University of Technology, Sydney (UTS)
Faculty of Engineering and Information Technology

DINCEL FLEXURAL TESTINGS

by

Berkay Dincel

Student Number: 10450854

Project Number: A10-029

Major: Civil Engineering

Supervisor: Dr Shami Nejadi

A 6 Credit Point Project submitted in fulfilment of the requirement for the Degree of Bachelor of Engineering, Diploma in Engineering Practice

Submitted: July 2010

Abstract

Dincel Construction System is an internationally patented permanent polymer formwork system, which when filled with concrete provides a strong, economic and durable structure. The purpose of this project was to compare Dincel Construction System to conventional concrete under flexural loads to determine the contribution of the polymer encapsulation for strength and ductility.

There have not been any testings of the Dincel Construction System placed under flexural loads. As an engineer, I strongly believed that the system's polymer encasing would benefit conventional concrete in terms of strength and ductility. My goal was to therefore prove my theory by completing a series of tests in the UTS Laboratory. Samples of Dincel Construction System and conventional concrete were therefore made and tested under short-term loading using two equal point loads applied at the third points on the span.

Dincel Construction System samples proved to be significantly stronger under flexural loads when compared to the equivalent conventional concrete samples with identical reinforcement. The maximum load carried by the average Reinforced Dincel sample was 2.5 times the value which was carried by the average Conventional Reinforced Concrete sample. Furthermore, the average Unreinforced Dincel sample carried 1.4 times the load which was carried by the average Conventional Reinforced Concrete sample.

The Pre-Cracking and Post-Cracking behaviour was also calculated and analysed for each set of testing samples. The Dincel samples proved to have more than twice the Pre-Cracking stiffness of the Conventional Reinforced Concrete samples. After cracking, the Dincel samples were significantly more ductile in comparison to the Conventional Reinforced Concrete samples.

These results show that the polymer encasing of Dincel significantly increases the strength, the pre-cracking stiffness and the ductility of concrete when placed under flexural loads.

Acknowledgements

I wish to recognize the contributions both direct and indirect of the entire University of Technology, Sydney engineering staff who have helped me over the course of my Bachelor of Engineering (Civil)/Diploma in Engineering Practice degree. I would like to give special thanks to the members of the Civil Laboratory staff for all their help during this semester.

I would like to thank my supervisor Dr Shami Nejadi for his advice and assistance throughout the entirety of my capstone project.

I would like to thank Burak Dincel, Alan Hamilton, and Ramon Gonzalez, from Dincel & Associates, for assisting and encouraging me throughout the duration of this project.

I would also like to thank Bora Dincel and Eser Usta, from Dincel Construction System, for helping me with the supply of material and also for their help during the construction of the testing samples.

Table of Contents

List of Tables

Chapter 1 - Introduction

1.1 Objectives and Scope

3400mm lengths of various Dincel and Conventional Reinforced Concrete samples would be tested using two equal point loads applied at the third points on the span. The tests would be done inside of the UTS Concrete Laboratory where the temperature is kept constant at 20ºC ± 2ºC.

In order to conclusively prove that the Dincel polymer adds strength and ductility to conventional concrete it was decided that a number of different samples would be used for testing as shown in Table 1.

Table 1 – Samples tested

Testing Sample	Number of samples tested
Conventional Reinforced Concrete	3
Reinforced Dincel	3
Unreinforced Dincel	3
Hollow Dincel	3

After the completion of all tests the results would be analysed with comparisons being made between the Dincel samples and the equivalent Conventional Reinforced Concrete samples with identical reinforcement.

1.2 Definition of the testing samples

1.2.1 Conventional Reinforced Concrete: A reinforced concrete sample consisting of 1N12 bar. The reinforcing bar was placed with 35mm clear cover from the bottom tension face. Each sample having a depth of 200mm and a width of 364mm.

1.2.2 Reinforced Dincel: A reinforced concrete sample formed and tested inside a Dincel P-1 polymer profile. The sample having 1N12 bar placed with 35mm clear cover from the bottom tension face. Each sample having a depth of 200mm and a width of 364mm.

1.2.3 Unreinforced Dincel: An unreinforced concrete sample formed and tested inside a Dincel P-1 polymer profile. Each sample having a depth of 200mm and a width of 364mm.

1.2.4 Hollow Dincel: A plain Dincel P-1 polymer profile sample. Each sample having a depth of 200mm and a width of 364mm.

1.3 Thesis Outline

Chapter 1 - Introduction: This chapter presents a brief summary of the objectives and scope of the project. A definition of each type of testing sample will also be provided.

Chapter 2 - Literature Review: This chapter reviews relevant literature on the project topic.

Chapter 3 - Experimental Methodology: This chapter describes the experimental program including the construction of the specimens and testing procedures.

Chapter 4 - Results: This chapter presents the results which were obtained from the testing and draws comparisons between different test samples.

Chapter 5 - Conclusion: This chapter contains a discussion and a conclusion based on the tests which were carried out.

Chapter 2 - Literature Review

Dincel Construction System has been developed in Australia by professional engineers and has been independently assessed and certified by leading authorities and institutions. Previous tests have proved that the system has excellent fire resistant and chemical resistant properties. The system has also been tested against earthquake loads by the University of Technology, Sydney with outstanding results. Furthermore, testings by the CSIRO have proven the system to be waterproof.

Dincel Construction System eliminates the need to use steel reinforcement for crack control purposes in both the horizontal and vertical directions. The system could eliminate the use of reinforcement for strength purposes in many cases as well.

The Dincel polymer is an impervious material and will not break down for at least 200 years even in corrosive or acidic environments. The Australian Standards Concrete Structures Code requires 40 Mpa concrete to be used if the building is located within 1km from the coastal zone. Adding on to the higher strength of concrete which is required to be used in these areas, clear cover to reinforcement of 45mm would also need to be provided. The Dincel polymer provides durability protection for both the concrete and steel. Therefore, even in such areas the concrete strength and clear cover required can be significantly decreased when using Dincel.

Without the need of reinforcement cover for durability purposes, the steel reinforcement can be placed very close to the extreme tension fiber for design. In this project a 35mm clear cover from the tension face was used for both the Conventional Reinforced Concrete samples and the Reinforced Dincel samples. However, in reality this clear cover would not even be required by Dincel for durability purposes. Moving the steel reinforcement closer to the tension face would allow for the engineer to utilise greater design capacity.

Chapter 3 - Experimental Methodology

3.1 Materials used during the construction of the test samples

Table 2 – Dincel polymer list

Item	Dincel profile	Length (mm)	Quantity
1	P-1	3400	12
2	P-TC	400	12
3	P-EC	3400	6

Table 3 – Timber/plywood list used to construct the Conventional Reinforced Concrete samples

Item	Timber Size (mm)	Quantity per testing sample	Total Quantity
4	90 × 45 × 3400	6	18
5	90 × 45 × 273	8	24
6	90 × 45 × 328	4	12
7	363 × 19 × 3400	2	6
8	418 × 19 × 3400	1	3
9	250 × 19 × 370	2	6

Table 4 – Timber/plywood list used to construct the reinforced and unreinforced Dincel samples

Item	Timber	Quantity per testing sample	Total quantity
10	190 × 19 × 3400	1	6
11	200 × 19 × 400	2	12

Item explanation

1. 9 pieces of P-1 to be used for the Hollow, Unreinforced and Reinforced Dincel samples. 3 pieces will have their faces cut off in order to be used for the construction of the Conventional Reinforced Concrete samples.
2. For the Unreinforced and Reinforced Dincel samples, both vertical ends will be closed off using a P-TC profile during concrete pouring.
3. For the Unreinforced and Reinforced Dincel samples, the horizontal end will be closed off using a P-EC profile during concrete pouring.
4. Horizontal timber pieces used to support the Conventional Reinforced Concrete formwork box.
5. Vertical timber pieces used on each side of Conventional Reinforced Concrete formwork box for support.
6. Horizontal timber pieces used for cross linking at the same points of Item 5.
7. Vertical plywood pieces used for Conventional Reinforced Concrete formwork box.
8. Horizontal plywood used for Conventional Reinforced Concrete formwork box.
9. For the Conventional Reinforced Concrete formwork box, both vertical ends will be closed off with this item while pouring.
10. For the Unreinforced and Reinforced Dincel samples, this item will be used inside of the P-EC profile.
11. For the Unreinforced and Reinforced Dincel samples, this item will be used on both vertical ends on the inside of P-TC.

Concrete

Supplier: Concrite

Table 5 – Slump and aggregate size of the used concrete

Slump	Aggregate size
80mm	20mm

Steel Reinforcement

Supplier: Australian Reinforcing Company (ARC)

Table 6 – Steel reinforcement used for Conventional Reinforced Concrete and Reinforced Dincel samples

Number of Bars	Bar size	Length of Bar
6	N12	3.3m

3.2 Construction of testing samples

There were a total of 6 reinforced test samples including:

- 3 Conventional Reinforced Concrete samples
- 3 Reinforced Dincel samples

Each of these samples had one steel reinforcement bar placed at mid width. The reinforcement bar was an N grade reinforcement bar of 12mm in diameter (1N12). As the total sample lengths were to be 3400mm long, the reinforcement bars were decided to be 3300mm in length. Adopting this length of bar allowed for an adequate steel development length for the samples and also gave 50mm of clear cover on each end of the sample.

For strain readings of the steel reinforcement during testing, electrical strain gauges were used. One strain gauge was placed at mid span of each steel reinforcement bar. Before attaching each strain gauge, a grinder was firstly used on each reinforcement bar in order to achieve a level surface. The strain gauge could then be carefully glued onto the bar. The two thin leads of the strain gauge would then need to be soldered down onto the plate.

Figure 1 - Attached strain gauges and two thin leads of each strain gauge

As can be seen from Figure 1, a long electrical cable was attached to each strain gauge. This cable was then connected to a computer during testing which allowed for the computer to read the strain in the reinforcement bar during loading and unloading of the testing samples.

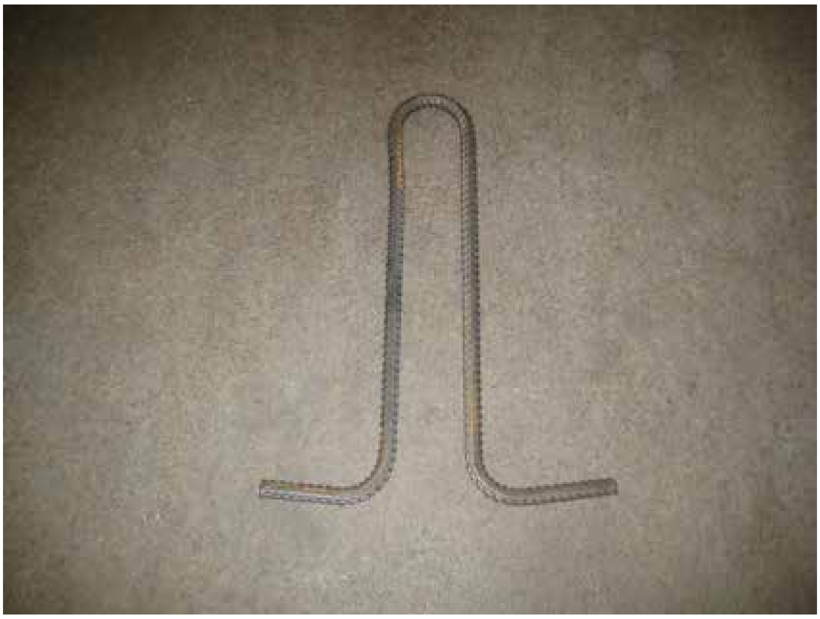


Figure 2 – Lifting eye

Two lifting eyes were used for each testing sample which was to be filled with concrete. These lifting eyes were N grade bars, 12mm in diameter. The bars would need to fit nicely into the cored holes of the Dincel samples, therefore the required dimensions were carefully calculated and the bars were purchased bent to these dimensions. Lifting eyes were placed at approximately third lengths for each of the samples. After concrete had been poured into the samples, the lifting eyes allowed for easier transportation of the samples from the pouring area to the testing area.

Figure 3 – P-J accessory profile

Figure 3 shows a "P-J" joiner accessory profile manufactured by Dincel Construction System. Each Dincel panel has a male clip and a female clip, with each being on opposite sides. When two panels are brought together, the male and the female sides very easily clip together. The joiner module is used to join two male clips together.

Builders are however widely using the P-J joiner accessory profile on construction sites to hold steel reinforcement bars in place during concrete pouring. The P-J is placed diagonally into the middle cell of the Dincel panel with the reinforcement bar tied to the P-J module.

The cross-sectional dimension of each testing sample required that the reinforcement bar would need to be held in place 182mm from the bottom and 35mm from the side of each sample. The 182mm distance being the middle of the sample width and the 35mm distance being the concrete cover. Holding the reinforcement bar in its exact intended place using bar chairs was not possible. Using the P-J module was the best option to hold the reinforcement bars in place.

The P-J module was firstly cut into short pieces as can be seen in Figure 3. The location of which the bar would need to sit on each P-J module was calculated and two small holes were drilled through the plastic to allow for the tie wire to be threaded through. Three of these assembled P-J pieces were placed at approximately third lengths for each sample. The reinforcement bar was then placed in between the two sides of the tie wire. The tie wire was then wrapped around the reinforcement bar using pliers.

Figure 4 – Side of the formwork box

In order to construct the Conventional Reinforced Concrete formwork boxes, much prior planning needed to be done. Firstly, a CAD drawing detailing the formwork boxes was produced. From this drawing, the materials needed to construct the formwork boxes were broken down to exact numbers. Completing a material breakdown allowed for more concise planning and significantly reduced the chance of ordering less or more materials than what was actually needed for the project.

Three extra P-1 profiles with a length of 3400mm were manufactured in order to construct the Conventional Reinforced Concrete samples. Each P-1 profile face was carefully cut off using a saw. Small hand tools were then used for more precise cutting of the faces. Each of these carefully cut faces were then screwed onto the plywood. The plywood was then in turn screwed onto the formed timber platform.

Figure 5 – Side of the formwork box from another view

Figure 5 shows one side of the formwork box assembled. Attaching these cut P-1 faces to the Conventional Reinforced Concrete formwork boxes allowed for a more direct comparison between the Dincel and Conventional Reinforced Concrete samples. Forming in this way allowed the different sets of samples to have the same concrete cross-section for comparison purposes.

Figure 6 – Formwork box construction

The construction of the Conventional Reinforced Concrete formwork boxes proved to be a time extensive task. Each piece of material was required to be either nailed or screwed onto another piece of material. The formwork boxes were constructed in a way where each of the three boxes could be broken down further to three separately formed sides. These three sides would then be held together using large screws to achieve one completed formwork box.

Figure 7 – Clamp for formwork box

In order to compare between different testing samples it was imperative that all samples were identical to one another. This required that each sample was 3400mm in total length and 200mm wide throughout the entire cross-section. Some of the pieces of timber used to form the boxes may have had a small natural bow. Several clamps were used in order to make sure that each side of the formwork box remained straight throughout its length. The clamps were tightened at different points along the length of the sample until both the top and the bottom sample was 200mm in width.

Figure 8 – Width measurement

Figure 9 – Close up of width measurement

A measuring tape was used in order to make sure that the width of the cross-section of each sample remained at 200mm throughout the entire length. It was difficult to keep the cross-section of each sample at exactly 200mm however all measurements throughout the length of the samples were between 198mm and 202mm.

Figure 10 – Cross-linking timber pieces

While the clamps were still in place, cross linking pieces of timber were screwed across the top of the formwork boxes so that the adjusted width remained at 200mm once the clamps were removed.

Figure 11 – Reinforcement bar placement

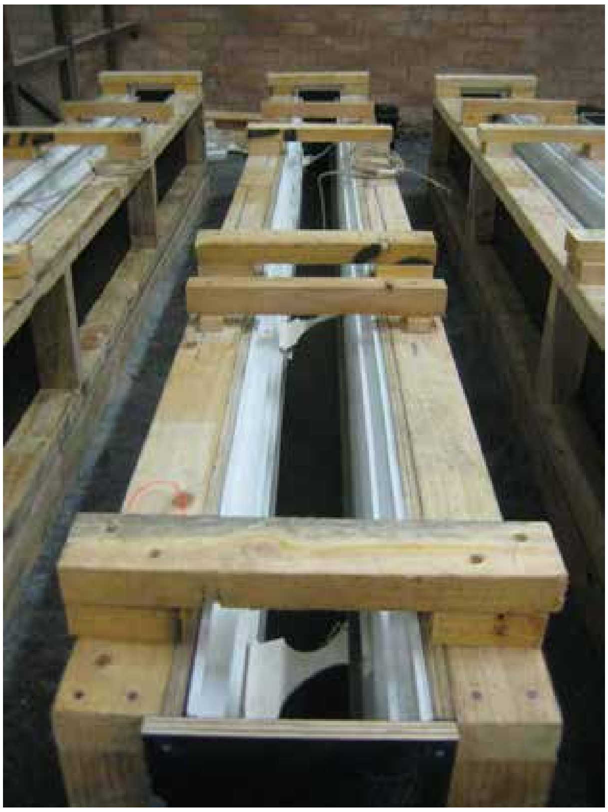


Figure 12 – Reinforcement bar placement using pieces of P-J joiner module

Figures 11 and 12 show the N12 steel reinforcement bar which was held in place using the pieces of P-J joiner module. It can be seen that the bar needed to be held in position from two faces inside the sample. With simple distance measurement, the P-J modules allowed for the reinforcement bar to be held in place rather easily. The P-J sat tightly in the formwork box and did not move when concrete was being poured inside of the testing samples.

Figure 13 – Cable attached to strain gauge

After the reinforcement bar had been placed for all samples it was very important to note on which side of the sample the reinforcement bar sat after concrete pouring. A marker pen was used to distinguish this.

The cable which was attached to the strain gauge was very carefully wrapped and placed outside of the testing sample which is illustrated in Figure 13 to avoid being concreted or damaged.

Figure 14 – Lifting eye placement

Thin timber pieces were used in order to hold the lifting eyes in place during concrete pouring.

Figure 15 – Completed formwork boxes

The formwork boxes have now been completely finished and ready for pouring. The ends of the formwork boxes were closed off by screwing a piece of plywood on each side. Using plywood not only stopped the concrete from spilling out the ends during concrete pouring, it also allowed for easier stripping of the concrete once the necessary curing period had been reached.

Figure 16 – P-EC accessory profile with timber placed inside

Figure 17 – Close up of P-EC accessory profile with timber placed inside

Figures 16 and 17 show a P-EC end cap accessory profile with a piece of timber inserted inside. The P-EC is used on construction sites to close off wall ends. A piece of timber may be inserted inside the profile itself or on the outside of the profile in order to maintain a flat end surface once concrete has been poured.

For the construction of the Dincel samples the P-EC was firstly layed down on the ground and the main profile (P-1) was simply snapped on from the top. Using the P-EC for this purpose stopped the concrete from spilling out of the base of the samples during concrete pouring.

Figure 18 – P-TC accessory profile with timber placed inside

Figure 18 shows a P-TC top cap accessory profile which can be used as a capping for the top or at the end of a wall.

