Technical Report

Evaluation of Flexural Performance of 275 Dincel Structural Walling

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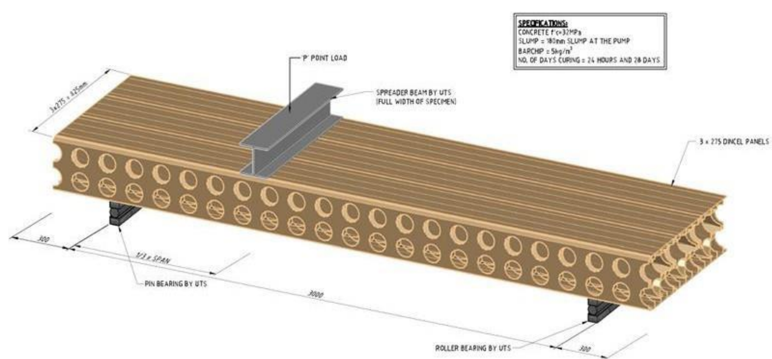
Rev 03
30/09/2020

1. Introduction

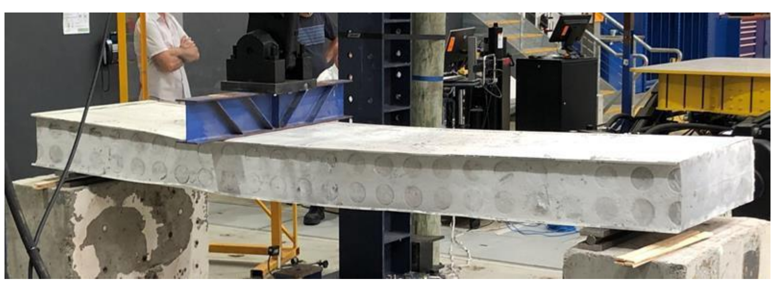
This technical report has experimentally evaluated the effects of using BarChip fibre reinforced concrete on flexural behaviour of 275 Dincel structural walling panels in comparison with 275 Dincel structural walling panels filled with conventional plain concrete and reinforced concrete. The ultimate 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.

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

2.1. 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.

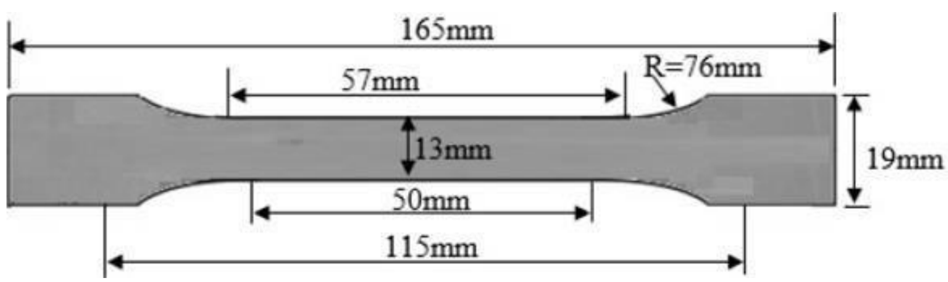


Figure 3: Dog-bone coupon specimens prepared for tensile tests according to ASTM D638

As illustrated in Figure 4, tensile tests were conducted by applying a constant rate of 0.083

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 PVC material

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

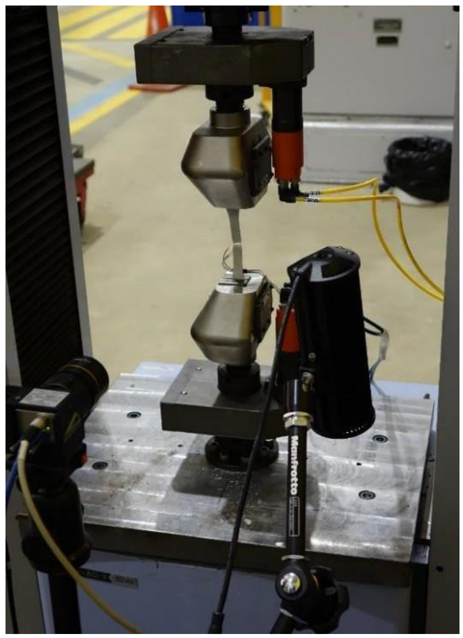


Figure 4: An overview of the tensile PVC testing at the UTS Tech Lab

2.2. 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:

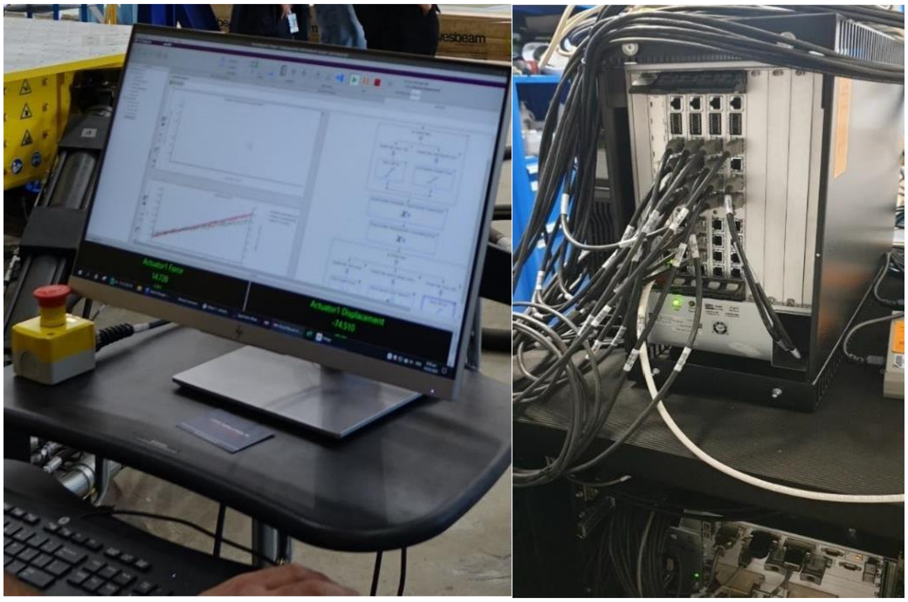
- Three 275 Dincel panel specimens, named *Flex-BarChip*, with concrete reinforced with 5kg/m^3 of BarChip 48 macro-synthetic fibres; and
- Three 275 Dincel panel specimens, named *Flex-Plain*, with plain concrete.

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 Figure 7.

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. 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.

