Verification and Validation of the technical outreach activities for the Civil discipline

A Thesis submitted by

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ABSTRACT

This dissertation research the activities in technical outreach programs based on the civil discipline. The research question is how effective existing STEM and outreach programs in are representing the civil discipline, and what modifications can be made to enhance their relevance and appeal to the younger generations. These activities can be outdated and not keeping with technology advancements. A series of tests were conducted to evaluate different configurations and determine how accurate the PASCO kit was. With the results to be used to develop workbooks with activities for years groups 5-12 displaying civil discipline aspects. Results show that overall that the PASCO kit was inaccurate compared to the theoretical calculations but was always accurate in determining axial forces in terms of compression and tension. The draft activities and workbooks developed based on this were tested with students and observations were made. These observations reiterated the fact that the younger prefer hands on activities and can be easily distracted. Further development should focus on the increasing engagement of students and relating to real world problems. This research contributes to the development of outreach programs and the continue developed to increase interest STEM areas to increase the amount of professional in the industries and graduates.

CERTIFICATION OF THESIS

I Ben Coultas declare that the Thesis entitled Verification and Validation of the technical outreach activities for the Civil disciplines is not more than 100,000 words in length including quotes and exclusive of tables, figures, appendices, bibliography, references, and footnotes. The thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work.

Date: 04/11/2024

Endorsed by:

Dr Zachary Quince
Principal Supervisor

Student and supervisors' signatures of endorsement are held at the University.

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TABLE OF CONTENTS

ABSTRACT i
CERTIFICATION OF THESIS ii
ACKNOWLEDGEMENTS iii
LIST OF TABLES vi
LIST OF FIGURES x
ABBREVIATIONS xiv
CHAPTER 1: INTRODUCTION 1
1.1. Background Information 1
1.2. Problem Statement 1
1.3. Objectives 1
1.4. Research Question 1
1.5. Scope 2
1.6. Limitations 2
CHAPTER 2: LITERATURE REVIEW 3
2.1. STEM Outreach Programs 4
2.1.1. Different Types of Programs 4
2.1.2. Attracting Students to STEM universities. 6
2.1.3. Engineering and Discipline Specific 9
2.1.4. Civil Engineering Outreach 10
2.1.5. Completion of Programs 15
2.2. Impacts on Students Decisions 16
2.2.1. Age Demographics 16
2.2.2. Sense of Belonging 17
2.3. Conclusion 19
CHAPTER 3: Methodology 21
3.1. Project Goals 21
3.2. Existing Literature 23
3.3. Resources validation and limitations 23
3.4. Conceptual design of the activities 24
3.5. Development of draft activity manuals 24
3.6. Field Testing observations and results 24
3.7. Evaluation Techniques 25

CHAPTER 4: Results 26
4.1. Resource and limitations 26
4.1.1. Desktop Assessment of products 26
4.1.2. PASCO Bridge Building Kit capabilities and limitations 26
4.1.3. Warren Truss Bridge Three Cell 28
4.1.4. Warren Truss Bridge Five Cell 30
4.1.5. Warren Truss Cantilever Bridge Three Cell 32
4.1.6. Warren Truss Cantilever Bridge Five cell 34
4.2. Conceptual design of the activities 36
4.2.1. Activity 1 – year 5 & 6 36
4.2.2. Activity 2 – year 7 & 8 37
4.2.3. Activity 3 – year 9 & 10 38
4.2.4. Activity 4 – year 11 & 12 39
4.3. Bridge Building Activity Workbooks 40
4.3.1. Student workbook 40
4.4. Field Testing observations and results 41
4.4.1. Year 5 & 6 42
4.4.2. Year 7 & 8 42
4.4.3. Year 9 & 10 43
4.4.4. Year 11 & 12 43
CHAPTER 5: DISCUSSION AND CONCLUSION 44
5.1. Validation of the PASCO Bridge Building Kit 44
5.2. Activities 45
5.3. Bridge Building Activity Workbooks 46
5.4. Evaluation 47
5.4.1. Accuracy of the resource/s 47
5.4.2. Where the activities sheet easy to understand and follow? 47
5.4.3. Meeting project goals 48
5.5. Conclusion 48
REFERENCES 50
APPENDIX A 52
APPENDIX B 114

LIST OF TABLES

Table 1 Decision making regarding university trajectories by year From Why are students choosing STEM and when do they make their choice? 7

Table 2 Who had the most influence on your decision to pursue a STEM degree From Why are students choosing STEM and when do they make their choice? 7

Table 3 Introducing High School Students into the Multidisciplinary World of Bridge Construction Using Project-Based Learning 15

Table 4 Requirements of research questions 23

Table 5 Warren Truss Bridge Three Cell recorded data from PASCO for Beam AB 30

Table 6 Warren Truss Bridge Three Cell data compassion between PASCO data and theoretical data 31

Table 7 Warren Truss Bridge Five Cell recorded data from PASCO Beam AB 32

Table 8 Warren Truss Cantilever Bridge Three Cell recorded data from PASCO for Beam AB 32

Table 9 Warren Truss Cantilever Bridge Three Cell recorded data from PASCO for Beam AB 33

Table 10 Table 10 - Warren Truss Cantilever Bridge Three Cell data compassion between PASCO data and theoretical data 34

Table 11 Warren Truss Cantilever Bridge Five Cell recorded data from PASCO for Beam AC 35

Table 12 Warren Truss Cantilever Bridge Three Five data compassion between PASCO data and theoretical data 36

Table 13 Warren Truss Bridge Three Cell recorded data from PASCO for node A 55

Table 14 Warren Truss Bridge Three Cell recorded data from PASCO for Beam AB 56

Table 15 Warren Truss Bridge Three Cell recorded data from PASCO for Beam AC 57

Table 16 Warren Truss Bridge Three Cell recorded data from PASCO for Beam BD 58

Table 17 Warren Truss Bridge Three Cell recorded data from PASCO for Beam CD.. 59
Table 18 Warren Truss Bridge Three Cell recorded data from PASCO for Beam CE.. 60
Table 19 Warren Truss Bridge Three Cell recorded data from PASCO for Beam DE.. 61
Table 20 Warren Truss Bridge Three Cell recorded data from PASCO for node E.. 62
Table 21 Warren Truss Bridge Five Cell recorded data from PASCO for node A.. 68
Table 22 Warren Truss Bridge Five Cell recorded data from PASCO for Beam AB 69
Table 23 Warren Truss Bridge Five Cell recorded data from PASCO for Beam AC 70
Table 24 Warren Truss Bridge Five Cell recorded data from PASCO for Beam BC 71
Table 25 Warren Truss Bridge Five Cell recorded data from PASCO for Beam BD 72
Table 26 Warren Truss Bridge Five Cell recorded data from PASCO for Beam CD 73
Table 27 Warren Truss Bridge Five Cell recorded data from PASCO for Beam CE 74
Table 28 Warren Truss Bridge Five Cell recorded data from PASCO for Beam DE 75
Table 29 Warren Truss Bridge Five Cell recorded data from PASCO for Beam DF 76
Table 30 Warren Truss Bridge Five Cell recorded data from PASCO for Beam EF.. 77
Table 31 Warren Truss Bridge Five Cell recorded data from PASCO for Beam EG 78
Table 32 Warren Truss Bridge Five Cell recorded data from PASCO for Beam FG 79
Table 33 Warren Truss Bridge Five Cell recorded data from PASCO for node G 80

Table 34 Warren Truss Cantilever Bridge Three Cell recorded data from PASCO for Beam AB 87
Table 35 Warren Truss Cantilever Bridge Three Cell recorded data from PASCO for Beam AC 88
Table 36 Warren Truss Cantilever Bridge Three Cell recorded data from PASCO for Beam BC 89
Table 37 Warren Truss Cantilever Bridge Three Cell recorded data from PASCO for Beam AD 90
Table 38 Warren Truss Cantilever Bridge Three Cell recorded data from PASCO for Beam CD 91
Table 39 Warren Truss Cantilever Bridge Three Cell recorded data from PASCO for Beam CE 92
Table 40 Warren Truss Cantilever Bridge Three Cell recorded data from PASCO for Beam DE 93
Table 41 Warren Truss Cantilever Bridge Five Cell recorded data from PASCO for Beam AB 99
Table 42 Warren Truss Cantilever Bridge Five Cell recorded data from PASCO for Beam AC 100
Table 43 Warren Truss Cantilever Bridge Five Cell recorded data from PASCO for Beam AD 101
Table 44 Warren Truss Cantilever Bridge Five Cell recorded data from PASCO for Beam BC 102
Table 45 Warren Truss Cantilever Bridge Five Cell recorded data from PASCO for Beam CD 103
Table 46 Warren Truss Cantilever Bridge Five Cell recorded data from PASCO for Beam CE 104
Table 47 Warren Truss Cantilever Bridge Five Cell recorded data from PASCO for Beam DE 105
Table 48 Warren Truss Cantilever Bridge Five Cell recorded data from PASCO for Beam DF 106
Table 49 Warren Truss Cantilever Bridge Five Cell recorded data from PASCO for Beam EF.. 107
Table 50 Warren Truss Cantilever Bridge Five Cell recorded data from PASCO for Beam EG 108

Table 51 Warren Truss Cantilever Bridge Five Cell recorded data from PASCO for Beam FG 109

LIST OF FIGURES

Figure 1 Priorities of German engineering Students. 11
Figure 2 Reasons for never considering studying Engineering 18
Figure 3 Percentage of woman in different scientific majors at German universities 19
Figure 4 Example of PASCO Wireless Load cell 28
Figure 5 Example for Spark Vue output... 29
Figure 6 Diagram Warren Truss Bridge Three Cell 30
Figure 7 Warren Truss Bridge Three Cell axial force acting in Beam AB 30
Figure 8 Diagram Warren Truss Bridge Five Cell 31
Figure 9 Warren Truss Bridge Five Cell axial force acting in Beam AB. 32
Figure 10 Diagram Warren Truss Cantilever Bridge Three Cell 33
Figure 11 Warren Truss Cantilever Bridge Three Cell axial force acting in Beam AB 34
Figure 12 Diagram Warren Truss Cantilever Bridge Five Cell........... 35
Figure 13 Warren Truss Cantilever Bridge Five Cell axial force acting in Beam AC 36
Figure 14 Simple beam bridge activity for year 5 & 6 37
Figure 15 Diagram simple beam with forces 38
Figure 16 Simple Truss bridge activity for year 7 & 8 38
Figure 17 Diagram for a simple Truss Bridge with forces 39
Figure 18 Asymmetrical Truss bridge activity for year 9 & 10............ 39
Figure 19 Diagram of asymmetrical Truss bridge with forces............ 40
Figure 20 Asymmetrical Truss bridge activity for year 11 & 12 40
Figure 21 Diagram of asymmetrical Truss bridge with forces............ 41
Figure 22 Example workbook part two with theoretical equations 41
Figure 23 Outside factors effecting PASCO data collection 46
Figure 24 Beam layout for 9-10 & 11-12 Activity 48
Figure 25 Diagram Warren Truss Bridge Three Cell 54

Figure 26 Warren Truss Cantilever Bridge Three Cell reaction force acting in node A 55
Figure 27 Warren Truss Cantilever Bridge Three Cell axial force acting in Beam AB 56
Figure 28 Warren Truss Cantilever Bridge Three Cell axial force acting in Beam AC 57
Figure 29 Warren Truss Cantilever Bridge Three Cell axial force acting in Beam BD 58
Figure 30 Warren Truss Cantilever Bridge Three Cell axial force acting in Beam CD 59
Figure 31 Warren Truss Cantilever Bridge Three Cell axial force acting in Beam CE 60
Figure 32 Warren Truss Cantilever Bridge Three Cell axial force acting in Beam DE 61
Figure 33 Warren Truss Cantilever Bridge Three Cell reaction force acting in node E 62
Figure 34 Warren Truss Cantilever Bridge Three Cell Ski Civ axial forces 63
Figure 35 Diagram Warren Truss Bridge Five Cell 67
Figure 36 Warren Truss Cantilever Bridge Five Cell reaction force acting in node A 68
Figure 37 Warren Truss Cantilever Bridge Five Cell axial force acting in Beam AB 69
Figure 38 Warren Truss Cantilever Bridge Five Cell axial force acting in Beam AC 70
Figure 39 Warren Truss Cantilever Bridge Five Cell axial force acting in Beam BC 71
Figure 40 Warren Truss Cantilever Bridge Five Cell axial force acting in Beam BD 72
Figure 41 Warren Truss Cantilever Bridge Five Cell axial force acting in Beam CD 73
Figure 42 Warren Truss Cantilever Bridge Five Cell axial force acting in Beam CE 74

Figure 43 Warren Truss Cantilever Bridge Five Cell axial force acting in Beam DE 75
Figure 44 Warren Truss Cantilever Bridge Five Cell axial force acting in Beam DF 76
Figure 45 Warren Truss Cantilever Bridge Five Cell axial force acting in Beam EF.......... 77
Figure 46 Warren Truss Cantilever Bridge Five Cell axial force acting in Beam EG 78
Figure 47 Warren Truss Cantilever Bridge Five Cell axial force acting in Beam FG 79
Figure 48 Warren Truss Cantilever Bridge Five Cell reaction force acting in node G 80
Figure 48 Warren Truss Cantilever Bridge Five Cell Ski Civ axial forces 81
Figure 49 Warren Truss Cantilever Bridge Three Cell.......... 86
Figure 50 Warren Truss Cantilever Bridge Three Cell axial force acting in Beam AB 87
Figure 51 Warren Truss Cantilever Bridge Three Cell axial force acting in Beam AC.......... 88
Figure 52 Warren Truss Cantilever Bridge Three Cell axial force acting in Beam BC.......... 89
Figure 53 Warren Truss Cantilever Bridge Three Cell axial force acting in Beam AD.......... 90
Figure 54 Warren Truss Cantilever Bridge Three Cell axial force acting in Beam CD.......... 91
Figure 55 Warren Truss Cantilever Bridge Three Cell axial force acting in Beam CE.......... 92
Figure 56 Warren Truss Cantilever Bridge Three Cell axial force acting in Beam DE 93
Figure 57 Warren Truss Cantilever Bridge Three Cell Ski Civ axial forces 94
Figure 58 Warren Truss Cantilever Bridge Five Cell 98
Figure 59 Warren Truss Cantilever Bridge Five Cell axial force acting in Beam AB 99

Figure 60 Warren Truss Cantilever Bridge Five Cell axial force acting in Beam AC 100
Figure 61 Warren Truss Cantilever Bridge Five Cell axial force acting in Beam AD 101
Figure 62 Warren Truss Cantilever Bridge Five Cell axial force acting in Beam BC 102
Figure 63 Warren Truss Cantilever Bridge Five Cell axial force acting in Beam CD 103
Figure 64 Warren Truss Cantilever Bridge Five Cell axial force acting in Beam CE 104
Figure 65 Warren Truss Cantilever Bridge Five Cell axial force acting in Beam DE 105
Figure 66 Warren Truss Cantilever Bridge Five Cell axial force acting in Beam DF 106
Figure 67 Warren Truss Cantilever Bridge Five Cell axial force acting in Beam EF 107
Figure 68 Warren Truss Cantilever Bridge Five Cell axial force acting in Beam EG 108
Figure 69 Warren Truss Cantilever Bridge Five Cell axial force acting in Beam FG 109
Figure 70 Warren Truss Cantilever Bridge Five Cell Ski Civ axial forces 110

ABBREVIATIONS

CSIRO – Commonwealth Scientific and Industrial Research Organisation

EA – Engineers Australia

MEMS - micro-electromechanical system (MEMS)

QUT – Queensland University of Technology

SES - Socio economic status

SIEF – Science and Industry Endowment Fund

STEM – Science, Technology, Engineering and Mathematics

USA – Untied States of America

UTS – University of Technology Sydney

CHAPTER 1: INTRODUCTION

1.1. Background Information

As the title states, this research investigates the technical outreach activities and validating how effective they are at representing the civil discipline. With the increase in job vacancies as the show in by Engineers Australia research of 31% from January 2022 to December 2022. This indicates that there is potential an insufficient number of professional in the industry. Especially with research completed shows only 1,117 graduates in 2018. This thesis is about looking at existing STEM and outreach programs activities and how they are related to Civil engineering and if they are relevant to the current generations. With the idea for activities being developed in the past how as a profession have with grown with the times. With the younger generations having technology involved from a young age and in everyday life have we as an industry kept you with this.

1.2. Problem Statement

Based on the topic I have determined this to be the problem statement.

"To find a resource that can be used to develop activities for the younger generation that represents the Civil discipline, that also can potentially attract students into studying Civil engineering in the future."

1.3. Objectives

The objectives of the study and research are the following.

- Review existing outreach programs and determine how effective they are.
- What year groups should be focused on delivering STEM activities too
- Develop an outreach program that addresses any of these opportunities
- Determine if there are any on the market resources available that could be used to develop activities for students

1.4. Research Question

The reason I choose this topic was due to the impact it can have in the long term. I understand that we can only continue to develop with engaging students more then we currently do.

The research question is as follows

"How effective are existing STEM and outreach programs in representing the civil discipline, and what modifications can be made to enhance their relevance and appeal to the younger generations?"

This is formulated on trying to address the issues that I currently see in the industry.

1.5. Scope

The scope of the research is as follows:

- Assess existing outreach programs.
- Determine the year groups that the activities are aimed at.
- Develop activities that would be suitable for the year groups.
- Assess the activities and validated the accuracy comparing it to theoretical data and software
- Determine resources required
- Evaluate the effectiveness of the activities based on field testing with students

1.6. Limitations

The limitations that can have been foreseen for this thesis

- Limited field testing due to time constraints for this project
- Can only acquire on resources to test and validate
- Finding an on the market product that could be used including technology

CHAPTER 2: LITERATURE REVIEW

Civil Engineering is having an increasing demand throughout Australian and the world. As the would continue to grow in technology and population, the industry needs to continue to grow with it. From completing research, it shows that Australia as of December 2022 has a 31% increase is vacancies from January 2022. This roughly equates to 2,500 vacancies in 2022 (Australia, 2023). With the increase in vacancies and the growth in the industry a plan must be put in place to fill these gaps. Looking into the number of graduates it is shown that in 2018 only 1,117, this is lower than previous years. (Kaspura, 2020).

With these figures shown the number of graduates each year are never going to fill vacancies throughout Australia. As such, it is more important than ever to get students interested in STEM and specifically civil engineering. In the current world of artificial intelligence and robotics, traditional careers are less in ticking to students. This starts with getting the younger generation interested and educating them about civil engineering. In Australia there are many events such as the defence force with STEM Cadetship programs, universities with STEM packages like Australian National University and government programs like Engineers Australia 'Bridging the gap with university outreach programs' that have developed outreach projects which are designed to introduce the younger generation to engineering. The question remains how effective these programs and how many people are going onto complete a degree in civil engineering. Research shows that STEM programs can have a positive impact on the decisions made for future study. (Reed et al., 2021)

The outreach programs successfulness reliefs of the type of activities delivered in the program. When talking about civil engineering activities used in these programs the cliché is always the paddle pop stick bridge. These materials do not provide accurate information for prototyping, not sustainable and don't provide a great experience overall. As technology advances the industry also needs to move along with the times.

Universities had always been obligated to attract students to undertake studies. This is more involved in engineering due to the wide variety of majors that individuals can elected to study. Interactions with university staff can set the baseline of what a specific major might entail. Each discipline typically has a range of activities that can be used to demonstrate the challenges, uniqueness, and interactivity of an engineering discipline. Activities can come in many different forms such as on compulsory on campus experiences, voluntary open days and travelling activities. Academics typically design the activities that best aligns with their cutting-edge research but is this too technical for some demographics.

As such this thesis looks to design an interactive civil engineering outreach activity that is interchangeable for the age demographic and event type. Furthermore, the design will be grounded in the literature about what engages different age groups and demographics. It will also investigate the mechanisms that lead to successful articulation from outreach activities into enrolment.

2.1. STEM Outreach Programs

The idea of STEM programs has been mentioned in the education system of the USA since the early 1980’s (Breiner et al., 2012; Risk, 1983), where the AAAS developed the Project 2061 to assist with the growth in education of STEM subjects. With this idea slowly growing over the years it had an influx and gained momentum in 2001. This was based on poor performance for students on subjects of science and mathematics. The Committee on Prospering in the Global Economy of the 21st Century published *Rising above the gathering storm,* with this report being refer to by multiple individuals to increase the focus and commitment to STEM programs. This include the focus on improving K-12 science and mathematics education as a recommendation of the committee (America, 2007). With the focus and growth in programs there is a call for changing the STEM education and incorporating problem or inquiring based approach into the teaching methods as it focuses on more real-world applications within these approaches. There are also arguments opposing this approach including a body of literature (Unsworth et al., 2022)

2.1.1. Different Types of Programs

The management of outreach programs can differ in different universities with two main types of programs. The programs are known as Top-down and Bottom-up scenarios. The top-down scenarios are programs managed by the university under a high institutional legitimacy. The bottom-up scenarios rely on individual academic's initiatives to develop the programs and other departments supporting in a limited way. The main differences are how much involvement the institution provides support to the programs. The bottom-up program tends to be a start stop basis, this based on the academic's willingness to keep the program running and any limited funding the institution may supply. The issues that STEM programs have in obtaining a Top-down structure is that if it funded it relies on clients which maybe other institutions participation of students and demand for the programs. (‘Universities Conducting STEM Outreach’)

These STEM programs are generally run with different activities that relate to practical and theoretical analysis. These programs can range from a two-hour session to a six-week camp/program. With these different programs different activities can generally be part of it, focusing on one area or multiple to give students different exposure.

The short session (two hour) can is generally focused on one area of focus, such as engineering. The expert will more than likely be part of the industry or had training from industry experts. They will deliver an activity that focus on industry problems solving requirements, in the case of engineering such activities as bridge building out of different household materials such as paddle pop sticks or a deck playing cards. This will be a short presentation about the industry and different aspects then a hands activity.

The longer programs (six-week camp) can have different arrangements where they focus on STEM as a whole or break it down to a particular area such as mathematics or science focused. The programs will have activities to be completed like the short program but can have multiple stages or a range of different programs that have similar focus. An example is a program can have activities focused on science and engineering such as a make rocket launches and Engineering and Maths such as make a building out of household materials that needs to meet certain requirements. There are also programs that have opportunities to visit sites that may have technology that is being developed such as simulators for flying planes or driving trains that can also educated the students regarding STEM areas. (Davis & Hardin, 2013)

These programs are normally a collaborative effort between secondary schools and universities to organise and develop the programs.

2.1.2. Attracting Students to STEM universities.

Universities are important part in society as it provides training that start the development of professional careers in the right direction. The idea is to provide the resources that will give students the opportunity to learn in a safe and stable environment. These are the types of messages given to students in the classroom starting from a young age.

Research that has conducted peers to assess how STEM programs works with students in high school to attract to programs showed there are multiple factors that influence the decision of students and at different ages have different affects. The paper published by QUT '*Why are students choosing STEM and when they make their choice'* highlights the difference in year and what factors affect choices when choosing a career in STEM related fields. The research showed that the consideration of each year group has difference thoughts on their careers and studies. From surveys conducted in the research that year 12 students that 73% of students a decision on which university to attend and prior to that only a small number of students had decided that. (Dawes et al., 2015).

	Year 8 or below		Year 9		Year 10		Year 11		Year 12	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%
You decided on a broad area of study	105	18.82	77	13.80	153	27.42	109	19.53	114	20.43
You chose a specific course/degree	8	1.43	9	1.61	66	11.81	137	24.51	339	60.64
You chose a university	9	1.61	10	1.79	38	6.8	94	16.82	408	72.99

Table 1 Decision making regarding university trajectories by year From Why are students choosing STEM and when do they make their choice? (p. 7) by Dawes, L., Long, S., Whiteford, C., & Richardson, K Proceedings of the

Students in the lower years still where undecided on what universities what they wanted to attend. The specific career choices were also like the choices in university expected increasing in the decisions made in year 10 which students had made more of a choice. The only consistent factor what the choice in the broad area of study and this start from year 8 (Dawes et al., 2015).

These choices that the young students can be influenced by many factors but what are they is the questions that universities and careers advisers are asking themselves. Further research from QUT conducted a survey asking these questions with many options.

Choices	*n*	%
A teacher in class	221	36.29
TV, movies or books	199	32.68
Games or toys	186	30.54
A parent or relative	142	23.32
Visiting University	166	27.26
Clubs or activities	73	11.99
Work/Internship	56	9.20
A mentor	41	6.73
A famous person in the field	65	10.67
Science fairs/contests	44	7.22
Other	75	12.32

Table 2 Who had the most influence on your decision to pursue a STEM degree From Why are students choosing STEM and when do they make their choice? (p. 9) by Dawes, L., Long, S., Whiteford, C., & Richardson, K Proceedings of the 26th Annual Conference of the Australasian Association for Engineering Education (AAEE2015) Copywright 2015 by Australasian Association for Engineering Education

With the results in figure 4 it shows that the biggest influence are teachers in a class and the other that stands out to be a factor not really considered is a parent of relatives with 23.32%. The fact that parents and teachers are a major influencing factor also needs to be considered when developing a program. When targeting students STEM should be targeted to earlier years to introduce students in years 5-9 to this types of subjects and programs and years 10-12 should be to retain students in STEM programs (Dawes et al., 2015). A significant issue noted is the practice in Australia where teachers may instruct in STEM fields without proper qualifications, which can undermine effective teaching. The report calls for a focus on training graduate teachers to not only be knowledgeable in STEM subjects but also proficient in appropriate teaching methods. Overall, there are unresolved questions about which teaching approaches should be prioritized in the context of STEM education. (Unsworth et al., 2022)

Reaching out to students has always been a developing process to keep the younger generations interested and keeping up with technology. Using resources that are available to universities is marketing and communications. One of the ways outreach programs have been advised is through short videos on universities websites or other websites such as YouTube and social media. Recent studies completed has showed that YouTube is the second most visited website after google, with 78% of total traffic by 2021 (Mwenda et al., 2019)

The videos developed include information about the universities including and not limited to course experience, discussing the curriculum, teaching culture and academic extra-curricular activities. In the videos that also had a wide variety of different individuals with different backgrounds and ethnicity to target a wider audience.

A couple opportunities that were made clear was the content of the videos should have more information regarding the STEM programs and including videos directly focus on STEM part of websites advertising future career opportunities and the possibilities with dual degrees. Increasing the content on STEM related fields, with more in depth discussions will help draw in more students to universities (Mwenda et al., 2019)

Updating the materials used in recruiting and advertising regularly to stay up to date with the times and course. Using other current students to serve as ambassadors and supporting on going activities to enhance retention.(Hubbard & Hubbard, 2009) Being able to advertise to multiple schools with this update to date information shows that the universities cares about the program.

With reaching out to student's programs needed to be developed that meet needs of the students. A program developed by the UTS the Wanago program which keys aims for long term development included:

Achieve 50% Gender Diversity

Access for low socioeconomic students

Build teacher capacity from industry experts.

Raise students, parents, and community awareness for future of STEM career opportunities.

Advocate for STEM education and facilitating pathways.

This program focused on providing resources and experts to make the experience easier on secondary education facilities and more attractive to them to participate in the program. (Maher & Ng, 2020)

Part of attracting students to universities have been known to have big events such as outreaches days for potential students to get an understanding of the programs and universities. These days can include presentations for industry specialists from the university to talk about real world experience and how their built their career. Workshops involving activities that hands on participation and understand different career options, with competitions part of the activities. Some universities offer a short-term work experience normally a 5-day programs that allows for students to experience what the professional would face each day. There are also some universities looking into the options for after school programs.

Studies have shown there are serval factors that affect the choices the of students when choosing a university to study engineering at. These factors can be broken down into five main factors, academic programme, institutional ranking, support systems, learning environment and student life. (Gille et al., 2022)

2.1.3. Engineering and Discipline Specific

Different outreach programs are run all over the country with multiple universities supplying these programs with a range of STEM activities. These can range from focusing on a particular discipline such as engineering or focusing on a broad range of topics that the universities can offer.

Programs focus on engineering that are delivered by different universities/ collages “Engineering the World” at Lawrence Technological University which is focused on civil engineering activities to explore the types of problems and challenges that engineers face. (Hanson et al., 2003)

Griffith University have a program that is focused on STEM pathways for year 11 and 12 students to complete first year course of engineering. This gives them the opportunity to get an understanding of the requirements for STEM course and with opportunity to get credits in undergraduate engineering degree. (Harris, 2024)

The CSIRO have the program “CREST” which is designed to focus on all areas of STEM, with hands on activities online to introduce students to different aspect. Over the program the different activities are available for students to complete with some being structured and others being open innovative with guidance from an industry professional. (Csiro, 2021)

The university of Newcastle have a couple of different STEM programs with one being “Discovery Day” with a single day of activities and presentation at the university. The day has up to two hands on activities focus on engineering and science to choose from. Presentation from an industry expert ranging from different STEM topics pending what is available at the time. The day also includes a competition part of the hands-on activities that student compete against each other. (Uni_Newcastle, 2014)

2.1.4. Civil Engineering Outreach

Attracting students to civil engineering starts with how it is perceived in society and what type of career can the individual have. With young students being influenced by role models they see in society. This can come from family influences and idols seen in society on tv. Engineering isn’t known to have the media attention that musician or actors/ress get in society. This can also influence the decisions made on the career path at an early age. The young generation will tend to follow the industry that the rewards are more social accepted such as actors and celebrities. (Becker, 2010) (Dias, 2011)

Studies shows that students choosing to study civil engineering can be broken down into a couple of factors, with the main factors being good work life balance and Safe job/ employment. These factors and results are based on survey competed on 4200 engineering professionals in Germany but give a good representation of factors that influence choices (Becker, 2010)

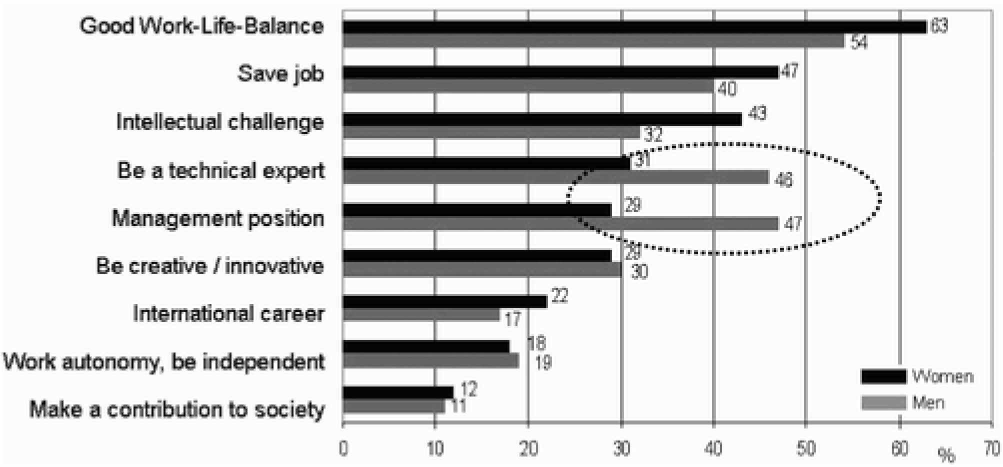

Figure 1 Priorities of German engineering Students – From Why don't young people want to become engineers? Rational reasons for disappointing decisions (p. 362) by Becker, F. S. European journal of engineering education Copywright 2010 by SEFI

An area to highlight with these finding that different genders have different influences that can impact what the expectations are and what the individual is looking for. With the main difference is that men tend to be a technical expert and or in management positions in their career compared to the woman who don't see this as important. (Becker, 2010)

With the younger generations coming through the education techniques needs to develop with the technology in the world. With the use of different technology in everyday life, it should be part of the curriculum and resources available. Including this with practical work like site visits and even developing new products to be used in the industry. This will also require the training for education professional to be experts in the technology with ongoing training and education. The education professional should also be from different backgrounds and gender as this will give opportunities for students to develop a relationships and mentorship (Becker, 2010)

Breaking down the programs one after school program called "Engineering the World" was developed at Lawrence Technological University by Civil Engineering professors and the help of undergraduate engineering students. This program was focused on civil engineering with different aspects including structural, construction, transport, hydraulic, geotechnical, environmental, and surveying engineering. This program was delivered to a middle school age student (year five to nine). The program successfulness relied on student interactions with the hands-on activities available made the sessions educational but also fun. The students were also able to visit the university, for some this was their first experience at a collage. Able to see what facilities are available not just at the collage but also what engineers have access to in the industry. (Hanson et al., 2003)

The program also had challenges to maintain student interests, identifying level for instruction, assisting with problematic students' teams dynamics, and continuing to improve learning activities. Being able to maintain interest in activities is an important aspect of every STEM program, this could be due to students not understanding the underlying theory of the activity. (Hanson et al., 2003)

The Griffith University STEM pathways programs is a way of introducing to students early to engineering course that would be required to complete part of a degree. It is focus on engineering discipline a hole, including different practical components of various disciplines. The idea is to introduce students to real world problems and guide them through possible solutions incorporating the environment, stakeholders, and engineering systems. (Harris, 2024)

The "discovery day" from university of Newcastle is to provide a wide range of STEM opportunities but does have activities focus directly on civil engineering such as bridge building and testing the bridge built by students. The days is about teambuilding and problem-solving real-world problems and understanding what professionals would experience through their careers. The students also look at the facilities that are available at the university that could help their career.

The QUT have a STEM activity which is designed to be delivered in a classroom at a school with their teachers. The activity is a bridge building activity to discuss the understanding of how bridges work and different types there are. Students go through the design process of a bridge then put these skills into action by building their own bridge based on a problem provided and testing it. (Faculty, 2019)

Activities from other outreach programs

The activities from the above outreach programs can range from different activities but a common factor is the bridge building was a major part as seen in the “Discovery Day”, “Engineering the World” and QUT Bridge building activity. These activities were used for a different range of ages from primary school to secondary school. As previously found through the research the most successful outreach programs had hands on activities to keep students engaged.

