Failure Load Prediction for Dapped-End Beam

By

Mohd Imran Bin Nasir Khan

15180

Dissertation submitted in partial fulfillment of

the requirements for the

Bachelor of Engineering (Hons)

(Civil)

MAY 2014

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CERTIFICATION OF APPROVAL

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Approved by,

____

(DR ZUBAIR IMAM SYED)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

May 2014

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MOHD IMRAN BIN NASIR KHAN

ABSTRACT

Dapped-end beams are members of precast concrete structures that widely used nowadays in construction industry, especially in buildings and bridges due to its good lateral stability. The design analysis of dapped-end connections is complex and the re-entrant corner is identified as the weakest point because stress concentration develops in that area, which also known as disturbed regions. The accuracy of different codes and approaches in predicting failure load is yet to be fully explored. Therefore, investigation of the relative performance of different methods in predicting failure load capacity is crucial to be done. Besides, the incident of collapsed of Concorde Bridge has risen up many researchers' attention and interest to conduct deeper research on design and strengthening of dapped-end connections to determine the load capacity for future design work purposes. Thus, this research project intended to determine the failure load of the dapped-end beams by using two-dimensional non-linear finite element analysis (FEA) software called Vector2 and also using PCI design approach. The results from the Vector2 and also from PCI design approach will be used to compare with the load capacity obtained experimentally by Wang et al (2005) in their experimental research project as validation to determine which code or method is providing better accuracy in determining the failure load capacity. The analysis result obtained from FEA software and PCI Design Handbook is 47.6kN and 36.7kN, which is quite near compared to the experimental value, 42.24kN. Parametric study conducted to determine the sensitivity of different dapped-end parameters on the failure load capacity. As a conclusion, it is proven that the FEA software can be used to predict the failure load capacity accurately and can be used for parametric study.

ACKNOWLEDGEMENT

First and Foremost, I am grateful to Allah S.W.T. for the blessing and His will that I am able to complete my final year project successfully and managed to come up with this report.

I take this opportunity to express my thankfulness to the people who have been helpful in the successful completion of this report. I would like to show my greatest appreciation to my beloved supervisor, Dr Zubair Imam Syed for his guidance, encouragement and support throughout the final year project period. I can't say thank you enough for his great support and help.

Not to forget, Mr. Mohd Aswin (Postgraduate student of Civil Engineering Department) that guided me personally in completing the project. Thanks for all the assistance, knowledge and experience shared throughout the project period.

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INTRODUCTION

1.1 Background of Study

Precast concrete structures are widely used nowadays in the construction industry as it capable to shorten the construction methodologies. Besides, it able to reduce project completion time, decrease amount of site labour, produce very minimal wastage and most importantly, provide better quality control to reduce the construction fault since production take place in factory under sheltered condition. Precast concrete structure elements can be pre-stressed to increase the effectiveness by extending the span to longer distances and carry higher loads compared to those reinforced with steel bar only. In the meantime, usages of precast concrete structure can contribute to reduction of floor height, where the minimum headroom clearance requirement is not affected when deeper beam is used. In point of fact, precast concrete structure is actually an assembly of single members with different types of connections that often used in buildings and bridges including dapped-end. A dapped-end is formed when the bearing is moved at a higher location in the cross-section due to the web of a beam is notched at the bottom corner. The bottom part of the beam is known as dap and the above part is called nib.

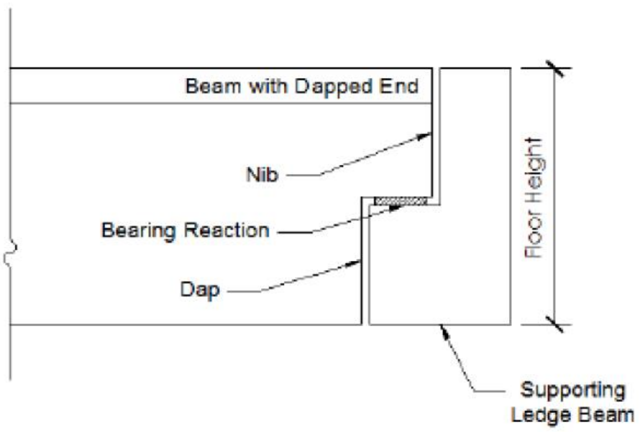


Figure 1: Beam with Dapped-End

The sudden reduction of cross section of dapped-end beams caused the complex flow of internal stresses (Daescu et al., 2013). In other word, the re-entrant corner of dapped-end beam is identified as where the stress concentration grows and that particular region is also recognized as disturbed regions (Ahmad et al., 2013). Therefore, the design and detailing of the dapped-end beam must consider the stress concentration that grows in that particular region to avoid the development of diagonal tension crack which then will lead to failure.

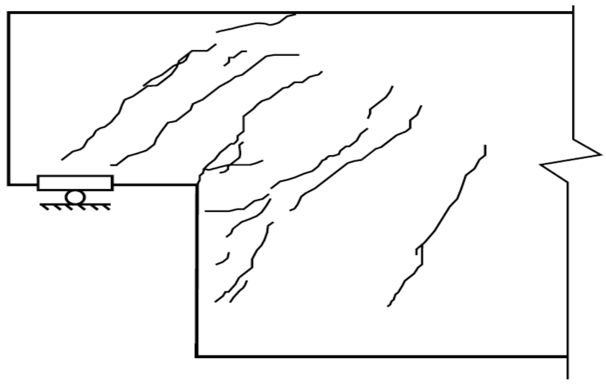


Figure 2: Typical cracking approaching failure of a reinforced dapped-end beam (Mattock, 2012)

Deep and thorough researches have been performed by many top researchers since from the year 1969 to provide the best method to design and strengthen dapped-end beams. There are various design codes available such as the Pre-stressed Concrete Institute (PCI Design Handbook), American Concrete Institute (ACI 318-08) and British Standard (BS 8110 and BS-EN1992-1-1:2004) that can be used to design dapped-end beams. However, PCI design handbook is identified as the most preferable design code to be used in the precast concrete industry. Meanwhile, for strengthening aspect, researchers have done a quite number of experimental research to increase the strength of dapped-end beam externally as well as internally by using various techniques, including using fiber reinforced polymer (FRP), steel fibers contribution and many more.

Thus, this study aimed to predict the failure load and study the structural behaviour of dapped-end beams using Finite Element modelling software called Vector2 simultaneously using PCI design handbook. The analysis results obtained from both methods are compared with the failure load obtained from experimental results that has been done by previous researchers. This research project will yield whether Finite Element modelling able to match the results obtained from PCI design handbook or other relevant codes.

1.2 Problem Statement

Precast concrete had turn out to be a famous construction method around the world due to its advantages during the construction. However, the design of precast concrete member is very complex compared to normal reinforced concrete member. The ultimate reason is because of the unusual change of cross section of the member like dapped-end that caused complex flow of internal stresses at the disturbed region or at the re-entrant corner of the beam. Diagonal tension crack will develops when the design and reinforcement detailing of dapped-end beam is not proper or inaccurate. Furthermore, dapped-ends are frequently subjected to high bearing reactions and also pre-stressing strands that presence below the nib. Various design codes like PCI, ACI and British Standard can be used to design this kind of beam but the accuracy of different codes and approaches in predicting failure load is yet to be fully explored. There is still a barrier in determining which codes are providing the best method to predict the failure load capacity of dapped-end beam. Therefore, investigation of the relative performance of different methods in predicting failure load capacity is crucial to be done.

Moreover, the incident of the Concorde Bridge collapsed (south half portion) in Laval, Quebec on September 30, 2006 that caused death of five people and six people injured has raised up many researchers attention or interest on the design fault of dapped-end precast concrete members.

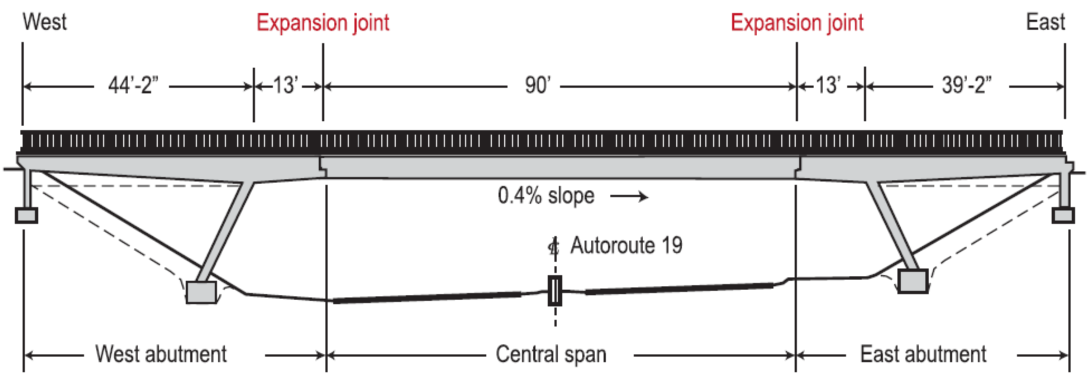


Figure 3: Elevation view of Concorde Bridge with geometry (Mitchell et al., 2011).

Figure 4: Bird's eye view of collapse of south portion of Concorde Bridge (Johnson et al., 2007)

The root cause of failure of the bridge under its self-weight after 36 years of service are because of insufficient shear strength (no stirrups), improper detailing of the disturbed region and improper anchorage of the large diameter top reinforcement (Mitchell et al., 2011). This collapse also urged comprehensive investigations of other bridges of a similar age. Therefore research and experimental studies of the dapped-end connection especially for beams are crucial to be conducted for further understanding and to provide solution whenever issue involving this kind of structure arise.

1.3 Objectives and Scope of Study

1.3.1 Objectives

The objectives of this project are listed as follows:

- To predict the **failure load** of dapped-end beams by using two dimensional non-linear finite element analysis (FEA) software and PCI Design Handbook.
- To perform **parametric study** to determine the sensitivity of different dapped-end beam parameters.

1.3.2 Scope of study

The scope of this research project focus only on the reinforced concrete design of dapped-end beam. The design works comprising failure load prediction of the beam by using Non-linear Finite Element Method (FEM) analysis software named Vector2 and also using PCI design approach. The analysis results obtained from both FEM and PCI are compared with the failure load obtained from the experimental results that has been done by previous researchers. In general, this research project intended to determine which design code or method is predicting better failure load capacity of the dapped-end beams. Parametric study also conducted to study or determines the sensitivity of different dapped-end parameters on the failure load capacity.

1.4 Relevancy of the Project

The purpose behind the idea is to identify the problems that rise up from the beginning until the project completed and discover solution on how to overcome it. The assessment of dapped-end beams behavior requires tool that can be used to analyze and design structural element that will improve the state of the art of protective design.

1.5 Feasibility of the Project

As stated in the scope of study, this research project focus on reinforced concrete design work which comprising failure load prediction of the beam by using Non-linear Finite Element Method (FEM) analysis software, Vector2 and also using PCI design approach. Parametric study also involved in this project to study the effects of different dapped-end beam parameters on the failure load capacity. Basically, this research project has been conducted smoothly in accordance to the plan (as shown in the Gantt chart). It can be concluded that this project is feasible and the proposed project works are achievable within 28 weeks of timeline.

CHAPTER 2

LITERATURE REVIEW

2.1 Dapped-End Beams

Precast concrete structure is an assembly of single members with different types of connections that often used in buildings and bridges including dapped-end. The concept of dapped-end is widely used in bridges or buildings because of its feasibility to offer better lateral stability and can contribute to reduction of floor-to-floor height, where the minimum headroom clearance requirement is not affected when deeper beam is used. Several typical applications of dapped ended beams (as shown in the figure below) are including a cantilever and suspended span type of structure, as a drop-in beam between corbels, and as a hide-away type of beam-to-beam and beam-to-column connection.

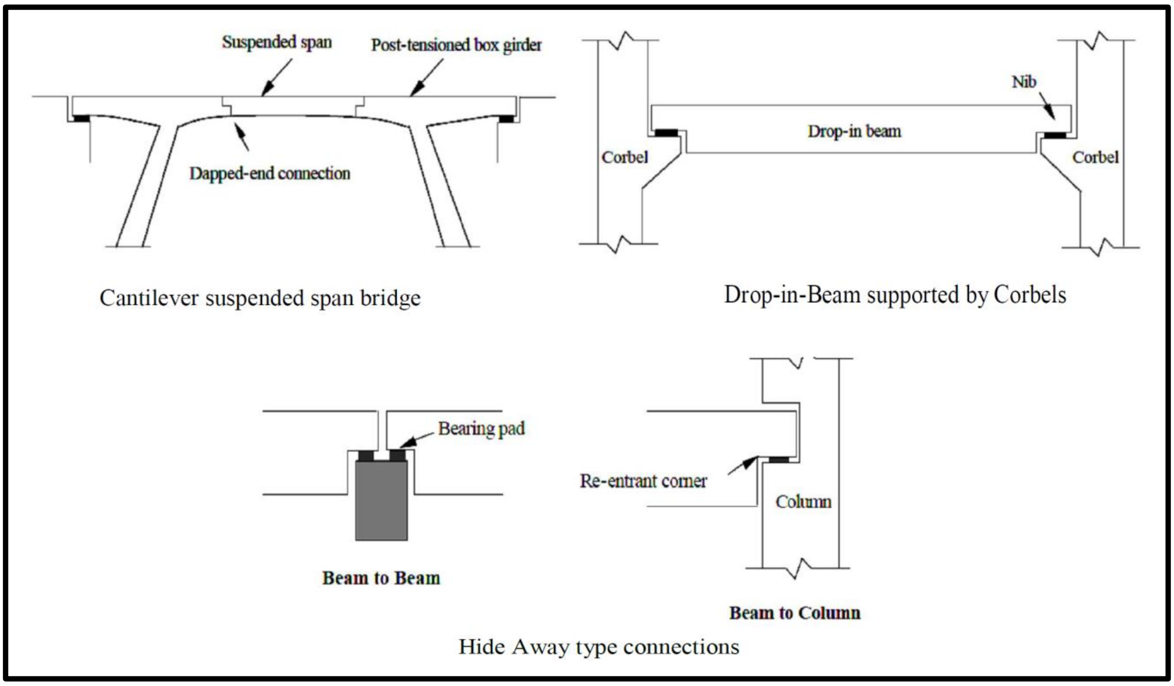


Figure 5: Several applications of dapped-end beams in precast structures (Ahmad et al, 2013).

It is very crucial to include the design of dapped-end connections in a precast structure but the analysis of connections is very complex. The abrupt changes in cross section of dapped-end beams caused the complex flow of internal stresses at the re-entrant corner of the beam which also recognized as disturbed region by researchers. In addition, Huang and Nanni (2006) believe that dapped-ends are also delicate to horizontal tension forces arising from restraint of shrinkage or creep shortening of the precast concrete member beside the calculated forces from external loads. Hence, the design and detailing of the dapped-end beam must consider the stress concentration that grows in that particular region to avoid the development of diagonal tension crack and failure. There are five potential failures of dapped-end connection that have been proposed in PCI Design Handbook (1999) that need to be studied separately as shown in the figure 2.2 below.

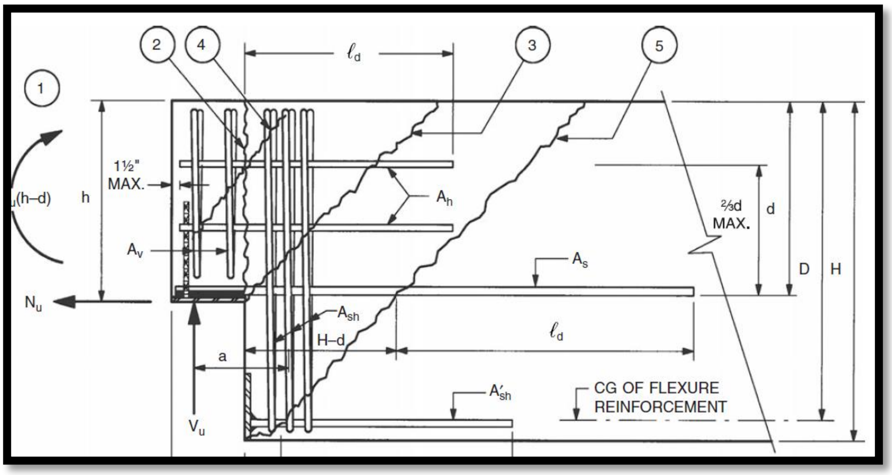


Figure 6: Potential failure modes in dapped-end connections (Huang and Nanni 2006; PCI Design Handbook 1999).

The five potential failures as displayed above are:

(1) Flexure and axial tension failure in the extended end triggered by the nib's flexure crack.

(2) Direct shear failure caused by direct shear crack.

(3) Diagonal tension failure caused by the re-entrant corner crack.

(4) Diagonal tension failure in the extended end caused by the nib's inclined crack.

(5) Anchorage of reinforcement which is the concern of the diagonal tension crack.

Moreover, Mattock and Chan (1979) stressed that all the potential failure modes must be investigated if design of connections which are dapped into the end of the member greater than 0.2 times the height (H) of the member.

2.2 Dapped-End Beams Design Works By Previous Researchers.

Historically, there are many detailing and analytical methods have been used to design dapped-end members, but Reynold is the one that started first with the design works in year 1969 where he developed proper reinforcement details for dapped-end beams. In his paper, Reynold concluded with suggestion in detailing guideline of dapped-end members. The suggestions given by him are including, horizontal stirrups must be included to perform against axial tension, tension reinforcement have to be extended to the end of the beam to provide anchorage for stirrups and joints can be designed based on equilibrium.