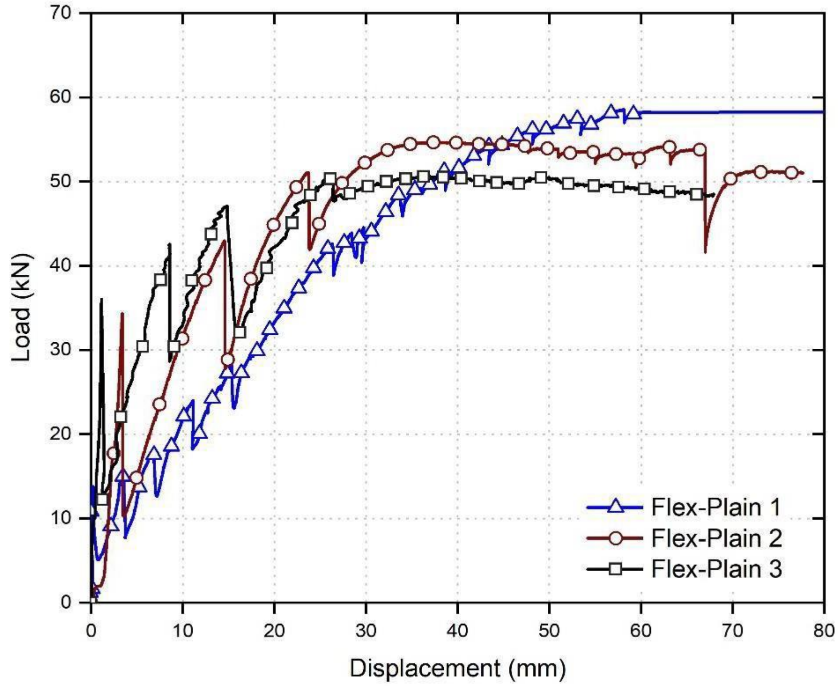


Figure 9: Load-deflection curves for Flex-Plain specimens at the age of 24 hours

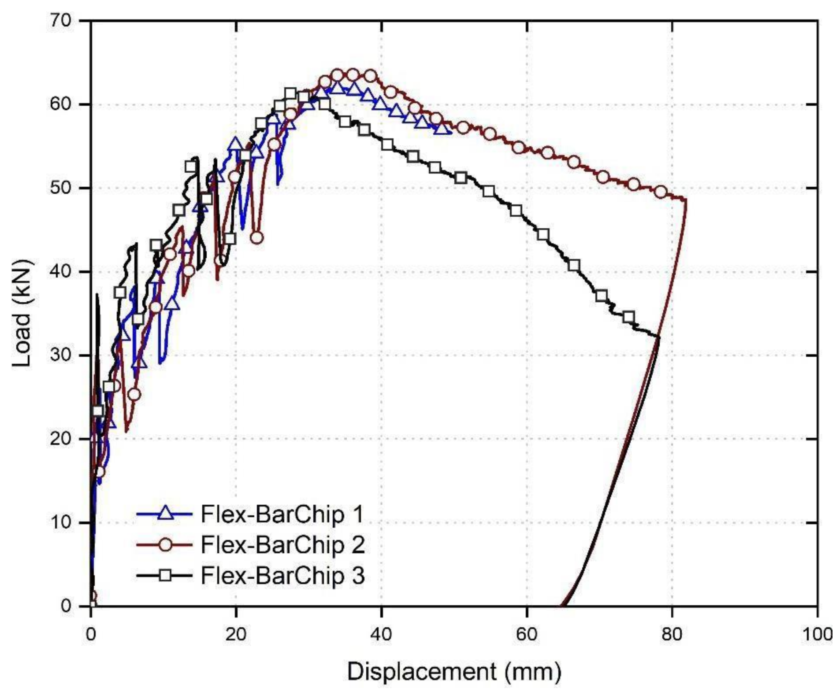


Figure 10: Load-deflection curves for Flex-BarChip specimens at the age of 24 hours

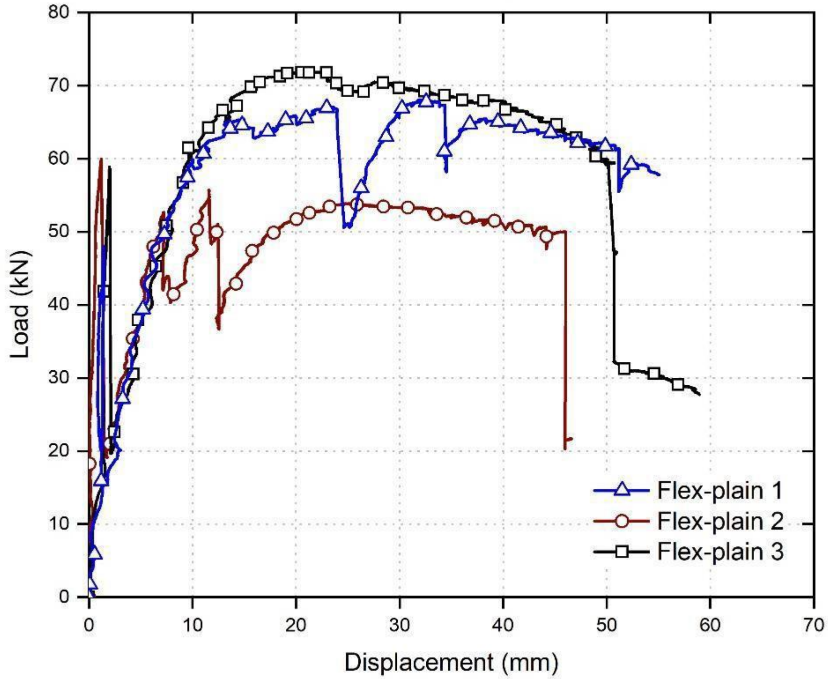


Figure 11: Load-deflection curves for Flex-Plain specimens at the age of 28 days

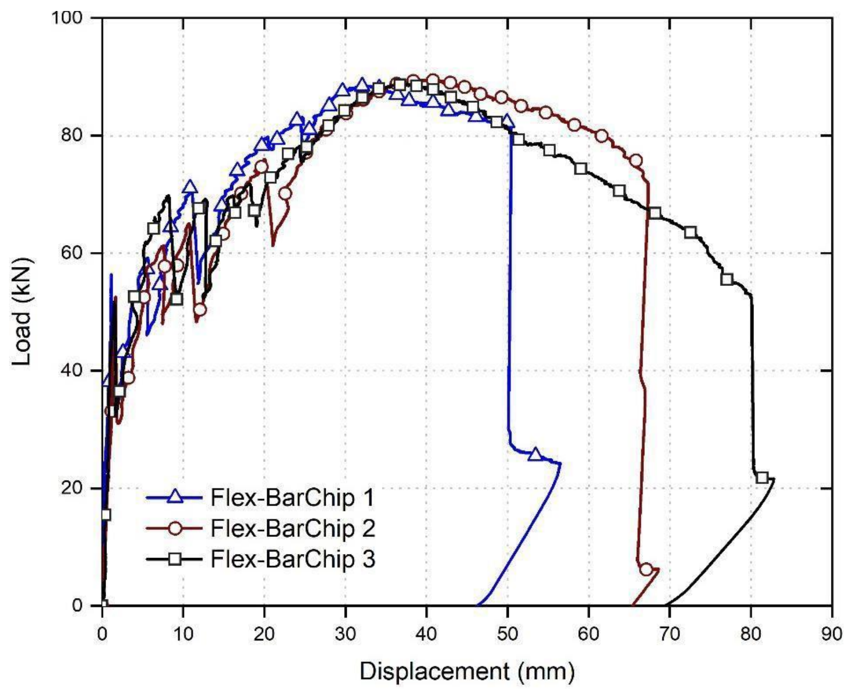


Figure 12: Load-deflection curves for Flex-BarChip specimens at the age of 28 days

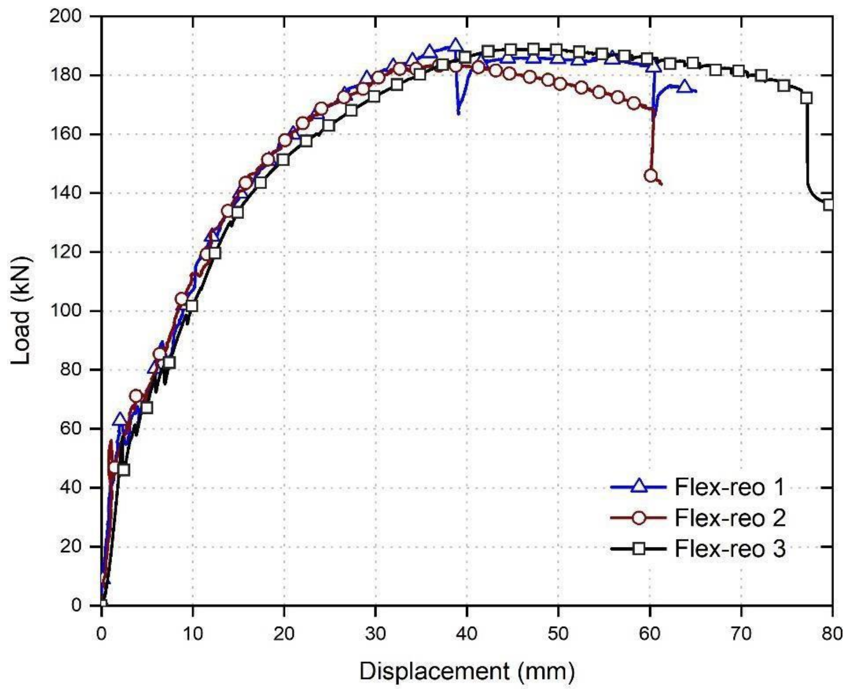


Figure 13: Load-deflection curves for Flex-Reo specimens at the age of 28 days

3.1. Flexural Strength

3.1.1. 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.