The bridge building is not the only activity that was used part of a civil engineering outreach programs as seen from the “Engineering the world” program. This program ranged into many activities that included civil engineering such as “Potholes in Motown”, “Don’t miss the Boat”, “Do you dig dirt?”, “Who’s trying to get you” and “From inchworms to lightyears”. These activities had a different aspect of civil engineering not just statics. These activities still had the same objects to get hands on for students but also show real world problems. (Hanson et al., 2003)

The “London Bridge falling down?” activity was design to address structural and civil engineering problems. The activity included in the design of a virtual bridge but also a physical bridge from K’NEX kits provided. These activities introduced students to different common terminology used such as compression, tension, and loading. From the learning with the teacher/presentator the students are sent into groups to compete creating a bridge to meet certain constraints. The virtual bridge was similar in to design bridged using a design program but the bridge winner was based on the cost of material but also meet the requirements. (Hanson et al., 2003)

The geotechnical activities involved hands on aspects as well but a had different range to introduce students to different concepts. One of the activities focus on effective stress in soils using the rubber glove with sand in it that have been subjected to vacuum pressure. Another activity was showing how reinforcement in a sand pile could stand up to greater weight applied to it rather than a control sand pile before failing. (Hanson et al., 2003)

The Hydraulic engineering activities was design to show students the effect of erosion on water systems and introducing different objects into the environment affected the flow of water. The idea was to create a model of a water way system, then introducing different objects such as model boulders and logs to show how it affects the environment. The activity was had issues with maintain focus from students due to the time it took for changes to take place after changing the environment. (Hanson et al., 2003)

A study that was completed titled '*Introducing High School Students into the Multidisciplinary work of Bridge construction using Project Based Learning*' reviewed the delivery of a program to students and what were the impacts. The study focused on determining the best resources to use based on available bridge building kits at the time. These including Lego, Lupo, Meccano, PASCO, K'NEX and Geomag. A comparison was completed between the different resources, comparing eight different characterises

Construction set	Element type	Connector type	Auxiliary elements	Average cost	Length of the longest element (mm)	Easiness of assembly	Main strength
Lego	Plastic blocks	—	No	€0.04	33	100	Widespread use and specific software: Robolab
Lupo	Building blocks of different materials	Binding wedges	No	€3.00	250	100	Large blocks
Meccano	Metal elements	Nuts and screws	Yes	€0.17	300	60	Widespread use and stiffness
Pasco	Plastic beams	Connectors and screws	Yes	€0.21	240	60	Sensors and devices specifically developed
K'NEX	Plastic rods	Plastic connectors	No	€0.05	86	100	Easy assembly
Geomag	Magnetic rods and bars	Steel spheres	No	€0.20	27	90	Magnetic connections

Table 3 Introducing High School Students into the Multidisciplinary World of Bridge Construction Using Project-Based Learning Page 2 López-Moya, S. S.-C., Jose, A. L.-G., Francisco, J. C., Elisa, P., Álvaro, G., Rocio, P

The K'NEX was deemed to be the best based on the characteristics assessed in Figure 6 according to the paper. The reason it was selected over the PASCO set was due to construction speed, they did also state they was issues with the K'NEX set due to rotation between bars and connectors. The paper suggested other technology and sensor on the market to test forces that are low cost.

The PASCO set was deemed to be one of the slower construction times and slightly more expensive when compared to the other, the area of strength compared to others was able to test forces. The PASCO kit is potentially able show's reaction and axial forces acting on the beams when a load is placed on a structure. Based on the element types there are limited structure that can be built. (López-Moya et al., 2020)

2.1.5. Completion of Programs

The activities completed can have a positive impact made about the successful of STEM outreach programs. These activities seem to be more affective in students participating based on how they relate to current high school learning styles. Students will be more engaged and have better participation(Zhou, 2020). Another factor is that the STEM programs should be more closely linked to current and future classroom work. Keeping the activities challenging and engaging is a difficult task that needs to be considered. Student will take more responsibility with the learning and not treat it like an excursion. (Colvin et al., 2013)

The activities that have the most effectiveness are hands on and combine practical learning and theoretical. To be able to adapt the activities to match the learning styles of the year group that it is being delivered to is important. With these activities they were found to be more effective with an external influencing factor also help the success. Having an opportunity for outreach program directors and educators to be about to intervene (Zhou, 2020). A more hands on delivery method where the educator works through activity with the students seems to work better than just given a work sheet. The activities that can have a larger focus on the hands-on activities rather than the discussing them were more successful. Combing this with some sort of competition for the students also drives success (Colvin et al., 2013) (Zhou, 2020).

The goals of the activities can also influence the students as they were more receptive to activities that enact communal goals and values. Activities that show civil infrastructure and technology that helps people and society (Colvin et al., 2013). The activities need to give an opportunity for students to be able to resonate with the identity of an engineer. To have different aspects that engineer would face in projects (Rosner et al., 2023).

2.2. Impacts on Students Decisions

2.2.1. Age Demographics

Studies completed on students in the Year 5-6 age group shows that they are emotional driven with decision making about difficult choices. The studies also show that the main impacts on students' decision are fears regarding career future, Investment in decision making process and knowledge of world of work. Having these area of concern addresses bring confidence to students about their future in the work force. The students receiving recognition for a task completed also provide a positive experience and growth (Sidiropoulou-Dimakakou et al., 2013)

As students mature the decisions on careers can change based on understanding of their abilities and achievement levels in as they age. This was noticed in a study completed for year 3- 9. The results relating to science and engineering there was only a ±1% difference in each year group. As students mature, they also get a greater understanding of what each career may entail which can affect their choices. This shows that getting to students at a younger age and naturing their career path choices can help them on track to stay on this path or can also provide opportunities to understand if they are suited for the profession. (Wallington et al., 2017)

Studies showed that the effects from outside influences had a major impact on the students. These influences include career advisor, parental support, and careers. The students that had the opportunity to discuss careers with advisors found it to be a better experience especially if it was a face-to-face conversation. The parents career also had a role to play when choosing a career in STEM or any fields. Students that had parents in the STEM career would be more likely to follow and understand the career path assuming they received support from parents. Parents where the greatest influence compared to the career advisor.(Murcia et al., 2020)

2.2.2. Sense of Belonging

A sense of belonging is an important factor when choosing a career with different factors affecting this. Different genders, sociocultural backgrounds, social acceptance from peers and disabilities experience different situations that impact life and career choices.

Studies shows that in engineering it is still a male dominated profession, with only 16% Australian engineering graduates and 16% of the Australian engineering workforce (Romanis, 2022). The questions are why do woman still have minimal interest in engineering?

Surveys completed with woman to determine factors that affect the choices made mainly why they didn't choose to study engineering are seen in the below figure.

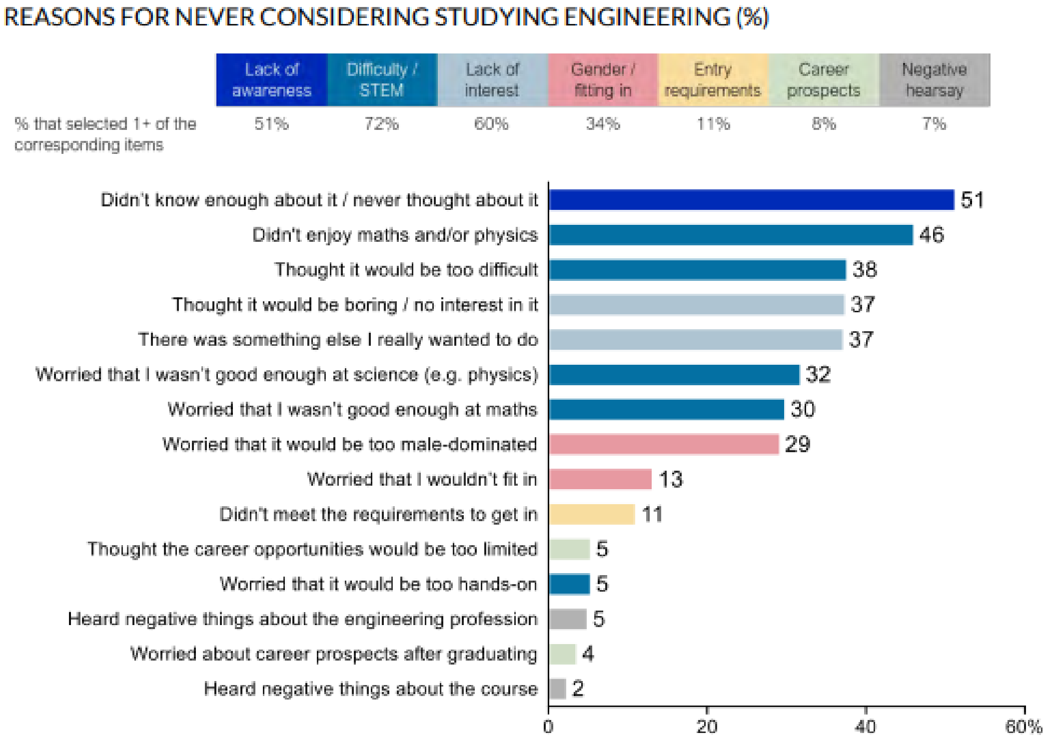

Figure 2 Reasons for never considering studying Engineering – From Woman in Engineering. (p. 18) by Romanis, J *Copywright 2022 by Engineer Australia*

The standout being that the subjects could be difficult to complete and lack of awareness as the main contenders. The one that stands out the most is "worried that it will be male dominated" with a 29% and "worried that I wouldn't fit in" with 13%.

This is a good indication that culture in the profession is still has a way to go to continue to change. (Romanis, 2022)

It is not just in civil engineering the issues with encouraging woman to make a career out of it. Studies completed in Germany also found that when considering the term engineering in the career path seem to dramatically drop the participation of woman. This can be attribute to young woman starting a career in engineering but will at some point in their career experience discrimination. (Becker, 2010)

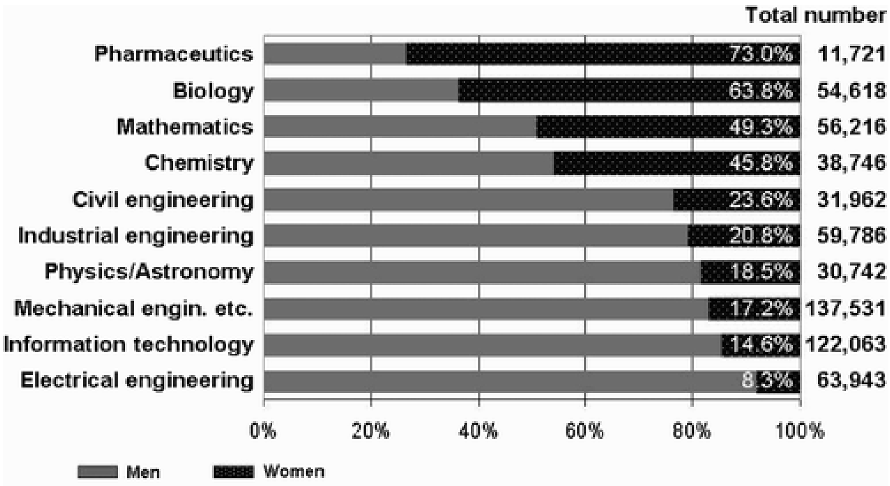

Figure 3 Percentage of woman in different scientific majors at German universities – From Why don't young people want to become engineers? Rational reasons for disappointing decisions (p. 359) by Becker, F. S. European journal of engineering education Copywright 2010 by SEFI

Studies completed on students being accepted at universities have also been conducted. A particular study showed that students in the first six weeks of their freshman year experiences had the most impact on their choice to continue studying. It was found that in the first six weeks students showed the most sensitive to marginality. The universities involvement with new students affects the voluntary dropout rates. The universities running programs such as learning communities and orientation course will help students become more open and expose them to broad educational opportunities (Hoffman et al., 2003)

The change of student stereotypes of culture is another area that needs to be addressed. The representation of the industry and experts can also help change students minds on the industry. Advising different cultures and genders in the profession can help students create a connection and feel included. Strategically picking teachers and media advertising to target different cultures and genders (Cheryan et al., 2024)

Disabilities can range from physical and mental, which impact individuals in different ways. The mainstream education curriculum doesn’t always suit disabilities and make it hard for students to be successful in their studies. They experience different challenges in everyday life that is not always easy to overcome. The support provided to these students need to be looked at during studying and career choices. Support is lacking in the resources provided from universities and secondary school, also professionals being able to identify other teaching methods. In the study participants highlighted that studying an undergraduate engineering programs can be complex and draining. Trying to align with the expected normal education and study methods made students not choose to further their education into university study and would drop out of secondary school. Gaining an understanding from students and listening will help develop programs and study method on how professional can help these individuals. (McCall et al., 2020)

The socio-economic status (SES) of students has always been an impact on how students choose their career. The students from low SES and higher SES backgrounds have similar career goals and aspirations. The factors affecting the low SES students' careers path choices are finical implications and capacity to navigate university paths ways. (Unpacking the career aspirations of Australian school students) The focus of outreach program should focus on more nurturing current career choices and provide more information and guidance for students facing low SES Important Factors in the Outreach Programs

2.3. Conclusion

Civil Engineering is facing an increased demand in Australia and other countries, and this can be attributed to technology advancements and population growth. The literature review showed from January to December 2022 there was a 31% increase in job vacancies which equates to approximately 2500 jobs. On the other hand, in 2018 there was only 1,117 graduates reported in the civil discipline.

Reports like the "Rising Above the Gathering Storm" emphasized the need for increased focus in the year groups K-12 education with regards to STEM subjects.

However, the effectiveness of outreach programs can vary based on management styles, top-down initiatives tend to receive more institutional support, while bottom-up programs depend on individual efforts to develop programs and can face sustainability challenges with support. There is still limited data available with the most successful program structure should be adopted.

Universities can contribute in shaping future professionals and should provide an engaging learning environment that communicates the opportunities of civil engineering. Outreach programs need to shift perceptions of the field, which often lacks the visibility enjoyed by more socially celebrated careers. As students are influenced by role models, it is crucial to promote civil engineering as a rewarding career option.

Research indicates that hands-on, problem-based learning activities can significantly enhance student engagement and understanding. Programs that incorporate real-world applications and are closely aligned with classroom curriculum not only capture students' interests but could show students what a career in civil engineering would be like.

Incorporating findings from studies on student decision-making, particularly for those in the year groups 5- 12. Providing positive reinforcement and recognition can significantly impact their confidence and engagement in the learning process.

A concerted effort to develop and improve STEM outreach programs is essential for filling the potential future vacancies in the civil discipline. By developing these programs with the interests and needs of students, the industry can better equip professionals to meet future challenges.

CHAPTER 3: Methodology

The framework of the methodology has been developed to assess the objectives and problem statement. It has been broken down into multiple steps to determine how the process that I will be following. This has been developed based on reference from the literature review complete in chapter 3. The following steps have been adopted.

1. Project Goals
2. Existing literature
3. Resources validation and Limitations
4. Conceptual design of configurations
5. Development of draft activities and manuals
6. Field testing on activities
7. Evaluations of Activities

3.1. Project Goals

The project goals have been developed based on the competing more literature review. These goals consider the research and findings of other papers. An area of focus is around how activities have been previously delivered and using the successful sections and learning from the opportunities. Taking the learning of other and the data from the research. These goals are designed not only to teach students about the concepts but also draw students in to want to learn more about the civil discipline.

Goal	Comments
Determine a resource that can be used for the activities.	Review on the market kits and materials that can be used meeting the following requirements - Hands on activities - Reuseable materials - Different bridge configuration - Shows different forces (axial and reactions minimum) - Simple to use - Use of Technology

Develop an activity that will work for year groups 5-12	Develop an activity that will be able to address the following: Hands on and fun for all ages Concepts for all ages to understand. Being able to keep students engaged for the whole activity. An activity that encourages participation for all involved
Develop suitable goals for activity	Represent an aspect of civil engineer
Develop activity sheet and instruction manual.	Make the activity sheets in practical order that is easy to follow for all and practical.
Involvement of Technology	The activity to have some involvement of technology, as the younger generation have increased interest in this.

Table 4 - Requirements of research questions

The program designed to display applications of the civil discipline in real world activities. To demonstrate how civil engineers consider forces and their effects on objects. The program is to introduce these concepts to 5-12 year groups, with the develop being age appropriate. With the younger groups introducing them to forces and the older groups expanding on their knowledge.

The idea for the program is to have a hands-on approach and make it educational by also attractive for the different groups. Adopting the objectives from the table 1 will be how the program is built.

3.2. Existing Literature

From the existing literature learning and developed of determine what types of activities to complete with the students. As mentions in section 2.1.2 activities to be developed should be focus on year 5-12 as their decisions on future career paths are never fully locked in. The year groups 5-9 are a group of students that are still looking for directions but also less interested in making that decision. The duration of activities is also an import are to consider when developing the activities, with the younger year groups can be easily distracted and a short focus span.

With different year groups the education levels tend to be different with introduction to different levels of STEM syllabus. It is important to make sure that the activities are suitable for each year group. The groups will be broken up in the year groups of 5-6, 7-8, 9-10 and 11-12. The idea will be to have a mix of different genders to allow different observation. The delivery of each activity is just as important, having knowledge in the subject is import for students gaining respect for the teacher and will have a higher chance of listening.

3.3. Resources validation and limitations

To determine the on the market resource that will be validated is determined by a desktop assessment completed based on the literature and further research. The initial assessment will begin based on the resources mention in figure XXX. The decision of what will be used will be based on the project goals and what will potentially achieve all sections. The idea is to have a resource that is potentially a full kit or with minimal outside resources to be used.

Assessment criteria is as follows:

- On the market and single product
- Innovative Technology
- Sustainable and environmentally friendly
- Easy to use and understand
- Cost
- Relation to Civil discipline

The second stage will be the validation of the product will be based on the capabilities of the resource and limitations. The validation will need to have a method developed that can be measurable and repeatable to get accurate results. These results will also need to be validated against a benchmark. This benchmark will be based on theoretical results and or a software, this may also require some assumptions to be determined.

3.4. Conceptual design of the activities

The activities that will be developed will need to be age appropriate and meet the project goals. The activities will need to group that will be broken up in the year groups of 5-6, 7-8, 9-10 and 11-12. Being able to compare the objectives and activities to real world problems and activities will be key in helping explain to the different year groups.

With the 5–6year group only going through the basic's concepts of statics for example resultant forces and 11–12year group assessing the compression and tensions forces in a truss bridge design.

3.5. Development of draft activity manuals

The instruction manuals will be developed to aid the presenter/teacher to deliver the activities. This will be made in conjunction with the activity sheet to align the program. They will have information to help explain the engineering terminology and objectives. With the range in students' year groups there will need to be different approaches to explain the activities and definition of terminology They should also be compared to the existing curriculum that the schools use and what the students have learned. There will be different manuals developed to address the different years groups of 5-6 , 7-8, 9-10, and 11-12. The key will be to create the content that is applicable to the year groups.

3.6. Field Testing observations and results

The field testing is about taking the draft activities and manuals out to a group of students and getting feedback from students and teachers. This will be complete with each year group respective to the activity. The testing environment will be based on the following

- Onsite at the school
- Groups to be made up of a minimum of four and maximum of ten

- Mixture of genders and cultures would be desirable
- The session will be delivered
- Each year group will be only available for one hour
- Each student will receive a draft activity manual

Due to not having any ethical approval no survey will be taken only observations from time in the sessions will be considered.

3.7. Evaluation Techniques

The successfulness of the program will be measured with quantitative and qualitive data collected from field testing and resource testing. Part of the development of the program the observations of the students will help analysis the opportunities for the draft program. With this data the activity sheets can be adjusted accordingly to benefit the delivery.

The data that will be measured:

- Accuracy of the resource/s
- Where the activities sheet easy to understand and follow?
- Where the instructions easy to follow from the presenter?
- Engagement from the students e.g. questions and participation?
- Meeting project goals

CHAPTER 4: Results

Following the methodology outlined in the previous section, results of the analysis concerning *"How effective are existing STEM and outreach programs in representing the civil discipline, and what modifications can be made to enhance their relevance and appeal to the younger generations?"* **Resource and limitations**

The assessment of the potential products was completed based on the criteria in section 3.3. From this the resource was determined to take into practical testing phase.

4.1.1. Desktop Assessment of products

The assessment of the products was limited based on the information available on the products used in a STEM capacity. Based on this the figure XXX was used to determine the product to be select.

Based on desktop criteria there was only two products that was considered for further testing these bring the PASCO and K'NEX. Further investigation into these products only one product was able to meet most of the requirements. This was the PASCO Bridge building kit; it has technology available with the kit that is designed to demonstrate civil aspects. This concepts that was advertised was the following

- Forces in Equilibrium
- Strength of Members
- Internal Forces
- Truss Analysis
- Moments in Equilibrium

4.1.2. PASCO Bridge Building Kit capabilities and limitations

The PASCO Model Kit has limited uses when it comes to the configurations and experiments. With the limited factors this reduces the opportunity for different types of assessment and analysis conducted on the structures. As stated in the methodology the results will be compared to the hand calculations and software to determine accuracy. The method of hand calculations will be to use the method of joints, and the software will be ski civ.

In the assessment for configurations, it was determined that a limited different number of truss, beam and cantilever bridges were available based on the standard supplied material in the kits.

Truss Connectors

The major limiting factors in the kits the truss connectors with only 16 available and limited angles that could be used. The angles of the truss connectors are limited to 180, 90 & 45 degrees, which reduces options to show how the changes in angles can affect the axial forces in the structures.

Wireless Load Cell

The Wireless Load cell has limited options that it can be used for when completing experiments on structures. The cell is limited to only an accuracy of ±50N, assuming it has been calibrated correctly. The sensor uses a micro-electromechanical system (MEMS) device The way the MEMS produces the results is with in conjunction of a compatible software such as "Spark Vue" or "Capstone" which the sensor must be Bluetooth connected to the software and is available on computer or an application on apple and android devices. The sensor transfers the data via Bluetooth to the software which computes the data with a pre-programmed algorithm use the equations below

Equations 1

$$\alpha_R = \sqrt{\alpha_x{}^2 + \alpha_y{}^2 + \alpha_z{}^2}$$

The equation 1 calculate the magnitude of the resulting acceleration based on the direction acting in the x, y and z.

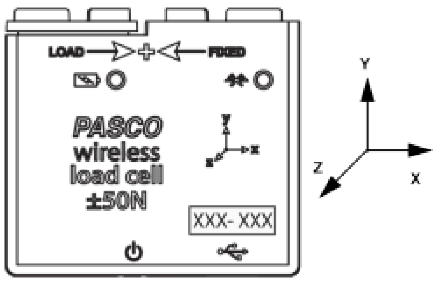

Figure 4 Example of PASCO Wireless Load cell

Based on the parts provided in the kit, there was four configurations that were assessed including a two Truss bridge and two cantilever truss bridges.

Spark Vue program

This program was identified to be used as it was compatible with an apple device which was able to be resourced. This program had multiple options include making custom experiments and using examples developed. Reviewing options available it with the examples only one could be selected that would be suitable for the testing. This example was only able to be used to determine axial forces in beam.

Figure 5 Example for Spark Vue output

It was able to produce graph comparing the force over time, and could recorded the data at different intervals ranging for 0.2s to 5s.There is preset field to help conduct experiments including programming stop times or to stop recorded when a specific force has been reached.

4.1.3. Warren Truss Bridge Three Cell

This bridge had a length of 0.5m and height of 0.125m, with beam 4 and 5 making up the main components. The weight of the load placed on the structure was 385grams which calculated to 3.78N. The structure was supported at node A and E, with the weight placed at C. See figure 6

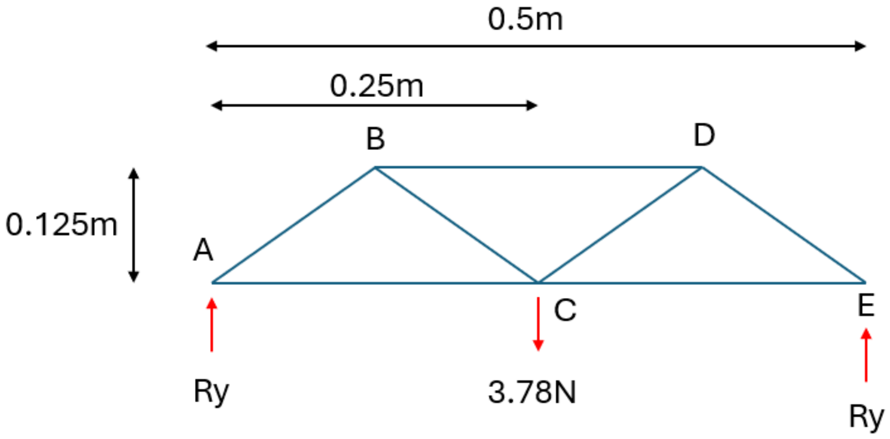

Figure 6 Diagram Warren Truss Bridge Three Cell

The data was tableted based on a ten second interval with data record at every second. This process was completed five times due to the fluctuation shown in the Spark Vue program receiving data from the wireless load sensor. With an average produced and used to compare this data to the theriacal data

Beam AB												
Time (s)	0	1	2	3	4	5	6	7	8	9	10	Average
Force (N) - 1	-2.54	-2.52	-2.55	-2.54	-2.56	-2.55	-2.54	-2.56	-2.52	-2.52	-2.55	**-2.54**
Force (N) - 2	-2.48	-2.48	-2.51	-2.5	-2.51	-2.5	-2.49	-2.46	-2.47	-2.46	-2.49	**-2.49**
Force (N) - 3	-2.47	-2.46	-2.48	-2.46	-2.44	-2.46	-2.51	-2.48	-2.47	-2.47	-2.45	**-2.47**
Force (N) - 4	-2.47	-2.46	-2.47	-2.47	-2.46	-2.45	-2.48	-2.47	-2.5	-2.47	-2.47	**-2.47**
Force (N) - 5	-2.48	-2.48	-2.49	-2.46	-2.45	-2.47	-2.46	-2.47	-2.46	-2.43	-2.45	**-2.46**

Table 5 - Warren Truss Bridge Three Cell recorded data from PASCO for Beam AB

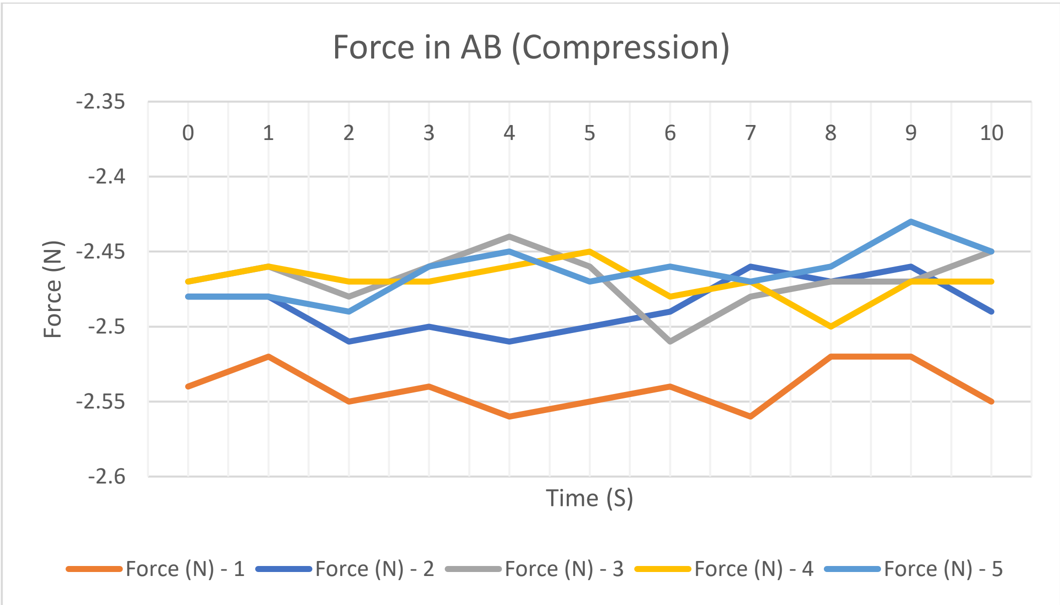

Figure 7 Warren Truss Bridge Three Cell axial force acting in Beam AB

Comparing the data there was significant difference in the data collected. See table 2 for results based on results in appendix A

Load at C					
Truss Bridge	PASCO	Theoretical	%	Sky Civ	%
Reaction at A	-1.89	-1.89	0.25%	-1.89	0.25%
Reaction at E	-1.89	-1.89	0.25%	-1.89	0.25%
Beam AB	-2.49	-2.67	6.90%	-2.67	6.90%
Beam AC	1.49	1.89	21.17%	1.89	21.17%
Beam BD	-3.43	-3.78	9.33%	-3.78	9.33%
Beam BC	2.52	2.67	5.61%	2.67	5.61%
Beam CD	2.56	2.67	4.17%	2.67	4.17%
Beam CE	1.51	1.89	20.33%	1.89	20.33%
Beam DE	-2.57	-2.67	3.80%	-2.67	3.80%

Table 6 - Warren Truss Bridge Three Cell data compassion between PASCO data and theoretical data

4.1.4. Warren Truss Bridge Five Cell

This bridge had a length of 0.75m and height of 0.125m, with beam 4 and 5 making up the main components. The weight of the load placed on the structure was 385grams which calculated to 3.78N. The structure was supported at node A and G, with the weight placed at C. See figure 8

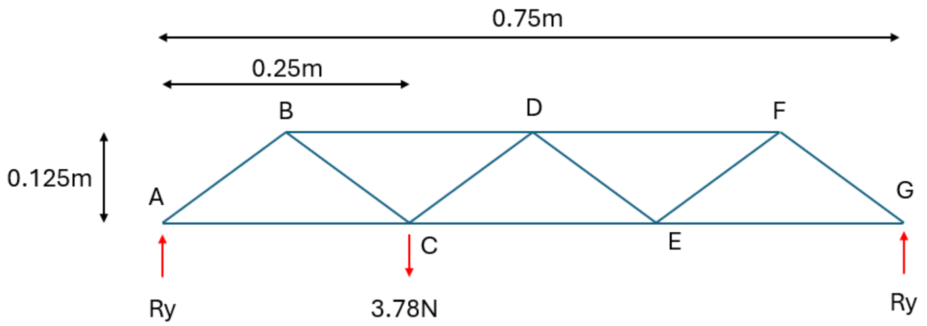

Figure 8 Diagram Warren Truss Bridge Five Cell

The data was tableted based on a ten second interval with data record at every second. This process was completed five times due to the fluctuation shown in the Spark Vue program receiving data from the wireless load sensor. With an average produced and used to compare this data to the theriacal data

Beam AB												
Time (s)	0	1	2	3	4	5	6	7	8	9	10	Average
Force (N) - 1	-3.22	-3.22	-3.24	-3.23	-3.23	-3.24	-3.25	-3.21	-3.22	-3.24	-3.24	**-3.23**
Force (N) - 2	-3.24	-3.24	-3.23	-3.22	-3.23	-3.24	-3.25	-3.25	-3.25	-3.23	-3.24	**-3.24**
Force (N) - 3	-3.23	-3.25	-3.26	-3.24	-3.26	-3.26	-3.26	-3.24	-3.23	-3.26	-3.25	**-3.25**
Force (N) - 4	-3.23	-3.24	-3.23	-3.23	-3.25	-3.23	-3.23	-3.24	-3.22	-3.23	-3.23	**-3.23**
Force (N) - 5	-3.25	-3.25	-3.28	-3.25	-3.28	-3.26	-3.27	-3.25	-3.26	-3.26	-3.25	**-3.26**

Table 7 - Warren Truss Bridge Five Cell recorded data from PASCO for Beam AB

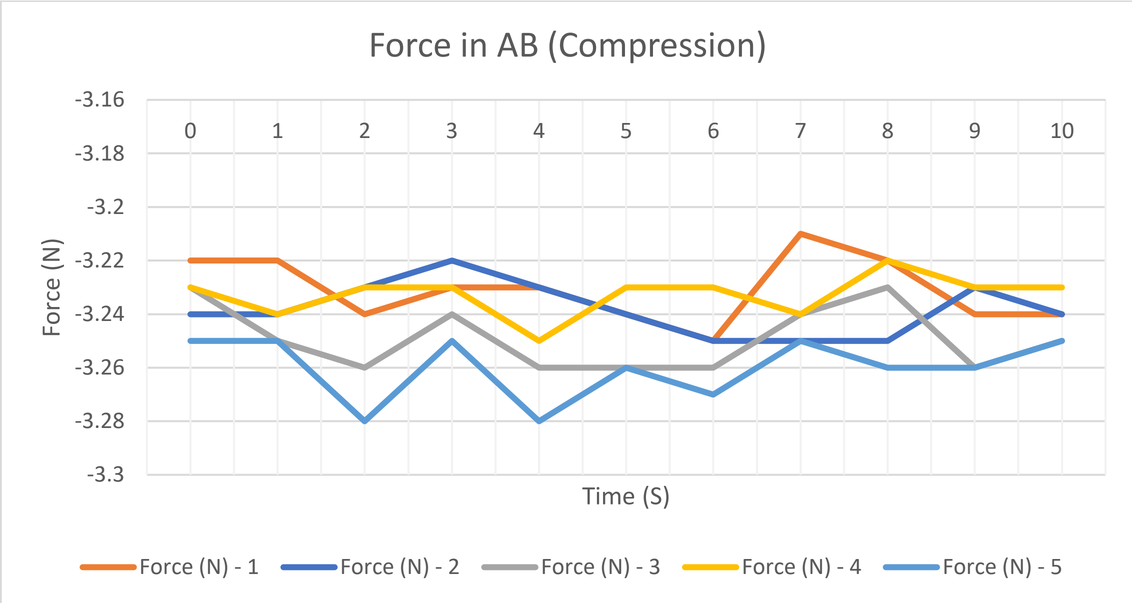

Figure 9 Warren Truss Bridge Five Cell axial force acting in Beam AB

Comparing the data there was significant difference in the data collected. See table 2 for results based on results in appendix A

Load at C					
Truss Bridge	PASCO	Theoretical	%	Sky Civ	%
Reaction at A	2.46	2.52	2.27%	2.52	2.27%
Reaction at G	1.24	1.26	1.53%	1.26	1.53%
Beam AB	-3.24	-3.56	8.93%	-3.56	8.93%
Beam AC	1.82	2.52	27.94%	2.52	27.94%
Beam BD	-4.48	-5.03	11.03%	-5.03	11.03%
Beam BC	3.43	3.56	3.58%	3.56	3.58%
Beam CD	1.70	1.78	4.45%	1.78	4.45%
Beam CE	3.00	3.78	20.60%	3.78	20.60%
Beam DE	-1.71	-1.78	3.84%	-1.78	3.84%
Beam DF	-2.20	-2.52	12.73%	-2.52	12.73%
Beam EG	0.67	1.26	47.22%	1.26	47.22%
Beam EF	1.65	1.78	7.16%	1.78	7.16%
Beam FG	-1.55	-1.78	12.81%	-1.78	12.81%

Table 8 - Warren Truss Bridge Five Cell data compassion between PASCO data and theoretical data

