conventional reinforced concrete walls.

The purpose of the below outlined tests is to demonstrate how 275 Dincel walls when filled with concrete works as a composite structural wall member rather than only being considered as a sacrificial permanent formwork for structural design purposes.

The composite action provided by 275 Dincel Wall as tested and verified by UTS in 2020 offers significant improvements for concrete walls. Namely, some benefits include higher flexural capacity, confinement of concrete, a high degree of ductility, ideal curing conditions (ongoing hydration by permanent encapsulation resulting higher tensile and compressive strength of concrete infill), longevity, reduction or elimination in steel bars usage leading to reduced carbon foot print.

In a separate study, the University of New South Wales (UNSW) originally certified that the concrete and steel reinforcement inside Dincel Walls comply with AS3600 (Concrete Structures Code) and that the polymer encapsulation can be considered as formwork for reinforced concrete.

However, AS3600 has been established for reinforced concrete and is not directly intended for composite members. The Australian National Construction Code (NCC) allows for design engineers to adopt innovative approaches such as composite walling behaviour and can be considered as a “Deemed to Satisfy” approach, provided that NCC clause A2.3 (2) (a) and/or (b) are satisfied.

At the request of Dincel Pty Ltd and BarChip Pty Ltd, A/Prof Shami Nejadi and Dr Harry Far from University of Technology (UTS) were engaged to test the 275 Dincel Wall in accordance with

AS3600 (2018) Appendix B, in order to provide design engineers with verified and tested capacities for use as design input for the composite behaviour of 275 Dincel Wall.

The testing and analytical program was carried out from February 2020 to November 2020. The testing is prepared and executed in accordance with the requirements of AS3600 (2018) Appendix B consisting of the following:

1. **<u>Stiffness Testing (Part A)</u>**

Determination of ductility factors (μ) and flexural rigidity (EI) of 275 Dincel Wall. The determined values can be utilised when designing 275 Dincel shear walls for high rise buildings which are required to resist lateral loads such as earthquake and wind loads. The test specimens consisted of:

- 3 x 275 Dincel specimens filled with plain concrete (f_c' = 40 MPa at 28 days)
- 3 x 275 Dincel specimens filled with plain concrete incorporating 5 kg/m^3 of BarChip 48 macro-synthetics fibres (f_c' = 40 MPa at 28 days)
- 3 x 275 Dincel specimens filled with plain concrete (f_c' = 40 MPa at 28 days) incorporating horizontal and vertical steel reinforcement bars at each face

2. **<u>Shear Testing (Part B);</u>**

Determination of the interface shear capacity of the walling system by testing the interface between two 275 Dincel Wall profiles (panels). The test specimens consisted of:

- 3 x 275 Dincel specimens filled with plain concrete (f_c' = 40 MPa at 28 days)
- 3 x 275 Dincel specimens filled with plain concrete incorporating 5 kg/m^3 of BarChip 48 macro-synthetics fibres (f_c' = 40 MPa at 28 days)
- 3 x 275 Dincel specimens filled with plain concrete (f_c' = 40 MPa at 28 days) with horizontal steel reinforcement bars to provide dowel action

3. **<u>Flexural Testing (Part C)</u>**;

Determination of the flexural capacity of 275 Dincel wall. The test specimens consisted of:

- 3 x 275 Dincel specimens filled with plain concrete, tested at 24 hours when compressive strength was approximately 5 MPa (f_c' = 32 MPa at 28 days)
- 3 x 275 Dincel specimens filled with plain concrete incorporating 5 kg/m^3 of BarChip 48 macro-synthetics fibres, tested at 24 hours when compressive strength was approximately 5 MPa (f_c' = 32 MPa at 28 days)
- 3 x 275 Dincel specimens filled with plain concrete, tested at 28 days (f_c' = 32 MPa at 28 days)
- 3 x 275 Dincel specimens filled with plain concrete incorporating 5 kg/m^3 of BarChip 48 macro-synthetics fibres, tested at 28 days (f_c' = 32 MPa at 28 days)
- 3 x 275 Dincel specimens filled with plain concrete (f_c' = 32 MPa at 28 days) incorporating vertical steel reinforcement bars, tested at 28 days.

Testing was completed in accordance with AS3600 (2018) Appendix B and the results provided can be utilised by design engineers as the equivalent of a 'deemed-to-satisfy' solution of AS3600. AS3600 Appendix B requires a minimum of 2 samples to be tested per condition, this testing regime adopted 3 tested samples per condition in order to determine the mean average values.

- <u>Stiffness Test (Part A):</u>
  - Results demonstrate a ductility factor ranging from 4-6 which is significantly above the capabilities of conventional reinforced concrete. Such a system will prevent the deterioration of stiffness and possible collapse by not allowing the concrete to spall after several loading cycles even if fully cracked.
  - The presence of 275 Dincel does not reduce the lateral stiffness in comparison to a conventional concrete wall.
  - The requirement to provide steel reinforcing bars to each face for a concrete wall was primarily introduced in AS3600 (2018). Clause 14.6.1 requires such reinforcement for ductility purposes during an earthquake (for limited ductile walls

which have a ductility factor of 2). Clause 11.5.2 requires such reinforcement when compressive stresses in the wall exceeds 3 MPa, which is provided to keep conventional brittle and non-ductile concrete walls under a low stress level. For Dincel Walls, the designer may choose to reinforce an adequate length for shear wall purposes only and the remaining walls can be left unreinforced (or reinforced with synthetic fibres) due to the high ductility factors achieved. This way, a progressive collapse during an earthquake is prevented due to the polymer encapsulation of the unreinforced concrete wall subject to positive connections (steel "L "bars at each face connecting to the slab) being provided at the top and bottom of the walls.

- Shear Test (Part B)
    - Within the investigation, it was found that the shear interface failure plane between two Dincel panels/profiles is not flat, but rather consists of a series of dome/conical shaped protrusions at web hole locations. The array of domes provides a keying action throughout the section and subsequently this aids in achieving a higher shear capacity to what is possible by calculation to AS3600 (2018) for the concrete bound within the web holes alone.

- Flexural Testing (Part C)
    - Concrete Cured for 24 hours

      275 Dincel formwork itself due to its unique webbing and perforated internal ring provides significant bending capacity. It was determined within the tests that 275 Dincel walls can be backfilled 24 hours after concrete placement. The system due to its lightweight, snap connections enables the product to be fast and straightforward to install whilst also reducing skilled labour use. Backfilling basement walls 24 hours after concrete infill will allow for early installation of scaffolding for the construction of the super structure.

- Concrete Cured for 28 days

  The polymer shell of 275 Dincel increases the flexural capacity in comparison to what can be achieved with a conventional concrete wall of equivalent thickness. This enables propped cantilever 275 Dincel basement walls spanning in a one-way direction to be designed without the use of steel reinforcement bars, consisting of either a mass concrete infill or mass concrete reinforced with macro synthetic fibres, provided there are suitable steel bars connection at the top and bottom of the walls.

- Other important conclusions include:
  - For a typical building, most walls (i.e. 90%) are designed as non-shear walls which only carry gravity loads. Such walls can include basement walls or super structure walls. Where these walls are constructed from 275 Dincel they can be left unreinforced or reinforced with 5 kg/m^3 of BarChip macro synthetic fibres. The use of steel reinforcement within construction:
    - Represents one of the most significant contributions of carbon emissions amongst standard construction materials, requiring an increase in embodied energy.
    - Imposes increased safety concerns during installation.
    - Requires increased time for installation.
    - Can lead to concrete cancer (concrete spalling due to steel corrosion) if cracks are not prevented, if adequate concrete cover is not achieved or if adequate compaction is not achieved which can ultimately lead to a premature structural life. The panel joints of Dincel profiles, as tested by CSIRO under 6m of water head pressure and confirmed by CSIRO as waterproof, provides protection to such a failure. Furthermore, Dincel walls which are unreinforced or reinforced with synthetic fibres eliminates the potential for concrete cancer all together.

Technical Report

Evaluation of In-Plane Lateral Stiffness and Degree of Ductility 275 Dincel Structural Walling

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1.1 Introduction

This study experimentally investigates the in-plane lateral stiffness and ductility of 275 Dincel structural walling panels (composite Dincel Polymer encased concrete walls) subject to lateral loads using pushover tests to determine lateral strength and ductility characteristics of the panels filled with plain concrete, macro-synthetic fibre reinforced concrete, and steel reinforced concrete. Dincel Polymer is re-engineered rigid PVC consisting of heavy metal free stabilisers, free of phthalates, with test results demonstrating superior fire, smoke, toxicity and chemical resistance in comparison to common PVC.

The procedure of evaluating the available ductility of walls is of importance to enable designers to ensure that structures have adequate available ductility to satisfy the requirements. In addition, Australian Standards including AS1170.4 (2007) and AS 3600 (2018) do not explicitly prescribe the ductility factors for composite 275 Dincel structural walling panels. Therefore, in order to enable structural designers to design 275 Dincel structural walling panels adequately, ductility factors for these types of walls have been extracted from the test results, satisfying the requirements of AS3600 (2018) – Appendix B for the three mentioned cases and proposed in Table 1 and Table 2 of this study for practical applications.

1.2 Experimental Testing Program

The experimental testing program has been carried out at the structural laboratory at University of Technology Sydney (UTS). It involved the construction and testing of eighteen 275 Dincel structural walling panel walls prepared as cantilever beams clamped at their end supports and subjected to a concentrated lateral load at the top of the beams. In fact, for each concrete type, six wall specimens (two specimens for each test) were tested for statistical analysis purposes. The base of each sample was also restrained to provide fixed boundary conditions as close as practicable. The experimental tests were conducted on specimens of 4000 mm long, 825 mm wide with 275 mm thickness. The test setup is displayed in Figures 1-3. The specimens were composed of Dincel Polymer panels anchored at their end and base supports and subjected to concentrated lateral loads by a hydraulic jack. As shown in Figure 1, hydraulic jack (Enerpak 2MN) for applying the lateral load, was mounted 2.5 m away from the end supports and the supports (i.e. base supports and end supports) were located 1 m apart from each other (edge to edge). For each test, ten displacement sensors (five sensors for each wall specimen) were used along the length of the walls (Figure 3) to capture the lateral deflection of each sample and subsequently to determine the stiffness of individual specimens. The test setup and loading rates of the tests were derived in a way that satisfy the requirements of AS3600 (2018) – Appendix B.

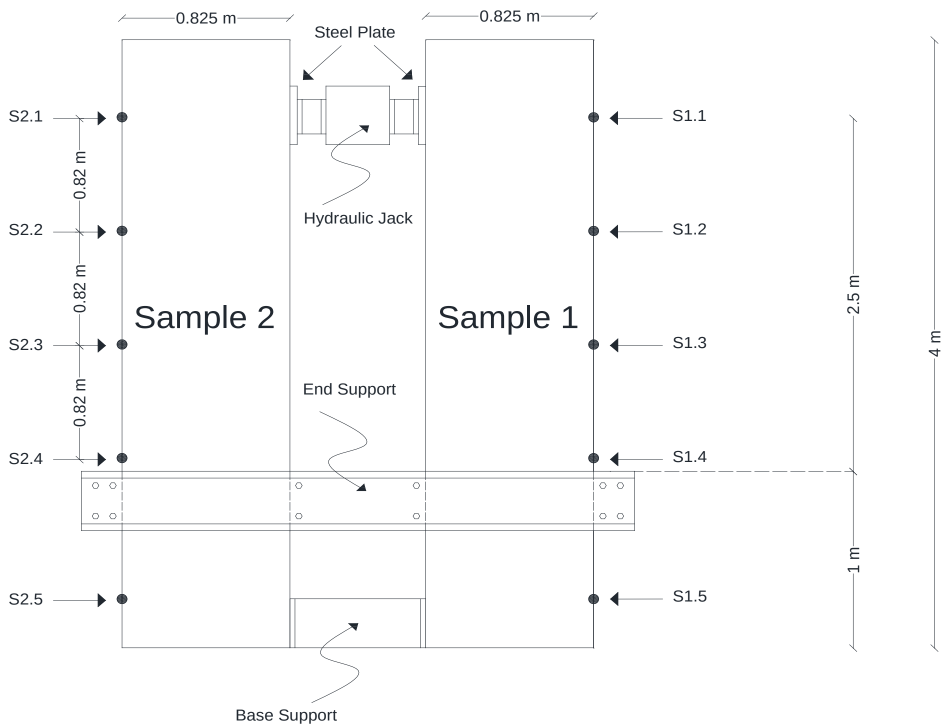


Figure 1: Schematic diagram of pushover test setup (S illustrates sensors)

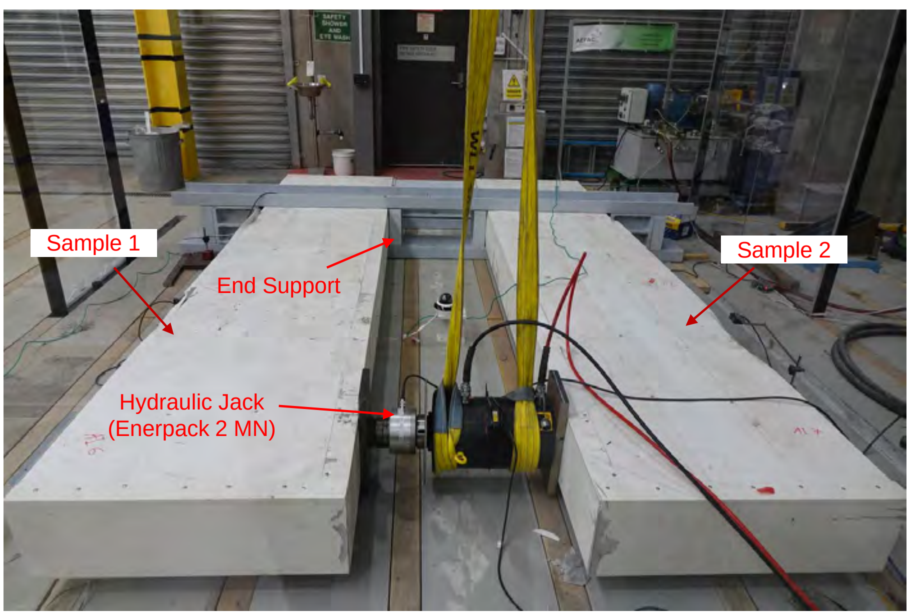


Figure 2: Non-linear static pushover test setup in experimental study

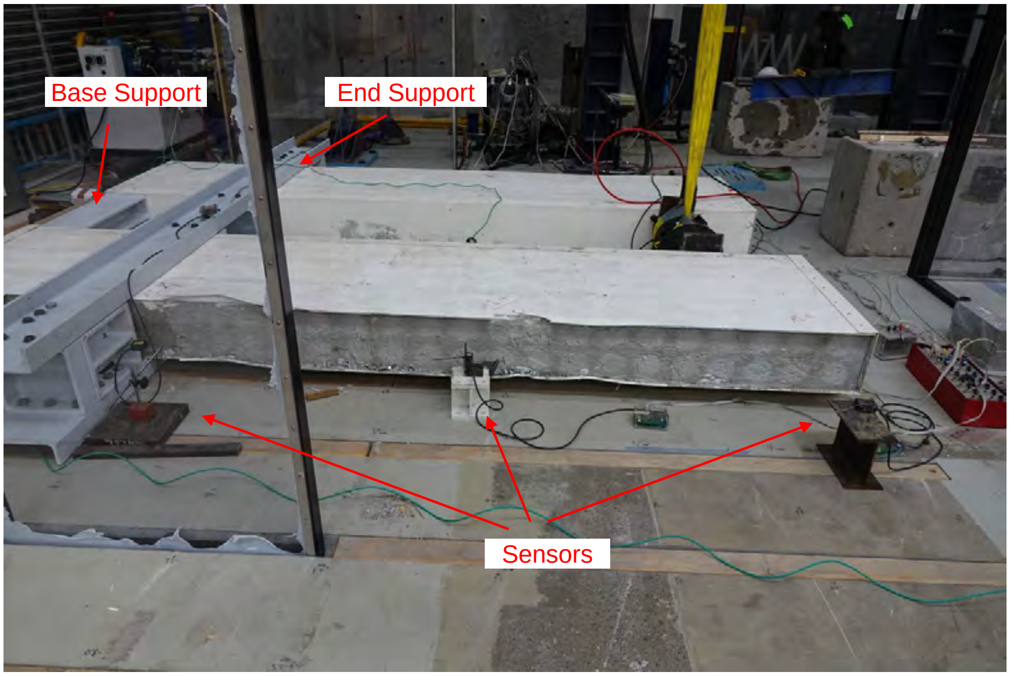


Figure 3: Base and end supports in 275 Dincel structural walling panels

1.3 Employed Materials

All eighteen 275 Dincel structural walling panels were prepared and poured with concrete having compressive strength of 40 MPa at 28 days with 200mm slump and cured on site at UTS Tech Lab. Cylinder testing for both tensile and compressive capacities were carried out by qualified UTS staff for each specimen at the age of 28 days when the testing on the specimens was carried out. The stay-in-place Dincel Polymer formwork system used in this study is known commercially as 275 Dincel structural walling panels. All Dincel panels were filled with three different concrete specimens including plain concrete, BarChip 48 fibre reinforced concrete, and steel reinforced concrete.

Figure 4 illustrates one Dincel Polymer encased wall with steel reinforcements made of three 275mm Dincel panels with overall dimensions of 825mm wide × 275 mm thickness. Three-dimensional views of 275 mm Dincel structural walling panels are shown in Figure 5.

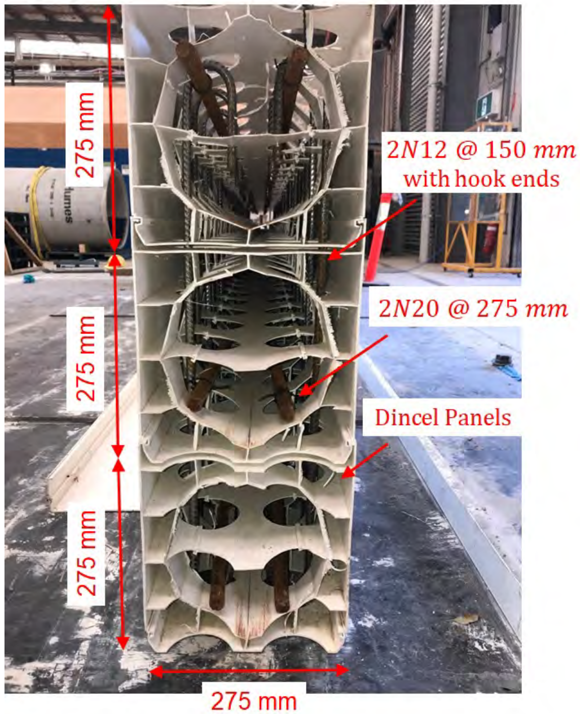


Figure 4: Front view of a Dincel Polymer encased wall with steel reinforcements

In addition, BarChip 48 synthetic fibre reinforcement (as shown in Figure 6) which is a high-performance polypropylene fibre used as structural reinforcement in concrete was added to some specimens. It works by distributing hundreds of thousands of high tensile strength fibres throughout the entire concrete mix. BarChip 48 reinforces every part of the concrete structure, front to back and top to bottom, leaving no vulnerable unreinforced concrete part.

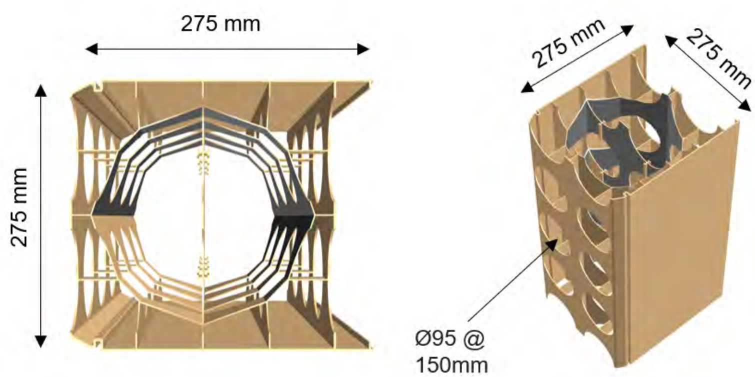


Figure 5: Three-dimensional views of 275 mm Dincel structural walling panels

Figure 6. BarChip 48 macro-synthetic fibre concrete reinforcement

The Dincel panels were orientated horizontally when filled with concrete (due to lifting and handling constraints). Even though a vertical orientation is preferred, adequate internal vibration and a high concrete slump ensured that the concrete compaction within the formwork was sufficient.

Figure 7. Placement and vibration of concrete within Dincel panels orientated horizontally

Specimens were cut following the test to observe the concrete compaction, as shown in Figure 8.

Figure 8. Cut Dincel specimen demonstrating adequate concrete compaction

The concrete slump used at the point of discharge was 180mm (220mm ± 40 mm at the batching plant). For replication of concrete compaction results, it is recommended that a concrete slump which is equal to or greater than this amount is used.

1.4 Test Procedure

In this study, Dincel structural walling panels were subjected to pushover test to determine the load-deflection curve for each specimen. The specimens were laterally loaded monotonically in stroke control (deflection) mode at a constant rate of 3.0 mm per minute equal to 1.5 mm per minute for each sample until failure occurred. The lateral load was controlled using a closed loop PID control system (FCS SmartTest One) and the lateral displacements were recorded using the sensors attached to the compression side of the specimens at different locations as shown in Figure 1. During the test, data was recorded using a data acquisition system (Figure 9). Pushover testing was conducted on the test specimens, which were cast with plain concrete, BarChip 48 fibre reinforced concrete, and steel reinforced concrete and tested at the age of 28 days with the following details:

- Six 275 Dincel structural walling panel specimens filled with plain concrete;
- Six 275 Dincel structural walling panel specimens filled with BarChip 48 macro-synthetic fibre (unit mass 5kg/m^3) reinforced concrete; and

- Six 275 Dincel structural walling panel specimens filled with steel reinforced concrete (N20@275mm normal ductility class deformed reinforcing bars grade D500N according to AS3600-2018)

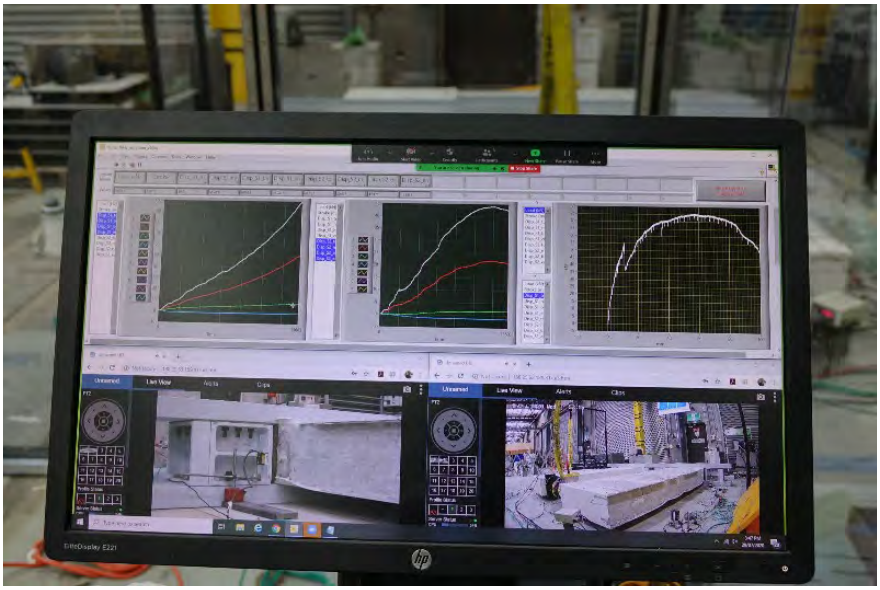


Figure 9: Data acquisition system used in the experimental study

Although the faces touching the base support had a slight curvature due to the fabrication of the specimens, the faces at the load point were reasonably flat. To apply the load laterally on the wall, a system was used at the load point consisting of a steel plate and a hydraulic jack. The steel plate was 10 mm thick by 300 mm wide by 300 mm long. During loading, Sample 2 indicated less movement at the end support compared to Sample 1 and consequently it led to less rotation. In order to prevent rotation in some samples, they were reasonably packed tight at the end support with packing plates to minimise looseness in the system during the test procedure. The quasi-static test was stopped when the specimen was completely cracked at the base of the wall. The crack pattern characterising the bending failure mode of sample 1 is illustrated in Figure 10 at maximum top displacement.

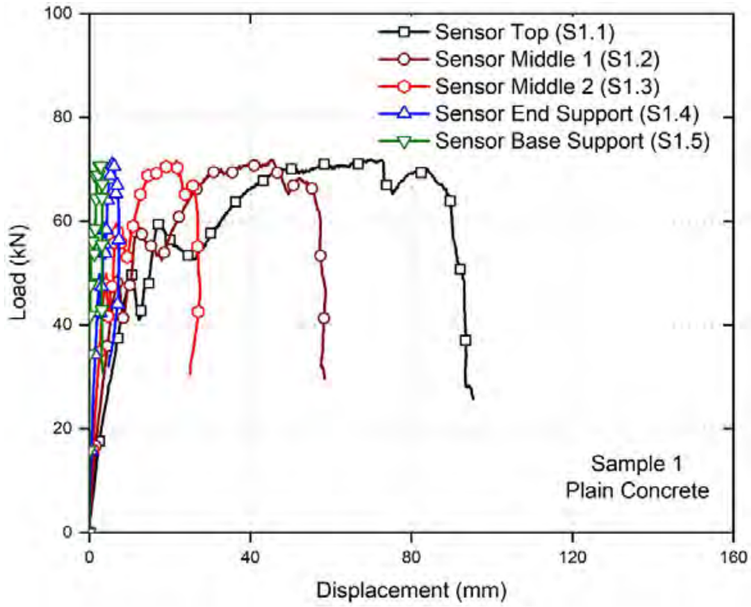
During the test, bending cracks developed at the tensile side of the wall, then horizontally propagated towards the centre line of the wall, and finally passed the centre line of the wall, towards the compressive side. Crack lengths continued to increase with the imposed top displacement. Prior to the bending failure of the wall, the bottom face of the wall was heavily cracked, emphasising the strong penetration of the bending crack in the core wall.

Figure 10: Failure mode of the walls consisting of plain concrete infill under compressive lateral loads

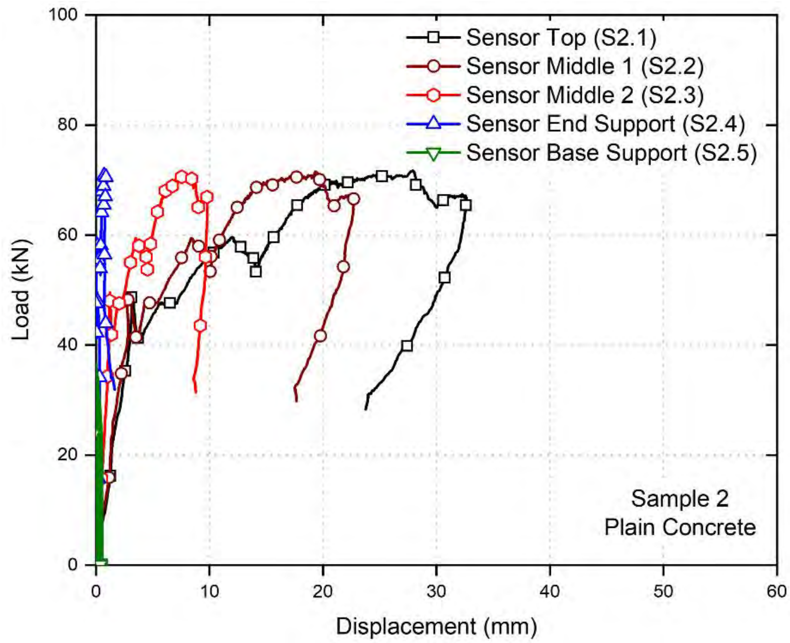
Figure 11: Section of specimen consisting of plain concrete infill at failure plane

1.5 Results and Discussion

The main focus of this study is the non-linear static (pushover) testing of composite Dincel Polymer encased concrete walls (Dincel structural walling panels) based on the provisions for seismic design of buildings to AS 1170.4 (2007). The average results of pushover tests for the structural walls subjected to lateral loads, which capture the material non-linearity of the structures, are presented in the form of load-deformation curves in Figures 12-14. As it can be seen in Figures 12-14, in all the conducted tests, Sample 2 exhibits less movement under the lateral load compared to Sample 1. A more careful look at the results reveals that although all walls show similar response patterns, Dincel Polymer encased concrete walls with steel reinforcements exhibit a considerable increase in strength during the test. The ultimate strength of Sample 1 is improved by nearly three times, from 72 kN and 75 kN for the plain and BarChip concrete specimens respectively to 228 kN for the steel reinforced concrete specimens. The enhancement in terms of ductility is also clearly noticeable, with a shear failure at 100 mm and 80 mm (measured by top laser), for steel reinforced and other specimens (plain and BarChip concrete), respectively. As a result, using steel reinforcements appears to be effective for delaying the shear failure.