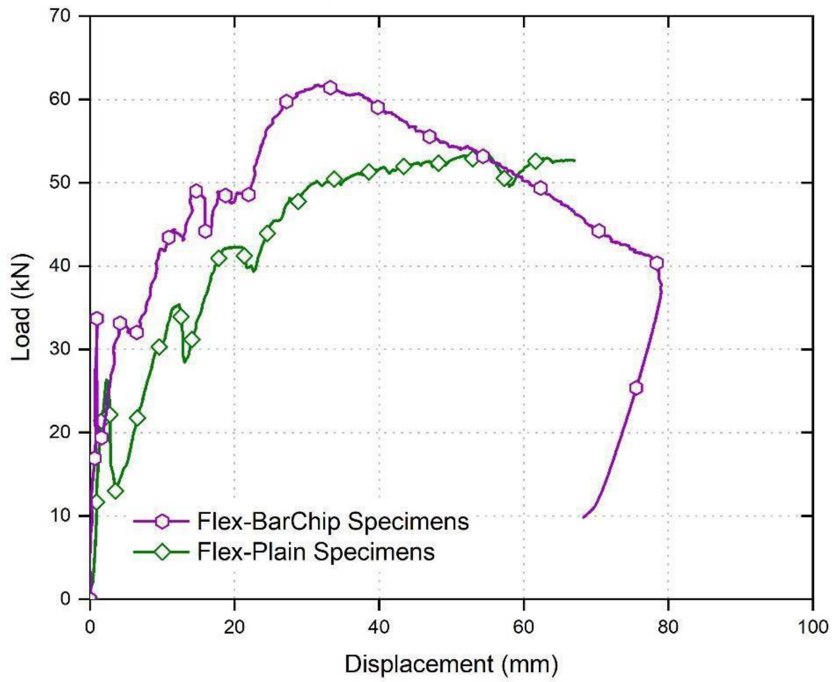


Figure 14: Comparison between Flex-BarChip and Flex-Plain average load-deflection curves at the age of 24 hours

3.1.2. 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

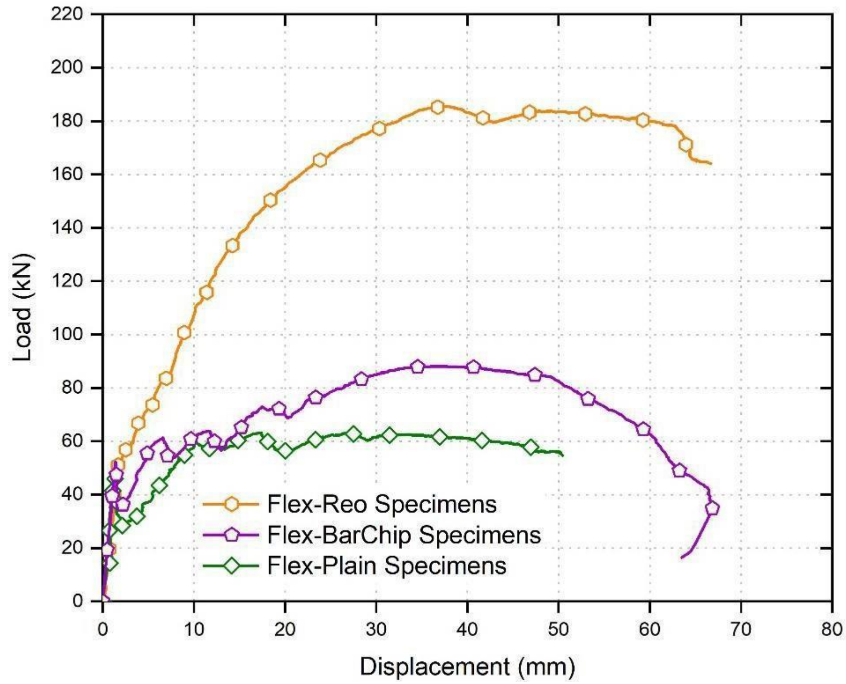


Figure 15: Comparison between Flex-BarChip, Flex-Plain and Flex-Reo average load-deflection curves at the age of 28 days

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.

3.1.3. 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.

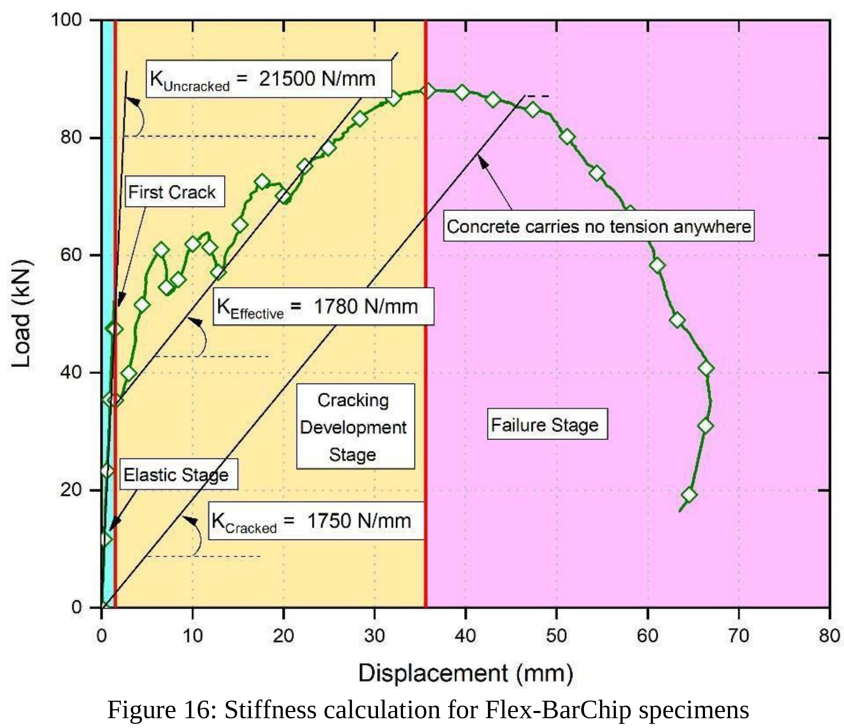


Figure 16: Stiffness calculation for Flex-BarChip specimens

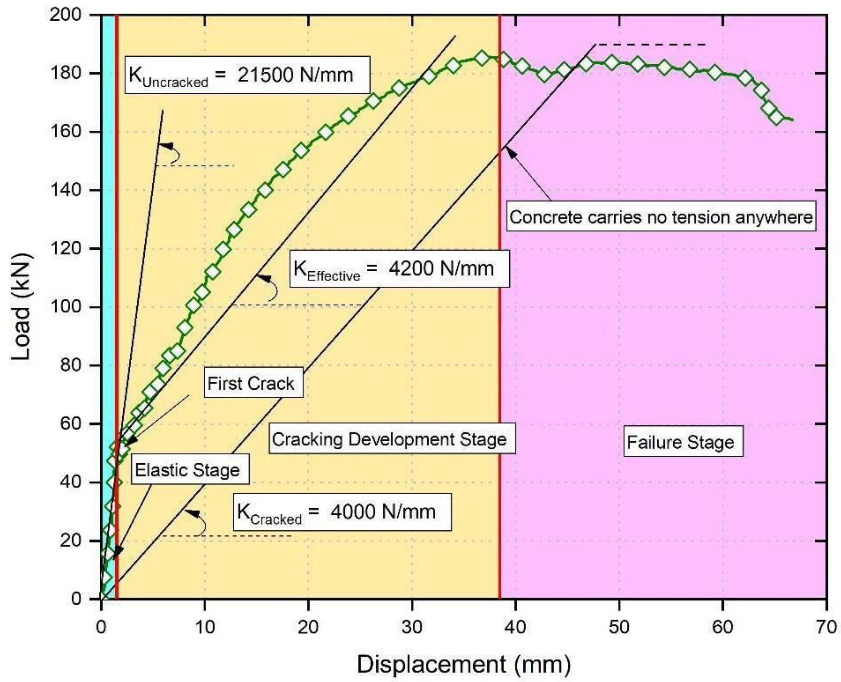


Figure 17: Stiffness calculation for Flex-Reo specimens

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.