In year 1970, Sargious and Tadros brought up the design works of dapped-end beam to further level by using Finite Element Method (FEM) analysis to determine the behavior and strength of dapped-end beams. They managed to propose several arrangements of pre-stressed cable profiles but unfortunately there is no experimental validation. FEM is then used by Werner and Dilger (1973) to determine the first cracking shear at the disturbed region and concrete contribution to cracking shear. Werner and Dilger concluded that "cracking shear at re-entrant corner is in agreement with FEM using concrete tensile strength $6\sqrt{f_c'}; 4\sqrt{f_c'}$ for practical design".

Another interesting design approach of dapped-end beams is corbel design concept. This concept is developed and applied by Mattock and Chan (1979) where the reduced depth of dapped-end is designed as corbel. However, they believe that the concept only could be possible if length of shear span "a" is measured to the center gravity of the hanger reinforcement. Several simple guidelines for detailing of main reinforcement and shear reinforcement at the re-entrant end of beam are proposed by them. One of the guidelines including, utilizing horizontal stirrups only in the nib if beams with a/d ratio less or equal to one, which actually was verified and supported by Khan (1981) through the results obtained in his research paper.

Beside FEM analysis, the behavior of a dapped-end member can also be modeled by using an analogous truss (Mattock and Theryo, 1986). Based on analogous truss method, Mattock and Theryo concluded that there is increase in shear resistance because of efficiency of vertical and inclined hanger reinforcement. In addition, the cracking at service also effectively controlled using the inclined hanger reinforcement but however a minimum of 1.0 inch thick bottom concrete cover must be provided instead of 0.75 inch. The analogous truss now is known as strut-and-tie method.

Strut-and-Tie Model (STM) for dapped end beam is the most famous method currently. It is started first by Barton (1988) where he detailed dapped-end beams using this method. Besides, STM also can be used to determine or estimate the failure load of dapped-end beams (So, 1989). Meanwhile, Mattock (2012) carried this method to model the behavior of dapped-end beams and initially the results supposed to contribute to more efficient reinforcement selection and narrower service-load cracks in the resulting member. Nevertheless, after testing 16 dapped-end beams that subjected to combined vertical and horizontal reactions, Mattock found out that his STM models are overestimating the amount of reinforcement needed. Similar results obtained by Barton back in year 1988, his STM model are being conservative in providing the anchorage requirements. Subsequently, a new STM model for the dapped-end beams is proposed, which is more simplified than previous models and this model " nearly corresponds to the flow of forces observed in dapped-end and requires a smaller amount of reinforcement" (Mattock, 2012).

Modeling and determining failure load capacity of dapped-end beams by using Finite Element Method (FEM) undeniably beneficial and this again proven when Daescu et al (2013) used FEM analysis to perform his research on "Assessment of the strengthening effectiveness of EBR and NSM techniques for beams' dapped-end". The FEM analysis is used to determine the ultimate capacities and failure modes involved for 17 different models with different configurations. Generally, there was an increase in the load bearing capacity when all the strengthening system is analyzed.

The main significance of this research is to predict the failure load of dapped-end beams by using Finite Element Method (FEM) and PCI Design Handbook. The literature review on the design works of dapped-end beams demonstrates that FEM analysis is a reliable and effective method in determining the behavior and failure load of dapped-end beams. Therefore, FEM and PCI design approach will be used to design dapped-end beams and the load calculated from both methods will be compared with the failure load obtained from the experimental results that has been done by previous researchers. Ultimately, this research project will directly reveal which design code or method are predicting better failure load capacity of dapped-end beams.

CHAPTER 3

METHODOLOGY

3.1 Project Methodology

The project methodology is scheduled and planned scientifically to ensure the whole activities performed efficiently.

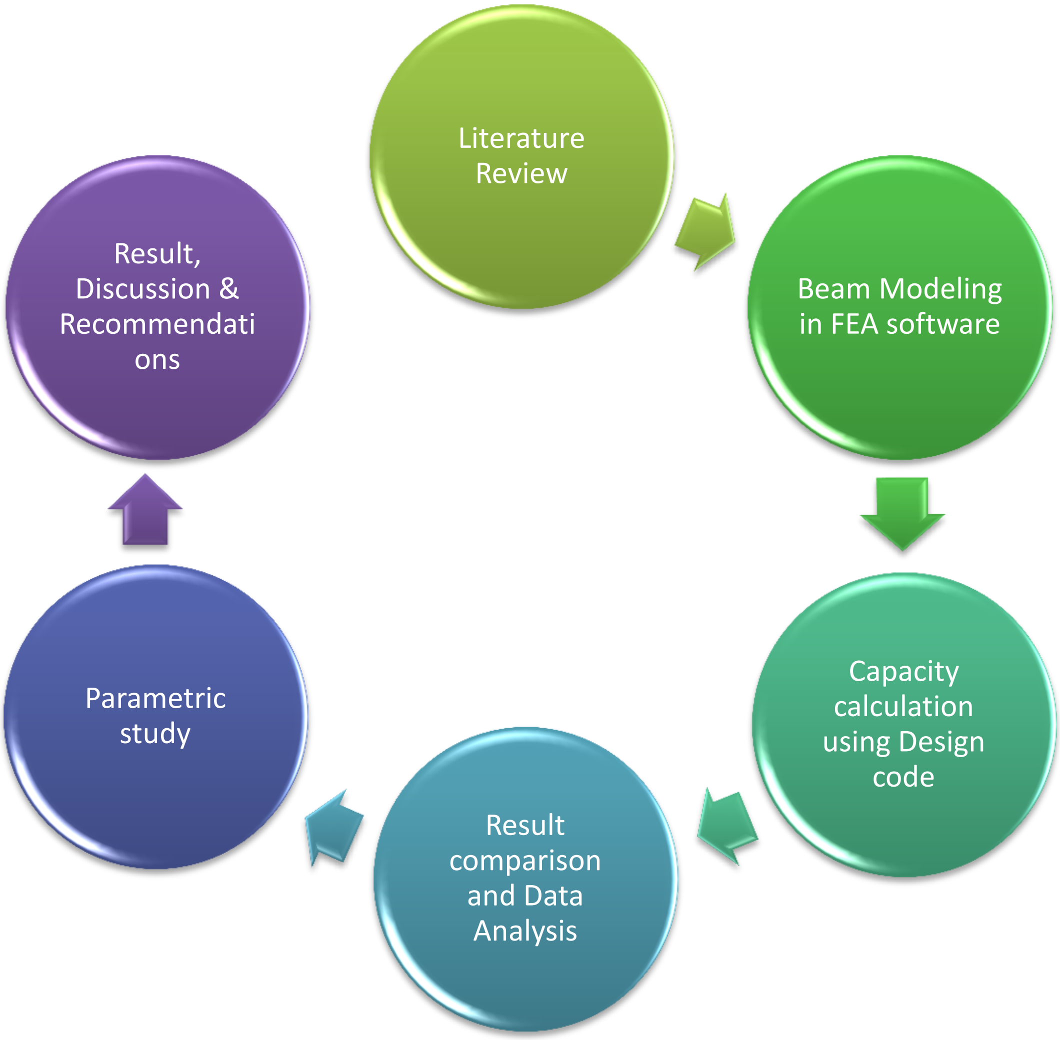


Figure 7: Project's Process Flow

3.1.1 Literature Review

Thorough research work about dapped-end beams is done in this part. Journals of previous work done by others on dapped-end beams are studied intensely to gain the knowledge and ideas to develop and execute this project. Some of the experimental data from the journals like load capacity are taken and used in results comparing section.

3.1.2 Beam Modeling in FEA (Finite Element Analysis) Software

Dapped-end beams are modeled in this section by using analysis software called Vector2. Vector2 is a non-linear finite element analysis program for the analysis of two-dimensional reinforced concrete membrane structures. It is very important to learn the way to operate this software first before proceeding with dapped-end beam modeling. Helps from tutorial book and from Mr.Aswin (Co-supervisor) are used as guidance to familiarize with the software in order to model the beam and come up with the full results. The details including dimension of the modeled dapped-end beam is taken from and is based on beam specimen B1.12 that tested experimentally by Wang et al. (2005).

3.1.3 Capacity Calculation Using Design Code

After the modeling of Dapped-end beam using FEA software is done, the failure load capacity of the same beam is then calculated manually using PCI Design Handbook. However, the design procedure or the failure load capacity calculation of that particular beam are quite complex. Therefore, guidance from supervisor (Dr.Zubair) and co-supervisor (Mr.Aswin) are used in order to complete the work.

3.1.4 Result Comparison and Data Analysis

The data (failure load capacity) obtained from both the FEA (Finite Element Analysis) modeling and PCI design approach are compared with the experimental data that obtained by Wang et al. (2005). After that, the accuracy of each methods used in predicting failure load capacity of dapped-end beams is determined.

3.1.5 Parametric Study

This section focus on analyzing parameters to determine the sensitivity of different dapped-end beam parameters on the failure load capacity. There are total three main parameters are studied in this project which include concrete strength, diameter of reinforcement bar, and finally the location of external load applied. These parameters are analyzed and studied carefully to study their effects on the failure load capacity.

3.1.6 Result, Discussion and Recommendations

All the data acquired will be compiled and presented properly. The results are discussed comprehensively to determine which design code or methods are predicting better failure load capacity for dapped-end beams. The parametric study that has been carried out is also discussed further in this section. Finally, some recommendations are proposed to improve the research study on dapped-end beam or any other relevant precast concrete member in future.

3.2 FEA Software (Vector2)

Vector2 is a nonlinear finite element program for the analysis of two-dimensional reinforced concrete membrane structures. This program has been developed at University of Toronto since year 1990 by researchers studying reinforced concrete behavior and applications of the finite element method over the last two decades. This software is used to analyze the concrete structures under various types of loads such as static, cyclic and thermal loads and the program is based on Modified Compression Field Theory formulations (Vecchio and Collins, 1986) and the Disturbed Stress Field Model (Vecchio, 2000). Vector2 consist of two subprogram called FormWorks and Augustus.

FormWorks is a pre-processor for Vector2 that generates input files. The role is to provide a user interface for generating, visualizing and checking the finite element model. Whereas, Augustus is a postprocessor for Vector2 where it provides graphical post-processing capabilities for the analysis results.

However, Vector2 is complex software, thus it is very important to learn the way to operate this software first before proceeding with dapped-end beam modeling. Below are the steps on how to model the dapped-end beam.

Procedures to model dapped-end beam in Vector2:

a) After create new workspace, the first step will be define the **Job Data**. All the necessary data are inserted as below.

- Monotonic type loading selected with initial factor of zero, final factor is 30 and the increment factor is 0.25

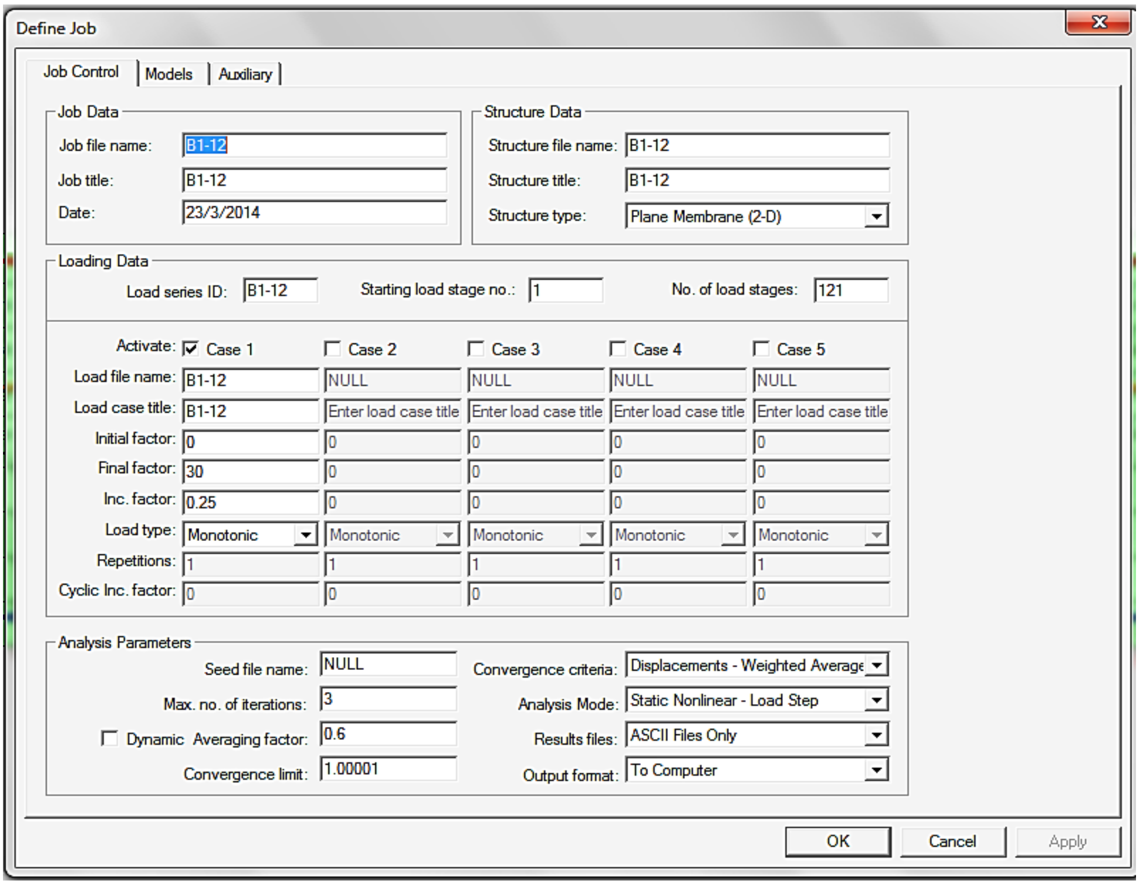


Figure 8: Job Control dialog box

After that, the **Models** page selected to choose the concrete models, reinforcement models, bond models and analysis models.

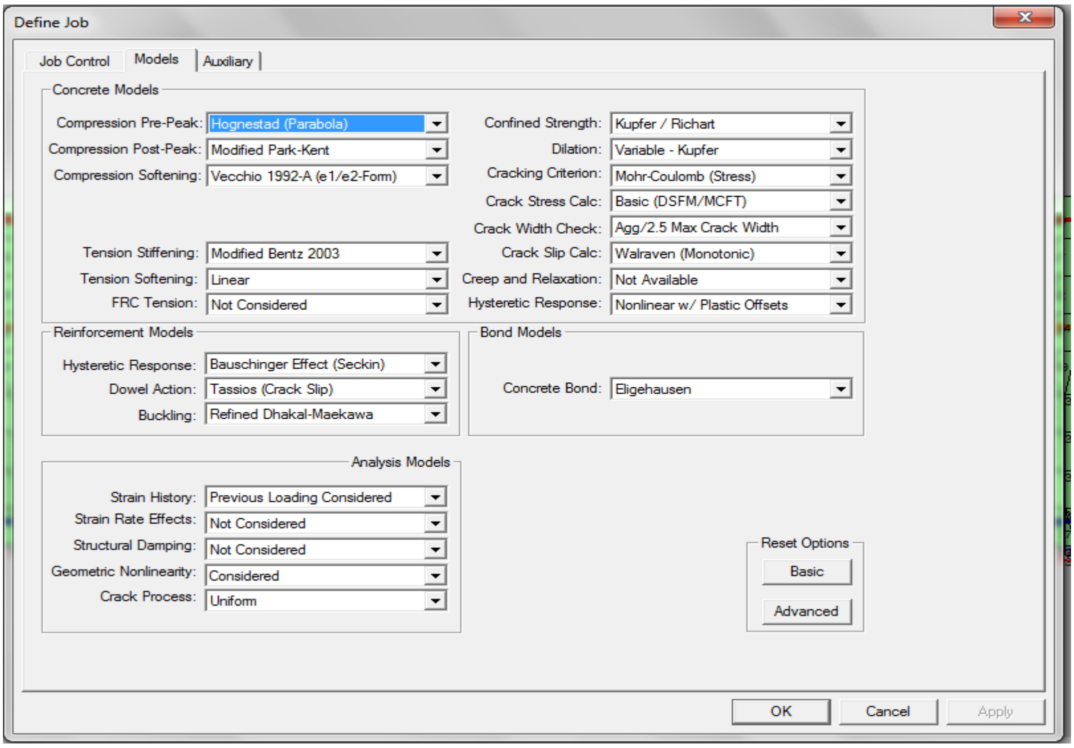


Figure 9: Models dialog box

b) Next, define **reinforced concrete properties**.

- Two types of different concrete properties have been defined. **Concrete 1** is for the dapped-end beam itself and **Concrete 2** is for the plate-like small concrete to transfer load from the support and also external load.
- All concrete properties are inserted as below.