4.1.5. *Warren Truss Cantilever Bridge Three Cell*

This bridge had a length of 0.5m and height of 0.125m, with beam 4 and 5 making up the main components. The weight of the load placed on the structure was 385grams which calculated to 3.78N. The structure was supported at node A and E, with the weight placed at C. See figure 10

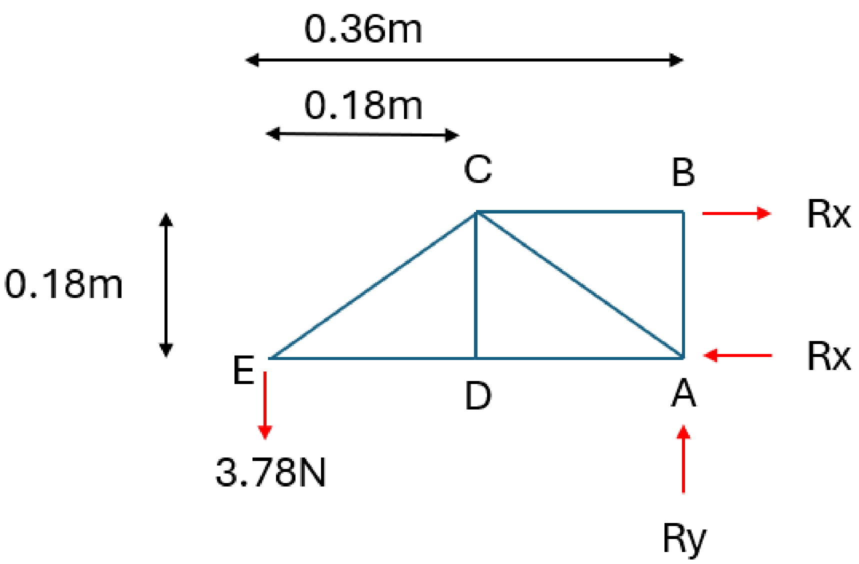

Figure 10 Diagram Warren Truss Cantilever Bridge Three Cell

The data was tableted based on a ten second interval with data record at every second. This process was completed five times due to the fluctuation shown in the Spark Vue program receiving data from the wireless load sensor. With an average produced and used to compare this data to the theriacal data

Beam AB												
Time (s)	0	1	2	3	4	5	6	7	8	9	10	Average
Force (N) - 1	-0.05	-0.05	0	0	0	-0.05	-0.05	-0.03	-0.01	-0.03	-0.01	**-0.03**
Force (N) - 2	-0.03	-0.04	-0.01	-0.01	-0.02	-0.05	-0.01	-0.03	0	-0.02	-0.01	**-0.02**
Force (N) - 3	0	-0.01	-0.02	-0.03	-0.03	-0.04	-0.05	0	0	-0.04	-0.01	**-0.02**
Force (N) - 4	-0.01	-0.05	0	-0.05	-0.05	-0.01	-0.01	0	0	-0.02	-0.05	**-0.02**
Force (N) - 5	0	-0.03	-0.01	-0.04	-0.03	-0.02	0	-0.02	-0.05	-0.04	0	**-0.02**

Table 9 - Warren Truss Cantilever Bridge Three Cell recorded data from PASCO for Beam AB

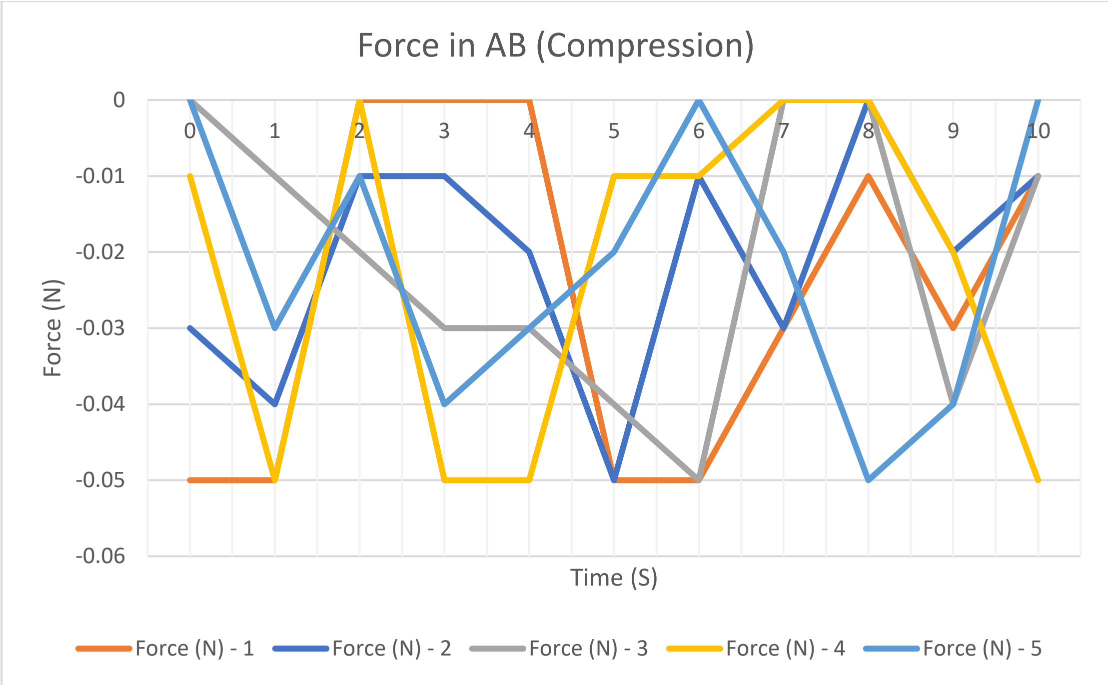

Figure 11 Warren Truss Cantilever Bridge Three Cell axial force acting in Beam AB

Comparing the data there was significant difference in the data collected. See table 2 for results based on results in appendix A

Load at E					
Truss Bridge	PASCO	Theoretical	%	Sky Civ	%
Reaction at Ax	[redacted]	-11.34	100.00%	-11.34	100.00%
Reaction at Ay	[redacted]	3.78	100.00%	3.78	100.00%
Reaction at Bx	[redacted]	11.34	100.00%	11.34	100.00%
Beam AB	-0.03	0	3.00%	0	3.00%
Beam AC	-4.90	-5.35	8.50%	-5.35	8.50%
Beam AD	3.71	3.78	1.73%	3.78	1.73%
Beam BC	7.35	7.56	2.83%	7.56	2.83%
Beam CD	0.04	0	4.00%	0	4.00%
Beam CE	4.75	5.35	11.29%	5.35	11.29%
Beam DE	-3.61	-3.78	4.56%	-3.78	4.56%

Table 10 - Warren Truss Cantilever Bridge Three Cell data compassion between PASCO data and theoretical data

During the data collection the reaction at joints A and B were not able to be captured using the wireless load sensor. The was this structure was secured to the table didn't allow the sensor to be attached that would allow accurate readings.

4.1.6. Warren Truss Cantilever Bridge Five cell

This bridge had a length of 0.5m and height of 0.125m, with beam 4 and 5 making up the main components. The weight of the load placed on the structure was 385grams which calculated to 3.78N. The structure was supported at node A and E, with the weight placed at C. See figure 12

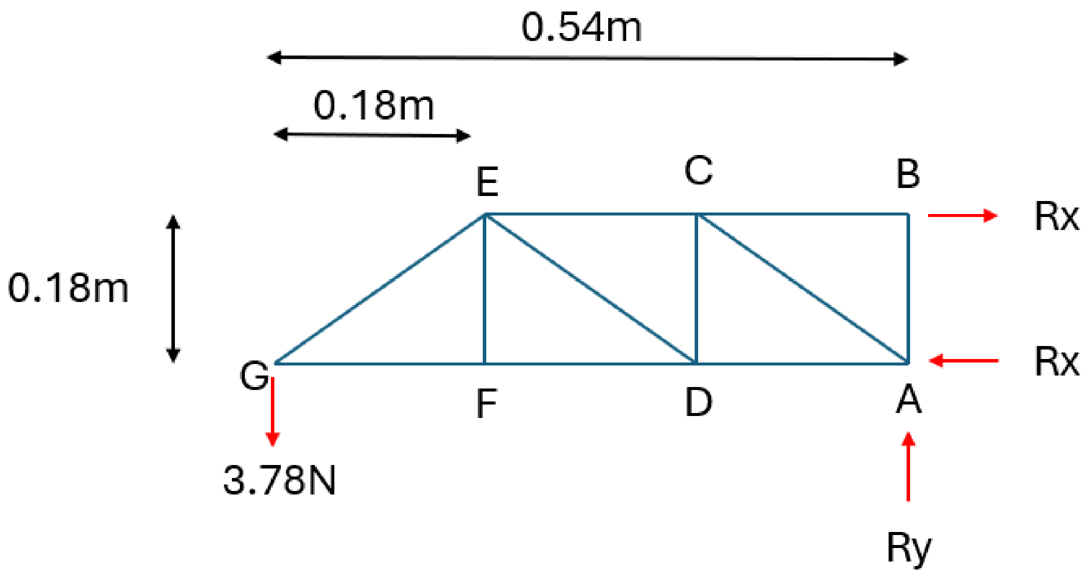

Figure 12 Diagram Warren Truss Cantilever Bridge Five Cell

The data was tableted based on a ten second interval with data record at every second. This process was completed five times due to the fluctuation shown in the Spark Vue program receiving data from the wireless load sensor. With an average produced and used to compare this data to the theriacal data

Beam AC												
Time (s)	0	1	2	3	4	5	6	7	8	9	10	Average
Force (N) - 1	-4.87	-4.89	-4.86	-4.9	-4.93	-4.88	-4.93	-4.89	-4.92	-4.89	-4.96	**-4.90**
Force (N) - 2	-4.94	-4.89	-4.95	-4.92	-4.92	-4.9	-4.9	-4.94	-4.91	-4.94	-4.93	**-4.92**
Force (N) - 3	-4.86	-4.9	-4.94	-4.88	-4.88	-4.92	-4.94	-4.89	-4.92	-4.87	-4.96	**-4.91**
Force (N) - 4	-4.95	-4.92	-4.91	-4.93	-4.94	-4.94	-4.9	-4.94	-4.93	-4.9	-4.89	**-4.92**
Force (N) - 5	-4.92	-4.96	-4.87	-4.92	-4.87	-4.94	-4.87	-4.87	-4.91	-4.96	-4.93	**-4.91**

Table 11 - Warren Truss Cantilever Bridge Five Cell recorded data from PASCO for Beam AC

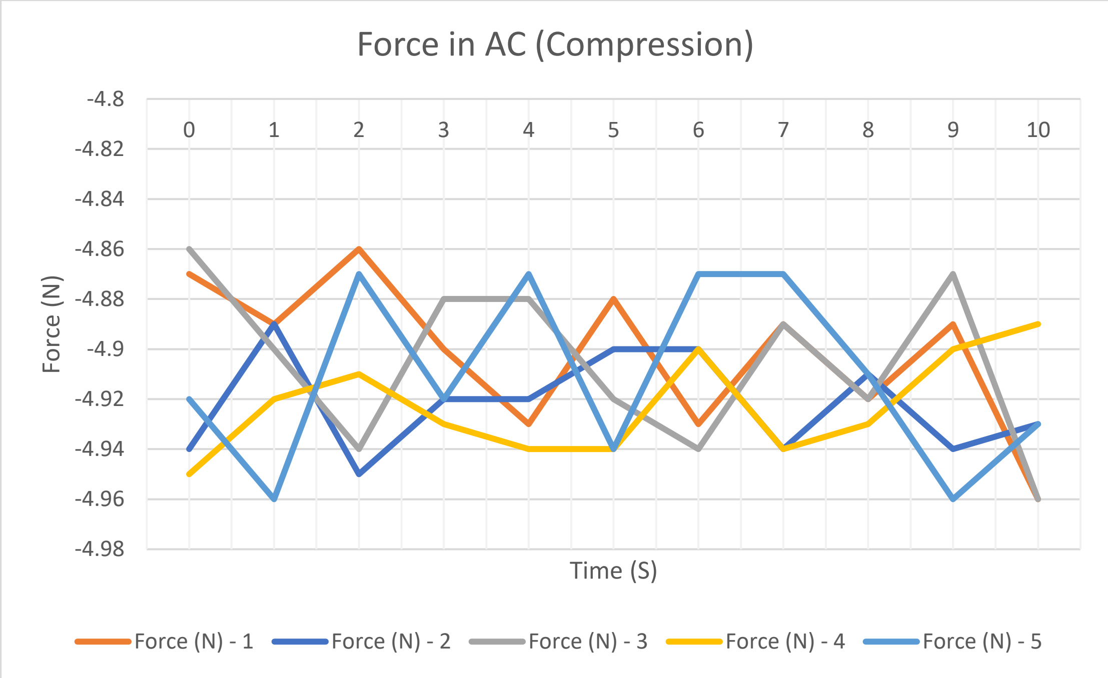

Figure 13 Warren Truss Cantilever Bridge Five Cell axial force acting in Beam AC

Comparing the data there was significant difference in the data collected. See table 2 for results based on results in appendix A

5 Cell Truss Cantilever					
Truss Bridge	PASCO	Theoretical	%	Sky Civ	%
Reaction at Ax	[redacted]	-11.34	100.00%	-11.34	100.00%
Reaction at Ay	[redacted]	3.78	100.00%	3.78	100.00%
Reaction at B	[redacted]	11.34	100.00%	11.34	100.00%
Beam AB	-0.03	0	3.00%	0	3.00%
Beam AC	-4.91	-5.35	8.18%	-5.35	8.18%
Beam AD	-7.41	-7.56	2.02%	-7.56	2.02%
Beam BC	11.17	11.34	1.49%	11.34	1.49%
Beam CD	3.59	3.78	4.92%	3.78	4.92%
Beam CE	7.34	7.56	2.94%	7.56	2.94%
Beam DE	-4.87	-5.35	8.88%	-5.35	8.88%
Beam DF	-3.69	-3.78	2.35%	-3.78	2.35%
Beam EG	4.71	5.35	11.95%	5.35	11.95%
Beam EF	0.02	0	2.00%	0	2.00%
Beam FG	-3.60	-3.78	4.77%	-3.78	4.77%

Table 12 - Warren Truss Cantilever Bridge Three Five data compassion between PASCO data and theoretical data

During the data collection the reaction at joints A and B were not able to be captured using the wireless load sensor. The was this structure was secured to the table didn't allow the sensor to be attached that would allow accurate readings.

4.2. Conceptual design of the activities

The conceptual design for the activities needs to allow four different activities that could accommodate for the different education levels and linking back to successful approaches found in the literature review.

4.2.1. Activity 1 – year 5 & 6

The activity developed for this year group was to encompass the forces in equilibrium. This was achieved using a simple beam structure.

Figure 14 Simple beam bridge activity for year 5 & 6

This structure used the available resources part of the PASCO kit with no extra resources required. The idea of this activity was is to build a structure show in figure 14 which could be tested to show how forces change when load different in sections of the beams. Showing how the reactions forces change in each support as they moved the weights. Once the activity was complete it would be compared to the theoretical data that is determined by the students. This was chosen as it introduces students to basics of the forces and has a hands-on approach.

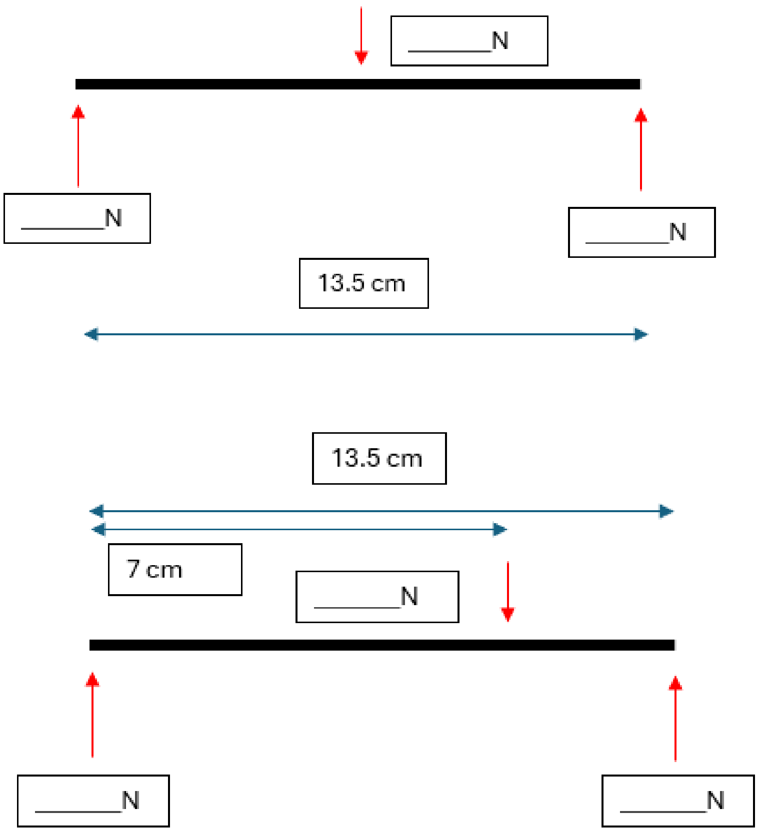

Figure 15 Diagram for a simple beam with forces

4.2.2. Activity 2 – year 7 & 8

The activity developed for this year group was to encompass the internal forces. This was achieved using a simple truss structure.

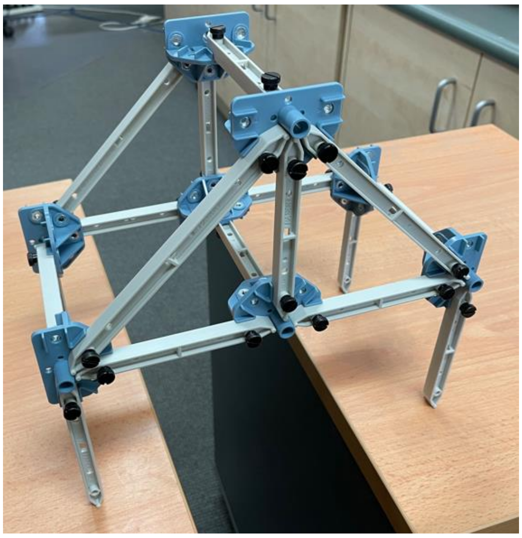

Figure 16 Simple Truss bridge activity for year 7 & 8

This structure used the available resources part of the PASCO kit with no extra resources required. The idea of this activity was is to build a structure show in figure 16 which could be tested to show how internal forces act when load different in joints. Showing how the reactions forces are shared in each support and beam when a force is applied. Once the activity was complete it would be compared to the theoretical data that is determined by the students. This was chosen as it introduces students to basics of the internal forces and has a hands-on approach.

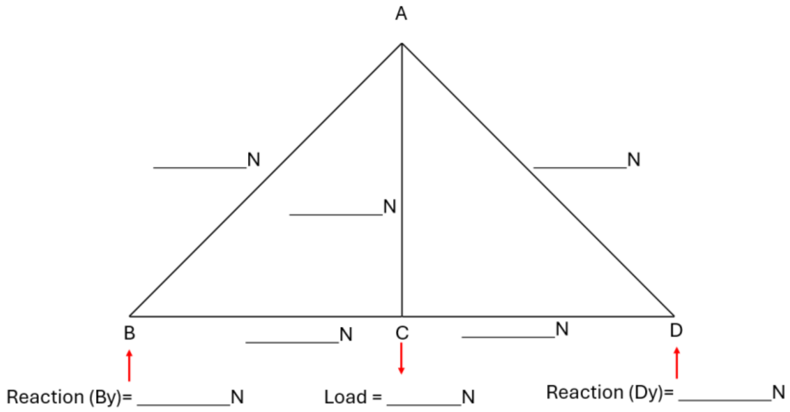

Figure 17 Diagram for a simple Truss Bridge with forces

4.2.3. Activity 3 – year 9 & 10

The activity developed for this year group was to encompass the truss analysis. This was achieved using a truss bridge structure.

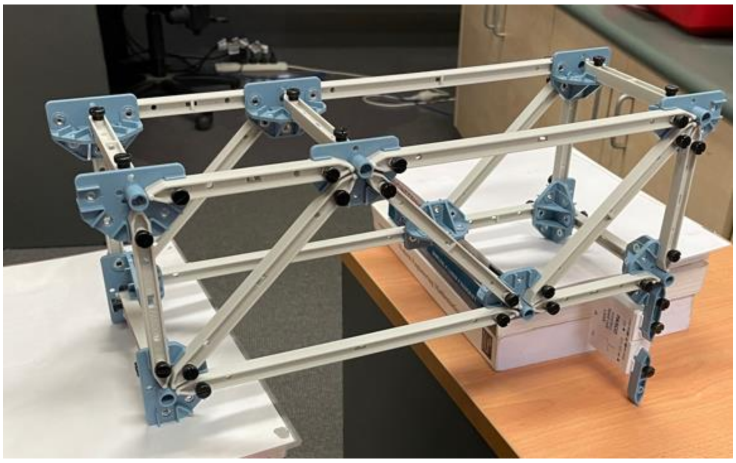

Figure 18 Asymmetrical Truss bridge activity for year 9 & 10

This structure used the available resources part of the PASCO kit with no extra resources required. The idea of this activity was is to build a structure show in figure 18 which could be tested to show how truss analysis is complete when load different in joints. Showing how the reactions forces are shared in each support and beam when a force is applied. The idea was showing how asymmetrical shapes act differently from symmetrical shapes. Once the activity was complete it would be compared to the theoretical data that is determined by the students. This was chosen as it introduces students to basics of the truss analysis and has a hands-on approach.

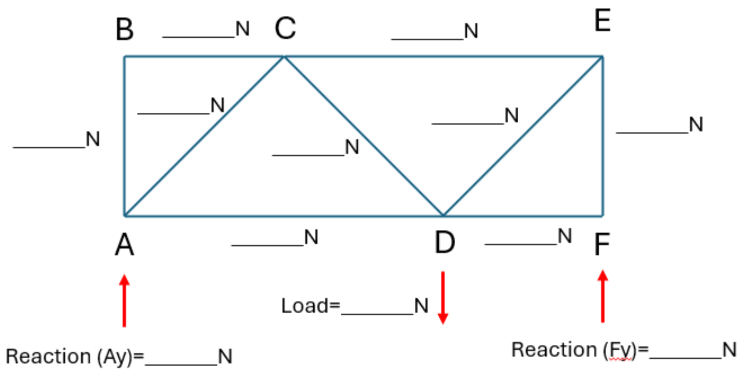

Figure 19 Diagram of asymmetrical Truss bridge with forces

4.2.4. Activity 4 – year 11 & 12

The activity developed for this year group was to encompass the truss analysis. This was achieved using a truss bridge structure. This was the same to activity three with the idea to test how the different education levels would participate and understand the activity.

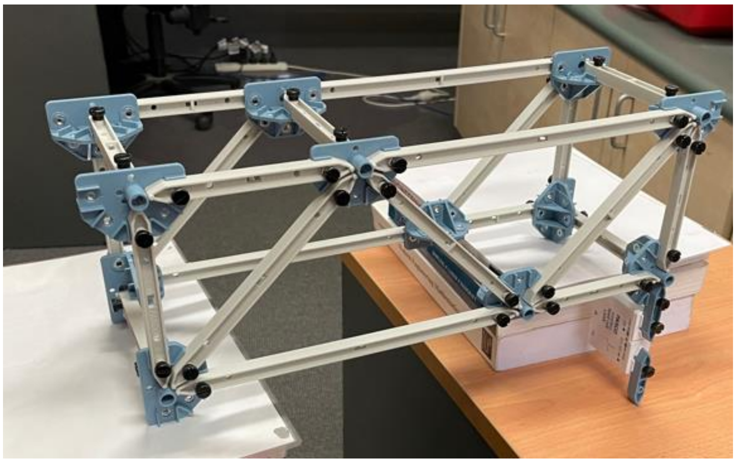

Figure 20 Asymmetrical Truss bridge activity for year 11 & 12

This structure used the available resources part of the PASCO kit with no extra resources required. The idea of this activity was is to build a structure show in figure 20 which could be tested to show how truss analysis is complete when load different in joints. Showing how the reactions forces are shared in each support and beam when a force is applied. The idea was showing how asymmetrical shapes act differently from symmetrical shapes. Once the activity was complete it would be compared to the theoretical data that is determined by the students. This was chosen as it introduces students to basics of the truss analysis and has a hands-on approach.

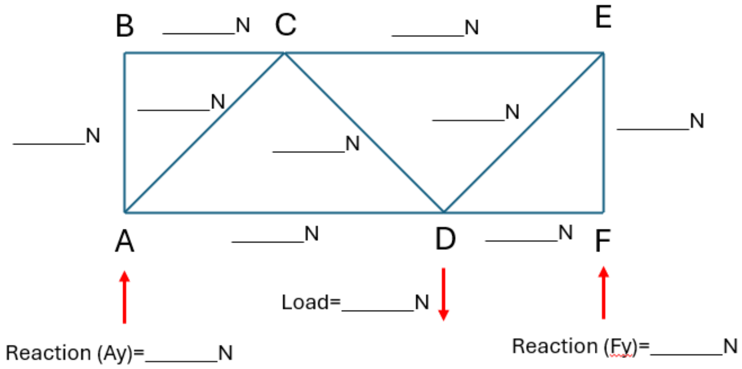

Figure 21 Diagram of asymmetrical Truss bridge with forces

4.3. Bridge Building Activity Workbooks

During the development of the activity sheets the objects stated in table 1 in section 2.3 this was the main driving factors for the development. To be able to structure the activities and learning objects around these would be able to develop a strong basis for the program. Structuring the activities to make them inclusive all individuals and age groups is a focus. Each workbook was separated into three parts: introduction to the concepts of bridges, theoretical data and hands on activity. There was a teacher's manual developed to assist in the delivery of the session.

4.3.1. Student workbook

Part one to discuss what are bridges and different styles of bridges. This was to introduce the type of areas that the activities will focus on and give a visual image. This allows for questions open discussion between the teacher and students.

Part two was to show how the theoretical based, to show how the concepts of axical forces and reaction forces are determined and why they are important. This was to allow students to have gain an idea of what should happen and compare it to the practical side. Showing a real-world application that it could be used for. An example was developed like the practical activity with certain sections for students fill out based on what was show from the teacher.

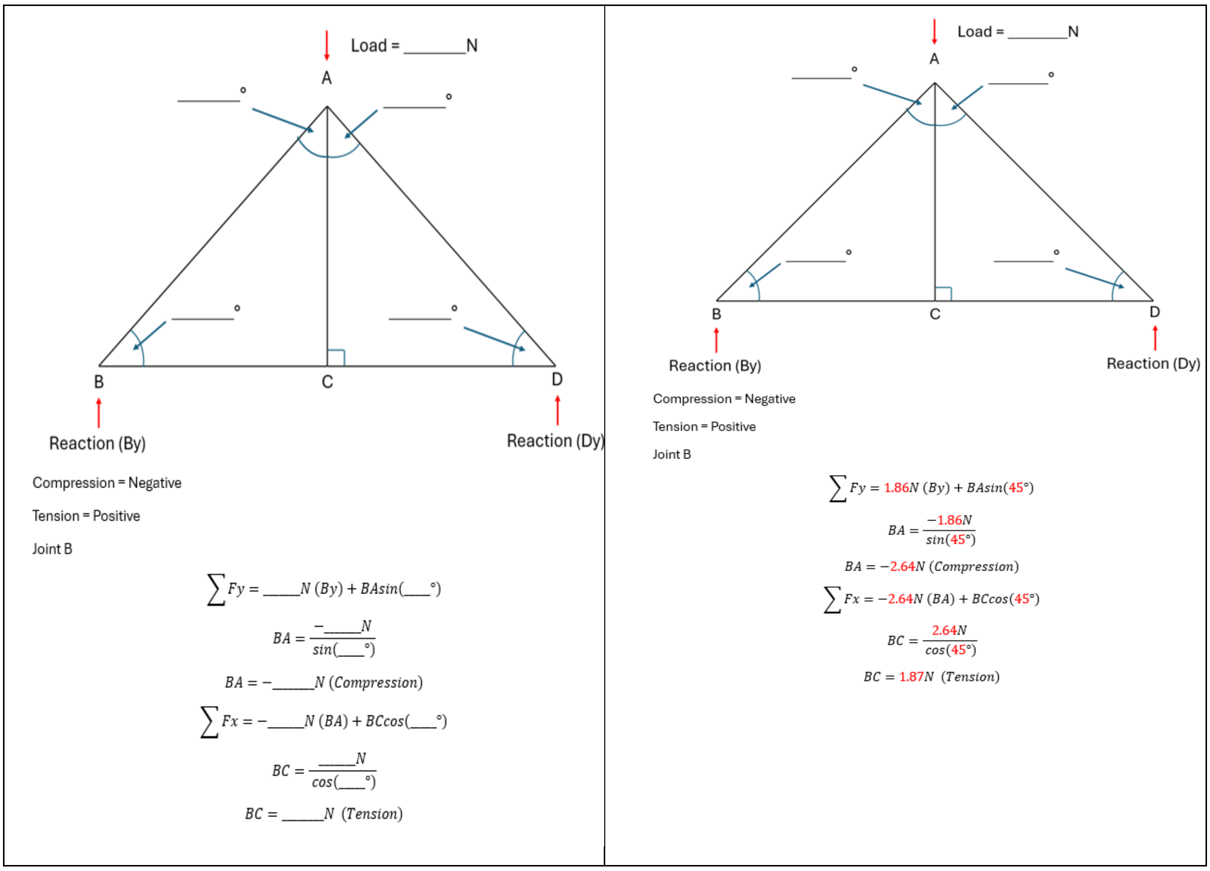

Figure 22 Example workbook part two with theoretical equations

Part three was the practical activity that gave instructions and visual aids to complete the activity. These had step by step guides on how to build the structure and complete the experiment. These were to be used once a teacher showed the basics of the activity e.g. how to use the PASCO kit and software. The student was to record the results and compare them to part two and all open floors discuss.

See Appendix B for the activity workbooks and instruction manuals

4.4. Field Testing observations and results

A field test was conducted of the instruction sheets with two sessions held for each year range. The groups were in an range from five to ten students with a mixture of genders and ethnicity. These students had to opportunity to attend and were not forced by the school. This was requested as it would potential limit directions created in the classroom. Observations that were noted in the sessions listed below:

4.4.1. Year 5 & 6

- A lot of questions relating directly to bridge structure which were outside the scope of the session e.g " How often does the harbour bridge get painted"
- Easily distracted when waiting for instruction or not sure how to continue the activity
- Excited about making the bridge and would want to rush to the next part
- Based on the interactions about 85% of the students were interactive with the activity and concepts
- Struggled to load the weights and understand how sensitive the wireless load sensor was, getting inaccurate results
- The activity wasn't fully completed due to the distraction from the questions being asked and discussion that happened.
- Only about 75% of students keep the activity sheets
- 10 students in the groups, made it difficult for students to complete the whole process

4.4.2. Year 7 & 8

- Easily distracted when waiting for instruction or not sure how to continue the activity
- Based on the interactions about 80% of the students were interactive with the activity and concepts
- Females in this age group didn’t want to get hands on while conducting the experiment as a group
- The activity wasn't fully completed due to the distraction from the questions being asked and discussion that happened.
- Only about 50% of students keep the activity sheets
- 10 students in the groups, made it difficult for students to complete the whole process

4.4.3. Year 9 & 10

- Easily distracted when waiting for instruction or not sure how to continue the activity
- Based on the interactions about 75% of the students were interactive with the activity and concepts
- With a more stable structure where able to get better results that reflected the theoretical predictions
- The activity was fully completed
- Only about 25% of students keep the activity sheets
- 10 students in the groups, made it difficult for students to complete the whole process

4.4.4. Year 11 & 12

- Worked as a small team and wanted to make it competitive at every point e.g. " who can make the bridge structure the quickest"
- Based on the interactions about 95% of the students were interactive with the activity and concepts
- With a more stable structure where able to get better results that reflected the theoretical predictions
- The activity was fully completed
- Only about 25% of students keep the activity sheets
- 4 Students in the sessions, where able to be interactive with all parts of the activity.

CHAPTER 5: DISCUSSION AND CONCLUSION

5.1. Validation of the PASCO Bridge Building Kit

When using this equipment, the sensitivity was found to be high with movements creating vibrations of the supporting structure could put the sensor of out zero prior to starting the data collection.

The direction the sensor is placed is important to getting a high accuracy reading, based on the configuration and programming. The sensor has a "Load" and "Fixed" direction, which determines the recommend placement direction. The cell is connected using the supplied I beams, and "Load" side is to be attached the expected component that will move or shift when loaded. The fixed is placed in the opposite component that is not expected to move when loaded. Testing of this has shown that it can create up to ± 2% in the results. This is also on top of the sensor showing fluctuations of ± 0.05N without any load placed on the structure which results in another ± 2%.

These configurations that were chosen are to how structure that could be developed with the materials given and it would create a non-symmetrical load distribution at either end. This would be able to show if the force would be carried through the structure and the wireless load cell would be able to pick up the data.

The results show a substantial difference between the PASCO and Theoretical results. The main areas to highlight are all the horizontal sections. All these beams have at least a 6% difference in the section. The difference in this result can be attributed to the testing methods and provided materials. When collecting the data for the horizontal beams, due to the span it is required to use flexible beam three which can allow difference action in the beams with the weight of the sensor acting on it. The beam three is design to be flexible and to show any potential failure in the bridge or truss. With the diagonal beams the beam two was used which is a harder plastic designed not to have limited movement and rotation. In the longer spans the wireless load cell accuracy is axial force accuracy is affected. In terms of determining if it in compression or tension the model was able to represent this part accurately for each beam. The calibration of the of the wireless load cell is the only other part that could be assessed but based on the other results this is likely to be suitable for the experiments. As mentioned earlier the fluctuation of the wireless load cell and potential vibrations can have a ±4% difference. This would still not account for the major differences is the results.