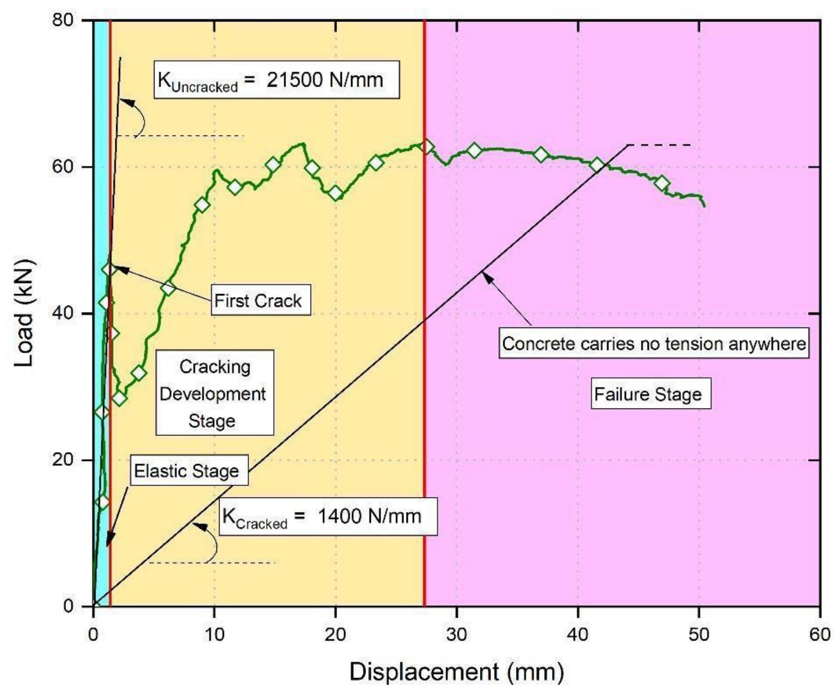


Figure 18: Stiffness calculation for Flex-Plain specimens

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 rigidityof 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.

4. 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. <u>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</u>.

5. 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

6. 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.

7. 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: Shami Nejadi Date: 24/07/2020

APPENDICES

Appendix 1 – Background

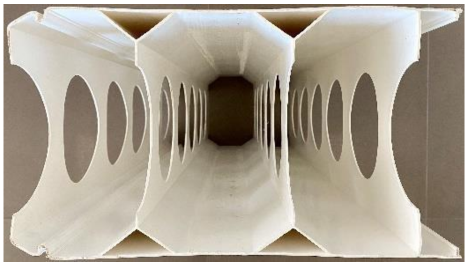
Dincel Construction System was invented by Structural Engineers in the early 2000s. It consists of a permanent polymer encasement for formwork with concrete infill. The world's most abundant construction material is concrete, which has many handicaps to resolve. Concrete being brittle, non-ductile, and 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.

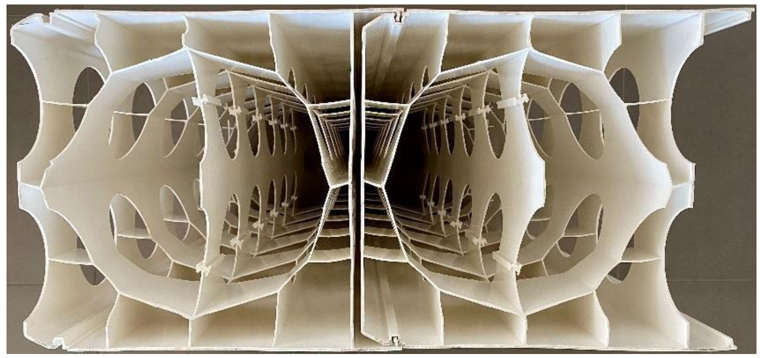
Earlier tests (utilising the 200 Dincel profile with 110mm slump concrete used) by CSIRO-Australia proved that the Dincel polymer skin is impervious and that the panel joints are waterproof even when tested under 6 metres of water head pressure (Reference – CSIRO Test Report No. 5091). Currently Dincel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

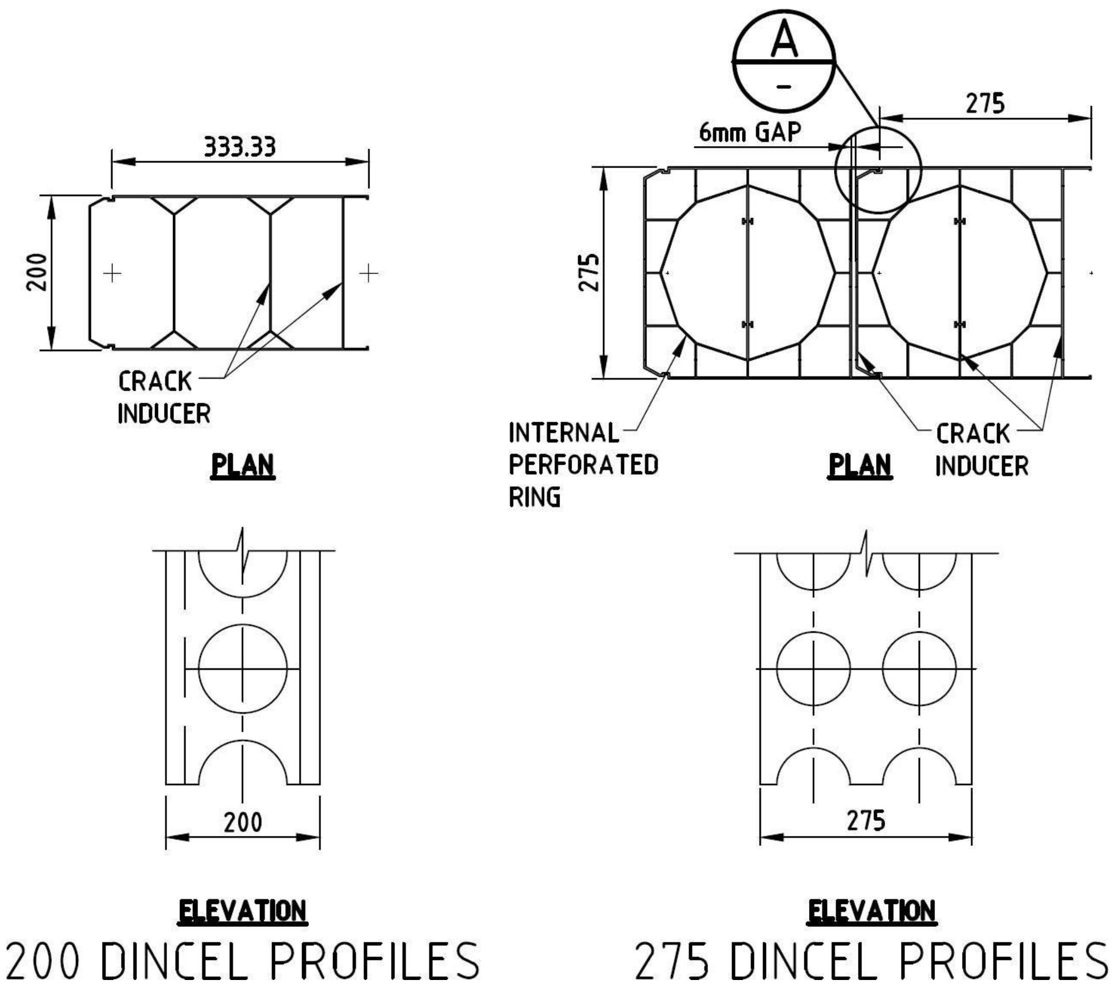
The webs which hold the outer faces of the Dincel profile ensure that plastic shrinkage cracking occurs at each web with very small controlled crack widths. These very small controlled crack widths are further sealed by the concrete's autogenous healing process, as the Dincel polymer encapsulation results 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).