The P-TC was used with a piece of timber screwed on the inside. The P-TC pieces were then screwed to the Dincel P-1 profiles in order to close the wall ends of the Dincel samples during concrete pouring.

Figure 19 – Unreinforced Dincel samples ready for concrete pouring

Figure 20 – Unreinforced Dincel sample ends closed off

Figures 19 and 20 show the three completed Unreinforced Dincel samples ready for concrete pouring once the lifting eyes have been placed. As explained before, each sample was constructed using:

- 1 P-1 profile
- 1 P-EC profile with a piece of timber inside
- 2 P-TC profiles with a piece of timber placed on the inside of each profile.

Figure 21 – Reinforcement bar placement inside Reinforced Dincel sample

The construction of the Reinforced Dincel samples followed similar steps to the construction of the Unreinforced Dincel samples. As with the Unreinforced samples, the P-1 profile was firstly snapped onto the P-EC profile with a piece of timber located inside. Three small pieces of the P-J profile were then drilled at the required points and threaded with a piece of tie wire. These P-J pieces were placed at approximately third lengths within each of the samples. The N grade 12mm diameter steel reinforcement bar was firstly passed through the P-1 profile and tied onto the P-J profiles.

Figure 22 – Reinforced Dincel samples ready for concrete pouring from closer angle

Figure 23 – Reinforced Dincel sample

After the steel reinforcement bar had been placed inside of each Reinforced Dincel sample the ends were closed up by screwing a P-TC piece to each side of the P-1 profile. As with the construction of the Conventional Concrete samples, timber pieces were used to hold the lifting eyes in place during concrete pouring.

Figure 24 – Testing samples after concrete pouring

The 9 testing samples to be filled with concrete were placed side by side. Each of the samples were then filled with concrete. During pouring the concrete was also vibrated inside each of the samples. After the concrete inside of the samples had gained some strength which was five days after concrete pouring, the samples were then transported to the testing area which was located on the level below.

3.3 Testing area and testing tools used

Figure 25 – Preparation for testing of samples

All samples were tested using two equal point loads applied at the third points on the span. The distance between end spans was 3300mm. The length of each testing sample being 3400mm meant that 50mm of the sample was overhanging at each end support.

The distance between each end support to the closest load point was 1100mm. The distance between the two load points was also 1100mm. Loading the samples in this way meant that the maximum moment in each sample would be uniform between the two load points. Between these two load points there would also be no shear and failure would be due to pure moment alone.

Although there would be no shear between the two load points, maximum shear would occur between each end support and the closest load point to the support. The bending capacity and shear capacity was calculated prior to any testing. Completing these calculations proved that the bending capacity would be reached before the shear capacity under the test loading.

Figure 26 – Load cell to be used during testing

Figure 26 is showing one of the two load cells used during testing of the samples. Each load cell is attached to the base of a loading jack. As the load cells are pushed down and against the testing sample the force is converted into a measurable electrical output which gets plotted by the computer which they are connected to.

Figure 27 – Steel plates used during testing

The steel plates shown in Figure 27 were used in order to simulate the testing samples working as a small section of a slab. Two sets of steel plates were placed close to the loading points with steel rods connecting the plates on each side. The plates were then hand tightened using a washer and a nut.

As these steel plates were used during the testing of Hollow Dincel Sample 1 and 2, it was decided that the plates would be used for all testing samples to maintain uniformity of the testing method for comparison purposes. Using the steel plates allowed for the full lateral restraint of the testing samples.

Figure 28 – Linear variable displacement transducer (LVDT)

Figure 28 shows the linear variable displacement transducer (LVDT) which was used for all testing samples. The LVDT was placed at exactly mid-span and was connected to the nearby computer through a cable. As the two point loads pushed down, the amount of deflection of the sample would be transmitted to the computer in order to plot the deflection values.

Figures 29 to 31 show the test setup and the steel structure which was used for the test.

Figure 29 – Front of testing platform

Figure 30 – Back of testing platform

Figures 29 to 31 show the test setup and the steel structure which was used for the test.

Figure 31 – Loading point

Figure 32 – Pin support

All samples were tested on a simply supported configuration. Figure 32 shows the pin support which was used. It can be seen that a small part of the steel cylinder is held in place by the top steel plate. The pin support is restraining two translation degrees of freedom, in the vertical and horizontal directions.

Figure 33 – Roller support

Figure 33 is showing the roller support. Unlike the pin support, the cylinder is not being held by the plate above it. The plate is only sitting on top of the cylinder which is allowing for movement in the horizontal direction. The roller is however restraining movement in the vertical direction.

3.4 Compression tests

Figure 34 – Compression testing machinery

Figure 34 shows the machines which were used in order to undertake the compression tests. Compression tests were done to determine the behaviour of the sample of concrete under crushing loads.

At the time of concrete pouring for the testing samples, a number of cylinders were also filled with concrete in order to do compression tests. Each cylinder was 100mm in diameter and 200mm in height. Roughly 36 hours after pouring, the concrete cylinders were stripped and were then air-cured.

Each of the concrete cylinders to be tested had a capping placed on top. This ensured that the end surface of the cylinder was flat prior to the load being placed.

For each set of flexural tests, 3 concrete cylinders were tested under compression loads in order to get the compressive strength of the concrete.

Figure 35 – Sample compression testing

Figure 35 shows a concrete cylinder sample ready to be tested under compression loads. The protective screen is raised during testing for the safety of the person conducting the test and for observers close to the testing area.

Figure 36 – Operation of compression test machinery

Figure 36 shows a UTS staff member operating the machinery for a compression test. There are two wheels that need to be carefully used in this process, one for loading the concrete cylinder sample and the other for unloading the sample.

Figure 37 – Concrete cylinder after failure

Figure 37 shows a sample of a concrete cylinder after failure due to compression.

3.5 Test Procedures

3.5.1 Loading procedure of Conventional Reinforced Concrete samples and Reinforced Dincel samples

1. Load up to 50% of theoretical maximum external load = 6.30 KN
2. Unload
3. Load up to 75% of theoretical maximum external load = 9.45 KN
4. Unload
5. Load up to the maximum load the sample can withstand.
6. Unload
7. Load until maximum load again.

3.5.2 Loading procedure of Unreinforced Dincel samples

1. Load up to 50% of assumed maximum load = 12 KN
2. Unload
3. Load up to 75% of assumed maximum load = 18 KN
4. Unload
5. Load up to the maximum load the sample can withstand.
6. Unload
7. Load until maximum load again.

3.5.3 Loading procedure of Hollow Dincel samples

1. Load up to the maximum load the sample can take.
2. Unload

3.6 Analysis of the test samples

3.6.1 Analysis of Conventional Reinforced Concrete samples and Reinforced Dincel samples

The Conventional Reinforced Concrete samples were analysed using the following steps:

1. The theoretical ultimate moment was found.
2. The maximum moment resulting from the self-weight of the sample was then found.
3. The maximum moment from the self-weight was then taken away from the ultimate moment calculation. This calculated value would be the resulting moment from the maximum external loading that could be placed.
4. The maximum total load which could be placed was then calculated and was found to be 12.60 KN. (**See Appendix for calculations**)

As it was not yet known what the effect of the polymer encasing would have on the concrete strength, the Reinforced Dincel samples were analysed and loaded the same way as the Conventional Reinforced Concrete samples.

3.6.2 Analysis of Unreinforced Dincel samples

The polymer encasing significantly increased the maximum load taken by the Reinforced Dincel samples when compared to the plain Conventional Reinforced Concrete samples. The average maximum load taken by the three Reinforced Dincel samples was 2.5 times the value of the average maximum load taken by the Conventional Reinforced Concrete samples. It was obvious at the time that the Unreinforced Dincel samples would take much more load when compared to a plain concrete block without the polymer encasing.

At this stage there were four sets of data at hand:

1. The theoretical maximum load calculated for the Conventional Reinforced Concrete samples.
2. The actual maximum load for the Conventional Reinforced Concrete samples.
3. The actual maximum load for the Reinforced Dincel samples.
4. The theoretical maximum load for an unreinforced concrete block with the same cross-section dimensions as the samples which were to be tested.

From these data sets it was approximated that the maximum load taken by the Unreinforced Dincel samples would be between 23 KN and 25 KN. A maximum load value of 24 KN was therefore used to calculate the different loads to be placed on the Unreinforced Dincel samples.

3.6.3 Analysis of Hollow Dincel samples

Each of the internal webs inside of the Dincel profile is approximately 1.85mm in thickness. As these webs are very slender, it was known that there would be a buckling problem with the webs during testing. The maximum load taken by the Hollow Dincel samples would therefore be controlled by the web buckling. The maximum load that would be taken by the Hollow Dincel samples was therefore very difficult to calculate. For that reason the samples were only loaded to the maximum load and then unloaded.

3.7 Definition of "Maximum Load"

Before any testing had even been done it was decided that the loading of the samples until the point of failure would be avoided as much as possible. This decision was made to avoid any damage to the deflection transducer and the loading cells. The samples were therefore tested until a maximum load was reached. Once this maximum load had been reached, testing was continued for a period of time in order to confirm that the samples had reached their load capacity and could not take any higher loading. Only Conventional Reinforced Concrete sample 3 and Unreinforced Dincel sample 1 were tested until failure. The testing for the remaining samples was stopped before failure. It must be noted that if these samples were tested until failure, the mid-span deflection values achieved would be much greater.

Chapter 4 – Results

Table 7 – Summary of total maximum load withstood by each sample

Sample	Maximum Load (kN)
Conventional Reinforced Concrete Samples	
1	17.35
2	16.33
3	16.86
AVERAGE	**16.85**
Reinforced Dincel Samples	
1	40.95
2	41.45
3	43.60
AVERAGE	**42.00**
Unreinforced Dincel Samples	
1	22.34
2	24.48
3	23.31
AVERAGE	**23.38**

Table 8 – Summary of total maximum load withstood by each sample

Hollow Dincel Samples	Maximum Load (kN)
Sample 1	
Maximum Applied Load from test	1.77
Weight of steel plates	0.52
Total load carried by sample	2.29
Sample 2	
Maximum Applied Load from test	1.89
Weight of steel plates	0.98
Total load carried by sample	2.87
Sample 3	
Maximum Applied Load from test	2.00
Weight of steel plates	0
Total load carried by sample	2.00

4.1 Comparison between test results

Comparison of Reinforced Dincel Samples (RDS) to Conventional Reinforced Concrete Samples (CRCS)

$$\frac{RDS}{CRCS} = \frac{42.00kN}{16.85kN} = 2.5$$

Reinforced Dincel Samples carried **2.5** times the load the Conventional Reinforced Concrete Samples carried.

Comparison of Unreinforced Dincel Samples (UDS) to Conventional Reinforced Concrete Samples (CRCS)

$$\frac{UDS}{CRCS} = \frac{23.38kN}{16.85kN} = 1.4$$

Unreinforced Dincel Samples carried **1.4** times the load the Conventional Reinforced Concrete Samples carried.

Comparison of Unreinforced Dincel Samples (UDS) to Theoretical Cracking Load of Concrete (TCLC)

The theoretical cracking moment of unreinforced concrete with the same cross-section as an Unreinforced Dincel sample was firstly calculated. From this value, the total cracking load was then found to be 7.52 kN. (**See Appendix for calculations**)

$$\frac{UDS}{TCLC} = \frac{23.38kN}{7.52kN} = 3.1$$

Unreinforced Dincel Samples carried **3.1** times the load the Theoretical Unreinforced Plain Concrete Samples would have carried.

4.2 Compression Test Results

Each set of three identical flexural testing samples were tested on different days. This means that all 3 Conventional Reinforced Concrete samples were tested in the same day. The 3 Reinforced Dincel Samples were then all tested throughout another day. The 3 Unreinforced Dincel Samples were tested last and again all of these samples were tested on a different day from the other two sets of samples. It was not possible to test all 9 of these samples on the same day as each test took a considerable amount of time to complete. As these 9 samples were tested on 3 different days, it meant that 3 sets of compression tests would need to be done in order to complete a thorough quality check of the concrete. Compression tests were done for concrete cylinders of size 100mm in diameter and 200mm in height. 3 concrete cylinders were tested for each set of flexural testing samples.

Table 9 – Compression test results

Sample	Compressive Load (kN)
Compression test sample results done at time of Conventional Reinforced Concrete Flexural Testing	
1	141.8
2	156.6
3	173.4
Average Compressive Load	157.3
Average Compression Strength (Mpa)	**20.03**
Compression test sample results done at time of Reinforced Dincel Flexural Testing	
1	154.0
2	159.2
3	164.8
Average Compressive Load	159.3
Average Compression Strength (Mpa)	**20.28**
Compression test sample results done at time of Unreinforced Dincel Flexural Testing	
1	143.9
2	170.7
3	165.0
Average Compressive Load	159.9
Average Compression Strength (Mpa)	**20.36**

Cross-sectional area of each concrete cylinder

$$Area = \frac{\pi \times d^2}{4}$$
$$= \frac{\pi \times 100^2}{4}$$
$$= 7854mm^2$$

Average Compression Strength

It can be seen from the above table that there is little variance in the compression strength of the concrete at the different times of testing. The average compressive strength at the time of testing for the Conventional Reinforced Concrete samples was 20.03 Mpa. The average compressive strength at the time of testing for the Reinforced Dincel samples was 20.29 Mpa.

$$Increase = \frac{(20.29Mpa - 20.03Mpa)}{20.03Mpa}$$
$$= 0.0130$$
$$= 1.3\%$$

These values are extremely minute when considering the fact that the average maximum load withstood by the Dincel Reinforced Samples during the flexural testings was 149% greater than the value of the average maximum load withstood by the Conventional Reinforced Concrete samples.

4.3 Conventional Reinforced Concrete Samples

Figure 38 – Conventional Reinforced Concrete sample ready for testing

The first set of flexural tests to be done were for the Conventional Reinforced Concrete samples. Each sample was placed on top of the two end supports and then loaded.

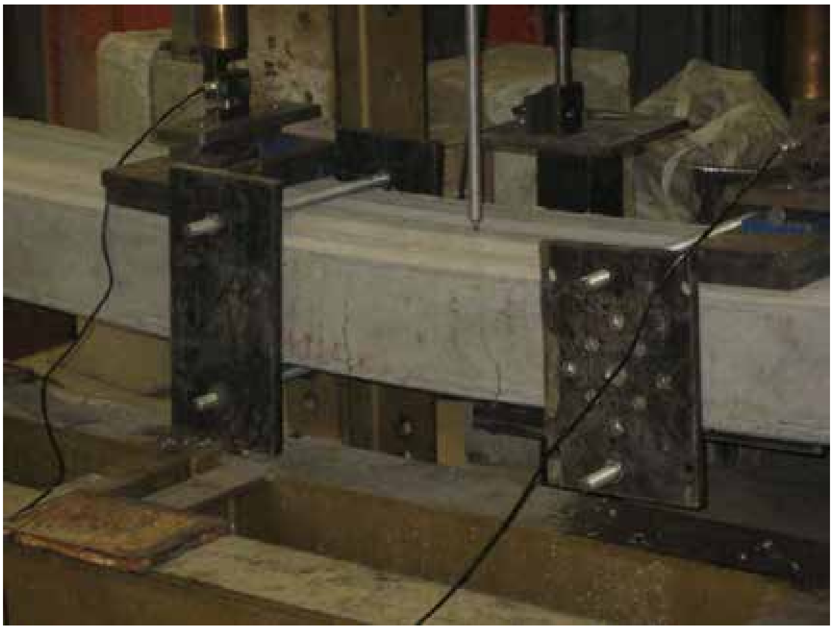


Figure 39 – Flexural cracks in sample

Shortly after loading, flexural cracks at mid-span started to develop.

Figure 40 – Conventional Reinforced Concrete sample during testing

Figure 41 - Conventional Reinforced Concrete sample during testing

Figures 40 and 41 show the change in amount of deflection in the test sample as the loads are increased.

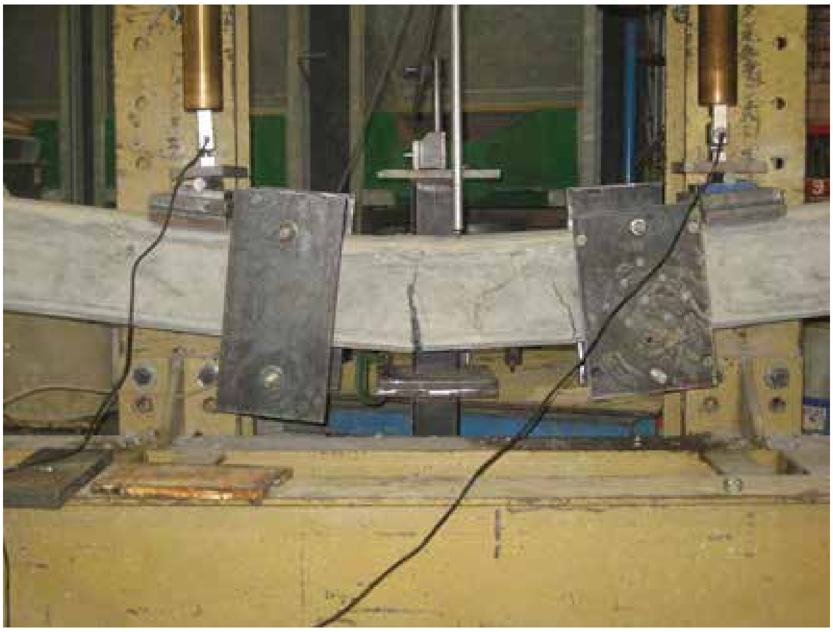


Figure 42 – Large flexural cracks developing in Conventional Reinforced Concrete sample 3

Figure 42 shows Conventional Reinforced Concrete Sample 3 after the maximum load had been reached. As the load was increased during testing, it could be seen that the flexural cracks kept growing in both length and width.

Figure 43 – Conventional Reinforced Concrete sample 3 after failure

Conventional Reinforced Concrete Sample 3 was loaded to failure. Loading to this point meant that there would be a risk of damaging the LVDT and the loading cells. Therefore, Sample 1 and Sample 2 were only tested until the maximum load was reached and not until failure.

Figure 44 – Conventional Reinforced Concrete sample 3 at failure cross section

After Conventional Concrete Sample 3 had failed, a picture was taken of the cross-section at the point where failure occurred. It can be seen that the quality of the concrete which was formed inside Dincel polymer is very high. The concrete surface quality was equally high as there were no voids or honeycombing evident for any of the testing samples.