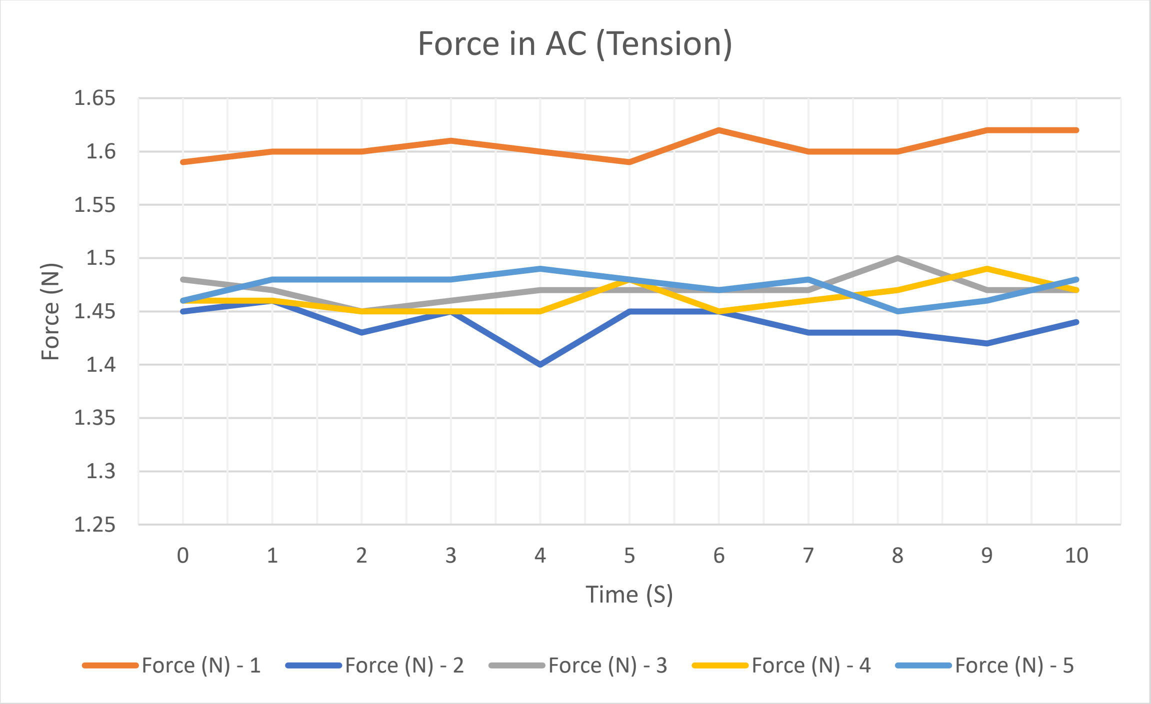

Figure 23 Outside factors effecting PASCO data collection

The figure 23 shows how the wireless sensor can be affected by outside factors. This graph has an outlier with Force (N) -1, this could be attributed to human error in the experiment or materials. As mentioned earlier the sensor is sensitive to movement and changes. Prior to placing the recording the data, the structure was slightly moved when the loading of the weight occur. The beams three, four and five are made from Thermoplastic 50D durometer which tends to have a low young's modulus. This allows the beams to change it shape considerably when a force is applied. This can be carried through the whole structure and can affect the results. Readjusting the whole structure is required to testing to continue, this can be seen in the other four attempts where the data was consisting of.

5.2. Activities

The field test of the instruction sheets provided valuable insights into student engagement and the effectiveness of the activities across different year groups.

While overall interaction rates were encouraging—ranging from 75% to 95%—the findings highlighted significant challenges related to distractions and group dynamics.

Younger students (Years 5 and 6) demonstrated enthusiasm but struggled with focusing and using of the kits, leading to incomplete activities. In Years 7 and 8, distractions persisted, and outside distraction affected participation, particularly among female students. However, as students progressed to Years 9 and 10, a more stable structure resulted in improved outcomes and successful completion of activities. By the time students reached Years 11 and 12, competitive teamwork fostered high engagement and completion rates. Despite these successes, the amount of activity sheets kept remained low across all groups, indicating a potential area for improvement. Overall, the test showed importance of structured guidance and smaller group sizes to enhance learning experiences, suggesting that further refinements to the instruction sheets and activity design could better support student engagement and understanding.

Areas that could also be addressed in the younger years would be to remove the theoretical all together and just focus on building an activity has a major hands-on focus. This would potentially increase the participation and increase the interest in students to continue looking into this career path. These activity at this younger year is about introducing and attracting students to the idea of the STEM not about teaching the concepts. The activity that was originally developed missed this mark and need to be adjusted and field tested again.

5.3. Bridge Building Activity Workbooks

The activity workbooks had positive and negatives when field tested with the different year groups. The setout of the workbook seems to be easy for students to follow with the diagrams and pictures gained larges amount of participation and open conversation. This should be kept with the further iterations of workbooks and activities.

The instructions for activities where not detailed enough and required a lot of direction from the teacher/presenter including how to build the structures and the aim of activities. With potential future students/teachers never having experience with the kits a more laid out step by step of how to build the structures should be detailed in the worksheets. As seen in figure 24 this was a diagram developed for the 9 -10 &

11 -12 workbooks that was able to assist and ease the construction of the structures. The only area that would need to be including is a list of required materials from the kit including the amount of each type of beam and joints. This would also decrease the amount of time for construction.

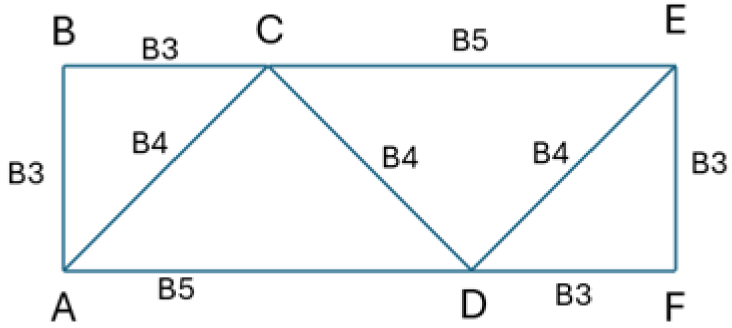

Figure 24 Beam layout for 9-10 & 11-12 Activity

5.4. Evaluation

As stated in the methodology the project successfulness was based evaluation methods. This would define it the PASCO kit would be able to be used for STEM purpose but also potentially any others

5.4.1. Accuracy of the resource/s

The PASCO kit overall was not very accurate in terms of comparison with the theoretical results. The reaction and axial forces that were compared was 17.5% accurate. This showed that using this product for modelling for construction purposes would not be suitable. The area that the PASCO kit was accurate in was the axial forces regarding compression and tension, there was 100% accuracy with all validation of the four structures. Activities that are not related to comparing to theoretical results would be suitable for using this resource for.

5.4.2. Where the activities sheet easy to understand and follow?

The activity workbooks in general were suitable for the pilot sessions for the draft activities. As mentioned in section 5.3 a further breakdown of activities and how to use the resources were required. This included the construction of the PASCO kit and using the wireless load cell to complete testing. Including more diagrams and image would be suitable for these workbooks. Having balance of written information and visual aids would also allow for student's different ways of interpreting instructions which would potentially decrease setup times and allow more time for students to complete the activities.

5.4.3. Meeting project goals

Comparing this to the project goals set out in section 3.1 Project goals, the PASCO kit was able to achieve the resources with the capabilities it was able to complete. The only areas it was limited in was types of bridges being limited to was configurations of beam, truss and cantilever and what forces could be shown using the wireless load cell. The use of technology was also part of the goals that this was able to achieve, using application and reusable materials was achieved.

The activities that were developed missed the balance of practical and theoretical, with leaning on the theoretical side too much. The scope of the activities and workbooks need to be redeveloped and further iterations to be test with students to make a successful program. The completion of the field testing was able to highlight this, and this can be achieved.

The activities need to be aspects of civil engineering involved and has the potential to involve more. This PASCO kit can be used to complete this goal, with the axial and reaction forces being the focus. Further investigation to other additions that could be compatible with this kit could be further investigation. The PASCO has the different advance's structure sets that could be included in further iterations of activities. This could help with expanding areas of focus and increasing interest in the outreach programs.

5.5. Conclusion

Overall, the PASCO Bridge building kit showed both its potential and limitations for educational purposes with demonstrating civil engineering concepts. The sensitivity of the wireless load cell was an area that showed issues with the results for the axial forces which was a challenge due to fluctuations and external impacts.

The field tests revealed different levels of student's engagements across the year groups 5-12. Students in years 5-8 had increased participation and engagement with the hands-on sections of the activities but sometimes had issues with social distractions. Student in years groups 9-12 showed more engagement overall and introduced competitive aspect without being promoted. This shows there is opportunity to redevelop the activities and continuing to complete iterations, socially with the year groups 5-8. Simplifying and limiting the theoretical components and increasing hands-on activities could increase engagement of students and develop interest in STEM fields at an early age.

Based on observations during sessions the activity workbooks there is improvements that could be made. With limited students taking the workbooks at the end of the sessions, this could indicate that students weren't interested. Future iterations should incorporate, step-by-step guides of how to complete the activity and clear material lists for the hands-on activities.

With its issues with accuracy when displaying results and comparing to theoretical data, the wireless load cell proved effective in demonstrating axial forces related to compression and tension. This allows for some educational activities, although its limitations in bridge configurations showed be furtherer investigated with potential attachments and materials. Overall, the findings highlighted the need for continuous refinement of workbooks and activity designs, aligning them more closely with practical engineering while maintaining a balance between theory and hands-on learning. Further investigation of attachments and resources could increase the different opportunities for activities that could increase student interest in civil engineering and STEM careers.

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APPENDIX A

Kit Limitations

The PASCO kit comes with the following item

- Truss connectors x 16
- Mass Hanger
- Wireless Load Cell (PS-3216)
- Sliding Connector
- Truss Screws x 80
- Flexible Member (#1) x 8
- Flexible Member (#2) x 8
- Flexible Member (#3) x 10
- Flexible Member (#4) x 10
- Flexible Member (#5) x 8
- Washers (10g) x 38

Based on the equipment provided the limitations are as follows

- Truss connectors are fixed with the angles of 0, 45 and 90 degrees.
- Length of member are set and can't be adjusted
- Maximum load that can be applied is 385g based on the number of weights (3.78N)
- Wireless load cell can only assess one section at a time
- Requires a phone application or access to a computer to use wireless load cell
- Only a beam or Truss bridge configuration can be built
- Limit configurations of a Truss bridge can be built due to angles of connectors
- When in place the wireless load sensor could fluctuate ±0.05N

The Wire load sensor is most important factor to when using the model and it represents the data produced. Understanding capabilities of this and how accurate it is compared to theoretical data.

Warren Truss Bridge Three Cell

To test and validate the data the process will be as follows

1. Build a Truss Structure shown in figure xxx
2. Apply weight at Truss connector C
3. Test all beam and reaction forces
4. Compare the results to the theoretical and software results

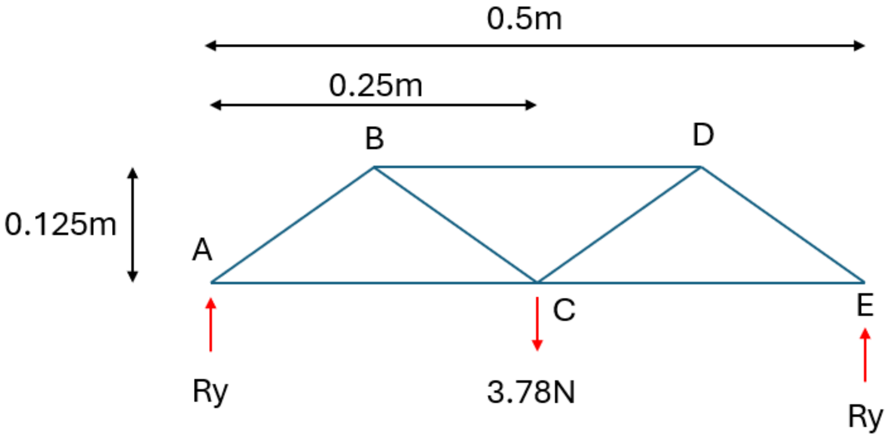


Figure 25 Diagram Warren Truss Bridge Three Cell

While completing the testing a major factor that was potential affected the data was the sensitivity of the wireless load sensor, a slight action that vibrated the structure change the sensor starting measurement in a positive or negative direction. To counteract this the model was tested multiple times with the steps of removing the weight and setting the sensor back to zero. The average number was adopted as the result for each beam.

Ry @ A												
Time (s)	0	1	2	3	4	5	6	7	8	9	10	**Average**
Force (N) - 1	-1.87	-1.89	-1.87	-1.89	-1.86	-1.84	-1.91	-1.91	-1.9	-1.89	-1.9	**-1.88**
Force (N) - 2	-1.88	-1.89	-1.89	-1.89	-1.86	-1.84	-1.91	-1.91	-1.9	-1.89	-1.87	**-1.88**
Force (N) - 3	-1.88	-1.89	-1.88	-1.89	-1.86	-1.9	-1.91	-1.91	-1.87	-1.89	-1.89	**-1.89**
Force (N) - 4	-1.86	-1.89	-1.88	-1.89	-1.88	-1.89	-1.92	-1.87	-1.87	-1.89	-1.89	**-1.88**
Force (N) - 5	-1.88	-1.89	-1.87	-1.89	-1.86	-1.84	-1.91	-1.91	-1.9	-1.89	-1.89	**-1.88**

Table 13 Warren Truss Bridge Three Cell recorded data from PASCO for node A

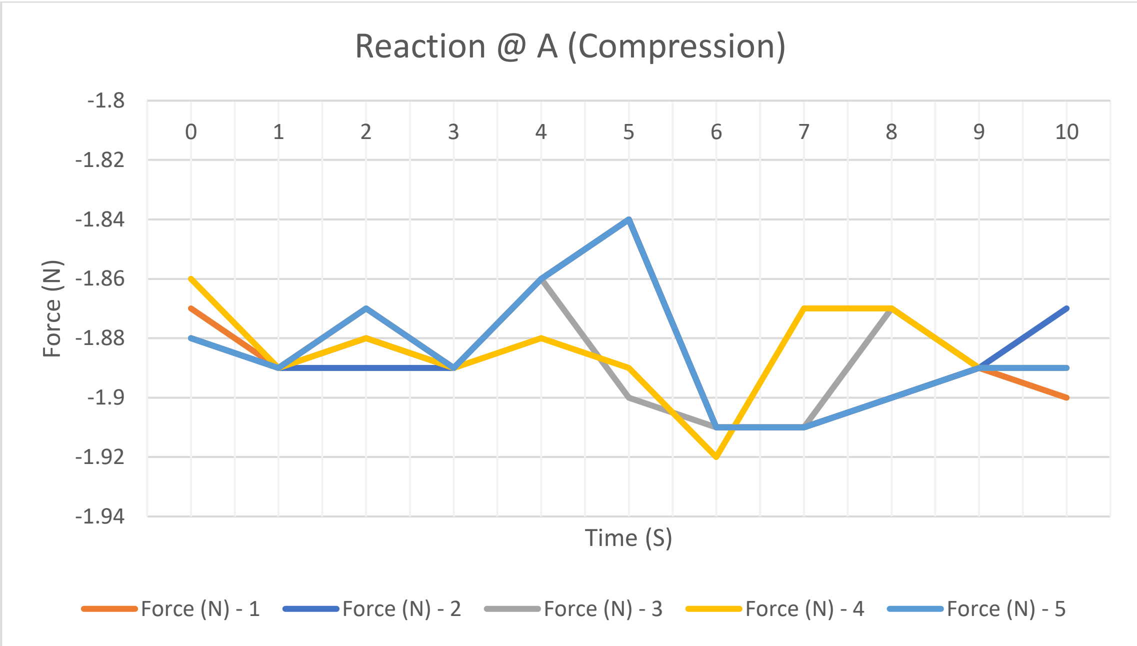


Figure 26 Warren Truss Cantilever Bridge Three Cell reaction force acting in node A

Beam AB												
Time (s)	0	1	2	3	4	5	6	7	8	9	10	Average
Force (N) - 1	-2.54	-2.52	-2.55	-2.54	-2.56	-2.55	-2.54	-2.56	-2.52	-2.52	-2.55	**-2.54**
Force (N) - 2	-2.48	-2.48	-2.51	-2.5	-2.51	-2.5	-2.49	-2.46	-2.47	-2.46	-2.49	**-2.49**
Force (N) - 3	-2.47	-2.46	-2.48	-2.46	-2.44	-2.46	-2.51	-2.48	-2.47	-2.47	-2.45	**-2.47**
Force (N) - 4	-2.47	-2.46	-2.47	-2.47	-2.46	-2.45	-2.48	-2.47	-2.5	-2.47	-2.47	**-2.47**
Force (N) - 5	-2.48	-2.48	-2.49	-2.46	-2.45	-2.47	-2.46	-2.47	-2.46	-2.43	-2.45	**-2.46**

Table 14 Warren Truss Bridge Three Cell recorded data from PASCO for Beam AB

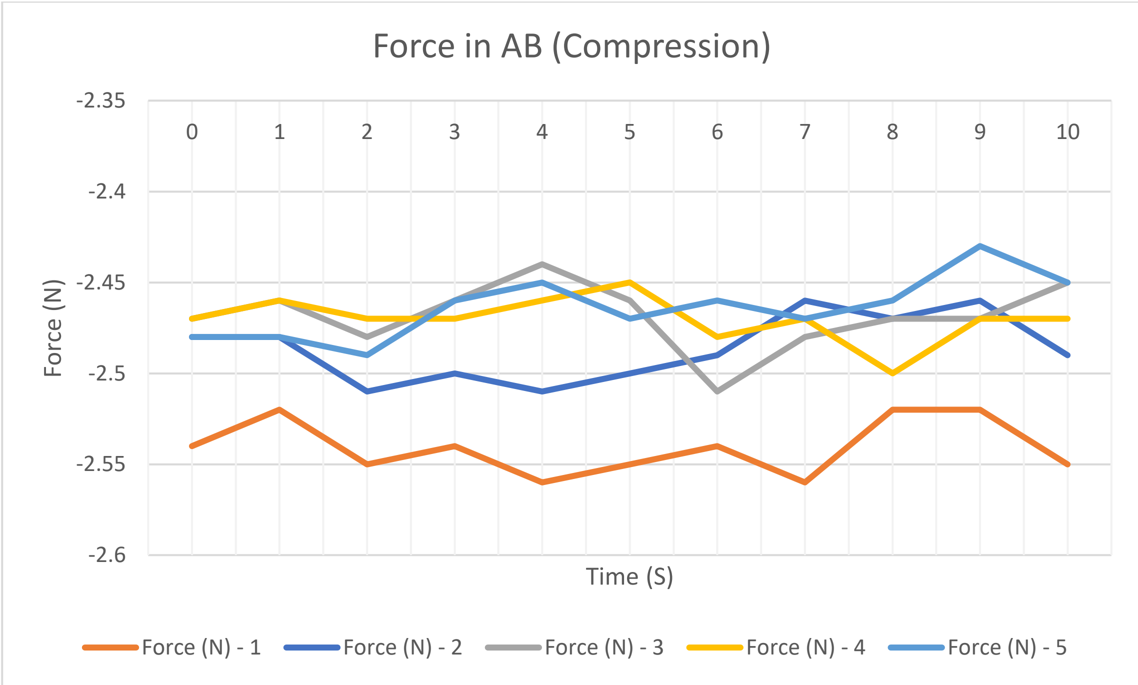


Figure 27 Warren Truss Cantilever Bridge Three Cell axial force acting in Beam AB

Beam AC												
Time (s)	0	1	2	3	4	5	6	7	8	9	10	Average
Force (N) - 1	1.59	1.6	1.6	1.61	1.6	1.59	1.62	1.6	1.6	1.62	1.62	**1.60**
Force (N) - 2	1.45	1.46	1.43	1.45	1.4	1.45	1.45	1.43	1.43	1.42	1.44	**1.44**
Force (N) - 3	1.48	1.47	1.45	1.46	1.47	1.47	1.47	1.47	1.5	1.47	1.47	**1.47**
Force (N) - 4	1.46	1.46	1.45	1.45	1.45	1.48	1.45	1.46	1.47	1.49	1.47	**1.46**
Force (N) - 5	1.46	1.48	1.48	1.48	1.49	1.48	1.47	1.48	1.45	1.46	1.48	**1.47**

Table 15 Warren Truss Bridge Three Cell recorded data from PASCO for Beam AC

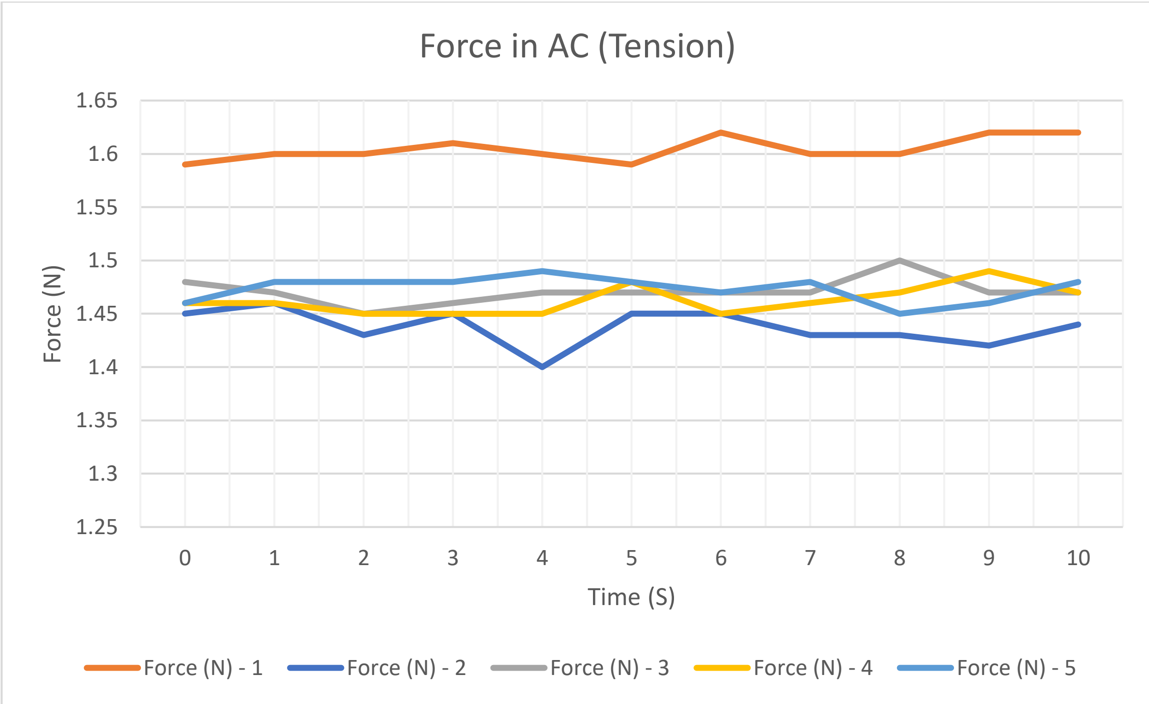


Figure 28 Warren Truss Cantilever Bridge Three Cell axial force acting in Beam AC

Beam BD												
Time (s)	0	1	2	3	4	5	6	7	8	9	10	Average
Force (N) - 1	-3.42	-3.42	-3.43	-3.42	-3.42	-3.42	-3.44	-3.43	-3.44	-3.42	-3.44	**-3.43**
Force (N) - 2	-3.43	-3.37	-3.42	-3.44	-3.45	-3.43	-3.41	-3.42	-3.44	-3.45	-3.44	**-3.43**
Force (N) - 3	-3.47	-3.43	-3.43	-3.4	-3.39	-3.43	-3.4	-3.41	-3.43	-3.44	-3.43	**-3.42**
Force (N) - 4	-3.43	-3.43	-3.43	-3.4	-3.41	-3.42	-3.41	-3.44	-3.41	-3.43	-3.43	**-3.42**
Force (N) - 5	-3.41	-3.46	-3.43	-3.46	-3.42	-3.42	-3.44	-3.43	-3.45	-3.45	-3.44	**-3.44**

Table 16 Warren Truss Bridge Three Cell recorded data from PASCO for Beam BD

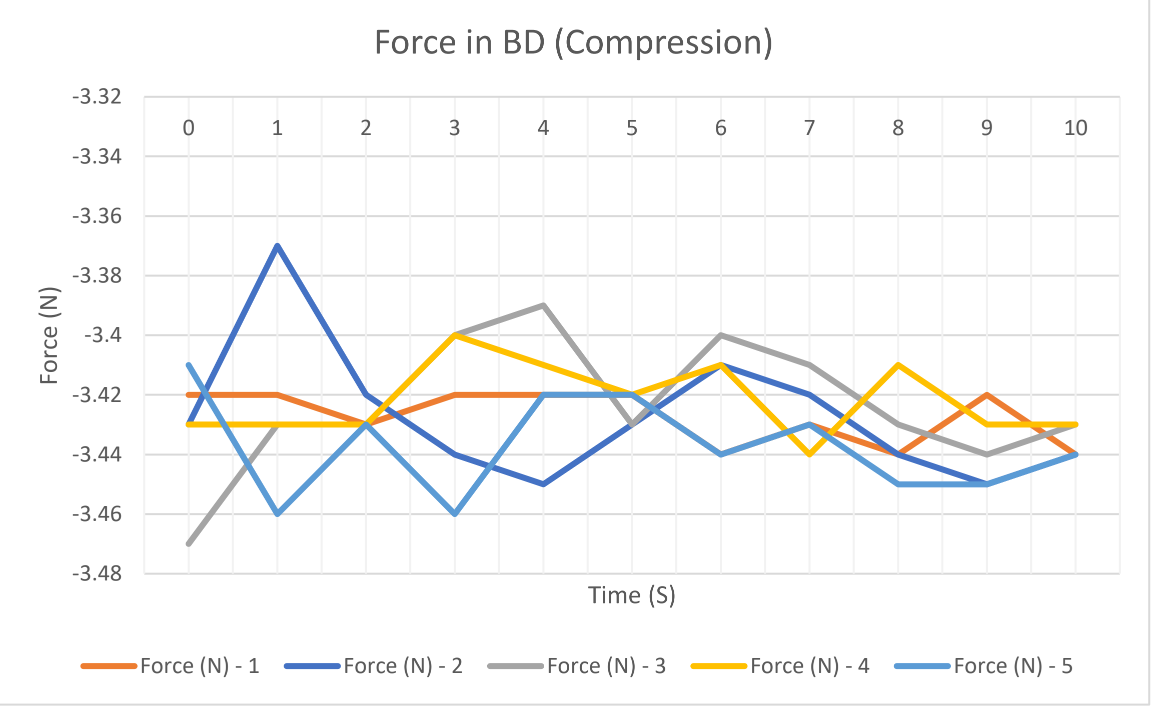


Figure 29 Warren Truss Cantilever Bridge Three Cell axial force acting in Beam BD

Beam CD												
Time (s)	0	1	2	3	4	5	6	7	8	9	10	Average
Force (N) - 1	2.55	2.55	2.53	2.55	2.55	2.56	2.55	2.55	2.54	2.54	2.55	**2.55**
Force (N) - 2	2.56	2.54	2.56	2.55	2.55	2.53	2.55	2.57	2.57	2.58	2.56	**2.56**
Force (N) - 3	2.56	2.55	2.55	2.53	2.58	2.55	2.56	2.55	2.59	2.57	2.56	**2.56**
Force (N) - 4	2.55	2.55	2.56	2.54	2.56	2.56	2.57	2.55	2.56	2.57	2.58	**2.56**
Force (N) - 5	2.55	2.55	2.59	2.58	2.57	2.56	2.59	2.58	2.57	2.59	2.55	**2.57**

Table 17 Warren Truss Bridge Three Cell recorded data from PASCO for Beam CD

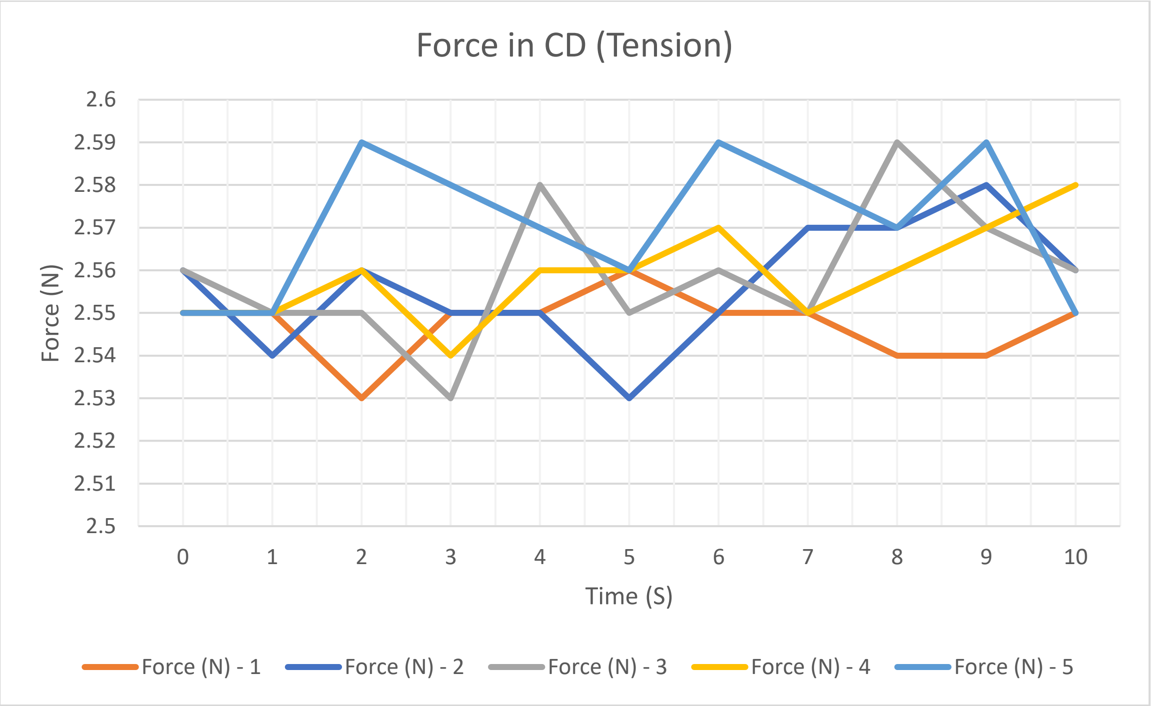


Figure 30 Warren Truss Cantilever Bridge Three Cell axial force acting in Beam CD

Beam CE												
Time (s)	0	1	2	3	4	5	6	7	8	9	10	Average
Force (N) - 1	1.59	1.6	1.6	1.6	1.57	1.58	1.6	1.58	1.61	1.58	1.57	**1.59**
Force (N) - 2	1.53	1.51	1.53	1.53	1.51	1.52	1.52	1.5	1.51	1.51	1.51	**1.52**
Force (N) - 3	1.5	1.47	1.47	1.48	1.47	1.49	1.48	1.48	1.48	1.47	1.48	**1.48**
Force (N) - 4	1.47	1.5	1.47	1.5	1.48	1.48	1.49	1.46	1.45	1.45	1.47	**1.47**
Force (N) - 5	1.48	1.47	1.46	1.48	1.47	1.49	1.48	1.46	1.48	1.45	1.45	**1.47**

Table 18 Warren Truss Bridge Three Cell recorded data from PASCO for Beam CE

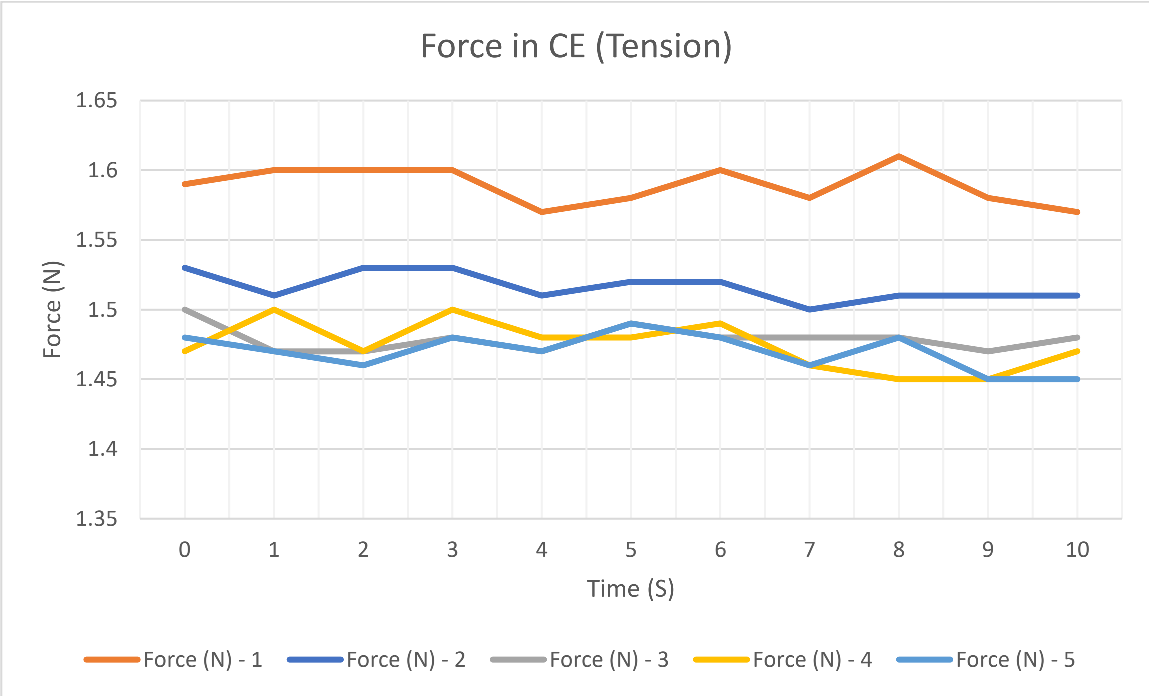


Figure 31 Warren Truss Cantilever Bridge Three Cell axial force acting in Beam CE

Beam DE												
Time (s)	0	1	2	3	4	5	6	7	8	9	10	Average
Force (N) - 1	-2.62	-2.62	-2.62	-2.58	-2.6	-2.61	-2.61	-2.61	-2.61	-2.6	-2.62	**-2.61**
Force (N) - 2	-2.56	-2.55	-2.57	-2.55	-2.54	-2.57	-2.55	-2.55	-2.56	-2.54	-2.55	**-2.55**
Force (N) - 3	-2.55	-2.58	-2.55	-2.58	-2.56	-2.57	-2.57	-2.58	-2.58	-2.55	-2.58	**-2.57**
Force (N) - 4	-2.58	-2.58	-2.56	-2.56	-2.55	-2.55	-2.55	-2.57	-2.57	-2.55	-2.54	**-2.56**
Force (N) - 5	-2.56	-2.56	-2.55	-2.56	-2.55	-2.54	-2.56	-2.56	-2.55	-2.54	-2.54	**-2.55**