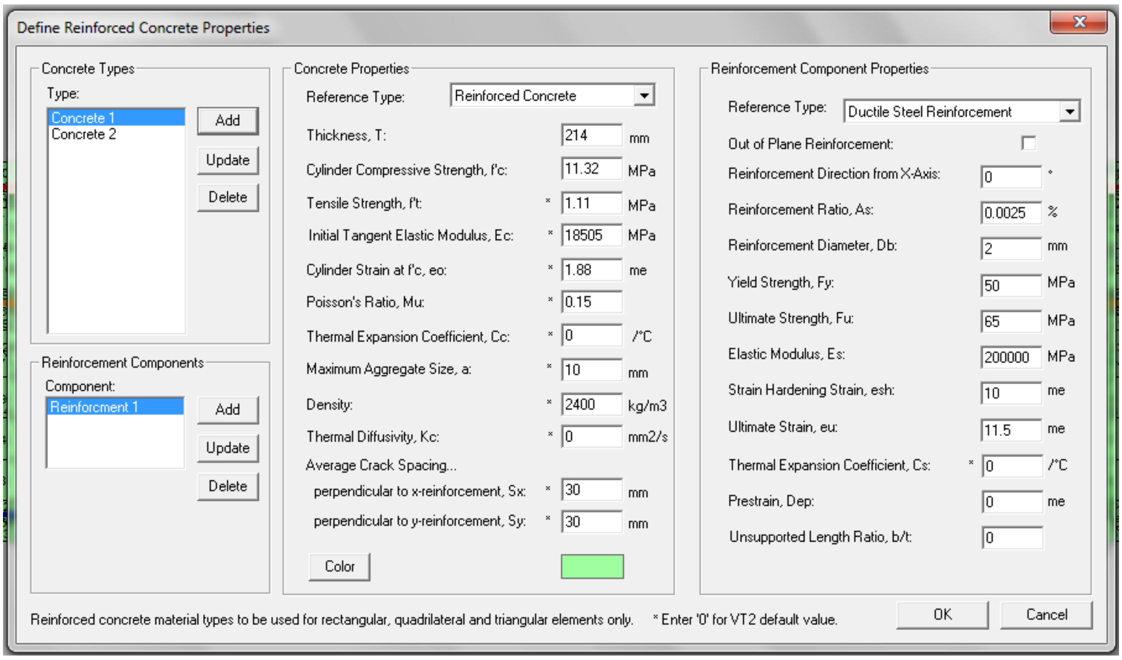


Figure 10: Define Reinforced Concrete Properties dialog box

c) Define **reinforcement properties**

- Reinforcement materials types describe steel or FRP reinforcement materials for truss bar elements.
- Total six different type of reinforcement are defined for the dapped-end beam. All differentiated by the color.
- All the necessary data are inserted as below.

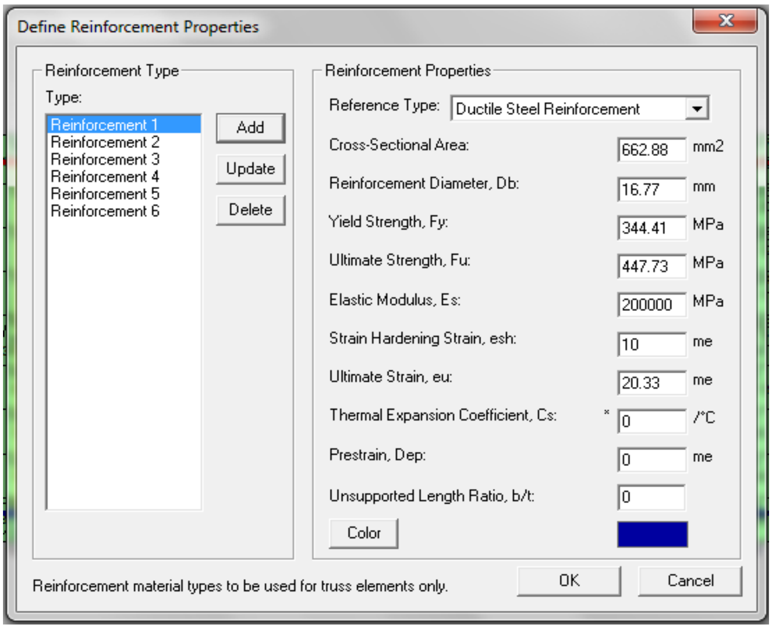


Figure 11: Define Reinforced Properties dialog box

d) **Define** and **Mesh Structure**

- This section is where the beam region, support region and reinforcement region are made.
- Then, the line and point constraints are added for each line and necessary points.
- The final step in this section will be define mesh size and create mesh as shown in the Figure 16.
- All data are inserted as shown in figures below.

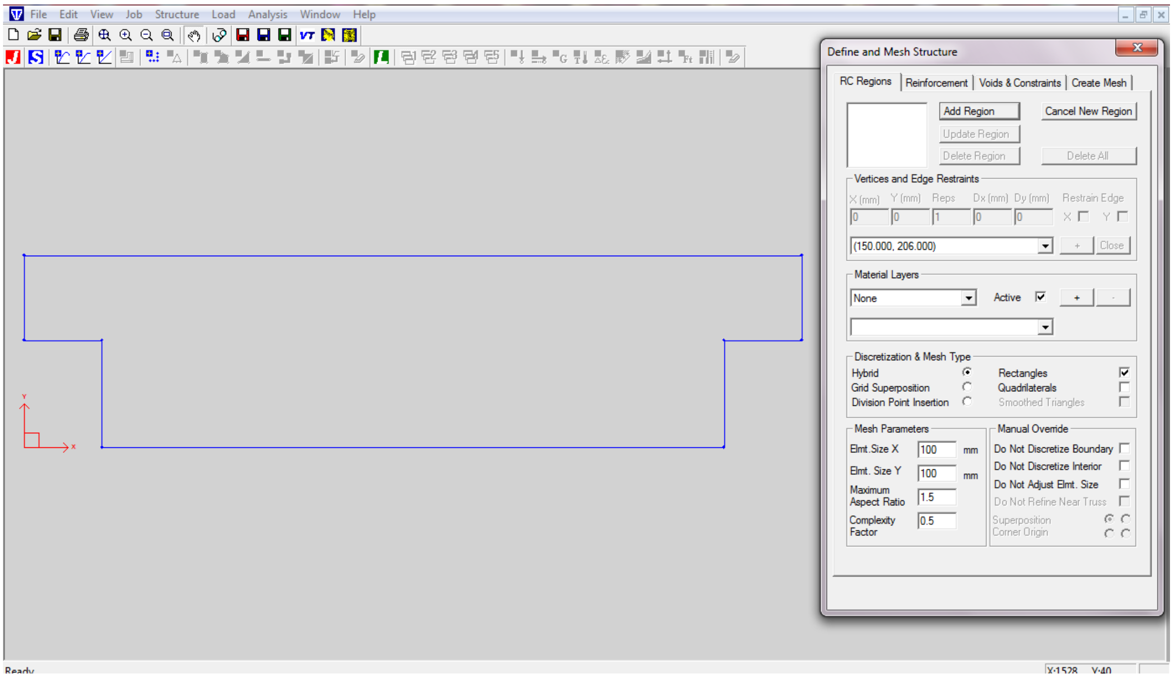


Figure 12: Defining RC Region of the beam

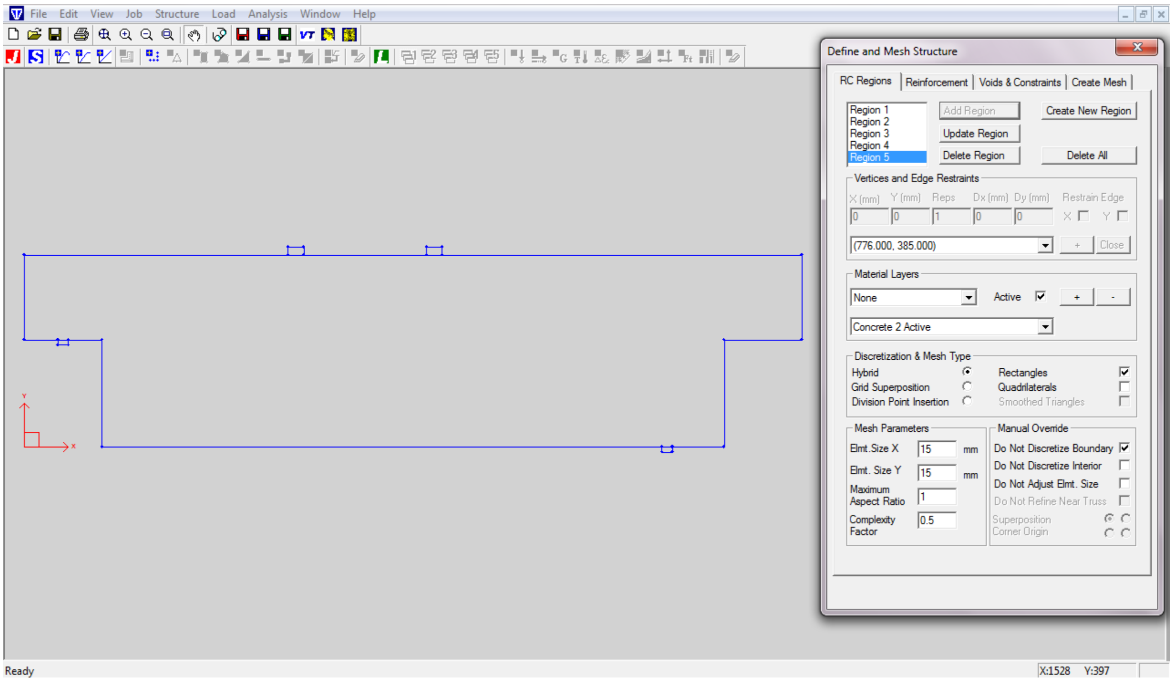


Figure 13: Defining Support and External load Region of the beam

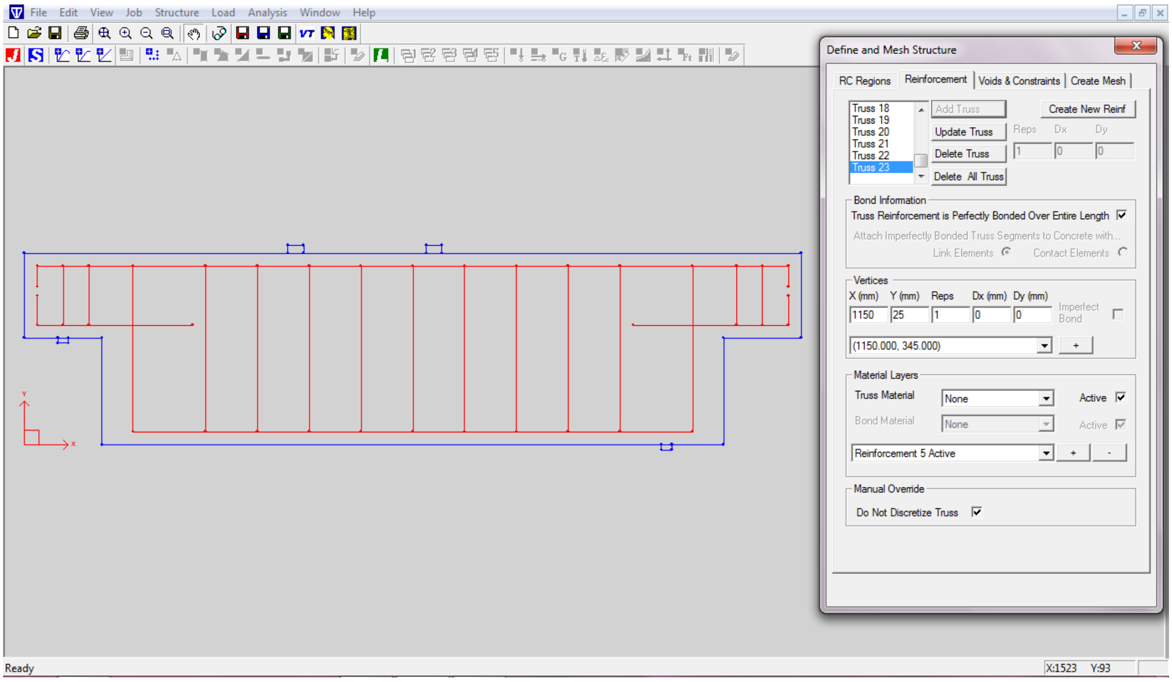


Figure 14: Defining Reinforcement Region of the beam

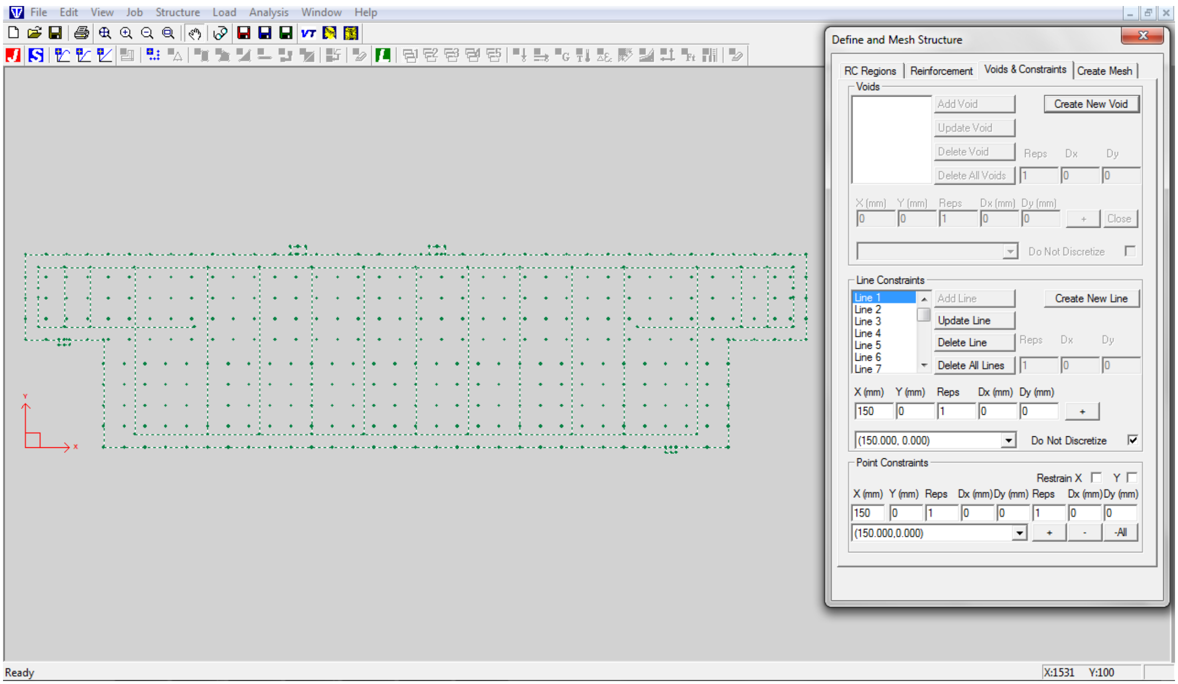


Figure 15: Defining Line and Point Constraint of the beam

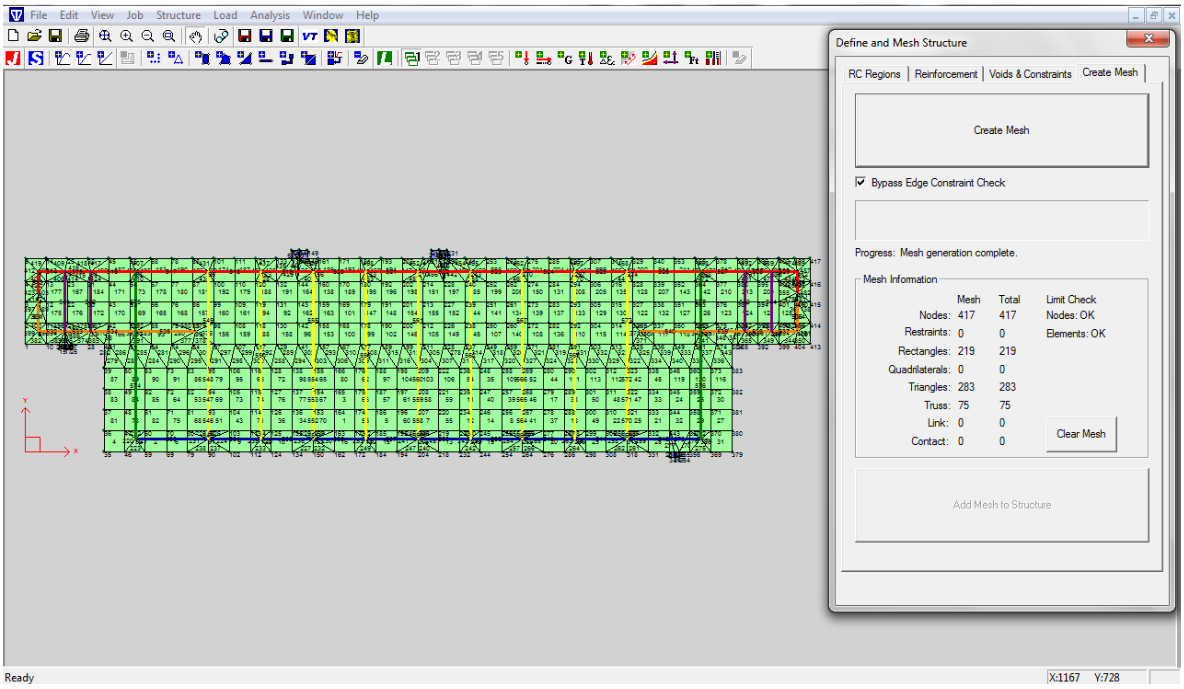


Figure 16: Defining Mesh Size and Creating Mesh Structure

e) Create Support Restraints

- The support restraints are created at the selected nodes.

Figure 17: Creating Support Restraint

f) Assign **Material Type**

- The material for concrete and steel reinforcement is selected in this part. Each material is assigned to the selected (green) area as shown below.