4.3.1 Total Applied Load vs Midspan Deflection Graphs for Conventional Reinforced Concrete Samples

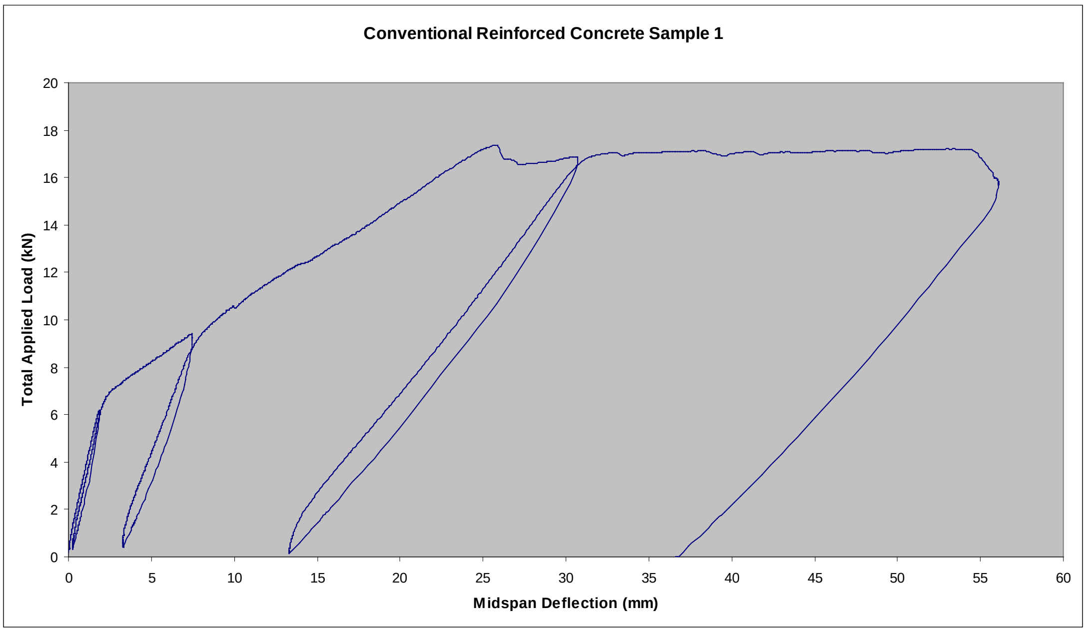


Figure 45 - Total applied load vs midspan deflection for Conventional Reinforced Concrete sample 1

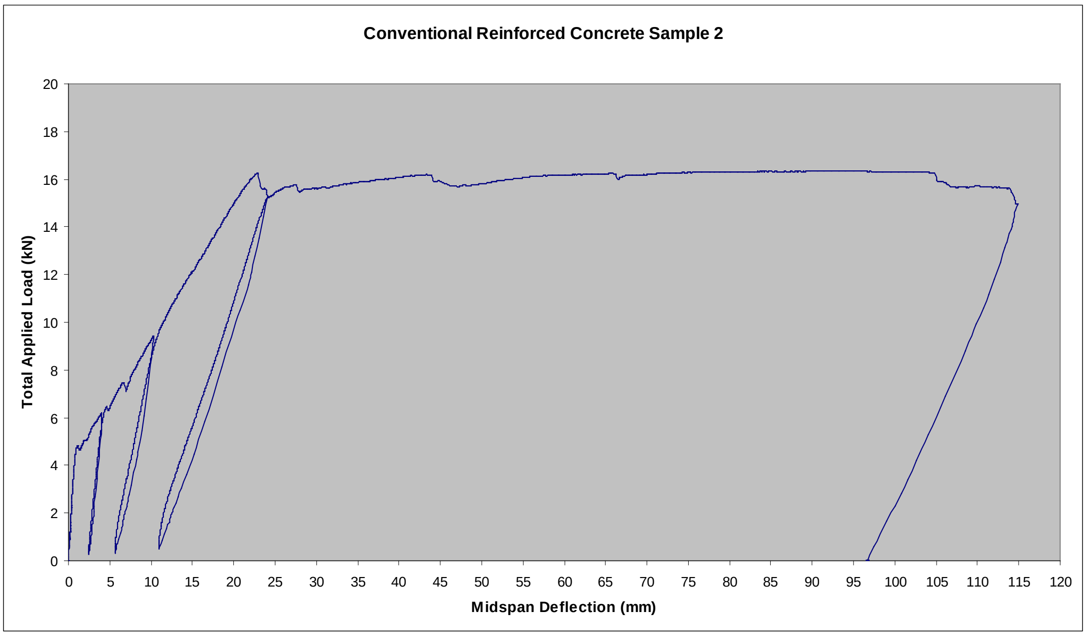


Figure 46 - Total applied load vs midspan deflection for Conventional Reinforced Concrete sample 2

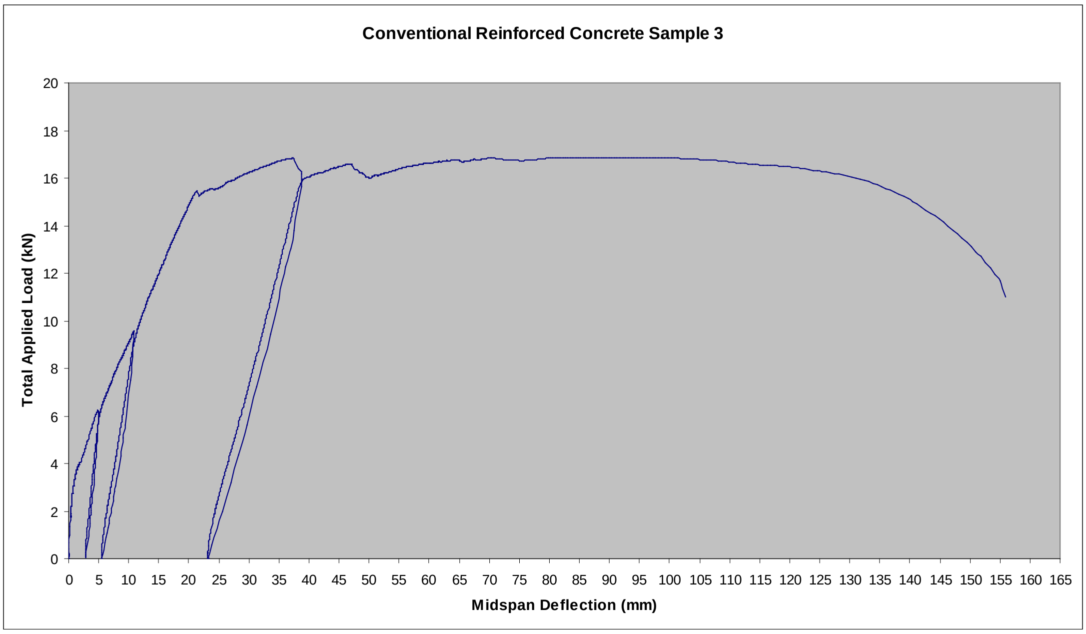


Figure 47 - Total applied load vs midspan deflection for Conventional Reinforced Concrete sample 3

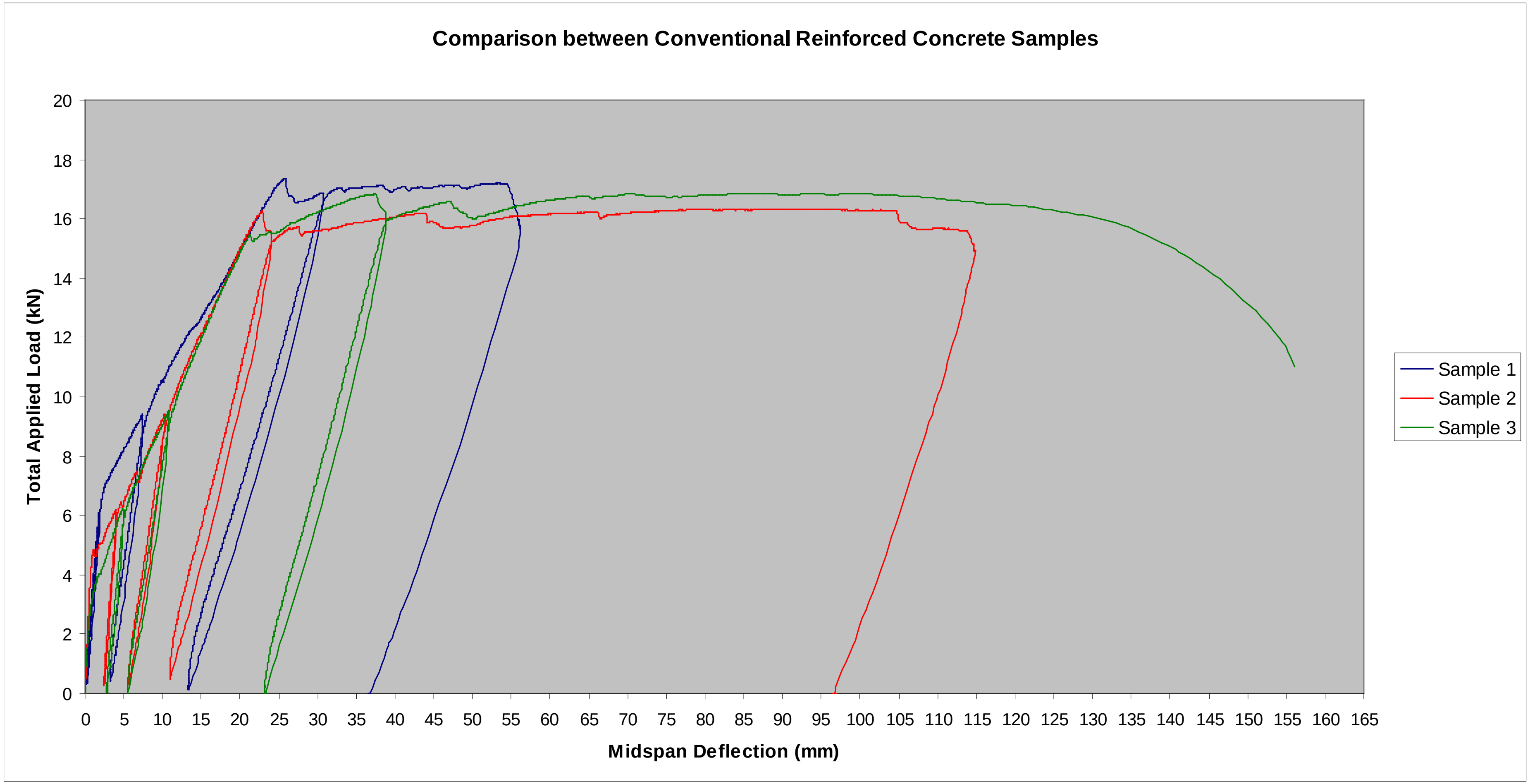


Figure 48 – Total applied load vs midspan deflection comparison between the three Conventional Reinforced Concrete samples

4.4 Reinforced Dincel Samples

Figure 49 – Reinforced Dincel Sample prior to loading

The second set of samples to be tested were the Reinforced Dincel samples.

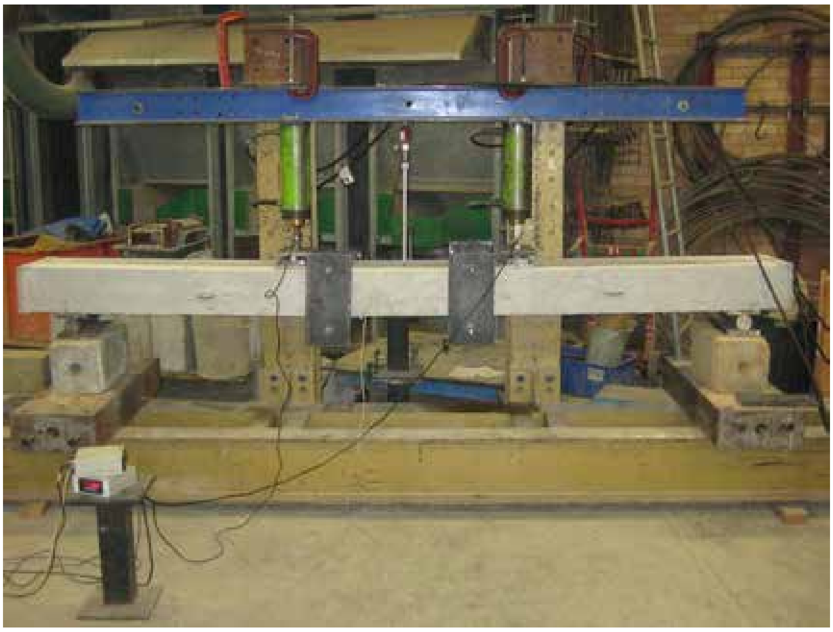


Figure 50 – Reinforced Dincel sample during loading

Figure 50 is showing a Reinforced Dincel Sample under a total load in excess of 23 kN during testing. Even under such a high load the deflection of the sample can be seen to be very minimal.

Figure 51 – Reinforced Dincel sample during loading

The Reinforced Dincel samples continued to carry load even after very large deflections. The maximum total load for Reinforced Dincel Sample 3 of 43.60 kN was reached after the beam had deflected 78mm at mid-span. The Reinforced Dincel samples proved to be much stiffer and ductile when compared to the Conventional Concrete samples.

Figure 52 – Reinforced Dincel sample load readings

Figure 52 shows the loads which were exceeded by Reinforced Dincel Sample 3. The top box reads 21.305 kN where as the box on the bottom reads 22.211 kN. Adding these two values together gives a total load in excess of 43 kN at this stage of the testing.

Figure 53 – Deflection in Reinforced Dincel sample 1 after unloading

Figure 53 illustrates the large amount of deflection which has been withstood by the Dincel polymer. Reinforced Dincel Sample 1 deflected 170mm at mid-span without failing. If testing was to continue until failure, much greater mid-span deflections would have been reached.

4.4.1 Total Applied Load vs Midspan Deflection Graphs for Reinforced Dincel Samples

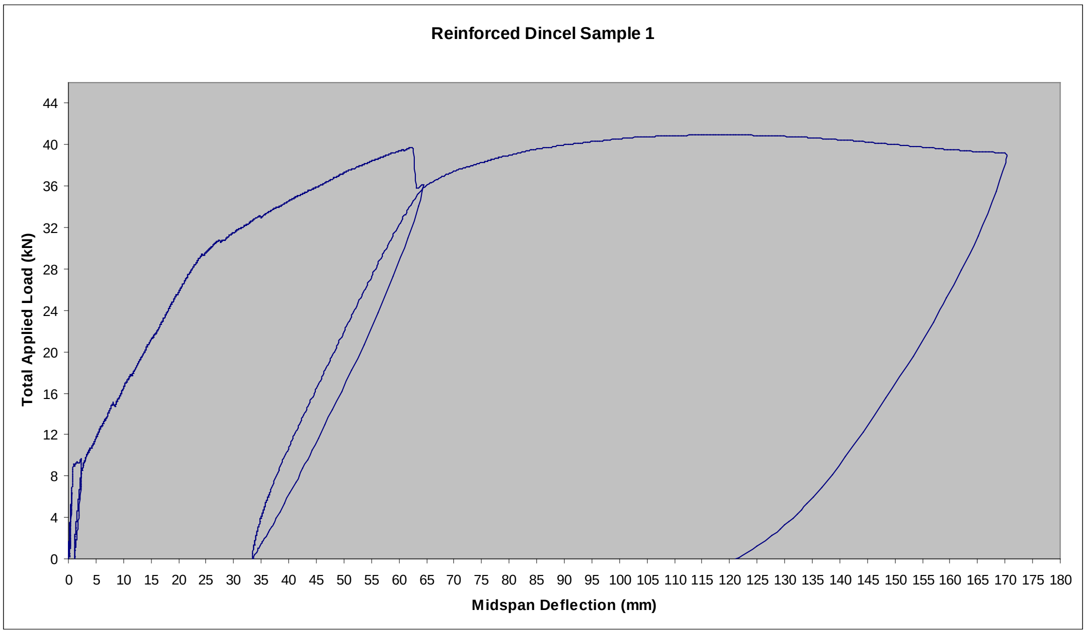


Figure 54 - Total applied load vs midspan deflection for Reinforced Dincel sample 1

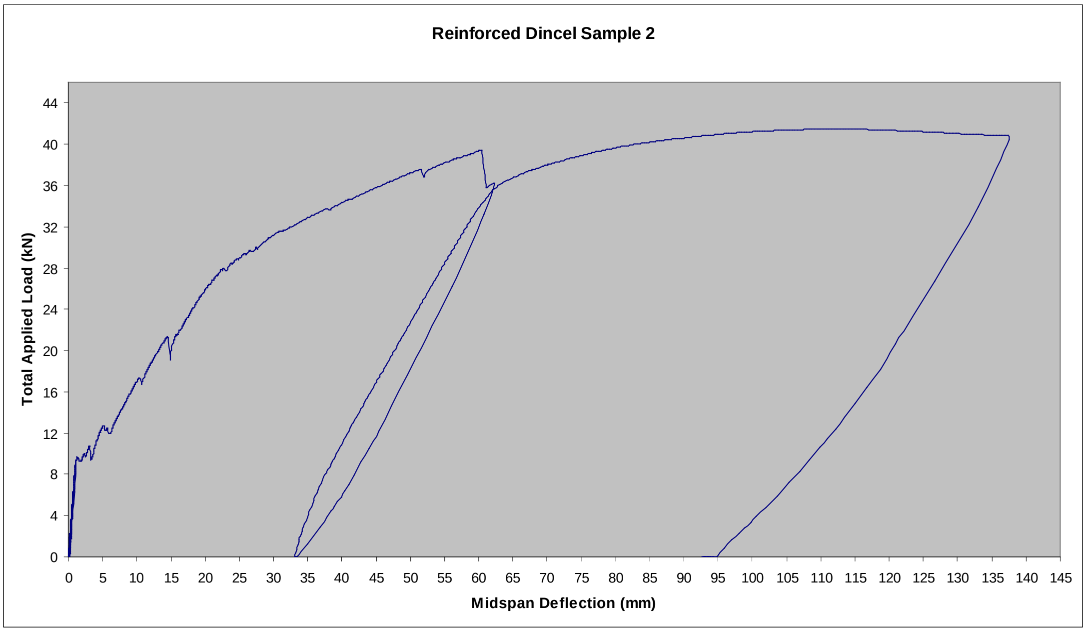


Figure 55 - Total applied load vs midspan deflection for Reinforced Dincel sample 2

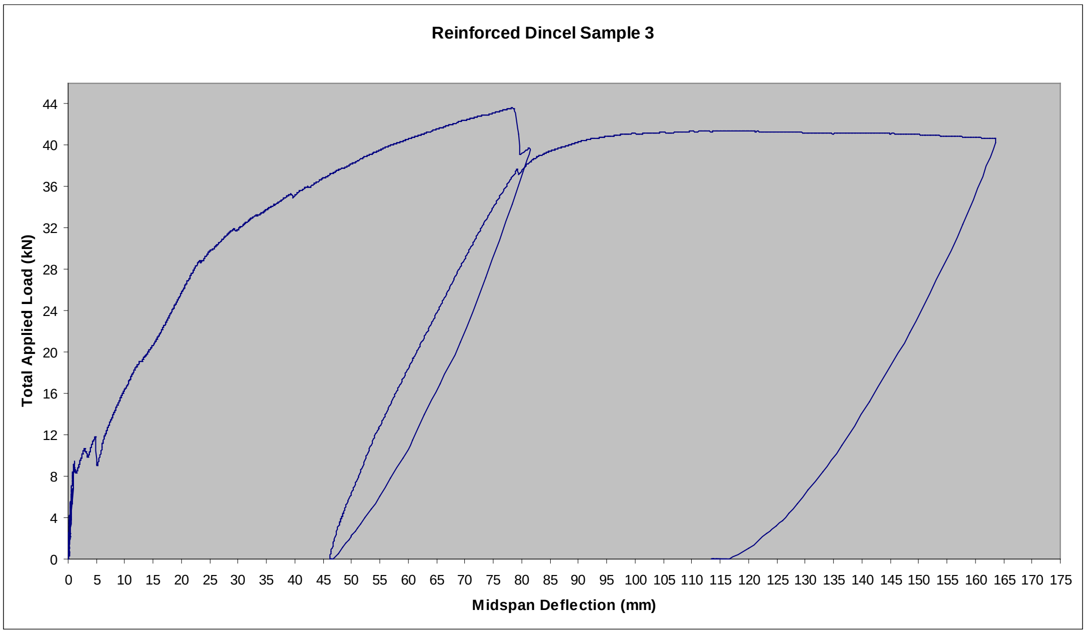


Figure 56 - Total applied load vs midspan deflection for Reinforced Dincel sample 3