Table 19 Warren Truss Bridge Three Cell recorded data from PASCO for Beam DE

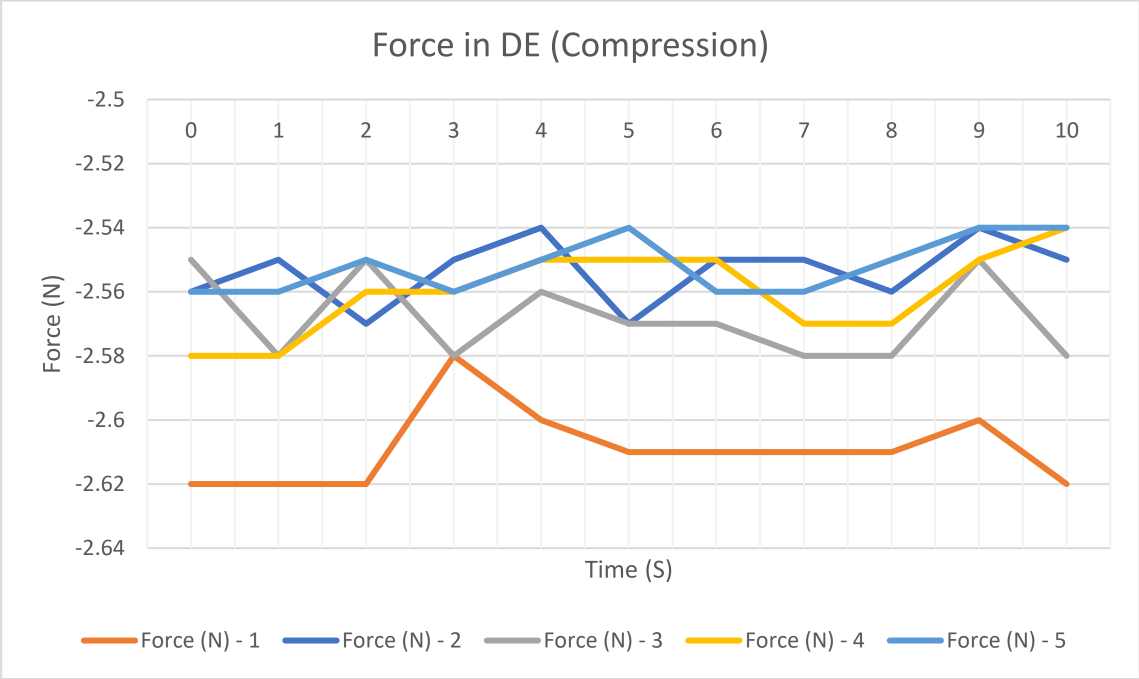


Figure 32 Warren Truss Cantilever Bridge Three Cell axial force acting in Beam DE

Ry @ E												
Time (s)	0	1	2	3	4	5	6	7	8	9	10	**Average**
Force (N) - 1	-1.88	-1.89	-1.88	-1.89	-1.86	-1.9	-1.91	-1.91	-1.87	-1.89	-1.89	**-1.89**
Force (N) - 2	-1.88	-1.89	-1.89	-1.89	-1.86	-1.84	-1.91	-1.91	-1.9	-1.89	-1.89	**-1.89**
Force (N) - 3	-1.86	-1.89	-1.88	-1.89	-1.88	-1.89	-1.92	-1.87	-1.87	-1.89	-1.89	**-1.88**
Force (N) - 4	-1.88	-1.89	-1.87	-1.89	-1.86	-1.84	-1.91	-1.91	-1.9	-1.89	-1.87	**-1.88**
Force (N) - 5	-1.88	-1.89	-1.87	-1.89	-1.86	-1.84	-1.91	-1.91	-1.9	-1.89	-1.89	**-1.88**

Table 20 Warren Truss Bridge Three Cell recorded data from PASCO for node E

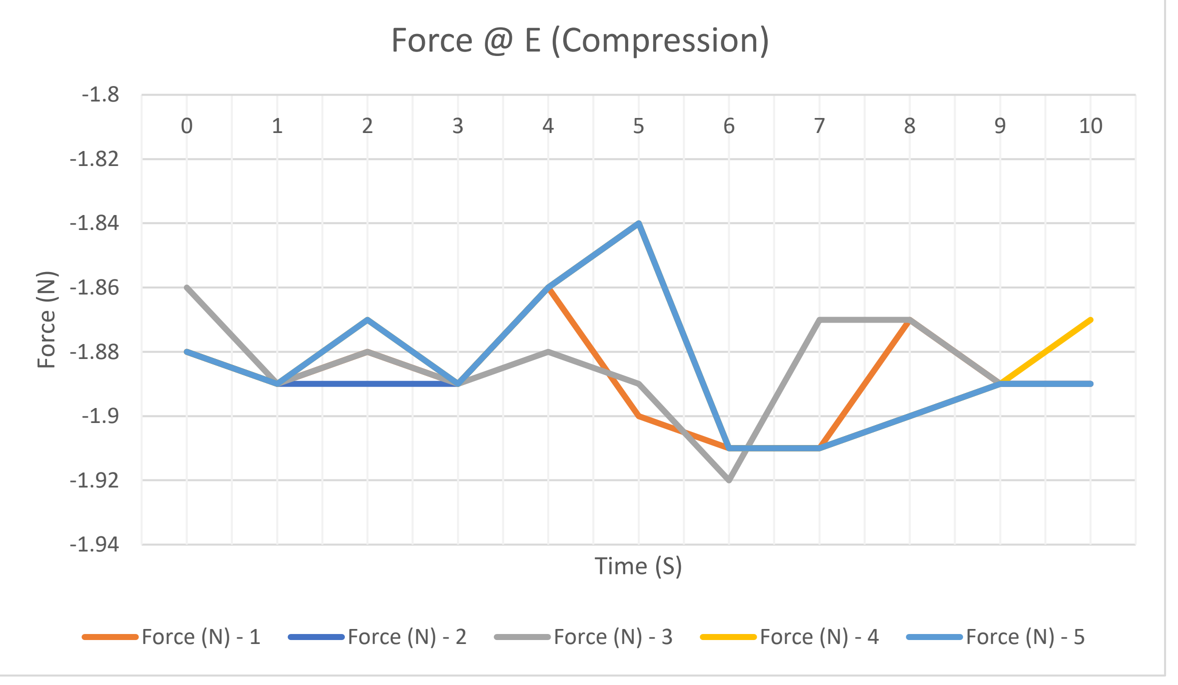


Figure 33 Warren Truss Cantilever Bridge Three Cell reaction force acting in node E

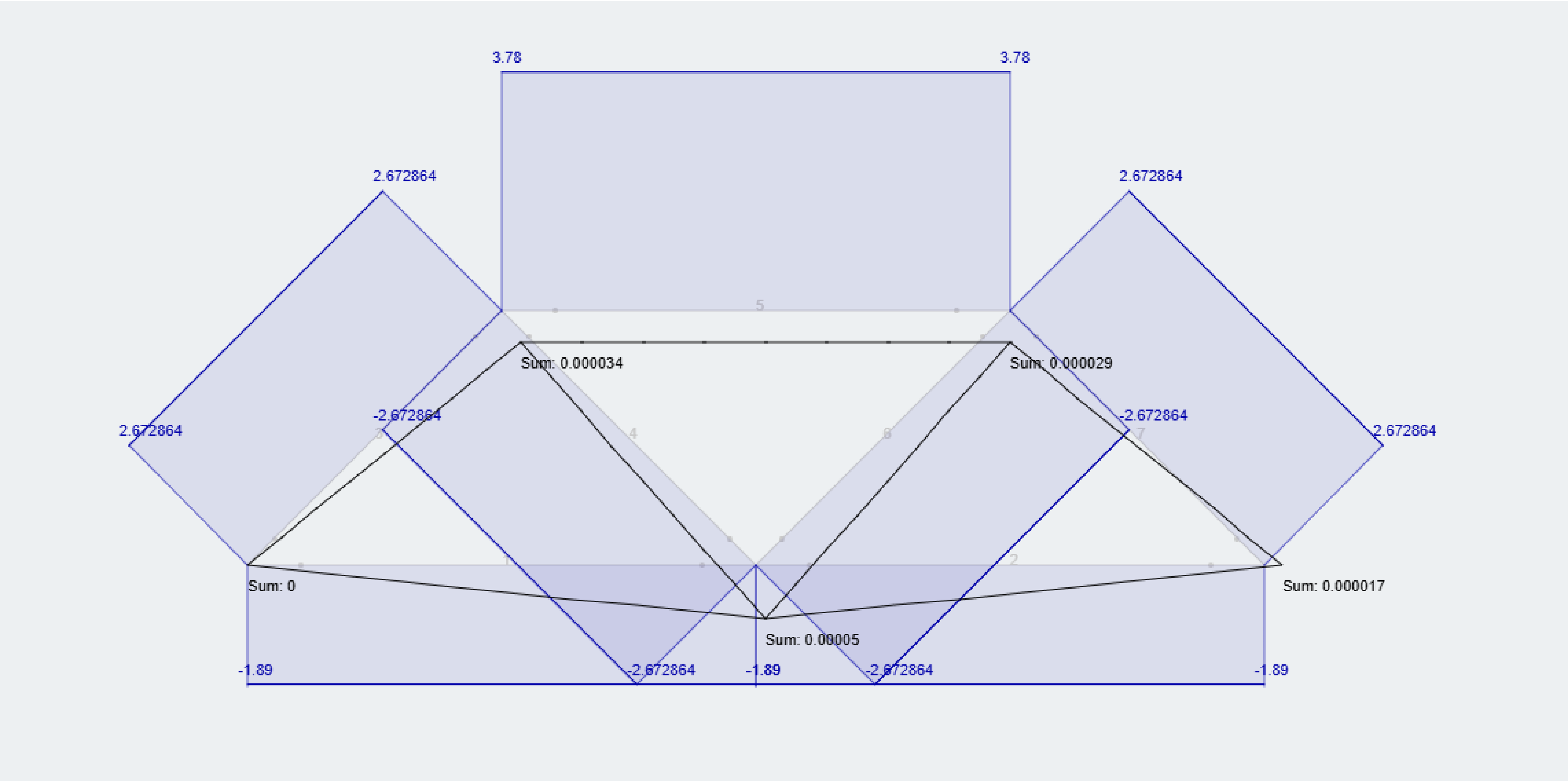


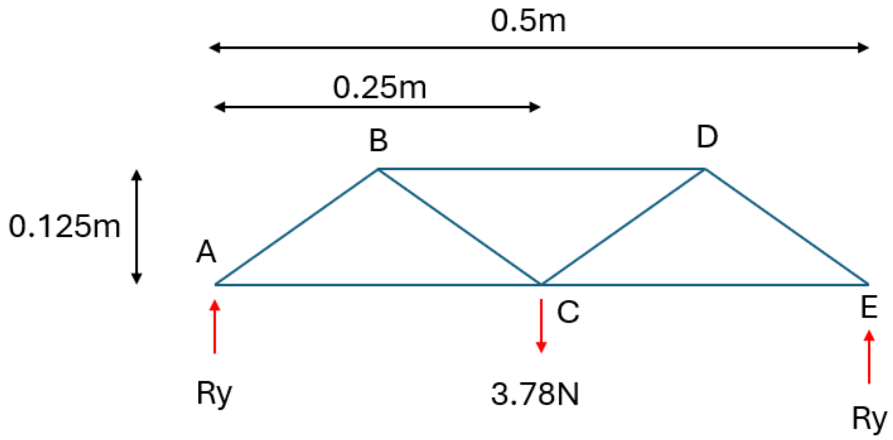
Figure 34 Warren Truss Cantilever Bridge Three Cell Ski Civ axial forces

Theoretical Data (Manual Calculations) – Joints Method

$$F = \text{mass} \times \text{accelectration}$$

$$F = 0.385\text{kg} \times 9.81\text{m}/s^2$$

$$F = 3.78N$$



$$\sum Fy = 3.78N + Ay + Gy$$

$$\sum Ma^+ = 3.78N \times 0.25m + Gy0.5m$$

$$Gy = \frac{0.945N}{0.5m}$$

$$Gy = 1.89N$$

$$\sum Fy = 3.78 - Ay - 1.89$$

$$Ay = 3.78 - 1.26$$

$$Ay = 1.89N$$

Joint A

$$\sum Fy = 2.52 + ABsin(45°)$$

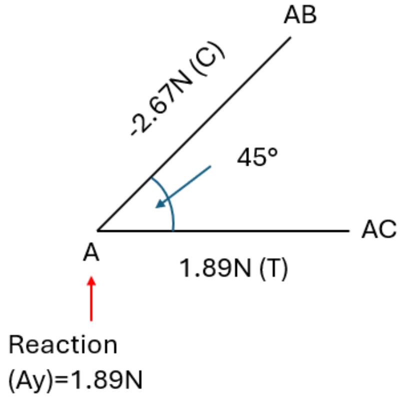
$$AB = -\frac{1.89}{sin(45°)}$$

$$AB = -2.67N\ (C)$$

$$\sum Fx = 2.67cos(45°) - AC$$

$$AC = 3.56cos(45°)$$

$$AC = 1.89N\ \ (T)$$



Joint B

$$\sum Fy = 2.67\ sin(45°) - BCsin(45°)$$

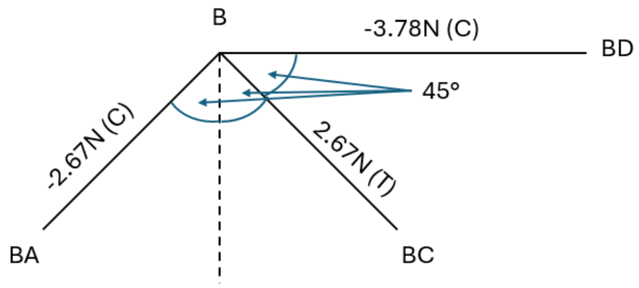
$$BC = \frac{1.888}{sin(45°)}$$

$$BC = 2.67N\ (T)$$

$$\sum Fx = 2.67\ cos(45°) + 2.67\ cos(45°) + BD$$

$$BD = -2.67\ cos(45°) - 2.67\ cos(45°)$$

$$BD = -3.78N\ (C)$$



Joint C

$$\sum Fy = 2.67\ sin(45°) + CD\ sin(45°) - 3.78$$

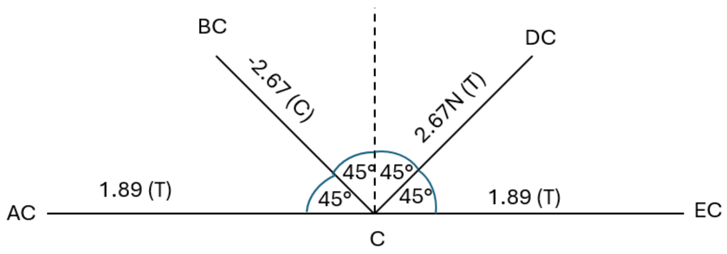
$$CD = \frac{3.78 - 2.67\ sin(45°)}{sin(45°)}$$

$$CD = 2.68N\ (T)$$

$$\sum Fx = -1.89 - 2.67\ cos(45°) + CE$$

$$CE = -1.89 - 2.67\ cos(45°)$$

$$CE = 3.78N\ (T)$$

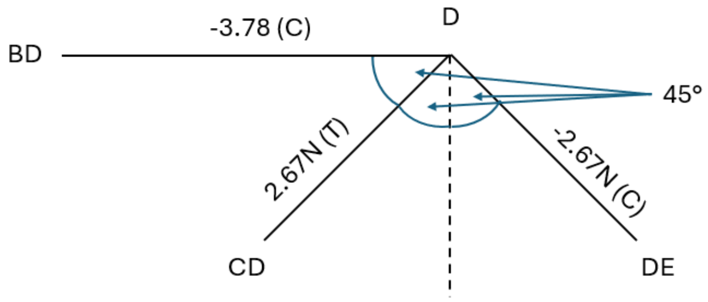


Joint C

$$\sum Fy = 2.67\ sin(45°) + DE\ sin(45°)$$

$$DE = -\frac{2.67sin(45°)}{sin(45°)}$$

$$DE = -2.67N\ (C)$$



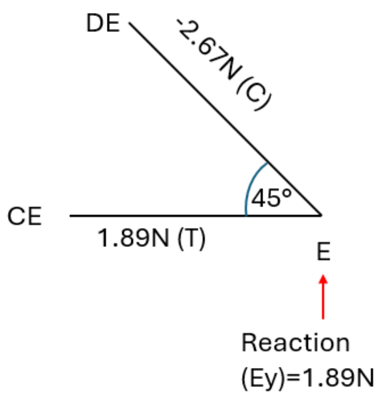
Check Joint E

$$\sum Fy = -2.67\ sin(45°) + 1.89 = 0$$

$$-1.89 + 1.89 = 0$$

$$\sum Fx = 2.67\ cos(45°) - 1.26 = 0$$

$$1.89 - 1.89 = 0$$



Warren Truss Bridge Five Cell

To test and validate the data the process will be as follows

1. Build a Truss Structure shown in figure xxx
2. Apply weight at Truss connector C
3. Test all beam and reaction forces
4. Compare the results to the theoretical and software results

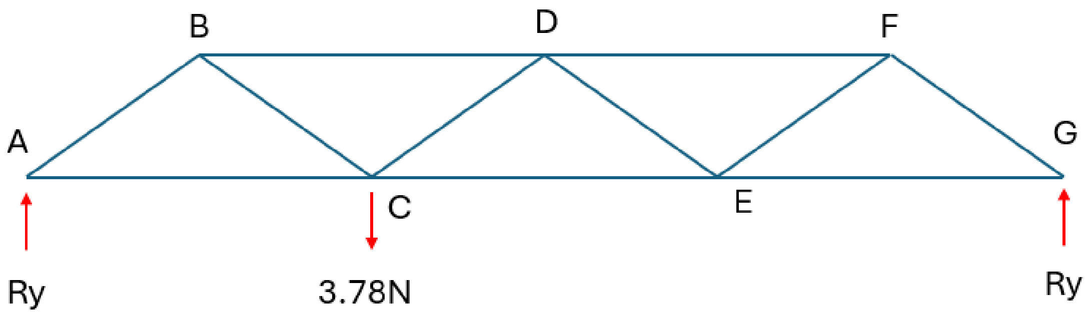


Figure 35 Diagram Warren Truss Bridge Five Cell

While completing the testing a major factor that was potential affected the data was the sensitivity of the wireless load sensor, a slight action that vibrated the structure change the sensor starting measurement in a positive or negative direction. To counteract this the model was tested multiple times with the steps of removing the weight and setting the sensor back to zero. The average number was adopted as the result for each beam.

Load at C												
Ry at A												
Time (s)	0	1	2	3	4	5	6	7	8	9	10	**Average**
Force (N) - 1	2.46	2.44	2.47	2.45	2.47	2.45	2.47	2.45	2.47	2.47	2.46	**2.46**
Force (N) - 2	2.48	2.44	2.46	2.47	2.46	2.46	2.48	2.47	2.47	2.46	2.45	**2.46**
Force (N) - 3	2.47	2.5	2.45	2.47	2.48	2.49	2.49	2.47	2.47	2.49	2.47	**2.48**
Force (N) - 4	2.45	2.44	2.46	2.45	2.42	2.45	2.44	2.45	2.44	2.45	2.44	**2.44**
Force (N) - 5	2.44	2.46	2.47	2.47	2.48	2.47	2.46	2.47	2.47	2.48	2.49	**2.47**

Table 21 Warren Truss Bridge Five Cell recorded data from PASCO for node A

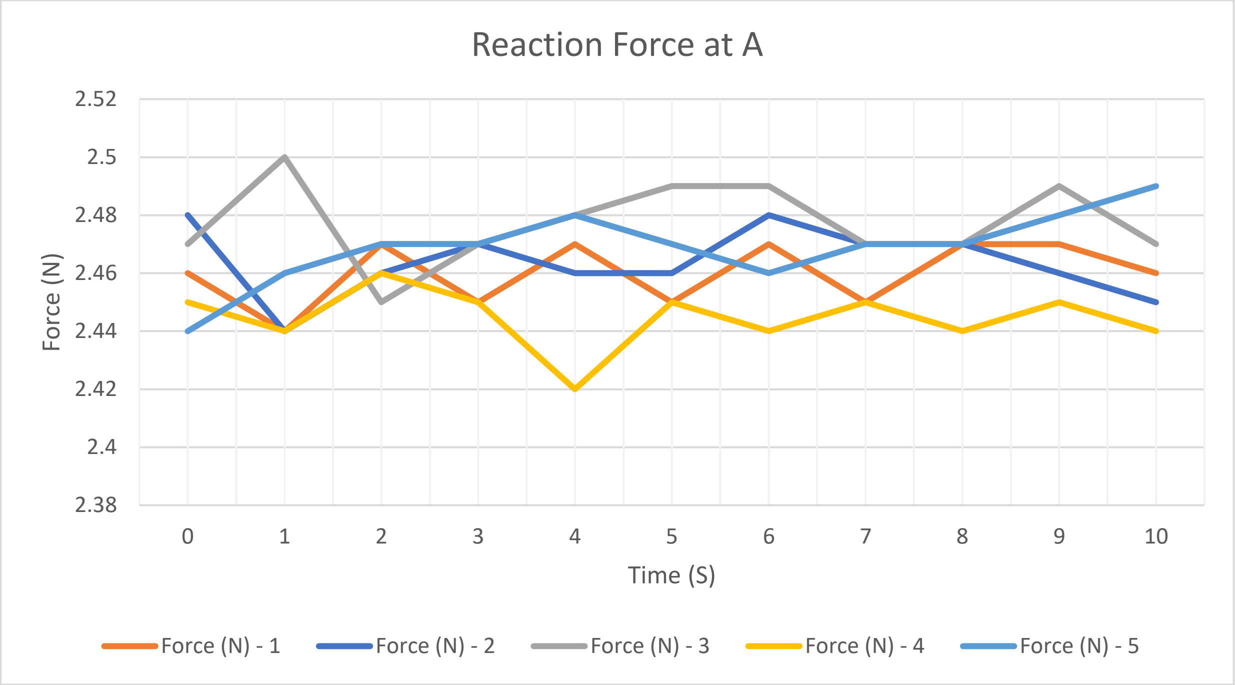


Figure 36 Warren Truss Cantilever Bridge Five Cell reaction force acting in node A

Beam AB												
Time (s)	0	1	2	3	4	5	6	7	8	9	10	Average
Force (N) - 1	-3.22	-3.22	-3.24	-3.23	-3.23	-3.24	-3.25	-3.21	-3.22	-3.24	-3.24	**-3.23**
Force (N) - 2	-3.24	-3.24	-3.23	-3.22	-3.23	-3.24	-3.25	-3.25	-3.25	-3.23	-3.24	**-3.24**
Force (N) - 3	-3.23	-3.25	-3.26	-3.24	-3.26	-3.26	-3.26	-3.24	-3.23	-3.26	-3.25	**-3.25**
Force (N) - 4	-3.23	-3.24	-3.23	-3.23	-3.25	-3.23	-3.23	-3.24	-3.22	-3.23	-3.23	**-3.23**
Force (N) - 5	-3.25	-3.25	-3.28	-3.25	-3.28	-3.26	-3.27	-3.25	-3.26	-3.26	-3.25	**-3.26**

Table 22 Warren Truss Bridge Five Cell recorded data from PASCO for Beam AB

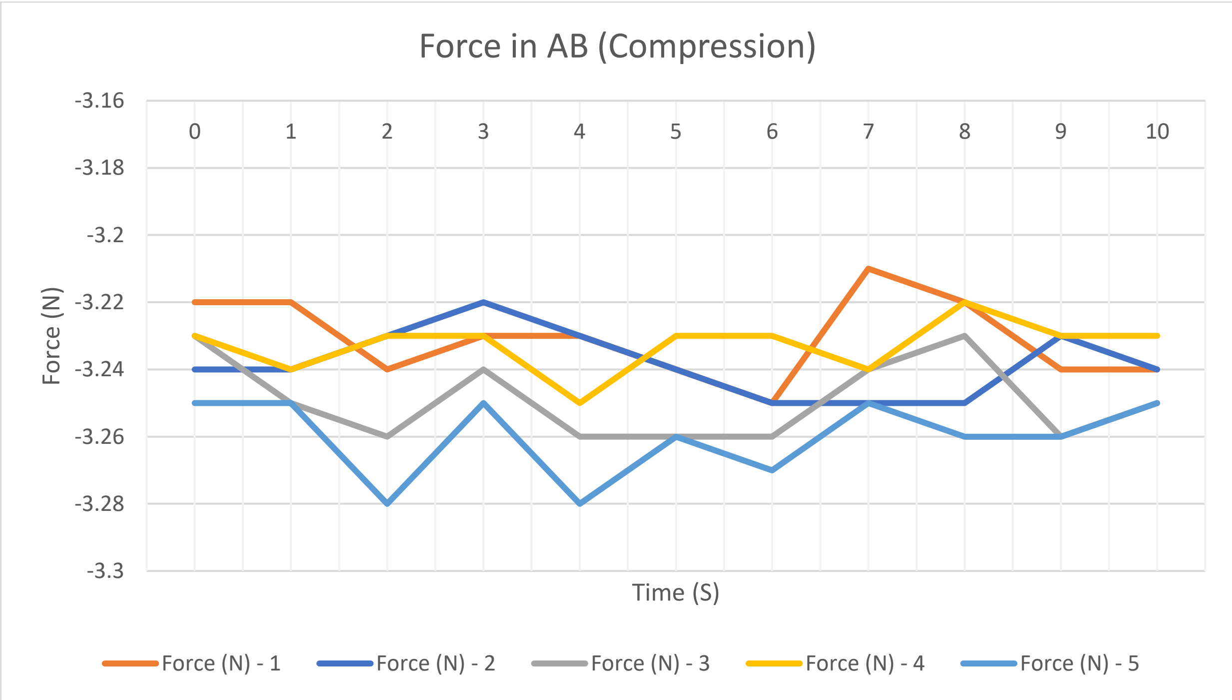


Figure 37 Warren Truss Cantilever Bridge Five Cell axial force acting in Beam AB

Beam AC												
Time (s)	0	1	2	3	4	5	6	7	8	9	10	**Average**
Force (N) - 1	1.72	1.72	1.72	1.71	1.72	1.69	1.7	1.7	1.7	1.72	1.73	**1.71**
Force (N) - 2	1.82	1.82	1.83	1.81	1.8	1.82	1.83	1.82	1.83	1.8	1.8	**1.82**
Force (N) - 3	1.98	1.98	1.98	1.96	1.96	1.95	1.95	1.95	1.96	1.93	1.98	**1.96**
Force (N) - 4	1.76	1.74	1.78	1.78	1.77	1.8	1.77	1.77	1.76	1.79	1.79	**1.77**
Force (N) - 5	1.79	1.82	1.82	1.82	1.82	1.81	1.81	1.8	1.82	1.84	1.82	**1.82**

Table 23 Warren Truss Bridge Five Cell recorded data from PASCO for Beam AC

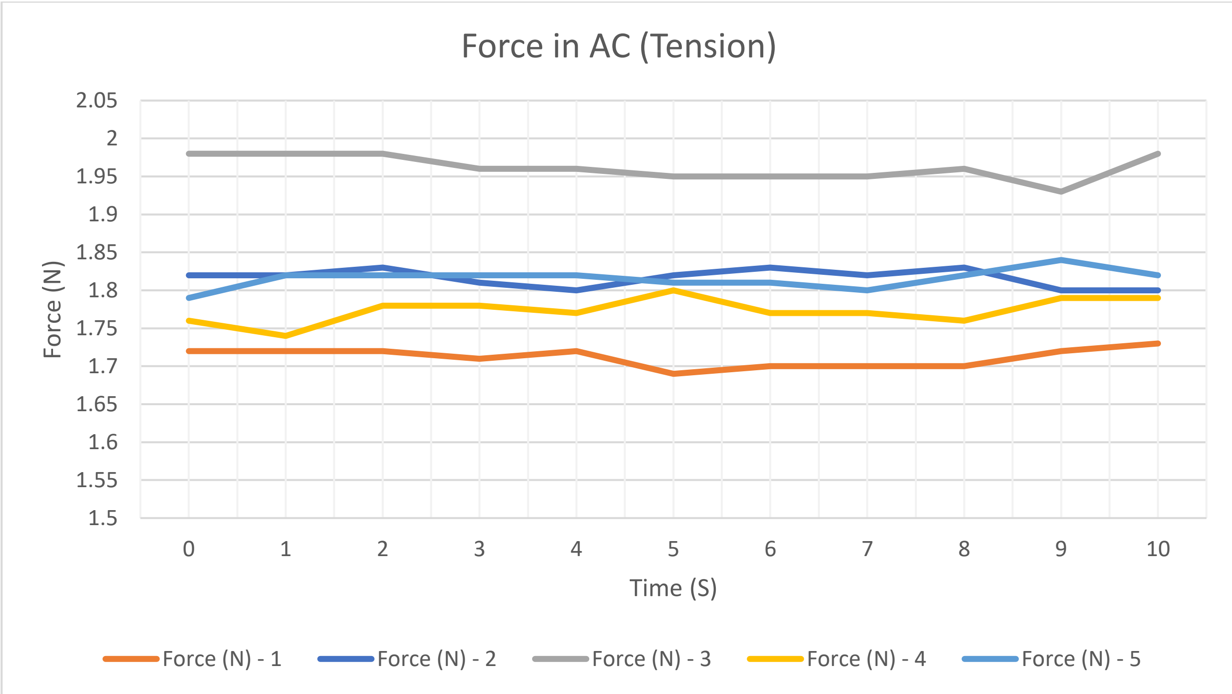


Figure 38 Warren Truss Cantilever Bridge Five Cell axial force acting in Beam AC

Beam BC												
Time (s)	0	1	2	3	4	5	6	7	8	9	10	**Average**
Force (N) - 1	3.5	3.54	3.5	3.52	3.52	3.5	3.51	3.51	3.49	3.52	3.51	**3.51**
Force (N) - 2	3.42	3.41	3.4	3.42	3.42	3.42	3.43	3.4	3.41	3.4	3.39	**3.41**
Force (N) - 3	3.42	3.45	3.43	3.41	3.4	3.45	3.43	3.44	3.43	3.44	3.45	**3.43**
Force (N) - 4	3.42	3.4	3.39	3.41	3.42	3.41	3.41	3.39	3.4	3.39	3.42	**3.41**
Force (N) - 5	3.43	3.4	3.39	3.41	3.4	3.38	3.4	3.41	3.42	3.41	3.4	**3.40**

Table 24 Warren Truss Bridge Five Cell recorded data from PASCO for Beam BC

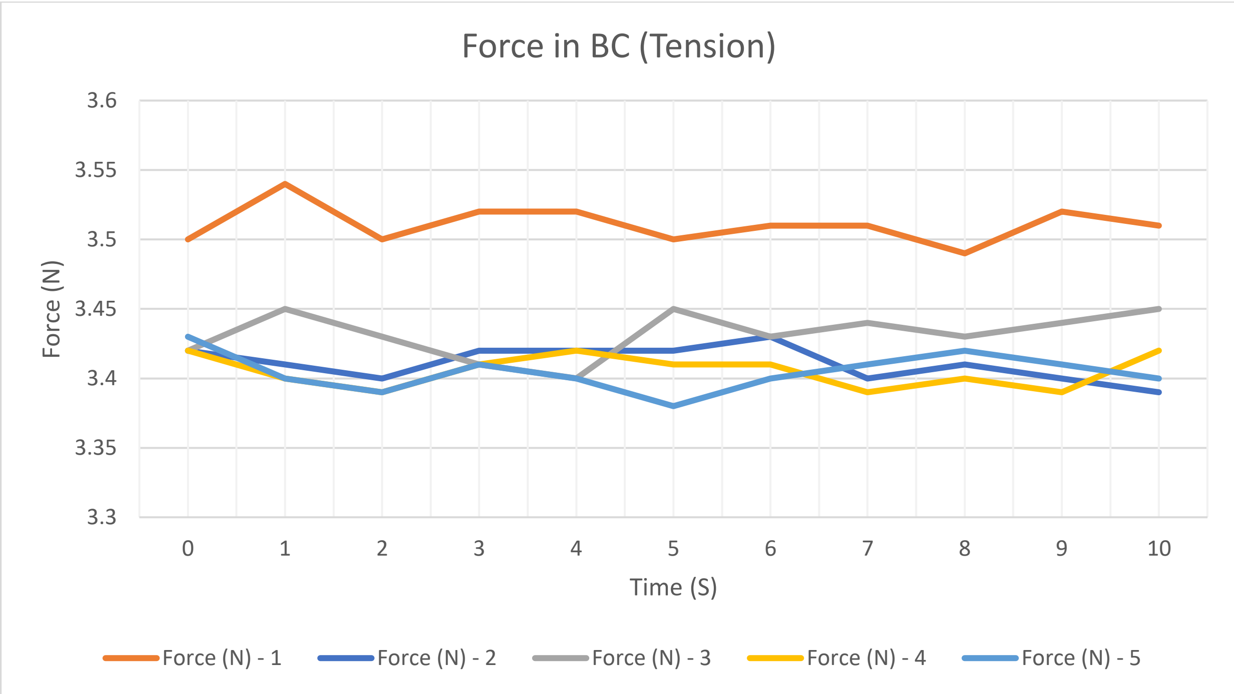


Figure 39 Warren Truss Cantilever Bridge Five Cell axial force acting in Beam BC

Beam BD												
Time (s)	0	1	2	3	4	5	6	7	8	9	10	**Average**
Force (N) - 1	-4.44	-4.45	-4.44	-4.45	-4.45	-4.45	-4.44	-4.45	-4.43	-4.45	-4.46	**-4.45**
Force (N) - 2	-4.47	-4.48	-4.49	-4.49	-4.51	-4.5	-4.51	-4.47	-4.51	-4.51	-4.5	**-4.49**
Force (N) - 3	-4.51	-4.48	-4.51	-4.48	-4.49	-4.5	-4.47	-4.5	-4.49	-4.5	-4.52	**-4.50**
Force (N) - 4	-4.51	-4.51	-4.45	-4.49	-4.48	-4.49	-4.47	-4.43	-4.47	-4.48	-4.47	**-4.48**
Force (N) - 5	-4.48	-4.47	-4.44	-4.45	-4.49	-4.46	-4.44	-4.46	-4.46	-4.47	-4.47	**-4.46**