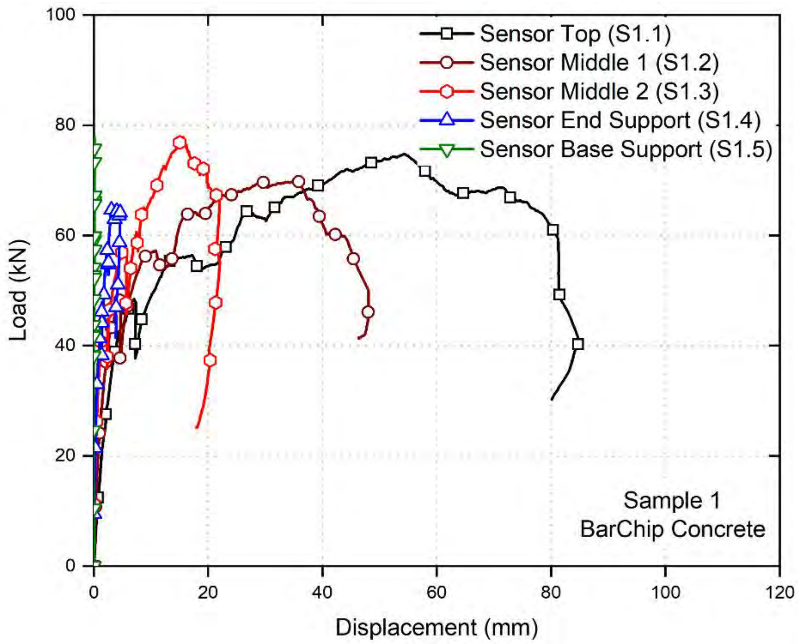


(a)

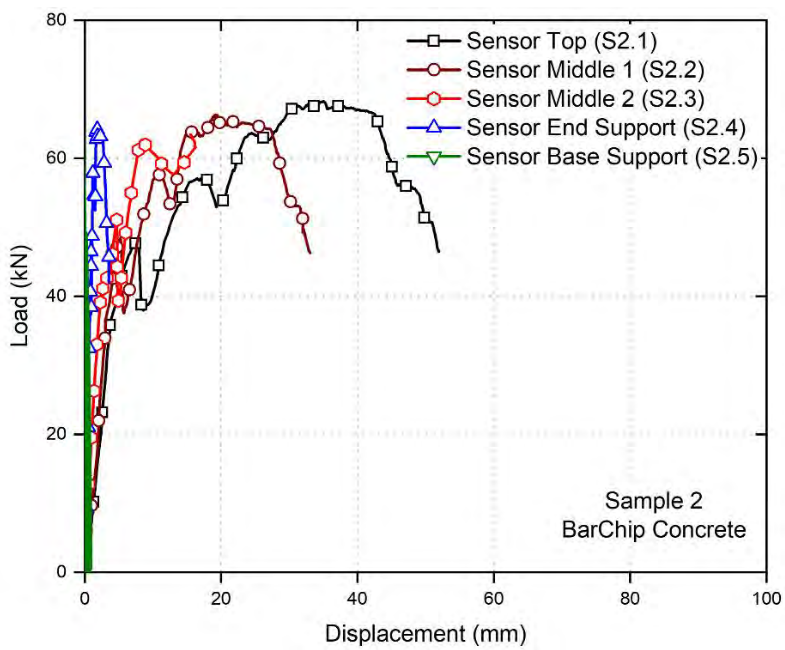


(b)

Figure 12: Average load-displacement curves measured by different sensors in composite Dincel Polymer encased walls filled with plain concrete for (a) Sample 1 (b) Sample 2

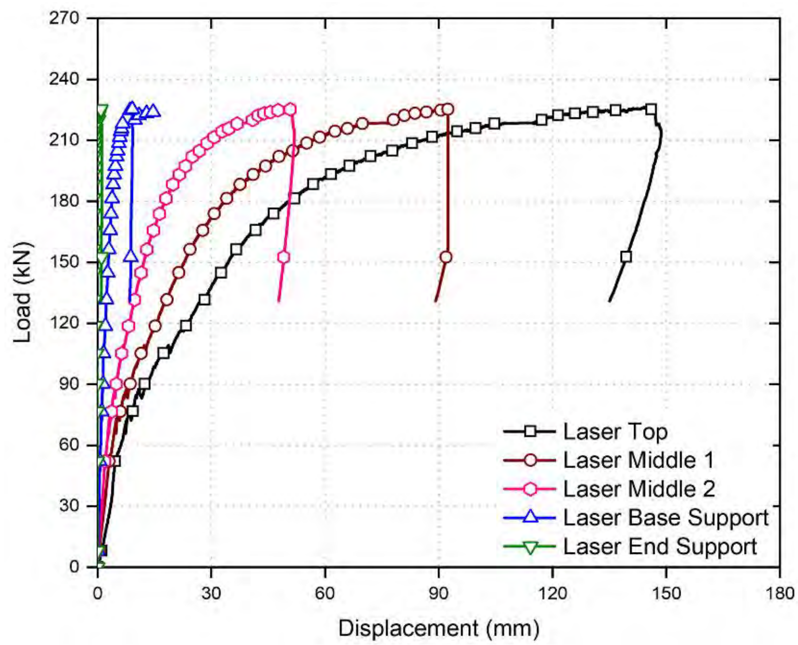


(a)

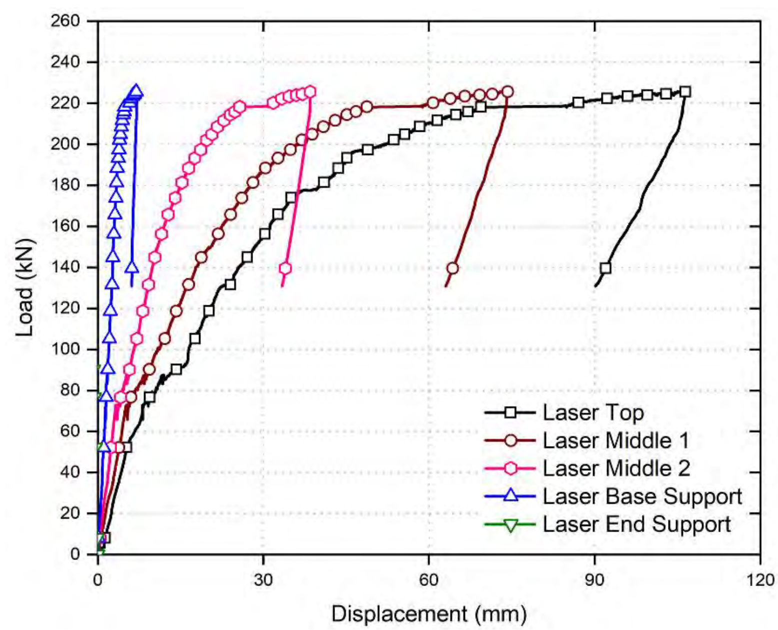


(b)

Figure 13: Average load-displacement curves measured by different sensors in composite Dincel Polymer encased walls filled with BarChip 48 concrete for (a) Sample 1 (b) Sample 2



(a)



(b)

Figure 14: Average load-displacement curves measured by different sensors in composite Dincel Polymer encased walls filled with steel reinforced concrete for (a) Sample 1 (b) Sample 2

Average results of non-linear static tests, measured by top sensors, on Dincel structural walling systems filled with three different types of concrete are shown in Figure 15.

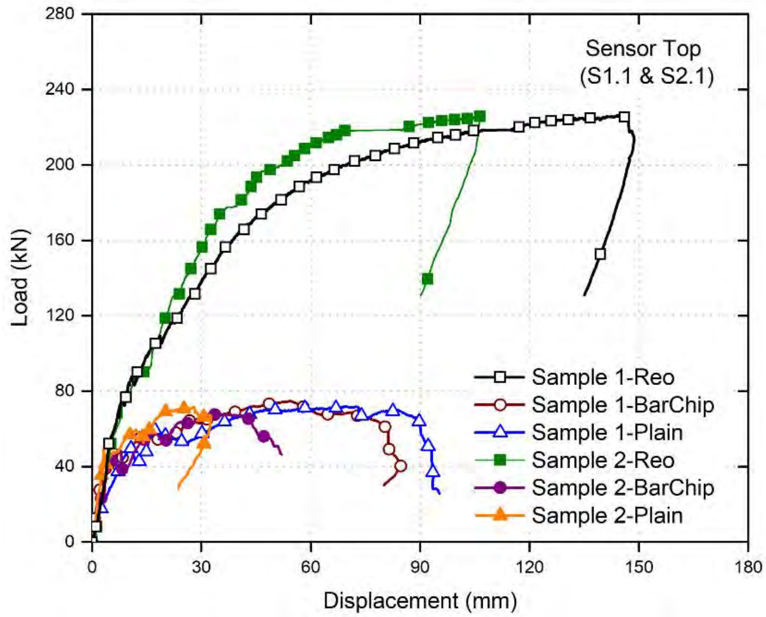


Figure 15: Average load-displacement curves measured by top sensors in Samples 1 and 2 for all specimens

As illustrated in Figure 15, the first stage of the load–displacement curve is very similar for both steel and BarChip 48 reinforced concrete specimens up to the displacement equal to 4 mm. Indeed, the initial stiffness remains almost unchanged by using reinforced concrete specimens. Using BarChip 48 macro-synthetic fibre reinforced concrete turns out to be very efficient by improving both strength and ductility compared to unreinforced concrete specimens. In addition, for BarChip 48 specimens, the failure becomes more ductile than plain concrete specimens for which displacement increases at the constant load of 70 kN. For BarChip 48 specimens, it can be remarked that the strength decrease is very progressive highlighting the ductility of the failure and it can be understood that the Dincel Polymer encased walls filled with BarChip 48 could be pushed to a higher level of displacement. However, filling Dincel panels with BarChip 48 concrete does not provide a significant gain of ultimate strength in comparison to the plain concrete specimens.

From the capacity curves, the yield displacement and the maximum expected displacement (target displacement) can be determined. In dynamic analysis of structures responding to a major earthquake in the inelastic range, it is usual to express the maximum deformations or displacements in terms of ductility factors, where the ductility factor (μ) is defined as the maximum deformation (Δ_u) divided by the corresponding deformation present when yielding occurs (Δ_y). In fact, the use of ductility factors permits the maximum deformations to be expressed in non-dimensional terms as indices of inelastic deformation for seismic design and analysis. Various methods have been presented by different studies to estimate the maximum and yield displacements based on the pushover test results. The most commonly known methodology for the determination of ductility values for reinforced concrete (not for composite materials) was introduced by "*Park, R. 1988, 'Ductility evaluation from laboratory and analytical testing', Proceedings of the 9th world Conference on Earthquake Engineering, Tokyo-Kyoto, Japan, pp. 605–16.*" Within this study, the recommendation proposed in Fig. 2d has been adopted as the basis of the 'AS1170.4 Commentary method' for the calculation of ductility factors. The latest work (Refer to Appendix 1 of this report) by J. C. Vielma, M. M. Mulder (*16th World Conference on Earthquake Engineering, 16WCEE 2017, Santiago Chile, January 2017*) demonstrates that the Park (1988) method is conservative for Dincel Polymer Composite.

In this study, the tangent stiffness method (refer above references) has been adopted which demonstrates very close agreement with the studies by J. C. Vielma, M. M. Mulder (Refer Appendix 1). In the Tangent Stiffness Method, yield displacement is determined based on the equivalent elasto-plastic curve with the same elastic stiffness and ultimate load as the real structure. In addition, the maximum deformation is defined as the displacement corresponding to the peak of the load-displacement curves. Average load-displacement curves, measured at the top laser, for both Samples 1 and 2 are shown in Figures 16-18. As illustrated in Figures 16-18, the maximum deformation (Δ_u) measured for steel reinforced concrete specimens (120 mm) is three times the deformations measured for plain and BarChip 48 specimens.

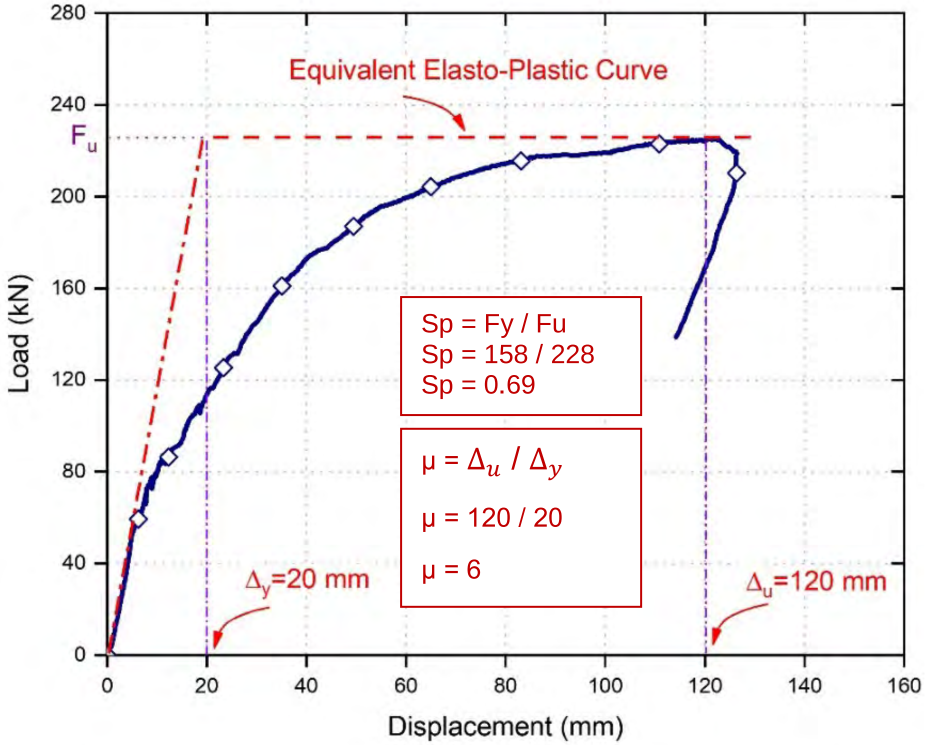


Figure 16: Finding yield and target displacements for 275 Dincel polymer encased reinforced concrete specimens (Average of Samples 1 and 2)

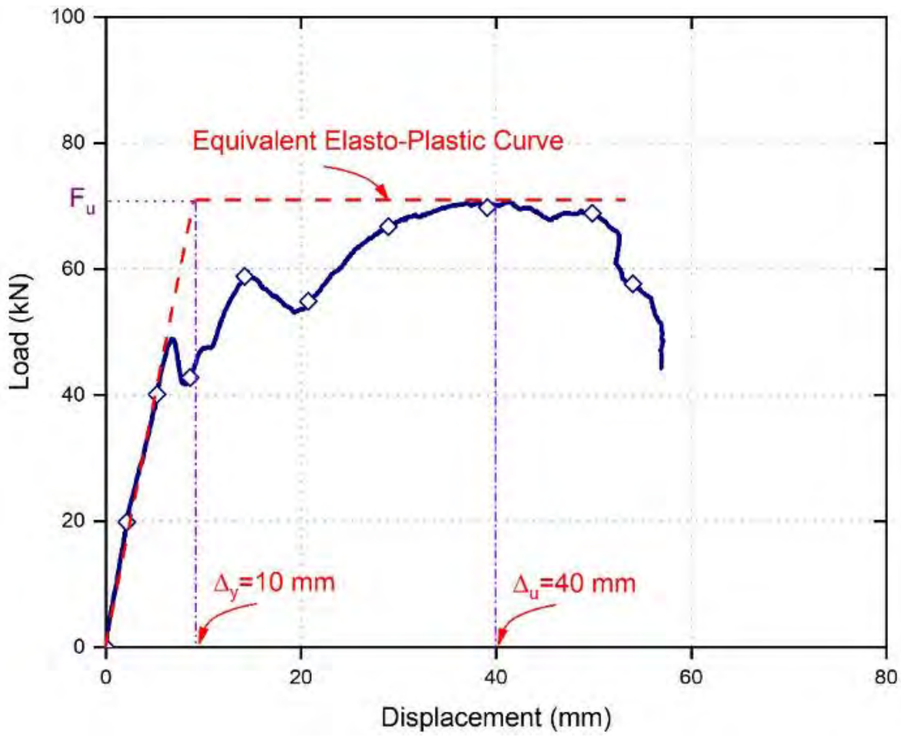


Figure 17: Finding yield and target displacements for 275 Dincel polymer encased plain concrete specimens (average of Samples 1 and 2)

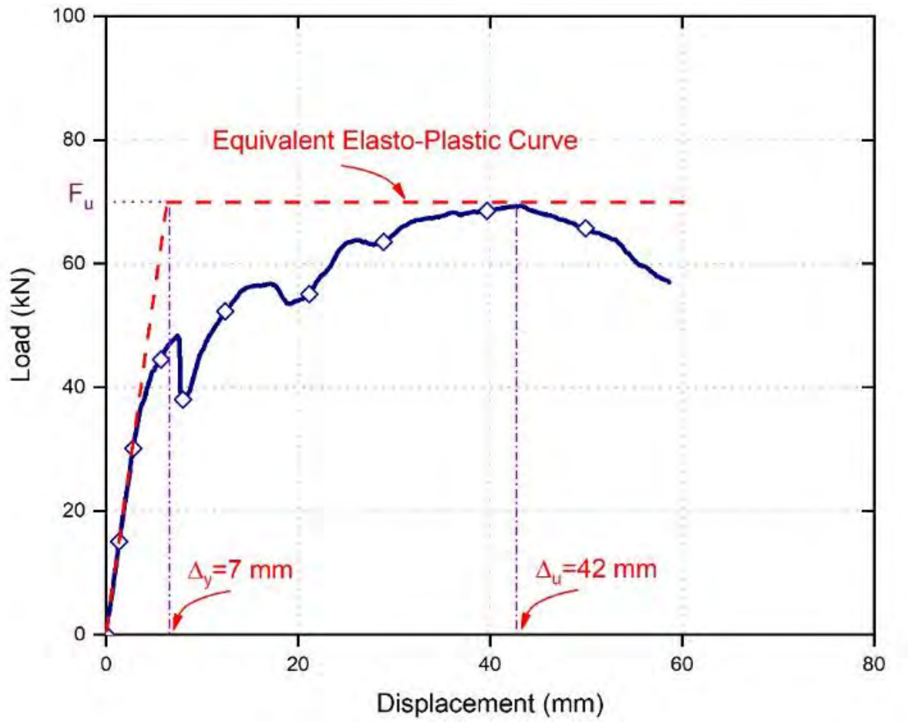


Figure 18: Finding yield and target displacements for 275 Dincel polymer encased BarChip 48 concrete specimens (average of Samples 1 and 2)

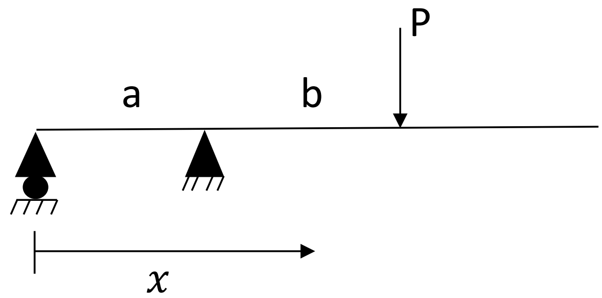
According to Figures 16-18, ductility factor (μ) calculated for plain concrete walls is 4 ($\mu = 4$), while this factor increases to 6 for BarChip 48 and steel reinforced concrete specimens. The ductility factor required by AS 1170.4 (2007) may vary between 1 for elastically responding structures to as high as 4 for fully ductile structures. In this way, all the 275 Dincel Polymer encased plain concrete walls evaluated in this study can be categorised as fully ductile structures according to Table 14.3 of AS3600 (2018), although 275 Dincel Polymer encased BarChip 48 specimens exhibit more ductility which indicates a higher performance from BarChip synthetic fibre reinforcements during lateral loading. In addition, structural performance factor (S_p) as an additional ability of the total structure, including Dincel Polymer panels and concrete specimens, for resisting earthquake motion can be determined based on AS 1170.4 (2007) and AS 3600 (2018). According to Table 14.3 of AS 3600 (2018) for all concrete walls with fully ductile behaviour, structural performance factor (S_p) can be considered equal to 0.67. Ductility factors (μ), structural performance factors (S_p) and effective flexural rigidity (EI) of composite Dincel Polymer encased concrete walls calculated in this study are summarised in Table 1 and Table 2.

Table 1: Ductility and stiffness parameters of composite 275 Dincel Polymer encased concrete walls

Specimen	Ductility Factor (μ)	Performance Factor (S_p)	Initial in-plane lateral Stiffness (K_i) (N/mm)	Effective in-plane lateral Stiffness (K_e) (N/mm)	Post-Yield Stiffness (αK_e) (N/mm)
275Dincel + Steel Reinforced	6	0.67	11000	6400	1100
275Dincel + BarChip Concrete	6	0.67	10000	5300	300
275Dincel + Plain Concrete	4	0.67	8000	4800	120

Note: The following equations have been used in calculation of the parameters shown in Table 1:

EI: Flexural Rigidity



$a = 1000\ mm$

$b = 2500\ mm$

$x = 0.0\ to\ 3500\ mm$

Initial Stiffness:

$$k_i = \frac{P}{\Delta} = \frac{(EI)_i}{\left[(a+b)\left(\frac{x^2}{2}\right) - \frac{x^3}{6} - \frac{3a^3+4ba^2}{6} + \frac{a^3}{6} - \frac{7}{6}ba^2\right]}$$

Effective Stiffness:

$$k_e = \frac{P}{\Delta} = \frac{(EI)_{eff}}{\left[(a+b)\left(\frac{x^2}{2}\right) - \frac{x^3}{6} - \frac{3a^3+4ba^2}{6} + \frac{a^3}{6} - \frac{7}{6}ba^2\right]}$$

The Effective Flexural Rigidity (EI) values for plain concrete, BarChip concrete and steel reinforced concrete have been determined in accordance with AS3600 Appendix B, using the test results and are shown in Table 2. The rigidity values for a 270mm conventionally reinforced concrete wall (with the same concrete grade, width and steel reinforcement as the test specimen) have also been provided for comparison purposes.

Table 2: Measured initial and effective flexural rigidity (EI)

Specimen	Initial Flexural Rigidity (N.mm^2)	Effective Flexural Rigidity (N.mm^2)
275Dincel+Plain	75×10^{12}	45×10^{12}
275Dincel+Barchip	94×10^{12}	49×10^{12}
275Dincel+Reo	103×10^{12}	60×10^{12}
Conventional-Reinforced Concrete Wall	429×10^{12}	55×10^{12}

Based on the capacity curves, also the initial stiffness (K_i), the effective stiffness (K_e), and the post-yield stiffness (αK_e) of the tested specimens can be determined. While initial stiffness (K_i) is defined as the slope of linear section (elastic part) of the load-displacement curves, the effective stiffness (K_e) can be defined as the slope of the line passing through a point corresponding to $0.6F_y$ where F_y is the yield load. Different in-plane lateral stiffness parameters of Dincel Polymer encased concrete walls investigated in this study are determined in Figures 19-21 and are summarised in Table 1. Referring to Figures 19-21 and Table 1, it is observed that 275Dincel + steel reinforced concrete walls generate the highest in-plane lateral stiffness value, followed by 275Dincel + BarChip 48 and then 275Dincel + plain concrete specimens. It is noticed that in Dincel Polymer encased concrete walls filled with steel reinforced concrete compared to BarChip 48 specimens, the initial in-plane stiffness is not considerably modified; the behaviour is almost identical up to the load of 40 kN corresponding to a lateral displacement of 4 mm. As shown in Figures 19-21, for the Dincel Polymer encased walls filled with reinforced concrete, the pushover analysis gives the in-plane lateral effective stiffness of 6400 N/mm, while it yields the in-plane lateral effective stiffness of 5300 and 4800 N/mm for BarChip and plain concrete walls, respectively.

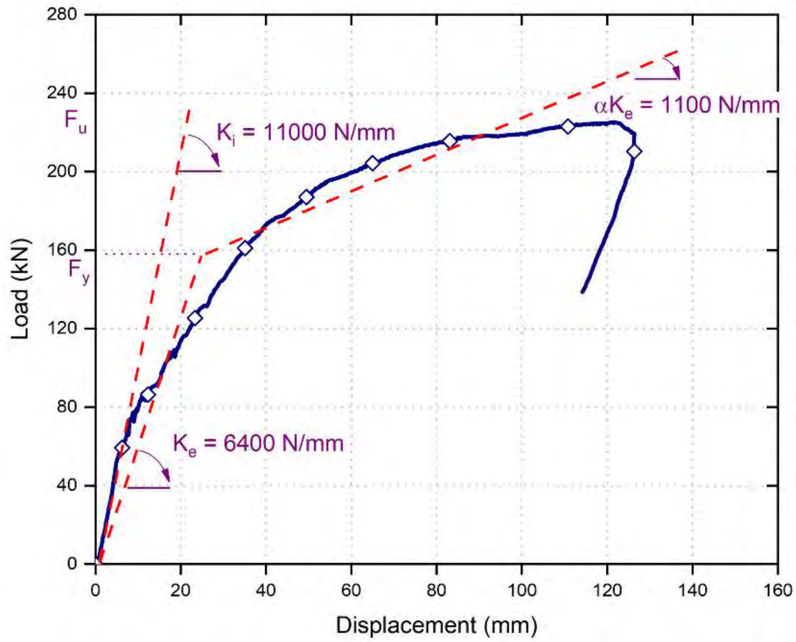


Figure 19: Finding lateral stiffness values for 275 Dincel encased reinforced concrete specimens (average of Samples 1 and 2)

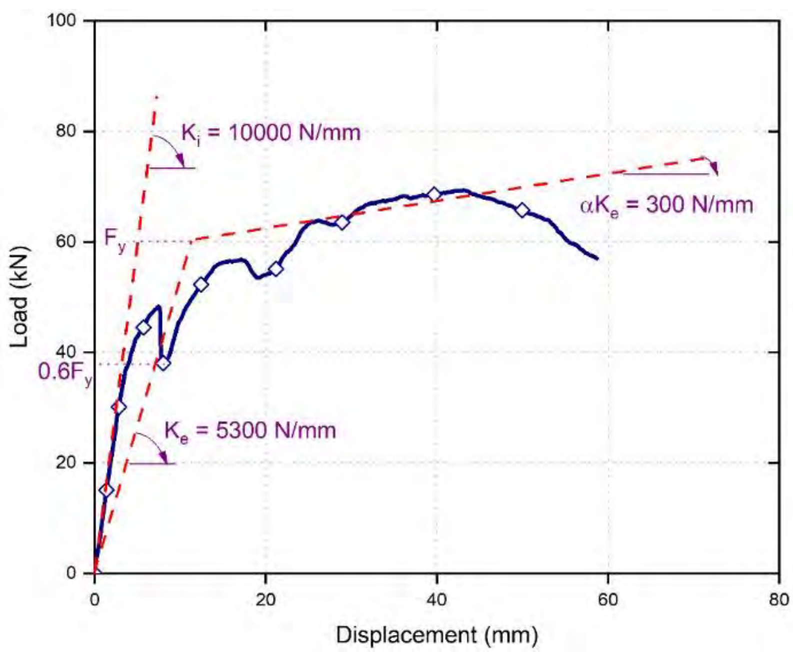


Figure 20. Finding lateral stiffness values for 275 Dincel encased BarChip 48 concrete specimens (average of Samples 1 and 2)

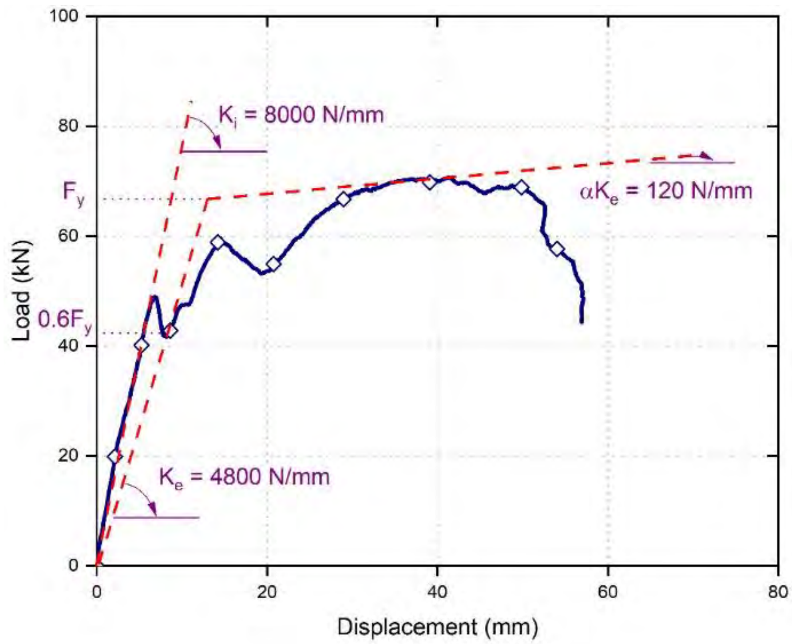


Figure 21: Finding lateral stiffness values for 275 Dincel encased plain concrete specimens (average of Samples 1 and 2)

1.6 Numerical Analysis and Verification of the Results

In order to verify and prove consistency of the calculated values with measured test results, we have conducted a nonlinear static analysis of composite Dincel polymer encased concrete wall based on the experimental tests. A finite element software (ATENA-GiD) has been used to determine the behaviour of structure under lateral load at the University of Technology Sydney (UTS).

This analysis simulated the structural behaviour of Dincel Wall under lateral load. For this modelling program, two cantilever beams subjected to concentrated lateral load at the top of the beams. The base of the beams was also restrained, so the boundary conditions are considered fixed.

The fracture-plastic model combines constitutive models for tensile (fracturing) and compressive (plastic) behaviour. The fracture model is based on the classical orthotropic smeared crack formulation and crack band model. It employs Rankine failure criterion, exponential softening, and it can be used as rotated or fixed crack model.

- **Geometry**

The geometry is created by using the ATENA-GiD graphical tools from elementary objects sequentially, starting from points, lines and finally surfaces and volumes. By means of lines, surfaces can be made, and using surfaces, volumes can be formed (solid objects). Details of this input shall be skipped since it belongs to standard GiD functions. In GiD, it is also possible to create volumes directly from step file format from other FEM software such as ABAQUS, as shown in Figure 22, which indicates the complex geometry of Dincel formwork which created by using SolidWorks mechanical software. The final geometrical models in GiD are shown in Figures 23 and 24 containing two types of objects: 3D volumes for concrete, plate, Dincel formwork, and 1D lines for discrete reinforcement bars respectively.