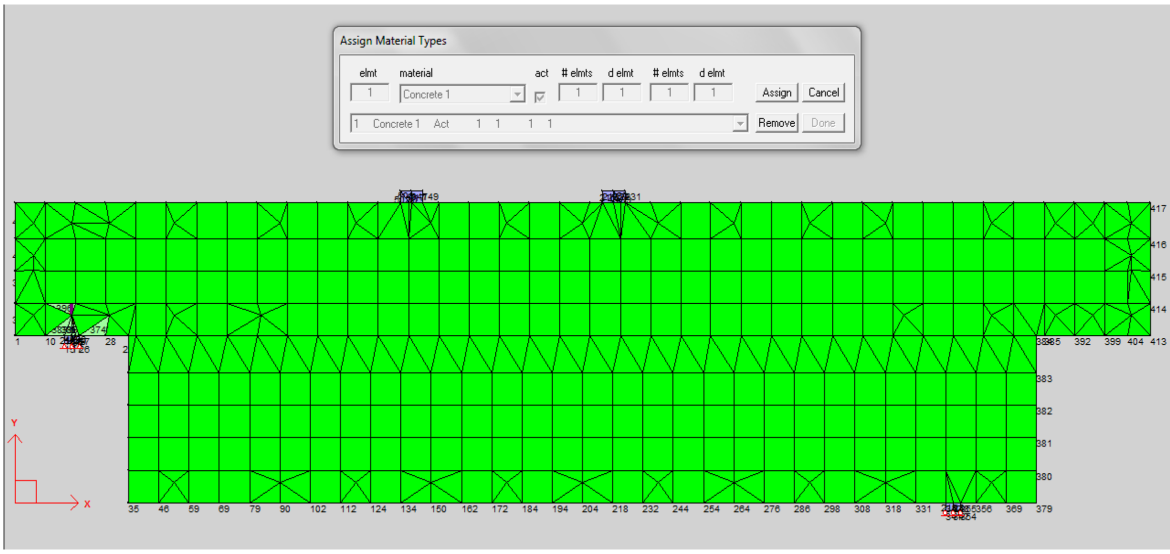


Figure 18: Assigning Material Type

g) Apply Nodal Load

- The loads applied at the selected nodes.

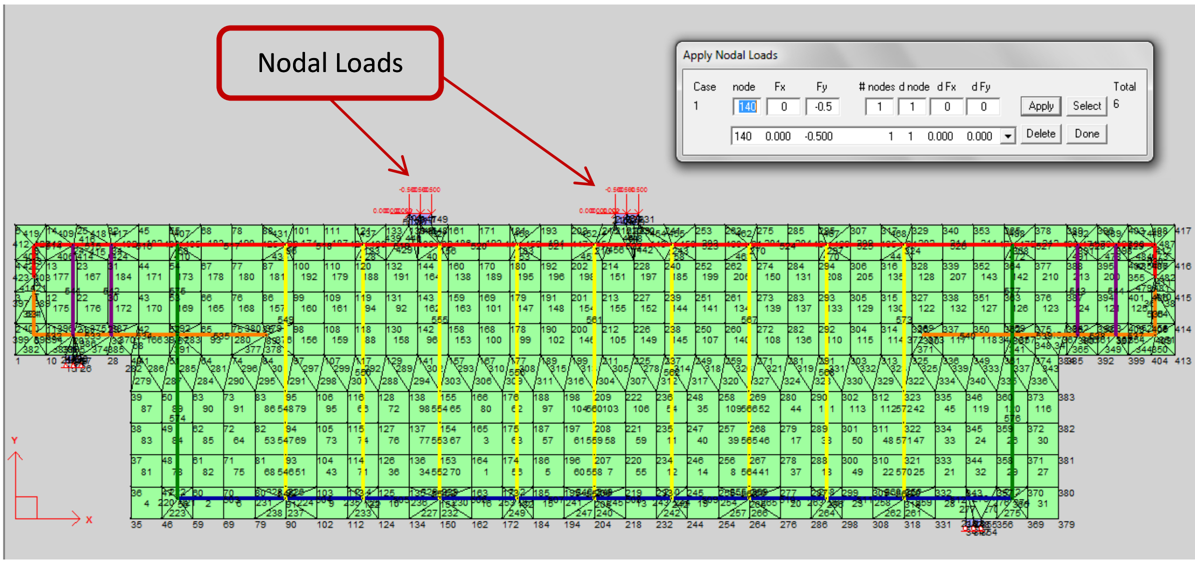


Figure 19: Applying Nodal Loads

h) Saving the file

- Three types of important files are saved before run the analysis.
- The three type of file are Job File, Structure File and Load File.

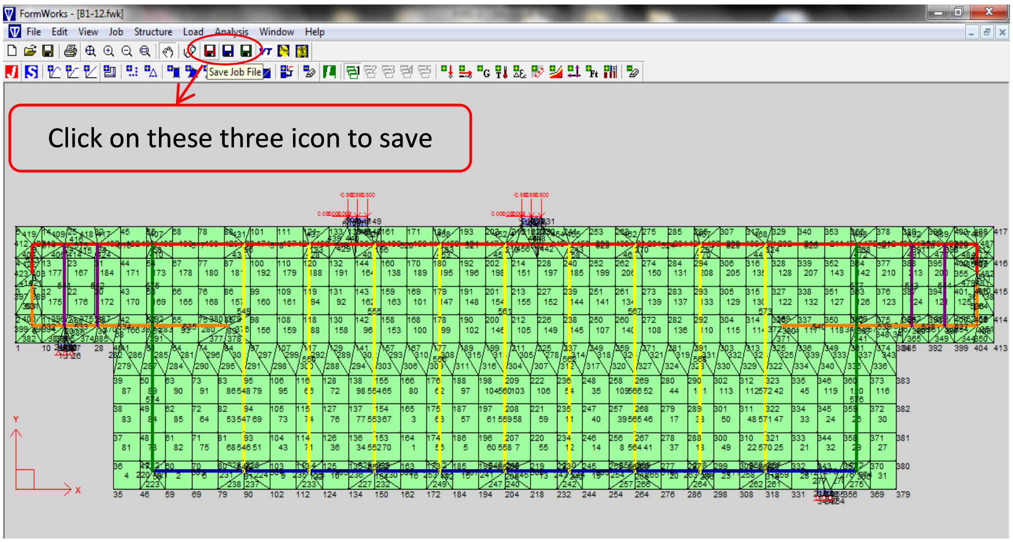


Figure 20: Saving Job, Structure and Load File

i) Run **Vector2 processor**

- FormWorks presents the option to attempt to reduce the bandwidth as shown in the Figure 21. A reduced bandwidth decreases the computation time by renumbering the nodes in a more computationally efficient manner.
- Then, analysis will run as shown in Figure 22.

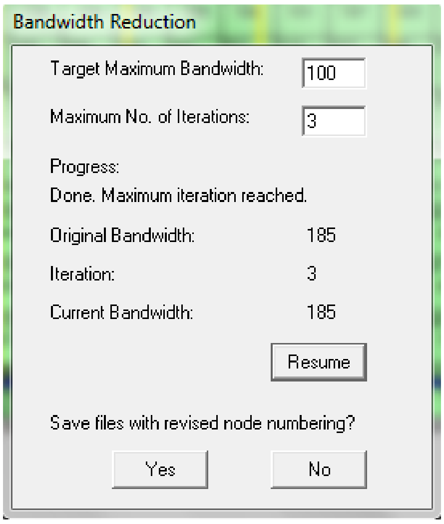


Figure 21: Bandwidth Reduction dialog box

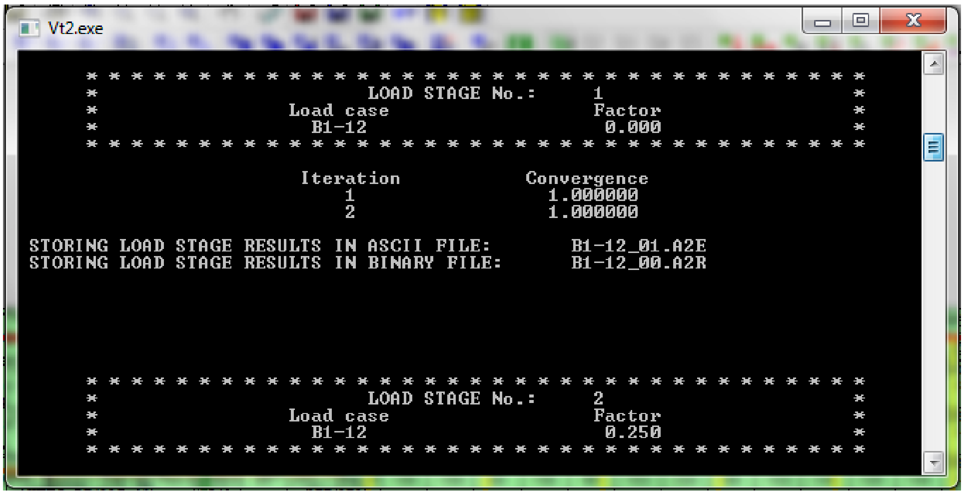


Figure 22: Vector2 Analysis running

j) Run **Augustus Software**

- The result of analysis can only be obtained using Augustus because it is postprocessor for Vector2.

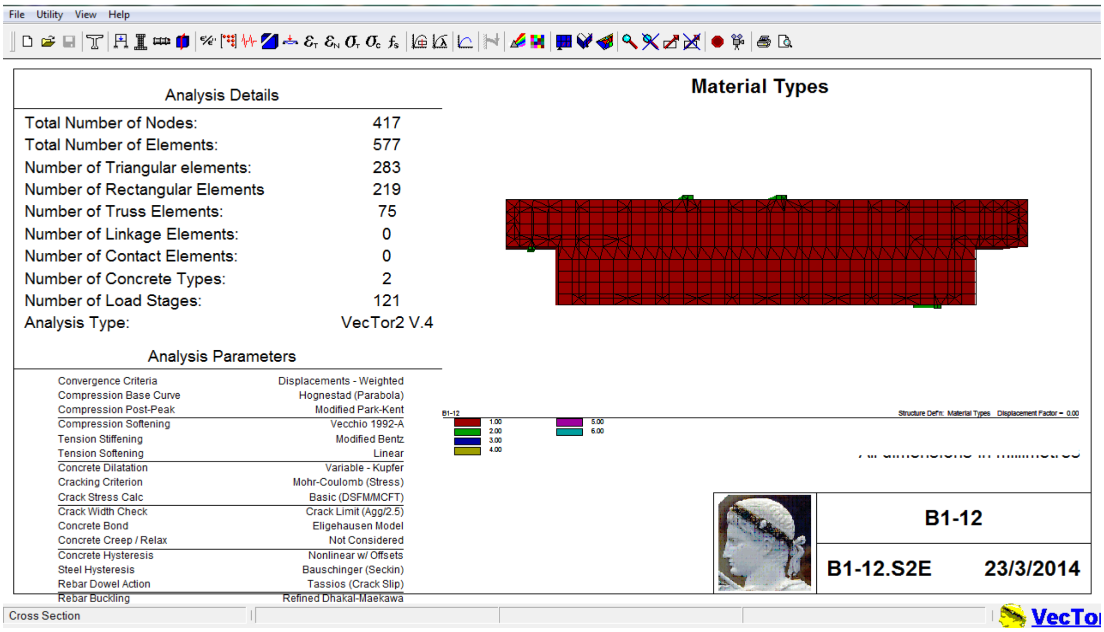


Figure 23: Analysis Results Summary by Augustus

3.3 PCI Design Procedures

The calculation to predict the failure load of the dapped-end beam (specimen B1.12) is referred to the PCI design handbook seventh edition. This is the newly released edition that includes the new and updated information as the design guidelines for precast and prestressed concrete structures.

The steps of the calculations are as follows:

1. The Flexure and Axial Tension in Extended End

$$A_s = A_f + A_n = \frac{1}{\phi f_y}\left[V_u\left(\frac{a}{d}\right) + N_u\left(\frac{h}{d}\right)\right]$$

Where,

ϕ = 0.75
a = shear span, measured from load to center of A_{sh}, in.
h = depth of component above dap, in.
d = distance from top to center of reinforcement A_s, in.
f_y = yield strength of flexural reinforcement, psi
N_u = 0.2 times sustained load portion of V_u unless otherwise calculated (when bearing pads are used),[11] lb

2. Direct Shear

- Refers to the potential vertical crack

$$A_s = \frac{2V_u}{3\phi f_y \mu_e} + A_n$$

Where,

$$A_n = \frac{N_u}{\phi f_y}$$

$$A_h = 0.5(A_s - A_n)$$

ϕ = 0.75
f_y = yield strength of A_s, A_n, A_h, psi

$$\mu_e = \frac{\phi 1000 \lambda b h \mu}{V_u}$$

- The shear strength of the extended end, μ_e (Equation above) is limited by the maximum values given in the table 1. Whereby, in this case the maximum value used is 3.4.

Table 1: Recommended Shear Friction Coefficients

Case	Crack interface condition	μ^a	Maximum μ_e	Maximum V_u/ϕ
1	Concrete to concrete, cast monolithically	1.4λ	3.4	$0.30\lambda f'_c A_{cr} \leq 1000\lambda A_{cr}$
2	Concrete to hardened concrete, with roughened surface	1.0λ	2.9	$0.25\lambda f'_c A_{cr} \leq 1000\lambda A_{cr}$
3	Concrete placed against hardened concrete not intentionally roughened	0.6λ	Not applicable[b]	$0.20\lambda f'_c A_{cr} \leq 800\lambda A_{cr}$
4	Concrete to steel	0.7λ	Not applicable[b]	$0.30\lambda f'_c A_{cr} \leq 800\lambda A_{cr}$

3. Diagonal Tension at Re-entrant Corner
   - Refers to the reinforcement that required resisting the diagonal tension cracking starting from the re-entrant corner.

$$A_{sh} = \frac{V_u}{\phi f_y}$$

Where,

ϕ = 0.75
V_u = applied factored load, lb
A_{sh} = vertical or diagonal bars across potential diagonal tension crack, in.^{2}
f_y = yield strength of A_{sh}, psi

4. Diagonal Tension in the Nib
   - Concrete Capacity

$$2bd\lambda\sqrt{f'_c}$$

   - Vertical Reinforcement in the Nib

$$A_v = \frac{1}{2f_y}\left(\frac{V_u}{\phi} - 2bd\lambda\sqrt{f'_c}\right)$$

3.4 Key Milestone and Gantt chart

3.4.1 FYP 1

Table 2: Key Milestone (FYP 1)

Activities	Week
Title Selection/Proposal	1
Preliminary Research & Literature Review	4
Submission of Preliminary Report or Extended Proposal	6
Modeling of dapped-end beam using Vector2	10
Proposal Defense and Progress Evaluation	11
Submission of Interim Draft Report	13
Submission of Interim Report	14

Table 3: Gantt chart (FYP 1)

Activity/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Selection of Project Topic														
Preliminary Research Work														
Vector2 Software learning process														
Submission of Extended Proposal														
Modelling of dapped-end beams														
Proposal Defence														
Project work continues														
Submission of Interim Draft Report														
Submission of Interim Report														

Completed work

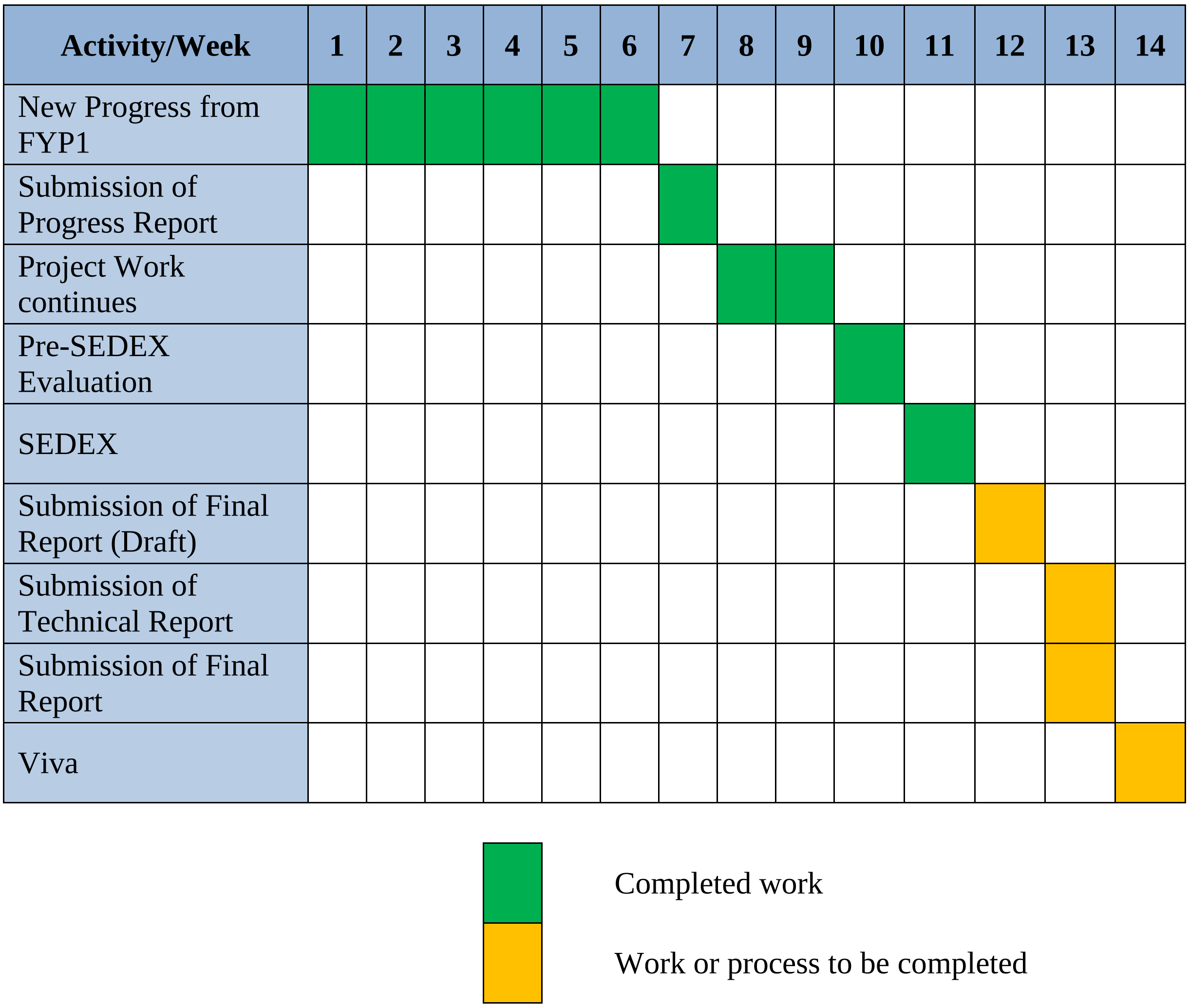
Work or process to be completed

3.4.2 FYP 2

Table 4: Key Milestone (FYP 2)

Activities	Week
Submission of Progress Report	7
Pre-SEDEX Evaluation	10
Submission of Draft Report	12
Submission of Technical Report	14
Submission of Final Report	14
Viva or Final Project Presentation	15

Table 5: Gantt chart (FYP 2)



3.5 Tools Required

To facilitate the author in the delivery of this research project, tools below are used:

Softwares

- Microsoft Office (Word, Excel, & PowerPoint)
- Vector2- FormWorks
- Augustus

Books

- Research journals on the topic of Dapped-end beams design
- Design Code (PCI Design Handbook 7^{th} Edition)

Hardware

- Personal computer (Laptop)
- Printer

CHAPTER 4

RESULT AND DISCUSSION

4.1 Results

4.1.1 Beam Modeling Using FEA (Finite Element Analysis) Software

In this research project, a dapped-end beam details has been taken out from Wang et al (2005) research paper. This specimen is labeled as B1.12 and the details of the beam are used to model the dapped-end beam using Vector2 software. Wang et al tested the specimen experimentally and the failure load capacity was recorded. The theoretical value obtained from the non-linear Finite Element Analysis program Vector2 can be compared with the experimental value obtained by Wang et al.