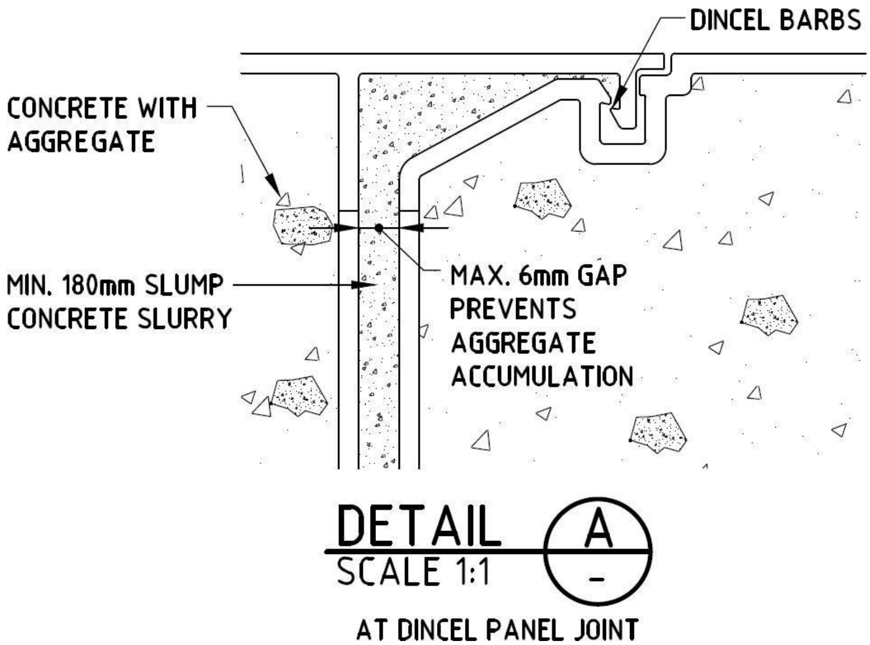
Tests were conducted at the University of Technology, Sydney in 2009-2010, including flexural beam tests and earthquake shake table tests using the 200 Dincel profile. The results demonstrated that there was increased flexural capacity, ductility and resilience in comparison to conventional reinforced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

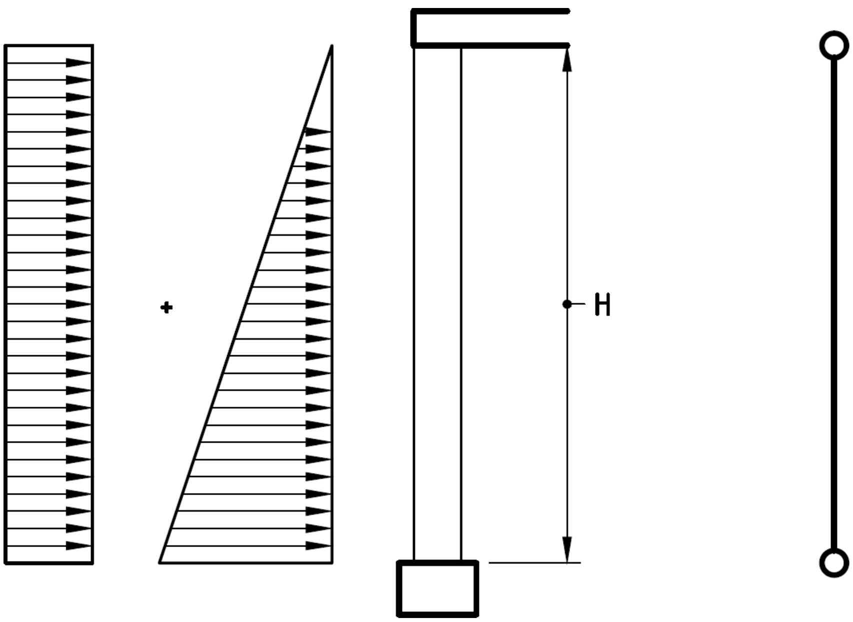
   For water pressure Clause 4.2.3 (e) states for a given (i.e. known) ground water level (e.g. water level confirmed by geotechnical report) the load factor nominatedis 1.2. Design engineer can make a decision on the water load factor when the water level is known and not subject to fluctuation. Naturally 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.

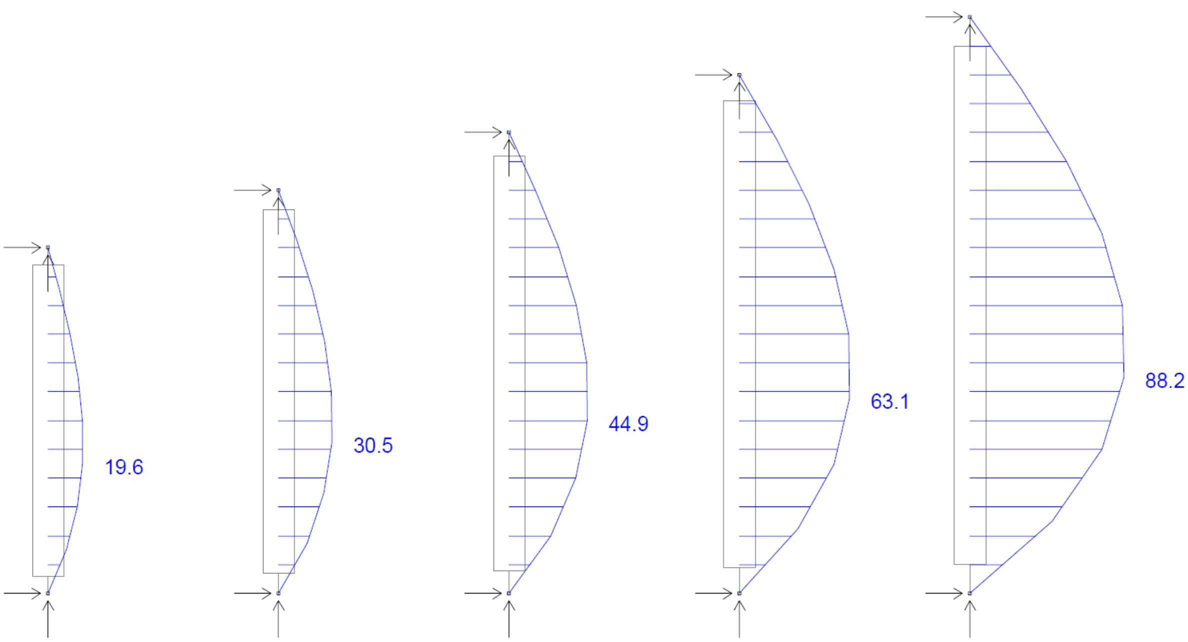
<u>Assumptions:</u>

- 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



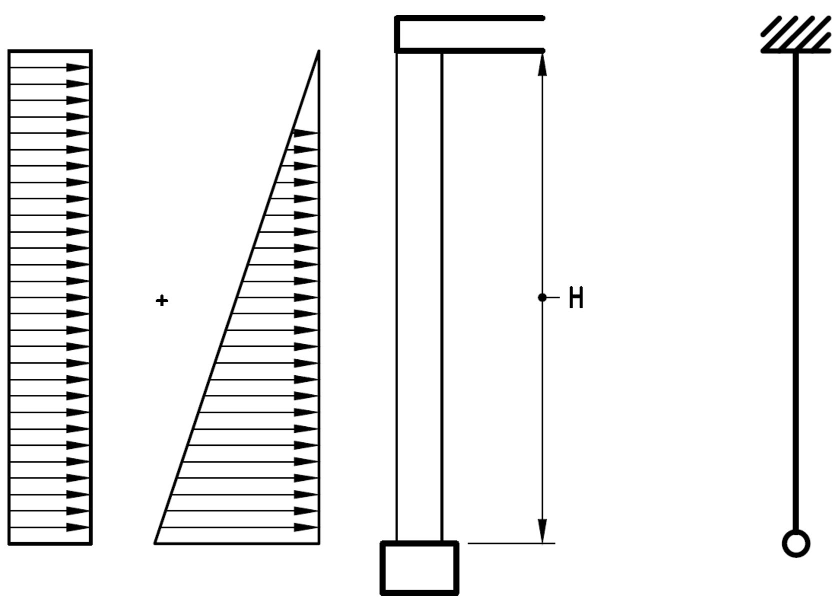


<u>Table A1</u> – Design/Factored positive bending moments (Case 1 Support Conditions - pin support at base, pin support at top) for wall heights 3, 3.5, 4 ,4.5 or 5 m respectively