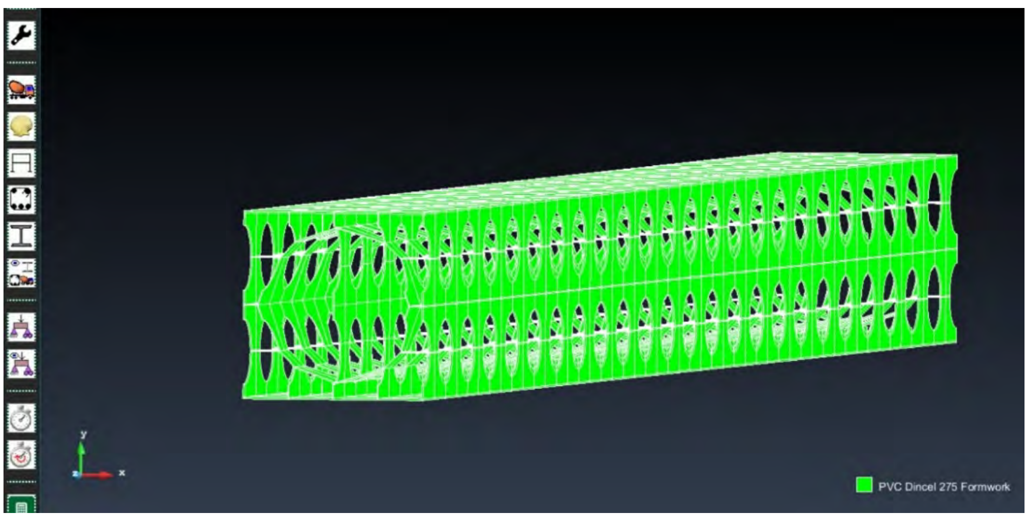


Figure 22: The geometry of Dincel 275 mm walling panel in GiD environment

- **Material**

The materials can be defined and assigned to the geometry. Since we intend to model the Dincel polymer formwork, we defined them in separate sections.

- **Concept of Material Model for Concrete**

The material model for concrete includes the following effects of concrete behaviour:

  - Nonlinear behaviour in compression including hardening and softening,

- Fracture of concrete in tension based on the nonlinear fracture mechanics,
- Biaxial strength failure criterion,
- Reduction of compressive strength after cracking,
- Tension stiffening effect,
- Reduction of the shear stiffness after cracking (variable shear retention),
- Two crack models: fixed crack direction and rotated crack direction.

A perfect bond between concrete and reinforcement is assumed within the smeared concept. No bond-slip can be directly modelled except for the one included inherently in the tension stiffening.

The reinforcement in both forms, smeared and discrete, is in the uniaxial stress state and its constitutive law is a multi-linear stress-strain diagram.

- **Reinforcement**

Reinforcement can be modelled in two distinct forms; discrete and smeared. In this case, discrete reinforcement is in the form of reinforcing bars is modelled by truss elements.

The longitudinal reinforcement is by bars 2N20 at 275 mm, and by stirrups N12 with spacing 150 mm in beams. Since there are different possibilities to model reinforced concrete, firstly a decision was made about the modelling approach. Concrete was modelled as 3D brick elements. For this, we chose the hexahedra elements. The longitudinal reinforcement was modelled as discrete bars. The stirrups were modelled as a smeared reinforcement within the reinforced concrete composite material. This is a simplified method, in which we avoid the input of detail geometry of stirrups. In the smeared model, individual stirrups' exact position is not captured, and only their average effect is taken into account.

- **BarChip 48**

Table 3 shows the characteristics of Barchip 48 fibre reinforcement used in the analysis. For modelling the FRC BarChips, the issue is to find the appropriate input material parameters to successfully model FRC. In particular, the tensile parameters that are important for FRC must be determined properly. The measured response of direct tensile test can serve as direct input of the parameters into the material model. Unfortunately, preparation of test sample is complicated, and the test is not performed very often. The three or four-point bending tests are more common. Results can also be used for the material model; however, they cannot be directly put into the model. Inverse analysis of the results has been performed to identify model parameters correctly.

Table 3: characteristic properties of BarChip 48 fibre reinforce material

Characteristic	EPC BarChip 48	Standard
Fibre Class II	For structural use in concrete, mortar and grout	EN 14889-2
Tensile Strength	640 MPa	JIS L 1013/ISO 2062
Young's Modulus	12 GPa	JIS L 1013/ISO 2062
Length	48 mm	
Anchorage	Continuous Embossing	
Base Material	Virgin Polypropylene	
Alkali Resistance	Excellent	
CE Certification		0120 - GB10/79678
ISO 9001:2008 Certification		JKT0402914

- **Creating FRC Material**

It is necessary to use results from laboratory tests, e.g. three-point bending tests, compression tests on cubes or cylinders and test for the elastic (Young´s) modulus. The data from three-point bending test (load-displacement diagrams), compression test (compressive strength) and Young´s modulus are available for the case presented in this study.

- **Dincel Formwork Interface**

In this case, we define PVC material for Dincel formwork. In order to provide simplicity to the interface surface between the concrete and formwork, we changed the formwork geometry. To define the interface connection between the surface of concrete and formwork, we adopted the experimental results of shear tests at Tech Lab.

Besides, the interface effects between concrete materials and Dincel Polymer are applied as interface surfaces in GiD.

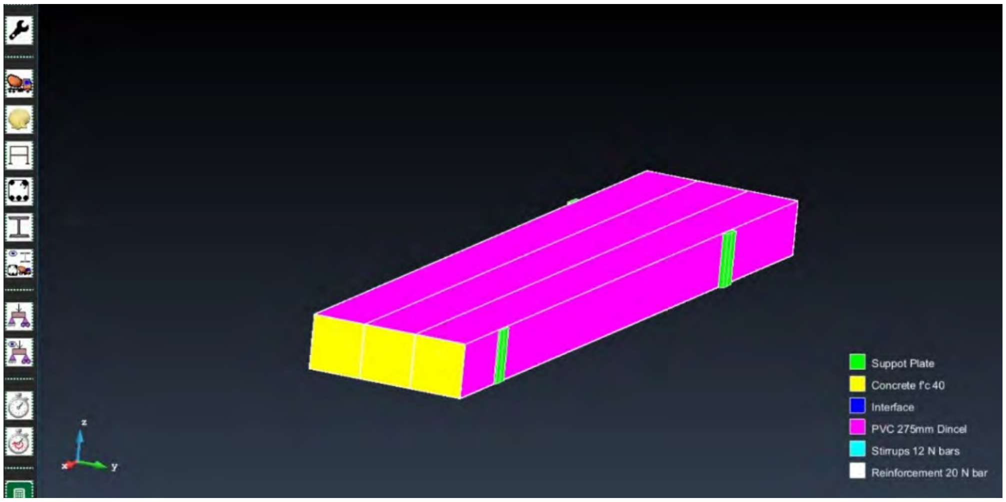


Figure 23: Defining different materials for specimens

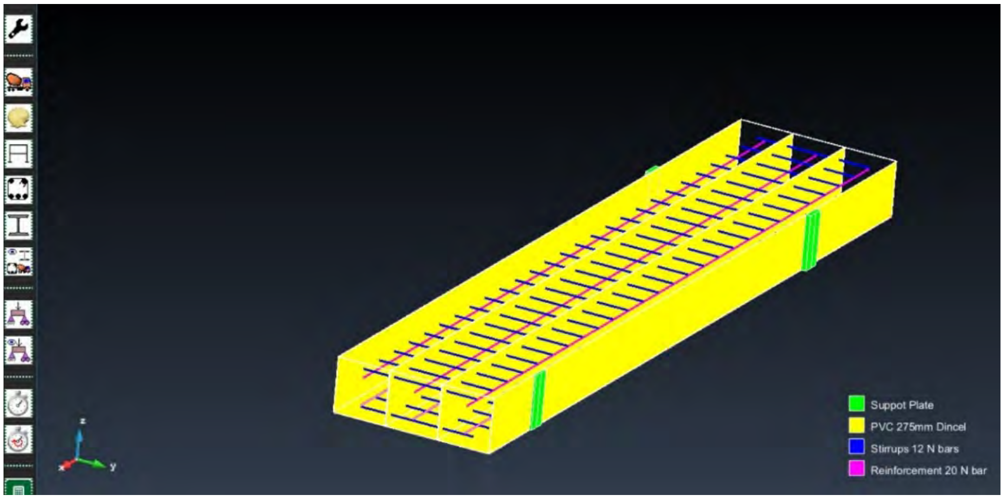


Figure 24: Defining different materials and reinforcement bars positions

- **Supports and Loading**

The supports and loading can be specified using three elastic plates. We define the fixed nodes by checking X, Y, Z Constrains. Also, we assigned the Point-displacement at the node of the load application. The load is applied as a vertical imposed displacement. Consequently, the force value is a reaction at this node.

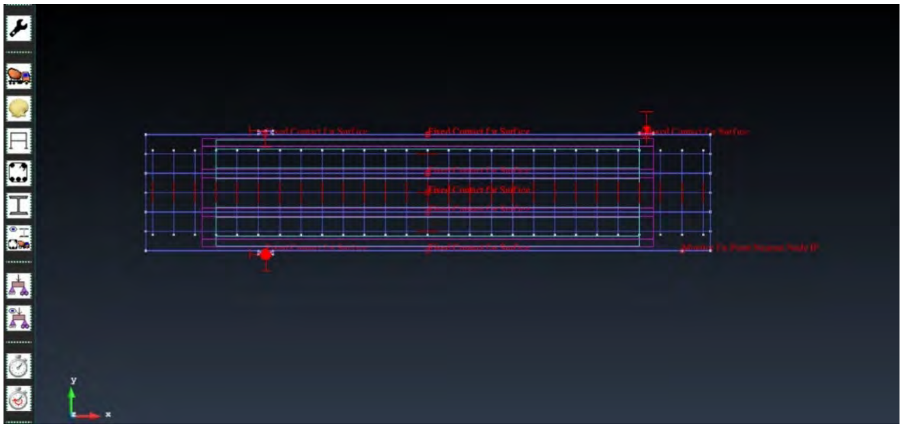


Figure 25: Assigning load point and support boundary conditions

- **Meshing**

In the preceding description, the geometry was defined, and all properties (material, supports, loading) were assigned to the geometry. In this case, we use a simple method, in which divisions on all lines are defined. If opposite lines have the same division, we can create a regular mesh.

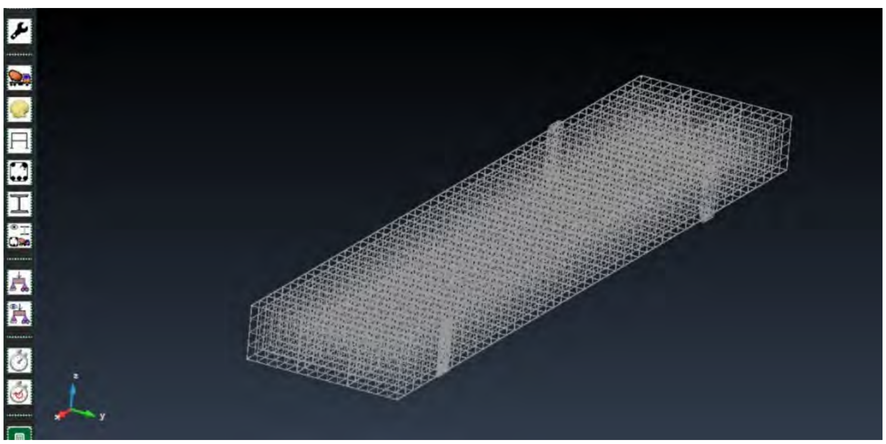
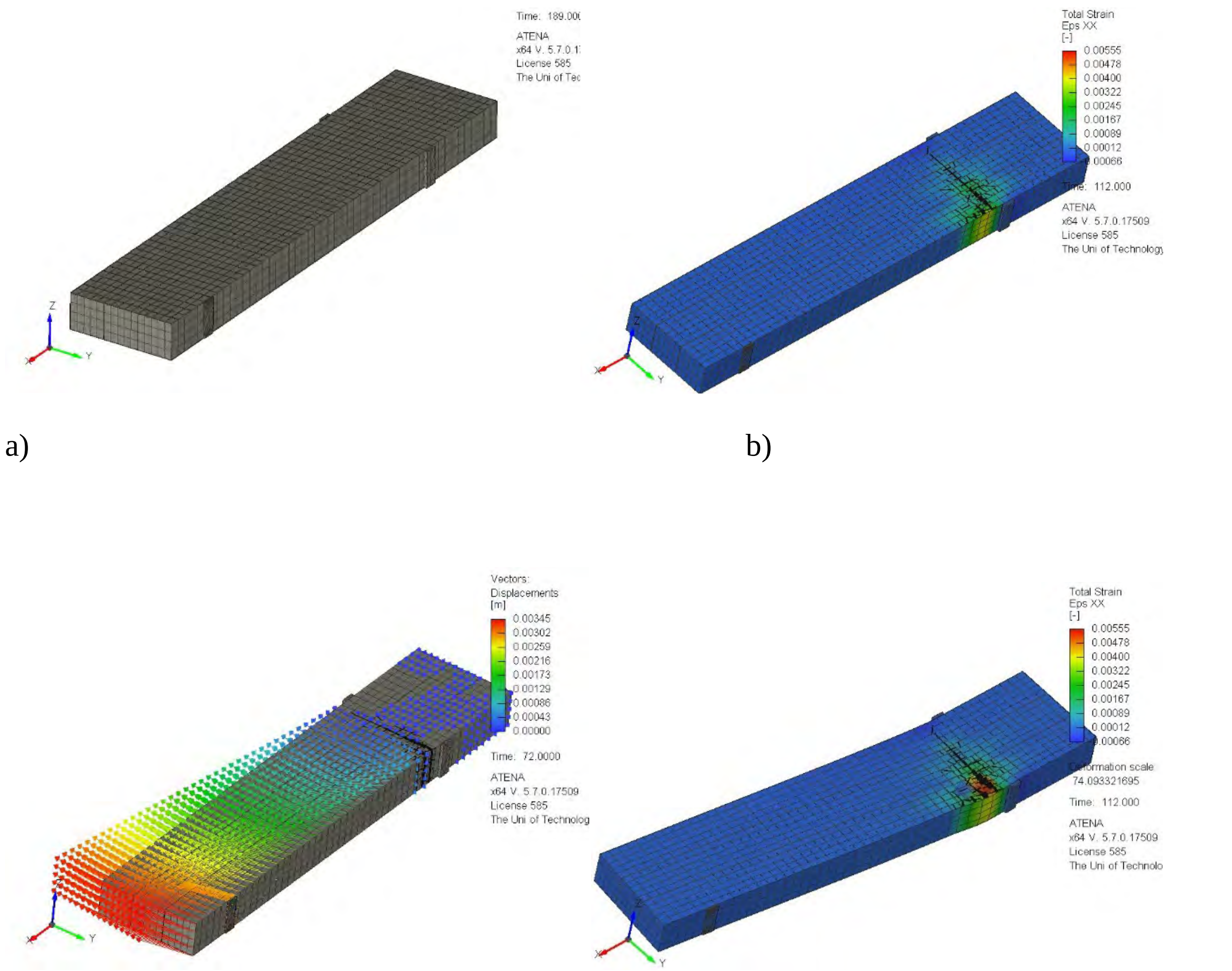


Figure 26: Mesh settings for specimens in pre-processing software

- **Results and Discussion**

The objective of this simulation is the nonlinear static analysis of composite Dincel polymer encased concrete wall based on the experimental tests conducted at UTS Tech Lab. The numerical results of this modelling are presented in the form of load-deformation curves in the following figures. Comparing the results by 3D FEM structural analysis and three different experimental tests, a good correlation was found.



a) b)

c) d)

Figure 27a. Indicates the geometry of the wall before loading. Figure 27b is the crack pattern at the end of the analysis. Figure 27c shows the displacement vector. Deformed shape and crack are shown in Figure 27d.

The load-deflection curve provided to compare the results of the experimental test and numerical modelling is shown in Table 4.

Table 4: Comparison of the experimental values and calculated values using numerical modelling of initial and effective flexural rigidity (EI)

Specimen	Initial Flexural Rigidity	Initial Flexural Rigidity Calculated	Effective Flexural Rigidity	Effective Flexural Rigidity Calculated
275Dincel + Plain Concrete	75 x 10^12	70 x 10^12	45 x 10^12	48 x 10^12
275Dincel + BarChip Concrete	94 x 10^12	90 x 10^12	49 x 10^12	52 x 10^12
275Dincel + Steel Reinforced	103 x 10^12	98 x 10^12	60 x 10^12	63 x 10^12
Conventional Concrete Wall	429 x 10^12	426 x 10^12	55 x 10^12	53 x 10^12

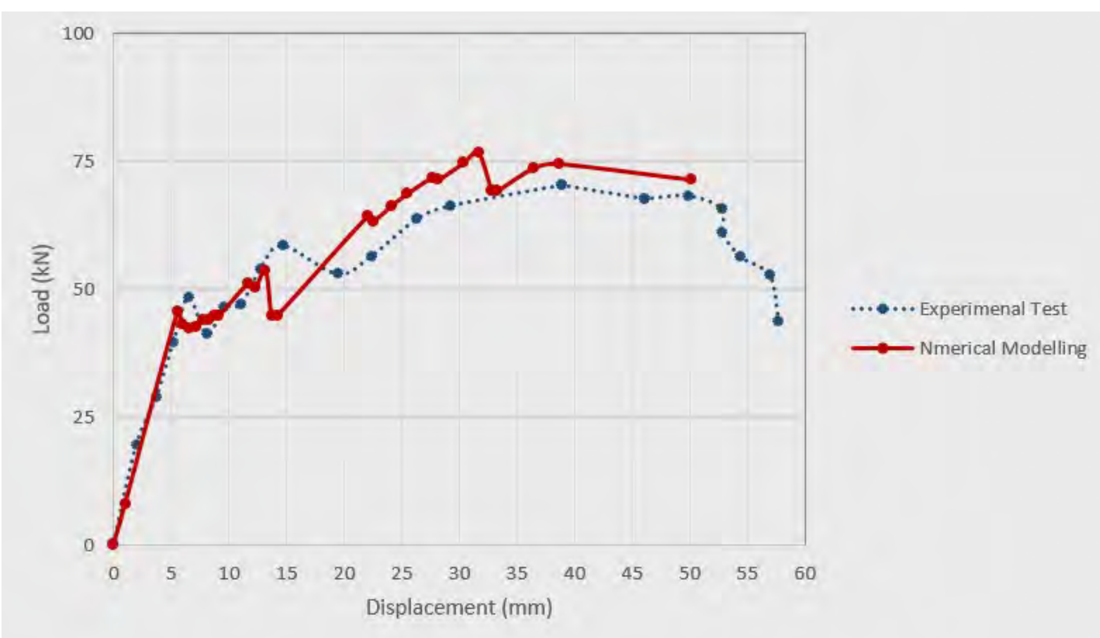


Figure 28: Load-deflection curve to compare the lateral stiffness values for 275 Dincel Polymer encased plain concrete specimens by both experiment and FEM analysis

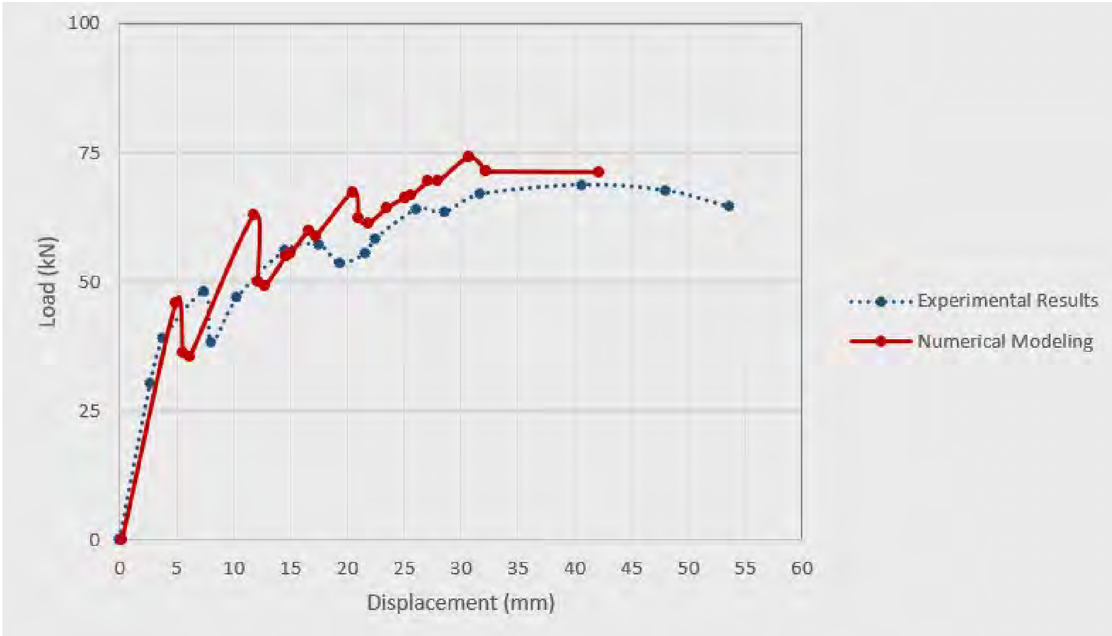


Figure 29: Load-deflection curve to compare the lateral stiffness values for 275 Dincel encased BarChip concrete specimens by both experiment and FEM analysis

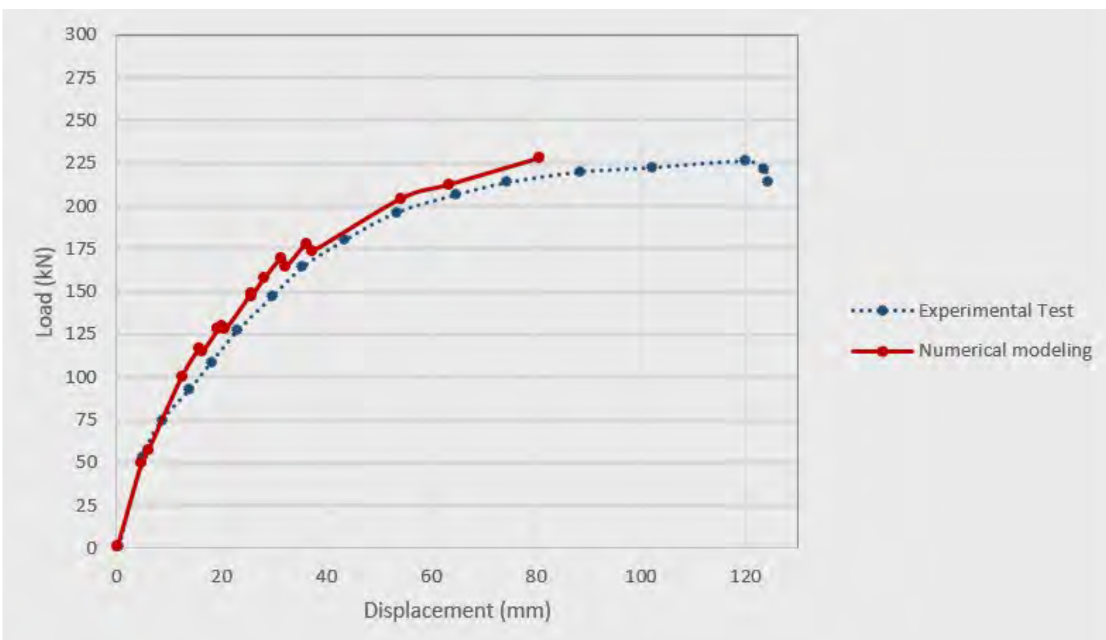


Figure 30: Load-deflection curve to compare the lateral stiffness values for 275 Dincel encased reinforced concrete specimens by both experiment and FEM analysis

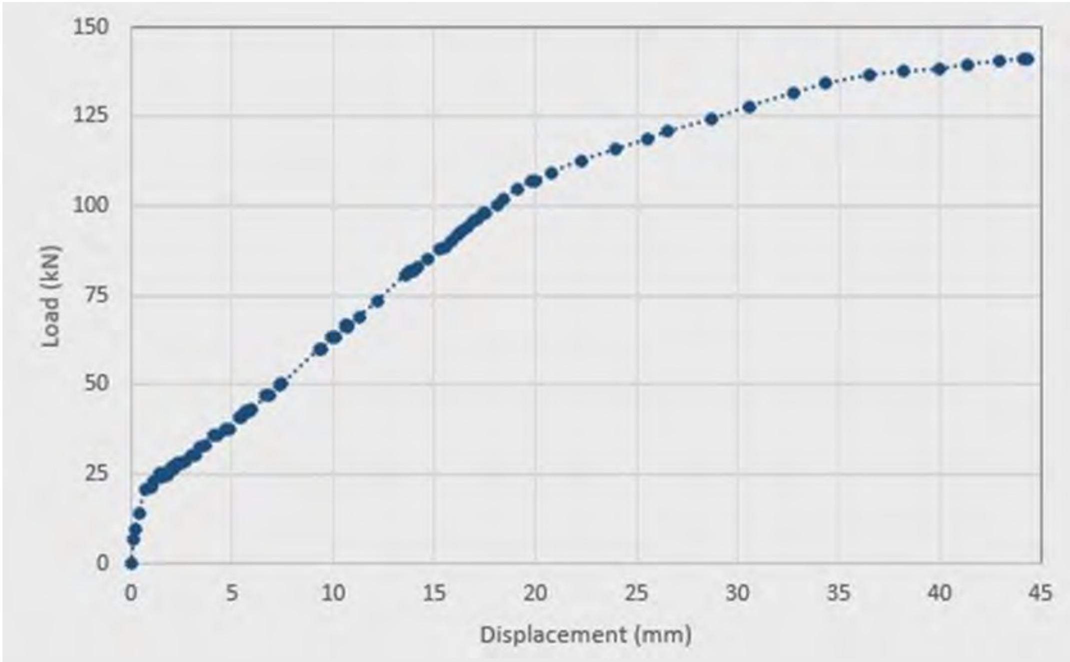


Figure 31: Load-deflection curve for conventional 270 mm thick reinforced wall (without 275 Dincel) subjected to lateral load by FEM analysis.

In this section, the in-plane lateral stiffness and ductility of composite Dincel Polymer encased concrete walls subjected to the lateral loads for composite Dincel Polymer encased wall filled with conventional plain concrete, macro-synthetic fibre reinforced concrete, and steel-reinforced concrete have been investigated and compared for both experimental and numerical analysis.

From the results of this investigation, it has become apparent that the FE model fairly well captured the tendency of the experimental load-displacement curve.

1.7 Conclusions

In this study, the in-plane lateral stiffness and ductility of composite Dincel Polymer encased concrete walls subjected to the lateral loads for composite Dincel Polymer encased walls filled with conventional plain concrete, BarChip macro-synthetic fibre reinforced concrete, and steel reinforced concrete have been investigated. The conclusion that can be drawn from the obtained results is that *all composite Dincel Polymer encased walls can be designed as fully ductile structures ($\mu = 4$) in accordance with Table 14.3 of AS3600 (2018)*, although higher performance of reinforced concrete and BarChip 48 fibre reinforcements increased the ductility factors of the walls to 6.0. For 275 Dincel + steel reinforced concrete walls, the pushover analysis indicated a target displacement of 120 mm, while it yields the maximum displacement of 40 and 42 mm for the 275Dincel + plain concrete and 275Dincel+BarChip 48 concrete, respectively. In addition, in case of using 275Dincel + BarChip 48 macro-synthetic fibre reinforced concrete, the initial and effective in-plane lateral stiffness values of the walls were clearly enhanced by 25% and 10%, respectively, compared to 275 Dincel + plain concrete.

The procedure of evaluating the available ductility of walls is of importance to enable designers to ensure that structures have adequate available ductility to satisfy the required ductility. Therefore, in order to enable structural designers to design composite Dincel Polymer encased concrete walls adequately, ductility factors for this type of walls have been extracted from the test results

The structural engineer can adopt the following for the three mentioned cases;

- Design parameters as shown in Table 1 and Table 2.
- For seismic and wind analysis, engineers can adopt that a 275 Dincel Wall is the equivalent of a 270mm thick concrete wall, incorporating the Effective Flexural Rigidity (EI) provided in Table-2.
- The effective flexural rigidity (EI) value for 275Dincel + steel reinforced concrete as per Table 2 is: 60×10^{12} N.mm^2 as determined by the tests and in accordance with AS3600 Appendix B. For comparison purposes, the effective flexural rigidity (EI) value of 270 mm thick conventional concrete with equivalent steel reinforcement is 55×10^{12} N.mm^2, which is calculated by FEM as illustrated in Figure 31. **A comparison between the effective flexural rigidity (EI) of 275 Dincel + steel reinforced concrete (EI= 60×10^{12} N.mm^2) and 270 mm thick conventional reinforced concrete (EI= 55×10^{12} N.mm^2) demonstrates that polymer encapsulation provided by Dincel permanent formwork does not reduce lateral stiffness of the conventional reinforced concrete wall with equivalent width, concrete thickness, concrete grade and steel reinforcement use.** In fact, the confinement by 275 Dincel provides a slight increase in the effective flexural rigidity (EI). The design engineer may also consider that Dincel polymer encapsulation, unlike conventional removable formwork, prevents rapid evaporation of the water from the wet concrete. The availability of moisture trapped by Dincel polymer encapsulation

promotes an ongoing hydration process of concrete which results in air and water voids available in the wet concrete being filled with a by-product of cement hydration. This autogenous healing process ensures a denser concrete and in turn provides a higher concrete compressive and tensile strength. In time the concrete strength, and associated effective flexural rigidity (EI), will be higher than the test results which is only based upon 28-day strength.

The findings from this report also correlate with previous earthquake testing carried out by UTS for 200 Dincel. Readers are encouraged to read the report "Analyses and Testing of Dincel Wall System Subjected to Severe Earthquake Loads" by UTS for 200 Dincel which can be accessed here – download. 275 Dincel is significantly upgraded from 200 Dincel as it incorporates a perforated inner tube which provides extra tensile capacity and robustness in comparison to 200 Dincel. The UTS report dated 2011 concluded that *"both plain concrete and Dincel Wall have similar lateral stiffness and that the polymer encapsulation of Dincel Wall does not reduce the lateral stiffness of the system".*

1.8 Design Certification in Accordance with AS3600 – 2018

275 Dincel Walls when designed by a structural engineer using the information provided in this report will satisfy the deemed-to-satisfy provisions of the National Construction Code for structural design. In accordance with test results shown in this report as per Appendix B of AS3600 – 2018, A/Professor Shami Nejadi as the Chief Investigator on behalf of UTS (in his capacity) confirms that 275 Dincel Structural Walling panels filled with mass concrete (with or without steel reinforcement) or filled with concrete containing BarChip 48 macro-synthetic fibres (with or without steel reinforcement), complies with AS3600–2018. A structural engineer may adopt the values shown in Table 1 and Table 2 of this report for design purposes.

A/Professor Shami Nejadi: Shami Nejadi Date: 14/01/2021

Appendix 1 – Calculation and Comparison of the Ductility Factor with other Methods

To verify the validity of the calculated ductility factors using the Elastic Stiffness, implemented the proposed method by J. C. Vielma, M. M. Mulder (*16th World Conference on Earthquake Engineering, 16WCEE 2017, Santiago Chile, January 2017*), the AS1170.4 Commentary Method is implemented and the results are compared.