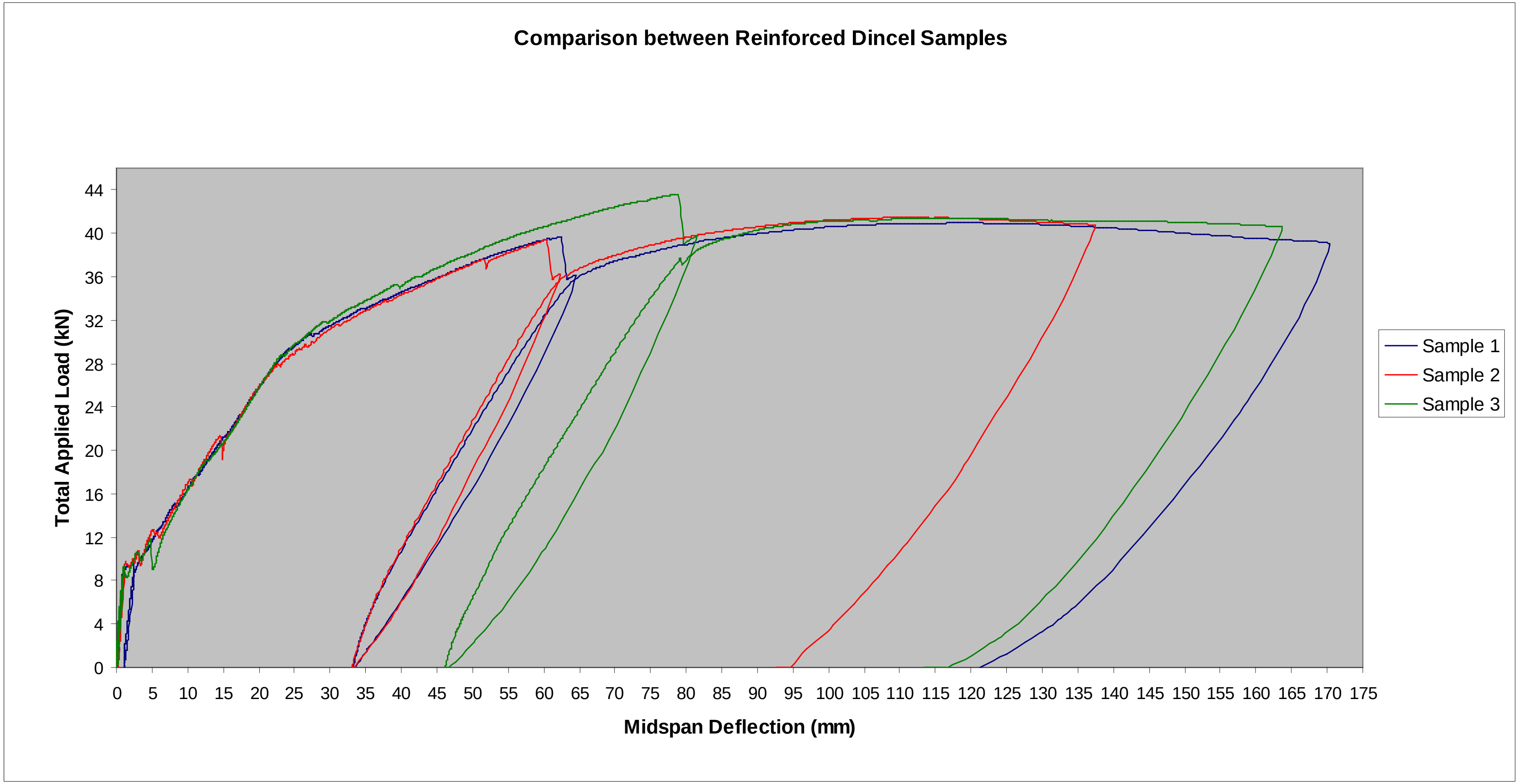


Figure 57 - Total applied load vs midspan deflection comparison between the three Reinforced Dincel samples

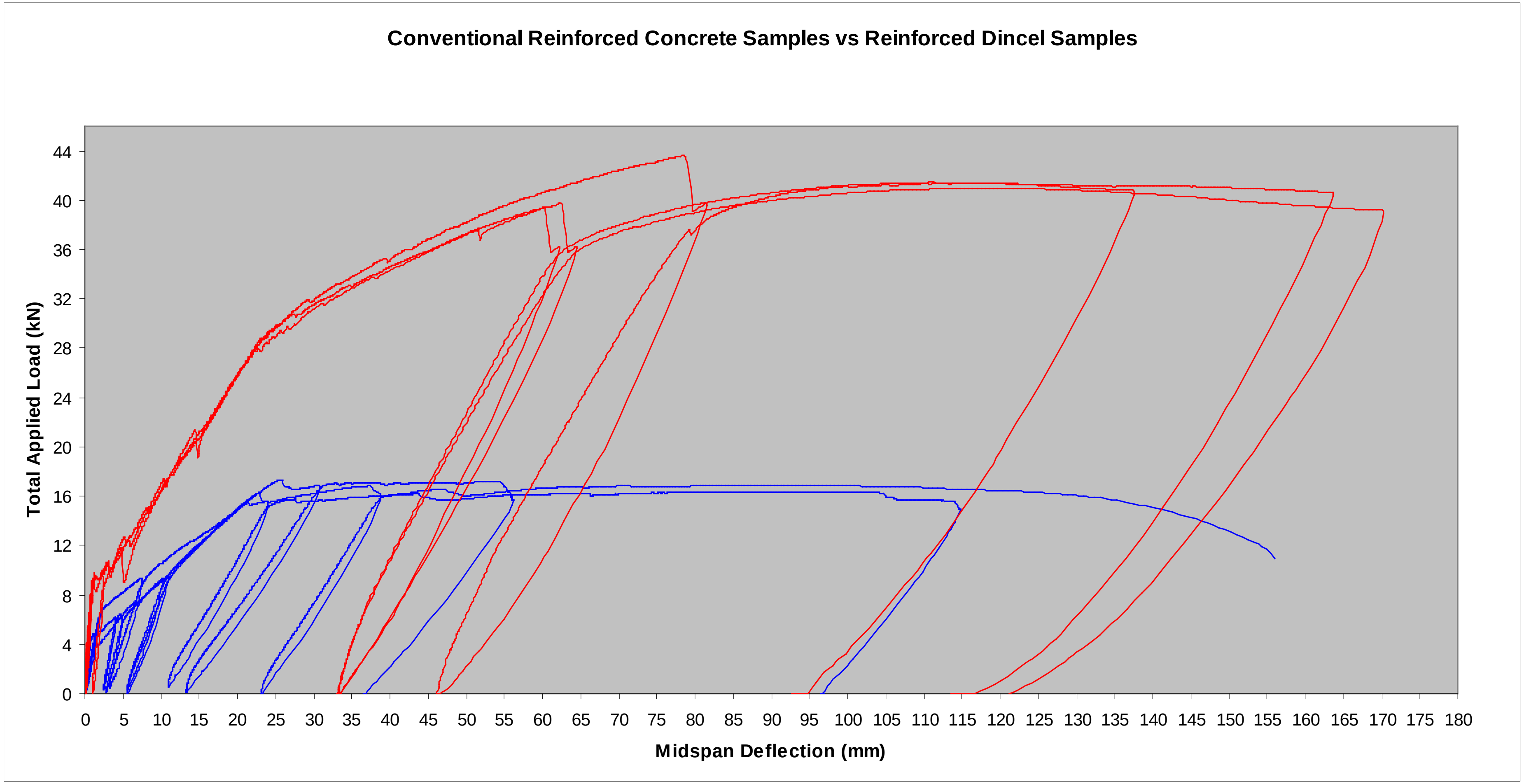


Figure 58 – Total applied load vs midspan deflection comparison between Conventional Reinforced Concrete samples (IN BLUE) and Reinforced Dincel samples (IN RED)

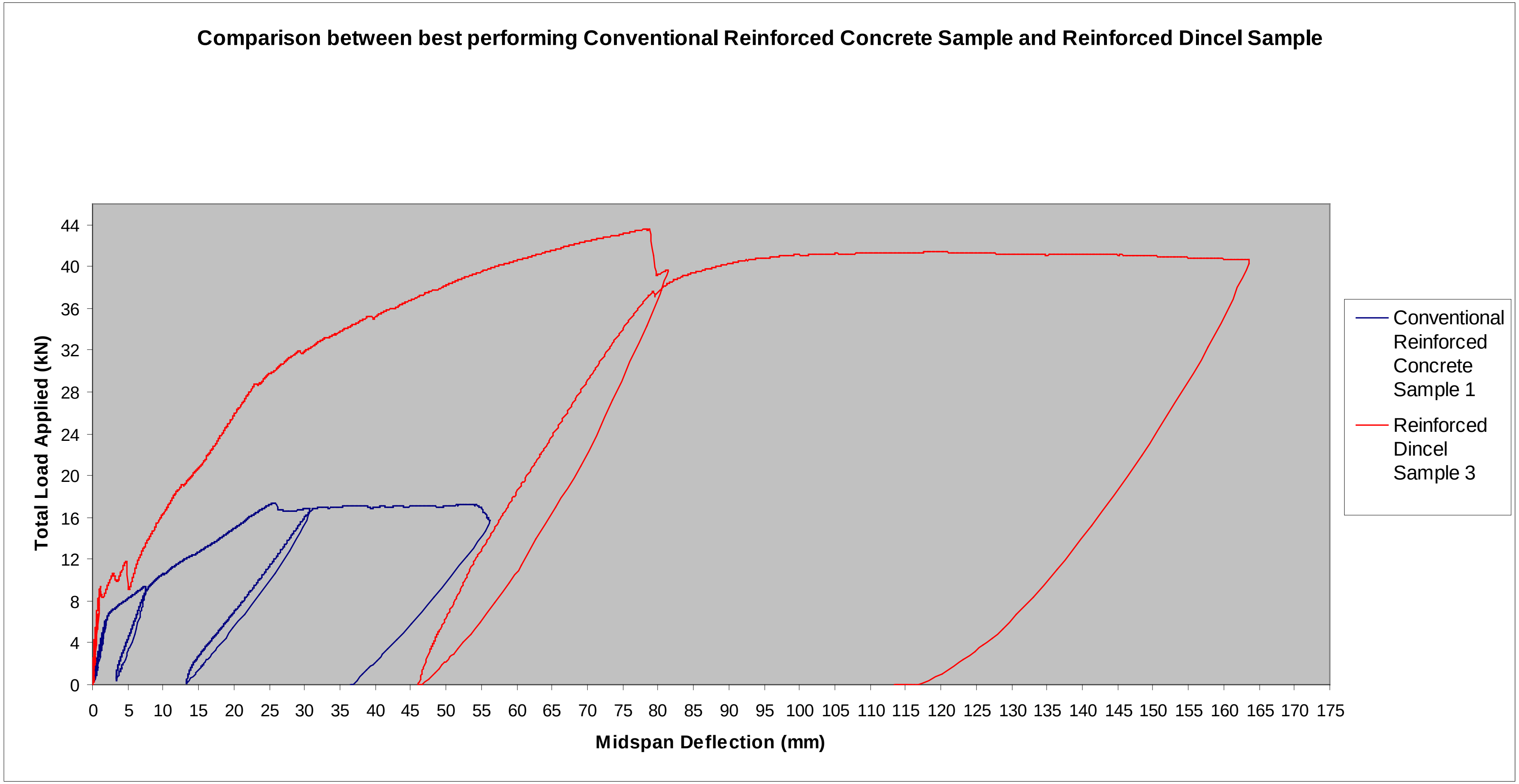


Figure 59 - Total applied load vs midspan deflection comparison between the Conventional Reinforced Concrete sample which withstood the largest load (sample 1) and the Reinforced Dincel sample which withstood the largest load (sample 3)

4.5 Unreinforced Dincel Samples

Figure 60 – Unreinforced Dincel sample prior to loading

Figure 60 shows an Unreinforced Dincel Sample ready for testing.

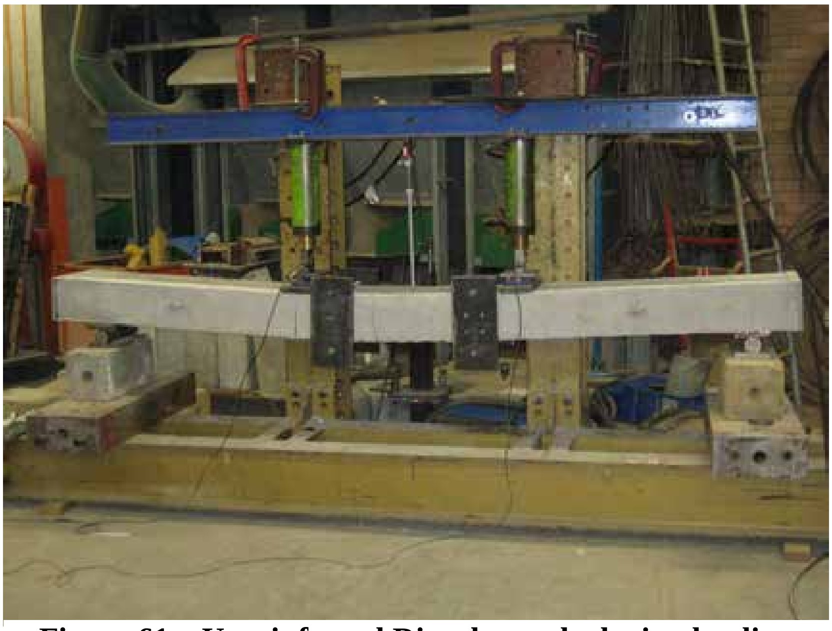


Figure 61 – Unreinforced Dincel sample during loading

Even at great loads, the Dincel polymer added significant ductility to the unreinforced concrete.

Figure 62 – Unreinforced Dincel sample 1 tested to failure

Unreinforced Dincel Sample 1 deflected 130mm at mid-span before failing. All 3 Unreinforced Dincel samples carried much more load than the 3 Conventional Reinforced Concrete samples. This shows that the polymer encasing which Dincel gives to concrete was far stronger compared to using a 12mm diameter steel reinforcement bar.

Figure 63 – Cross section of Unreinforced Dincel sample 1 after failure

Figure 63 shows the cross-section of Unreinforced Dincel Sample 1 at the point where failure occurred. The concrete quality inside of the Dincel polymer can be seen.

4.5.1 Total Applied Load vs Midspan Deflection Graphs for Unreinforced Dincel Samples

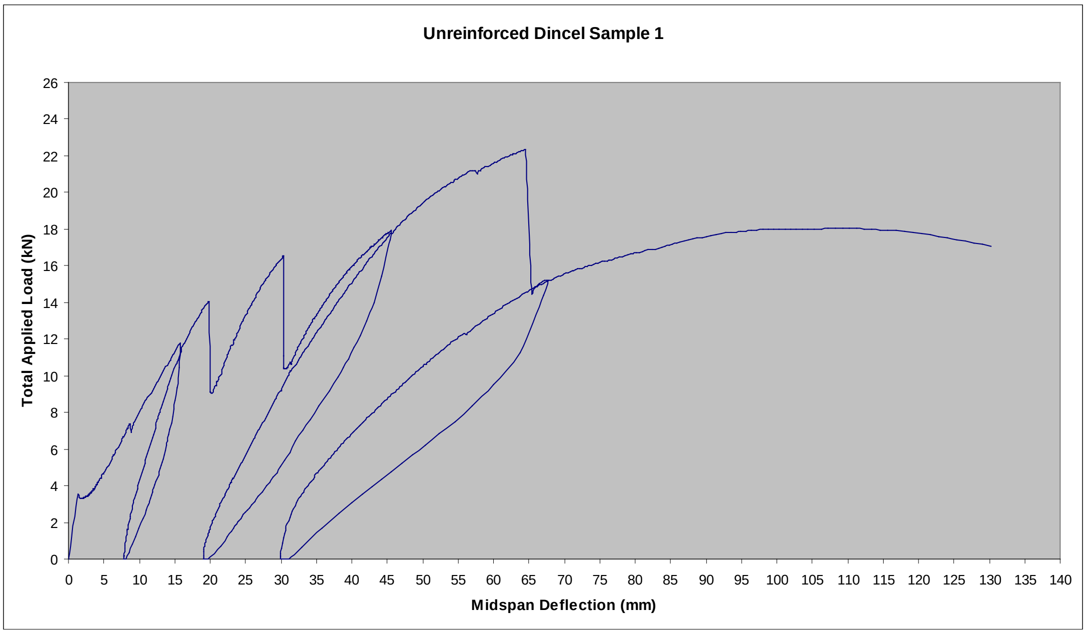


Figure 64 - Total applied load vs midspan deflection for Unreinforced Dincel sample 1

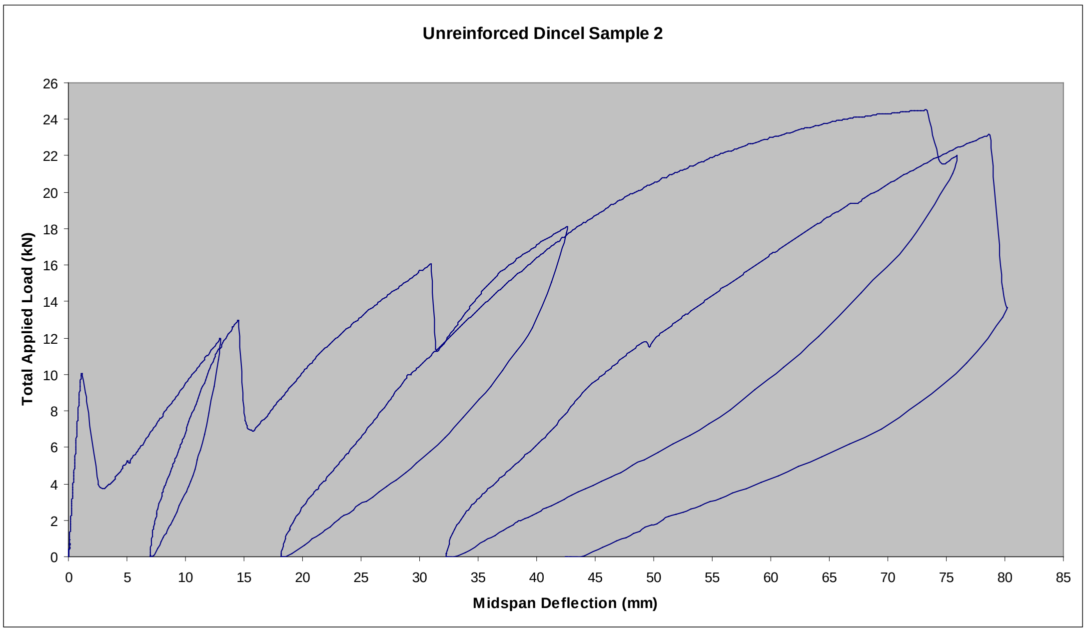


Figure 65 - Total applied load vs midspan deflection for Unreinforced Dincel sample 2