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

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

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



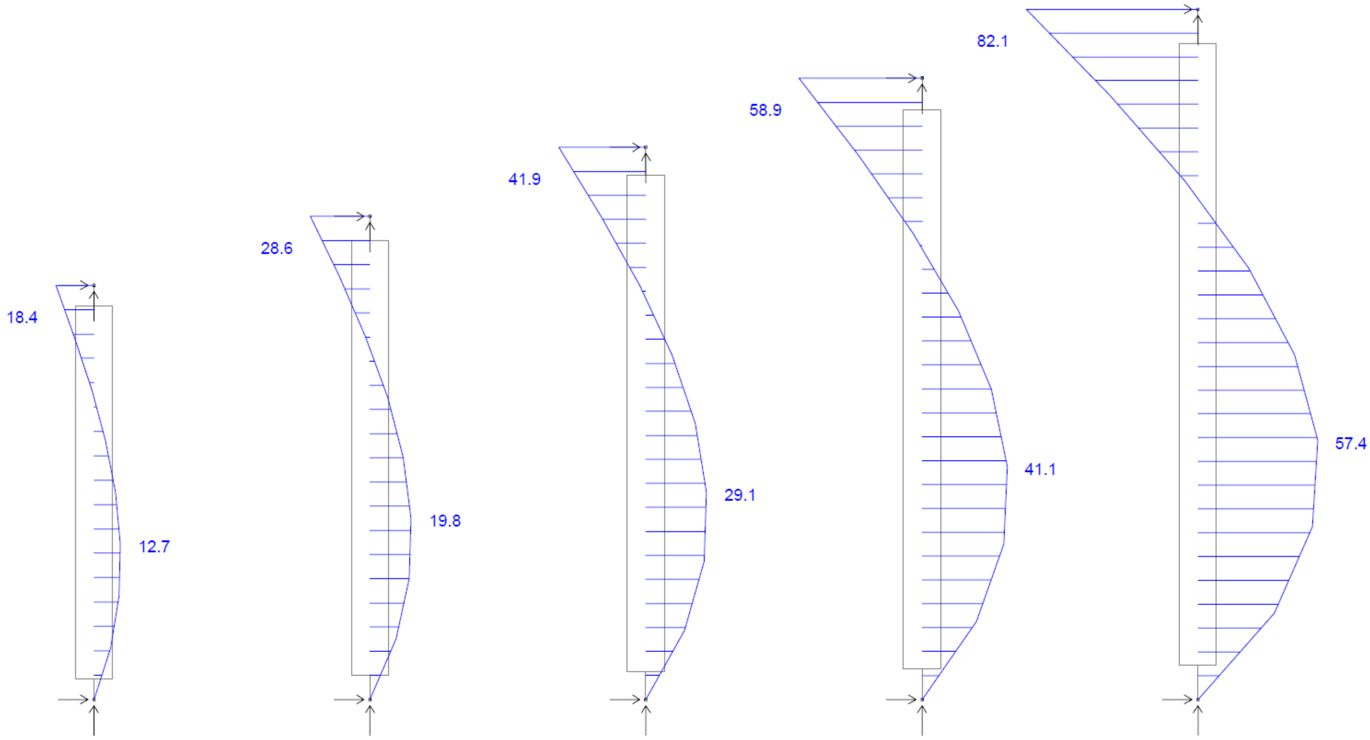
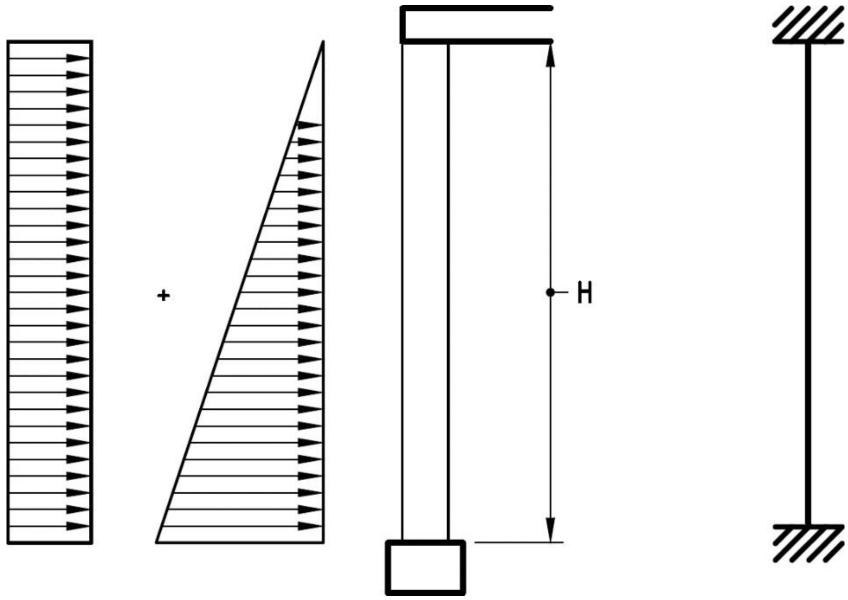


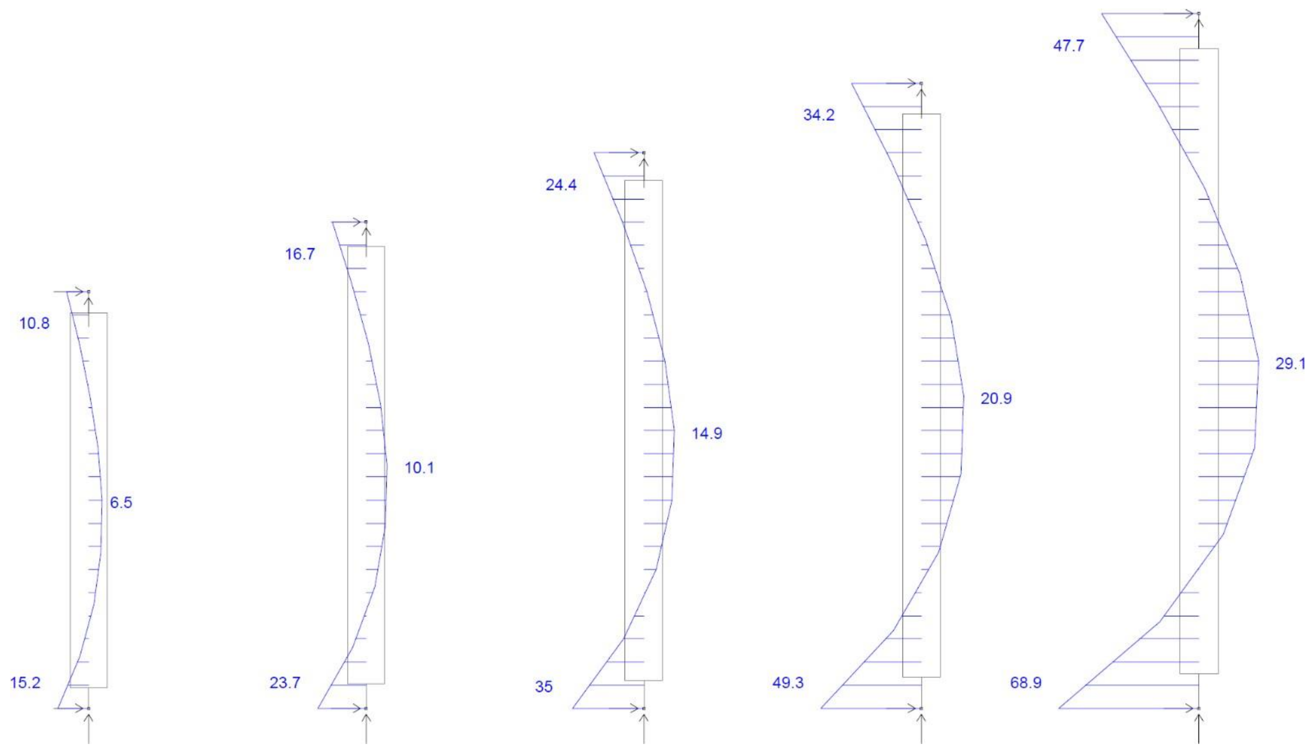
Table A2 – Design/Factored positive bending moments (Case 2 Support Conditions - pin support at base, fixed support at top) for wall heights 3, 3.5, 4 ,4.5 or 5 m respectively