1.1 Method by J. C. Vielma, M. M. Mulder

This method is based on non-linear analysis by determining of the shear for which ultimate rotation capacity in the extremes of the beams and the inferior extremes of the columns of any level are achieved as shown in Figure A1.1.The Maximum Rotation (θ_V), corresponding Displacement, Maximum Shear (V_{max}) and Pivot Point which are referred in the Fig.3 of the J. C. Vielma, M. M. Mulder method from raw test data and has compared the outcome with the previously released values based on the Tangent Stiffness Method (which is Park 1988-Fig.2b). **It was determined that for this type of composite material they are practically the same, as shown in below load-displacement diagrams**.

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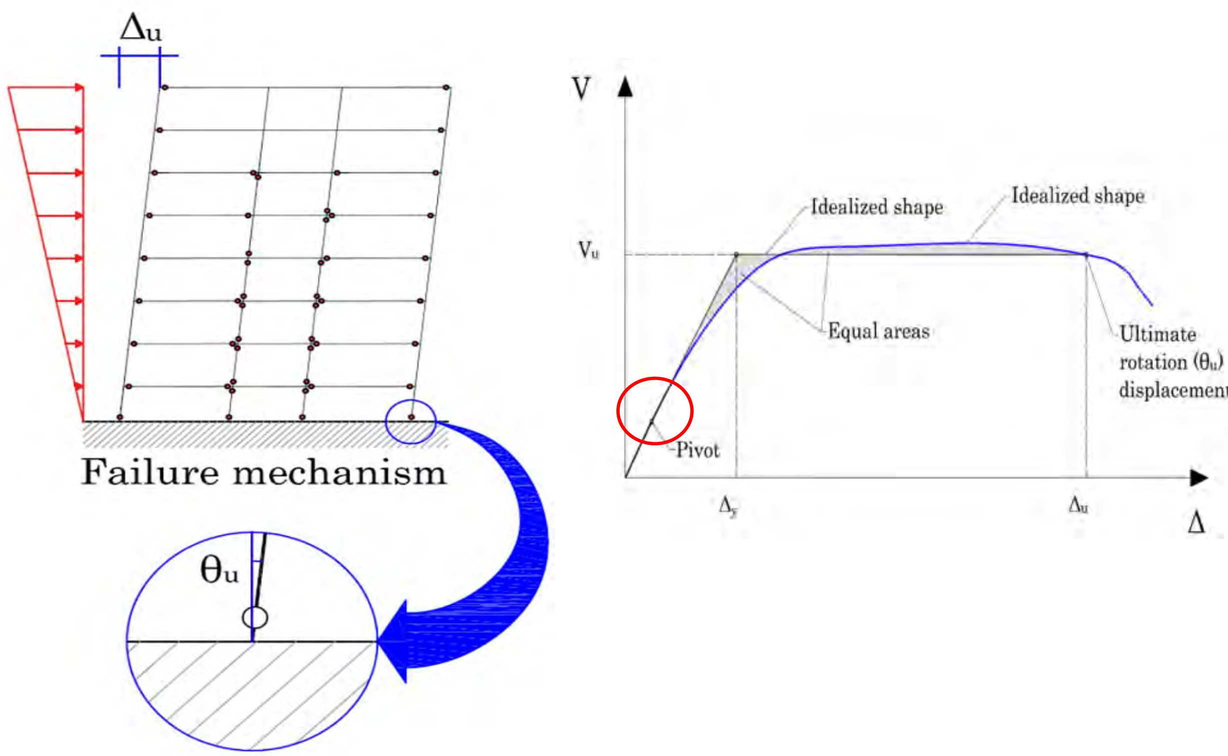


Figure A1.1 Ultimate Rotation and Pivot Point defined in the Proposed Model

One of the advantages of this method is that the values of displacement ductility are regardless of the structural type, failure mode or even the structural irregularities.

According to the test setup shown in Figure A1.2, the base shear for which ultimate rotation capacity and the corresponding maximum shear for each sample of the different types of concrete have been determined and presented in Table A1.1.

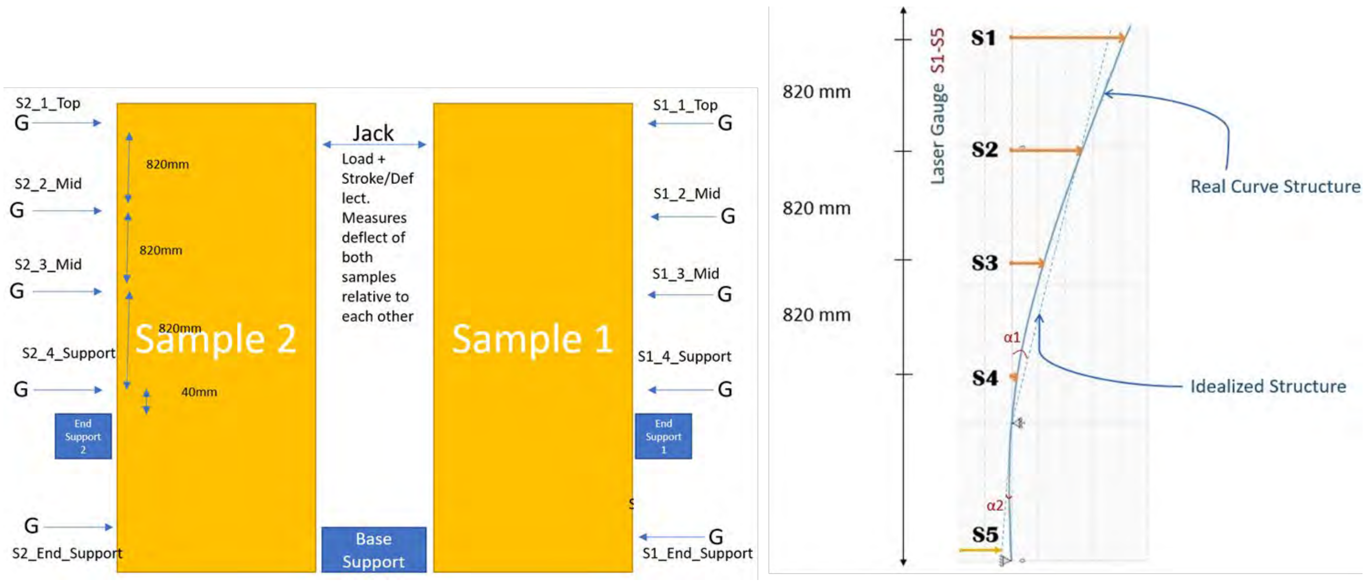


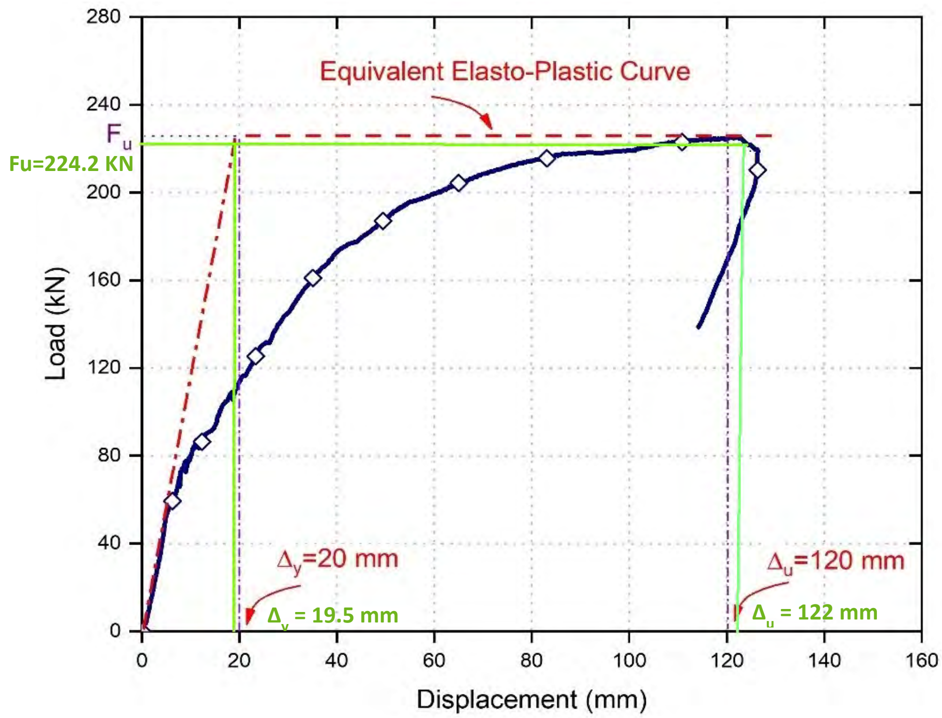
Figure A1.2 Test setup and idealized structure

Table A1.1 Ultimate rotation capacity and the corresponding shear

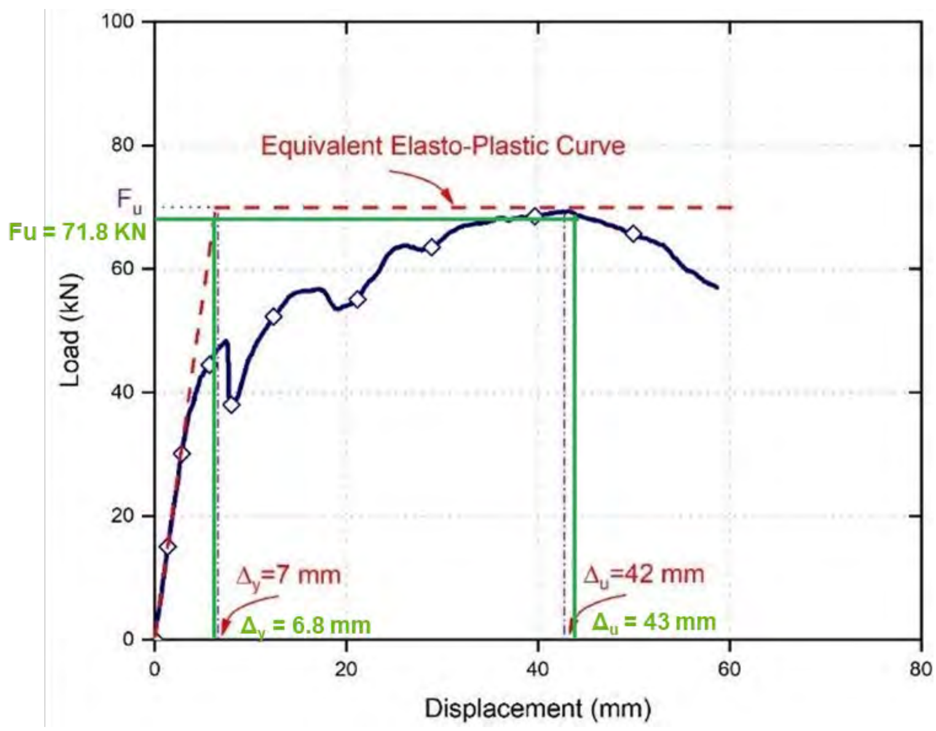
Specimen	Sample - 1		Sample - 2		Sample - 3		Average	
	Θmax	Vmax (KN)	Θmax	Vmax (KN)	Θmax	Vmax (KN)	Θmax	Vmax (KN)
Reinforced Concrete	2.05	226.12	3.15	221.22	2.81	225.101	2.7	224.15
BarChip Concrete	2.42	73.12	1.02	65.5	2.2	76.68	1.88	71.8
Plain Concrete	1.09	66.68	1.52	71.52	1.36	64.98	1.32	67.7

Note: In the below figures, the red line represents the tangent stiffness method and the green line represents the method proposed by J. C. Vielma, M. M. Mulder.

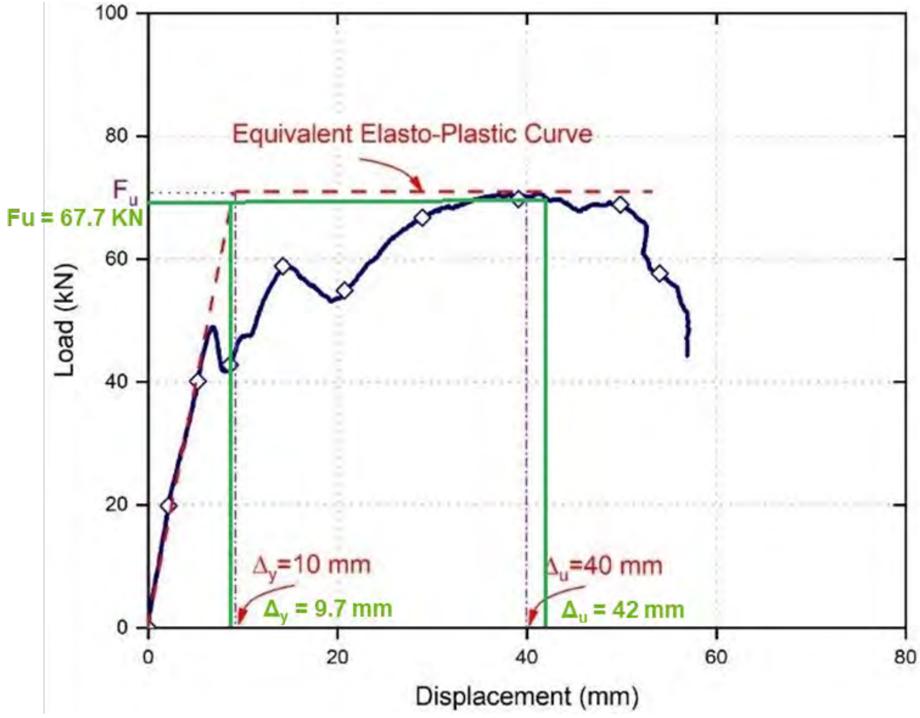
Finding the Yield and Ultimate Displacements for the **Reinforced Concrete** specimens:



Finding the Yield and Ultimate Displacements for the **BarChip Concrete** specimens:

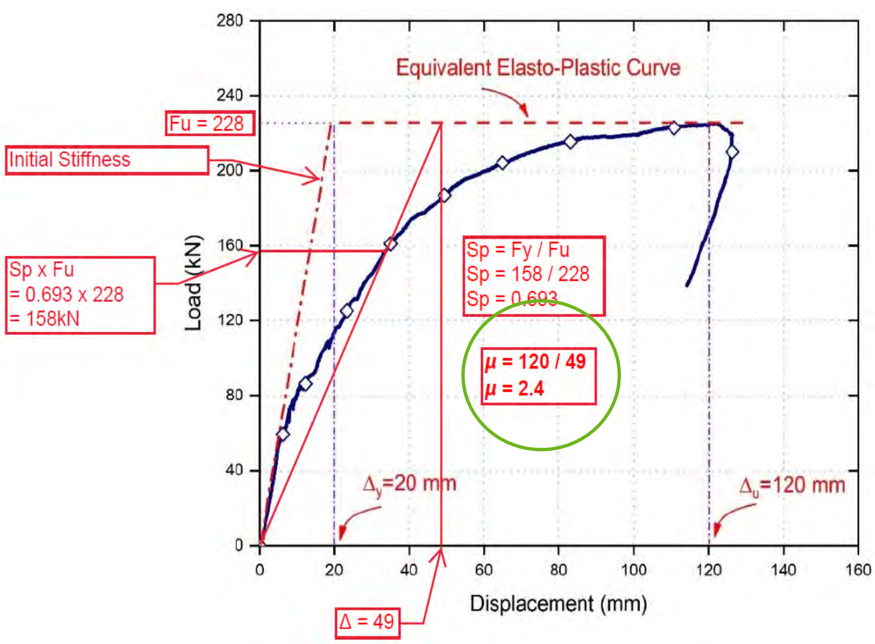


Finding the Yield and Ultimate Displacements for the **Plain Concrete** specimens:



1.2 AS1170.4 Commentary Method for 275 Dincel Reinforced with Steel Bars

The AS1170.4 Commentary Method is a generic method for calculating the ductility factor by assuming that the yield point occurs at Sp x Fu, where Sp is as per Table 6.5 (A) of AS1170.4. This table refers to a Sp value of 0.77 for limited ductile shear walls or 0.67 for moderately/fully ductile shear walls. For Dincel 275 walls, the Sp value has been determined as 0.69 as extracted from the test data. Sp is equal to Fu / Fy = 228 / 158 = 0.69.



The calculated values by means of different methods are presented in Table A1.2 for comparison purpose.

Table A1.2 Comparison of the ductility factor calculated different methods

Specimen	Tangent Stiffness Method			Method by J. Vielma & M. Mulder			Method of AS1170.4 Commentary		
	Fu (KN)	Fy (KN)	Δu / Δy	Θmax	Vmax (KN)	Δu / Δy	Fu (KN)	Fy (KN)	Δu / Δy
Reinforced Concrete	228	158	6	2.7	224.2	6.2	228	158	2.4
BarChip Concrete	75	45	6	1.9	71.8	6.3	75	45	2.3
Plain Concrete	72		4	1.3	67.7	4.3	72		2.3

Obviously, recommendation of the AS1170.4 commentary method, naturally does not take into account the above-mentioned topics such as **composite behaviour, confinement effect** and most importantly the presence of **axial compression** on the cross sections. These all influence the crack formation function, so to use Park (1988) and/or the AS1170.4 commentary method is not appropriate for determining the ductility factors of the reinforced Dincel composite section. On this basis it can therefore be stated that method of Park (1988) is not considered appropriate to apply to reinforced Dincel composite section. The confinement is provided by the presence of Dincel polymer encapsulation, it is therefore only logical to assume that Dincel 275 as a reinforced composite member will naturally display better ductility than the equivalent reinforced concrete section. This behaviour already proven in the 2011 Earthquake tests carried out for 200 Dincel.

Remarks

The test has demonstrated that methods which are applicable to Reinforced Concrete structures are not entirely compatible with the structures that are made by Composite Materials.

The UTS flexural tests has illustrated that 275 Dincel encapsulated reinforced concrete demonstrates a superior composite section behaviour and implementing of Park (1988) Method will yield over conservative results. The difference (compared to conventional concrete) is addition of 275 profile.

This study reveals that because of the dissipation of large amounts of energy by Composite Polymer Encapsulated Concrete, the Elastic Stiffness Method and the Proposed Method by J. C. Vielma, M. M. Mulder are capable to simulate the real behaviour of these particular type of composite structure.

In addition, the Confinement Effect on the compressed zone of the cross section and absence of Axial Loads which delay the cracking, should be taken into account.

All methodologies as analysed above confirm that Dincel 275 walls will qualify as at least 'limited ductile', which demonstrates that Dincel 275 walls can be used safely within existing design practices.

Appendix 2 - Testing and Analyses of Dincel Wall System Subjected to Severe Earthquake Loads

UTS has previously conducted comprehensive earthquake testing in 2011 with 200 Dincel, consisting of a shake table test and full-scale push over test.

Readers are encouraged to read the report "Analyses and Testing of Dincel Wall System Subjected to Severe Earthquake Loads" by UTS for 200 Dincel which can be accessed here – download.

275 Dincel is an improved version of 200 Dincel which is 75 mm thicker in the out of plane direction and incorporates a perforated internal ring, which supports the external faces against wet concrete pressure during concrete placement. 275 Dincel has been designed to handle the potential damages that can occur during transportation and installation, can accommodate a high concrete slump within a single concrete pour up to 4.5m height (without concrete aggregate segregation), is capable in handling the concrete pressures from vigorous vibrator use, and provides a much higher bending capacity in comparison to 200 Dincel.

For the shake table tests, the significant ground motion records of the 1995 Kobe earthquake and the 1940 El Centro, California earthquake were used as inputs in order to represent large magnitude near field and far field earthquakes, respectively. The shake table tests clearly demonstrated the strength of the unreinforced 200 Dincel wall specimen withstanding typical large magnitude earthquakes. However, due to the much larger relative stiffness of these wall specimens compared to those used in multi-storey buildings as part of the shear wall system, the resulting inter-storey drifts were well below those demanded by large earthquakes and hence it was decided to subject these walls to push over tests to confirm their adequacy in providing the required displacement demand of 5.3 mm arrived at by Finite element analysis of a typical 7 storey concrete building with shear walls as its lateral load resisting system.

An advantage of the Dincel Wall system is the provision of sound confinement to the concrete by the cellular polymer encapsulation which incorporates the outer skin as well as the integral internal webs. Such a system will prevent the deterioration of stiffness and possible collapse by not allowing the concrete to spall after several loading cycles even if fully cracked.

The findings of this UTS report dated 2011 conclusions include:

- The comparisons of the results conclude that *"both plain concrete and Dincel Wall have similar lateral stiffness and that the polymer encapsulation of Dincel Wall does not reduce the lateral stiffness of the system"*

- *"Conventional concrete structures are considered to be in the collapse range when displacement levels exceed 2.5%. The tests demonstrated that Dincel sample safely withstood 4.4% displacement level. This performance level will be particularly important to strengthen existing buildings and building structures which require post disaster functioning. This performance is not achievable with conventional materials when displacement levels exceed 2.5%.*

- *When an adequate length of Dincel Wall, reinforced as a shear wall, the Dincel Wall is capable of addressing the structural safety required to protect human life in damaging earthquakes with magnitude up to 9.0 on the Richter scale."*

"These tests proved to be very conclusive in demonstrating the capacity of unreinforced Dincel system in sustaining larger deformations caused by major earthquakes." (Quoted from page 7 of 2011 report).

Based on the flexural strength, shear strength and stiffness test results included in this report for 275 Dincel, it appears that 275 Dincel could potentially exhibit more resistance against earthquake/wind loadings in comparison to 200 Dincel.

Remarks

It is understood that designing buildings as fully ductile walls require special detailing and the design may be too onerous as many Australian engineers may not be familiar with NZ and other international codes. In these cases, limited ductile wall design can simply be adopted by Australian design engineers for Dincel 275 walls.

Technical Report

Evaluation of Interface Shear Strength of 275 Dincel Structural Walling

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Rev 02

23/10/2020

2.1 Introduction

This technical report experimentally evaluates the effects of using BarChip fibre reinforced concrete on interface shear strength of 275 Dincel structural walling panels in comparison with 275 Dincel structural walling panels filled with conventional plain concrete and reinforced concrete. In addition, since AS 3600 (2018) does not prescribe the shear plane surface coefficients for determining the interface shear strength of 275 Dincel structural walling panels, in order to enable structural design engineers to calculate the interface shear strength for those panels using Australian Standards, the friction and cohesion coefficients for the studied composite Dincel Polymer encased walls have been extracted from the test results and proposed for practical applications in this study.

2.2 Experimental Testing Program

Nine 275 Dincel structural walling panel specimens were cast and tested at the UTS Tech Lab. The first of its type in Australia, UTS Tech Lab is a new-generation 9000 m^2 facility that is designed to bring the university and industry together to innovate and disrupt traditional university approaches to research. As illustrated in Figure 1, each specimen consists of two 275 mm Dincel structural walling panels filled with concrete known as top panel and bottom panel. The panels were 1200 mm long with 275 mm thickness and filled with concrete having 200 mm slump and compressive strength 40 MPa at 28 days.

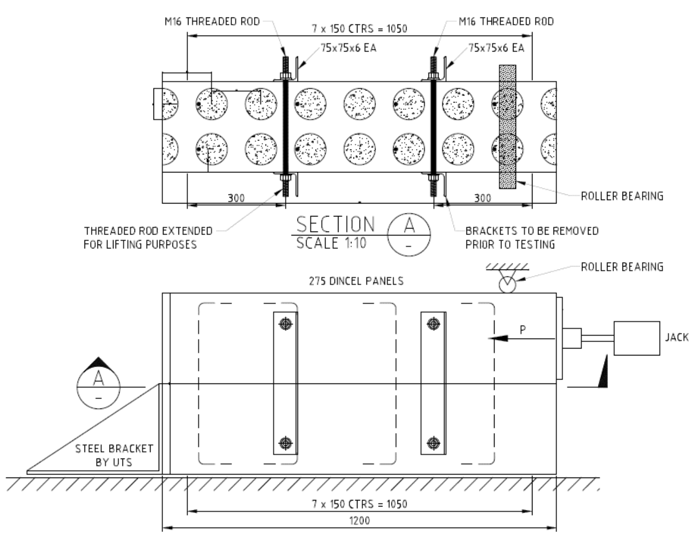

Figure 1: Overall test setup and dimensions of the test specimens

All nine composite Dincel Polymer encased concrete wall specimens were prepared, poured with concrete, and cured on site at UTS Tech Lab by Dincel technicians. The entire process has been overseen and reviewed by UTS scholars, during and post pour. All reinforcement details, mix designs and mix properties were reviewed and approved by suitably qualified UTS Tech Lab staff. Concrete compression cylinders were taken from the fresh concrete mix and tested to measure the concrete strength at various stages of curing to determine the concrete properties throughout curing strength predictions and validation of the concrete mechanical properties (Figure 2).

(a) **(b)**

Figure 2: Concrete compression cylinder tests; a) Samples taken from the fresh concrete mix, b) Concrete compression test in process at UTS Tech Lab

2.3 Mechanical Properties of 275 Dincel Panels

In order to determine mechanical properties of the employed Dincel Polymer materials in this study, five dog-bone coupon specimens from the Dincel panels were prepared according to ASTM D638 specifications as illustrated in Figure 3.

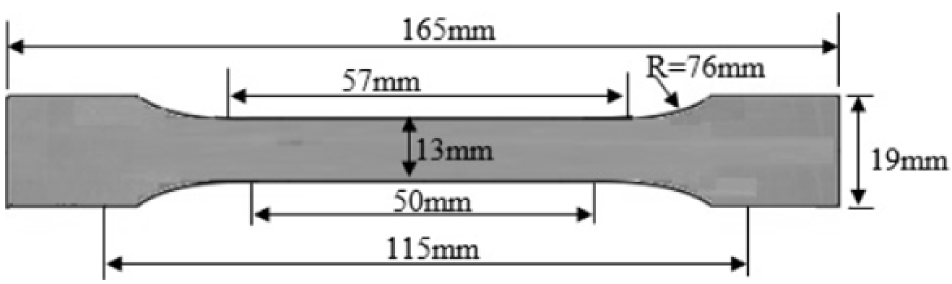

Figure 3: Dog-bone coupon specimens prepared for tensile tests according to ASTM D638

Tensile tests were conducted by applying a constant rate of 0.083 mm/s in accordance with ASTM D638 and the resulted average ultimate tensile strength, Young’s modulus of elasticity, and Poison’s ratio were determined and presented in Table 1.

Table 1: Mechanical properties of tested Dincel Polymer material

Young's Modulus *E* (*MPa*)	Tensile Strength σ_u (*MPa*)	Poisson's Ratio υ
2609	37.20	0.39

Figure 4: An overview of the tensile Dincel Polymer testing at the UTS Tech Lab

2.4 Test Specimens

The experimental testing program has aimed to investigate the effects of using macro-synthetic fibre reinforced concrete (BarChip 48 macro-synthetic reinforcement system), instead of conventional concrete, on shear capacity at the shear interface of composite Dincel Polymer encased 275 mm Dincel structural walling panels. In addition, the contribution of friction and cohesion to the interface shear strength of each specimen was aimed to be investigated. To achieve these goals, direct shear testing was conducted on the test specimens, which were cast with plain concrete, reinforced concrete and BarChip fibre reinforced concrete, and tested at the age of 28 days with the following details:

- Three composite Dincel Polymer encased concrete wall specimens, named *Shear-BarChip*, with 5kg/m^3 BarChip 48 macro-synthetic fibre reinforced concrete;
- Three composite Dincel Polymer encased concrete wall specimens, named *Shear-Plain*, with plain concrete; and

- Three composite Dincel Polymer encased concrete wall specimens, named *Shear-Reo*, with reinforced concrete.

In *Shear-Reo* specimens, the Dincel panels contained 2N12-300 steel reinforcement bars with hooks at both ends, placed in the centre of the circular formwork holes (see Figure 5 below).

Figure 5: Dincel panels with shear steel reinforcements (before pouring concrete)

2.5 Test Setup and Procedure

Composite members are generally designed to act monolithically. In concrete-to-concrete bonds, the horizontal shear stress between the two concrete surfaces is resisted by the shear capacity at the interface. To ensure whether this bond fails or not under constant normal and horizontal force, an experimental testing program was conducted using direct shear test method. This method has been used by several researchers to study the composite action between the two members in order to determine the interface shear strength. Figure 6 shows an overview of the direct shear test configuration at UTS Tech Lab.

Figure 6: An overview of the direct shear test configuration at the Tech Lab

The base panels in the test setup were fixed to the test frames and the top panels were pushed by the load cell. The jack shown in Figure 6 has a maximum capacity of 200 Tones. The steel reinforcing provided within the specimen (2N12-300) was selected as it was the maximum in which the jack could provide a failure to the walling system. A much greater jack capacity is required to achieve failure for steel bar sizes such as 2N16-150, 2N20-150, etc. The load was applied using a hydraulic cylinder (Figure 7) and controlled using a closed loop PID control system called FCS SmartTest One (Figure 8).

Figure 7: Hydraulic cylinder used in experimental study to apply horizontal load

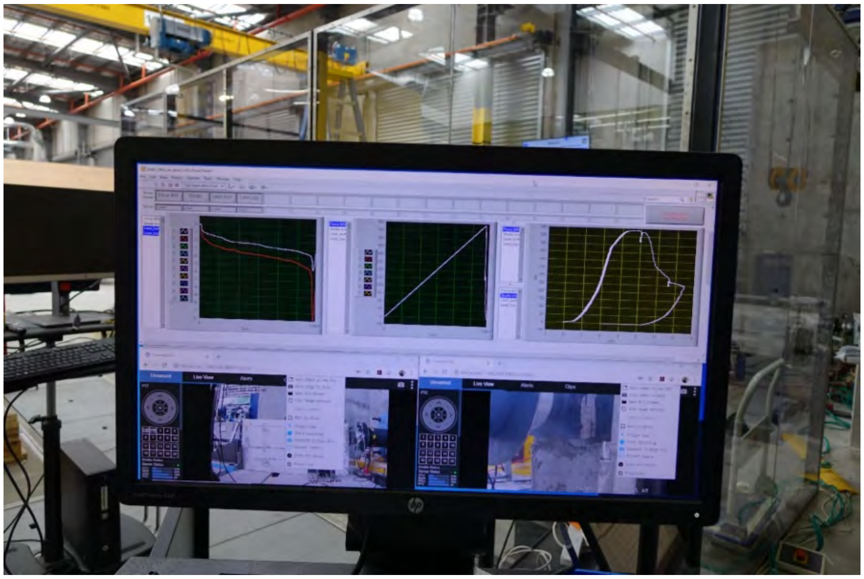

Figure 8: Closed loop PID Control system (FCS SmartTest One) used for recording and post processing

During the test, the horizontal load applied to the top specimen was increased steadily until the maximum shear capacity of the specimen was achieved and the bond failure happened (Figure 9).