Table 6: Details of Beam Specimen B1.12 taken from Wang et al. (2005) research paper

No.	Concrete Strength MPa		Dimension (mm)				$\lambda = a/h_{10}$	Web Reinforcement Provided	Range of Stirrups, mm		Failure Load, v (KN)
	f_{cu}	f_c	b	h	h_1	h_{10}			a_1	a_0	
B1.12	16.90	11.32	214	370	164	139	3.23	Ø6	60	60	42.24

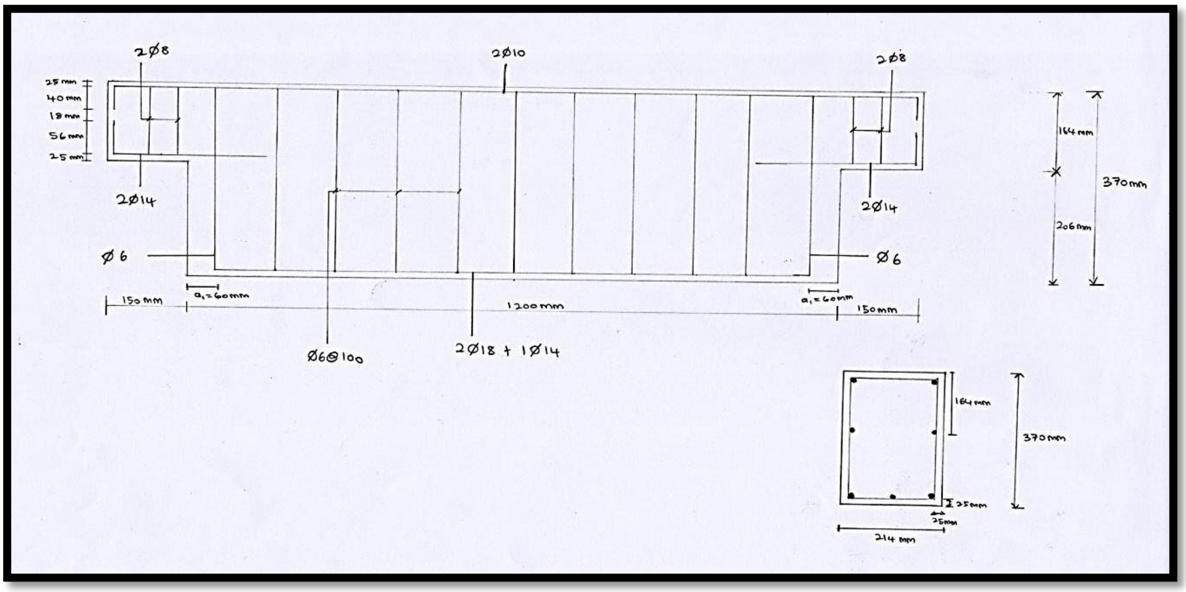


Figure 24: Beam Dimension and Reinforcement Detailing of B1.12

The result is obtained from Augustus (as shown in the figure below) after the analysis done in Vector2.

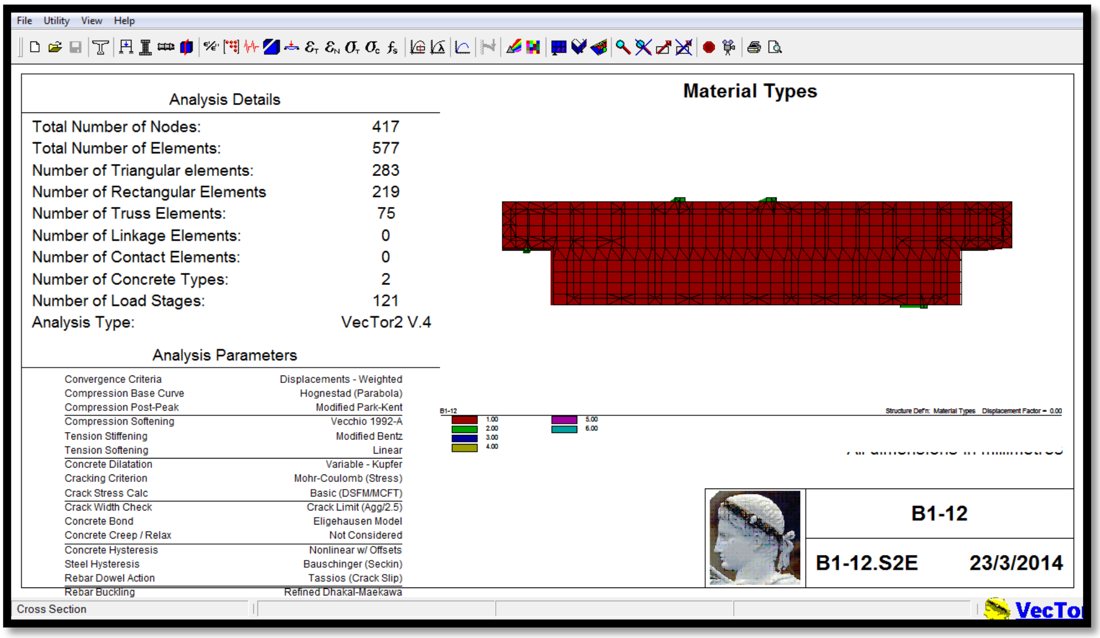


Figure 25: Result Summary by Augustus for of B1.12 beam specimen

From the Augustus, the failure load capacity can be determined and the structural behavior of the dapped-end beam can be observed while increasing the load capacity. Figure below showing the combined view of displacement and crack pattern formed when the load increased up to 47.6 kN.

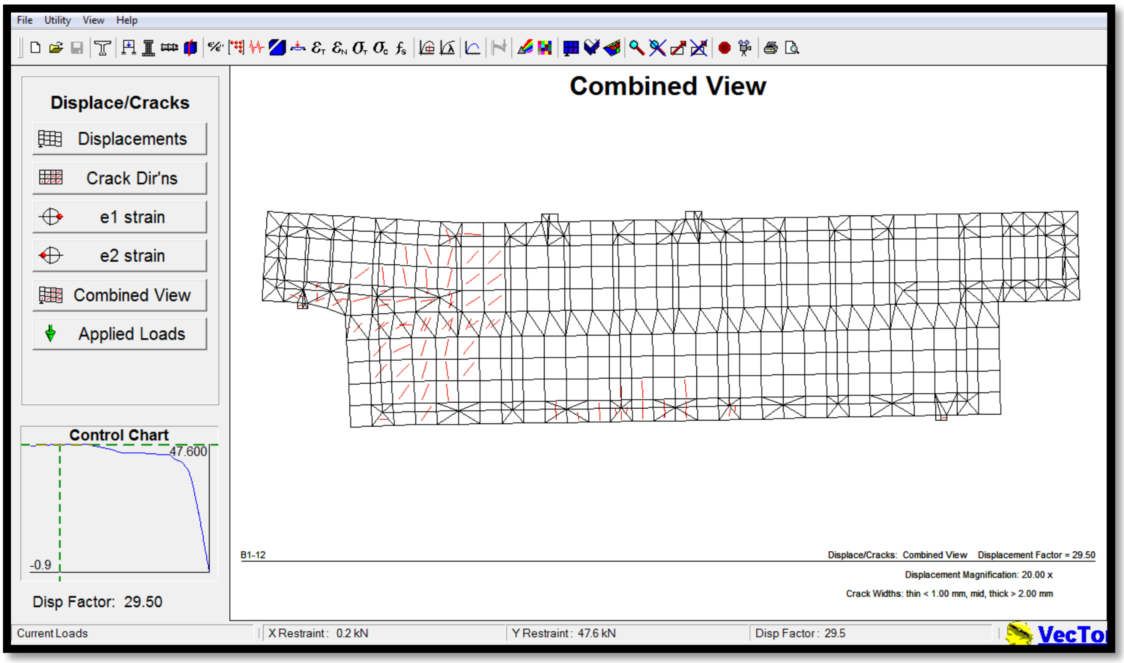


Figure 26: Combined view of displacement and crack pattern

Then, the load versus displacement chart is plotted as shown below.

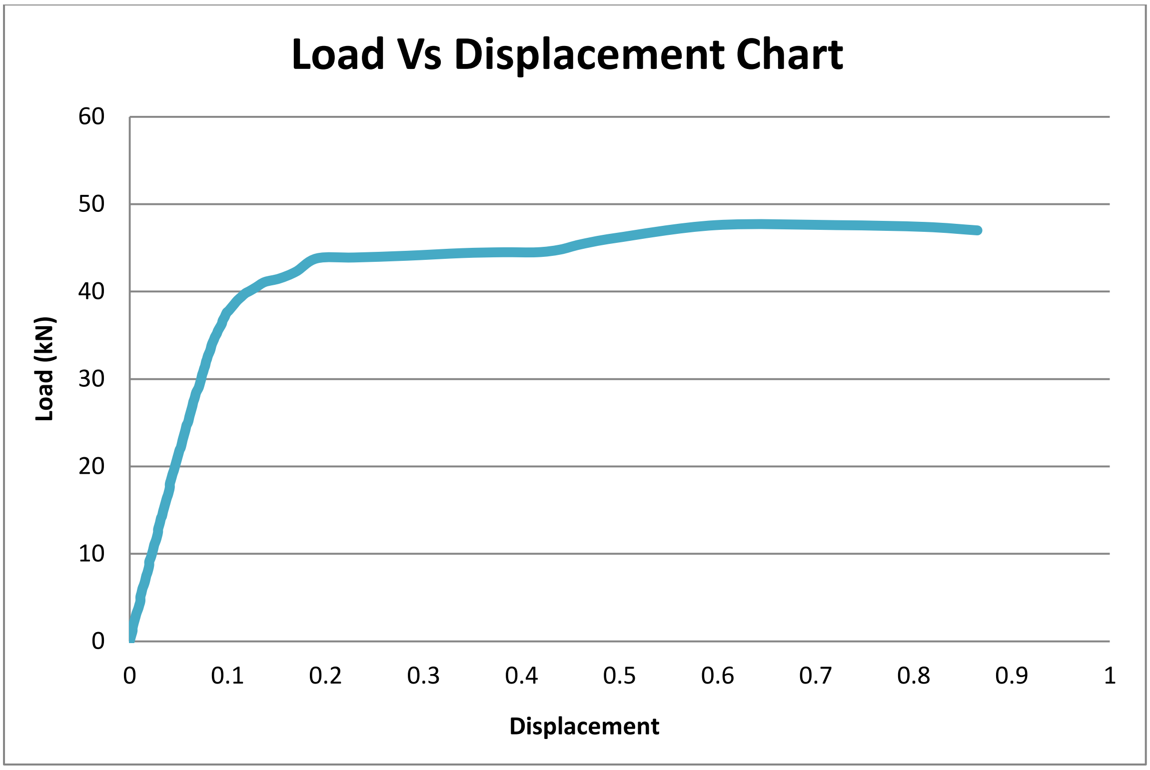


Figure 27: Load versus Displacement Chart

From the chart, the predicted failure load capacity of dapped-end beam is **47.6kN** which is quite near to the experimental value obtained by Wang et al (2005), **42.24kN.** The result obtained proven that FEA software (Vector2) is highly reliable in performing Finite Element Analysis modeling for dapped-end beams.

4.1.2 Failure Load Capacity Calculation Using Design Code

After the modeling of dapped-end beam using FEA software is done, the failure load capacity of the same beam is calculated manually using PCI Design Handbook.

From the calculation performed (refer to appendix), the failure load capacity of the dapped-end beam is 36.70kN. Since this value is quite near to the experimental value, thus it is considered correct and acceptable. Failure load capacity obtained from the two approaches is summarized in the table below.

Table 7: Results comparison between FEA software and PCI design code

<table>
<tr><th>Type of approaches used</th><th>Failure Load (kN)</th><th>Wang's experimental value</th><th>Difference (kN)</th></tr>
<tr><td>FEA Software</td><td>47.60</td><td rowspan="2">42.24kN</td><td>5.36</td></tr>
<tr><td>PCI Design Handbook</td><td>36.70</td><td>5.54</td></tr>
</table>

The results obtained from FEA software and PCI Design approach is very close to the experimental value. Both methods can predict the failure load capacity accurately but somehow the FEA software able to predict better.

4.1.3 Parametric Study

The beam modeled (as shown in 4.1.1 section) is used to perform this parametric study where the specifications and every parameter involved in order to model the beam are kept constant except few selected parameters. There are total three main parameters being studied in this project which include concrete strength, diameter of reinforcement bar, and finally the location of external loads. These parameters are analyzed and studied carefully to determine their effects on the failure load capacity. Below are the results of analysis performed.

4.1.3.1 Concrete Strength

In this part, all parameters of the beam are kept constant except the concrete strength value. All the data obtained are tabulated and a graph of failure load versus concrete strength is plotted as shown below.

Table 8: Failure load capacity with different concrete strength

Cylinder Compressive Strength, f'c (MPa)	Failure Load (kN)
11.32	42.3
20.0	55.0
30.0	64.7
40.0	73.3
50.0	79.9

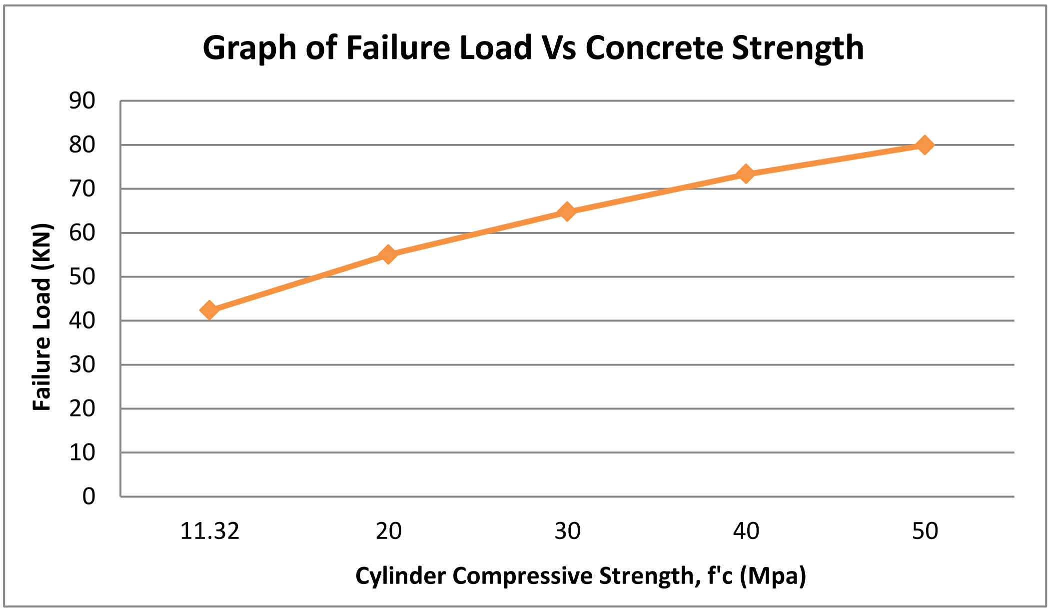


Figure 28: Failure Load versus Concrete Strength Graph

From the graph, it is clearly shown that the failure load capacity of dapped-end beam increase significantly when higher concrete strength is used. However, the maximum concrete strength used is 50MPa only, this is because the concrete strength above 60MPa will gives unreliable failure load values. Moreover, there will be a bonding problem between the concrete and the reinforcement steel if very high concrete strength is used. The curve formed also showing that the rate at which the value of failure load increasing will decrease and finally will be constant.

4.1.3.2 Diameter of Reinforcement Bar

The diameters of reinforcement bar are the variable in this part. There are total three main bar involved, which known as nib flexural reinforcement, hanger reinforcement and nib vertical reinforcement. These types of reinforcement are chosen to be the one of the parameters to be studied because these reinforcements are as the main support at the re-entrant corner of the dapped-end beam. All the data obtained are tabulated and a graph of failure load versus reinforcement diameter is plotted as shown below.