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





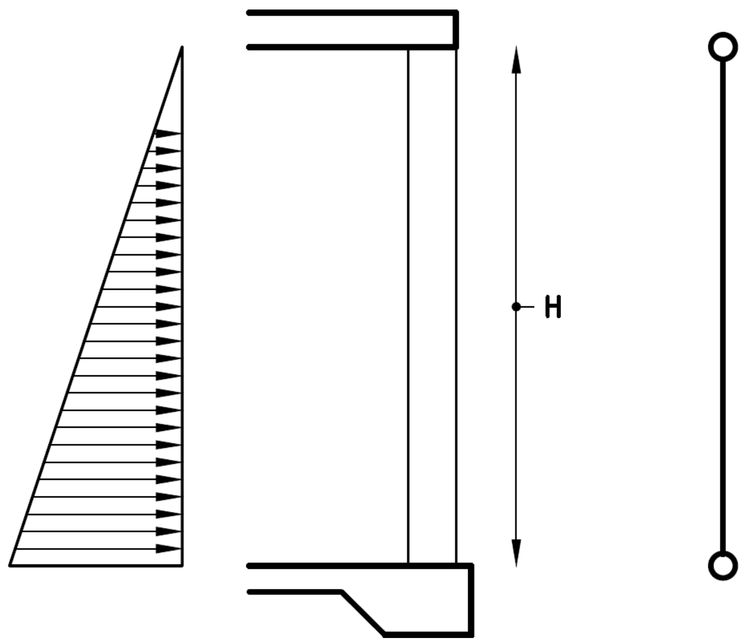
Negative bending moments are not tabulated in below Table B2. Design engineers to use steel bars for the negative bending moments.

<u>Table A3</u> – 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

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

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



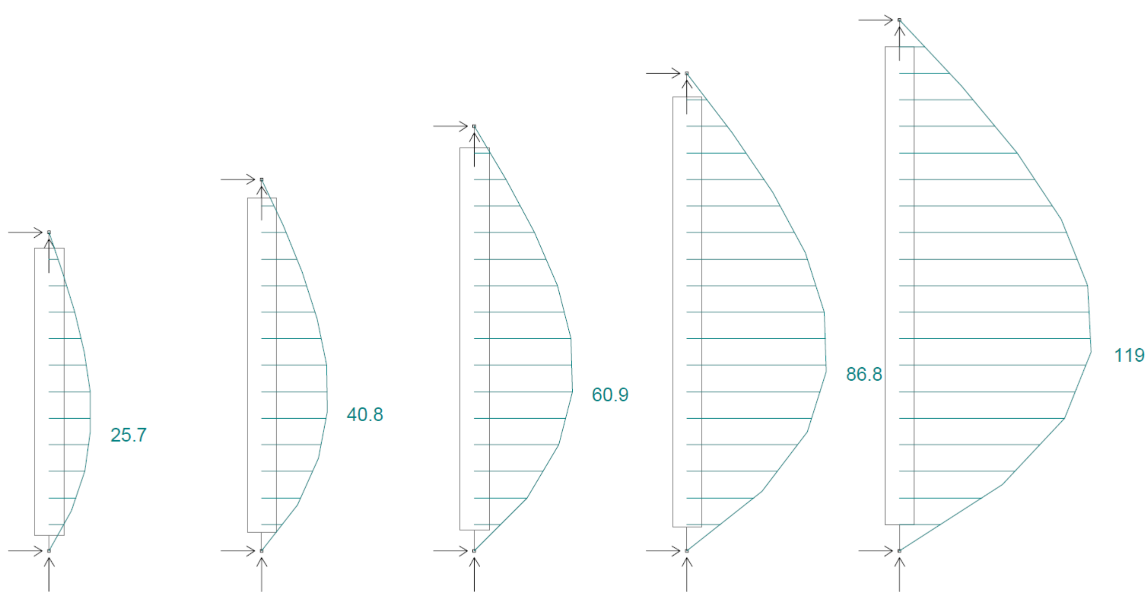
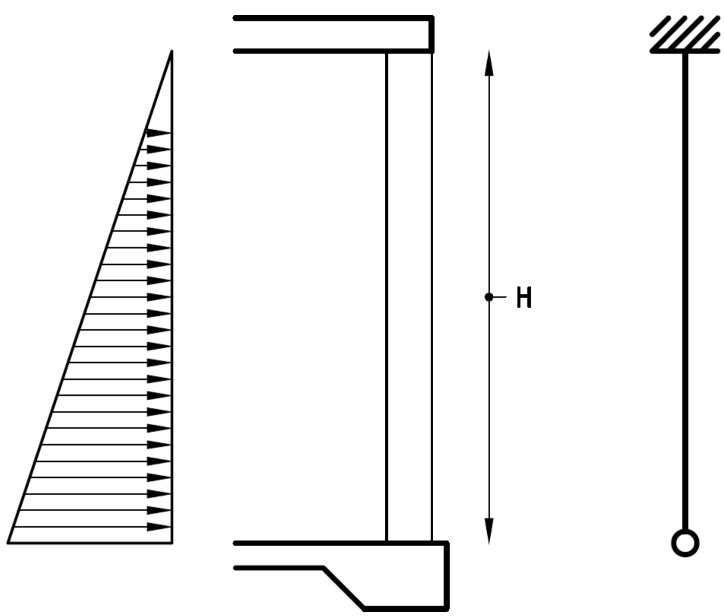


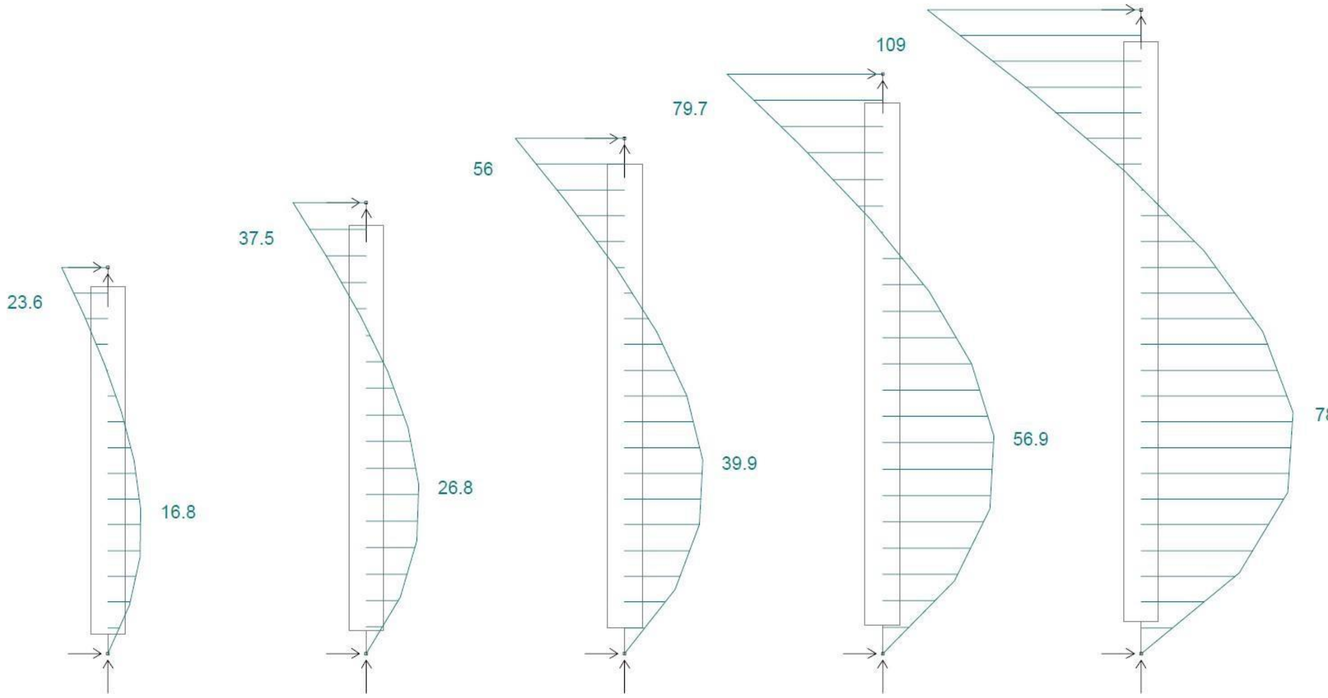
Table B1 – Design/Factored positive bending moments (Case 1 Support Conditions - pin support at base, pin support at top) for wall heights 3, 3.5, 4 ,4.5 or 5 m respectively