Table 25 Warren Truss Bridge Five Cell recorded data from PASCO for Beam BD

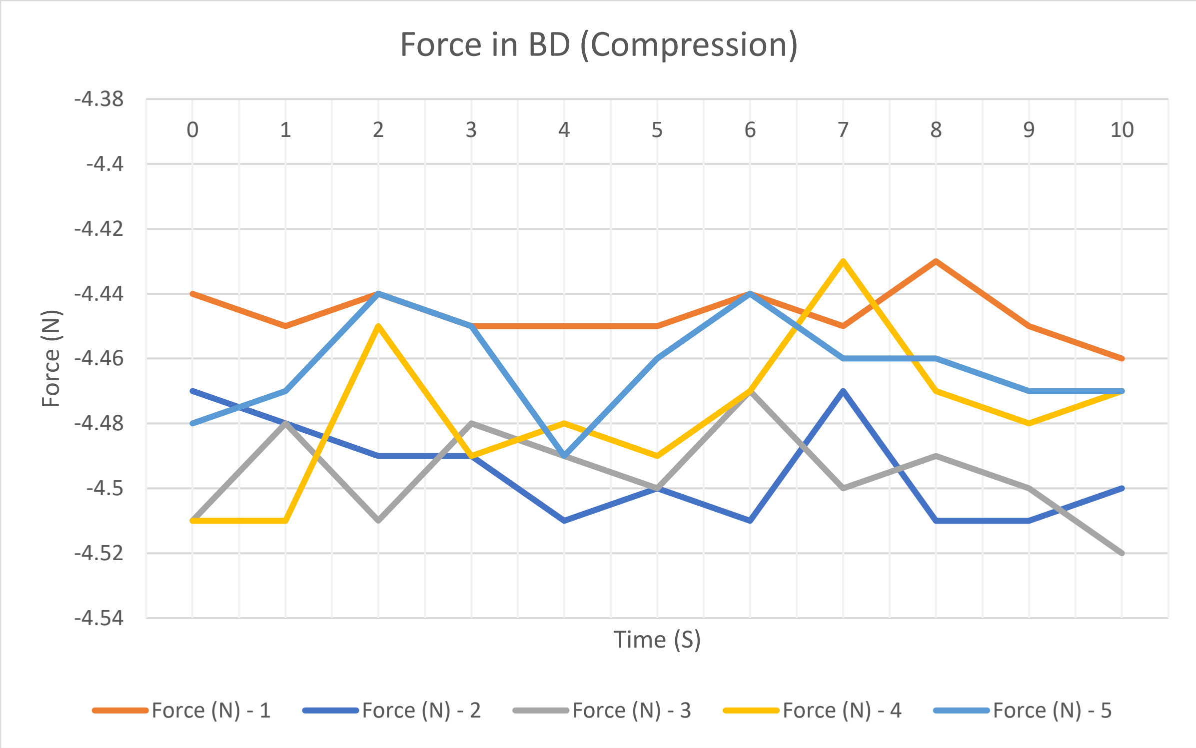


Figure 40 Warren Truss Cantilever Bridge Five Cell axial force acting in Beam BD

Beam CD												
Time (s)	0	1	2	3	4	5	6	7	8	9	10	Average
Force (N) - 1	1.72	1.74	1.75	1.75	1.75	1.73	1.78	1.74	1.74	1.75	1.74	**1.74**
Force (N) - 2	1.72	1.72	1.73	1.71	1.7	1.72	1.69	1.69	1.68	1.71	1.7	**1.71**
Force (N) - 3	1.71	1.71	1.71	1.7	1.69	1.7	1.69	1.72	1.68	1.71	1.71	**1.70**
Force (N) - 4	1.66	1.68	1.67	1.66	1.65	1.67	1.67	1.69	1.67	1.66	1.67	**1.67**
Force (N) - 5	1.69	1.68	1.69	1.68	1.68	1.66	1.68	1.67	1.69	1.69	1.69	**1.68**

Table 26 Warren Truss Bridge Five Cell recorded data from PASCO for Beam CD

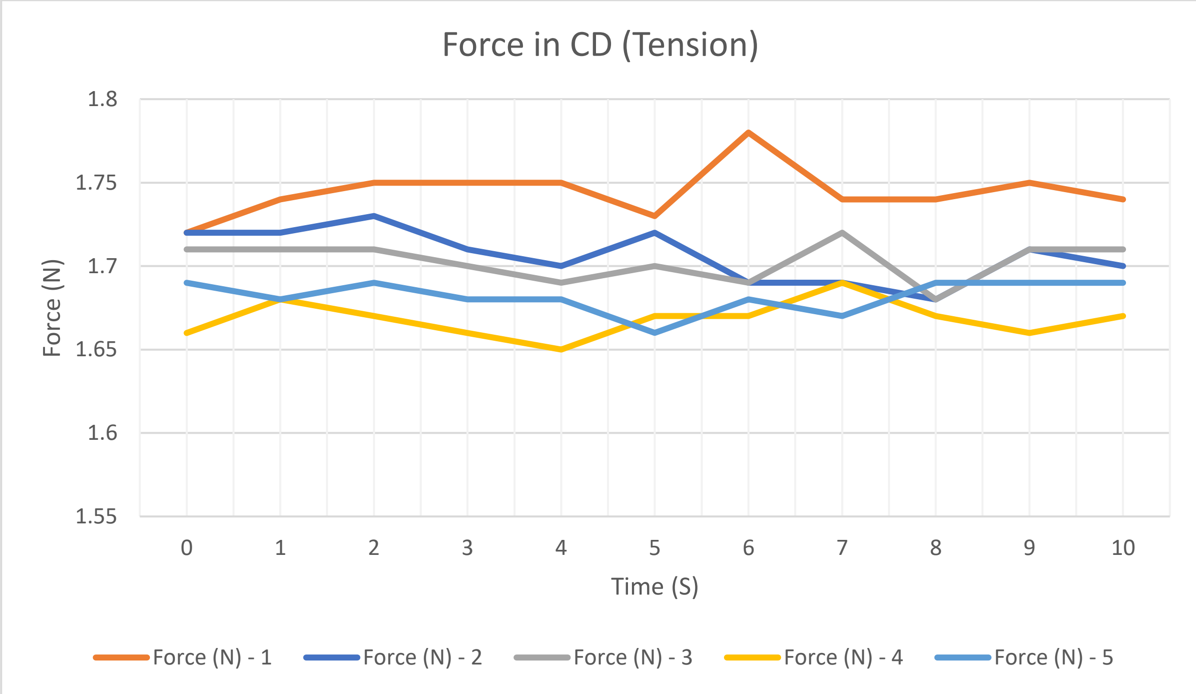


Figure 41 Warren Truss Cantilever Bridge Five Cell axial force acting in Beam CD

Beam CE												
Time (s)	0	1	2	3	4	5	6	7	8	9	10	Average
Force (N) - 1	3.06	3.04	3.05	3.03	3.02	3.03	3.02	3.02	3.05	3.03	3.02	**3.03**
Force (N) - 2	3.09	3.08	3.06	3.1	3.1	3.08	3.08	3.08	3.08	3.07	3.07	**3.08**
Force (N) - 3	2.98	3.01	3.02	2.99	2.98	2.97	3	3	2.99	2.98	2.97	**2.99**
Force (N) - 4	2.93	2.93	2.94	2.93	2.92	2.94	2.92	2.92	2.94	2.93	2.92	**2.93**
Force (N) - 5	2.97	2.97	2.97	2.99	2.96	2.98	2.96	2.99	2.97	2.97	2.98	**2.97**

Table 27 Warren Truss Bridge Five Cell recorded data from PASCO for Beam CE

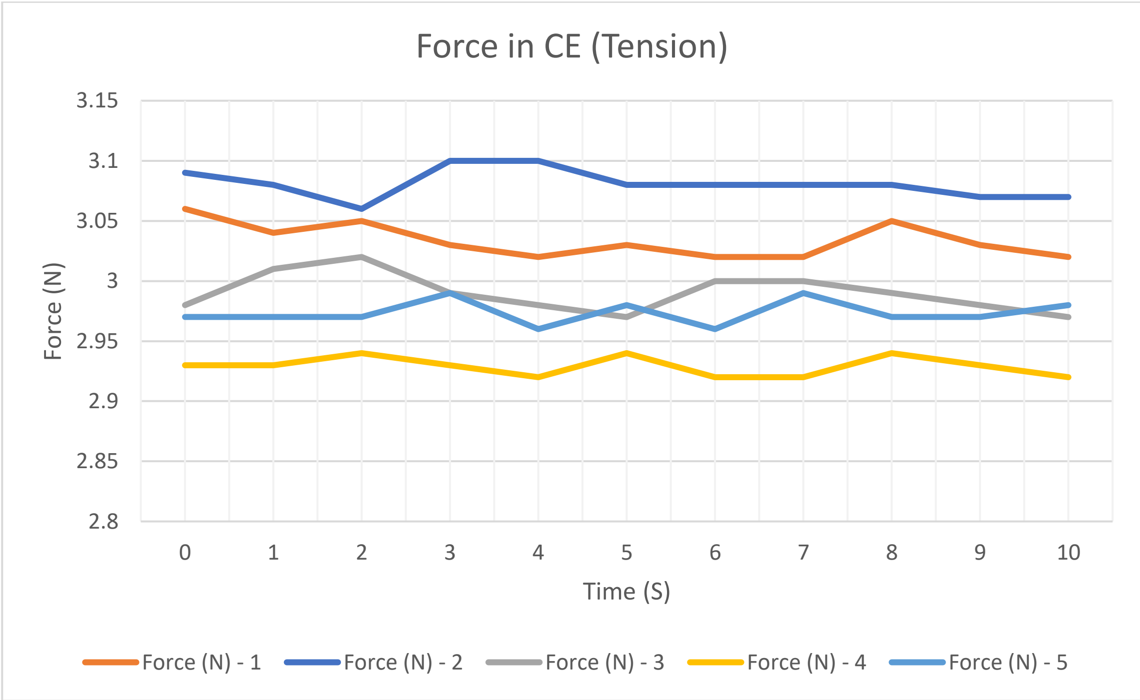


Figure 42 Warren Truss Cantilever Bridge Five Cell axial force acting in Beam CE

Beam DE											
Time (s)	0	1	2	3	4	5	6	7	8	9	10	**Average**
Force (N) - 1	-1.68	-1.69	-1.69	-1.69	-1.67	-1.68	-1.71	-1.68	-1.7	-1.68	-1.68	**-1.69**
Force (N) - 2	-1.72	-1.72	-1.72	-1.71	-1.71	-1.72	-1.69	-1.71	-1.73	-1.72	-1.73	**-1.72**
Force (N) - 3	-1.72	-1.72	-1.73	-1.73	-1.73	-1.73	-1.71	-1.71	-1.73	-1.7	-1.72	**-1.72**
Force (N) - 4	-1.71	-1.7	-1.69	-1.68	-1.7	-1.7	-1.69	-1.7	-1.7	-1.71	-1.71	**-1.70**
Force (N) - 5	-1.74	-1.74	-1.72	-1.72	-1.73	-1.74	-1.75	-1.75	-1.75	-1.72	-1.73	**-1.74**

Table 28 Warren Truss Bridge Five Cell recorded data from PASCO for Beam DE

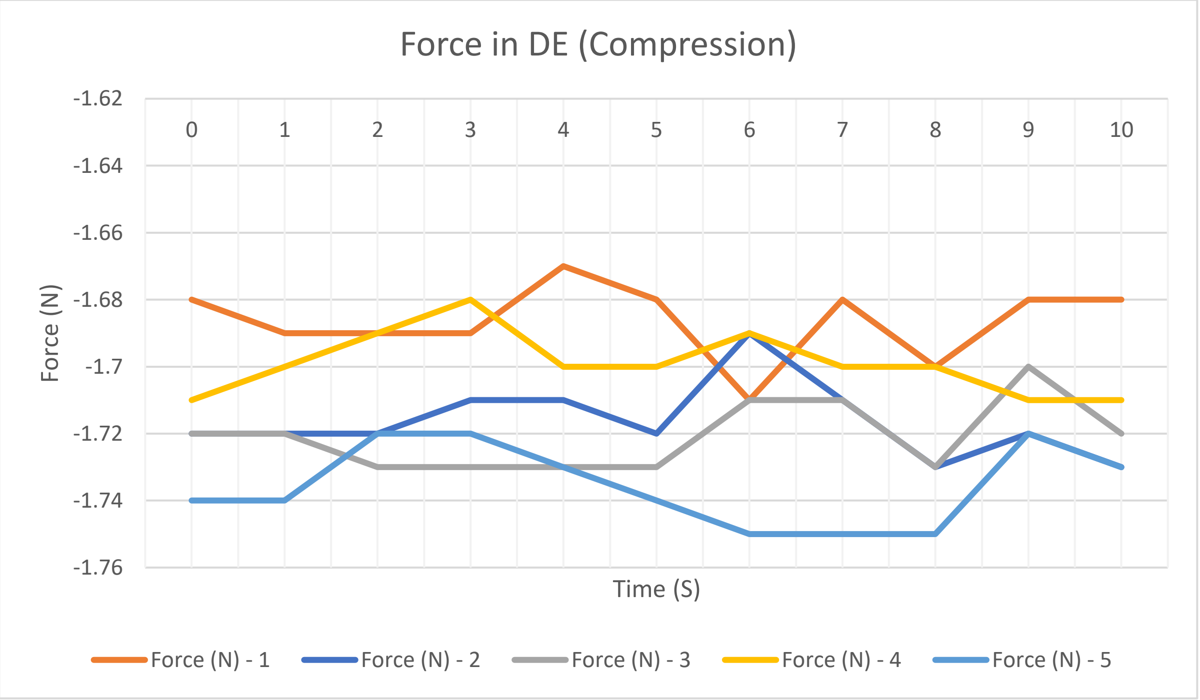


Figure 43 Warren Truss Cantilever Bridge Five Cell axial force acting in Beam DE

Beam DF											
Time (s)	0	1	2	3	4	5	6	7	8	9	10	Average
Force (N) - 1	-2.17	-2.16	-2.18	-2.16	-2.15	-2.16	-2.15	-2.19	-2.17	-2.18	-2.15	**-2.17**
Force (N) - 2	-2.24	-2.24	-2.24	-2.22	-2.24	-2.24	-2.23	-2.22	-2.24	-2.24	-2.25	**-2.24**
Force (N) - 3	-2.2	-2.21	-2.18	-2.18	-2.19	-2.19	-2.19	-2.19	-2.16	-2.21	-2.22	**-2.19**
Force (N) - 4	-2.19	-2.18	-2.2	-2.19	-2.19	-2.19	-2.19	-2.2	-2.17	-2.18	-2.18	**-2.19**
Force (N) - 5	-2.21	-2.23	-2.2	-2.19	-2.18	-2.22	-2.23	-2.22	-2.23	-2.23	-2.21	**-2.21**

Table 29 Warren Truss Bridge Five Cell recorded data from PASCO for Beam DF

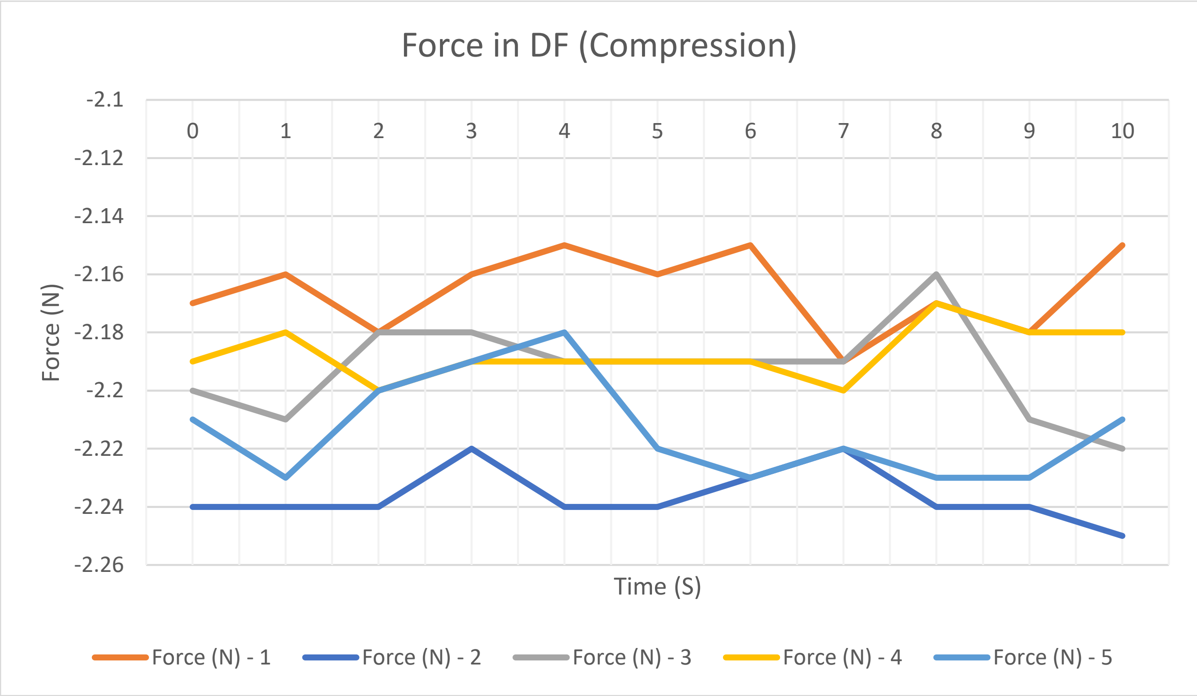


Figure 44 Warren Truss Cantilever Bridge Five Cell axial force acting in Beam DF

Beam EF												
Time (s)	0	1	2	3	4	5	6	7	8	9	10	**Average**
Force (N) - 1	1.66	1.67	1.67	1.68	1.67	1.67	1.67	1.71	1.7	1.71	1.67	**1.68**
Force (N) - 2	1.62	1.63	1.61	1.61	1.63	1.63	1.63	1.63	1.64	1.65	1.64	**1.63**
Force (N) - 3	1.66	1.67	1.66	1.66	1.66	1.65	1.65	1.68	1.67	1.7	1.68	**1.67**
Force (N) - 4	1.67	1.65	1.65	1.65	1.66	1.68	1.68	1.68	1.67	1.65	1.68	**1.67**
Force (N) - 5	1.63	1.64	1.6	1.64	1.61	1.62	1.61	1.62	1.64	1.6	1.62	**1.62**

Table 30 Warren Truss Bridge Five Cell recorded data from PASCO for Beam EF

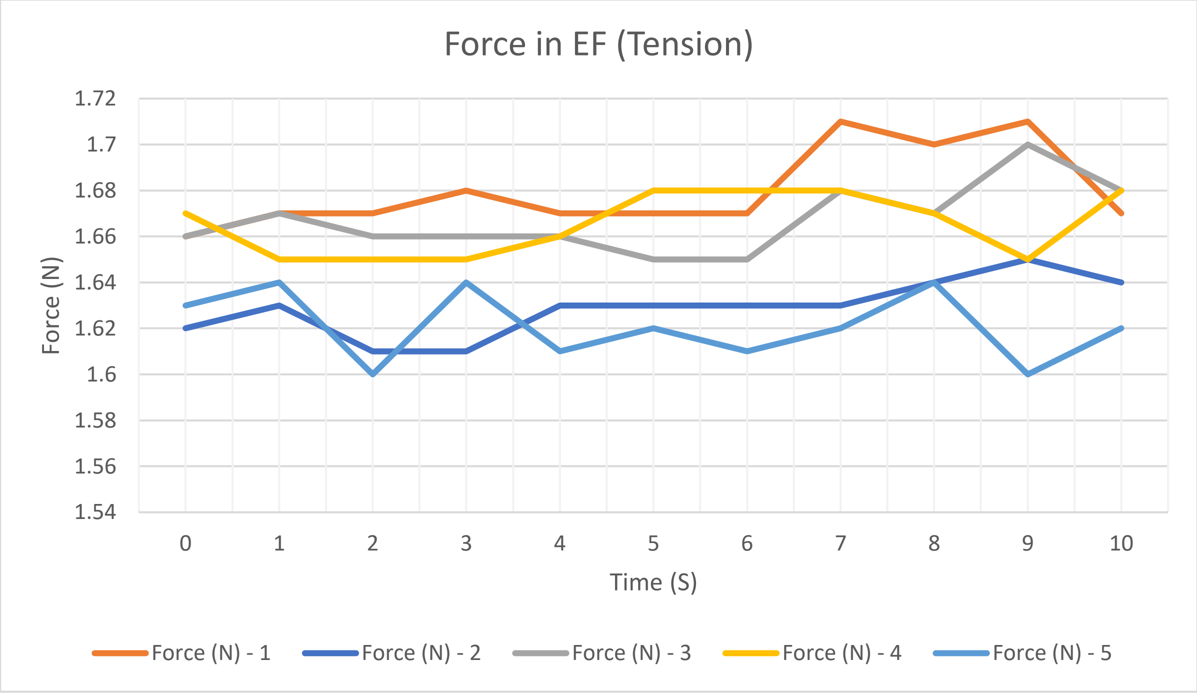


Figure 45 Warren Truss Cantilever Bridge Five Cell axial force acting in Beam EF

EG											
Time (s)	0	1	2	3	4	5	6	7	8	9	10	**Average**
Force (N) - 1	0.71	0.68	0.69	0.69	0.68	0.68	0.68	0.68	0.69	0.68	0.67	**0.68**
Force (N) - 2	0.73	0.78	0.76	0.74	0.75	0.72	0.73	0.76	0.72	0.73	0.72	**0.74**
Force (N) - 3	0.66	0.64	0.65	0.65	0.63	0.66	0.65	0.64	0.64	0.62	0.62	**0.64**
Force (N) - 4	0.59	0.6	0.63	0.61	0.62	0.63	0.6	0.63	0.62	0.63	0.63	**0.62**
Force (N) - 5	0.64	0.64	0.63	0.63	0.65	0.65	0.64	0.65	0.64	0.63	0.66	**0.64**

Table 31 Warren Truss Bridge Five Cell recorded data from PASCO for Beam EG

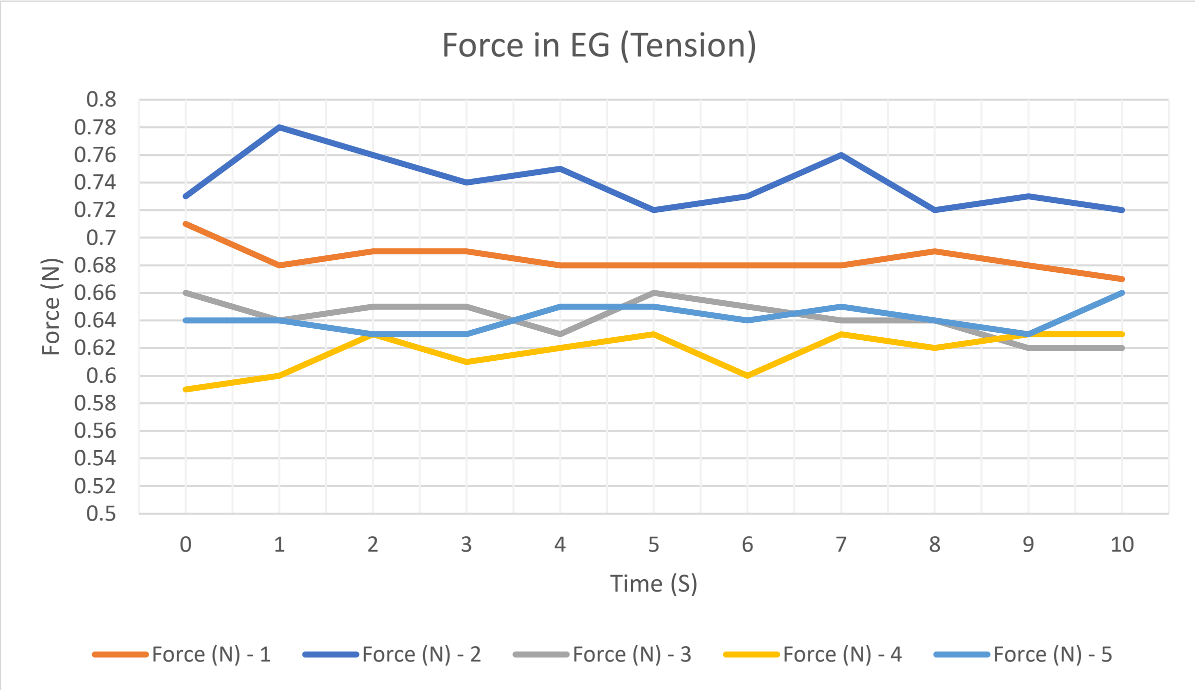


Figure 46 Warren Truss Cantilever Bridge Five Cell axial force acting in Beam EG

Beam FG												
Time (s)	0	1	2	3	4	5	6	7	8	9	10	**Average**
Force (N) - 1	-1.54	-1.51	-1.54	-1.55	-1.53	-1.5	-1.53	-1.52	-1.51	-1.51	-1.53	**-1.52**
Force (N) - 2	-1.56	-1.55	-1.55	-1.52	-1.51	-1.55	-1.55	-1.53	-1.53	-1.53	-1.55	**-1.54**
Force (N) - 3	-1.58	-1.6	-1.58	-1.58	-1.59	-1.6	-1.59	-1.59	-1.56	-1.57	-1.6	**-1.59**
Force (N) - 4	-1.54	-1.56	-1.55	-1.57	-1.55	-1.59	-1.56	-1.57	-1.56	-1.55	-1.55	**-1.56**
Force (N) - 5	-1.55	-1.57	-1.55	-1.56	-1.55	-1.55	-1.56	-1.53	-1.56	-1.55	-1.54	**-1.55**

Table 32 Warren Truss Bridge Five Cell recorded data from PASCO for Beam FG

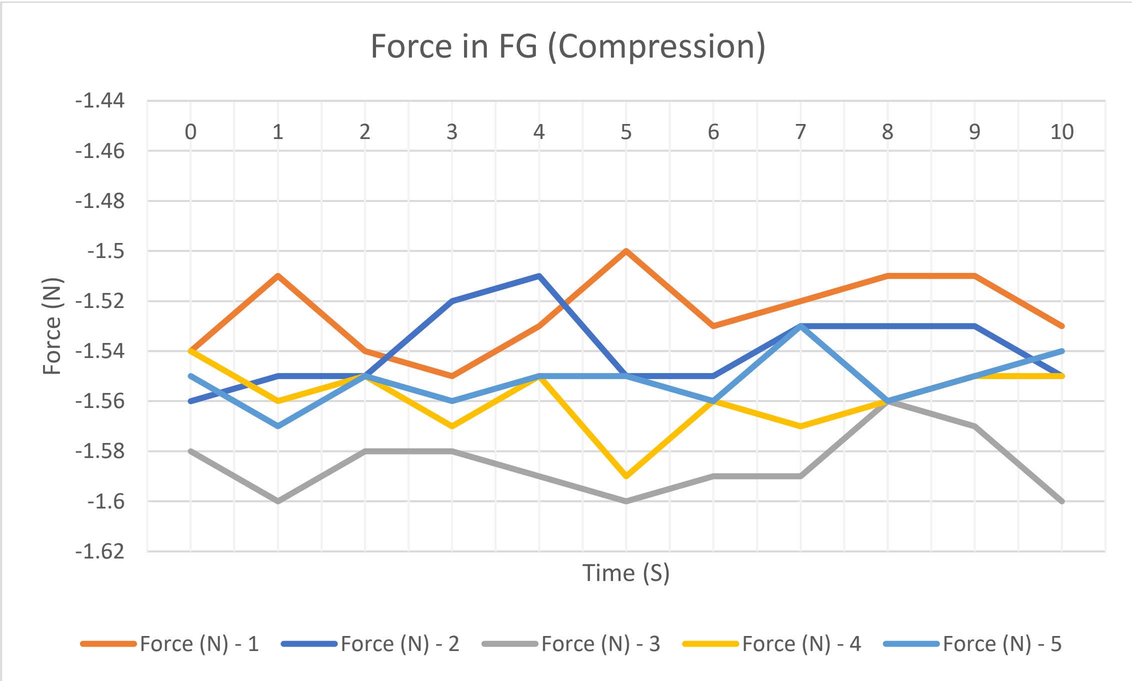


Figure 47 Warren Truss Cantilever Bridge Five Cell axial force acting in Beam FG

Ry at G												
Time (s)	0	1	2	3	4	5	6	7	8	9	10	**Average**
Force (N) - 1	1.24	1.24	1.21	1.23	1.23	1.21	1.22	1.2	1.21	1.22	1.22	**1.22**
Force (N) - 2	1.23	1.26	1.26	1.22	1.23	1.22	1.23	1.23	1.25	1.22	1.26	**1.24**
Force (N) - 3	1.23	1.27	1.24	1.25	1.26	1.25	1.25	1.21	1.23	1.24	1.25	**1.24**
Force (N) - 4	1.27	1.24	1.27	1.26	1.28	1.26	1.28	1.27	1.26	1.26	1.28	**1.27**
Force (N) - 5	1.24	1.23	1.24	1.23	1.25	1.24	1.24	1.24	1.24	1.22	1.22	**1.24**

Table 33 Warren Truss Bridge Five Cell recorded data from PASCO for node G

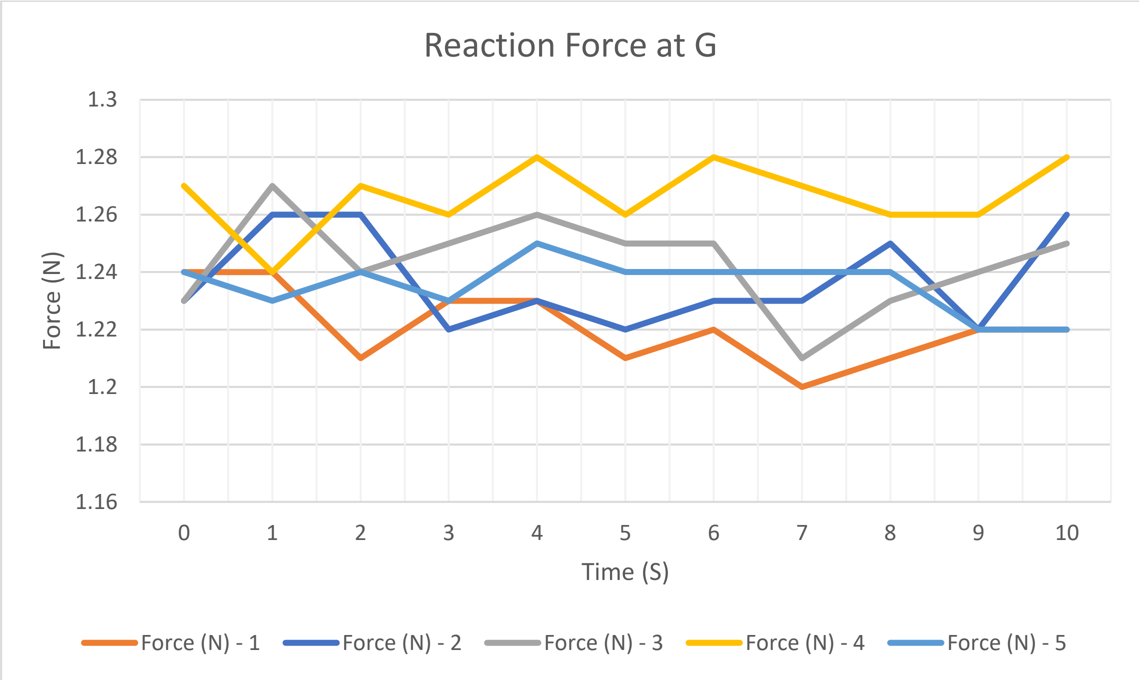


Figure 48 Warren Truss Cantilever Bridge Five Cell reaction force acting in node G

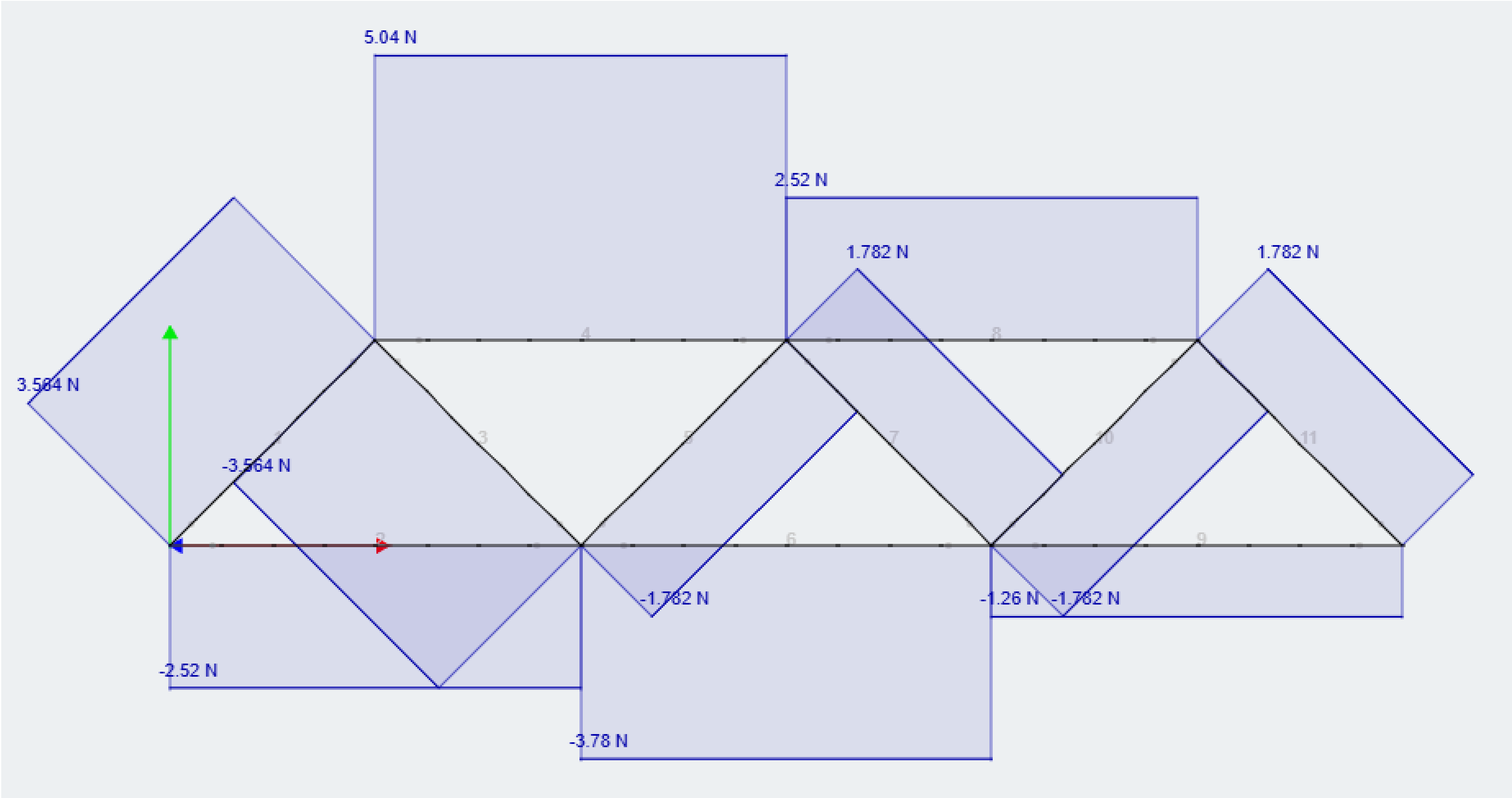
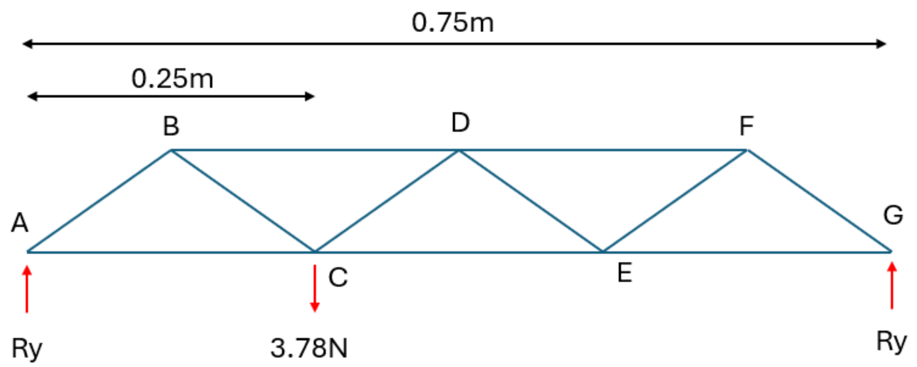