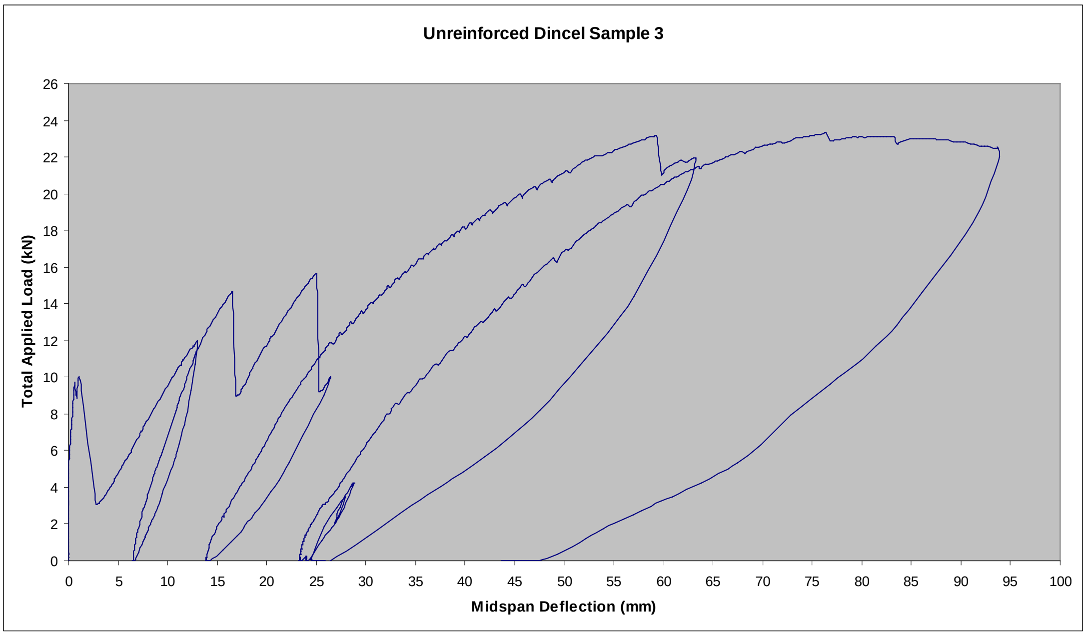


Figure 66 - Total applied load vs midspan deflection for Unreinforced Dincel sample 3

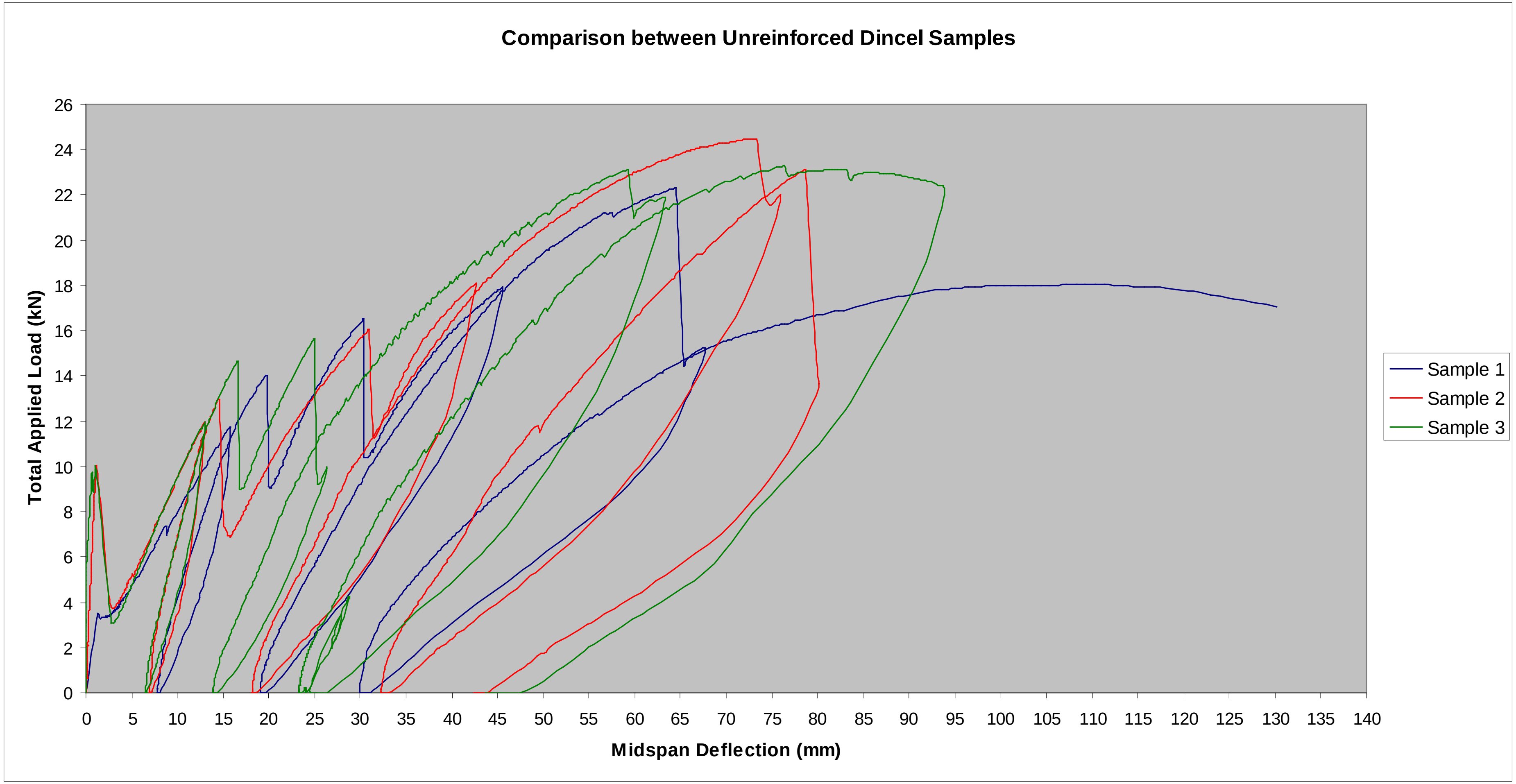


Figure 67 - Total applied load vs midspan deflection comparison between the three Unreinforced Dincel samples

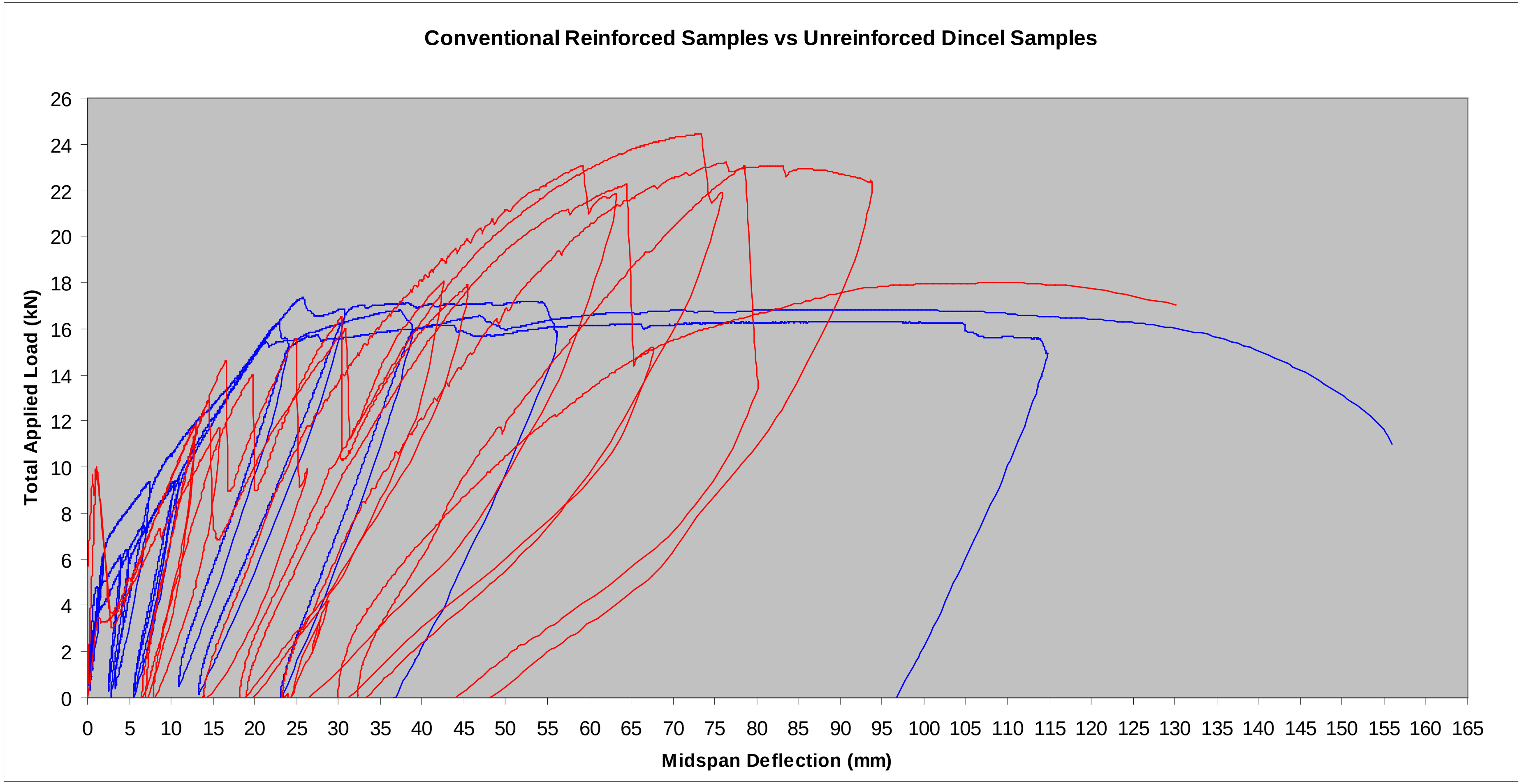


Figure 68 - Total applied load vs midspan deflection comparison between Conventional Reinforced Concrete samples (IN BLUE) and Unreinforced Dincel samples (IN RED)

4.6 Hollow Dincel Samples

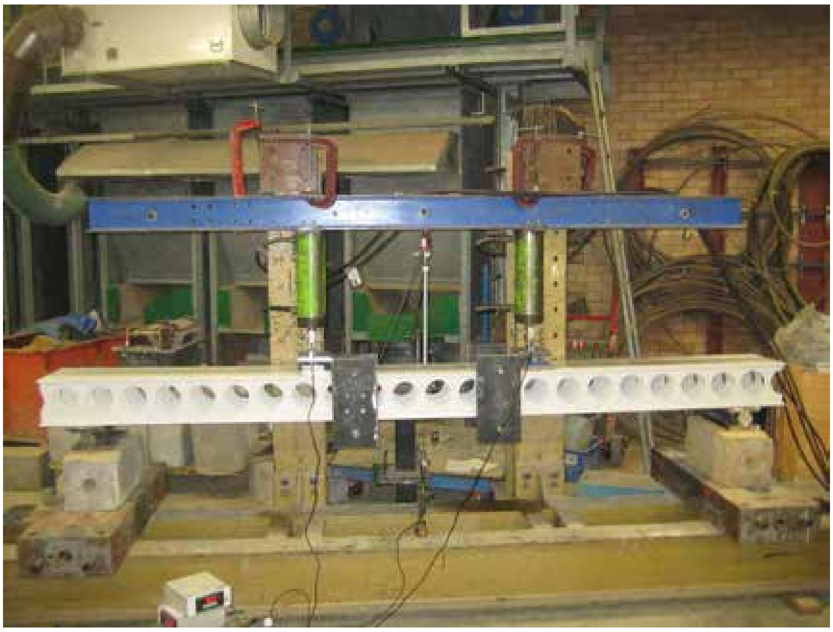


Figure 69 – Hollow Dincel sample 1 prior to loading

Figure 69 above shows Hollow Dincel Sample 1 which had 2 sets of steel plates placed close to the load points in order to control buckling.

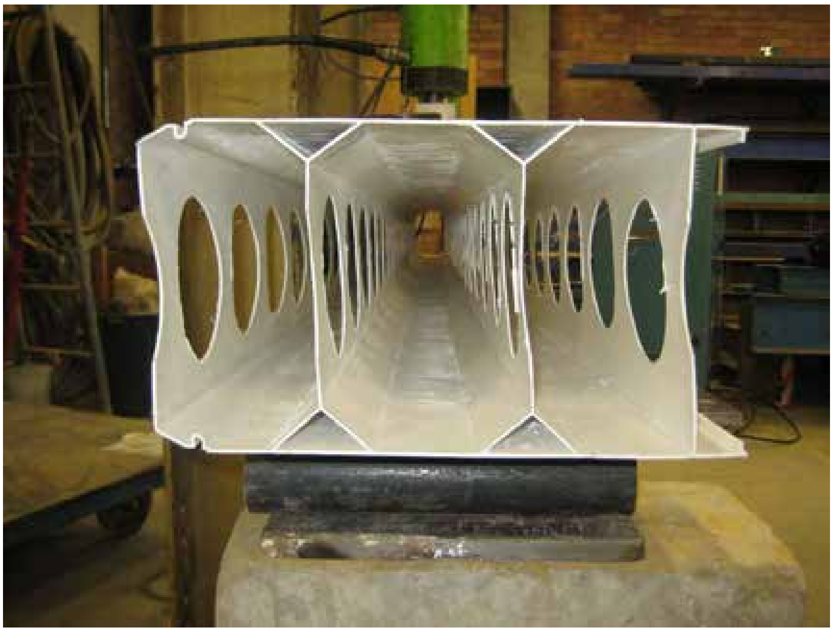


Figure 70 – Hollow Dincel sample 1 prior to loading

Figure 70 shows the cross-section of the sample before loading.

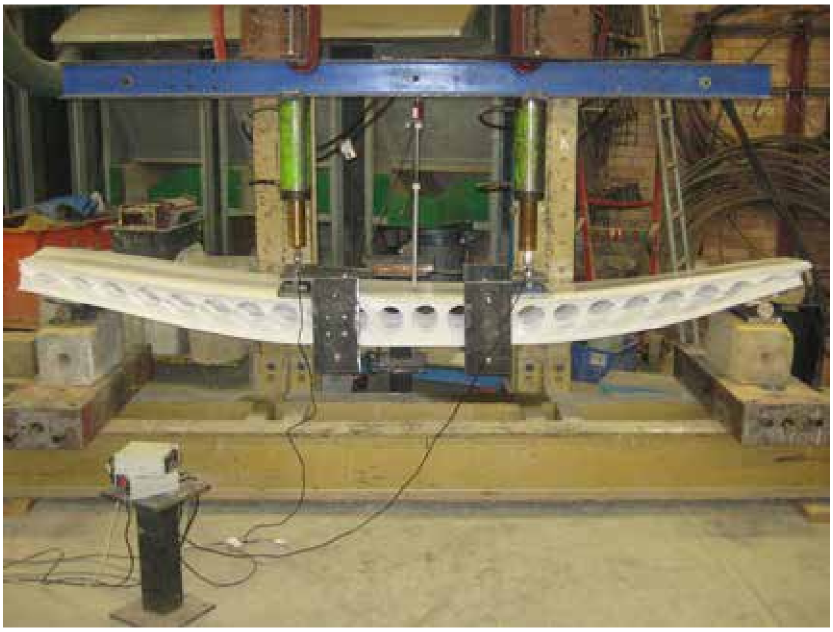


Figure 71 – Hollow Dincel sample 1 during loading

After loading, it can be seen that the section between the 2 steel plates has minimal buckling due to the plates helping against buckling.

Figure 72 – Hollow Dincel sample 1 at maximum loading

As there were no restraints near the end supports, the very slender section has buckled under the loads.

Figure 73 – Hollow Dincel sample 2 prior to loading

As Hollow Dincel Sample 1 had significant buckling near the end supports, more sets of steel plates were used for Hollow Dincel Sample 2 in order to try and control buckling.

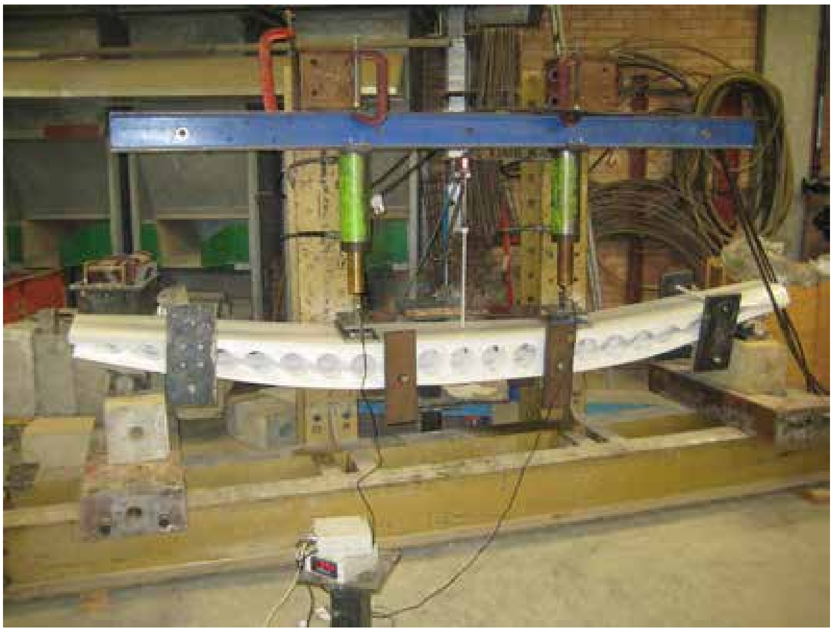


Figure 74 – Hollow Dincel sample 2 during loading

The extra lateral restraints did allow for more load to be taken by the sample, however the sample only failed due to excessive buckling once again.

Figure 75 – Hollow Dincel sample 2 at maximum loading

It can be seen that even when there were lateral restraints placed throughout the testing sample, buckling was not able to be controlled.