Figure 9: Failure of one of the test specimen after reaching the maximum shear capacity at the interface of composite Dincel Polymer encased 275 mm Dincel structural walling panels

The bond failure load then was defined as the load at which the interface bond was broken. The samples were restrained from lifting with a setup that offered minimal friction through the use of high load capacity skates (Figure 6). Boundary conditions were created so any stresses from moments and compression were negligible, to encourage the samples to fail in pure shear. The corresponding slip was measured through laser displacement sensors and the relative movement between the top panel (panel above the shear plane) and the bottom panel (panel below the shear plane) was defined as shear deflection or interface slip.

2.6 Results and Discussion

The load-deflection curves for all the test specimens have been obtained from the direct shear test results. In order to compare and interpret the results properly, the average load-deflection curves obtained from direct shear tests have been developed and presented in Figure 10.

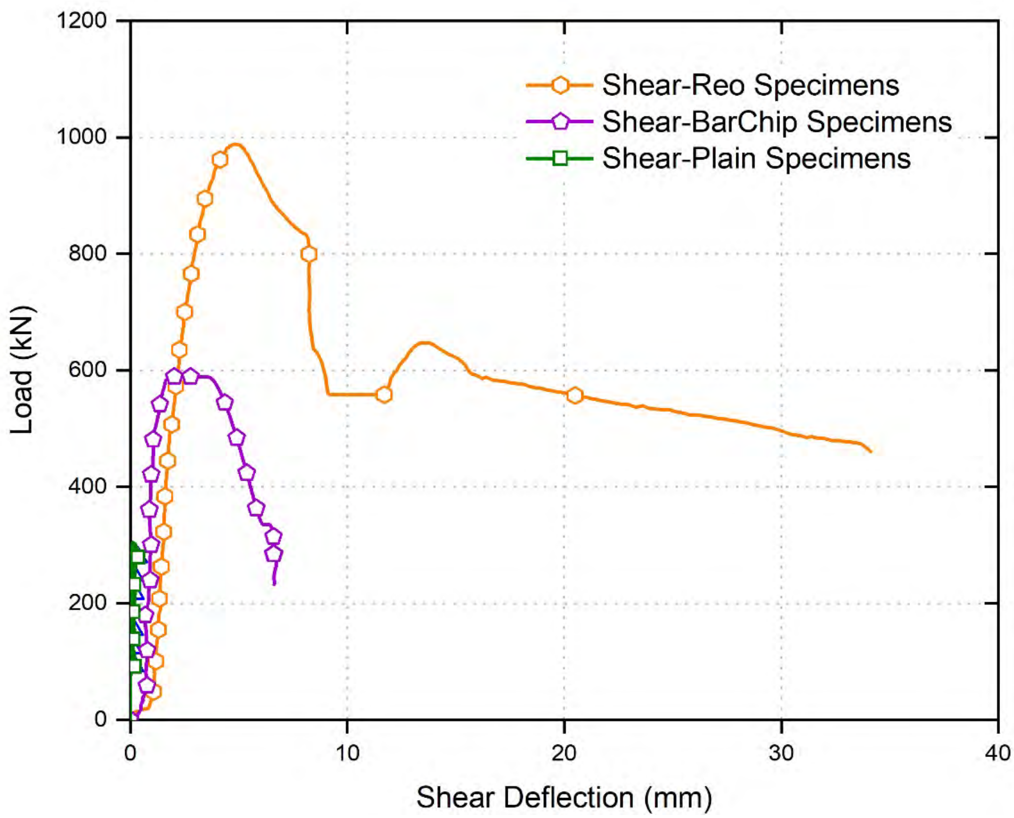

Figure 10: Average load-shear deflection curves obtained from direct shear tests

As it can be seen in Figure 10, for all the test specimens, the applied horizontal load keeps increasing until the bond between the two panels is broken. Then, if horizontal load is further applied, it will drop, since not much force is needed to cause sliding of the top panel. The interface shear strength was then calculated by determining the shear load before interface slip occurred. This is mainly attributed to the fact that once interface slip occurs, full composite action is lost and therefore interface shear strength does not exist anymore. In this study, the interface shear strength is determined by dividing the maximum horizontal load over the interface (shear plane) area according to the several researchers' recommendation. Table 2 summarises the measured shear deflection and shear strength parameters in test specimen interfaces.

Table 2: Summary of test results for different specimens

Specimen	Average peak shear load (kN)	Shear deflection at peak shear load (mm)	Unit interface shear strength (MPa)
Plain Concrete	304	0.10	1.11
BarChip 48 Fibre Reinforced Concrete	589	2	2.14
Steel Reinforced Concrete	988	5	3.60

Comparing the curves in Figure 10 and the determined values in Table 2, it is noted that the maximum shear load and the interface shear strength of *Shear-BarChip* specimens have increased by 93.5% compared to the corresponding values determined from the *Shear-Plain* specimens. Therefore, it has become apparent that using BarChip 48 macro-synthetic fibre reinforced concrete instead of plain concrete in the tested composite Dincel Polymer encased walls leads to 93.5% interface shear capacity enhancement for the studied composite Dincel Polymer encased concrete wall specimens. In addition, comparison between the results in Figure 10 and Table 2 has revealed that the shear capacity at the interface of *Shear-Plain* specimens (specimens filled with plain concrete) is 31% of the interface shear capacity of *Shear-Reo* specimens (specimens filled with reinforced concrete) while *Shear-BarChip* specimens (specimens filled with BarChip 48) have achieved almost 60% of the interface shear capacity of *Shear-Reo* specimens. It is an important observation that shows employing BarChip 48 macro-synthetic fibre reinforcement in composite Dincel Polymer encased walls can produce more than half of the interface shear capacity achieved by a fully reinforced composite Dincel Polymer encased walls while only one third of this capacity can be reached by using conventional plain concrete. These findings correlate very well with the fact that the shear strength of non-reinforced construction joints is resisted only by the concrete cohesion and friction along the interfacial failure plane. In other words, for the steel reinforced concrete construction joints, an increased shear strength is accepted under the assumption that the shear force is primarily resisted by the dowel action of the transverse steel reinforcement.

The average peak shear load above will need to be divided by 1.2m to convert to a capacity per metre length, and then multiplied by a reduction factor of 0.7 in accordance to AS3600 Table 2.2.2.

Table 3: Reduced peak shear loads

Specimen: 275 Dincel (f'c = 40MPa)	Peak Interface Shear Capacity with 0.7 Reduction Factor
Shear-Plain Concrete	304/1.2 × 0.7 = 177.3 kN/m
Shear-BarChip	589/1.2 × 0.7 = 343.6 kN/m
Shear-Reo	988/1.2 × 0.7 = 575.3 kN/m

2.7 Analysis and Comparison to AS3600 (2018)

The overall interface between Dincel panels can be seen in Figure 11 below.

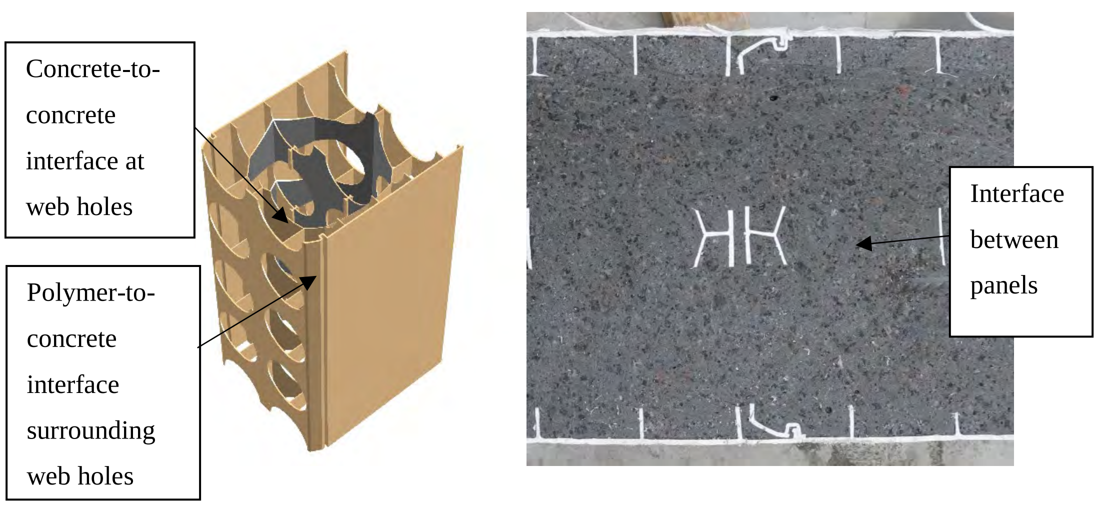

Figure 11: Dincel panel interface (left), cut test specimen showing interface (right)

There are two components of the concrete interface between 275 Dincel profiles:

1. Concrete-to-concrete interface – provided through 2 x 95mm diameter web holes at 150mm pitch. This provides a shear surface area of:

$$A = 2 \times \pi \times \left(\frac{95}{4}\right)^2 \times \left(\frac{1000}{150}\right) = 94510 \ \frac{mm^2}{m}$$

2. Concrete-to-polymer interface - In addition to direct concrete to concrete connection at the web holes as per above, the concrete between Dincel polymer surfaces surrounding the web holes also provides frictional resistance. This provides a shear surface area of:

$$A = [(275mm - 2 \times 2.5mm) \times 1000mm] - 94510 = 174490 \ \frac{mm^2}{m}$$

As the frictional resistance between a polymer surface and a concrete surface is relatively low, it can be stated that the primary interface shear capacity is provided by direct concrete-to-concrete connection at the web hole locations.

When calculating the interface shear capacity to AS3600 (2018), a shear plane width (b_f) is required. For this assessment, the area from the concrete-to-polymer interface is considered negligible, therefore leaving only the area from the concrete-to-concrete interface to provide the shear resistance, equating to a shear plane width of 94.5mm. Table 4 provides a comparison between the test results and the calculated capacity to AS3600 (2018) using this shear plane width.

Table 4: Comparison to AS3600 (2018) – Factored Capacities

Specimen	Dincel 275 Wall test result	Interface shear capacity calculated from AS3600 (2018) 8.4.3 ($b_f = 94.5mm$)
Plain Concrete (f'c = 40 MPa)	177.3 kN/m	75.3 kN/m

The results achieved within the test are 102kN higher than method of calculation to AS3600 (2018). Clearly, there are further mechanisms/behaviours which increase the interface shear capacity within a Dincel wall.

To investigate this, following failure of the test specimen, the panels where separated and the failure plane was observed. Figure 12 below demonstrates that the shear plane was not completely straight but rather consisted of dome or conical shaped protrusions at the web hole locations.

Figure 12: Dome/conical failure plane observed at web hole locations of Dincel 275 profile

For a conventional concrete wall, shear failure is primarily a flat plane rather than a series of concrete cones/domes. It was observed that the concrete encapsulated by the 275 Dincel polymer formwork provided ‘confinement’ to the concrete which led to the unique failure plane. The array of domes provided a keying action throughout the section and subsequently this aided in achieving a higher shear capacity.

The direct concrete-to-concrete interface, which provides the primary shear resistance, is a surface area of 94510mm^2/m as identified previously. However, this is assuming a flat failure plane rather than a series of domes which provides a greater surface area due to the curvatures, as illustrated in Figure 13.

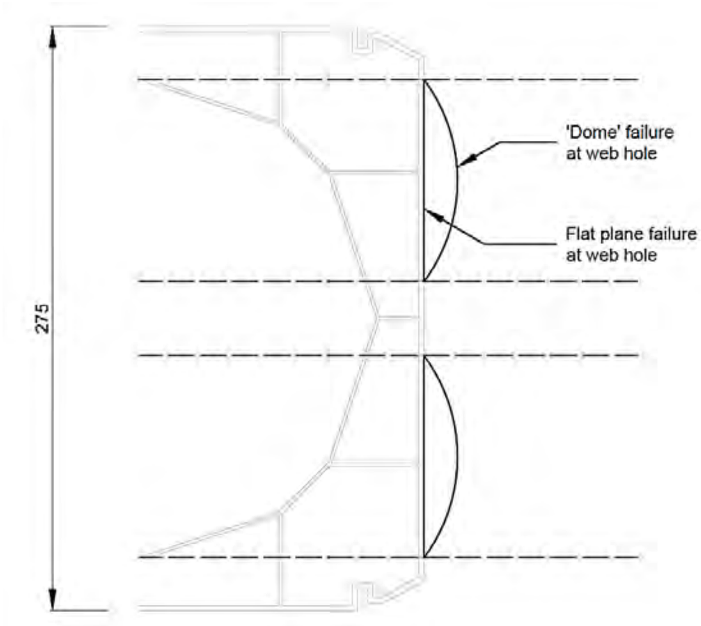

Figure 13: Illustration of dome shaped failure planes at web holes

Depending on the radius of the dome, the surface area provided could potentially be up to double the surface area of the flat plane. This type of failure most likely justifies why the test results are higher than what is capable through method of calculation to AS3600 (2018) for a conventional concrete member. The 'flat' shear plane area of 94,510mm^2/m is increased due to the curved concrete surfaces.

When steel reinforcement is added to the walling system, the results achieved are even more favourable. A comparison with the results and AS3600 (2018) has been provided in Table 5.

Table 5: Comparison to AS3600 (2018) – Factored Capacities

Specimen	Dincel 275 Wall test result	Interface shear capacity calculated from AS3600 (2018) 8.4.3 ($b_f = 94.5mm$)	Interface shear capacity calculated from AS3600 (2018) 8.4.3 ($b_f = 275mm$)
Reinforced Concrete (2N12-300, f'c = 40 MPa)	575.3 kN/m	306.1 kN/m	429.99 kN/m

As can be shown, by providing steel reinforcement the tested capacity is 269kN higher than the calculated capacity where a shear plane width of 94.5mm is used, and 145kN higher when a shear plane width of 275mm is used. These results are much greater than the 102kN difference observed with plain concrete only, and even demonstrate that the interface shear capacity for a Dincel wall is higher than the calculated capacity of a conventional concrete wall of equivalent thickness. It is hypothesised the reason for this is an increase in the 'dome' effect as illustrated in Figure 14 due to increased cohesion surrounding the steel reinforcement bars.

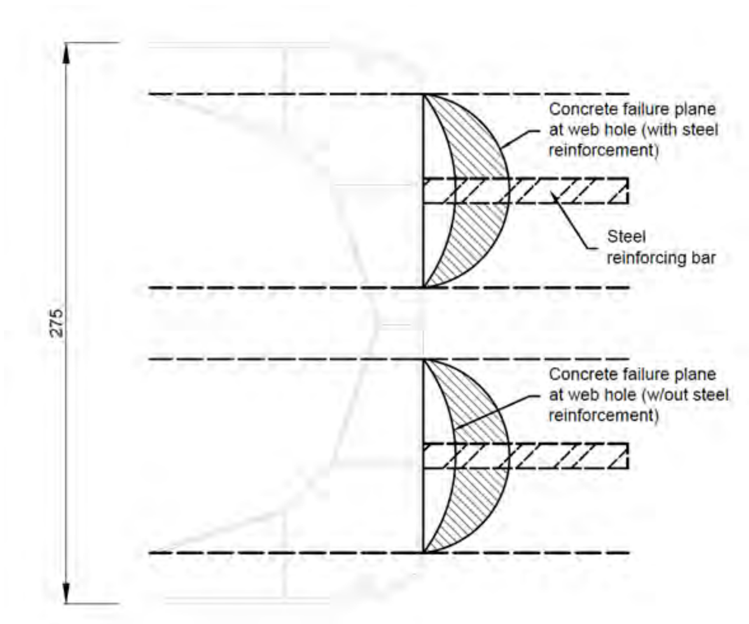

Figure 14: Illustration of dome shaped failure planes at web holes with steel reinforcement

It is not possible to derive a definitive surface area for these domes due to the complex behaviour, so instead of modifying the width of the shear plane, cohesion and friction parameters have been determined in Section 5 in order to be used within formula 8.4.3 of AS3600 (2018).

The effect of concrete confinement within Dincel polymer formwork was first observed from the UTS earthquake tests with 200 Dincel in the year 2011. For reference purposes, the earthquake report can be downloaded through the following link - download. It is important to note that 275 Dincel is significantly upgraded from 200 Dincel due to the perforated inner tube which provides additional tensile capacity as demonstrated within flexural testing by UTS.

It is therefore appropriate to state that 275 Dincel offers improved confinement behaviour and provides additional tensile or bending capacity in comparison to 200 Dincel.

2.8 Proposed Cohesion and Friction Parameters for the Studied Specimens

AS 3600 (2018) prescribes the shear plane surface coefficients, for concrete-to-concrete interfaces. The interface shear strength can be calculated by using those coefficients in Clause 8.4.3 AS 3600 (2018) equation for concrete surfaces. However, AS 3600 (2018) does not prescribe the shear plane surface coefficients for determining the interface shear strength of composite Dincel Polymer encased structural walling panels. Therefore, to enable structural designers to use Clause 8.4.3 AS 3600 (2018) and the presented equation in order to determine the interface shear strength for those panels, similar friction and cohesion coefficients need to be proposed. These modified coefficients also take into account the dome type failure as explained in Part 4 of this report.

According to AS 3600 (2018), the interface shear strength can be determined from Clause 8.4.3 AS 3600 (2018) equation in which:

$$\sigma_n = \frac{g_p}{b_f} \tag{1}$$

The presented equation in Clause 8.4.3 AS 3600 (2018) can be simplified and rewritten as follows:

$$\tau_u = \mu\left(\frac{A_{sf} f_{sy}}{s b_f} + \sigma_n\right) + k_{co} f'_{ct} \tag{2}$$

The coefficient μ in Eqn. 2 is related to dowel action effects which is considered 0 in the case of using plain concrete or BarChip 48 macro-synthetic reinforcement and can be assumed as a constant value in the case of using steel reinforced concrete. According to AS 3600 (2018), Table 8.4.3 and other international codes such as Eurocode, μ = 0.9 for monolithic reinforced concrete. This coefficient is for dowel action effects only and unchanged between a Dincel wall and a conventional concrete wall, so it is also taken as μ = 0.9 for Dincel walls. σ_n is taken as 0 unless there is external loading applied to the wall normal to the shear plane.

As the shear resistance provided by the concrete-to-polymer surface (174990mm^2/m) is relatively low, the shear plane width (b_f) has been taken as the concrete area bound within the web holes only, being 94.5mm. The coefficient k_{co} was derived by method of back-calculation as demonstrated below.

1. <u>Calculation of k_{co} for 275 Dincel filled with Plain Concrete</u>

Width of the shear plane $b_f = 94.51\ mm$

Shear plane area $\Longrightarrow 94.51 \times 1000 = 94510\ mm^2$

Measured maximum load $= 304000\ N$ (for specimen with 1.2 m length)

For finding unit shear strength, load is adjusted per metre length:

Unit shear strength $\Longrightarrow \frac{304000}{1.2} = 253333 = \frac{253333}{94510} \approx 2.68\ MPa$

According to Clause 3.1.1.3 $\Longrightarrow f'_{ct} = 0.36\sqrt{40} = 2.28\ MPa$

$2.68 = \mu\,(0) + k_{co} \times 2.28 \Longrightarrow 2.68 = 2.28\ k_{co} \rightarrow \boxed{k_{co} = 1.18}$

This k_{co} value accounts for the dome shape failure.

2. <u>Calculation of k_{co} for 275 Dincel filled with BarChip reinforced Concrete</u>

Width of the shear plane $b_f = 94.51\ mm$

Shear plane area $\Longrightarrow 94.51 \times 1000 = 94510\ mm^2$

Measured maximum load $= 589000\ N$ (for specimen with 1.2 m length)

For finding unit shear strength, load is adjusted per metre length:

Unit shear strength $\Longrightarrow \frac{589000}{1.2} = 490833 = \frac{490833}{94510} \approx 5.2\ MPa$

According to Clause 3.1.1.3 $\Longrightarrow f'_{ct} = 0.36\sqrt{40} = 2.28\ MPa$

$5.2 = \mu\,(0) + k_{co} \times 2.28 \Longrightarrow 5.2 = 2.28\ k_{co} \rightarrow \boxed{k_{co} = 2.28}$

The significant increase in k_{co} between plain concrete and BarChip reinforced concrete is attributed to the synthetic fibres providing an array of small dowels which

leads to an increased cohesion effect. Note that the above k_{co} coefficient can also be used where BarChip reinforced concrete is used in conjunction with steel reinforcement. This is because k_{co} is for concrete cohesion only and not steel dowel effects. This provides a conservative approach, as if tested and separately derived, k_{co} will be greater for a specimen with both BarChip reinforced concrete and steel reinforcement due to a larger shear plane surface area as illustrated in Figure 14. Another indication it is a conservative approach is the k_{co} value closely matches that of plain concrete with steel reinforcement as derived below.

3. Calculation of k_{co} for 275 Dincel with plain concrete and steel reinforcement

Shear plane area $\Longrightarrow 94.51 \times 1000 = 94510\ mm^2$

Measured maximum load $= 988000\ N$ (for specimen with 1.2 m length)

For finding unit shear strength, load is adjusted per metre length:

Unit shear strength $\Longrightarrow \frac{988000}{1.2} = 823333 = \frac{823333}{94510} \approx 8.71\ MPa$

According to Clause 3.2.1 $\Longrightarrow f_{sy} = 500\ MPa$

According to Clause 3.1.1.3 $\Longrightarrow f'_{ct} = 0.36\sqrt{40} = 2.28\ MPa$

Shear reinforcement area $\Longrightarrow A_{sf} = 2 \times 113.04 = 226\ mm^2$
According to Table 8.4.3 $\Longrightarrow \mu = 0.9$

$$8.71 = 0.9\left(\frac{226\times500}{300\times94.5}\right) + k_{co} \times 2.28 \Longrightarrow \boxed{k_{co} = 2.25}$$

Although a k_{co} value of 2.25 would apply where the exact steel reinforcement arrangement in the test is used in practice (2N12-300), it cannot be assumed that an identical k_{co} will be attained using different steel reinforcement arrangements. This is because the increased dome effect as illustrated in Figure 14 is a complex behavior which requires further investigation. Therefore, as a conservative approach, it is safe to assume and recommended that for all other steel reinforcement arrangements a k_{co} value of **1.18** is used, to replicate the concrete cohesion value derived for plain concrete.

2.9 Conclusions and Recommendations

In this study, the effects of using BarChip fibre reinforced concrete on interface shear strength of 275 Dincel structural walling panels in comparison with 275 Dincel structural walling panels filled with conventional plain concrete and reinforced concrete have been experimentally investigated. Nine composite Dincel Polymer encased concrete wall specimens were cast and tested using direct shear test at UTS Tech Lab. Based on the load-deflection curves obtained from the direct shear test, the maximum shear loads and the interface shear strength values were determined for three different cases including i) test specimens filled with plain concrete, ii) test specimens filled with macro-synthetic fibre reinforced concrete, and iii) test specimens filled with reinforced concrete.

Within the investigation, it was found that the shear failure plane is not flat, but rather consists of a series of dome/conical shaped protrusions at web hole locations. The array of domes provides a keying action throughout the section and subsequently this aids in achieving a higher shear capacity to what is possible by calculation to AS3600 (2018).

AS 3600 (2018) does not prescribe the shear plane surface coefficients for determining the interface shear strength of composite Dincel Polymer encased 275 mm Dincel structural walling panels. Therefore, in order to enable structural design engineers to use the equation found in Clause 8.4.3 of AS 3600 (2018) for determining the in-plane vertical shear strength, the friction and cohesion coefficients have been extracted from the test results in this study and proposed in Table 6 for practical applications.

Table 6: Recommended friction and cohesion coefficients for 275 Dincel based on experimental study results, for $b_f = 94.5\ mm$

275 Dincel Specimen Infill	Friction coefficient (μ)	Cohesion coefficient (k_{co})
Plain Concrete	0	1.18
BarChip Fibre Reinforced Concrete	0	2.28
Steel Reinforced Concrete with plain concrete infill	0.90	1.18
Steel Reinforced Concrete with BarChip Fibre reinforced concrete infill	0.90	2.28

2.10 Design Certification in accordance with AS3600-2018

275 Dincel walls, when designed by a structural engineer using the information provided in this report, will satisfy the deemed-to-satisfy provisions of the National Construction Code for structural design.

In accordance with test results shown in this report as per Appendix B of AS3600-2018, A/Professor Shami Nejadi as the chief investigator on behalf of UTS (in his capacity) confirms that 275 Dincel structural walling panels filled with mass concrete (with or without steel reinforcement), or filled with concrete containing BarChip 48 macro-synthetic fibres, complies with AS3600-2018. A structural engineer may calculate the interface shear capacity of any 275 Dincel wall using the method shown in Section 5 of this report or using the proposed values in Table 6.

Table A1 of Appendix 1 provides examples of capacities calculated using the determined coefficients, and can be used by a structural engineer in lieu of appropriate calculation.

A/Professor Shami Nejadi: Date: 23/10/2020

Appendix 2.1 – Design Process

To aid with the design process for engineers, the interface shear capacities for various Dincel 275 walling arrangements has been shown in Table A1.

Table A1: Interface shear capacity for various Dincel 275 walling arrangements

Material	**Calculation to AS3600 (2018)** **($b_f = 94.5\ mm$** **f'c = 40 MPa, ϕ = 0.7)**	**Test Results** **(f'c = 40MPa, ϕ = 0.7)**
Plain Concrete only (k_{co} = 1.18)	177.7 kN/m	304/1.2 × 0.7 = **177.3** kN/m
BarChip reinforced concrete only (k_{co} = 2.28)	343.4 kN/m	589/1.2 × 0.7 = **343.6** kN/m
Plain Concrete + 2N12 @ 300 (k_{co} = 1.18, μ =0.9)	408.5 kN/m	988/1.2 x 0.7 = **575.3** kN/m
Plain Concrete + 2N16 @ 150 (k_{co} = 1.18, μ =0.9)	1018.2 kN/m	N/A
Plain Concrete + 2N20 @ 150 (k_{co} = 1.18, μ =0.9)	1480.4 kN/m	N/A
BarChip reinforced concrete + 2N12 @ 300 (k_{co} = 2.28, μ =0.9)	574.2 kN/m	N/A
BarChip reinforced concrete + 2N16 @ 150 (k_{co} = 2.28, μ =0.9)	1183.9 kN/m	N/A
BarChip reinforced concrete + 2N20 @ 150 (k_{co} = 2.28, μ =0.9)	1646.1 kN/m	N/A

As can be seen from Table A1, the calculated capacity for a Dincel wall with 2N12-300 steel reinforcement is 29% less than the tested capacity. As explained in Section 5, this is due to a conservative adoption of the cohesion factor k_{co} which is taken to be the same as the derived coefficient for plain concrete within 275 Dincel, in order to be appropriate for all proposed steel reinforcement arrangement. Regardless, it should be noted that the values calculated by AS3600 (2018) for Dincel 275 with steel reinforced concrete closely trails the calculated capacity for a conventional 275mm thick steel reinforced concrete wall.

Before physical testing, the conventional method of determining the interface shear capacity for Dincel walls was by using the coefficients prescribed in AS3600 (2018) Table 8.4.3 and a shear plane width (b_f) equivalent to the area bound within the web holes. This study has concluded that this method is an overly conservative approach, and instead the coefficients and capacities provided in Tables 6 and A1 can be used in conjunction with the reduced shear plane width.

Technical Report

Evaluation of Flexural Performance of 275 Dincel Structural Walling

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Rev 03
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3.1 Introduction

This technical report has experimentally evaluated the effects of using BarChip fibre reinforced concrete on flexural behaviour of 275 Dincel structural walling panels in comparison with 275 Dincel structural walling panels filled with conventional plain concrete and reinforced concrete. The ultimate purpose of this study is to demonstrate that Dincel prototype walls/blade walls filled with mass concrete or with concrete containing BarChip fibres, with no steel bar reinforcement, can be used in sway prevented structures such as retaining walls. Refer to Appendix 1 for a background to the project.

3.2 Experimental Testing Program

Fifteen 275 Dincel structural walling panel specimens were cast and tested at the UTS Tech Lab. The first of its type in Australia, UTS Tech Lab is a new-generation 9000 m^2 facility that is designed to bring the university and industry together to innovate and disrupt traditional university approaches to research. As illustrated in Figure 1a, the test specimens have been made of three 275mm Dincel panels with overall dimensions of 825mm wide × 3600 mm long (3m clear span). Figure 1b shows an overall view of the test specimens.

(a)

(b)

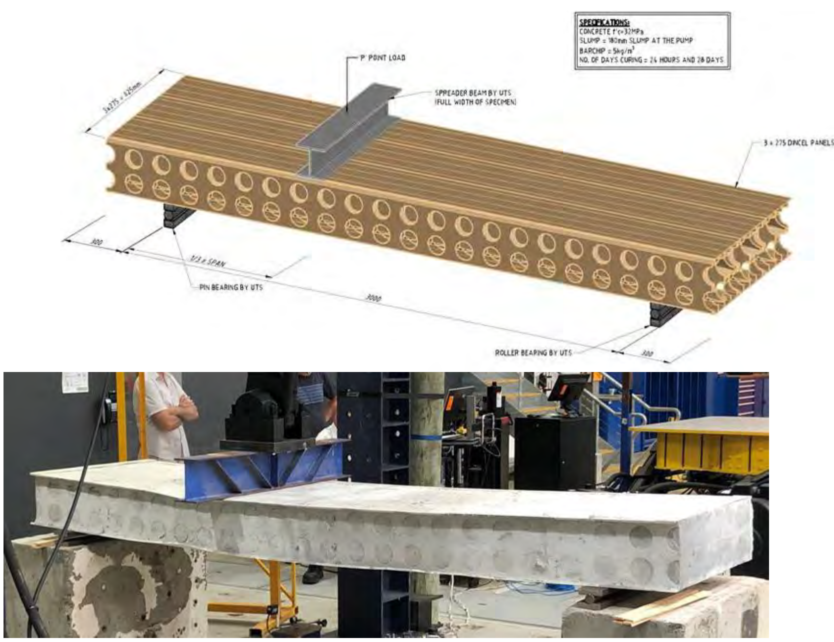


Figure 1: a) Dimensions of the test specimens, b) Overall view of the test specimens

All fifteen 275 Dincel structural walling panel specimens were prepared, poured with concrete (which possesses compressive strength of 32 MPa at 28 days and min. 180mm slump at the pump), and cured on site at UTS Tech Lab by Dincel technicians. The entire process has been overseen and reviewed by UTS staff prior, during and post pour. All reinforcement details, mix designs and mix properties were reviewed and approved by suitably qualified UTS staff. Concrete compression cylinders were taken from the fresh concrete mix and tested to measure the concrete strength at various stages of curing to determine the concrete properties throughout curing strength predictions and validation of the concrete mechanical properties (Figure 2).