Table 9: Nib Flexural Reinforcement

Nib Flexural Reinforcement	
Diameter (mm)	**Failure Load (kN)**
10	39.2
12	41.7
14	42.3
16	44.3
20	53.5
24	55.9
32	58.7

Table 10: Nib Vertical Reinforcement

Nib Vertical Reinforcement	
Diameter (mm)	**Failure Load (kN)**
6	41.3
8	42.3
12	43.8
16	44.1
20	44.3
24	44.4
32	44.4

Table 11: Hanger Reinforcement

Hanger Reinforcement	
Diameter (mm)	**Failure Load (kN)**
6	42.3
8	44.5
12	48.2
16	53.7
20	59.6
24	63.2
32	67.3

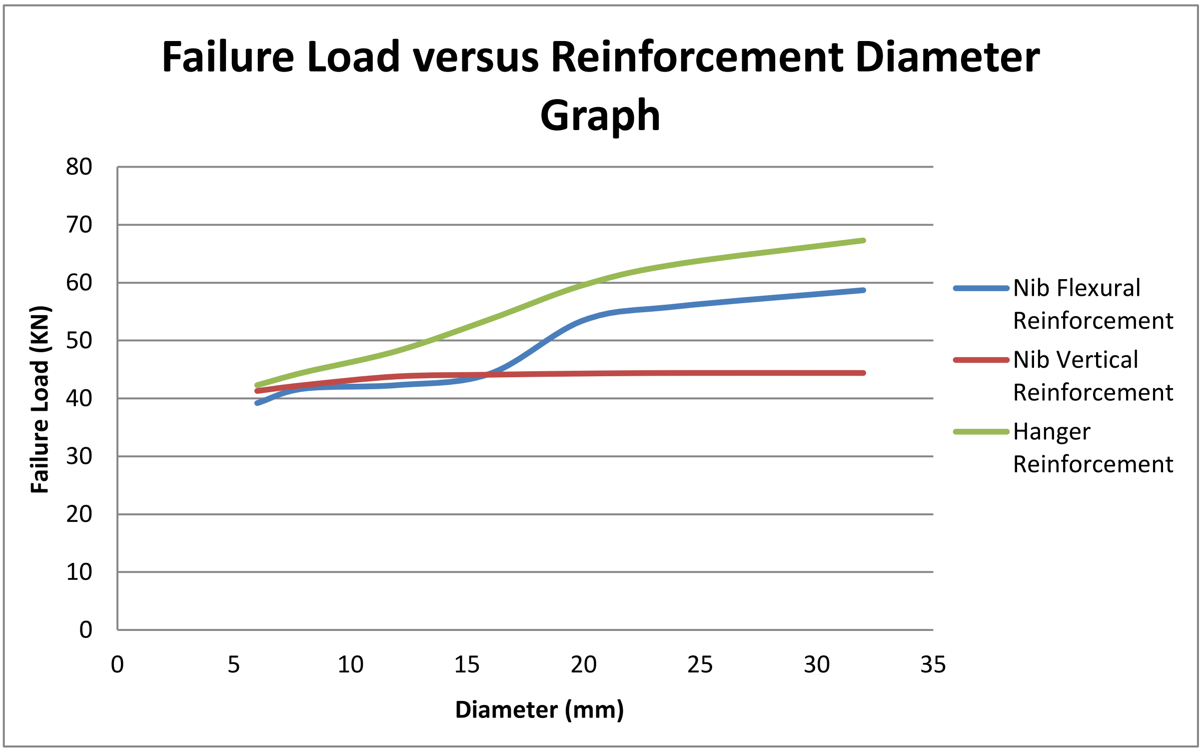


Figure 29: Failure Load versus Reinforcement Diameter Graph

The failure load capacity significantly affected by the hanger reinforcement as shown on the graph above. The larger the diameter of hanger reinforcement provided, the higher the failure load will be. The reason of providing hanger and nib flexural reinforcement is because to reduce or stop the diagonal tension cracks from developing. Thus, by providing thicker diameter, lesser cracks will be formed and the load at which the beams fail will increase.

Whereas, increasing the diameter of nib vertical reinforcement bar does not give major difference to the failure load capacity. As can be seen from the graph above, only 3.1kN extra load can be sustained if thicker diameter is used which clearly not economically efficient.

Increase the diameter of nib flexural reinforcement bar can also increase the failure load capacity. However, the percentage of increase in load capacity is not as much as compared to hanger reinforcement. Diameter of both hanger and nib flexural reinforcement shall be increased to have a greater failure load capacity.

4.1.3.3 Distance of External Load from Support

The distance from support to at which the external load is applied onto the beam is the variable in this part. This distance also known as "a" value (refer figure below). All the data obtained are tabulated and a graph of failure load versus distance of external load from support is plotted.

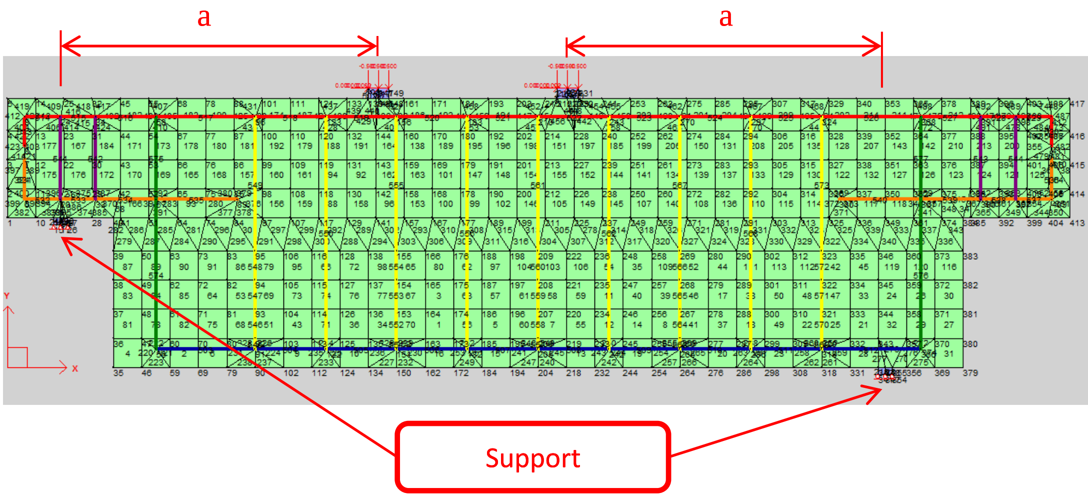


Figure 30: Distance of External Load from support (a)

Table 12: Failure Load Capacity with different 'a' value

Distance of External load from support, a (mm)	Failure Load (kN)
100	134.5
200	65.1
300	51.2
400	47.7
500	42.0

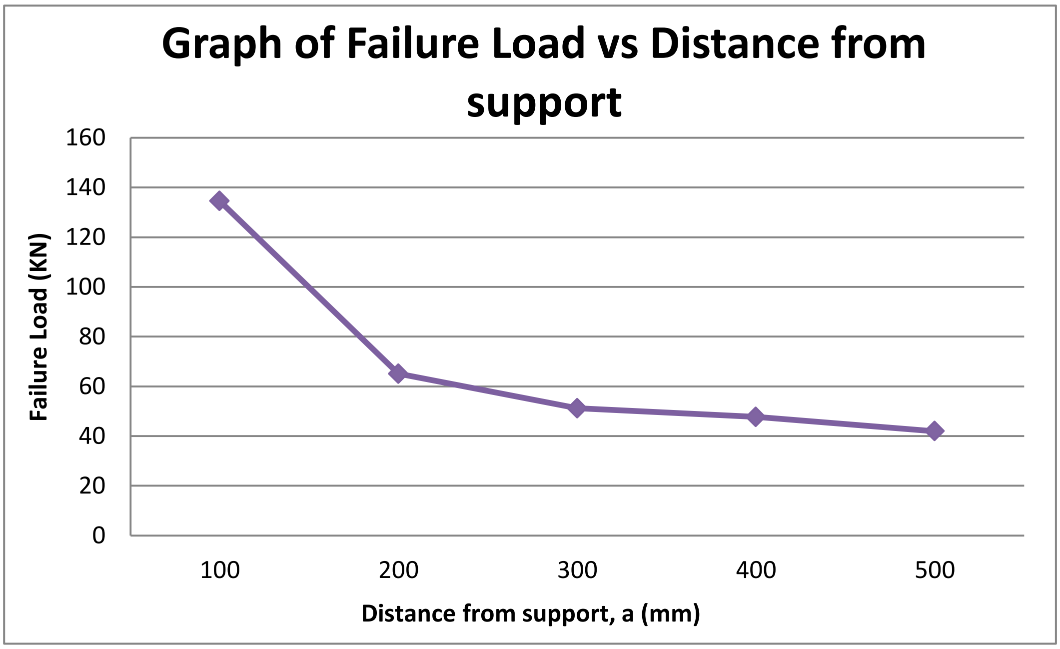


Figure 31: Graph of Failure Load versus Distance from Support

Based on the result obtained, the failure load capacity is significantly higher when the distance 'a' is smaller. In other words, if the external loads are positioned nearer to the support, the failure load will increase. This is because, there will be less deflection happens when the load applied onto the beam is nearer to the support. Thus, it can be concluded that the distance between the external load and support significantly affects the magnitude of failure load of the dapped-end beam.

4.2 Discussion

The failure load capacity obtained by using FEA (Finite Element Analysis) software is 47.6kN, which is quite near to the Wang's experimental value, 42.24kN. The difference in value is small which means that result obtained proven that the FEA software (Vector2) is highly reliable in performing Finite Element Analysis modeling for dapped-end beams. However, the result can be accurate only if the meshing size used in FEA is optimum. The result also confirmed that diagonal tension cracks will develop at the re-entrant corner of the beam when the load is increased continuously. Therefore, proper reinforcement detailing of dapped-end beams are crucial to be provided in order to increase the capacity of the beam.

Obtaining correct results from Augustus is quite challenging because the software is depending on the amount of load applied initially on the beam in the Vector2 before running the analysis. Therefore, trial and error method is used to determine the optimum initial load to be applied on the dapped-end beam. The optimum initial load applied can lead to more acceptable load versus displacement chart which will give more accurate failure load capacity of the beam.

Unfortunately, there is no additional data provided in Wang et al (2005) research paper which can help in plotting a load versus displacement chart for specimen B1.12. Therefore, it is hard to discuss further on the pattern of the load versus displacement chart obtained using Vector2 without doing any comparison with the load versus displacement chart for specimen B1.12. The chart obtained is assumed correct and acceptable.

The beam modeled earlier in FYP 1 section is used to perform the parametric study where the specifications and every parameter involved in order to model the beam are kept constant except few selected parameters. There are total three main parameters being studied in this project which include concrete strength, diameter of reinforcement bar, and finally the distance between the external loads and the support. These parameters are analyzed and studied carefully to determine their effects on the failure load capacity. The parametric study is done to support this research project because it is able to determine the sensitivity of different dapped-end beam parameters on the failure load capacity.

The first parametric study is to study the effect of concrete strength on the failure load capacity of dapped-end beam. From the result, the failure load capacity of dapped-end beam increase significantly when higher concrete strength is used. The second parametric study is to determine which reinforcement bar providing greater support to the re-entrant corner of dapped-end beam. The results obtained show that the failure load capacity significantly affected by the hanger reinforcement compared to the other two. The larger the diameter of hanger reinforcement provided, the higher the failure load will be. Nib flexural reinforcement also contributes in increasing the failure load capacity but not as great as the hanger reinforcement. Thus, diameter of both hanger and nib flexural reinforcement of dapped-end beams shall be increased to have a greater failure load. The last parametric study is to study how is the failure load capacity affected when the position of external load applied onto the beam is changed. The results show that when the external loads are positioned nearer to the support, the failure load will increase. The reason is because there will be less deflection happens when the load applied onto the beam is nearer to the support.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The main aim of this research is to predict the failure load capacity of dapped-end beams by using different approaches. The first approach is by using a sophisticated two-dimensional non-linear finite element program, Vector2 and the second approach is by using PCI Design Handbook. The failure load capacity of dapped-end beam has been predicted to be 47.6kN. Despite the fact that the predicted value is slightly higher compared to experimental value, the value is considered accurate because the difference between both values is very small. Based on the result obtained by using Vector2 software, it is proven that the non-linear finite element program, Vector2 can be used to predict the failure load capacity and structural behavior of dapped-end beams. Whereas the failure load capacity calculated by using PCI Design Handbook is 36.70kN. The results obtained from FEA software and PCI Design approach is very close to the experimental value. Both methods can predict the failure load capacity accurately but somehow the FEA software able to predict better. Parametric studies are conducted to determine the sensitivity of different dapped-end beam parameters on the failure load capacity. The concrete strength, diameter of hanger reinforcement, and location of external loads applied onto dapped-end beam significantly affects the magnitude of failure load. These parameters shall be taken into consideration while performing design works to improve the strength of dapped-end precast concrete members.

5.2 Recommendations

Beam B1.12 is the only specimen used and only three main parameters are studied in this research project. The author suggests that more specimen of beam to be used and more dapped-end parameters should be studied in future to increase the findings and to increase the accuracy of data obtained and thus strongly support this research.

Next, this project is limited to the scope of study which is using beam from Wang et al (2005). The type of external loads used in Wang's beam is point load. Therefore, this project should expand the scope of study by analyze the beam in FEA software using different type of loadings like UDL (Uniform Distributed Load).

Last but not least, the mesh size of the dapped-end beam must be optimum and it is only possible by using trial and error method. As a matter of fact, the smaller the mesh size or the larger the number of element, the more accurate the data will be. However, there is a point where the accuracy of the data will stop even though the number of element is increasing and at that point the optimum mesh size can be obtained. In future, this factor is crucial to be included in order to obtain more accurate data.

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APPENDICES

HAND CALCULATION USING PCI DESIGN HANDBOOK

Name : MOHD IMRAN B. NASIR KHAN

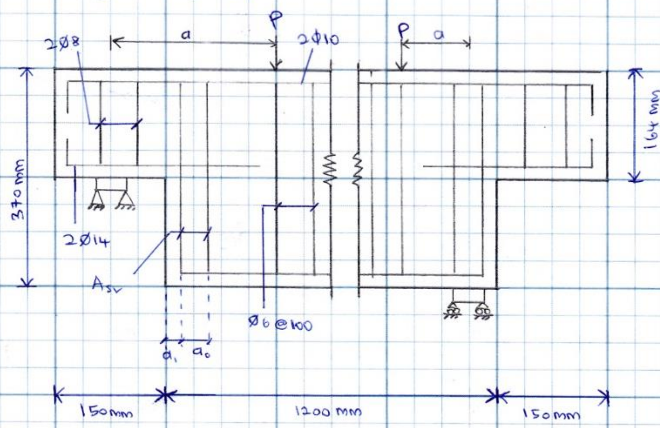
PCI Design Analysis

Student's No : 15180

Subject : FYP II

Based on PCI Design Handbook, 7^{th} Edition

Based on Wong et al (2005),



Beam B1-12,

$f_{cu} = 16.90$ MPa

$f_c = 11.32$ MPa

$b = 214$ mm

$h = 370$ mm

$h_1 = 164$ mm

$h_{10} = 139$ mm

$a_1 = 60$ mm

$a_0 = 60$ mm

$a/h = 1.2$

$a_1/h_d = 0.8$

$Ø_{sH} = 0.027$

$Ø_s = 0.118$

$Ø_v = 0.049$

$Ø_h = 0$

$a/h = 1.2$, $h = 164$

$a = 196.8$ mm

Step 1 : The flexure and axial tension in the rib

$$A_s = [V_u \cdot (a/d) + N_u \cdot (h/d)] / (Ø \cdot f_y)$$

$$0.48 = [V_u \cdot (1.42) + 0] / [0.75 \times 49{,}960.41]$$

$$0.48 = \frac{1.42\,V_u}{37{,}470.31}$$

$$V_u = \frac{17985.75}{1.42} = 12666.02 \text{ lbs}$$

$$\therefore V_u = (12666.02 \times 4.45 \times 10^{-3}) = 56.36 \text{ kN}$$

$$A_s = 2\left(\frac{1}{4} \times \pi \times 14^2\right) = 307.88 \text{ mm}^2 = [307.88 \times 10^{-2} \times 0.155] = 0.48 \text{ in}^2$$

$$f_y = 344.23 \text{ Mpa} \times 145.137 = 49{,}960.41 \text{ PSI}$$

$h/d = 164/139 = 1.18$, $N_u = 0$

$a/d = 196.8/139 = 1.42$, $Ø = 0.75$

Step 2: Direct Shear

$$m_e = \frac{1000\,\phi\lambda b h m}{V_u} \leq 3.4$$

⇒ $b = 214\text{ mm} = 8.43\text{ in}$

$h = 370\text{ mm} = 14.75\text{ in}$

$m = 1.4$

$\phi = 0.75$

$\lambda = 1$

$$m_e = \frac{1000(0.75)(1)(8.43)(14.57)(1.4)}{V_u}$$

* maximum value of $m_e = 3.4$

$$m_e = \frac{128{,}966.36}{V_u}$$

$$A_s = \frac{2V_u}{3\phi f_y m_e} + A_n$$

⇒ $A_n = 0$ since $N_u = 0$

$$0.48 = \frac{2V_u}{3(0.75)(49{,}960.14)\left(\frac{128{,}966.36}{V_u}\right)}$$