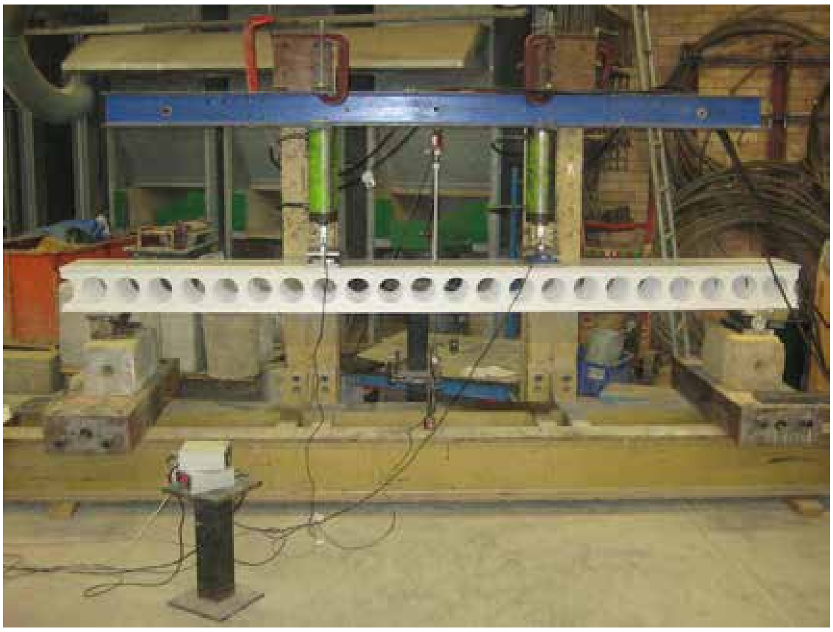


Figure 76 – Hollow Dincel sample 3 prior to loading

In order to evaluate the effectiveness of the lateral restraints, Hollow Dincel Sample 3 had no steel plates used to control buckling.

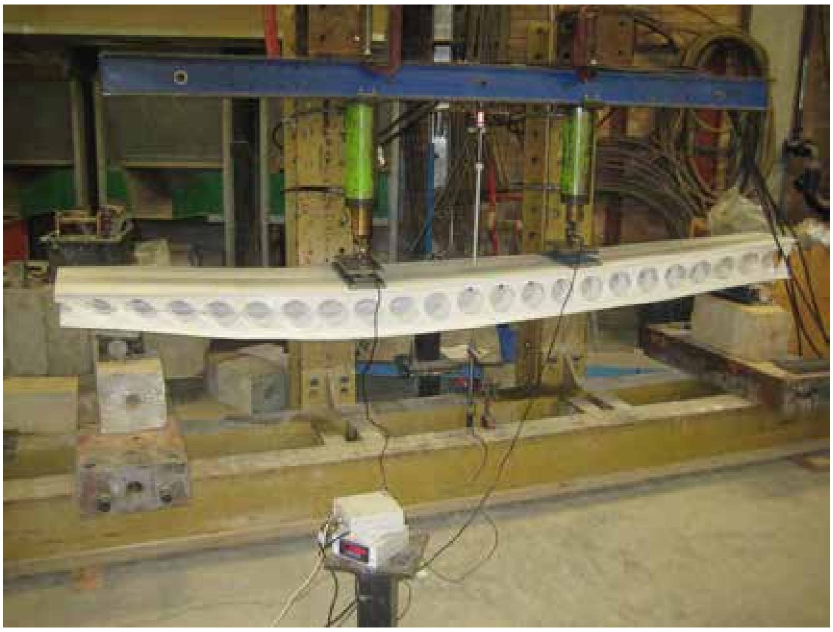


Figure 77 – Hollow Dincel sample 3 during loading

It should be noted that each set of steel plates used in the two previous tests were very heavy in weight. Hollow Dincel Sample 3 withstood the most load from the loading cells. However, when taking the weight of the steel plates into account Sample 3 withstood the least total load in comparison to Sample 1 and Sample 2.

Figure 78 – Hollow Dincel sample 3 during loading

As there were no lateral restrains used for this testing sample the large amount of lateral buckling can be seen.

Figure 79 – Hollow Dincel sample 3 after unloading

Figure 80 – Hollow Dincel sample 3 after unloading

After the loads were taken off the testing sample, the polymer panel sprang back close to its original shape. At the maximum load, the sample had deflected 124mm. Once testing had been stopped, the deflection at mid-span reduced to less that 12mm.

4.6.1 Total Applied Load vs Midspan Deflection Graphs for Hollow Dincel Samples

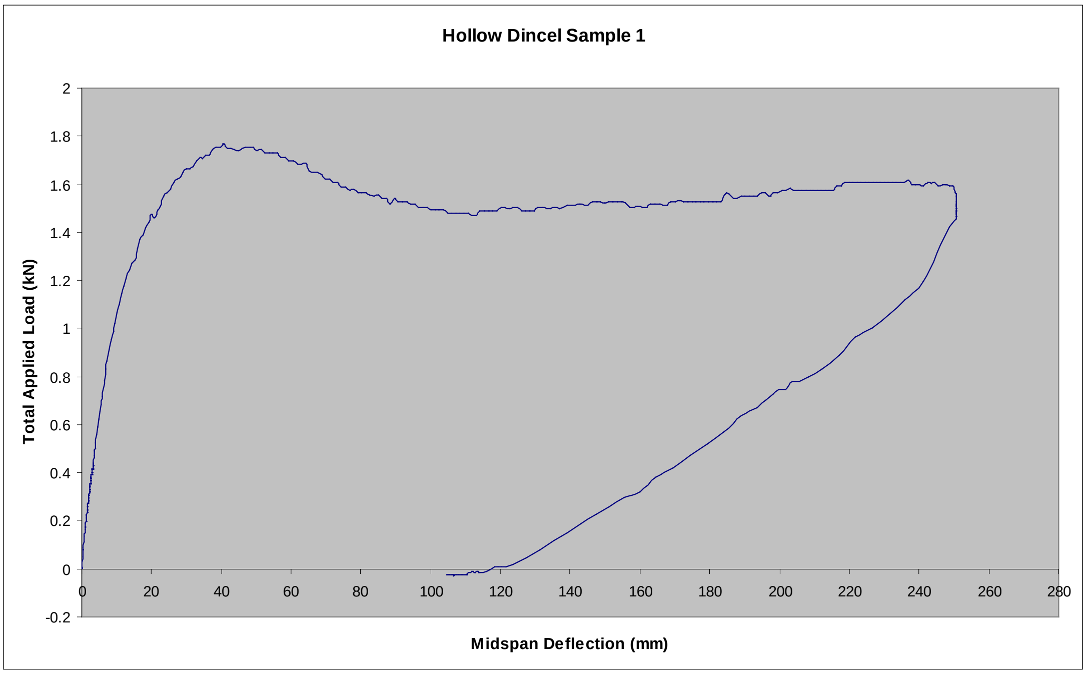


Figure 81 - Total applied load vs midspan deflection for Hollow Dincel sample 1

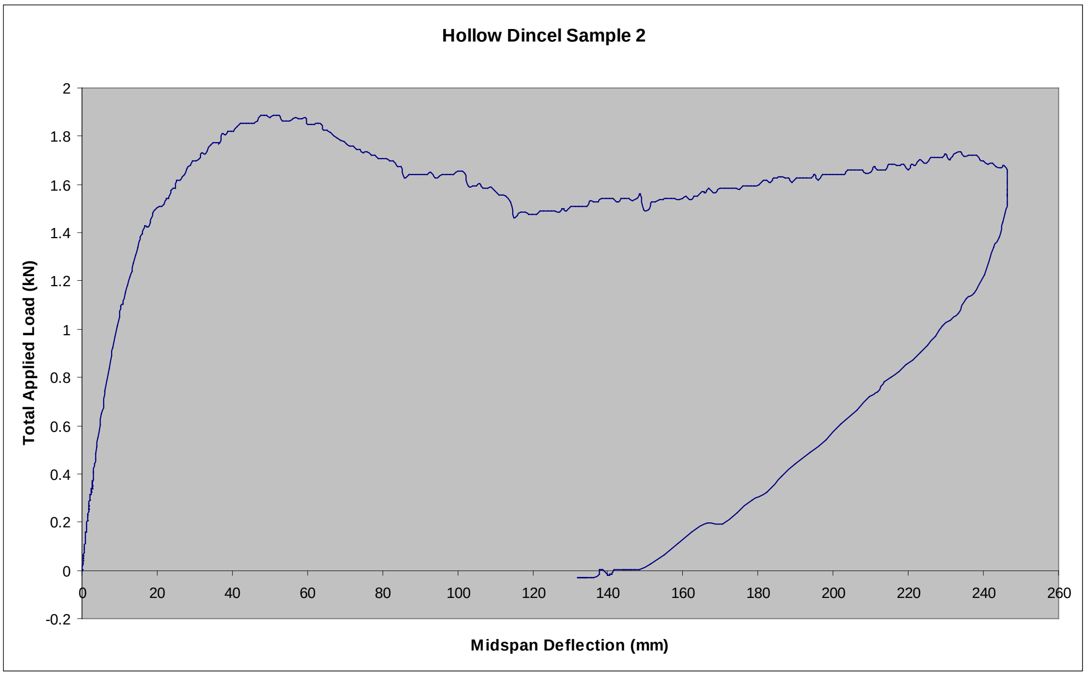


Figure 82 - Total applied load vs midspan deflection for Hollow Dincel sample 2

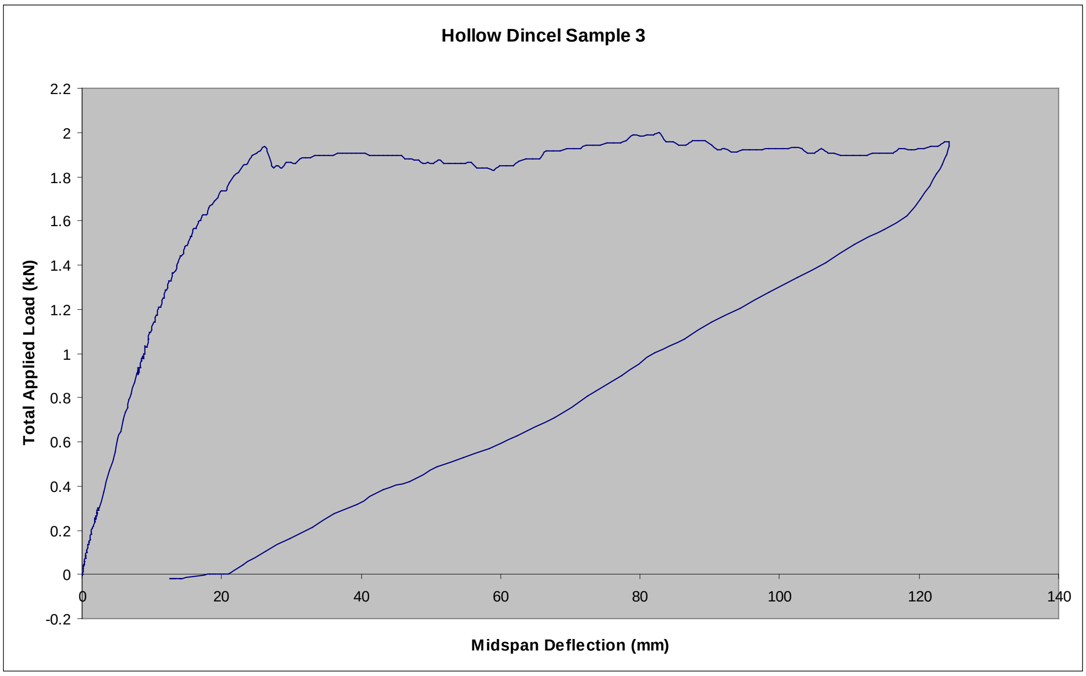


Figure 83 - Total applied load vs midspan deflection for Hollow Dincel sample 3

4.7 Strain Gauge Readings

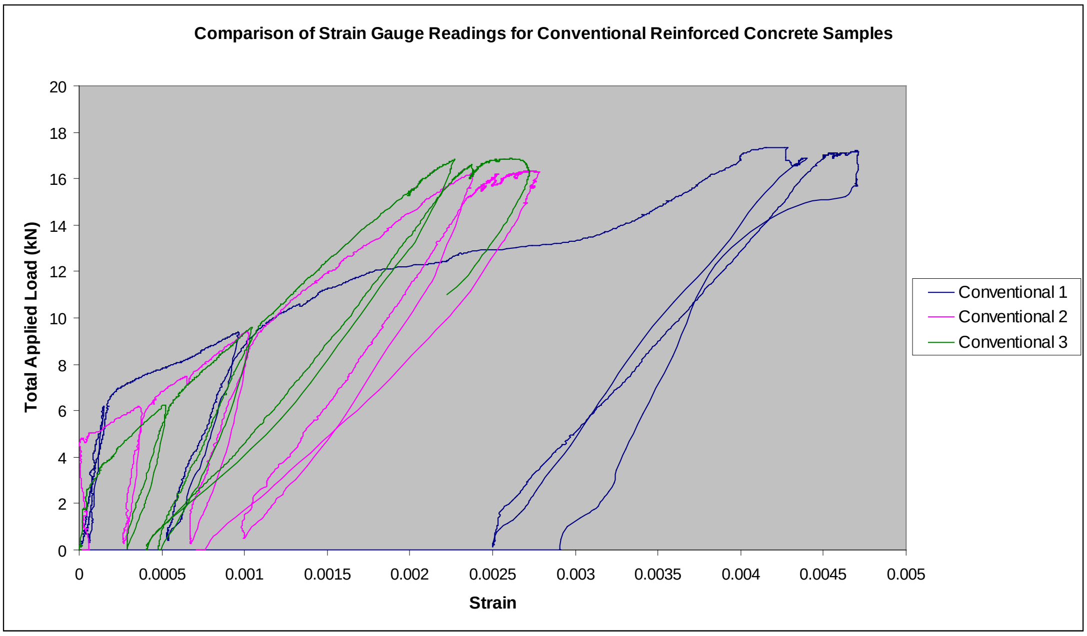


Figure 84 - Total applied load vs strain comparison between Conventional Reinforced Concrete samples

Figure 84 shows the comparison of the strain gauge readings for the 3 Conventional Reinforced Concrete Samples. It can be seen that the shape of the graph for sample 2 and sample 3 are relatively close. The maximum strain for sample 2 was 0.0028 while the maximum for sample 3 was 0.0027 which shows that these readings were both very close to each other and they also agreed with theoretical calculations. However, the results for sample 1 are very different compared to sample 2 and 3. It should be also noted that the strain gauge readings for sample 1 have stopped early as this is the point where the sample failed.

In total, strain gauges were used for 6 samples. Out of these 6 samples only the Conventional Reinforced Concrete samples 2 and 3 produced consistent and realistic results. Possible reasons why the remaining strain gauges may have been either faulty or inaccurate:

- The strain gauges may have been faulty prior to instalment.
- The strain gauges may have been damaged during the concrete pouring or concrete vibration process.
- There may have been a fault in the cable connecting the strain gauge to the electronic device which plotted the results, or a fault in the electronic device itself.

The Load -vs- Deflection results for all sets of testings samples proved to be very consistent. In comparison the Load -vs- Strain results were very inconsistent, therefore accurate conclusions can not be made from the Load -vs- Strain data.

Chapter 5 – Conclusion

The aim of this project was to examine if Dincel's polymer encasing would benefit conventional concrete in terms of both strength and ductility when placed under flexural loads. In order to accurately investigate this, 3 samples were tested for each different type of testing specimen. Conducting 3 tests for each specimen allowed for the statistical variance to be significantly decreased.

The variance of results for both the Reinforced Dincel samples and Unreinforced Dincel samples were very small. The average maximum load for the 3 Unreinforced Dincel samples was 23.38 kN. The sample with the maximum load value furthest from the average value was sample 2 which withstood 24.48kN. Therefore, the maximum load for each of the 3 Unreinforced Dincel samples was within 4.7% of the average.

$$Variance = \frac{(24.48kN - 23.38kN)}{23.38kN}$$
$$= 0.047$$
$$= 4.7\%$$

The average maximum load for the 3 Reinforced Dincel samples was 42.00 kN. The sample with the maximum load value furthest from the average value was sample 3 which withstood 43.60kN. The maximum load for each of the 3 Reinforced Dincel samples was therefore within 3.8% of the average.

$$Variance = \frac{(43.60kN - 42.00kN)}{42.00kN}$$
$$= 0.038$$
$$= 3.8\%$$

In the Australian Standards for bending design (without axial tension or compression) where $k_u \leq 0.4$, a strength reduction factor of 0.8 must be used. However, this strength reduction factor can be as low as 0.6 when $k_u > 0.4$. In any case, there is at least a 20% reduction factor required for bending design. As can be seen from the testing results, the maximum loads withstood by the Dincel samples are very consistent. The Dincel polymer encasing has also significantly increased the strength of regular conventional concrete.

There is currently no composite design code incorporating the usage of polymer with concrete. Both the Reinforced and Unreinforced Dincel samples withstood greater load than the Conventional Reinforced Concrete samples.

The introduction of a composite design code would therefore allow the engineer to have greater design flexibility. There would also be a decrease of the amount of steel reinforcement needed for strength purposes.

The information in the Tables 10, 11, 12, 13 & 14 have been calculated using the average line which has been incorporated in the Figures 85, 86 & 87. In order to draw the average line the average load value at each unit of deflection was firstly calculated and plotted. From the plot, a number of distinct points were selected in order to draw an average line which consisted of straight lines. Using this approach to draw the average line allowed for more distinct point readings and calculations.

5.1 Pre-Cracking Behaviour of Testing Samples

Table 10 – Average total load at cracking moment and the corresponding midspan deflection at the cracking moment for each set of samples

Sample	Average Load at Cracking Moment (kN)	Midspan Deflection at Cracking Moment (mm)
Conventional Reinforced Concrete Samples	5.34	2.30
Reinforced Dincel Samples	9.06	1.67
Unreinforced Dincel Samples	7.81	1.44
Theoretical value for Concrete Cross-Section	7.52	0.78

Table 11 – Average pre-cracking stiffness for each set of samples

Sample	Average Pre-Cracking Stiffness (Nmm^2)
Conventional Reinforced Concrete Samples	1131.18×10^9 Nmm^2
Reinforced Dincel Samples	2599.47×10^9 Nmm^2
Unreinforced Dincel Samples	2598.79×10^9 Nmm^2

Table 12 – Difference between calculated theoretical cracking load and actual cracking load for each set of samples

Sample	Average Load at Cracking Moment (kN)	Difference between Theoretical Cracking Load and Sample Cracking Load (%)
Conventional Reinforced Concrete Samples	5.34	- 28.99%
Reinforced Dincel Samples	9.06	+ 20.48%
Unreinforced Dincel Samples	7.81	+ 3.86%

The above tables show that the Pre-Cracking Stiffness of the Reinforced and Unreinforced Dincel samples are almost identical. The Pre-Cracking Stiffness for the Conventional Reinforced Concrete samples is less than half than that of the Dincel samples. This shows that the Dincel polymer encasing provides a stiffening effect to the concrete section. This is also observed in the resulting deflection readings with both sets of Dincel samples having much less deflection than the Conventional Reinforced Concrete samples at the Cracking Load.

All samples have already cracked even before the load is applied as their average deflection values are almost double the calculated cracking deflection. It is however noticeable that the cracking load for both sets of Dincel samples are higher than the calculated cracking load. This shows that the Dincel polymer encasing and the concrete are already acting compositely as soon as the concrete sets. Using the results above it can be concluded that the Dincel polymer encasing and concrete act as a composite section once the concrete sets.