(a) **(b)**

Figure 2: Concrete compression cylinder tests; a) Samples taken from the fresh concrete mix, b) Concrete compression test in process at UTS Tech Lab

3.3 Mechanical Properties of 275 Dincel Panels

In order to determine mechanical properties of the employed PVC materials in this study, five dog-bone coupon specimens from the Dincel panels were prepared according to ASTM D638 specifications as illustrated in Figure 3.

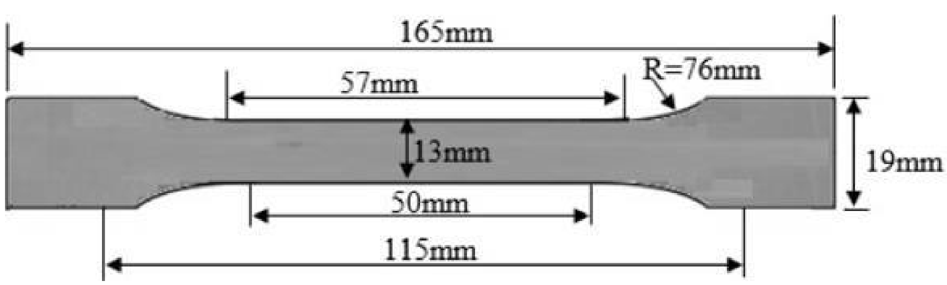


Figure 3: Dog-bone coupon specimens prepared for tensile tests according to ASTM D638

As illustrated in Figure 4, tensile tests were conducted by applying a constant rate of 0.083mm/s in accordance with ASTM D638 and the resulted average ultimate tensile strength, Young's modulus of elasticity, and Poison's ratio were determined and presented in Table 1.

Table 1: Mechanical properties of tested PVC material

Young's Modulus E (MPa)	Tensile Strength σ_u (MPa)	Poisson's Ratio υ
2609	37.20	0.39

Figure 4: An overview of the tensile PVC testing at the UTS Tech Lab

3.4 Test Procedure

The experimental testing program has aimed to investigate the effects of using BarChip fibre reinforced concrete on flexural behaviour of 275 Dincel structural walling panels in comparison with 275 Dincel structural walling panels filled with conventional plain concrete and reinforced concrete. To achieve this goal, flexural testing was conducted on the test specimens, which were cast with plain concrete, reinforced concrete and BarChip fibre reinforced concrete, respectively, and tested at the age of 28 days with the following details:

- Three 275 Dincel panel specimens, named *Flex-BarChip*, with concrete reinforced with 5kg/m^3 of BarChip 48 macro-synthetic fibres;

- Three 275 Dincel panel specimens, named *Flex-Plain*, with plain concrete; and
- Three 275 Dincel panel specimens, named *Flex-Reo*, with reinforced concrete (N16@275mm normal ductility class deformed reinforcing bars grade D500N according to AS3600-2018).

It should be noted that three samples were tested for each different test detail for statistical analysis purposes. In order to investigate the flexural behaviour of Dincel panels filled with concrete containing BarChip 48 at the early age of 24 hours, when the backfilling of the retaining walls may potentially start, six test specimens (three samples for each test detail) were cast and tested 24 hours after pouring the concrete with the following details:

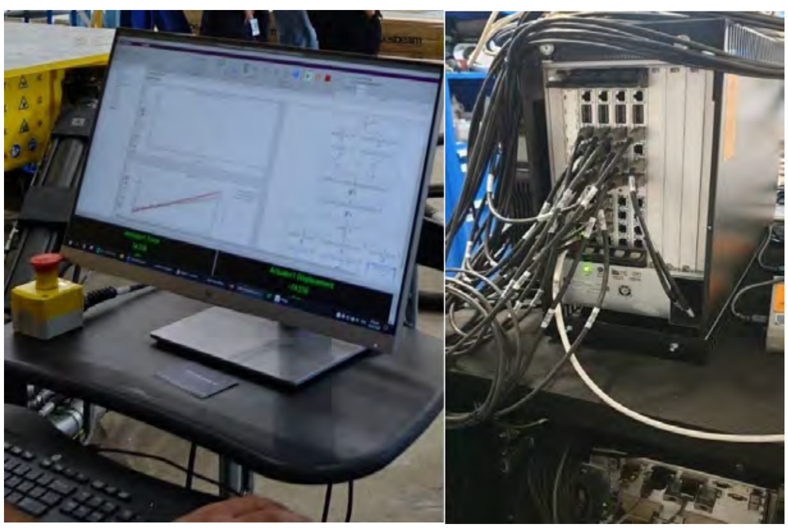
- Three 275 Dincel panel specimens, named *Flex-BarChip*, with concrete reinforced with 5kg/m^3 of BarChip 48 macro-synthetic fibres; and
- Three 275 Dincel panel specimens, named *Flex-Plain*, with plain concrete.

For flexural testing, three-point bending test on a three-metre span was chosen, with the load point at 3rd span (Figure 1) in order to apply a load that conservatively resembled the pressure applied by soil or ground water (hydrostatic pressure) to a propped cantilever such as basement retaining walls. As illustrated in Figure 5, the supports and the load point used in the test configuration represented a simply supported beam to provide the maximum bending moment and shear force at one-third of the span.

Figure 5: Three-point bending test configuration

The load was applied using a hydraulic actuator (MTS 201.35 fatigue rated actuator) and controlled using a PID controller (MTS Flex Test 60) in stroke control. The test load was applied with a suitably stiff spreader beam to distribute the load across the full width of the three modules. Laser displacement sensors were positioned at one-third and half of the span length on the underside of the test specimens to monitor displacement throughout the whole tests (Figure 6), with all the sensors and actuator properties (force and stroke) recorded for post processing purposes using the computerised controller system shown in Figure7.

Figure 6: One of the laser displacement sensors under its protective stand



(a) **(b)**

Figure 7: Controller system used for recording and post processing purposes; a) Front view, b) Rear view

Loading was applied until the maximum bending moment capacity of the specimens had been reached. Figure 8 shows one of the BarChip 48 fibre reinforced concrete failed samples from both sides after reaching the maximum bending moment capacity.

(a) **(b)**

Figure 8: Failure of one of the BarChip 48 fibre reinforced concrete specimens after reaching the maximum bending moment capacity; a) Front side cracks, b) Underside cracks

The test setup and loading rates of the tests were derived in a way that satisfies the requirements of AS3600-2018 Appendix B 'Testing of members and structures'.

3.5 Results and Discussion

The load-deflection curves for all the test specimens have been obtained and plotted in Figures 9 to 13. Figures 9 and 10 show the load-deflection curves for Flex-Plain specimens (specimens filled with plain concrete) and Flex-BarChip specimens (specimens filled with BarChip 48 macro-synthetic fibre reinforced concrete) at the age of 24 hours, respectively, when the backfilling of the retaining walls may potentially start. Figures 11 to 13 illustrate the load- deflections curves for Flex-Plain specimens (specimens filled with plain concrete), Flex-BarChip specimens (specimens filled with BarChip 48 macro-synthetic fibre reinforced concrete) and Flex-Reo specimens (specimens filled with reinforced concrete with N16@275mm normal ductility class deformed reinforcing bars) at the age of 28 days when the concrete has reached the intended strength of 32 MPa. In order to compare and interpret the results properly, the average load-deflection curves for Figures 9 to 13 have been developed and presented in Figures 14 and 15. Figure 14 compares Flex-

BarChip and Flex-Plain average load-deflection curves at the age of 24 hours while Figure 15 presents a comparison between Flex-BarChip, Flex-Plain and Flex-Reo average load-deflection curves at the age of 28 days.

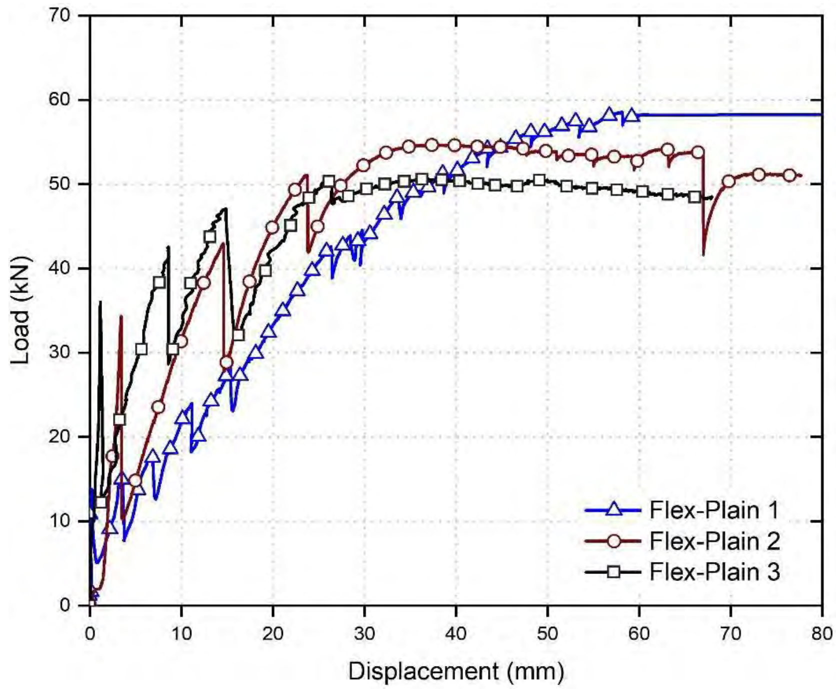


Figure 9: Load-deflection curves for Flex-Plain specimens at the age of 24 hours

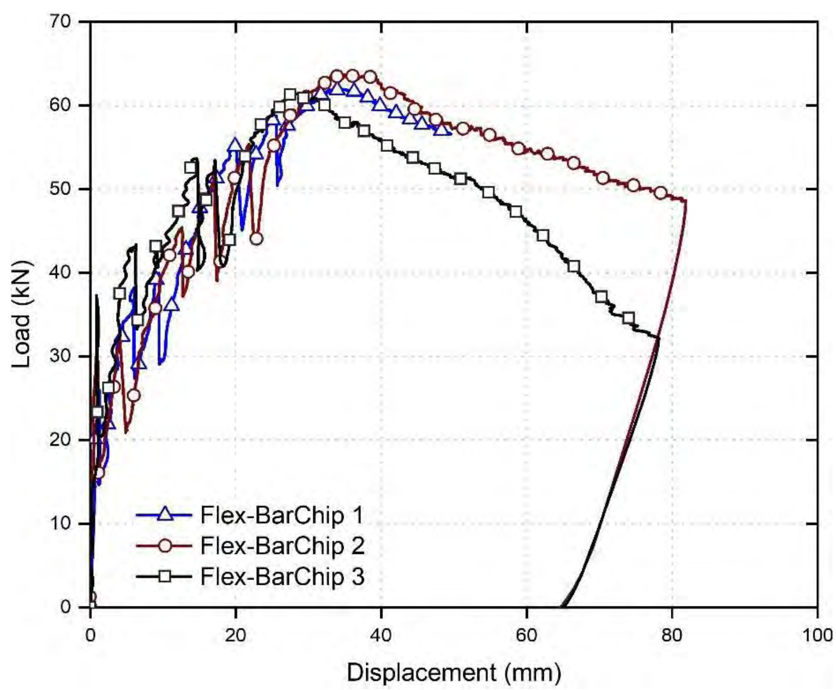


Figure 10: Load-deflection curves for Flex-BarChip specimens at the age of 24 hours

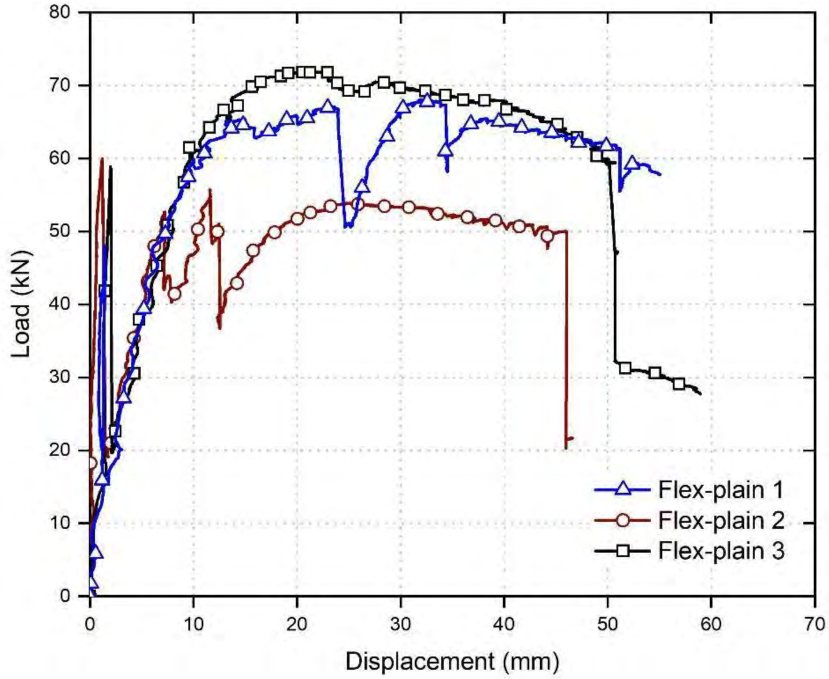


Figure 11: Load-deflection curves for Flex-Plain specimens at the age of 28 days

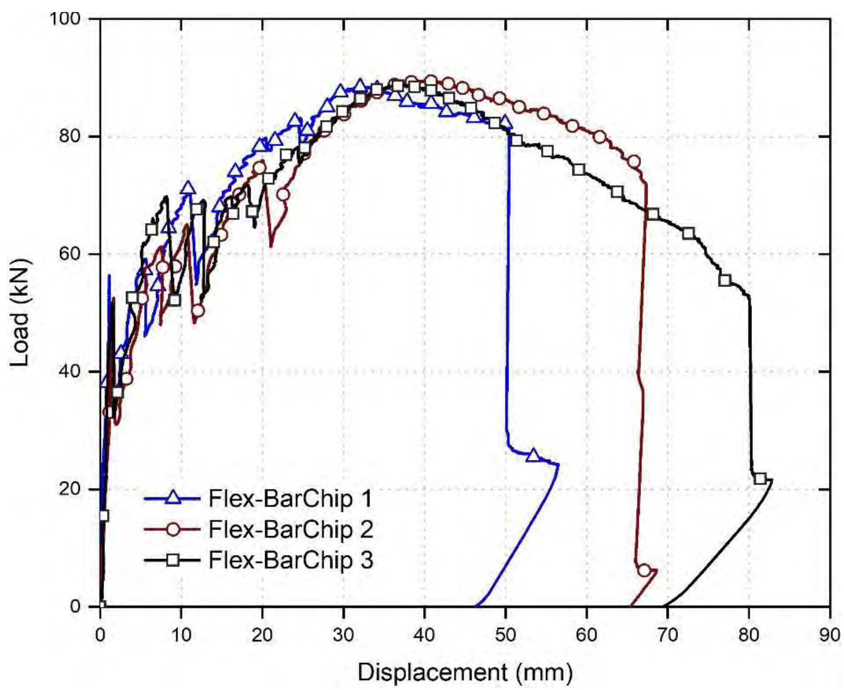


Figure 12: Load-deflection curves for Flex-BarChip specimens at the age of 28 days

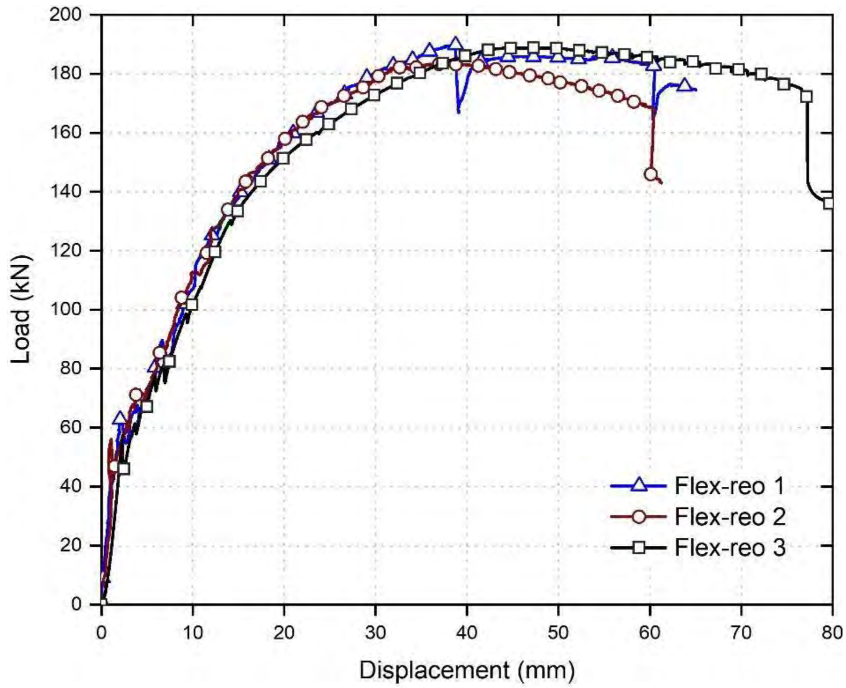


Figure 13: Load-deflection curves for Flex-Reo specimens at the age of 28 days

3.6 Flexural Strength

3.6.1 Flexural Strength at the Age of 24 Hours

Since Dincel Construction commences backfilling retaining walls with compacted material after 24 hours, it is important to understand the flexural behaviour and strength of the retaining walls at this early age, in particular the ones without the steel reinforcement. Therefore, this study has only tested the two cases of Flex-BarChip and Flex-Plain specimens at the age of 24 hours. Based the average results presented in Figure 14, the average ultimate loads, P_u, (the maximum load that the specimens can tolerate before breaking) and the average modulus of rupture values (ultimate flexural strength), M_u, have been determined and tabulated in Table 2.

Table 2: Ultimate loads and module of rupture values for tested specimens at the age of 24 hours

	Flex-Plain	Flex-BarChip
Ultimate Load P_u (kN)	51	63
Modulus of Rupture M_u ($kN.M$)	34	42

Comparing the curves in Figure 14 and the results in Table 2, it can be seen that the ultimate load and the modulus of rupture value of Flex-BarChip specimens are 23.5% larger than the corresponding values obtained from the Flex-Plain specimens. Therefore, it is understood that using BarChip 48 fibre reinforced concrete instead of plain concrete in the tested specimens can increase the flexural strength by 23.5% at the early age of 24 hours.

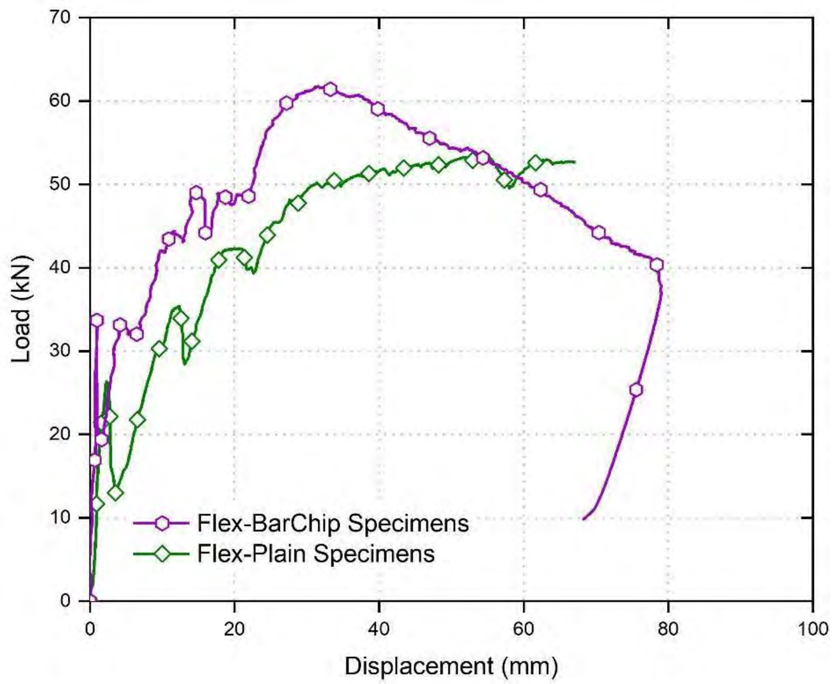


Figure 14: Comparison between Flex-BarChip and Flex-Plain average load-deflection curves at the age of 24 hours

3.6.2 Flexural Strength at the Age of 28 Days

In order to investigate the flexural strength of the test specimens at the age of 28 days, the average ultimate loads and the average modulus of rupture values (ultimate flexural strength) have been extracted from Figure 15 and summarised in Table 3.

Table 3: Ultimate loads and module of rupture values for tested specimens at the age of 28 days as well as the empty cell

	Flex-Plain	Flex-BarChip	Flex-Reo
Ultimate Load P_u (kN)	62	89	186
Modulus of Rupture M_u ($kN.M$)	41.3	59.3	123

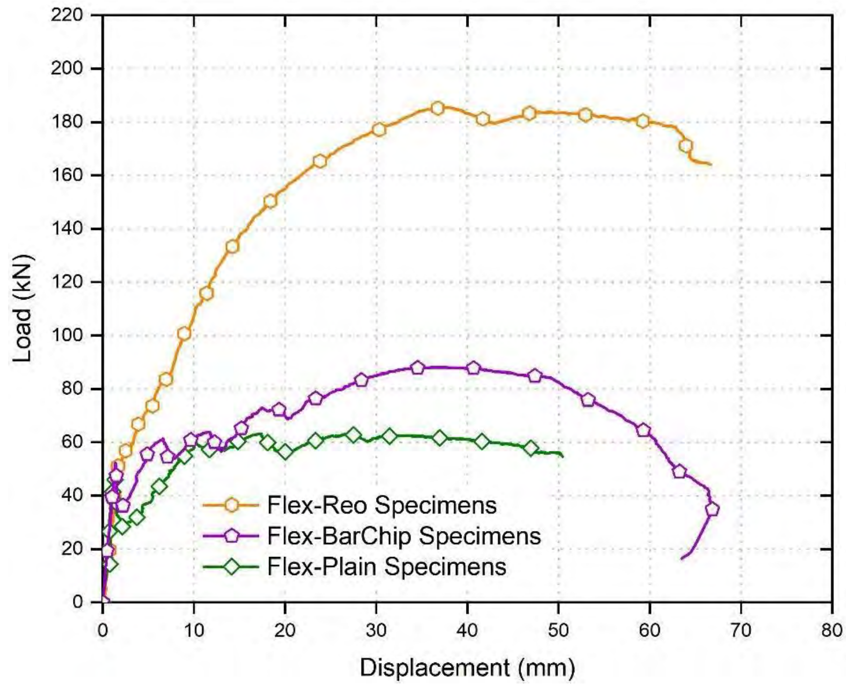


Figure 15: Comparison between Flex-BarChip, Flex-Plain and Flex-Reo average load-deflection curves at the age of 28 days

Comparing the average curves in Figure 15 and the determined values in Table 3, it is noted that the ultimate load and the modulus of rupture value of Flex-BarChip specimens have increased by 43.5% compared to the corresponding values determined from the Flex-Plain specimens after 28 days. Therefore, it has become apparent that using BarChip 48 macro- synthetic fibre reinforced concrete instead of plain concrete in the studied specimens leads to 43.5% flexural strength enhancement at the age of 28 days. It should be noted that this increase is 20% more than what has been observed at the age of 24 hours showing that the flexural strength improves over time. In addition, comparison between the three groups of the tested specimens in Figure 15 and Table 3 has revealed that the flexural strength of Flex- Plain specimens (specimens filled with plain concrete) is 33% of the flexural strength of Flex- Reo specimens (specimens filled with reinforced concrete) while Flex-BarChip specimens (specimens filled with BarChip 48) have achieved almost 50% of the flexural strength of the Flex-Reo specimens. It is an important observation that shows employing BarChip 48 fibre reinforcement in 275 Dincel structural walling panels can produce half of the flexural strength achieved by a fully reinforced panels while only one third of this capacity can be reached by using conventional plain concrete.

3.6.3. Stiffness and Flexural Rigidity at the Age of 28 Days

In order to develop a better understanding of the flexural performance of the tested specimens at the age of 28 days, in addition to flexural strength, flexural rigidity (*EI*) and stiffness (*K*) values for cracked and un-cracked conditions considering tension stiffening effect have been determined based on the load-deflection curves presented in Figure 15. As shown in Figures 16 to 18, when the applied force *P* is plotted against the displacement δ, straight lines can be fitted in both elastic and cracking stages. The gradient of these lines can estimate the stiffness values for the specimens in un-cracked, effective and fully cracked conditions.

In Figures 16 and 17, where BarChip48 and steel reinforcement were used in the concrete to provide resistance against tensile stresses, tension stiffening effects are generated due to the bond between the reinforcement and concrete. Those effects have been taken into account in determining the stiffness of Flex-BarChip and Flex-Reo specimens and the corresponding un-cracked, effective and fully cracked stiffness values have been estimated and tabulated in Table 4.

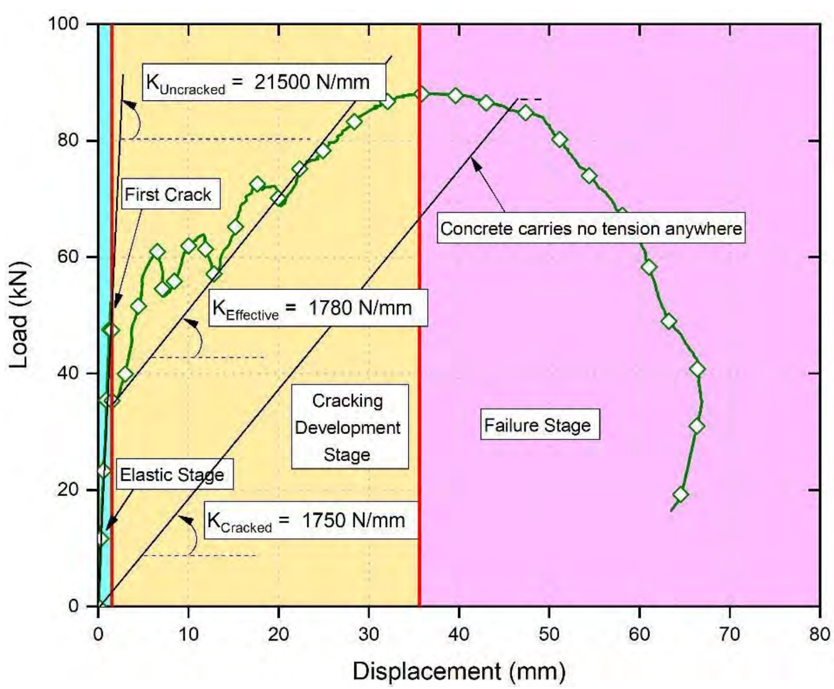


Figure 16: Stiffness calculation for Flex-BarChip specimens

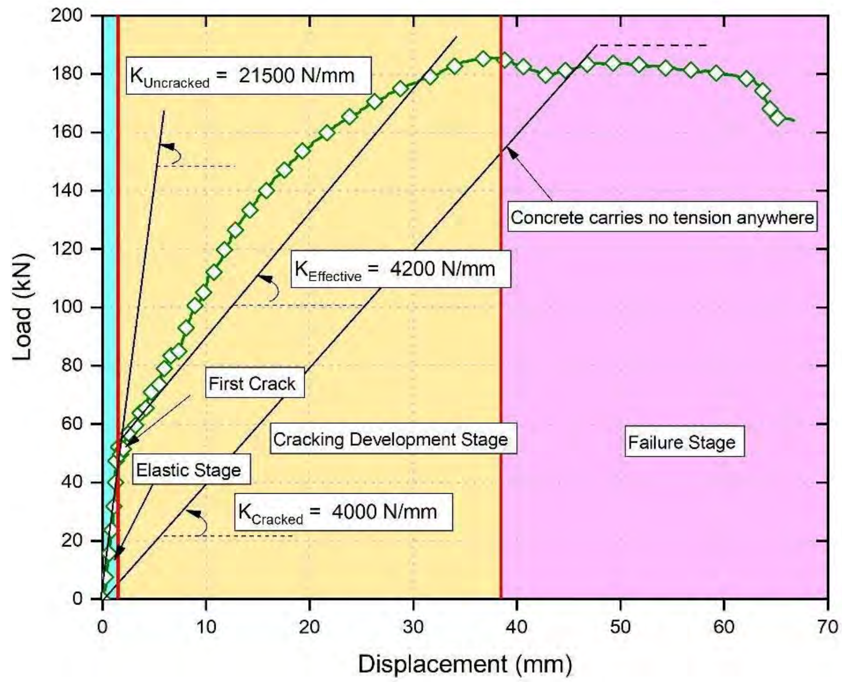


Figure 17: Stiffness calculation for Flex-Reo specimens

For Flex-Plain specimens shown in Figure 18, the stiffness values were only determined in un- cracked and fully cracked phases (Table 4) since there is no tension stiffening effects observed.