⇒ Check $m_e \leq 3.4$

$$m_e = \frac{128{,}966.36}{V_u} = \frac{128{,}966.36}{58985.88} = 2.19 \leq 3.4 \text{ OK!}$$

$$0.48 = \frac{2V_u^2}{(1.4497\times10^{10})}$$

$$V_u = 262.49\text{ kN}\ *$$

Step 3: Diagonal Tension at Re-entrant Corner

Hanger Reinforcement ⇒ 1Ø6

$\phi = 6\text{mm} = 0.24\text{ in}$ (2 nos; 2 legs)

$$A_s = 2\left[2\left(\tfrac{1}{4}\times\pi\times6^2\right)\right] = 11.097\text{ mm}^2 = 0.175\text{ in}^2$$

$$A_s = V_u / (\phi f_y)$$

$$V_u = A_s(\phi f_y) = 0.175(0.75\times62{,}674.51) = 8240.17\text{ lbs}$$

$$= 8240.17\times(4.45\times10^{-3}) = 36.7\text{ kN}\ *$$

f_y value given

$A_{sv} f_{yv} = 24.42\text{ kN}$

⇒ $A_s = 1\left[2\times\frac{1}{4}\times\pi\times6^2\right] = 56.55\text{ mm}^2$

$$\therefore f_y = \frac{24.42\times10^3}{56.55} = 62{,}674.51\text{ PSI}$$

<u>Step 4: Diagonal Tension in the nib</u>

i) Concrete capacity $= 2\lambda bd\sqrt{F'c}$

$= 2(1)(8.43)(6.46)(\sqrt{1642.95})$

$= 4414.71$ lbs

$\Rightarrow h_1 = d = 164$ mm

$= 6.46$ in

$\Rightarrow f'c = 11.32$ MPa

$= (11.32 \times 145.137)$

$= 1642.95$ Psi

ii) Vertical Reinforcement in the nib

$$A_v = \frac{(V_u/\varnothing) - 2\lambda bd\sqrt{F'c}}{2f_y}$$

$$2A_v f_y = (V_u/\varnothing) - (2\lambda bd\sqrt{f'c})$$

$$V_u = \varnothing\left[2A_v f_y + (2\lambda bd\sqrt{f'c})\right]$$

$= 0.75\left[2(0.312)(62,674.51) + 4414.71\right]$

$= 32642.70$ lbs

$= [32642.70 \times (4.45 \times 10^{-3})]$ kN

$= 145.26$ kN

$\varnothing = 8$ mm $= 0.31$ in

(2 nos; 2 legs)

$A_v = 2\left[2\left(\frac{1}{4} \times \pi \times 8^2\right)\right]$

$= 201.06$ mm^2

$= [201.06 \times 10^{-2} \times 0.155]$

$= 0.312$ in^2

$f_y = 431.83 \times 145.137$

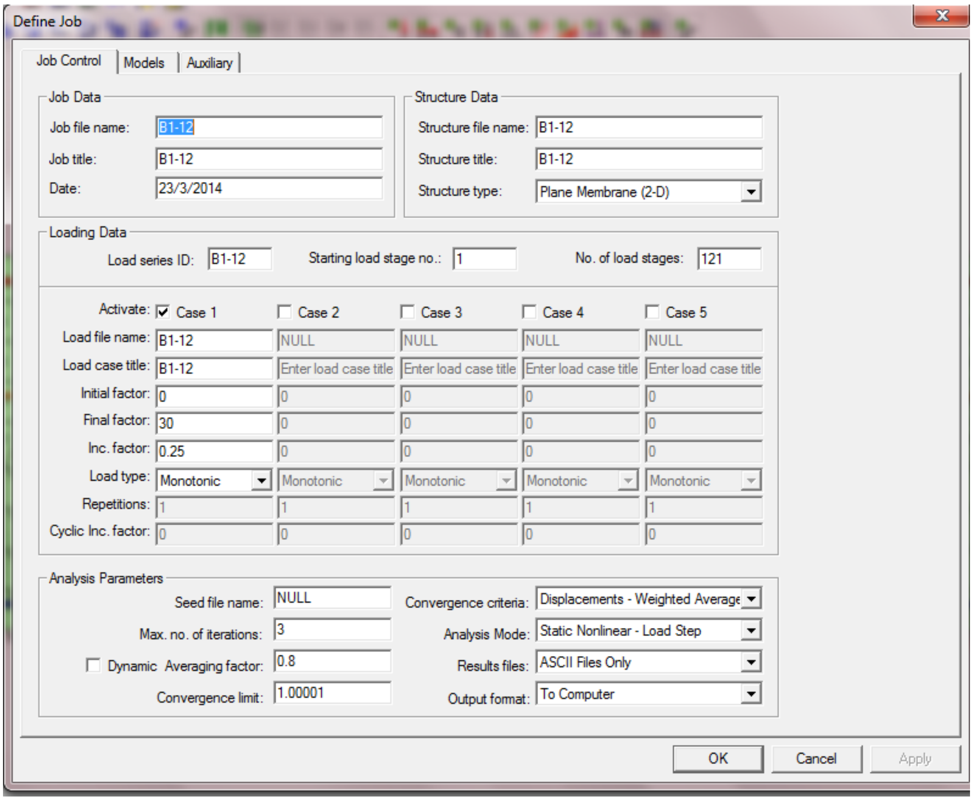
$= 62,674.51$ Psi

$\therefore$ - The predicted failure load for this beam is 36.70 kN (smallest value)

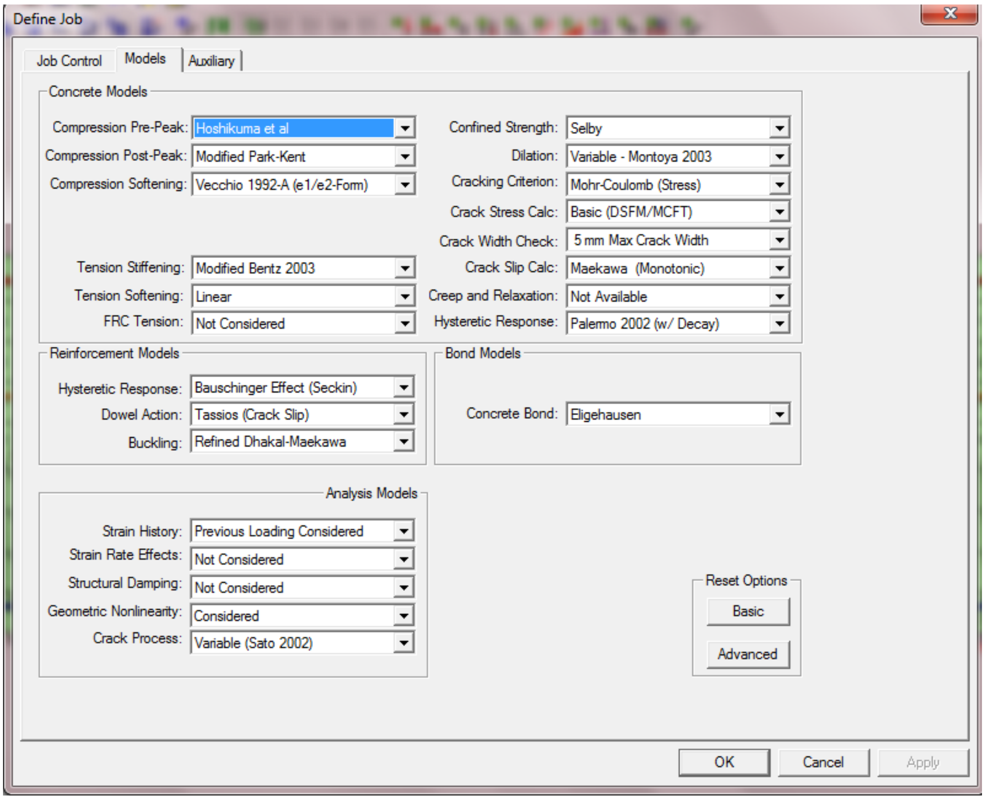
- This specimen failed at the diagonal tension at re-entrant corner which is at the hanger reinforcement.