5.2 Post-Cracking Behaviour of Samples

Table 13 – Calculated theoretical load, the actual load and the corresponding midspan deflection at the ultimate moment for each set of samples

Sample	Average Theoretical Load at Ultimate Moment (kN)	Average Test Load at Ultimate Moment (kN)	Midspan Deflection at Ultimate Moment (mm)
Conventional Reinforced Concrete Samples	12.60	16.30	23.80
Reinforced Dincel Samples	33.52	39.87	61.05
Unreinforced Dincel Samples	17.60	21.80	65.30

Table 14 – Average post-cracking stiffness for each set of samples

Sample	Average Post-Cracking Stiffness (Nmm^2)
Conventional Reinforced Concrete Samples	328.08×10^9 Nmm^2
Reinforced Dincel Samples	312.92×10^9 Nmm^2
Unreinforced Dincel Samples	160.08×10^9 Nmm^2

As shown in the appendix, the theoretical total load at the Ultimate Moment was calculated for each different set of testing samples. It can be seen in Table 13 that the theoretical calculated values are all less but very close to the actual test values. This shows that the calculation methods shown in the appendix are conservative and can be used to estimate the ultimate strength of the section.

The stiffness of the Conventional Reinforced Concrete samples are very close to the Post-Cracking Stiffness values of the Reinforced Dincel samples. Table 14 also shows that the Post-Cracking Stiffness values of the reinforced samples are greater than the unreinforced samples. This shows that after the concrete is cracked, the steel reinforcement bar is adding some stiffness to the section while the polymer encasing of Dincel is not adding any extra stiffness.

Based on Figures 85, 86 and 87, it can be seen that that the Dincel samples have much higher ductility when compared to the Conventional Reinforced Concrete samples. This is evident when comparing the area which is bounded between the Load vs Deflection curves and the x-axis.

The composite action between the concrete and Dincel polymer encapsulation offers reserve strength and increased ductility which can be highly effective for forces such as earthquake, hurricane, or blast loading. In simple terms, the composite behaviour of Dincel as a new material can be placed above the Conventional Reinforced Concrete members as demonstrated by the tests in this study.

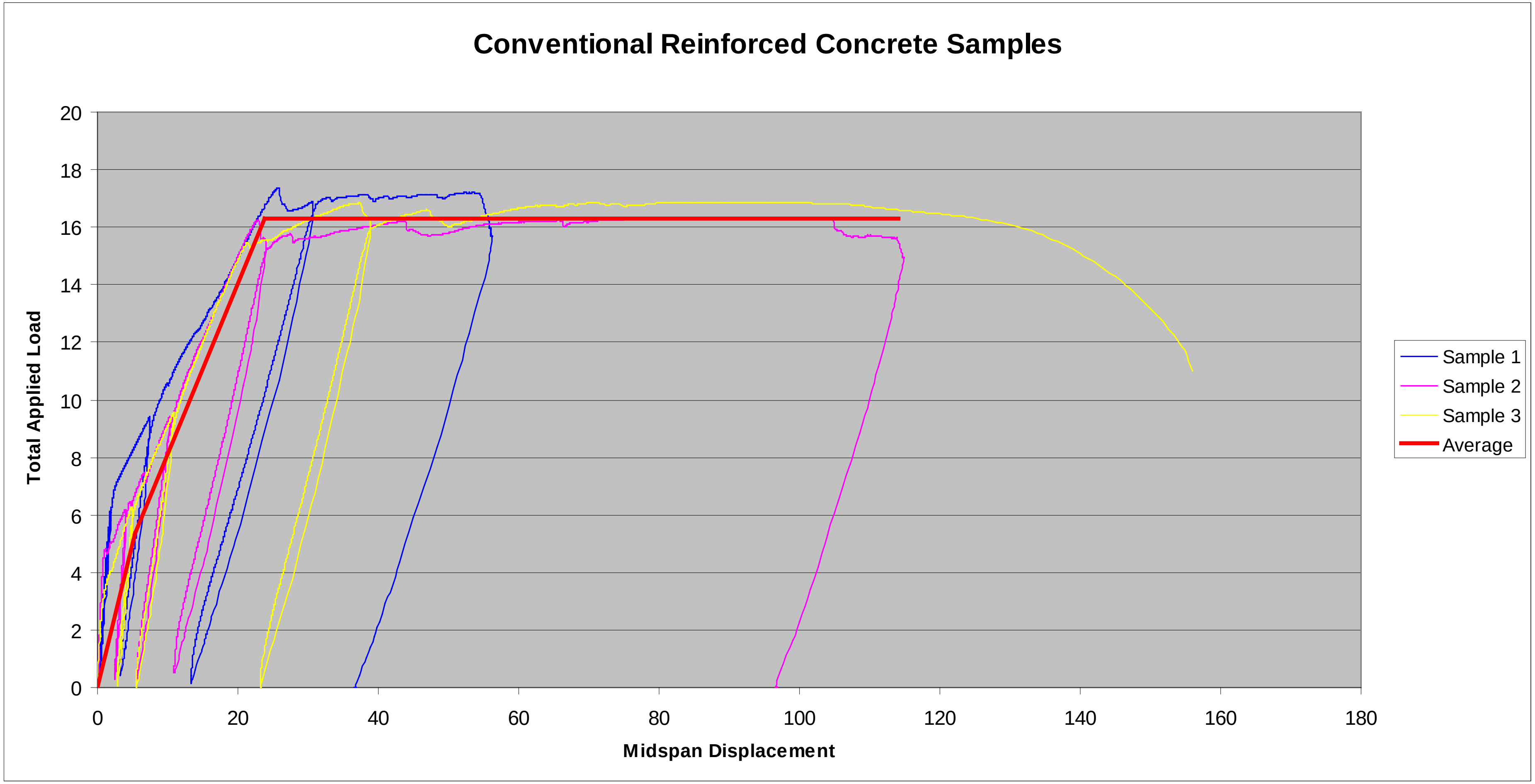


Figure 85 – Total applied load vs midspan deflection comparison between Conventional Reinforced samples with average line

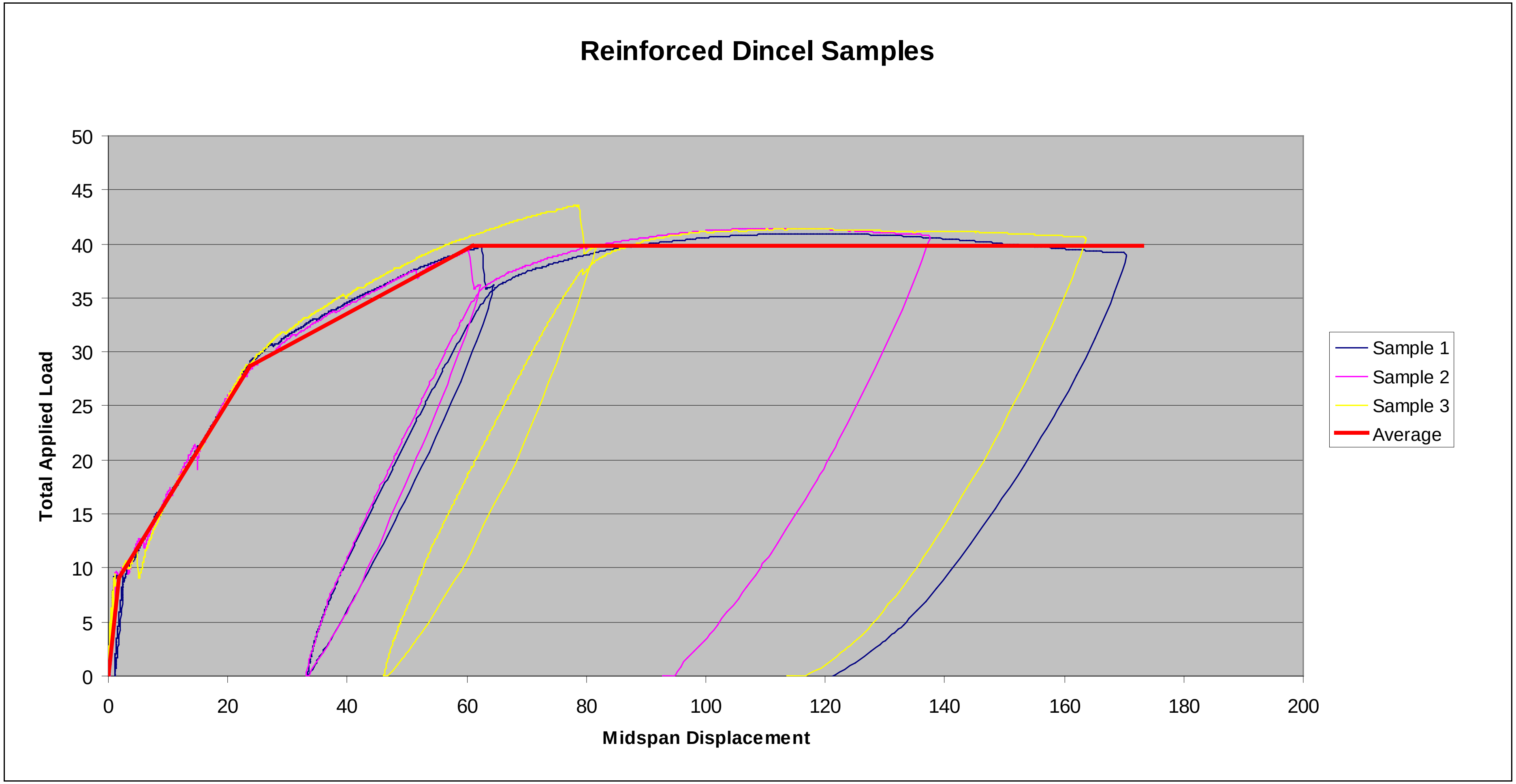


Figure 86 - Total applied load vs midspan deflection comparison between Reinforced Dincel samples with average line

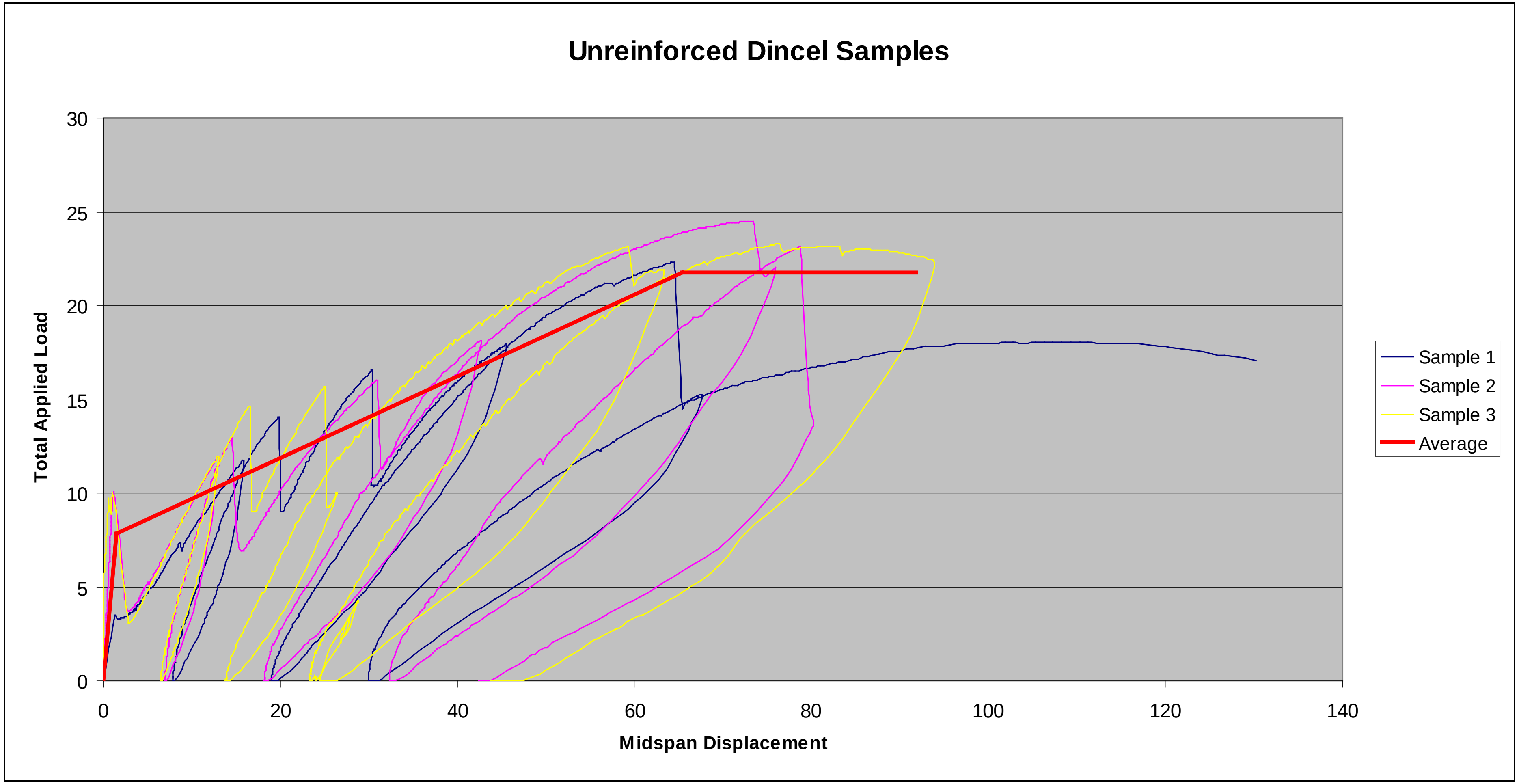


Figure 87 - Total applied load vs midspan deflection comparison between Unreinforced Dincel samples with average line

5.3 Recommendations for further study

- The Dincel samples are already significantly stronger than the Conventional Reinforced Concrete samples after a short curing period. This difference in strength would even be greater if the Dincel samples were allowed to self cure for a longer period of time. Therefore a great opportunity is available to study the curing effect of the Dincel polymer encasing and the further increased compressive and tensile concrete strength this would achieve.

- All reinforced samples in this project used 1N12 reinforcement bar placed with 35mm clear concrete cover from the tension face. Further flexural tests could be done using samples consisting of varying reinforcement and concrete cover.

- All samples were filled with the same strength of concrete in this project. The flexural tests could be expanded further by testing samples consisting of varying concrete strengths.

References

- Warner, R.F., Rangan, B.V., Hall, A.S. 1989, *Reinforced Concrete*, 3rd edn, Longman Cheshire, Hong Kong.

- Hibbeler, R.C 2005, *Mechanics of Materials*, Prentice Hall, Singapore.

- Blockley, D. 2005, *The New Penguin Dictionary of Civil Engineering*, Penguin Group, London.

- Warner, R.F., Foster, S.J., Kilpatrick, A.E. 2007, *Reinforced Concrete Basics*, Prentice Hall, Malaysia.

- Dincel Construction System, Sydney, last viewed 22 March 2010, <http://www.dincelconstructionsystem.com>

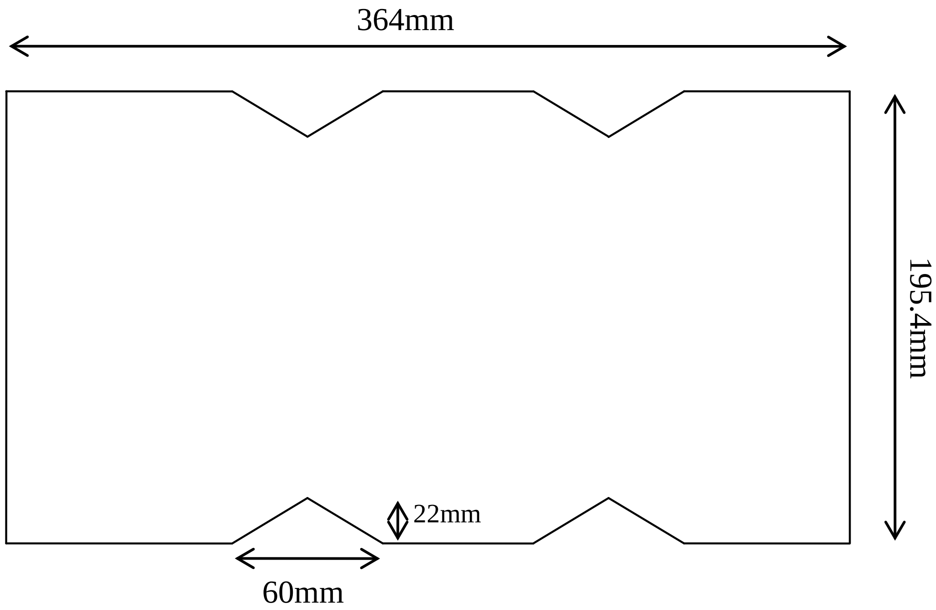
- Standards Australia 2009, *AS 3600 – 2009*, Standards Australia, Sydney

- Engineers Edge 2000, *Structural Beam Bending Equations/Calculation Supported on Both Ends Loaded Two Equal Loads*, viewed 02 July 2010, <http://www.engineersedge.com/beam_bending/beam_bending4.htm>

- Enviropax, *PVC Material Tube Settlers*, viewed 02 July 2010, <http://www.enviropax.com/pvcspec.htm>

Appendix

Analysis of Unreinforced Concrete Block with the same cross-section as the Dincel samples at cracking



Moment of Inertia (I) of rectangular block (including triangles)

$$= \frac{bd^3}{12}$$
$$= \frac{364mm \times 195.4mm^3}{12}$$
$$= 226.30 \times 10^6 mm^4$$

Moment of Inertia (I) of triangular voids

$$= 4 \times \left(\frac{bd^3}{36} + Ad^2 \right)$$
$$= 4 \times \left[\frac{bh^3}{36} + \frac{bh}{2} \times \left(\frac{d}{2} - \frac{h}{3} \right)^2 \right]$$
$$= 4 \times \left[\frac{60mm \times 22mm^3}{36} + \frac{60mm \times 22mm}{2} \times \left(\frac{195.4mm}{2} - \frac{22mm}{3} \right)^2 \right]$$
$$= 21.63 \times 10^6 mm^4$$

Effective Moment of Inertia = I_{eff}

I_{eff} = I of rectangular block – I of triangular voids

$$= 226.30 \times 10^6 mm^4 - 21.63 \times 10^6 mm^4$$
$$= 204.67 \times 10^6 mm^4$$

Calculating Cracking Moment (M_{cr})

$$\sigma = \frac{My}{I}$$
$$M_{cr} = \frac{\sigma \times I}{y}$$
$$f'_{cf} = 0.6\sqrt{fc'}$$
$$= 0.6\sqrt{20}$$
$$= 2.68 Mpa$$
$$M_{cr} = \frac{2.68 Mpa \times 204.67 \times 10^6 mm^4}{\left(\frac{195.4 mm}{2}\right)}$$
$$= 5.61 kNm$$