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

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

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





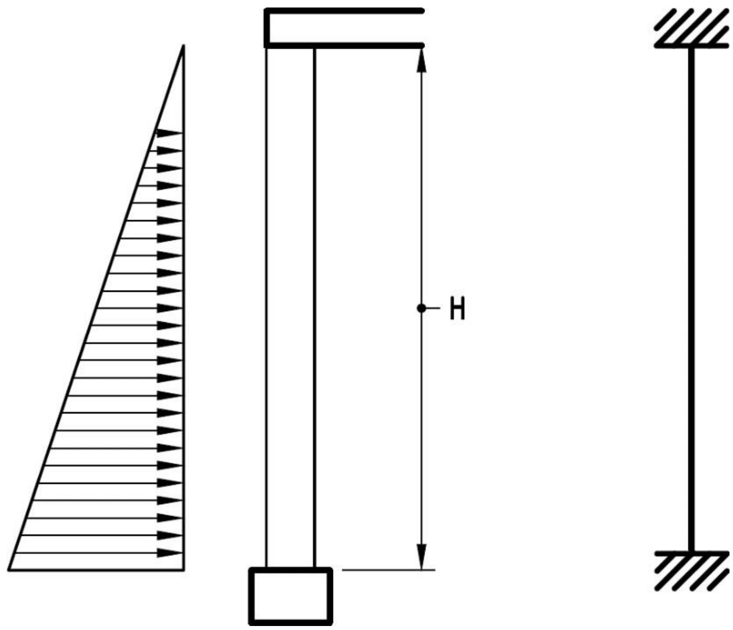
Negative bending moments are not tabulated in below Table B2. Design engineers to use steel bars for the negative bending moments.

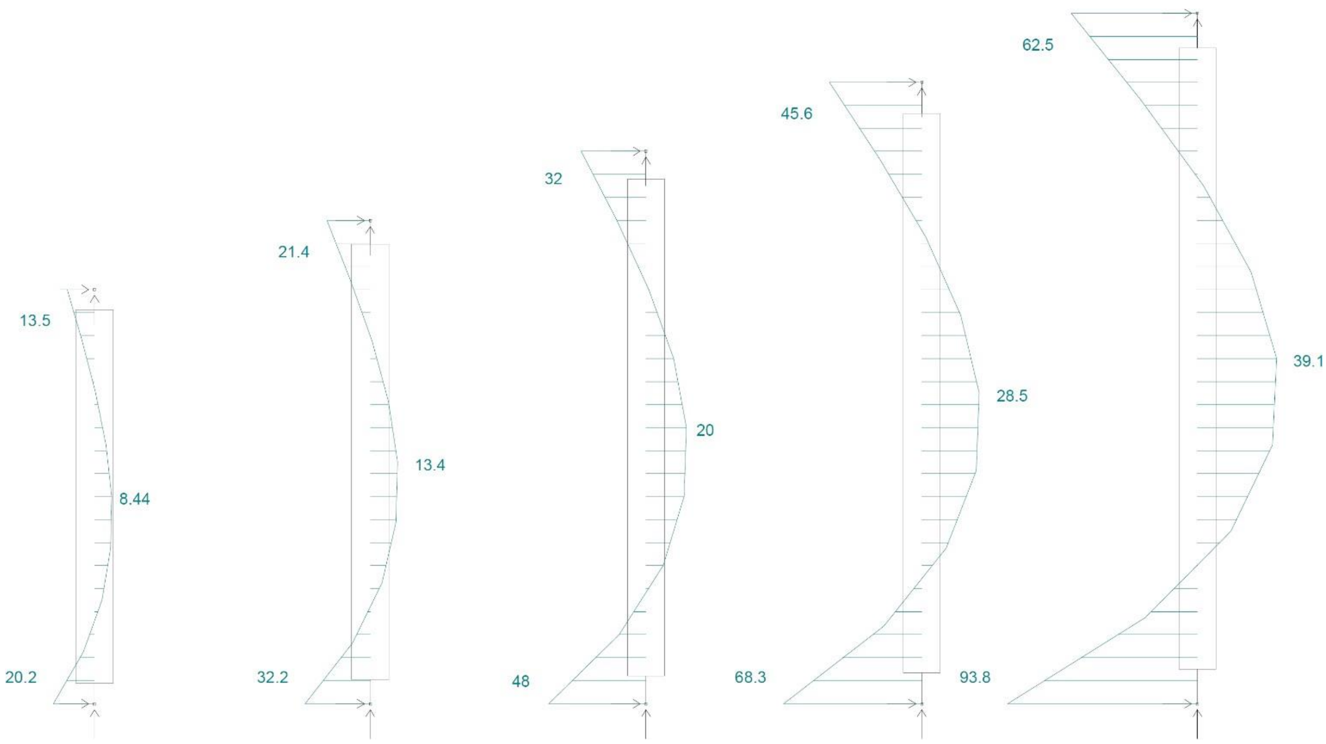
<u>Table B2</u> – Design/Factored positive bending moments (Case 2 Support Conditions - pin support at base, fixed support at top) for wall heights 3, 3.5, 4 ,4.5 or 5 m respectively

Wall Height (H)	**+M* (kN.m per metre run)**
3.0 metres	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.

<u>Table B3</u> – 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 – Design in accordance to AS 3600 – 2018

<u>Capacity Table in accordance to AS 3600 – 2018 ,</u> <u>Design information:</u>

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 by UTS 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

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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 ;

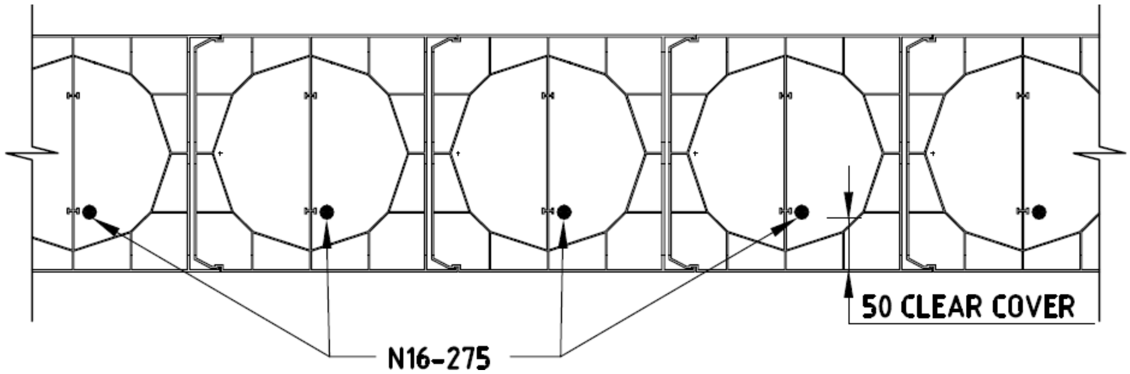
   Theoretical strength values calculated from first principles as follow;

   Width= 3 × 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 × 825 × 0.25% = 557 mm^2 *adopted for comparison purposes.*

   d_{st} *= 270 - (50-2.5) - 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.