Figure 48 Warren Truss Cantilever Bridge Five Cell Ski Civ axial forces

Theoretical Data (Manual Calculations) – Joints Method

$$F = \text{mass} \times \text{accelectration}$$
$$F = 0.385\text{kg} \times 9.81\text{m}/s^2$$
$$F = 3.78N$$

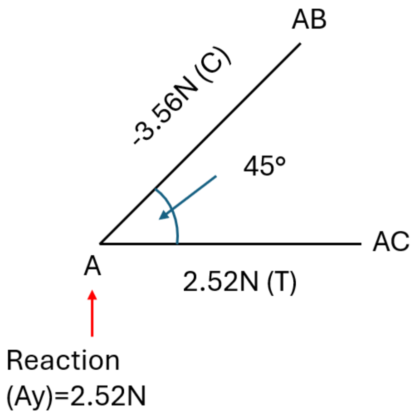


$$\sum Fy = 3.78N + Ay + Gy$$
$$\sum Ma^{+} = 3.78N \times 0.25m + Gy0.75m$$
$$Gy = \frac{0.945N}{0.75m}$$
$$Gy = 1.26N$$

$$\sum Fy = 3.78 - Ay - 1.26$$
$$Ay = 3.78 - 1.26$$
$$Ay = 2.52N$$

Joint A

$$\sum Fy = 2.52 + ABsin(45°)$$
$$AB = -\frac{2.52}{sin(45°)}$$
$$AB = -3.56N\ (C)$$
$$\sum Fx = 3.56cos(45°) - AC$$
$$AC = 3.56cos(45°)$$
$$AC = 2.52N\ \ (T)$$



Joint B

$$\sum Fy = 3.56\,sin(45°) - BCsin(45°)$$

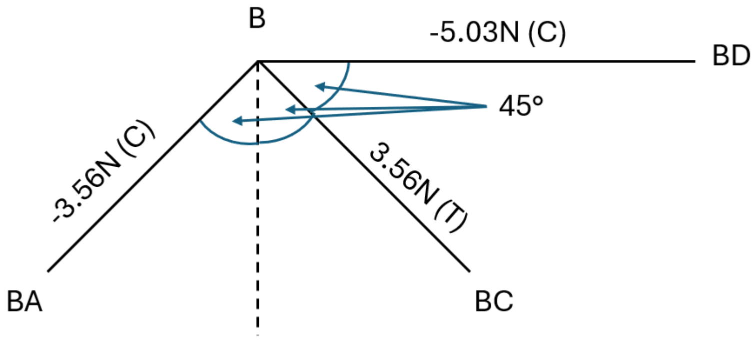
$$BC = \frac{2.517}{sin(45°)}$$

$$BC = 3.56N\ (T)$$

$$\sum Fx = 3.56\,cos(45°) + 3.56\,cos(45°) + BD$$

$$BD = -3.56\,cos(45°) - 3.56\,cos(45°)$$

$$BD = -5.03N\ (C)$$



Joint C

$$\sum Fy = 3.56\,sin(45°) + CD\,sin(45°) - 3.78$$

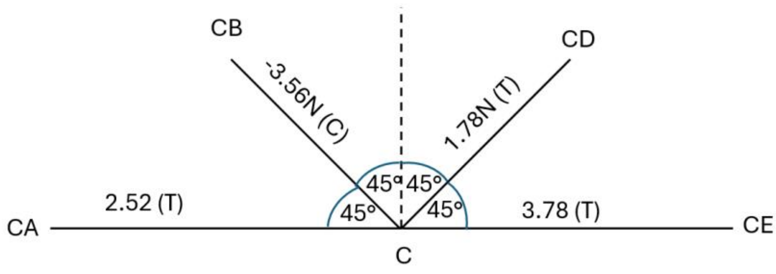
$$CD = \frac{3.78 - 3.56\,sin(45°)}{sin(45°)}$$

$$CD = 1.78N\ (T)$$

$$\sum Fx = -2.52 - 1.78\,cos(45°) + CE$$

$$CE = -2.52 - 1.78\,cos(45°)$$

$$CE = 3.78N\ (T)$$



Joint D

$$\sum Fy = 1.78\ sin(45°) + DE\ sin(45°)$$

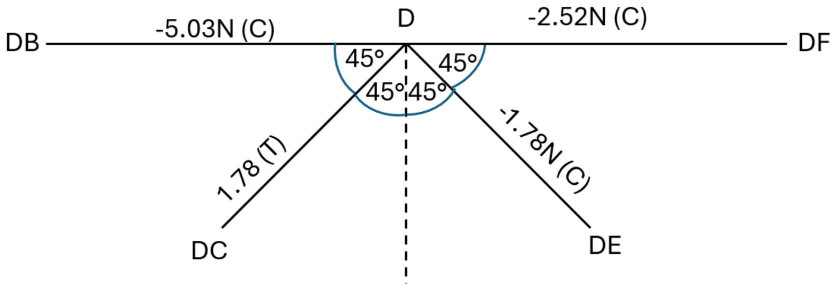
$$DE = -\frac{1.78 sin(45°)}{sin(45°)}$$

$$DE = -1.78N\ (C)$$

$$\sum Fx = 5.04 + 1.78\ cos(45°) + 1.78\ cos(45°) + DF$$

$$DF = -5.04 + 1.78\ cos(45°) + 1.78\ cos(45°)$$

$$DF = -2.52N\ (C)$$



Joint E

$$\sum Fy = -1.78\ sin(45°) + EF\ sin(45°)$$

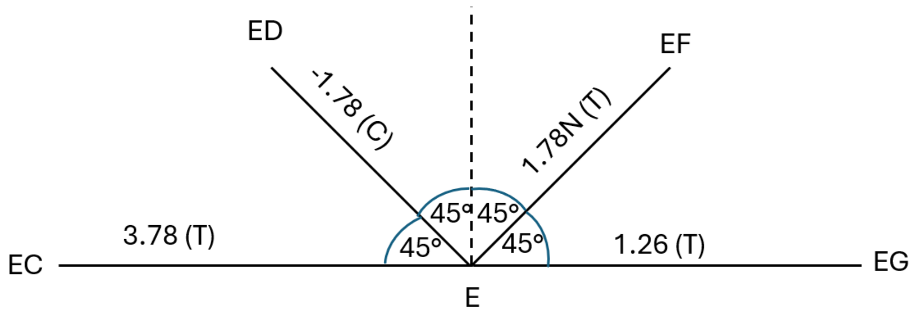
$$EF = \frac{1.78 sin(45°)}{sin(45°)}$$

$$EF = 1.78N\ (T)$$

$$\sum Fx = -3.78 + 1.78\ cos(45°) + 1.78\ cos(45°) + EG$$

$$EG = 3.78 - 1.78\ cos(45°) - 1.78\ cos(45°)$$

$$EG = 1.26N\ (T)$$

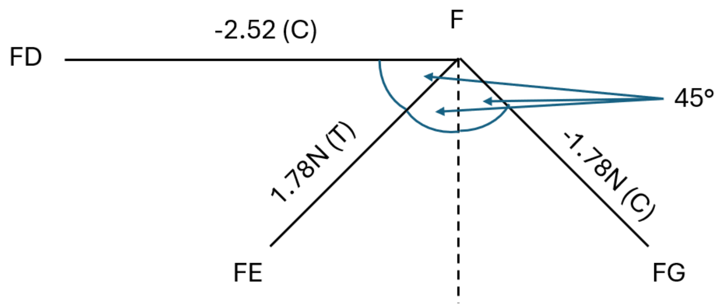


Joint F

$$\sum Fy = 1.78\,sin(45°) + FG\,sin(45°)$$

$$FG = -\frac{1.78sin(45°)}{sin(45°)}$$

$$FG = -1.78N\ (C)$$



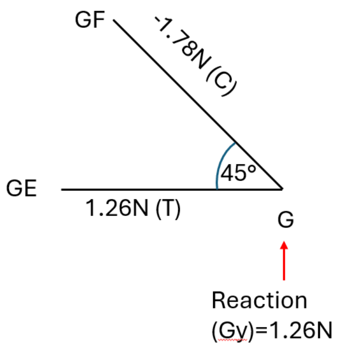
Check Joint G

$$\sum Fy = -1.78\,sin(45°) + 1.26 = 0$$

$$-1.26 + 1.26 = 0$$

$$\sum Fx = 1.78\,cos(45°) - 1.26 = 0$$

$$1.26 - 1.26 = 0$$



Cantilever Warren Truss Bridge Three Cell

To test and validate the data the process will be as follows

1. Build a Truss Structure shown in figure xxx
2. Apply weight at Truss connector C
3. Test all beam and reaction forces
4. Compare the results to the theoretical and software results

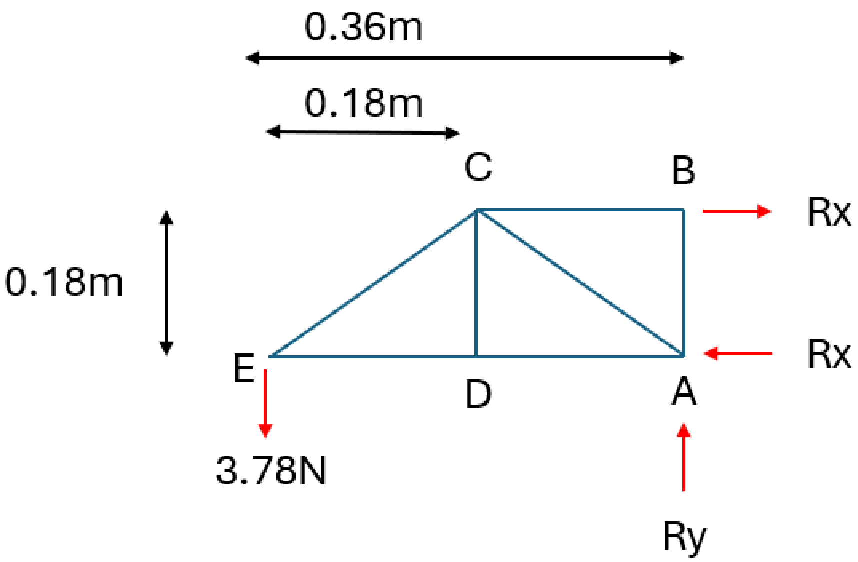


Figure 49 Warren Truss Cantilever Bridge Three Cell

While completing the testing a major factor that was potential affected the data was the sensitivity of the wireless load sensor, a slight action that vibrated the structure change the sensor starting measurement in a positive or negative direction. To counteract this the model was tested multiple times with the steps of removing the weight and setting the sensor back to zero. The average number was adopted as the result for each beam.

Beam AB											
Time (s)	0	1	2	3	4	5	6	7	8	9	10	Average
Force (N) - 1	-0.05	-0.05	0	0	0	-0.05	-0.05	-0.03	-0.01	-0.03	-0.01	**-0.03**
Force (N) - 2	-0.03	-0.04	-0.01	-0.01	-0.02	-0.05	-0.01	-0.03	0	-0.02	-0.01	**-0.02**
Force (N) - 3	0	-0.01	-0.02	-0.03	-0.03	-0.04	-0.05	0	0	-0.04	-0.01	**-0.02**
Force (N) - 4	-0.01	-0.05	0	-0.05	-0.05	-0.01	-0.01	0	0	-0.02	-0.05	**-0.02**
Force (N) - 5	0	-0.03	-0.01	-0.04	-0.03	-0.02	0	-0.02	-0.05	-0.04	0	**-0.02**

Table 34 Warren Truss Cantilever Bridge Three Cell recorded data from PASCO for Beam AB

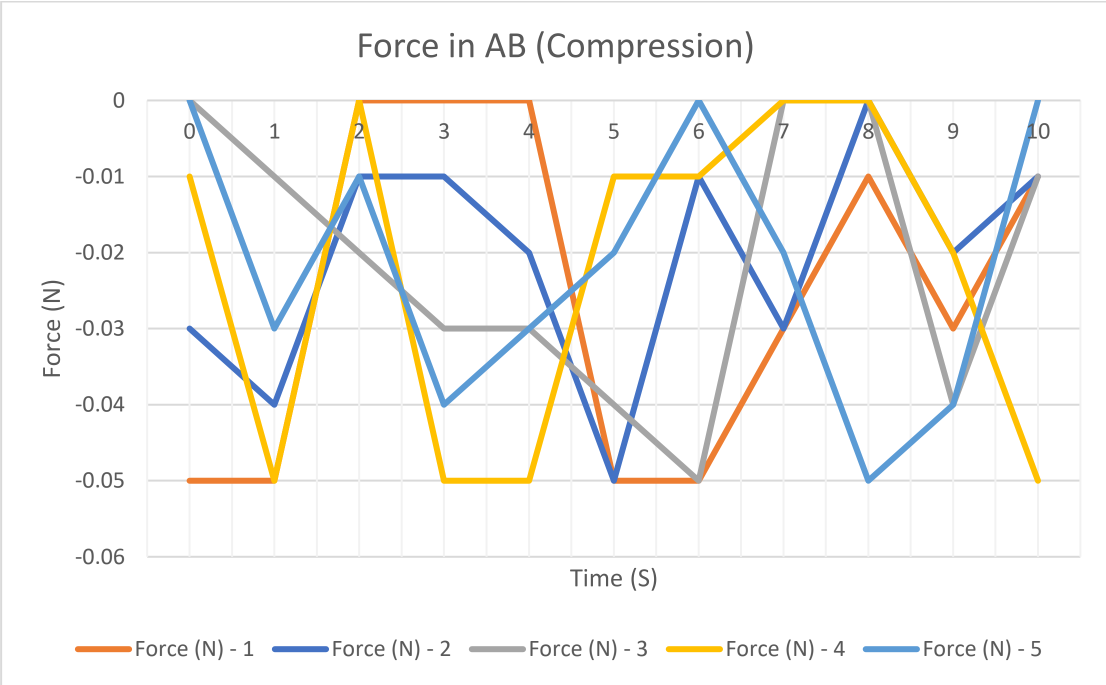


Figure 50 Warren Truss Cantilever Bridge Three Cell axial force acting in Beam AB

Beam AC												
Time (s)	0	1	2	3	4	5	6	7	8	9	10	Average
Force (N) - 1	-4.88	-4.9	-4.92	-4.85	-4.86	-4.9	-4.86	-4.9	-4.92	-4.89	-4.87	**-4.89**
Force (N) - 2	-4.87	-4.91	-4.93	-4.88	-4.86	-4.95	-4.88	-4.92	-4.93	-4.85	-4.94	**-4.90**
Force (N) - 3	-4.94	-4.85	-4.88	-4.95	-4.88	-4.86	-4.94	-4.95	-4.89	-4.94	-4.87	**-4.90**
Force (N) - 4	-4.87	-4.94	-4.91	-4.9	-4.9	-4.87	-4.85	-4.88	-4.95	-4.86	-4.89	**-4.89**
Force (N) - 5	-4.89	-4.92	-4.94	-4.95	-4.87	-4.93	-4.87	-4.85	-4.86	-4.86	-4.87	**-4.89**

Table 35 Warren Truss Cantilever Bridge Three Cell recorded data from PASCO for Beam AC

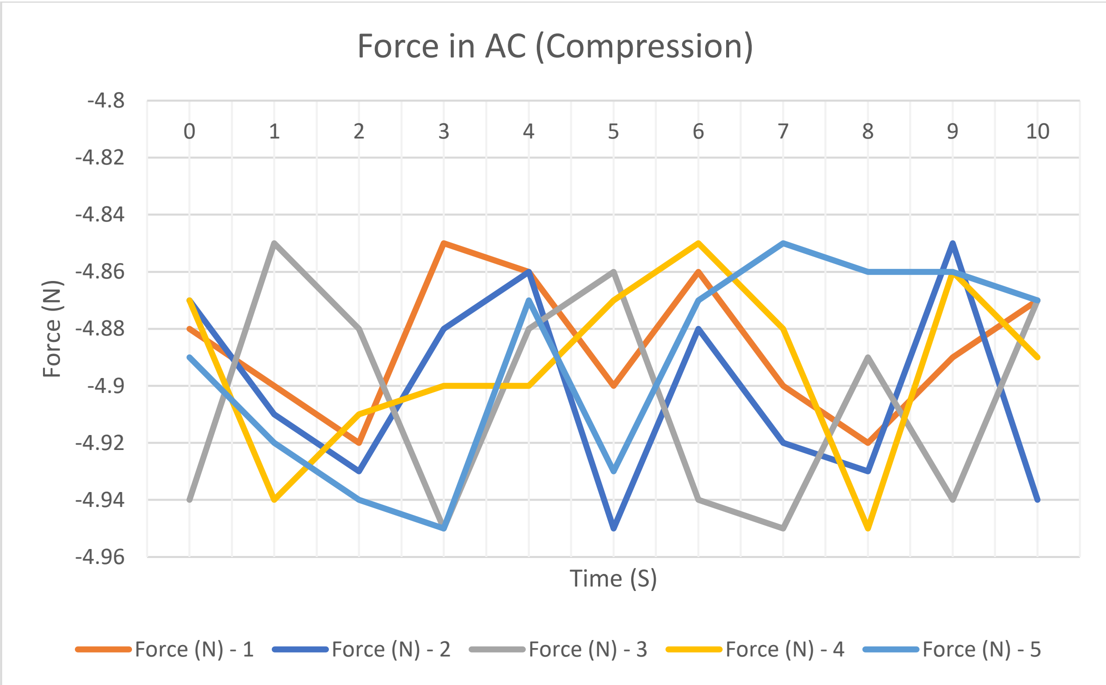


Figure 51 Warren Truss Cantilever Bridge Three Cell axial force acting in Beam AC

Beam BC											
Time (s)	0	1	2	3	4	5	6	7	8	9	10	Average
Force (N) - 1	7.36	7.31	7.33	7.38	7.32	7.31	7.37	7.34	7.35	7.31	7.39	**7.34**
Force (N) - 2	7.36	7.35	7.31	7.36	7.34	7.35	7.35	7.34	7.38	7.38	7.37	**7.35**
Force (N) - 3	7.32	7.33	7.34	7.37	7.38	7.36	7.35	7.3	7.37	7.34	7.31	**7.34**
Force (N) - 4	7.39	7.4	7.39	7.31	7.33	7.37	7.34	7.3	7.4	7.37	7.4	**7.36**
Force (N) - 5	7.3	7.33	7.34	7.31	7.33	7.34	7.33	7.31	7.3	7.34	7.36	**7.33**

Table 36 Warren Truss Cantilever Bridge Three Cell recorded data from PASCO for Beam BC

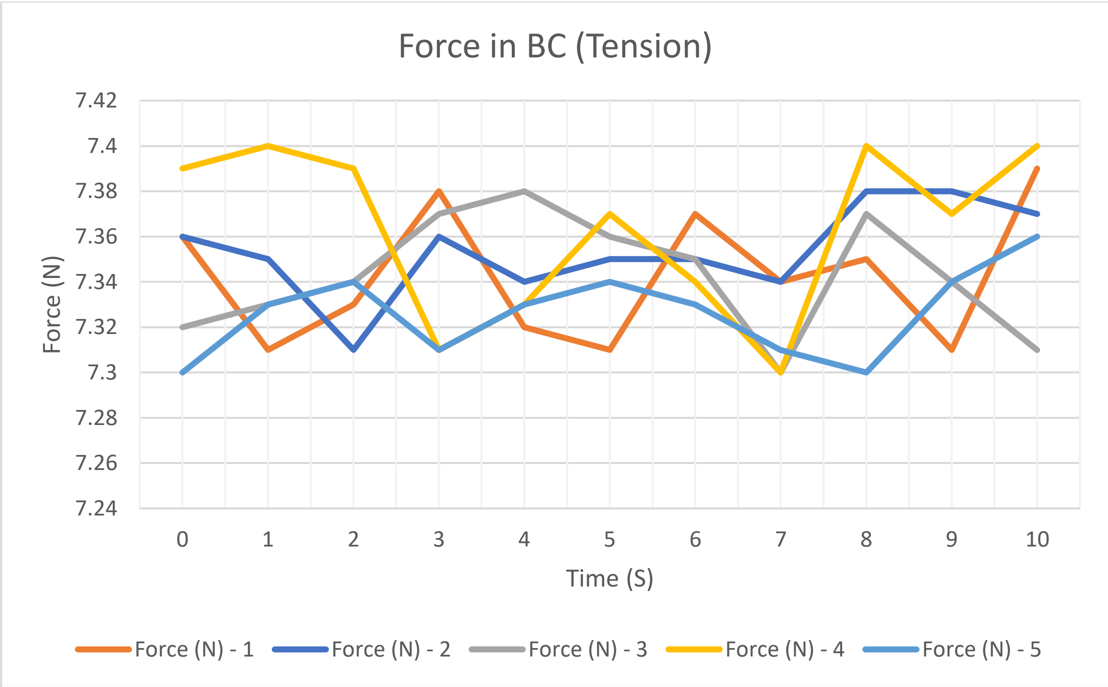


Figure 52 Warren Truss Cantilever Bridge Three Cell axial force acting in Beam BC

Beam AD											
Time (s)	0	1	2	3	4	5	6	7	8	9	10	Average
Force (N) - 1	3.72	3.73	3.71	3.74	3.67	3.73	3.72	3.74	3.74	3.76	3.67	**3.72**
Force (N) - 2	3.77	3.7	3.67	3.75	3.7	3.72	3.72	3.69	3.67	3.7	3.67	**3.71**
Force (N) - 3	3.68	3.76	3.73	3.69	3.67	3.67	3.69	3.73	3.71	3.68	3.75	**3.71**
Force (N) - 4	3.75	3.68	3.77	3.77	3.73	3.68	3.74	3.77	3.74	3.77	3.68	**3.73**
Force (N) - 5	3.67	3.67	3.67	3.69	3.71	3.73	3.74	3.7	3.77	3.73	3.7	**3.71**

Table 37 Warren Truss Cantilever Bridge Three Cell recorded data from PASCO for Beam AD

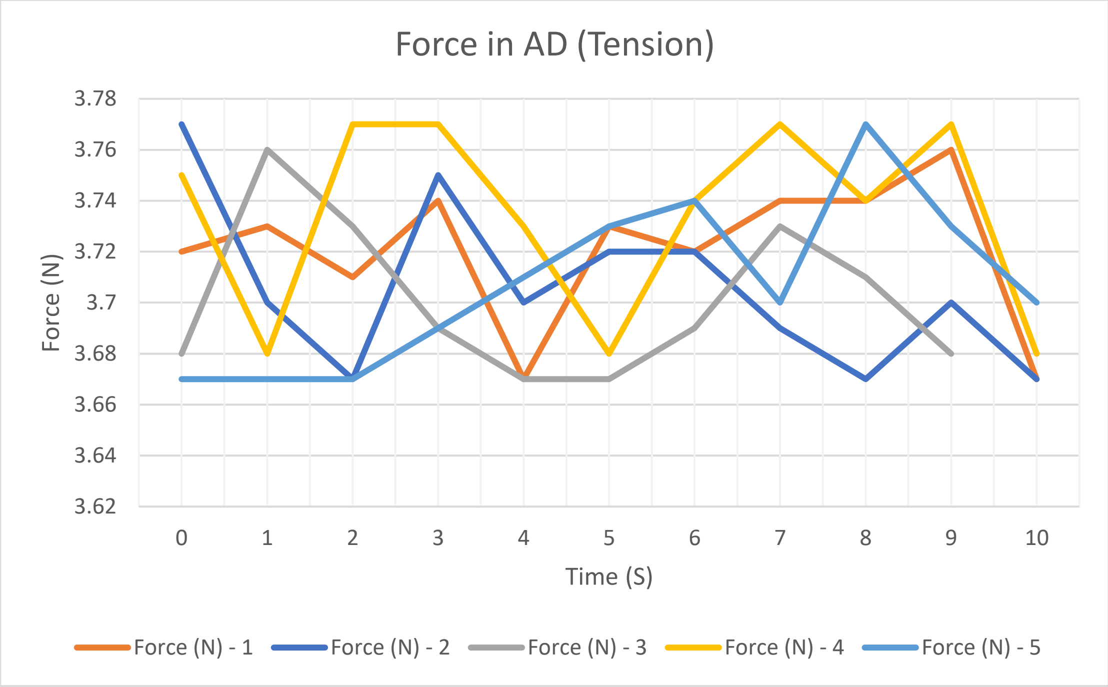


Figure 53 Warren Truss Cantilever Bridge Three Cell axial force acting in Beam AD

Beam CD											
Time (s)	0	1	2	3	4	5	6	7	8	9	10	Average
Force (N) - 1	0.07	0.07	0	0.08	0.04	0.05	0	0.03	0.01	0.09	0.03	**0.04**
Force (N) - 2	0.02	0.05	0.04	0.03	0.07	0.03	0.08	0.03	0.04	0.01	0	**0.04**
Force (N) - 3	0.01	0.06	0.04	0.09	0.05	0.04	0.01	0.04	0	0.05	0.06	**0.04**
Force (N) - 4	0.08	0	0.07	0.05	0.06	0.08	0.02	0.09	0.06	0.03	0.02	**0.05**
Force (N) - 5	0.02	0.07	0.07	0.06	0.06	0.01	0.02	0.08	0.03	0.03	0.03	**0.04**

Table 38 Warren Truss Cantilever Bridge Three Cell recorded data from PASCO for Beam CD

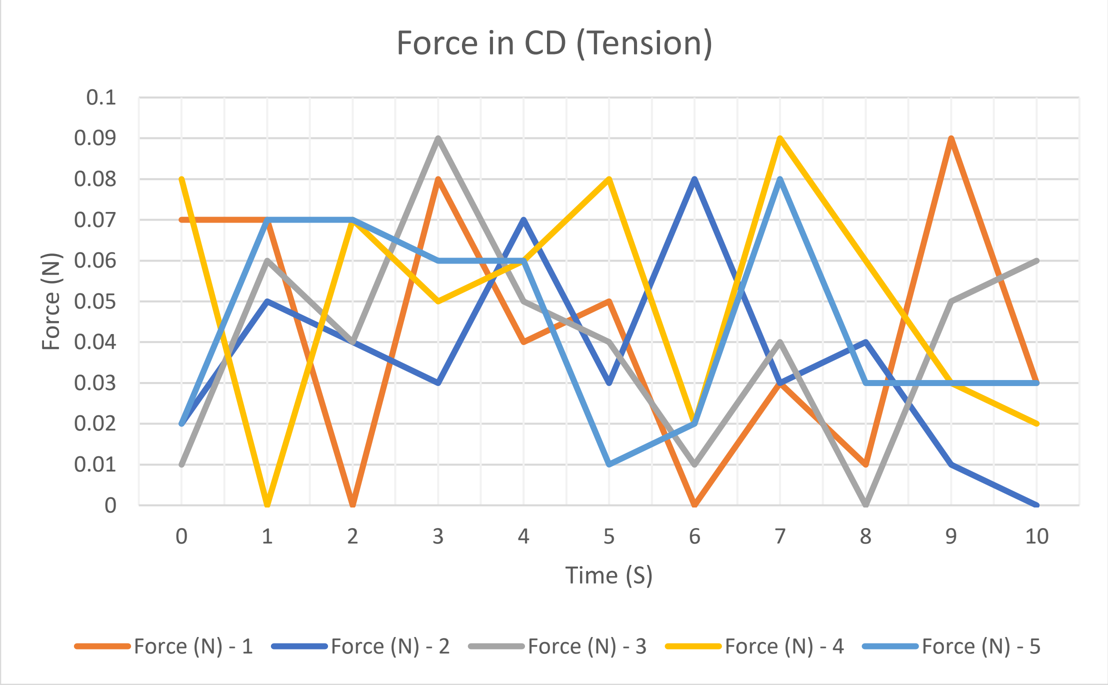


Figure 54 Warren Truss Cantilever Bridge Three Cell axial force acting in Beam CD

Beam CE												
Time (s)	0	1	2	3	4	5	6	7	8	9	10	Average
Force (N) - 1	4.77	4.7	4.71	4.76	4.79	4.74	4.71	4.74	4.77	4.79	4.79	**4.75**
Force (N) - 2	4.72	4.77	4.75	4.79	4.79	4.69	4.72	4.79	4.75	4.71	4.76	**4.75**
Force (N) - 3	4.75	4.7	4.74	4.73	4.73	4.76	4.73	4.71	4.77	4.74	4.74	**4.74**
Force (N) - 4	4.73	4.7	4.77	4.77	4.79	4.74	4.73	4.78	4.7	4.79	4.76	**4.75**
Force (N) - 5	4.78	4.78	4.76	4.72	4.73	4.71	4.75	4.72	4.7	4.75	4.76	**4.74**

Table 39 Warren Truss Cantilever Bridge Three Cell recorded data from PASCO for Beam CE

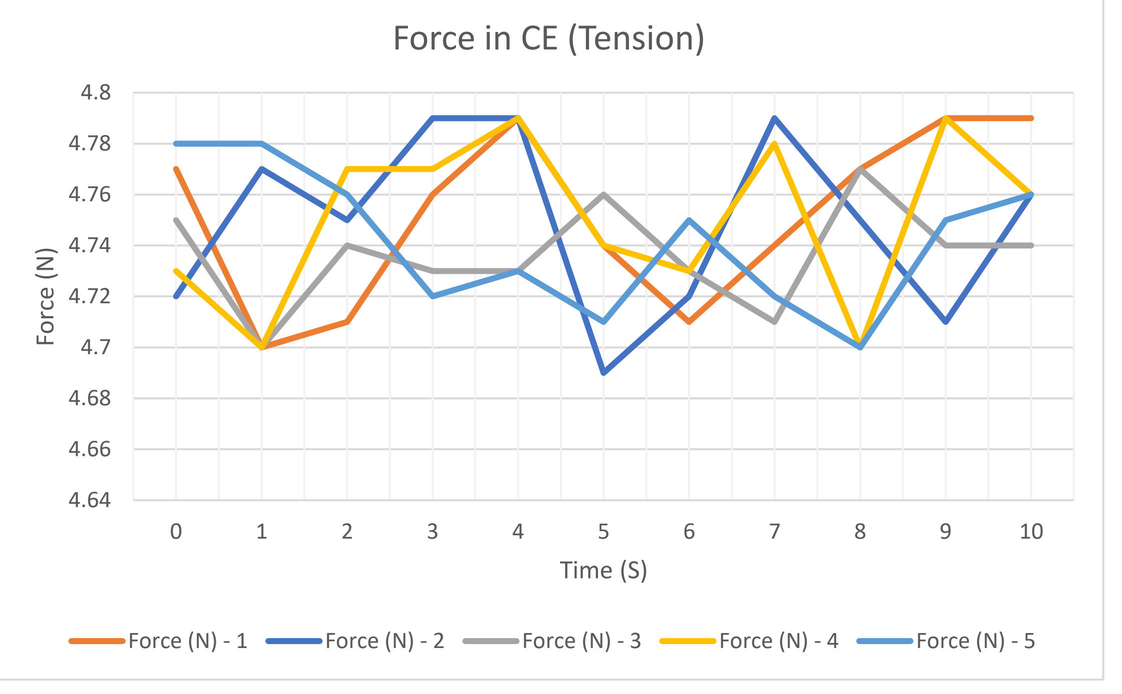


Figure 55 Warren Truss Cantilever Bridge Three Cell axial force acting in Beam CE

Beam DE												
Time (s)	0	1	2	3	4	5	6	7	8	9	10	Average
Force (N) - 1	-3.59	-3.59	-3.6	-3.6	-3.57	-3.57	-3.57	-3.59	-3.63	-3.56	-3.56	**-3.58**
Force (N) - 2	-3.61	-3.58	-3.64	-3.59	-3.63	-3.63	-3.62	-3.66	-3.65	-3.66	-3.57	**-3.62**
Force (N) - 3	-3.66	-3.58	-3.58	-3.57	-3.62	-3.65	-3.64	-3.63	-3.56	-3.6	-3.61	**-3.61**
Force (N) - 4	-3.62	-3.57	-3.65	-3.66	-3.58	-3.62	-3.63	-3.66	-3.65	-3.63	-3.57	**-3.62**
Force (N) - 5	-3.57	-3.61	-3.65	-3.58	-3.62	-3.56	-3.58	-3.56	-3.63	-3.59	-3.66	**-3.60**

Table 40 Warren Truss Cantilever Bridge Three Cell recorded data from PASCO for Beam DE