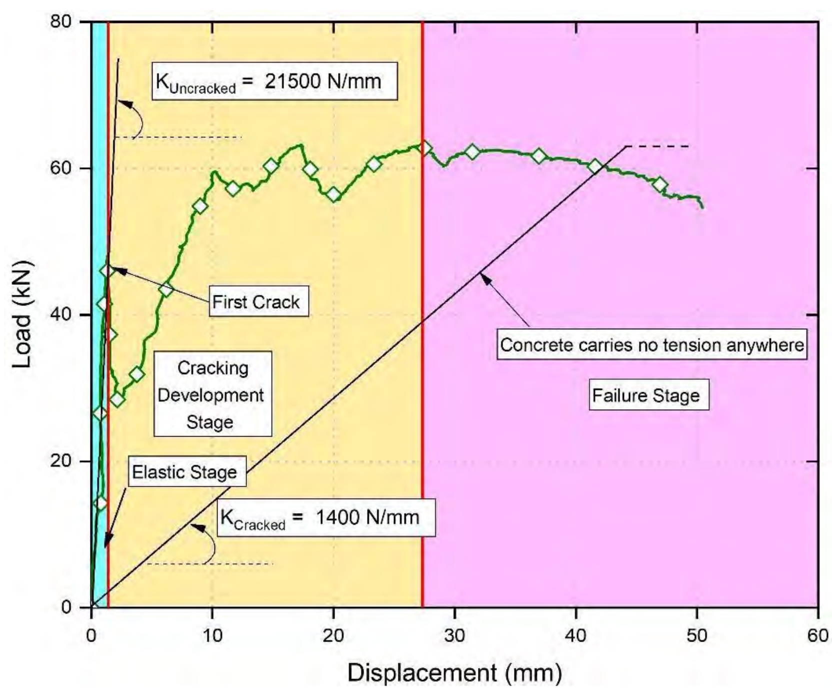


Figure 18: Stiffness calculation for Flex-Plain specimens

Table 4: Un-cracked, effective, and cracked stiffness values for the tested specimens

	Flex-Plain	Flex-BarChip	Flex-Reo
Uncracked Stiffness (*N/mm*)	21500	21500	21500
Effective Stiffness (*N/mm*)	N/A	1780	4200
Fully Cracked Stiffness (N/mm)	1400	1750	4000

As reflected in Figures 16 to 18, in all the tested specimens, a sudden drop occurs in section stiffness when the first crack appears that correlates very well with previous studies in this area. According to well-established methods used by other researchers, using the estimated stiffness values, flexural rigidity values in un-cracked, effective and fully cracked conditions for the tested specimens have been calculated and summarised in Table 5.

Table 5: Un-cracked, effective, and cracked flexural rigidity values for the tested specimens

	Flex-Plain	Flex-BarChip	Flex-Reo
Uncracked Flexural Rigidity (N/mm^2)	9555×10^9	9555×10^9	9555×10^9
Effective Flexural Rigidity (N/mm^2)	N/A	791×10^9	1866×10^9
Fully Cracked Flexural Rigidity (N/mm^2)	622×10^9	777×10^9	1777×10^9

As the results in Tables 4 and 5 indicate, Flex-Plain, Flex-Reo and Flex-BarChip specimens have similar stiffness and flexural rigidity values in elastic (un-cracked) stage which corresponds well with the previous studies. However, the fully cracked stiffness and flexural rigidity values of Flex-BarChip specimens are 25% higher than the corresponding values determined from Flex-Plain specimens after 28 days. Thus, it can be understood that using BarChip 48 fibre reinforced concrete instead of plain concrete in 275 Dincel structural walling panels can result in noticeable improvement in stiffness and flexural rigidity at the age of 28 days. In addition, it has been observed that Flex-BarChip specimens have achieved 44% of the stiffness and flexural rigidity of Flex-Reo specimens while Flex-Plain specimens obtained 34% of those. It clearly indicates that using BarChip 48 macro-synthetic fibre reinforcement in 275 Dincel structural walling panels can produce nearly half of the flexural rigidity and stiffness achieved by a fully reinforced 275 Dincel structural walling panels while only about one third of those values can be reached by using conventional unreinforced concrete.

Furthermore, it is noted in Tables 4 and 5 that the cracked and effective stiffness and flexural rigidity values are slightly different. Those minor differences observed between the effective and fully cracked stiffness and flexural rigidity values are attributed to the tension stiffening effects caused by the bond between the reinforcement and concrete.

3.7 Suitability of Using 275 Dincel Structural Walling Panels as Sway- prevented Structures

One of the main factors concerning durability and service life of retaining walls is corrosion of steel bars especially when exposed to harsh environment. The use of fibre-reinforced concrete, as non-corrosive material, in 275 Dincel structural walling panels with no steel reinforcement can potentially solve the corrosion related problems. This can reduce the maintenance cost and increase the service life of the retaining walls. Several researchers have pointed out that PVC encased concrete walls can function as retaining walls and foundation walls with no need for steel reinforcement, except for steel dowels, which are conventionally used to anchor the wall to the concrete foundation. Therefore, in this study, the suitability of the tested 275 Dincel structural walling panels (Flex-Plain and Flex-BarChip specimens) for being used without steel reinforcement in sway-prevented structures such as retaining walls has been examined (refer to Appendix 2 for typical loading scenarios). To achieve this goal, a conventional reinforced concrete retaining wall with the height of 3m that has been designed according to AS3600-2018 to safely function as a retaining wall has been selected as the base for assessing suitability of the tested specimens. The selected retaining wall has 275 mm thickness, the same thickness as the tested specimens, and is poured with concrete with the compressive strength of 32 MPa at 28 days. The minimum reinforcement of 0.25 % normal ductility class deformed reinforcing bars grade D500N, prescribed in Clause 11.7.1 of AS3600-2018 for concrete walls, has been adopted for this concrete retaining wall and the ultimate flexural strength of this wall has been calculated.

The ultimate flexural strength (M_u) of the tested Flex-Plain specimens (specimens filled with plain concrete) and Flex-BarChip specimens (specimens filled with BarChip 48 macro- synthetic fibre reinforced concrete) have been compared with the ultimate flexural strength of the described conventional reinforce concrete retaining wall at the age of 28 days. The calculated ultimate flexural strength of the conventional reinforced retaining wall as well as the measured ultimate flexural strength values for Flex-Plain and Flex-BarChip specimens from Table 3 are presented in Table 6 for comparison purposes.

Table 6: Comparison between the ultimate flexural strength values (at 28 days) for 825mm wide specimens

	Tested Specimens Filled with Plain Concrete	Conventional Reinforced Wall (with p=0.25% reinforcement as per AS3600 11.7.1.a)	Tested Specimens filled with BarChip 48 Fibre Reinforcement
Ultimate Flexural Strength M_u ($kN.M$)	41.3	57.9	59.3

Comparison between the results in Table 6 shows that the flexural strength (M_u) of the tested Flex-Plain specimens is 28.7 % lower than the flexural strength of the conventional reinforced concrete retaining wall while the flexural strength of the tested Flex-BarChip specimens is 2.4 % more than the flexural strength of the conventional reinforced wall.

The relatively higher flexural capacity of 275 Dincel structural walling panels filled with BarChip 48 fibre reinforced concrete without steel reinforcement bars compared to the base reinforced concrete walls makes this type of PVC encased walls also a suitable option to be used as retaining walls. As a result, it can be concluded that since 275 Dincel structural walling panels filled with BarChip 48 fibre reinforcement without steel bar reinforcement exhibit more flexural capacity of conventional reinforced concrete retaining walls (that can safely function as a retaining wall), this type of wall can be deemed suitable for being used as sway-prevented structures such as retaining walls.

3.8 Capacity Table from Test Results

The Dincel prototype walls/blade walls provided to UTS were tested in accordance with AS3600-2018, Appendix B at UTS Tech Lab. The test procedure and results are complying with the requirements of Clause 2.2 with respect to strength and Clause 2.3 with respect to serviceability. Summary of the test results for a simply supported 3m long beam are presented in Table 7. For the capacities which can be used by design engineers for design in accordance to AS 3600 – 2018, refer to Appendix 3.

Table 7 - Summary of tested loads and modulus of rupture values for a simply supported 3m long beam

	Capacity at 24 hours old concrete		**Capacity at 28 days old concrete**	
WALL TYPE	Pu (kN per 0.825m width)	Mu (kN.m per 0.825m width)	Pu (kN per 0.825m width)	Mu (kN.m per 0.825m width)
Flex-Plain (275 Dincel + plain concrete)	51	34	62	41.3
Flex-BarChip (275 Dincel + fibre reinforced concrete)	63	42	89	59.3
Flex-Reo (275 Dincel + concrete reinforced with N16 steel bars @ 275mm centres)	N/A	N/A	186	123

3.9 Conclusions and Recommendations

Based on the outcomes of this experimental investigation, it has been observed that using BarChip 48 fibre reinforced concrete in 275 Dincel structural walling panels instead of plain concrete can lead to 43.5% flexural strength improvement and 25% stiffness enhancement at the age of 28 days. As a result, it can be concluded that 275 Dincel structural walling panels filled with fibre reinforced concrete can noticeably exhibit higher flexural strength, flexural rigidity and stiffness compared to the walls filled with plain concrete. It is also understood that using BarChip 48 fibre reinforcement in 275 Dincel structural walling panels can produce nearly half of the flexural strength, flexural rigidity and stiffness achieved by fully reinforced 275 Dincel structural walling panels while only about one third of those values can be reached by using conventional plain concrete in 275 Dincel structural walling-panels.

Based on the experimental measurements and theoretical comparison in this study, it has become apparent that 275 Dincel structural walling panels filled with BarChip 48 without steel reinforcement bars exhibit more flexural capacity of conventional reinforced concrete walls, designed in accordance with AS3600-2018 to function safely as retaining wall.

3.10 Design Certification in accordance with AS3600-2018

Dincel walls, when designed by a structural engineer using the information provided in this report, will satisfy the deemed-to-satisfy provisions of the National Construction Code for structural design.

In accordance with test results shown in this report as per Appendix B of AS3600-2018, A/Professor Shami Nejadi as the chief investigator on behalf of UTS (in his capacity) confirm that 275 Dincel structural walling panels filled with mass concrete (with or without steel reinforcement), or filled with concrete containing BarChip 48 macro-synthetic fibres, complies with AS3600-2018 for being used as sway-prevented structures for flexural members such as retaining walls. The capacities found in Table C of Appendix-3, can be used by a structural engineer in lieu of appropriate calculation.

A/Professor Shami Nejadi: Date: 24/07/2020

APPENDICES

Appendix 3.1 – Background

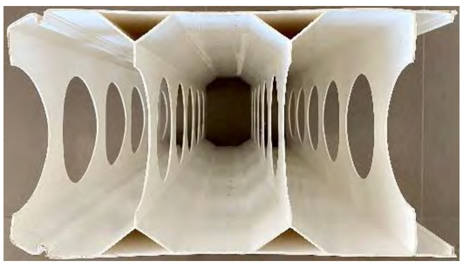
Dincel Construction System was invented by Structural Engineers in the early 2000s. It consists of a permanent polymer encasement for formwork with concrete infill. The world's most abundant construction material is concrete, which has many handicaps to resolve. Concrete being brittle, non-ductile, and weak in tension requires the need to be reinforced with steel reinforcement bars. The use of steel reinforcement bars often leads to construction site safety issues and air voids (particularly with the presence of horizontal bars) whichsteel corrosion, and concrete spalling may occur under fire conditions. Wet concrete also requires formwork, which needed to be in the form of a fast and safe to install formwork system.

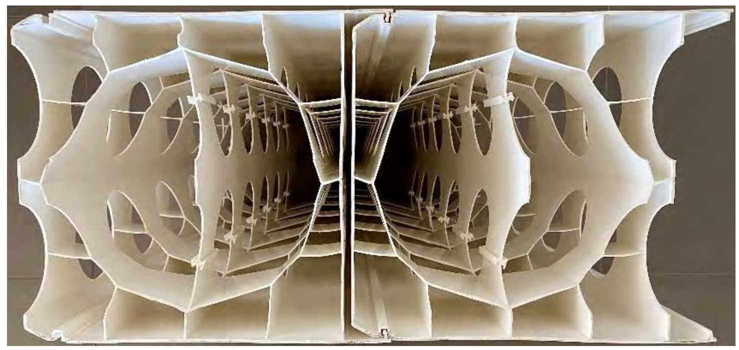
Earlier tests (utilising the 200 Dincel profile with 110mm slump concrete used) by CSIRO- Australia proved that the Dincel polymer skin is impervious and that the panel joints are waterproof even when tested under 6 metres of water head pressure (Reference – CSIRO Test Report No. 5091). Currently Dincel recommends that a vibrator use with minimum 180mm slump concrete at the pump to avoid potential formation of air voids.

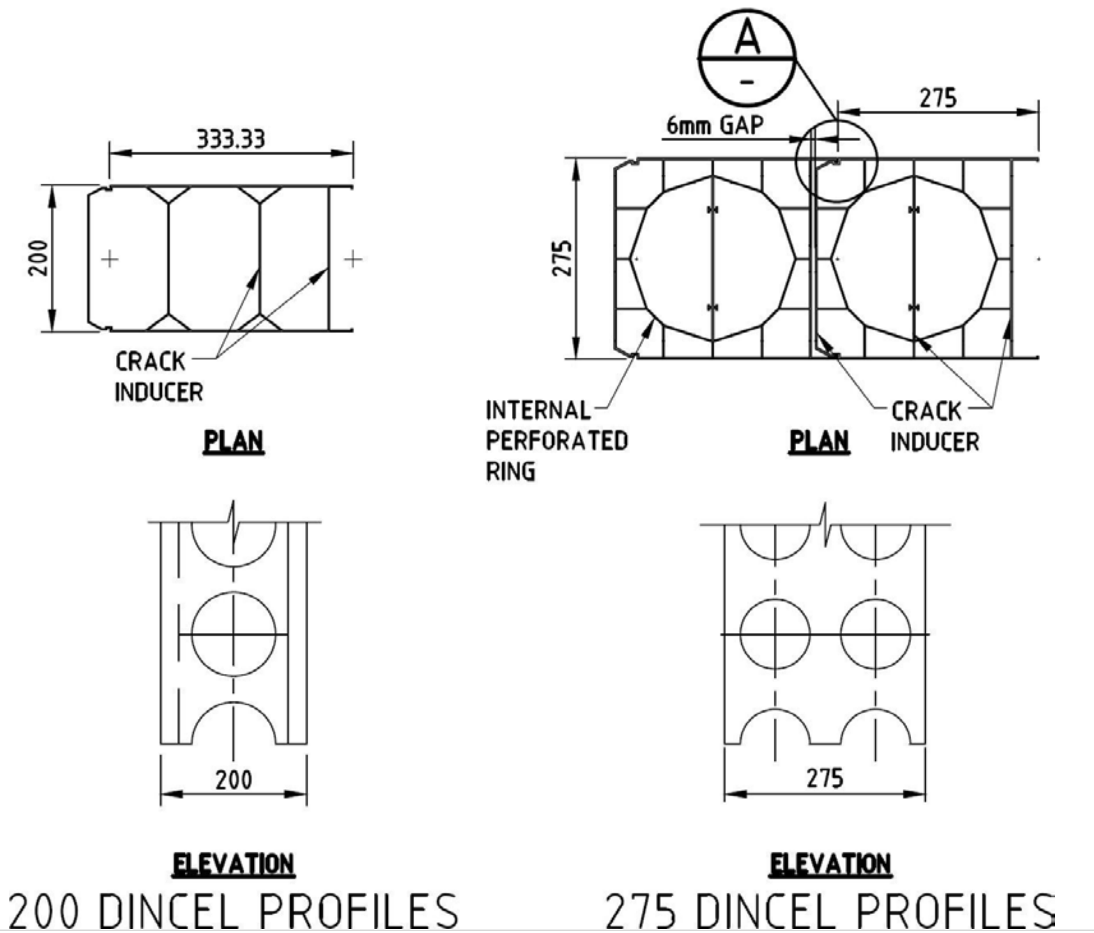
The webs which hold the outer faces of the Dincel profile ensure that plastic shrinkage cracking occurs at each web with very small controlled crack widths. These very small controlled crack widths are further sealed by the concrete's autogenous healing process, as the Dincel polymer encapsulation results in the continuation of concrete hydration for a long period time, thus ensuring denser concrete in compression and increased tensile capacity. The provision of a plastic shrinkage crack control mechanism, as recognised by Eurocode, eliminates the need for crack control reinforcement (Refer to Dincel Structural Engineering Design Manual – Version 5 by UNSW for shrinkage calculations, where webs function as crack control joints).

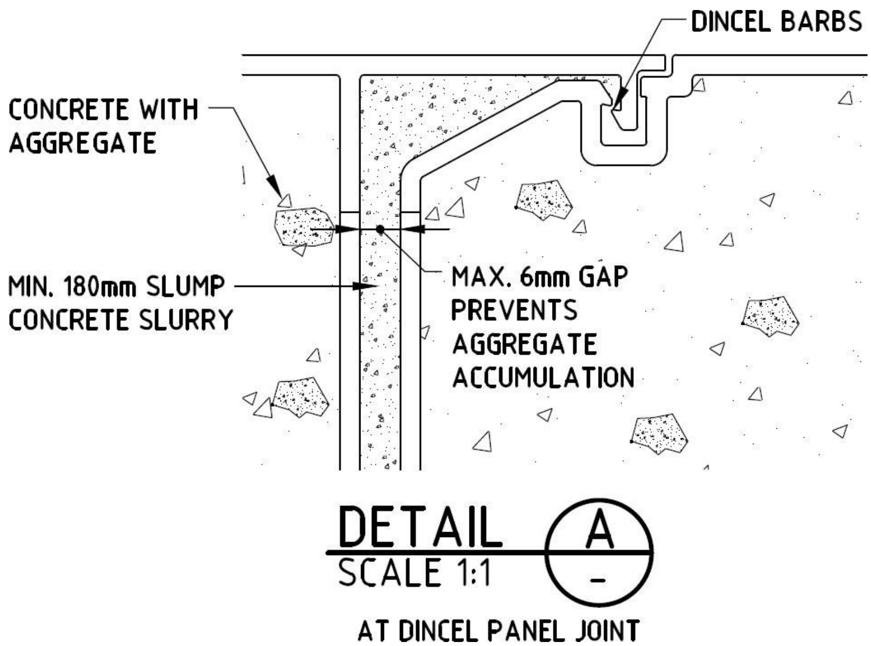
Tests were conducted at the University of Technology, Sydney in 2009-2010, including flexural beam tests and earthquake shake table tests using the 200 Dincel profile. The results demonstrated that there was increased flexural capacity, ductility and resilience in comparison to conventional reinforced concrete due to the concrete being encapsulated within the Dincel polymer formwork.

Following the conclusion of the tests, Dincel developed the 275 Dincel profile. A visual comparison of 275 Dincel profiles to a 200 Dincel profile can be sighted within the below drawings and images.









The 275 Dincel profile achieves the following:

1) The internal ring structure allows the 275 Dincel profile to withstand significantly more wet concrete pressure, with pour heights of up to 6.5 metres in a single day being possible.
2) The perforated internal ring prevents the free fall of concrete aggregates; thus, segregation is prevented. Where required the concrete pump hose can be lowered as well.
3) The perforated internal ring provides a form of anchor, where with conventional formwork the wet concrete normally lifts the conventional formwork. Therefore, the elaborate anchoring typically required for conventional formwork is eliminated.
4) It is significantly more robust when compared to the 200 Dincel profile, thus can handle foot traffic, and resist product failure due to damage to the webs (i.e. due to transportation, carnage, incorrect lifting of product packs, and construction abuse issues).
5) Capability of a single pour height in excess of 4.5 metres with high slump wet concrete. This together with the patented barbed joint connection at the snapped panel locations, and a 6mm gap between interconnecting panels, ensure that concrete slurry without aggregates fully invades the panel joints to add further waterproofing assurance at the panel joints. Refer to Detail 'A' within the above drawing.

Appendix 3.2 – Load Tables

The test specimens were subject to a span of 3 metres and are supported by a roller and a pin at UTS Tech Lab. Such a support case does not exist in real life based on the typical concrete wall to footing connection, and concrete wall to the slab-over connection in a propped cantilever such as a basement wall. If these partial restraints which are present in real-life are considered, the test results become very conservative.

In real-life, the following are more realistic to adopt:

i) For a wall supported by buttresses. Adopt the wall spanning horizontally between buttresses where at one end there will be a pin support (i.e. moment = zero), and the other end the element will be continuous (i.e. moment at support point is not zero).

ii) For a wall which is designed as a propped cantilever. Assume that the support condition at the base/footing can be pin support (i.e. moment = zero), or a fixed support (i.e. moment $\neq 0$) and at the top the wall is supported by a floor concrete slab (i.e. moment at support point is not zero).

Load Combination; All structures must be designed to support their own weight along with any superimposed forces, such as the dead loads from other materials, live loads, wind pressures, seismic forces, snow and ice loads, and earth pressures. These vertical and lateral loads may be of short duration such as those from earthquakes, or they may be of longer duration, such as the dead loads of machinery and equipment. Because various loads may act on a structure simultaneously, load combinations should be evaluated to determine the most severe conditions for design. These load combinations vary from one document to another, depending upon the jurisdiction. The goal of strength design is to proportion the structures that it can resist rarely occurring loads without reaching a limit or failure state. “Rarely occurring” is understood to be a load that has about a 10% chance of occurring within the 50- year life of a typical structure. Since most of the loads prescribed by the building code are expected to occur during the life of the structure, these actual or specified code loads are increased by prescribed load factors to determine the rarely occurring, ultimate load for which failure is to be avoided. The load factors used in the strength design load combinations have been determined to account for the following:

- Deviations of the actual loads from the prescribed loads.
- Uncertainties in the analysis and distribution of forces that create the load effects.
- The probability that more than one extreme load effect will occur simultaneously.

In accordance to AS/NZS 1170.0:2002, Clause 4.2.3 (page-17), the standard clearly mentions

1. **For earth pressure** Clause 4.2.3 (f) that the load factor is 1.5 if the load has not been determined by an ultimate limit states method. The design engineer need to be aware that many Geotechnical Engineering Reports currently provides the loads according to ultimate limit states method. The example shown below adopts the load factor of 1.5 in case such Geotechnical Engineering input not available to the design engineer.

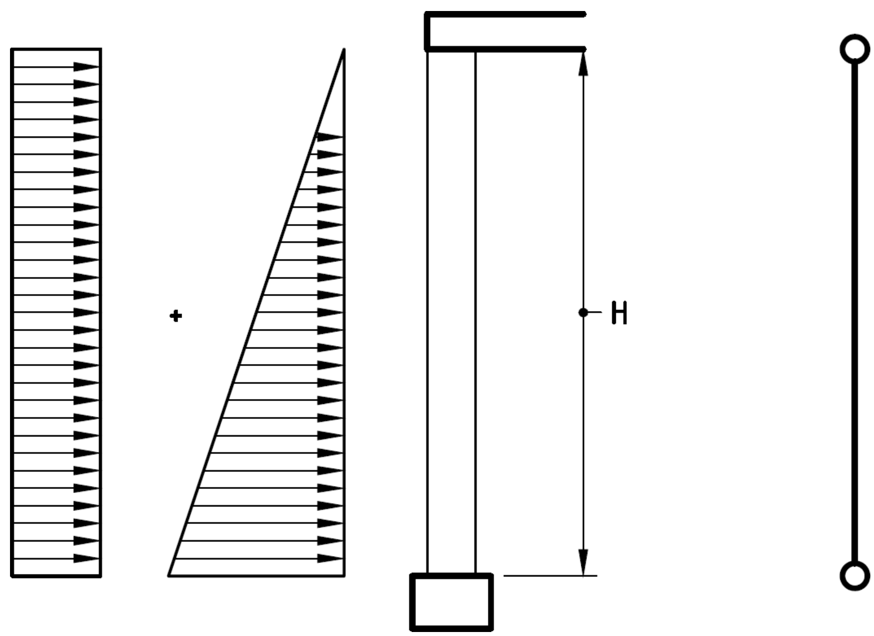
   For water pressure Clause 4.2.3 (e) states for a given (i.e. known) ground water level (e.g. water level confirmed by geotechnical report) the load factor nominated is 1.2. Design engineer can make a decision on the water load factor when the water level is known and not subject to fluctuation. Naturally water level cannot be higher than the total wall height hence the factor of 1.2 can be adopted when water load is considered for the full height of the wall. The following example adopts the load factor of 1.5 for the full wall height as the object of this exercise that the proposal presented in this appendix conservatively addresses the design intent.

Assumptions:

- Ka = 0.33, Earth/Soil density = 20 kN/m^3
- Water density = 9.8 kN/m^3
- Surcharge loading = 5 kPa
- Safety factors used for calculation of M* (factored bending moment):
    - Surcharge loading = 1.5
    - Earth loading = 1.5
    - Water loading = 1.5

Earth + Compaction/Surcharge loading (for example – a retaining wall) - Case 1 Support Conditions

- Base support = **Pin** connection
- Top support = **Pin** connection



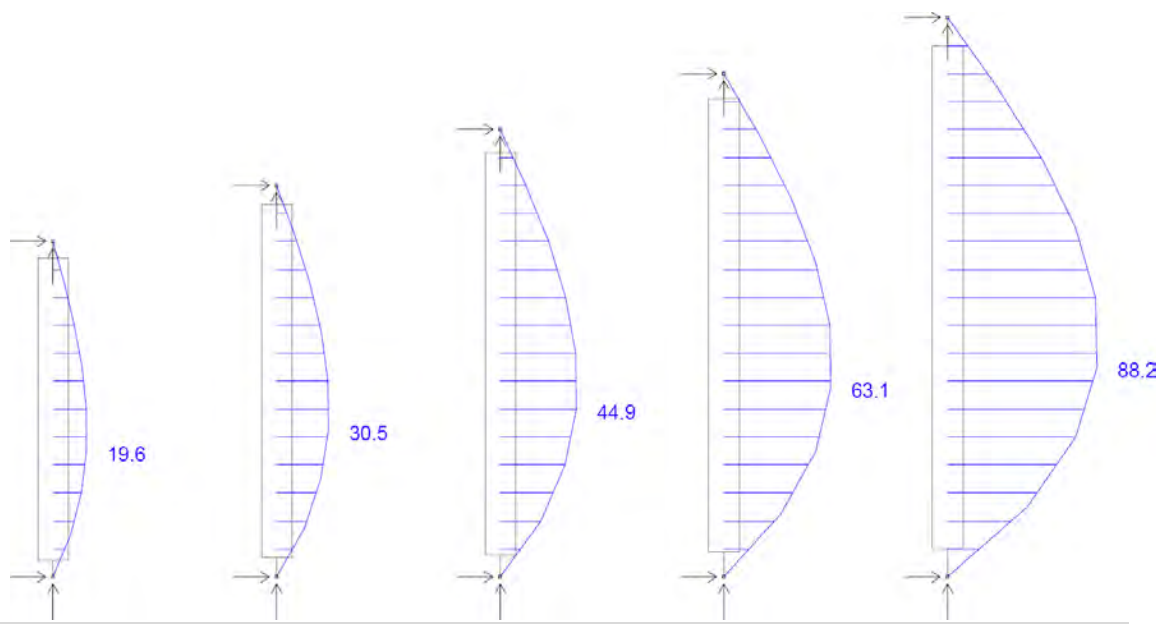
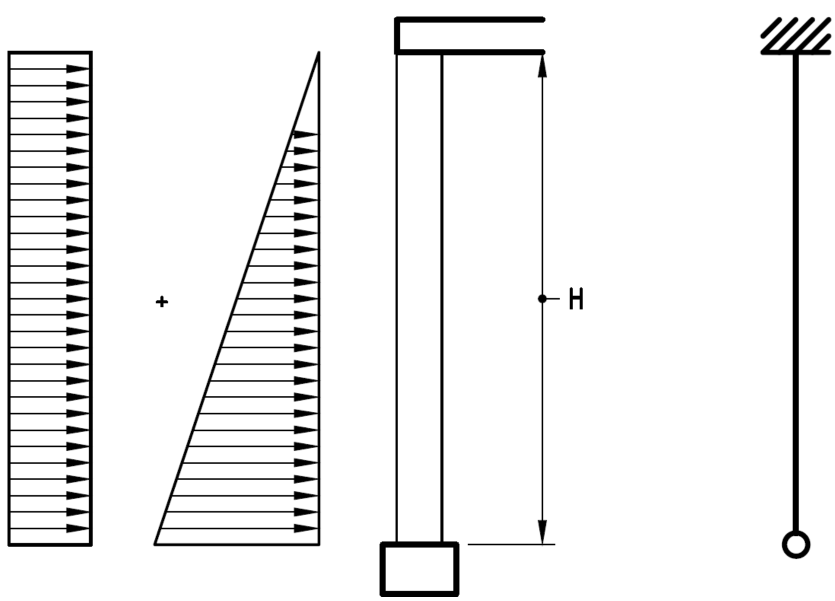


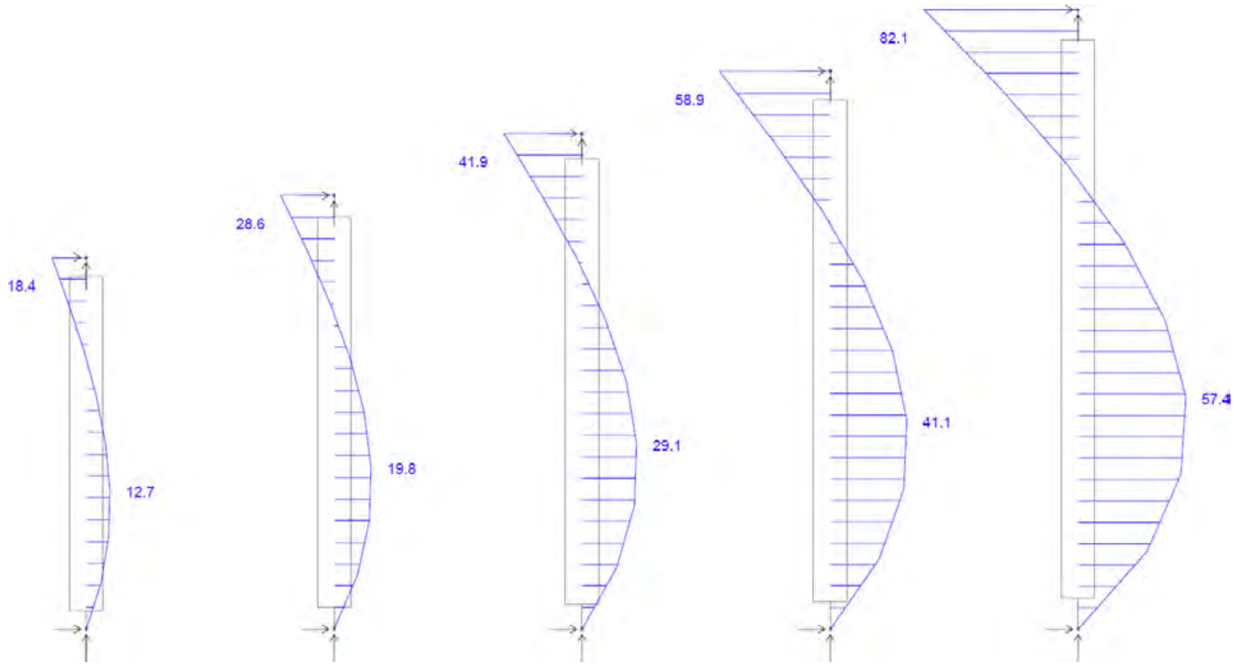
Table A1 – Design/Factored positive bending moments (Case 1 Support Conditions - pin support at base, pin support at top) for wall heights 3, 3.5, 4 ,4.5 or 5 m respectively