Self weight of unreinforced concrete block

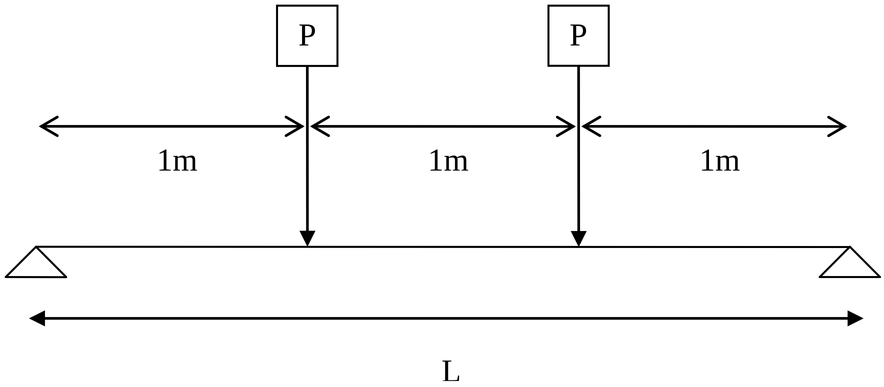
$$= \left[195.4 mm \times 364 mm - 4 \times \frac{(22 mm \times 60 mm)}{2}\right] \times 24 KN/m^3$$
$$= 1.64 kN/m$$

Maximum moment due to self weight (M_{sw})

$$= \frac{wl^2}{8}$$
$$= \frac{1.64 kN/m \times 3m^2}{8}$$
$$= 1.85 kNm$$

Cracking external moment capacity

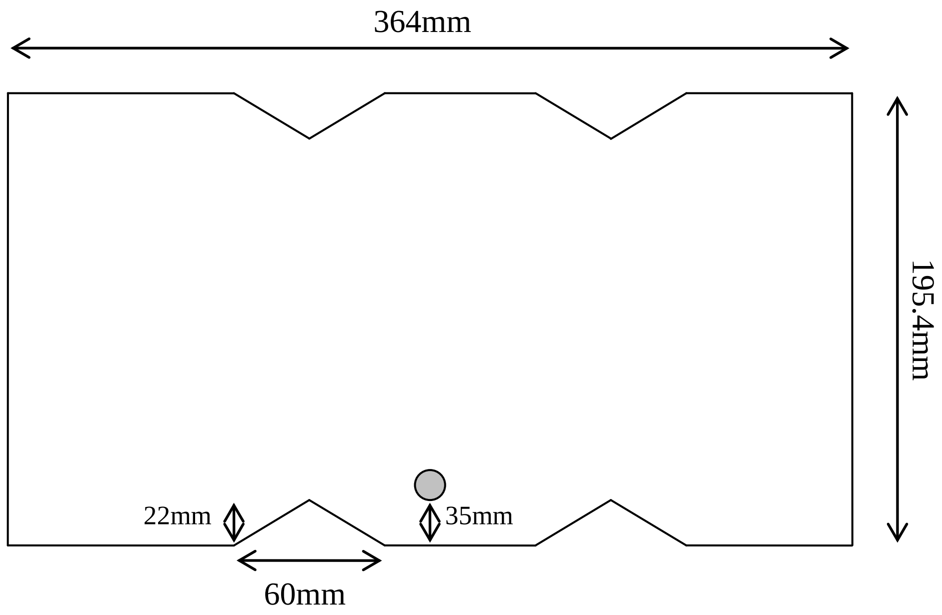
$M = M_{cr} - M_{sw}$
$= 5.61kNm - 1.85kNm$
$= 3.76kNm$



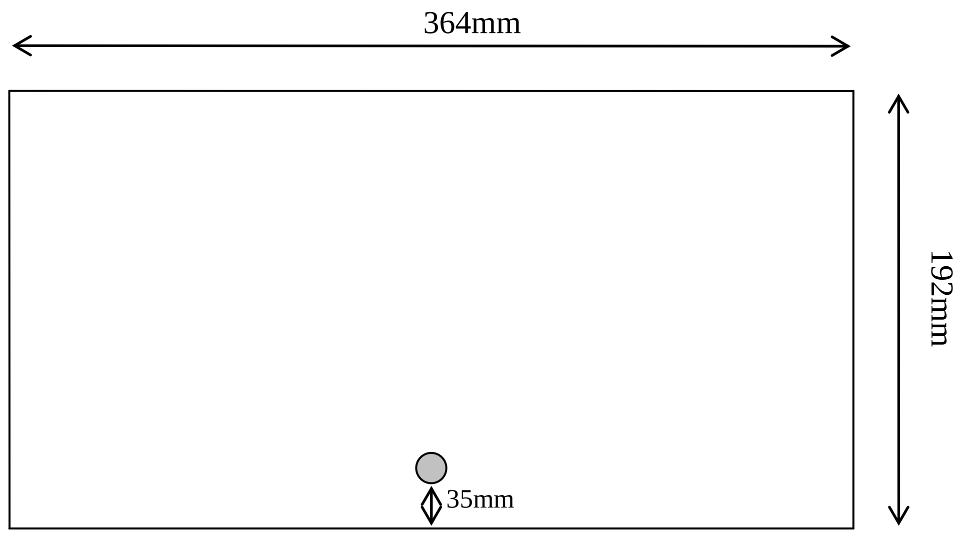
External load capacity

$M = P \times \frac{L}{3}$
$3.76kNm = P(1)$
$P = 3.76kN$
$2P = 7.52kN$

Analysis of Reinforced Concrete Block with the same cross-section as the Dincel samples at ultimate stage



The profile of the Dincel cross-section is not rectangular due to the triangular voids; however it is close to being rectangular. Removing the triangular voids, the equivalent cross-section shown below can be used for analysis. Using this equivalent cross-section for analysis is still very accurate as the area of the triangular voids are very small compared to the entire cross-section



Tensile Steel Force (T)

$$= A_{st} \times f_{sy}$$
$$= 113mm^2 \times 500Mpa$$
$$= 56.5 \times 10^3 N$$

Concrete Compression Force (C)

$$= (\alpha_2 f'_c)(\gamma dn)b$$
$$= (0.85 \times 20)(\gamma dn)364$$
$$= 6188\gamma dn$$

Force equilibrium requires that C-T=0

Therefore, the height of the stress block

$$6188\gamma dn = 56.5 \times 10^3 N$$
$$\gamma dn = \frac{56.5 \times 10^3 N}{6188}$$
$$= 9.13mm$$

Calculating Ultimate Moment (M_u)

$$M_u = T \times z$$
$$z = d - \frac{\gamma dn}{2} = 151mm - \frac{9.13mm}{2} = 146.44mm$$
$$T = 56.5 \times 10^3 N$$
$$M_u = 56.5 \times 10^3 N \times 146.44mm$$
$$= 8.27kNm$$

Self weight of reinforced concrete block

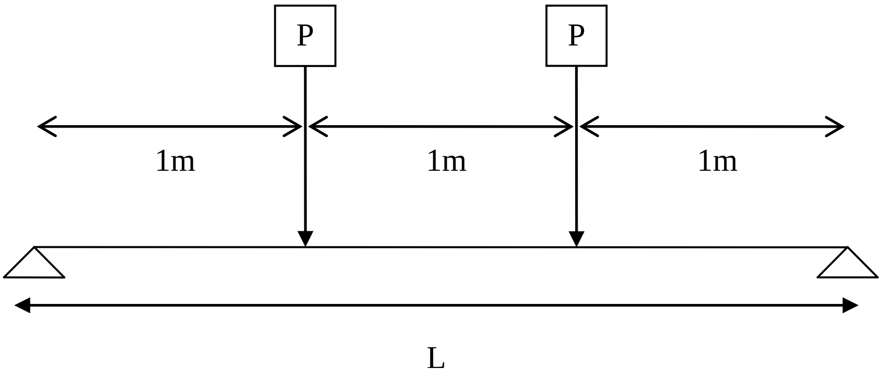
$$= (0.192m \times 0.364m) \times 25kN/m^3$$
$$= 1.75kN/m$$

Maximum moment due to self weight (M_{sw})

$$= \frac{wl^2}{8}$$
$$= \frac{1.75kN/m \times 3m^2}{8}$$
$$= 1.97kNm$$

Ultimate external moment capacity

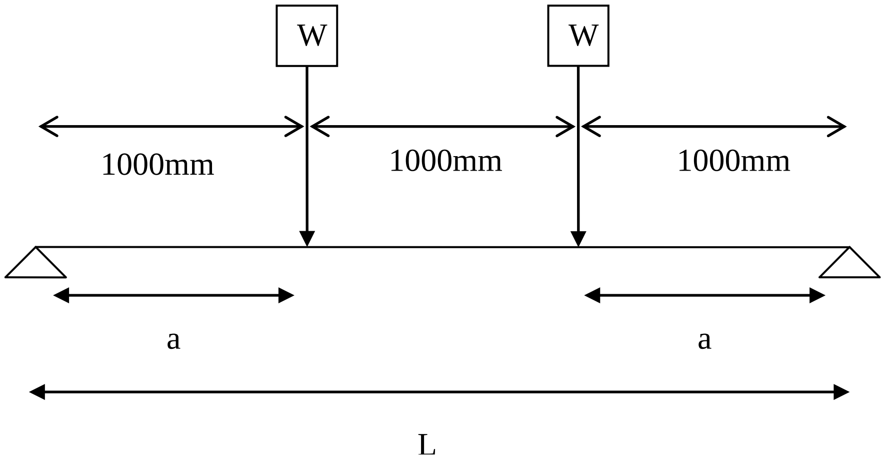
$$M = M_u - M_{sw}$$
$$= 8.27kNm - 1.97kNm$$
$$= 6.30kNm$$



Ultimate external load capacity

$$M = P \times \frac{L}{3}$$
$$6.30kNm = P(1)$$
$$P = 6.30kN$$
$$P \times 2 = 12.60kN$$

Theoretical Midspan Deflection at Cracking Load



Theoretical Cracking Load

$= 7520N = 2P$
$P = 7520/2$
$P = 3760N$

Gross Moment of Inertia of Cross Section

$= 204.67 \times 10^6 mm^4$

Modulus of Elasticity (calculated from Australian Standards)

$= (Density)^{1.5} \times (0.043\sqrt{f_{cm}})$
$= (2400)^{1.5} \times (0.043\sqrt{20Mpa})$
$= 22610Mpa$

Midspan Deflection at Cracking Load (Engineers Edge, 2000)

W = Load (N)

a = Distance between end support and nearest point load (mm)

E = Modulus of Elasticity (Mpa)

I = Moment of Inertia (mm^4)

l = Length between end supports (mm)

$$= \frac{Wa}{24EI}(3l^2 - 4a^2)$$
$$= \frac{3760N \times 1000mm}{24 \times 22610Mpa \times 204.67 \times 10^6 mm^4} \times (3 \times 3000^2 - 4 \times 1000^2)$$
$$= 0.78mm$$

Theoretical Average Pre-Cracking Stiffness of Theoretical Concrete Cross Section

Average Cracking Load

$$= 7520N = 2P$$
$$P = 7520/2$$
$$P = 3760N$$

Midspan Deflection at Cracking Load

$$= 0.78mm$$

Pre-Cracking Stiffness

$$= EI$$
$$= 22610Mpa \times 204.32 \times 10^6 mm^4$$
$$= 4619.68 \times 10^9 Nmm^2$$

Measured Average Pre-Cracking Stiffness of Conventional Reinforced Concrete Samples

Measured Average Cracking Load

$$= 5430N = 2P$$
$$P = 5430/2$$
$$P = 2715N$$

Measured Midspan Deflection at Cracking Load

$$= 2.30mm$$

Measured Cracking Moment of Inertia

$$Deflection = \frac{Wa}{24EI}(3l^2 - 4a^2)$$
$$2.30mm = \frac{2715N \times 1000mm}{24 \times 22610Mpa \times I} \times (3 \times 3000^2 - 4 \times 1000^2)$$
$$I = 50.03 \times 10^6 mm^4$$

Measured Pre-Cracking Stiffness

$$= EI$$
$$= 22610Mpa \times 50.03 \times 10^6 mm^4$$
$$= 1131.18 \times 10^9 Nmm^2$$

Measured Average Pre-Cracking Stiffness of Reinforced Dincel Samples

Measured Average Cracking Load

$$= 9060N = 2P$$
$$P = 9060/2$$
$$P = 4530N$$

Measured Midspan Deflection at Cracking Load

$$= 1.67mm$$

Measured Cracking Moment of Inertia

$$Deflection = \frac{Wa}{24EI}(3l^2 - 4a^2)$$
$$1.67mm = \frac{4530N \times 1000mm}{24 \times 22610Mpa \times I} \times (3 \times 3000^2 - 4 \times 1000^2)$$
$$I = 114.97 \times 10^6 mm^4$$

Measured Pre-Cracking Stiffness

$$= EI$$
$$= 22610Mpa \times 114.97 \times 10^6 mm^4$$
$$= 2599.47 \times 10^9 Nmm^2$$

Measured Average Pre-Cracking Stiffness of Unreinforced Samples

Measured Average Cracking Load

$= 7810N = 2P$
$P = 7810/2$
$P = 3905N$

Measured Midspan Deflection at Cracking Load

$= 1.44mm$

Measured Cracking Moment of Inertia

$$Deflection = \frac{Wa}{24EI}(3l^2 - 4a^2)$$
$$1.44mm = \frac{3905N \times 1000mm}{24 \times 22610Mpa \times I} \times (3 \times 3000^2 - 4 \times 1000^2)$$
$$I = 114.94 \times 10^6 mm^4$$

Measured Pre-Cracking Stiffness

$= EI$
$= 22610Mpa \times 114.94 \times 10^6 mm^4$
$= 2598.79 \times 10^9 Nmm^2$

Measured Average Post-Cracking Stiffness of Conventional Reinforced Concrete Samples at Ultimate

Measured Average Ultimate Load

$$= 16300N = 2P$$
$$P = 16300/2$$
$$P = 8150N$$

Measured Midspan Deflection at Ultimate Load

$$= 23.8mm$$

Measured Effective Moment of Inertia

$$Deflection = \frac{Wa}{24EI}(3l^2 - 4a^2)$$
$$23.80mm = \frac{8150N \times 1000mm}{24 \times 22610Mpa \times I} \times (3 \times 3000^2 - 4 \times 1000^2)$$
$$I = 14.51 \times 10^6 mm^4$$

Measured Stiffness

$$= EI$$
$$= 22610Mpa \times 14.51 \times 10^6 mm^4$$
$$= 328.08 \times 10^9 Nmm^2$$

Measured Average Post-Cracking Stiffness of Reinforced Dincel Samples at Ultimate

Measured Average Ultimate Load

$$= 39870N = 2P$$
$$P = 39870/2$$
$$P = 19940N$$

Measured Midspan Deflection at Ultimate Load

$$= 61.05mm$$

Measured Effective Moment of Inertia

$$Deflection = \frac{Wa}{24EI}(3l^2 - 4a^2)$$
$$61.05mm = \frac{19940N \times 1000mm}{24 \times 22610Mpa \times I} \times (3 \times 3000^2 - 4 \times 1000^2)$$
$$I = 13.84 \times 10^6 mm^4$$

Measured Stiffness

$$= EI$$
$$= 22610Mpa \times 13.84 \times 10^6 mm^4$$
$$= 312.92 \times 10^9 Nmm^2$$

Measured Average Post-Cracking Stiffness of Unreinforced Dincel Samples at Ultimate

Measured Average Ultimate Load

$$= 21800N = 2P$$
$$P = 21800 / 2$$
$$P = 10900N$$

Measured Midspan Deflection at Ultimate Load

$$= 65.3mm$$

Measured Effective Moment of Inertia

$$Deflection = \frac{Wa}{24EI}(3l^2 - 4a^2)$$
$$65.30mm = \frac{10900N \times 1000mm}{24 \times 22610Mpa \times I} \times (3 \times 3000^2 - 4 \times 1000^2)$$
$$I = 7.08 \times 10^6 mm^4$$

Measured Stiffness

$$= EI$$
$$= 22610Mpa \times 7.08 \times 10^6 mm^4$$
$$= 160.08 \times 10^9 Nmm^2$$

Composite Strength of Reinforced and Unreinforced Dincel Wall

- Assume compression to top PVC skin is negligible with concrete taking the entire compression load. As the PVC skin is very thin, it is assumed that the top PVC skin will buckle under compression.
- Assume bottom of PVC skin acts as tensile reinforcement.
- Entire Cross Sectional area of PVC profile is approximately 2640mm^2. Area of PVC used for calculation is therefore 2640/2 = 1320mm^2.
- Tensile strength of PVC taken as 6100psi which is equal to 42Mpa. (Enviropax)

Composite Strength of Unreinforced Dincel Wall

Tensile Force

$$= A_{pvc} \times f_{upvc}$$
$$= 1320mm^2 \times 42Mpa$$
$$= 55440N$$

Force Equilibrium requires that Compression = Tension

Therefore, the height of the stress block:

$$= 0.85 f_c \times b \times a = A_{pvc} \times f_{upvc}$$
$$a = \frac{A_{pvc} \times f_{upvc}}{0.85 f_c \times b}$$
$$a = \frac{1320mm^2 \times 42Mpa}{0.85 \times 20Mpa \times 364mm}$$
$$a = 8.96mm$$

Calculating Ultimate Moment (M_u)

$$= T_{upvc} \times (d - \frac{a}{2} + \frac{2.3mm}{2})$$
$$= 55440N \times (195.4mm - \frac{8.96mm}{2} + \frac{2.3mm}{2})$$
$$= 10.65kNm$$

Maximum Moment due to self weight (M_{sw})

$$= 1.85 kNm$$

Ultimate External Moment Capacity

$$M = M_u - M_{sw}$$
$$= 10.65 kNm - 1.85 kNm$$
$$= 8.80 kNm$$

Ultimate External Load Capacity

$$M = P \times \frac{L}{3}$$
$$8.80 kNm = P(1)$$
$$P = 8.80 kN$$
$$P \times 2 = 17.60 kN$$

Composite Strength of Reinforced Dincel Wall

Tensile Steel Force

$$= A_s \times f_{sy}$$

Tensile PVC Force

$$= A_{pvc} \times f_{upvc}$$

Force Equilibrium requires that Compression = Tension

Therefore, the height of the stress block:

$$= 0.85 f_c \times b \times a = A_{pvc} \times f_{upvc} + A_s \times f_{sy}$$
$$a = \frac{A_{pvc} \times f_{upvc} + A_s \times f_{sy}}{0.85 f_c \times b}$$
$$a = \frac{1320 mm^2 \times 42 Mpa + 500 Mpa \times 113 mm^2}{0.85 \times 20 Mpa \times 364 mm}$$
$$a = 18.09 mm$$

Calculating Ultimate Moment (M_u)

$$= T_{upvc} \times (d - \frac{a}{2} + \frac{2.3mm}{2}) + A_s \times f_{sy}(dn - \frac{a}{2})$$
$$= 55440N \times (195.4mm - \frac{18.09mm}{2} + \frac{2.3mm}{2}) + 113mm^2 \times 500Mpa(154.4 - \frac{18.09}{2})$$
$$= 18.61kNm$$

Maximum Moment due to self weight (M_{sw})

$$= 1.85kNm$$

Ultimate External Moment Capacity

$$M = M_u - M_{sw}$$
$$= 18.61kNm - 1.85kNm$$
$$= 16.76kNm$$

Ultimate External Load Capacity

$$M = PL$$
$$16.76kNm = P(1)$$
$$P = 16.76kN$$
$$P \times 2 = 33.52kN$$