INPUT FILES FROM FEA SOFTWARE

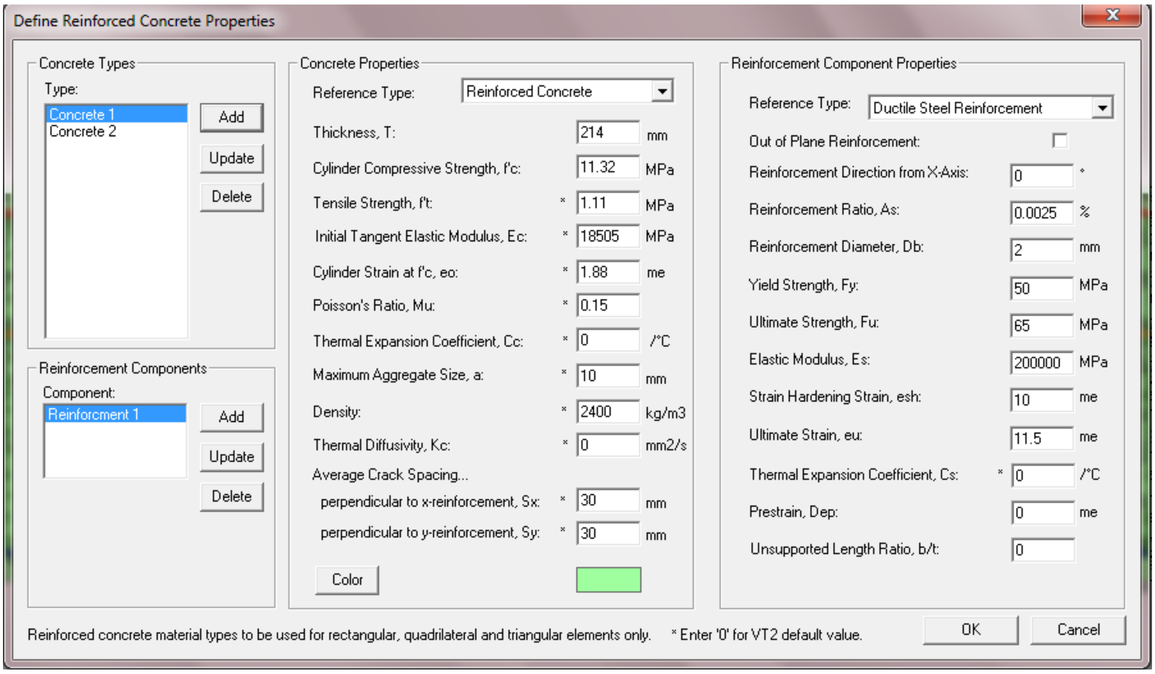
i. Job Data



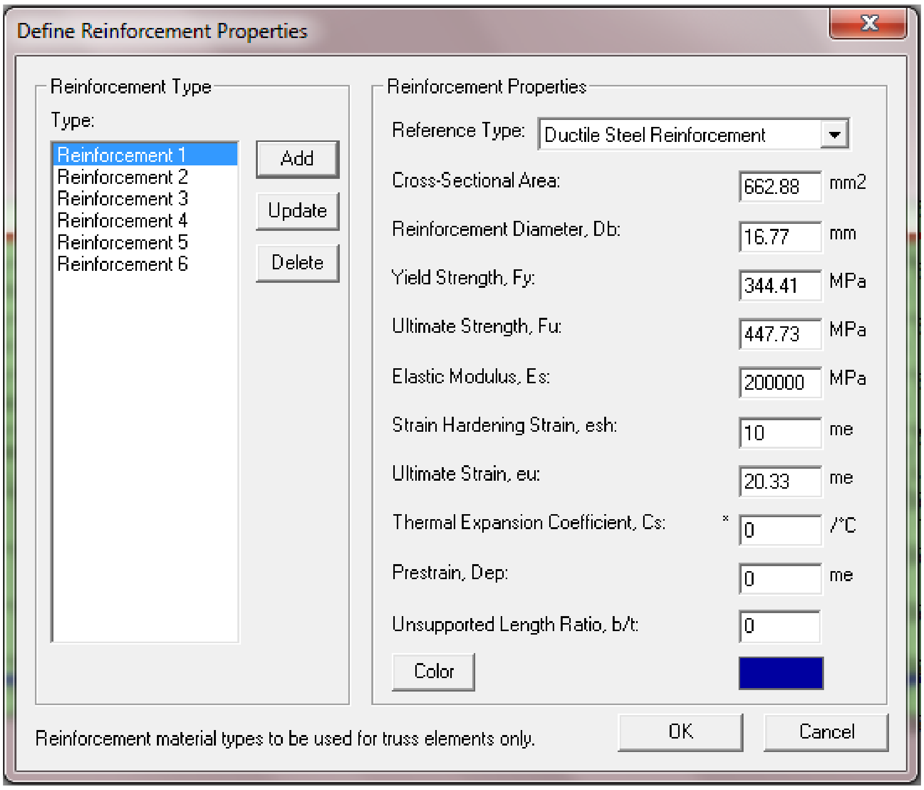
ii. Models used

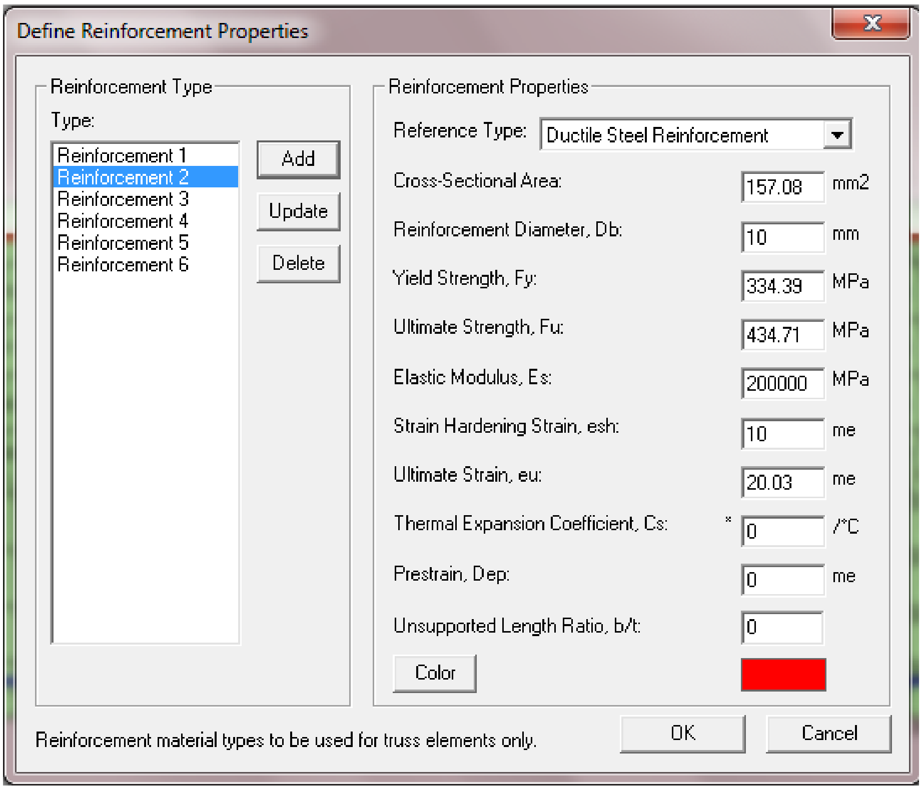


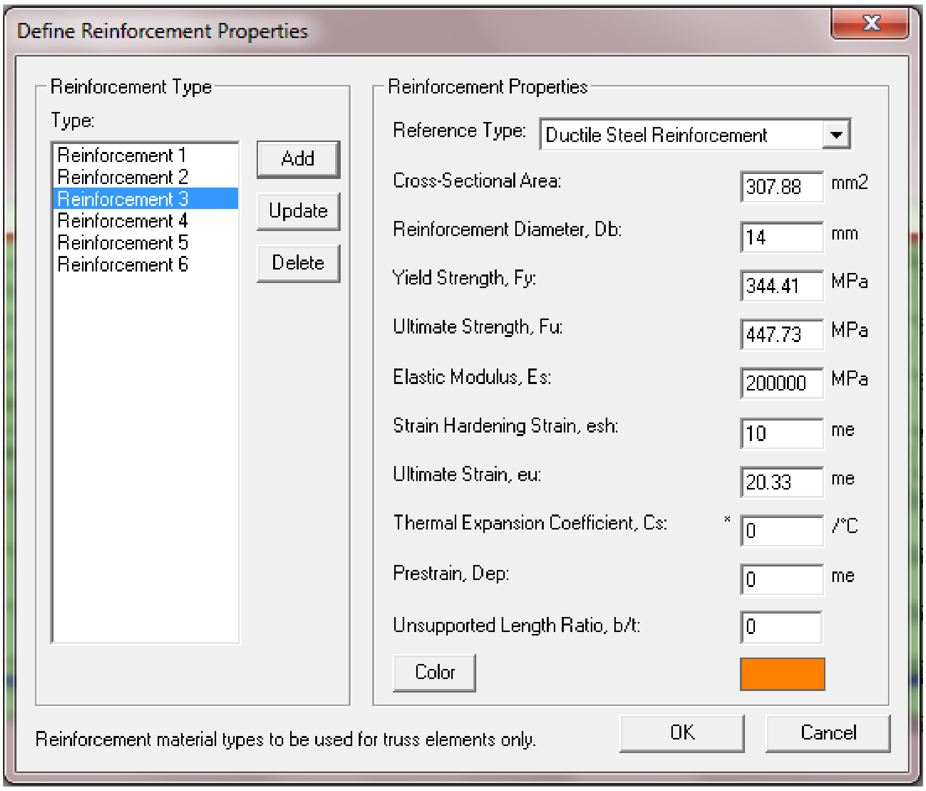
iii. Reinforced Concrete Properties

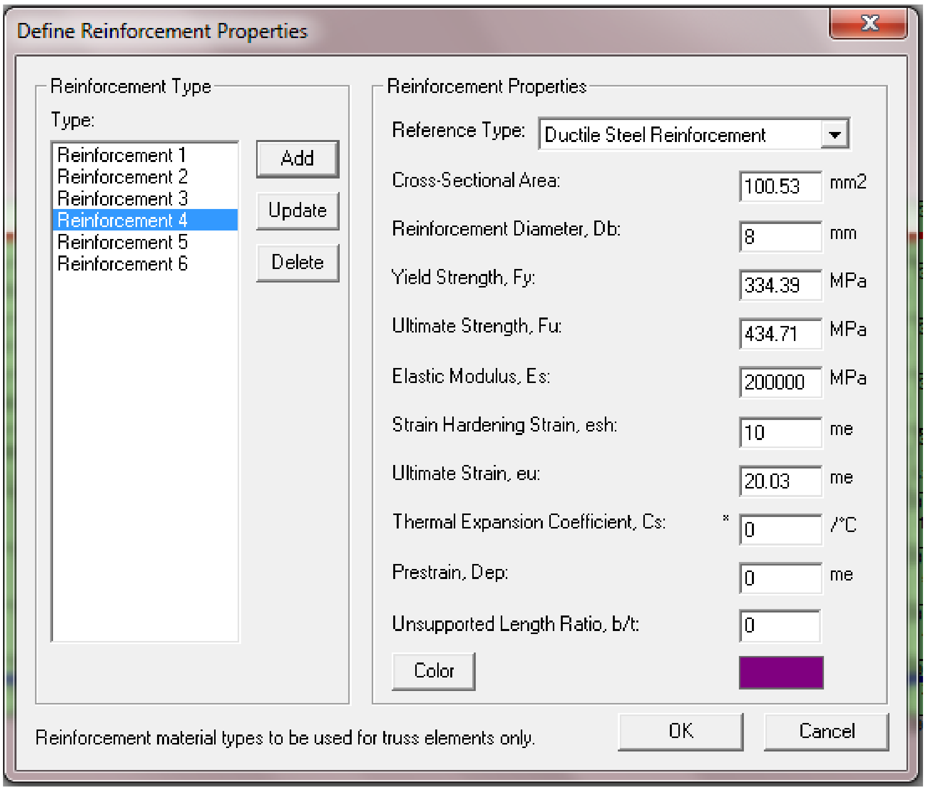


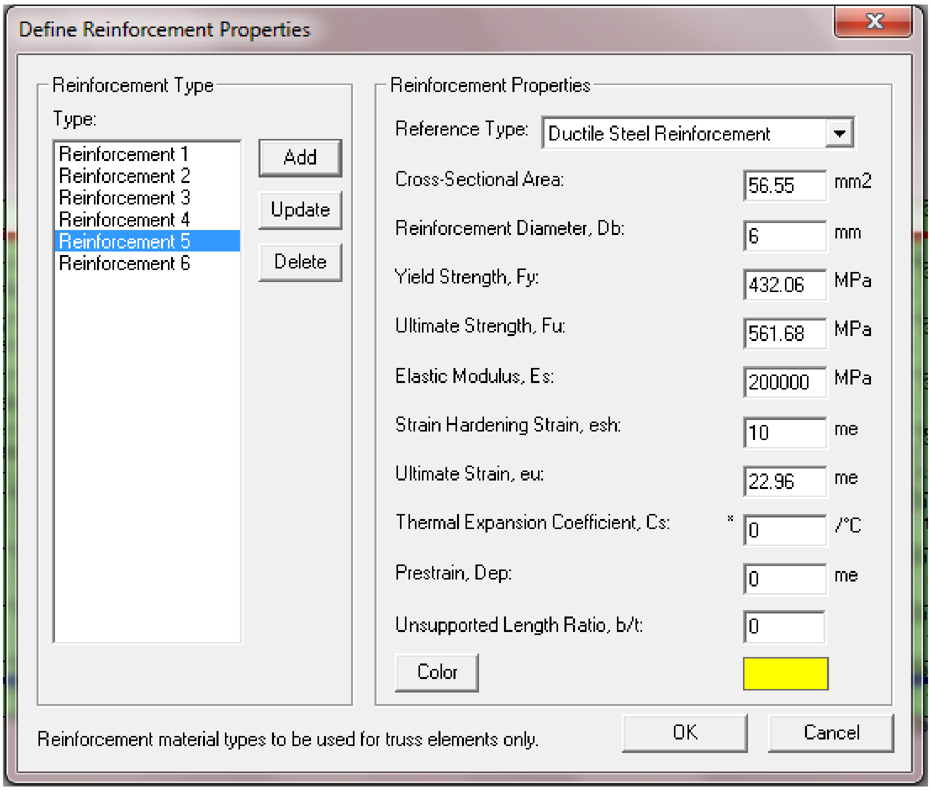
iv. Reinforcement Properties

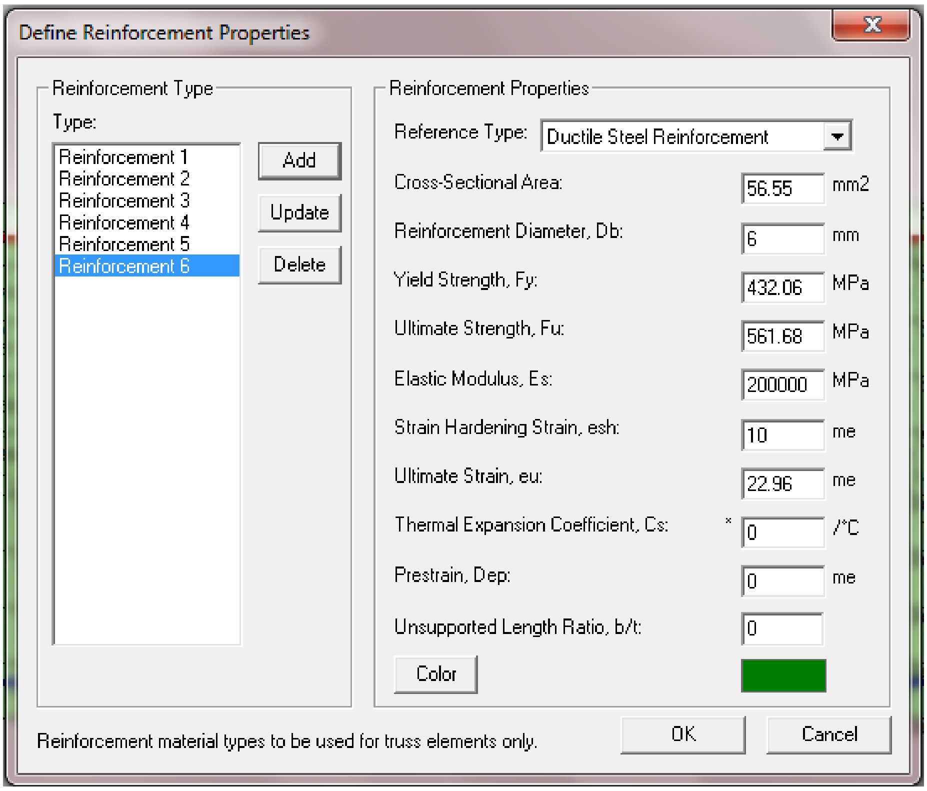



Define Reinforcement Properties
Reinforcement Type
Type:
Reinforcement 1
Reinforcement 2
Reinforcement 3
Reinforcement 4
Reinforcement 5
Reinforcement 6
Add
Update
Delete
Reinforcement Properties
Reference Type:
Ductile Steel Reinforcement
Cross-Sectional Area:
157.08
mm2
Reinforcement Diameter, Db:
10
mm
Yield Strength, Fy:
334.39
MPa
Ultimate Strength, Fu:
434.71
MPa
Elastic Modulus, Es:
200000
MPa
Strain Hardening Strain, esh:
10
me
Ultimate Strain, eu:
20.03
me
Thermal Expansion Coefficient, Cs:
*
0
/°C
Prestrain, Dep:
0
me
Unsupported Length Ratio, b/t:
0
Color
Reinforcement material types to be used for truss elements only.
OK
Cancel

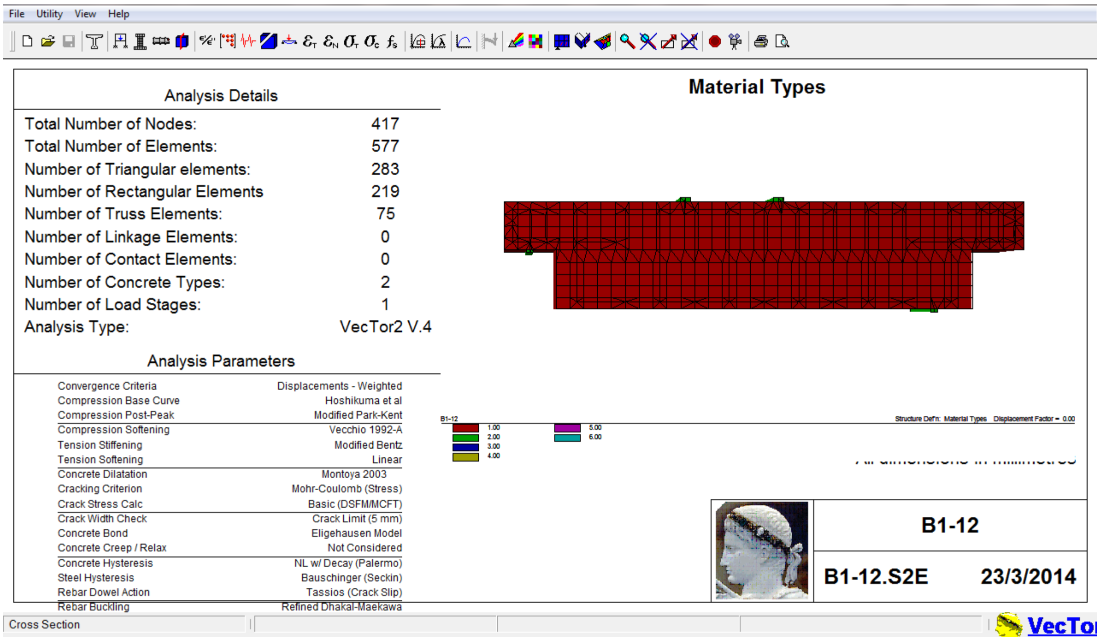

Define Reinforcement Properties
Reinforcement Type
Type:
Reinforcement 1
Reinforcement 2
Reinforcement 3
Reinforcement 4
Reinforcement 5
Reinforcement 6
Add
Update
Delete
Reinforcement Properties
Reference Type:
Ductile Steel Reinforcement
Cross-Sectional Area:
307.88
mm2
Reinforcement Diameter, Db:
14
mm
Yield Strength, Fy:
344.41
MPa
Ultimate Strength, Fu:
447.73
MPa
Elastic Modulus, Es:
200000
MPa
Strain Hardening Strain, esh:
10
me
Ultimate Strain, eu:
20.33
me
Thermal Expansion Coefficient, Cs:
*
0
/°C
Prestrain, Dep:
0
me
Unsupported Length Ratio, b/t:
0
Color
Reinforcement material types to be used for truss elements only.
OK
Cancel

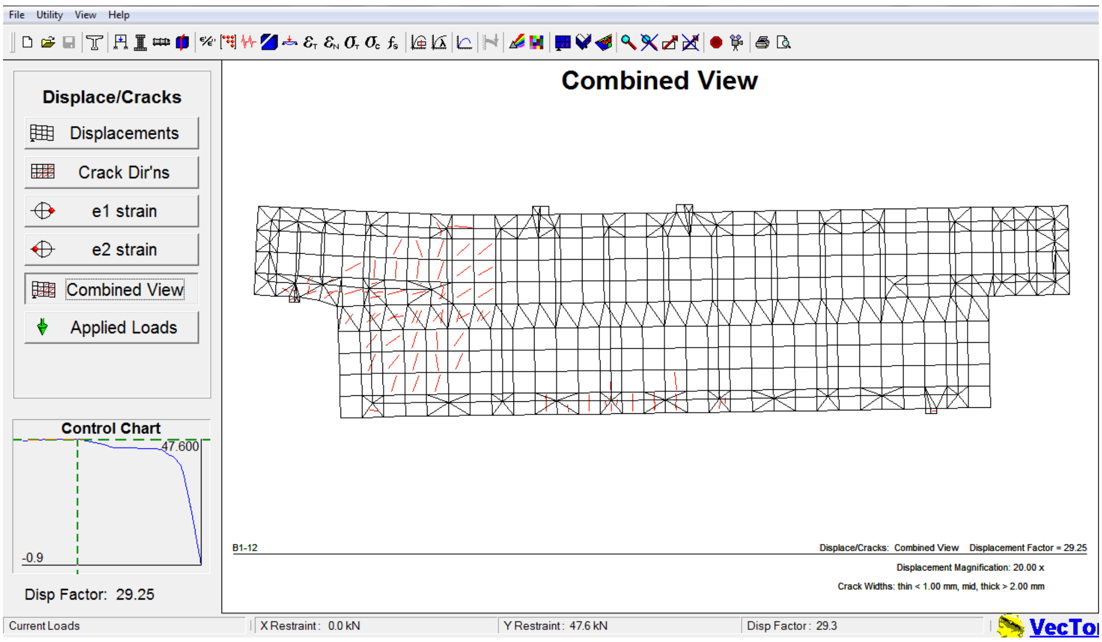

Define Reinforcement Properties
Reinforcement Type
Type:
Reinforcement 1
Reinforcement 2
Reinforcement 3
Reinforcement 4
Reinforcement 5
Reinforcement 6
Add
Update
Delete
Reinforcement Properties
Reference Type:
Ductile Steel Reinforcement
Cross-Sectional Area:
100.53
mm2
Reinforcement Diameter, Db:
8
mm
Yield Strength, Fy:
334.39
MPa
Ultimate Strength, Fu:
434.71
MPa
Elastic Modulus, Es:
200000
MPa
Strain Hardening Strain, esh:
10
me
Ultimate Strain, eu:
20.03
me
Thermal Expansion Coefficient, Cs:
*
0
/°C
Prestrain, Dep:
0
me
Unsupported Length Ratio, b/t:
0
Color
Reinforcement material types to be used for truss elements only.
OK
Cancel


Define Reinforcement Properties
Reinforcement Type
Type:
Reinforcement 1
Reinforcement 2
Reinforcement 3
Reinforcement 4
Reinforcement 5
Reinforcement 6
Add
Update
Delete
Reinforcement Properties
Reference Type:
Ductile Steel Reinforcement
Cross-Sectional Area:
56.55
mm2
Reinforcement Diameter, Db:
6
mm
Yield Strength, Fy:
432.06
MPa
Ultimate Strength, Fu:
561.68
MPa
Elastic Modulus, Es:
200000
MPa
Strain Hardening Strain, esh:
10
me
Ultimate Strain, eu:
22.96
me
Thermal Expansion Coefficient, Cs:
*
0
/°C
Prestrain, Dep:
0
me
Unsupported Length Ratio, b/t:
0
Color
Reinforcement material types to be used for truss elements only.
OK
Cancel


Define Reinforcement Properties
Reinforcement Type
Type:
Reinforcement 1
Reinforcement 2
Reinforcement 3
Reinforcement 4
Reinforcement 5
Reinforcement 6
Add
Update
Delete
Reinforcement Properties
Reference Type: Ductile Steel Reinforcement
Cross-Sectional Area: 56.55 mm2
Reinforcement Diameter, Db: 6 mm
Yield Strength, Fy: 432.06 MPa
Ultimate Strength, Fu: 561.68 MPa
Elastic Modulus, Es: 200000 MPa
Strain Hardening Strain, esh: 10 me
Ultimate Strain, eu: 22.96 me
Thermal Expansion Coefficient, Cs: * 0 /°C
Prestrain, Dep: 0 me
Unsupported Length Ratio, b/t: 0
Color
Reinforcement material types to be used for truss elements only.
OK
Cancel

OUTPUT FILES FROM FEA SOFTWARE





Data from Graph	
==============	
Title	: Control Chart
x-axis	y-axis
Line type : 0	
0	0
-0.001	0.4
-0.002	0.8
-0.003	1.2
-0.003	1.5
-0.004	2
-0.005	2.4
-0.006	2.8
-0.007	3.2
-0.008	3.5
-0.009	3.8
-0.01	4.2
-0.011	4.6
-0.011	5.1
-0.012	5.5
-0.013	6
-0.014	6.3
-0.015	6.6
-0.016	7
-0.017	7.5
-0.018	7.8
-0.019	8.2
-0.02	8.7
-0.02	9.1
-0.021	9.4
-0.022	9.7
-0.023	10.1
-0.024	10.5
-0.025	11
-0.026	11.3
-0.027	11.6
-0.028	12
-0.029	12.5
-0.029	12.8
-0.03	13.2
-0.031	13.6
-0.032	14.1
-0.033	14.3
-0.034	14.8
-0.035	15.2
-0.036	15.6
-0.037	16
-0.038	16.4
-0.039	16.7
-0.04	17.1
-0.041	17.6
-0.041	18
-0.042	18.4
-0.043	18.8
-0.044	19.2
-0.045	19.5
-0.046	19.9
-0.047	20.3
-0.048	20.7
-0.049	21.1
-0.05	21.5
-0.051	21.9
-0.052	22.1
-0.053	22.5
-0.054	23
-0.055	23.4
-0.056	23.8
-0.057	24.2
-0.058	24.7
-0.059	24.9
-0.06	25.2
-0.061	25.7
-0.062	26.1
-0.063	26.5
-0.064	26.9
-0.065	27.4
-0.066	27.7
-0.067	28.1
-0.068	28.5
-0.07	28.9
-0.071	29.2
-0.072	29.6
-0.073	30
-0.074	30.5
-0.075	30.8
-0.076	31.2
-0.077	31.5
-0.078	32
-0.079	32.3
-0.08	32.7
-0.082	33.2
-0.083	33.6
-0.084	34
-0.086	34.5
-0.087	34.8
-0.089	35.2
-0.09	35.5
-0.092	35.9
-0.094	36.3
-0.095	36.7
-0.097	37.1
-0.099	37.6
-0.101	37.8
-0.104	38.2
-0.107	38.6
-0.11	39
-0.114	39.4
-0.118	39.8
-0.123	40.1
-0.129	40.5
-0.138	41.1
-0.153	41.5
-0.17	42.3
-0.191	43.8
-0.229	43.9
-0.283	44.1
-0.339	44.4
-0.381	44.5
-0.416	44.5
-0.439	44.8
-0.46	45.4
-0.494	46.1
-0.598	47.6
-0.721	47.6
-0.811	47.4
-0.865	47