Wall Height (H)	**+M* (kN.m per metre run)**
3.0 metres	19.6
3.5 metres	30.5
4.0 metres	44.9
4.5 metres	63.1
5.0 metres	88.2

Earth + Compaction/Surcharge loading (for example – a retaining wall) - Case 2 Support Conditions

- Base support = **Pin** connection
- Top support = **Fixed** connection



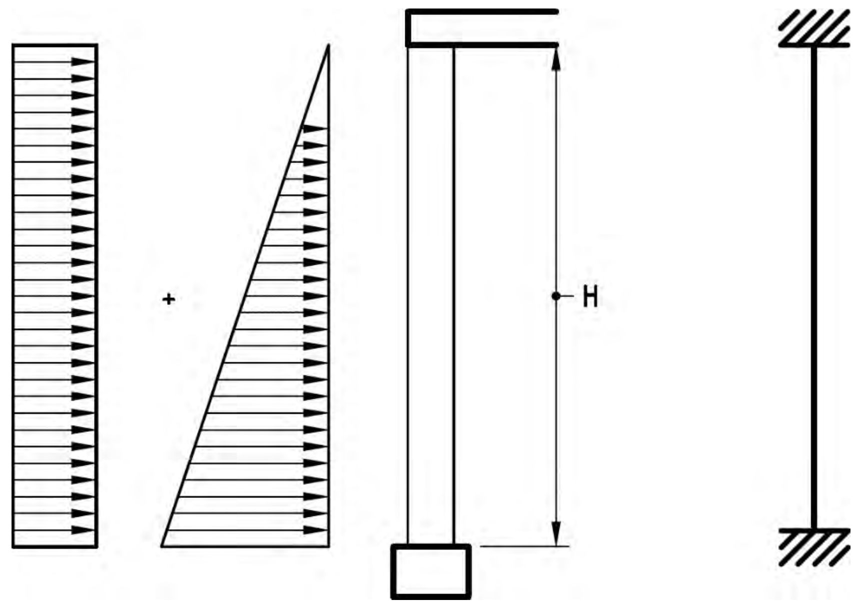


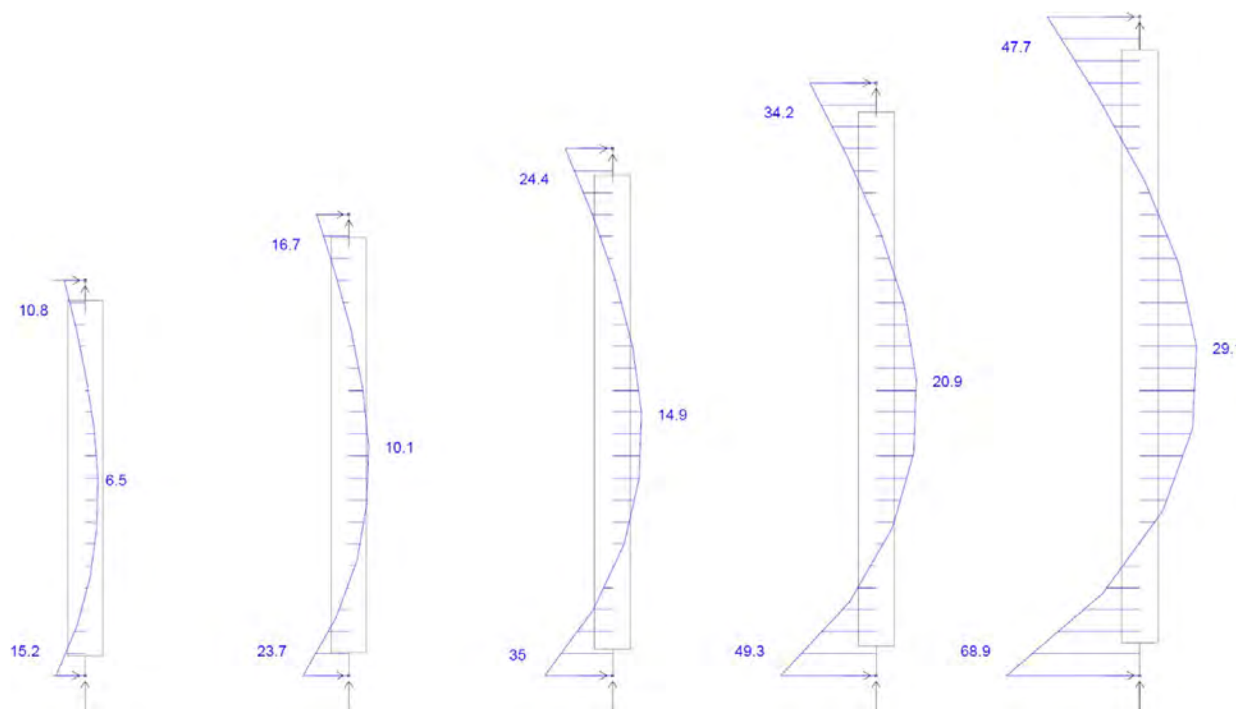
<u>Table A2</u> – Design/Factored positive bending moments (Case 2 Support Conditions - pin support at base, fixed support at top) for wall heights 3, 3.5, 4, 4.5 or 5 m respectively

Wall Height (H)	+M* (kN.m per metre run)
3.0 metres	12.7
3.5 metres	19.8
4.0 metres	29.1
4.5 metres	41.1
5.0 metres	57.4

Earth + Compaction/Surcharge loading (for example – a retaining wall) - Case 3 Support Conditions

- Base support = **Fixed** connection
- Top support = **Fixed** connection





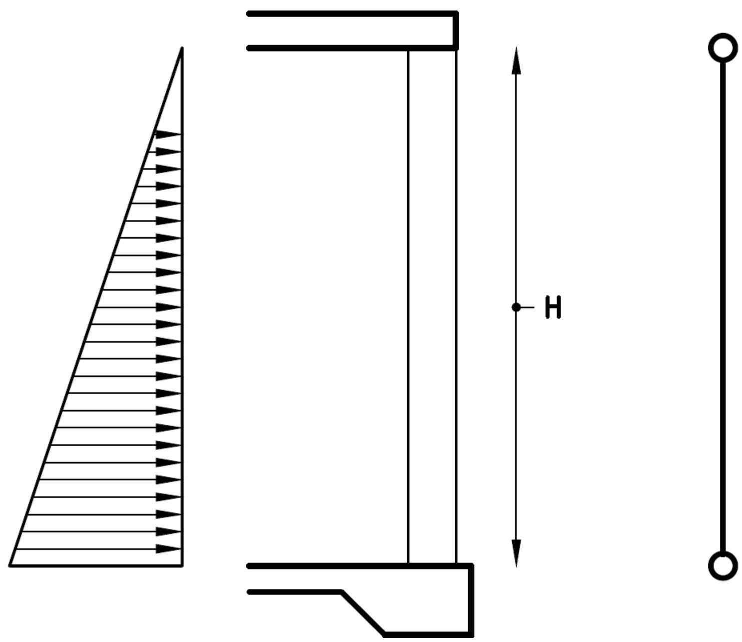
Negative bending moments are not tabulated in below Table B2. Design engineers to use steel bars for the negative bending moments.

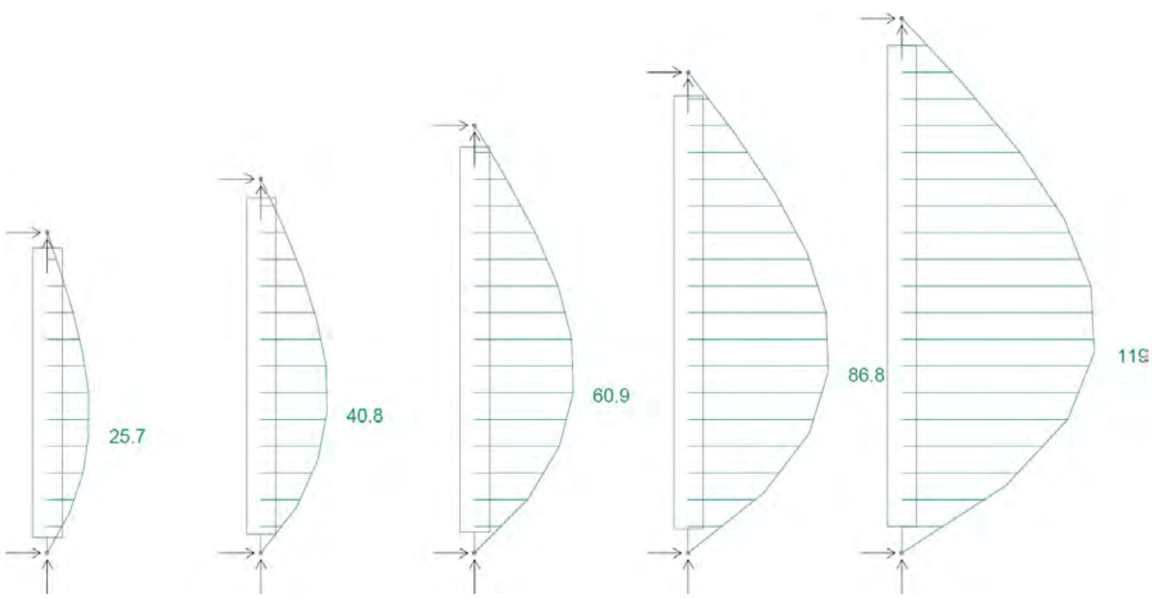
Table A3 – Design/Factored positive bending moments (Case 3 Support Conditions - fixed support at base, fixed support at top) for wall heights 3, 3.5, 4 ,4.5 or 5 m respectively

Wall Height (H)	**+M* (kN.m per metre run)**
3.0 metres	6.5
3.5 metres	10.1
4.0 metres	14.9
4.5 metres	20.9
5.0 metres	29.1

<u>Water pressure loading (for example – a water retention tank wall) - Case 1 Support Conditions</u>

- Base support = **Pin** connection
- Top support = **Pin** connection



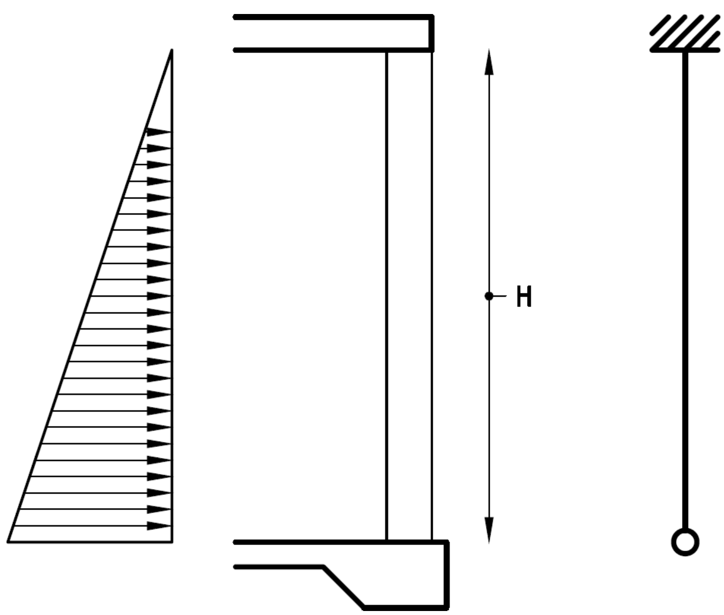


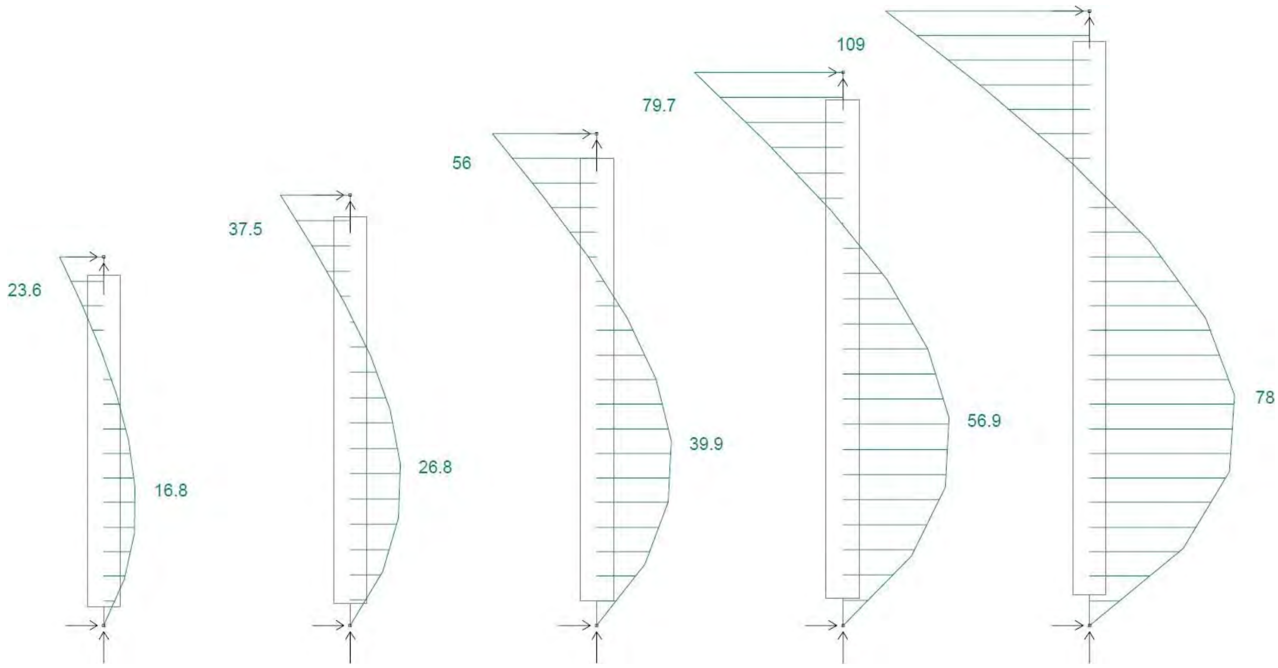
<u>Table B1</u> – Design/Factored positive bending moments (Case 1 Support Conditions - pin support at base, pin support at top) for wall heights 3, 3.5, 4 ,4.5 or 5 m respectively

Wall Height (H)	**+M* (kN.m per metre run)**
3.0 metres	25.7
3.5 metres	40.8
4.0 metres	60.9
4.5 metres	86.8
5.0 metres	119

<u>Water pressure loading (for example – a water retention tank wall) - Case 2 Support Conditions</u>

- Base support = **Pin** connection
- Top support = **Fixed** connection





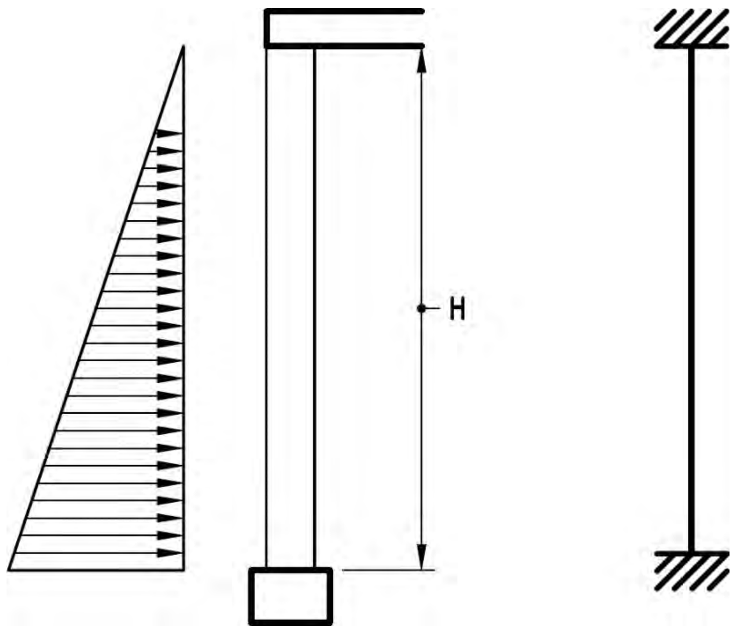
Negative bending moments are not tabulated in below Table B2. Design engineers to use steel bars for the negative bending moments.

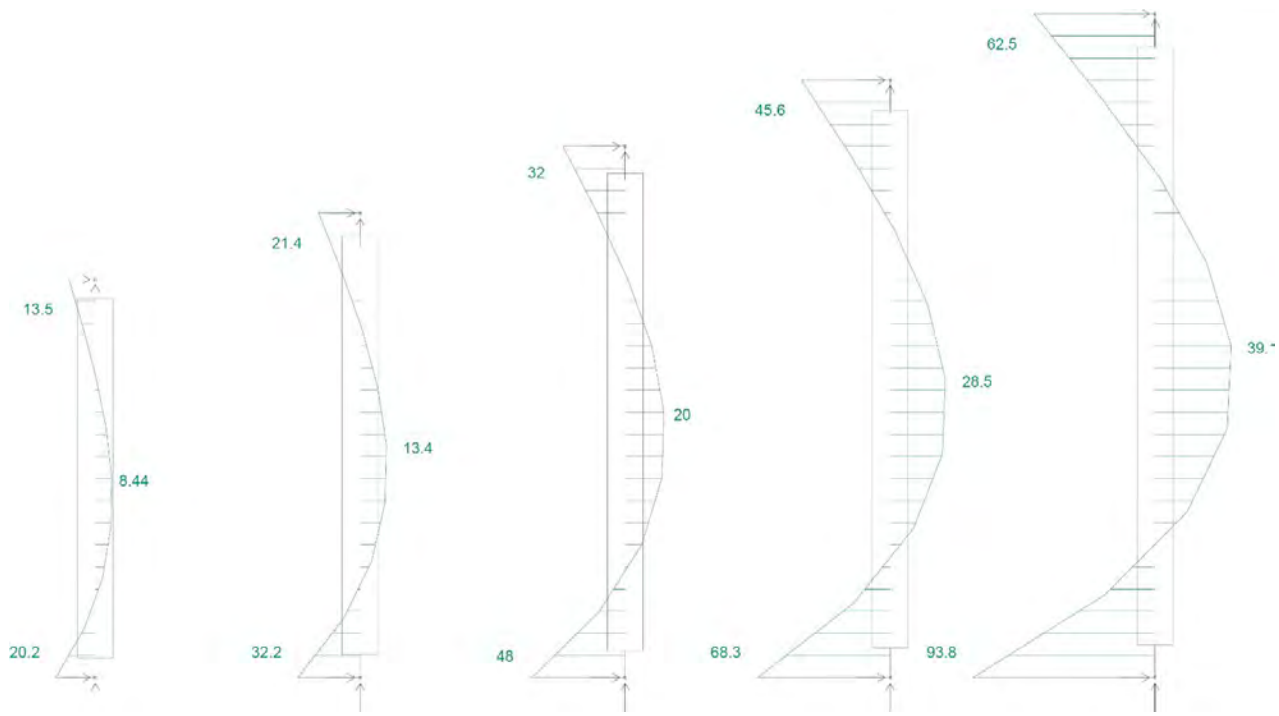
Table B2 – Design/Factored positive bending moments (Case 2 Support Conditions - pin support at base, fixed support at top) for wall heights 3, 3.5, 4, 4.5 or 5 m respectively

Wall Height (H)	+M* (kN.m per metre run)
3.0 metres	16.8
3.5 metres	26.8
4.0 metres	39.9
4.5 metres	56.9
5.0 metres	78

<u>Water pressure loading (for example – a water retention tank wall) - Case 3 Support Conditions</u>

- Base support = **Fixed** connection
- Top support = **Fixed** connection





Negative bending moments are not tabulated in below Table B3. Design engineers to use steel bars for the negative bending moments.

Table B3 – Design/Factored positive bending moments (Case 3 Support Conditions - fixed support at base, fixed support at top) for wall heights 3, 3.5, 4 ,4.5 or 5 m respectively

Wall Height (H)	+M* (kN.m per metre run)
3.0 metres	8.4
3.5 metres	13.4
4.0 metres	20.0
4.5 metres	28.5
5.0 metres	39.1

<u>Summary of Loadings , Relevant Positive Bending Moments and Support Conditions</u>

Negative bending moments are not shown on the below table. Refer each load case calculation page for negative Bending Moments.

Wall Height (m)	Load Type 1			Load Type 2			Load Type 3		
	+M* Case 1	**+M* Case 2**	**+M* Case 3**	**+M* Case 1**	**+M* Case 2**	**+M* Case 3**	**+M* Case 1**	**+M* Case 2**	**+M* Case 3**
3	19.6	12.7	6.5	25.7	16.8	8.4	45.3	29.5	14.9
3.5	30.5	19.8	10.1	40.8	26.8	13.4	71.3	46.6	23.5
4	44.9	29.1	14.9	60.9	39.9	20.0	105.8	69	34.9
4.5	63.1	41.1	20.9	86.8	56.9	28.5	149.9	98	49.4
5	88.2	57.4	29.1	119	78	39.1	207.2	135.4	68.2

Load Type 1 – Earth + Compaction/Surcharge loading

Load Type 2 – Water pressure loading

Load Type 3 – Earth + Surcharge + Water Pressure loading. The buoyancy effect on the soil in waterlogged conditions has been ignored by adopting the dry soil density for conservatism. Load Type 3 has been derived through the addition of Types 1 and 2, which is also a conservative approach (as the maximum bending moments occurs at different wall heights). The design engineer can calculate the exact bending moments if necessary.

Case 1 Support Conditions – Where pin connections have been provided at both the top and bottom of the wall. May be applicable for when early backfilling a Dincel wall, where the concrete is only cured for 24 hours. In this case, there is not an adequate bond strength developed between the starter bars and the concrete, therefore there is no bending moment at the connections and both connections are considered as pin supports.

Case 2 Support Conditions – Where a fixed connection has been provided at the top of the wall, such as where a high degree of bars are used to tie the slab to the top of the wall and concrete has sufficiently cured. Pin connection at the bottom of the wall if a lower amount of starter bars are utilised.

Case 3 Support Conditions - Where a fixed connection has been provided at the top and bottom of the wall, such as where a high degree of bars are used to tie the wall to the slabs and the concrete has sufficiently cured.

Appendix 3.3 – Design in accordance to AS 3600 – 2018

Capacity Table in accordance to AS 3600 – 2018 , Design information:

1. Concrete with 10mm max aggregate size, 180mm slump at the pump. f'c (28 days) = 32 MPa, f'c (24 hours) = approx. 5 MPa

2. For convenience purposes, the test results (based on a test width of utilising 3 × 275 Dincel profiles = 0.825m width) have been converted to 1 metre design widths in the table below.

   The Capacity Reduction Factor (Ø) should be determined in accordance with the current version of AS3600-Section2. In this example following comments are considered;

   AS3600-2018 Table 2.2.2 Capacity Reduction Factors (Ø) is strictly applicable to when steel bars are used. Dincel 275 has been tested at UTS, the data obtained by UTS demonstrates significant ductility as shown in the diagrams provided byUTS at the first part of this report. The designer can adopt the following;

   - Table 2.2.4 fibres in tension Ø= 0.7 Or
   - More appropriately, Dincel is a tested system by UTS which demonstrates high ductility performance therefore Table 2.2.5 Ø= 0.7 can be adopted

3. For testing purposes, the Dincel wall specimens were all tested in the horizontal orientation (whereas in real-life, walls are vertically orientated). As a result, there is the effect of the self-weight of the specimens creating an additional load and bending moment, which are not present in real-life application of vertically orientated Dincel walls. Ignoring the weight of the 275 Dincel formwork, the self-weight = 1m width × 0.27m concrete thickness × 24 kN/m3 = 6.48 kN/m per metre width. For simplicity, use 2/3 of the maximum moment (i.e. moment

coinciding at the location of the externally applied point load) due to the self-weight UDL = (6.48 kN/m × 3m × 3m/ 8) × 2/3 = 4.86 kN.m per metre width. The table below accounts for the self-weight when used as a wall for the tested specimens. Wall type 4 in Table C below is the theoretically calculated value by UTS which does not include M= 4.86 kN.m per metre width

4. The designer can compare the capacities given in the table below to the load tables A 1, A2 and B1 and B2 from Appendix 2 for their design decision.

Table C – Capacity table for tested samples (wall Types 1, 2 and 3) or theoretically calculated conventionally formed reinforced concrete wall Type 4

Wall Type		**Capacity at 24 hours old concrete**			**Capacity at 28 days old concrete**		
		Mu (kN.m per metre)	Mu (kN.m per metre) with addition of self-weight	**ØMu (kN.m per metre) Ø=0.7**	Mu (kN.m per metre)	Mu (kN.m per metre) with addition of self-weight	**ØMu (kN.m per metre) Ø=0.7**
1	Flex-Plain (275 Dincel Formwork + plain concrete)	41.21	46.07	**32.25**	50.06	54.92	**38.44**
2	Flex-BarChip (275 Dincel Formwork + fibre reinforced concrete)	50.91	55.77	**39.04**	71.88	76.74	**53.72**
3	Flex-Reo (275 Dincel Formwork + concrete reinforced with N16 steel bars @275mm centres	N/A (Note 1)	N/A (Note 1)	N/A (Note 1)	149.09 (Note 3)	153.95	**107.77**
4	Conventionally formed reinforced concrete wall with *p=0.25%* as per AS 3600 clause 11.7.1.a	N/A (Note 2)	N/A (Note 2)	N/A (Note 2)	70.18 (Note 4)	N/A	**49.13**

The above capacity values for Modulus of Rupture for Wall Types 1, 2, and 3 are based from Table 7 (which show the capacity values for 0.825m wide tested, simply supported 3m spanning specimens). The above capacity values have been converted to 1m wide design strips for the purposes of direct comparison with Tables A1, A2 and/or B1, B2 shown in Appendix 2.

Table Notes

1. 275 Dincel formwork + 24 Hours old concrete; Concrete has a low strength at 24 hours, the bond strength between concrete and steel bars would not represent any considerable value. Hence no tests at 24 hours old concrete for system 3 took place.
2. Conventional concrete wall with removable formwork + 24 hours old concrete; Concrete has a low strength at 24 hours, the bond strength between concrete and steel bars would not represent any considerable value, therefore ignore any capacity.
3. 275 Dincel formwork + 28 old concrete Flex-Reo specimens are reinforced with N16 steel reinforcement vertical bars spaced at 275mm centres in Dincel Wall. These bars are only required to be installed at the face of the wall which will be in tension, with 50mm clear cover (see drawing below).
4. Conventional Formwork + 28 days old concrete ;

   Theoretical strength values calculated from first principles as follow:

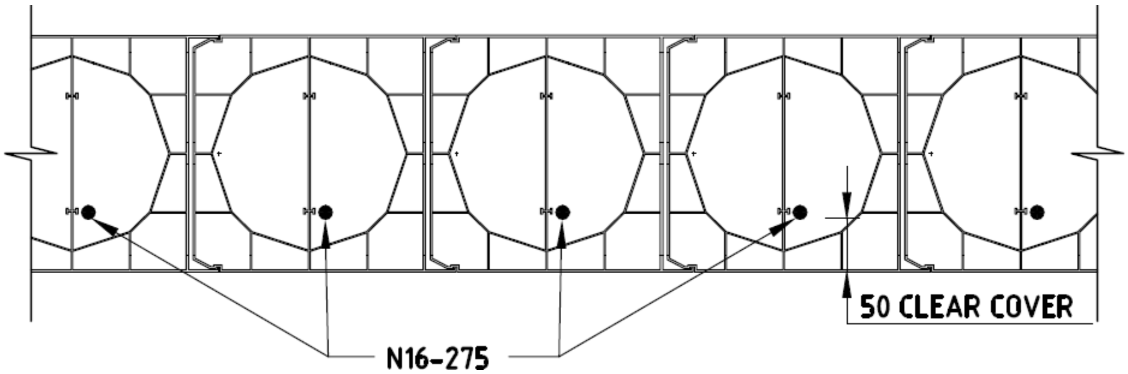
   Width $= 3 \times 275 = 825$ *mm, Formwork Depth including Dincel Formwork* $= 275$ *mm, Overall Concrete Depth* $= 270$ *mm,*

   $p = 0.25\%$ *(minimum AS3600 clause 11.7.1.a);* $270 \times 825 \times 0.25\% = 557\ mm^2$

   adopted for comparison purposes.

   $d_{st} = 270 - (50\text{-}2.5) - 16/2 = 214.5$ *mm for 16 mm diameter bar use, and* $f_c' = 32$ *MPa*

   $M_u = 57.9$ *kNm for 825 wide panel OR* $M_u = 70.18$ *kNm per 1m wide panel*



Where more capacity is required, 275 Dincel with N16, N20, or N24 longitudinal reinforcement bars at 275mm centres (Dincel webs work as crack inducers/controllers, hence horizontal steel for crack control purposes is not required) can also be used in any harsh environment for the following reasons:

1. Technical literature demonstrates that there is nothing within the natural environment which can destroy PVC.
2. Dincel panel joints as tested by CSIRO are waterproof.
3. Adequate concrete cover within the permanent membrane encapsulation is always provided to any steel reinforcement bars.
4. Dowel bars at the cold joint between the footing and Dincel Wall can be over-sized for corrosion allowance and/ or hot-dip galvanised.