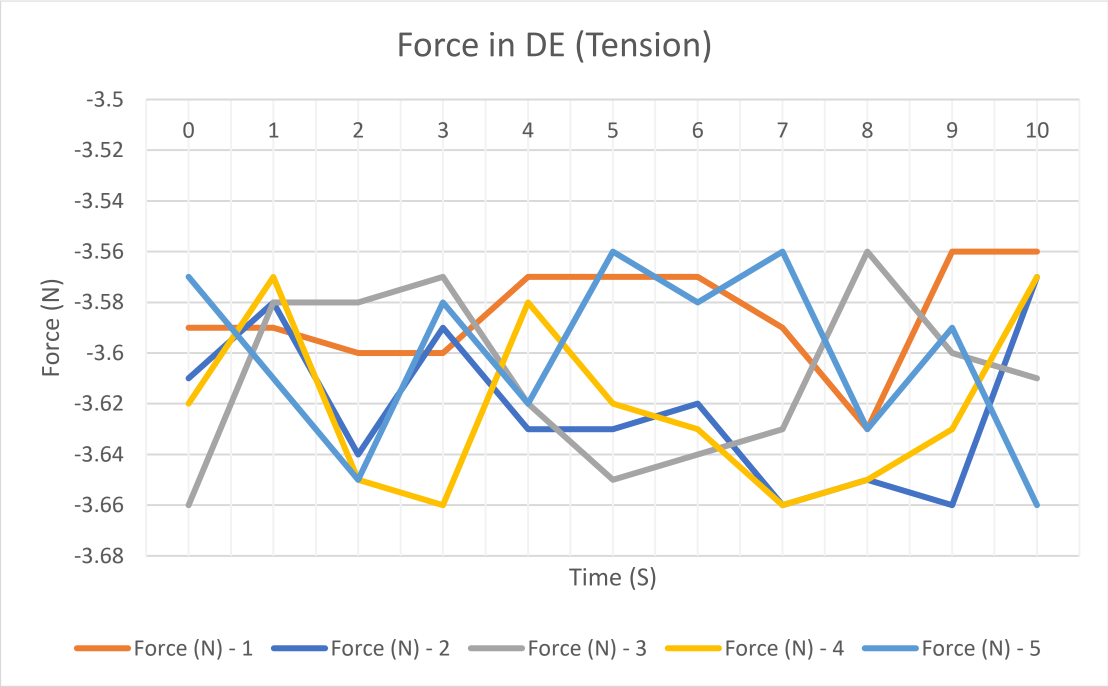


Figure 56 Warren Truss Cantilever Bridge Three Cell axial force acting in Beam DE

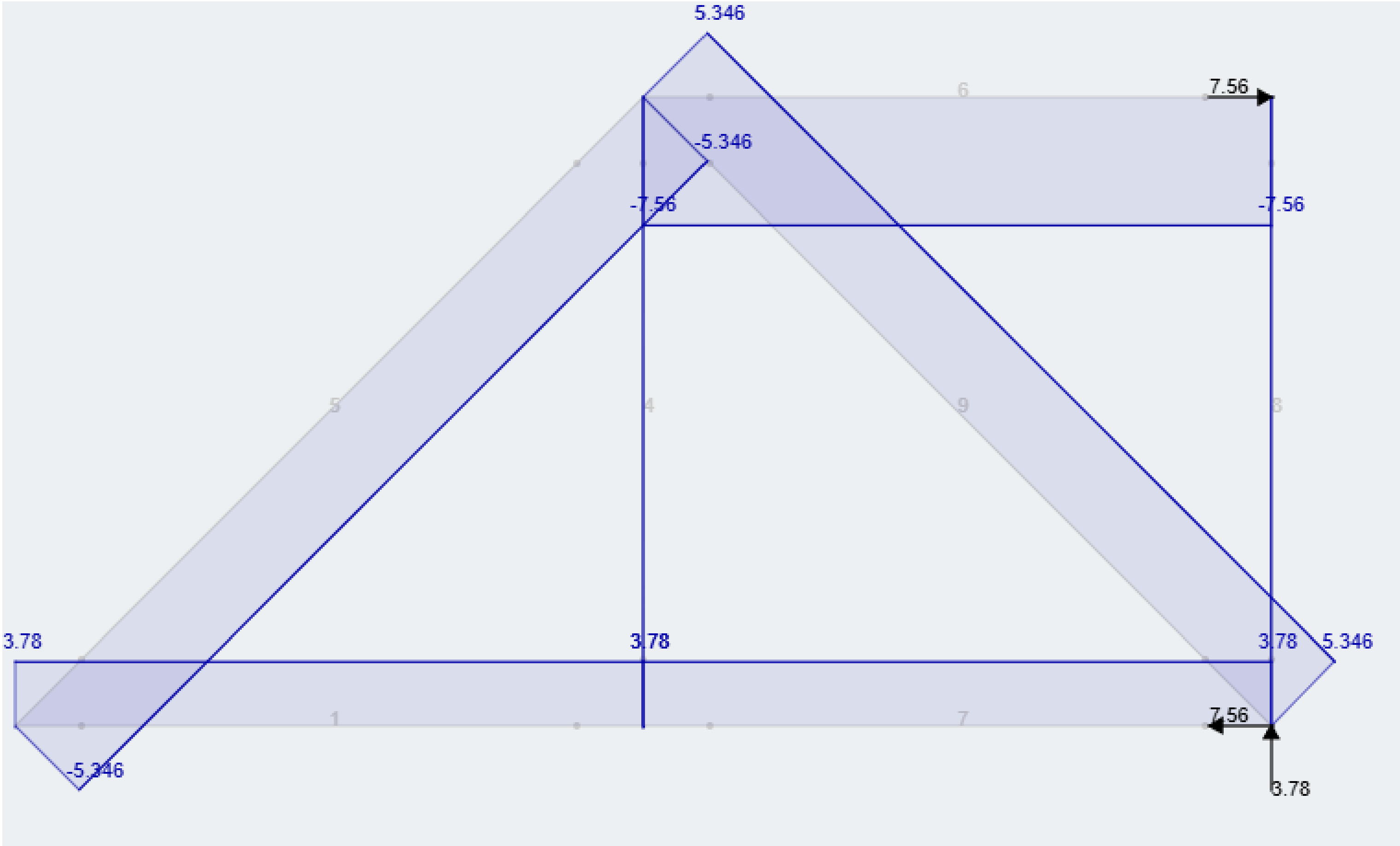


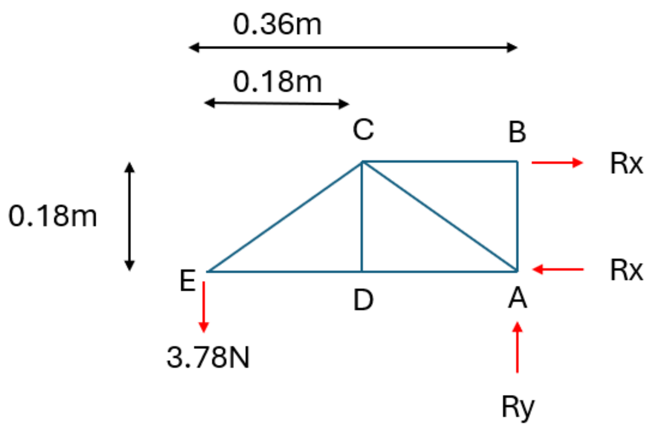
Figure 57 Warren Truss Cantilever Bridge Three Cell Ski Civ axial forces

Theoretical Data (Manual Calculations)

$$F = \text{mass} \times \text{accelectration}$$

$$F = 0.385\text{kg} \times 9.81\text{m}/s^2$$

$$F = 3.78N$$



$$\sum Fy = -3.78N + Ay$$

$$Ay = 3.78N$$

$$\sum Ma^{+} = 3.78N \times 0.36m + Bx \times 0.18m$$

$$Gy = \frac{1.3608N}{0.18m}$$

$$Bx = 7.56N$$

$$\sum Fx = Ax + Bx$$

$$0 = Ax + 7.56$$

$$Ax = -7.56N$$

Joint E

$$\sum Fy = -3.78 + CEsin(45°)$$

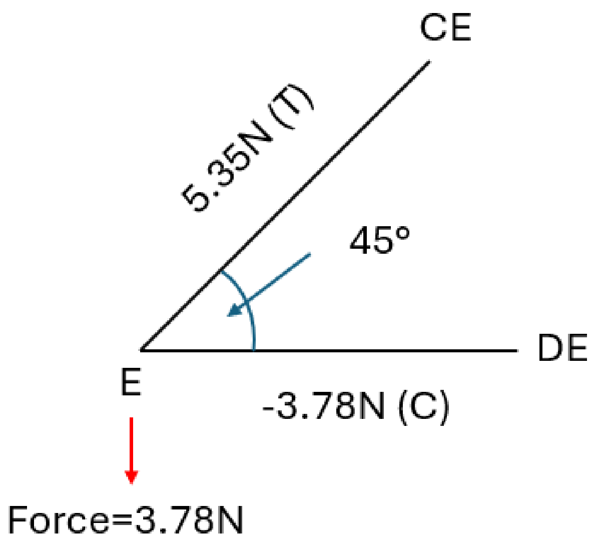
$$CE = \frac{3.78}{sin(45°)}$$

$$CE = 5.35N\ (T)$$

$$\sum Fx = 5.35cos(45°) - DE$$

$$DE = -5.35cos(45°)$$

$$DE = -3.78N$$



Joint C

$$\sum Fy = 5.35sin(45°) + ACsin(45°)$$

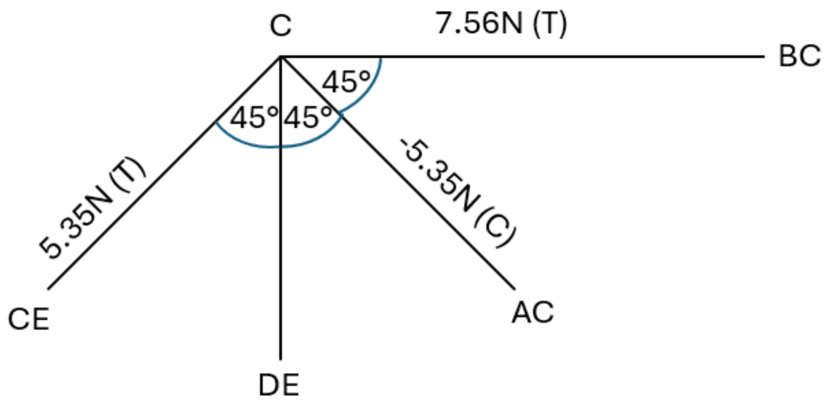
$$AC = -\frac{3.78}{sin(45°)}$$

$$AC = -5.35N\ (C)$$

$$\sum Fx = -5.35cos(45°) - 5.35\ cos(45°) + BC$$

$$BC = 5.35cos(45°) + 5.35\ cos(45°)$$

$$BC = 7.56N\ (T)$$



Joint D

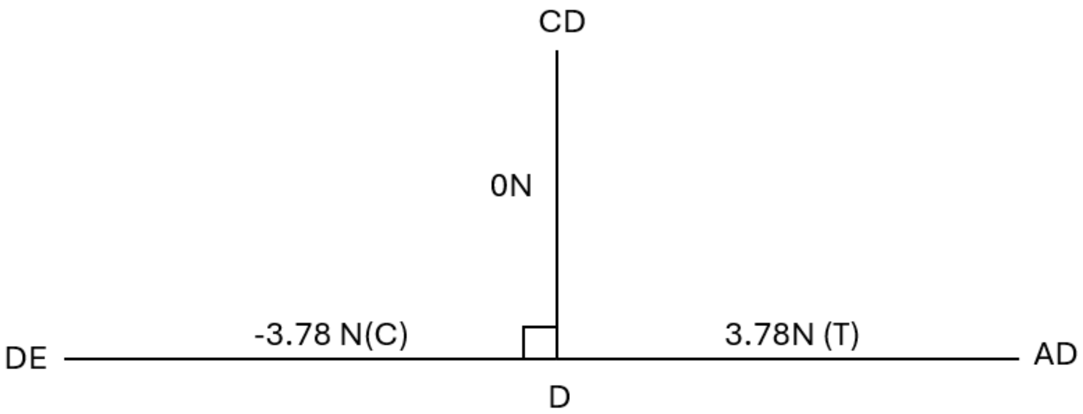
$$\sum Fy = 0$$

$$CD = 0$$

$$\sum Fx = 3.78cos(180°) \ + AD$$

$$AD = 3.78cos(180°)$$

$$AD = -3.78N \ (C)$$

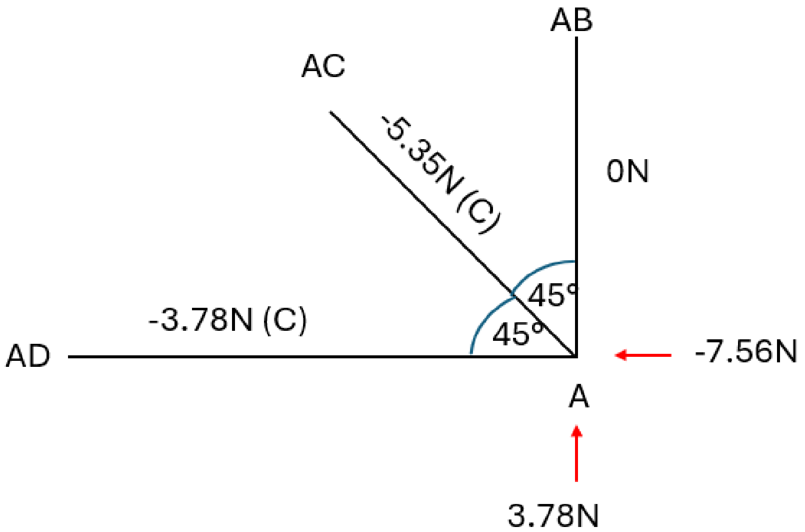


Joint A

$$\sum Fy = 3.78 + AB - 5.35sin(45°)$$

$$AB = -3.78 + 5.35sin(45°)$$

$$AB = 0N$$



Cantilever Warren Truss Bridge Five Cell

To test and validate the data the process will be as follows

1. Build a Truss Structure shown in figure xxx
2. Apply weight at Truss connector C
3. Test all beam and reaction forces
4. Compare the results to the theoretical and software results

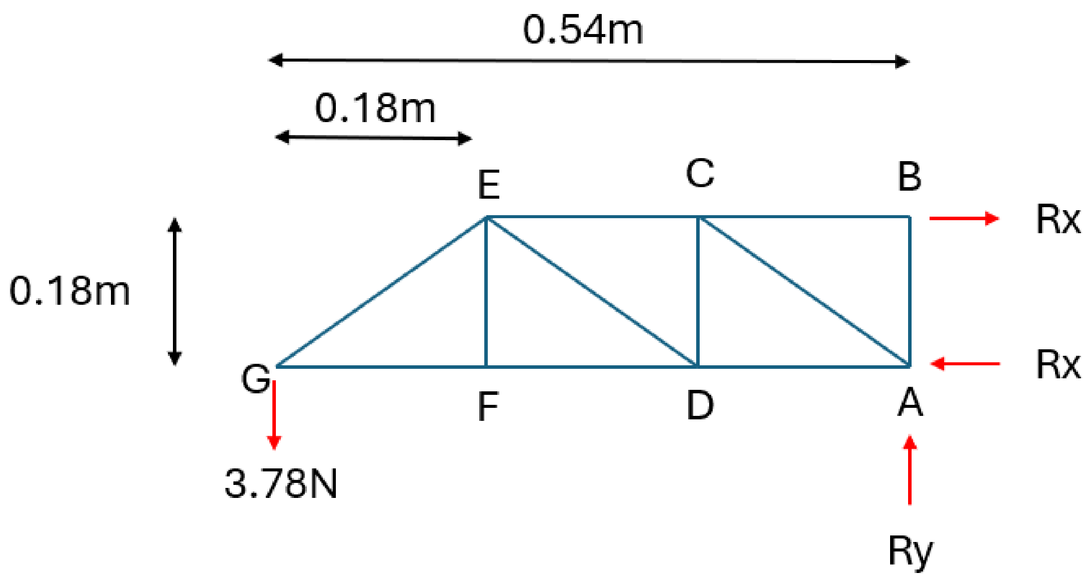


Figure 58 Warren Truss Cantilever Bridge Five Cell

While completing the testing a major factor that was potential affected the data was the sensitivity of the wireless load sensor, a slight action that vibrated the structure change the sensor starting measurement in a positive or negative direction. To counteract this the model was tested multiple times with the steps of removing the weight and setting the sensor back to zero. The average number was adopted as the result for each beam.

Beam AB											
Time (s)	0	1	2	3	4	5	6	7	8	9	10	**Average**
Force (N) - 1	-0.02	0	-0.05	0	-0.04	-0.03	-0.01	-0.02	-0.01	-0.05	-0.05	**-0.03**
Force (N) - 2	-0.03	-0.03	-0.04	-0.02	-0.03	0	-0.03	-0.05	-0.02	0	-0.02	**-0.02**
Force (N) - 3	-0.02	-0.04	-0.05	-0.02	0	-0.03	-0.02	-0.04	-0.03	-0.05	-0.01	**-0.03**
Force (N) - 4	-0.05	-0.03	0	-0.04	-0.02	-0.01	-0.01	-0.05	0	-0.05	-0.04	**-0.03**
Force (N) - 5	0	-0.03	-0.02	-0.01	-0.03	0	-0.01	-0.01	-0.05	-0.05	-0.05	**-0.02**

Table 41 Warren Truss Cantilever Bridge Five Cell recorded data from PASCO for Beam AB

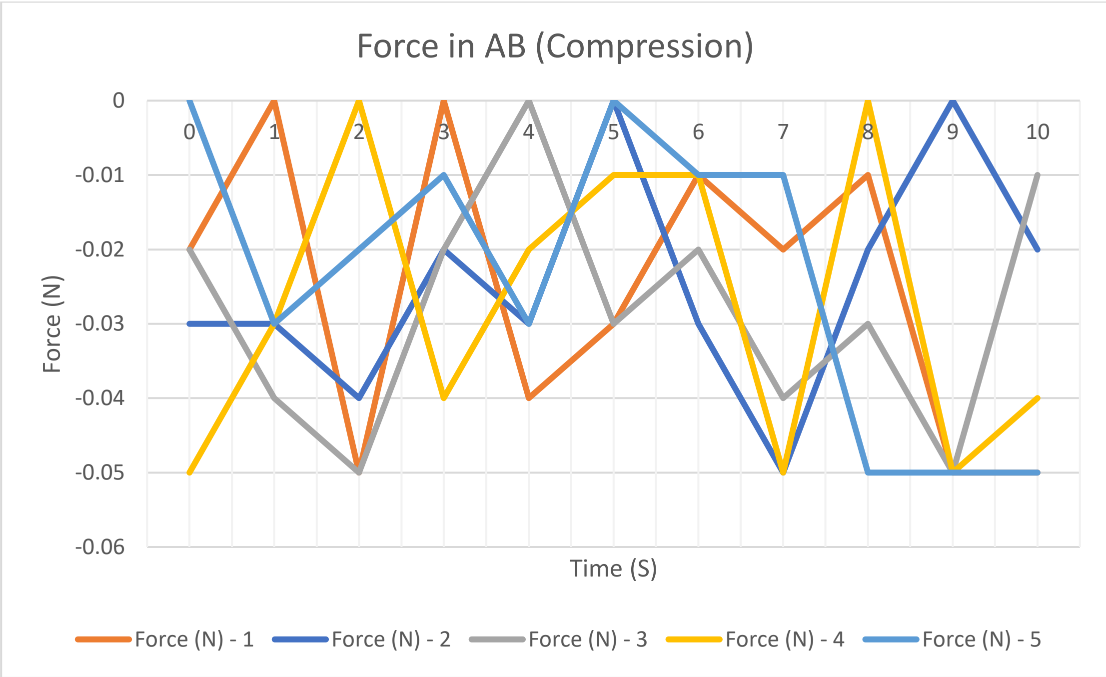


Figure 59 Warren Truss Cantilever Bridge Five Cell axial force acting in Beam AB

Beam AC												
Time (s)	0	1	2	3	4	5	6	7	8	9	10	**Average**
Force (N) - 1	-4.87	-4.89	-4.86	-4.9	-4.93	-4.88	-4.93	-4.89	-4.92	-4.89	-4.96	**-4.90**
Force (N) - 2	-4.94	-4.89	-4.95	-4.92	-4.92	-4.9	-4.9	-4.94	-4.91	-4.94	-4.93	**-4.92**
Force (N) - 3	-4.86	-4.9	-4.94	-4.88	-4.88	-4.92	-4.94	-4.89	-4.92	-4.87	-4.96	**-4.91**
Force (N) - 4	-4.95	-4.92	-4.91	-4.93	-4.94	-4.94	-4.9	-4.94	-4.93	-4.9	-4.89	**-4.92**
Force (N) - 5	-4.92	-4.96	-4.87	-4.92	-4.87	-4.94	-4.87	-4.87	-4.91	-4.96	-4.93	**-4.91**

Table 42 Warren Truss Cantilever Bridge Five Cell recorded data from PASCO for Beam AC

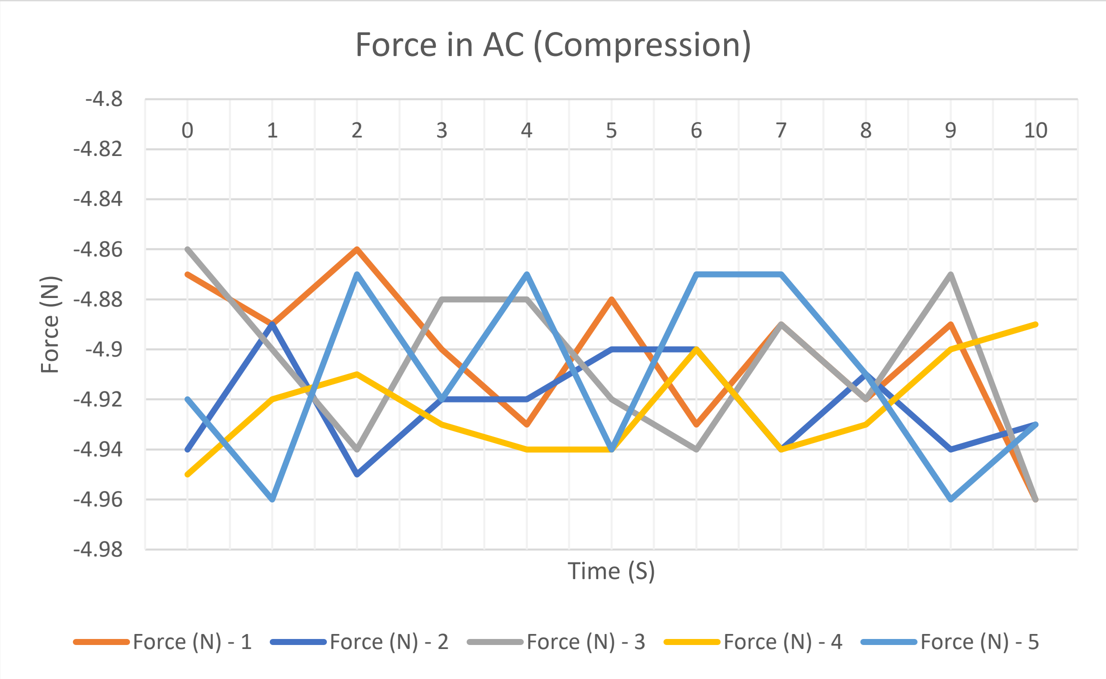


Figure 60 Warren Truss Cantilever Bridge Five Cell axial force acting in Beam AC

Beam AD												
Time (s)	0	1	2	3	4	5	6	7	8	9	10	**Average**
Force (N) - 1	-7.31	-7.3	-7.42	-7.39	-7.42	-7.41	-7.49	-7.39	-7.37	-7.36	-7.48	**-7.39**
Force (N) - 2	-7.41	-7.48	-7.41	-7.43	-7.46	-7.4	-7.42	-7.36	-7.32	-7.47	-7.49	**-7.42**
Force (N) - 3	-7.47	-7.37	-7.49	-7.46	-7.48	-7.48	-7.36	-7.39	-7.37	-7.45	-7.47	**-7.44**
Force (N) - 4	-7.3	-7.44	-7.3	-7.42	-7.3	-7.45	-7.35	-7.38	-7.37	-7.47	-7.4	**-7.38**
Force (N) - 5	-7.31	-7.39	-7.4	-7.43	-7.39	-7.41	-7.44	-7.5	-7.36	-7.47	-7.33	**-7.40**

Table 43 Warren Truss Cantilever Bridge Five Cell recorded data from PASCO for Beam AD

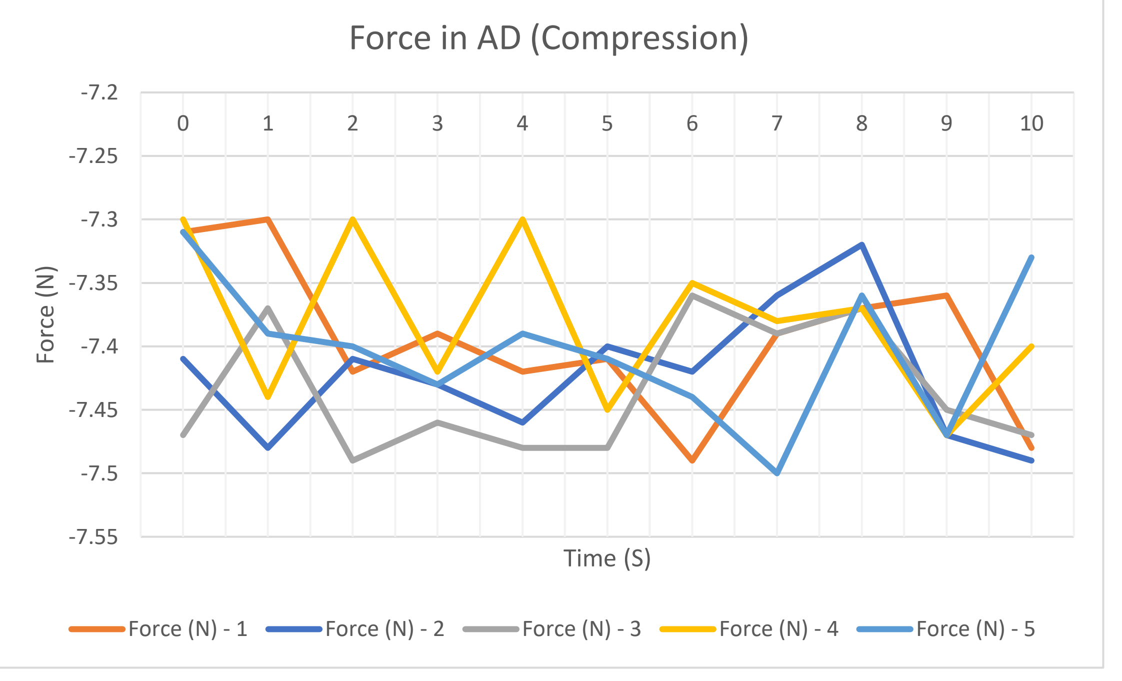


Figure 61 Warren Truss Cantilever Bridge Five Cell axial force acting in Beam AD

Beam BC											
Time (s)	0	1	2	3	4	5	6	7	8	9	10	Average
Force (N) - 1	11.09	11.19	11.15	11.2	11.18	11.05	11.27	11.22	11.25	11.24	11.08	**11.17**
Force (N) - 2	11.29	11.11	11.21	11.27	11.01	11.3	11.09	11.17	11.27	11.28	11.3	**11.21**
Force (N) - 3	11.05	11.29	11.06	11.04	11.09	11.17	11.3	11.29	11.16	11.28	11.11	**11.17**
Force (N) - 4	11.16	11.25	11.01	11.07	11.07	11.29	11.26	11.18	11.1	11.11	11.07	**11.14**
Force (N) - 5	11.09	11.26	11.2	11.26	11.3	11.05	11.08	11.02	11.26	11.18	11.06	**11.16**

Table 44 Warren Truss Cantilever Bridge Five Cell recorded data from PASCO for Beam BC

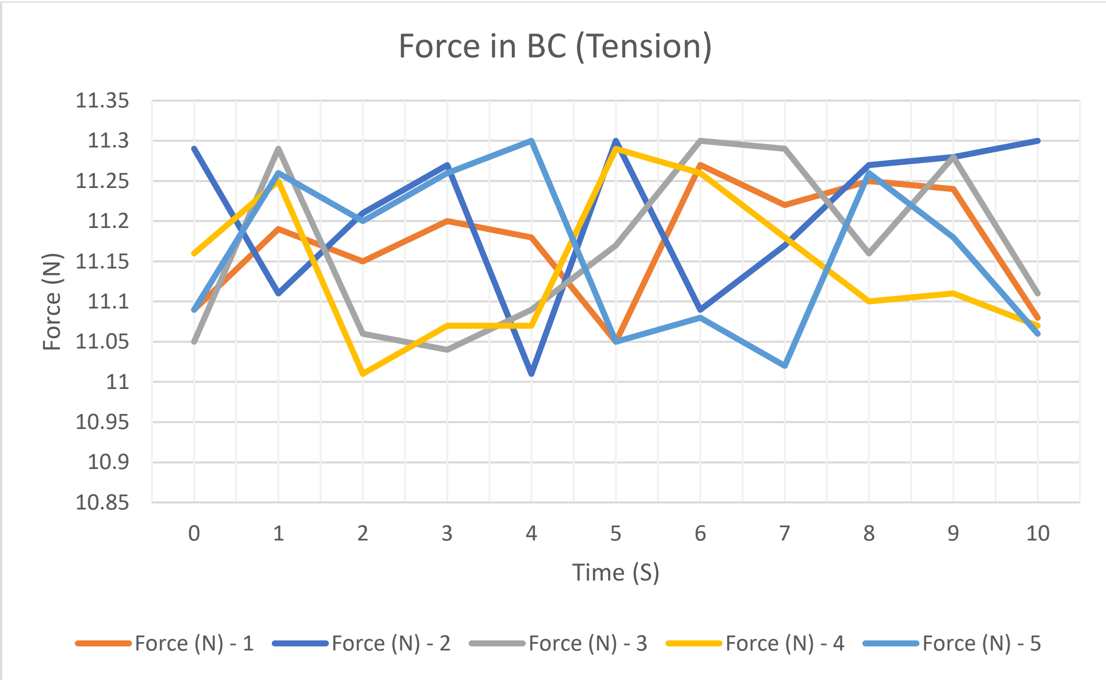


Figure 62 Warren Truss Cantilever Bridge Five Cell axial force acting in Beam BC

Beam CD												
Time (s)	0	1	2	3	4	5	6	7	8	9	10	Average
Force (N) - 1	3.53	3.6	3.7	3.68	3.61	3.52	3.53	3.61	3.56	3.53	3.65	**3.59**
Force (N) - 2	3.53	3.53	3.6	3.51	3.5	3.68	3.56	3.5	3.66	3.57	3.61	**3.57**
Force (N) - 3	3.52	3.66	3.52	3.56	3.69	3.54	3.5	3.67	3.61	3.58	3.7	**3.60**
Force (N) - 4	3.68	3.65	3.6	3.67	3.67	3.59	3.65	3.5	3.57	3.53	3.53	**3.60**
Force (N) - 5	3.54	3.56	3.53	3.68	3.67	3.59	3.7	3.59	3.7	3.53	3.62	**3.61**

Table 45 Warren Truss Cantilever Bridge Five Cell recorded data from PASCO for Beam CD

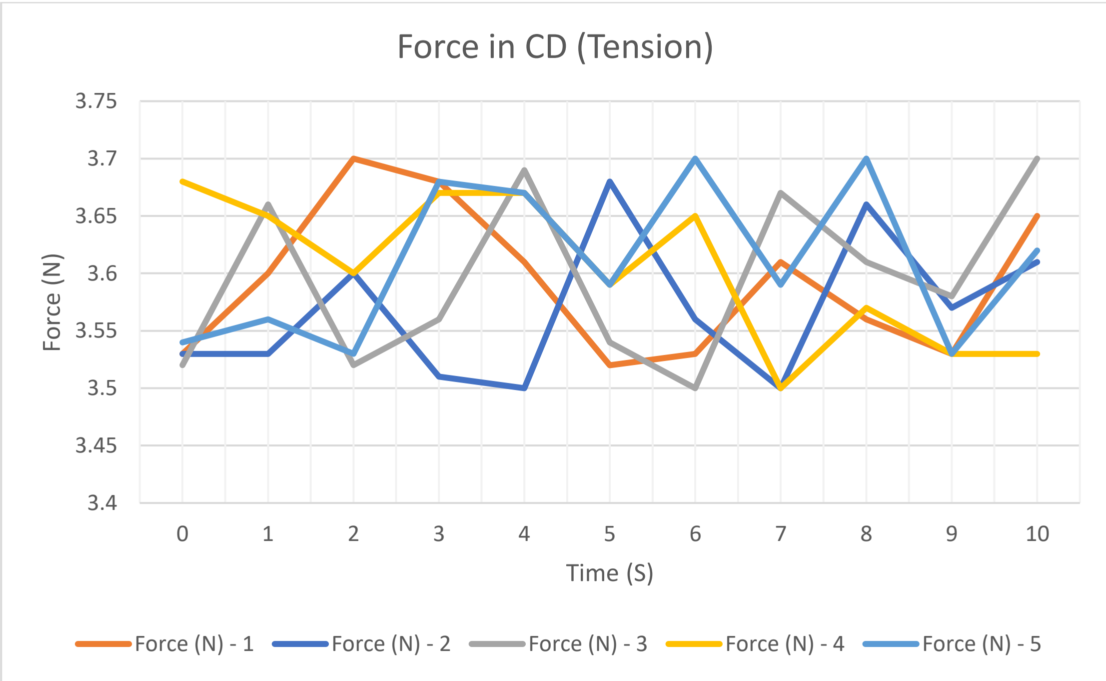


Figure 63 Warren Truss Cantilever Bridge Five Cell axial force acting in Beam CD

Beam CE												
Time (s)	0	1	2	3	4	5	6	7	8	9	10	Average
Force (N) - 1	7.27	7.29	7.28	7.28	7.3	7.39	7.4	7.28	7.43	7.37	7.27	**7.32**
Force (N) - 2	7.43	7.42	7.25	7.45	7.31	7.25	7.27	7.39	7.41	7.34	7.45	**7.36**
Force (N) - 3	7.26	7.26	7.28	7.38	7.4	7.29	7.42	7.25	7.36	7.44	7.26	**7.33**
Force (N) - 4	7.31	7.31	7.25	7.44	7.29	7.35	7.38	7.28	7.34	7.34	7.3	**7.33**
Force (N) - 5	7.36	7.33	7.31	7.42	7.41	7.38	7.31	7.34	7.44	7.26	7.31	**7.35**

Table 46 Warren Truss Cantilever Bridge Five Cell recorded data from PASCO for Beam CE

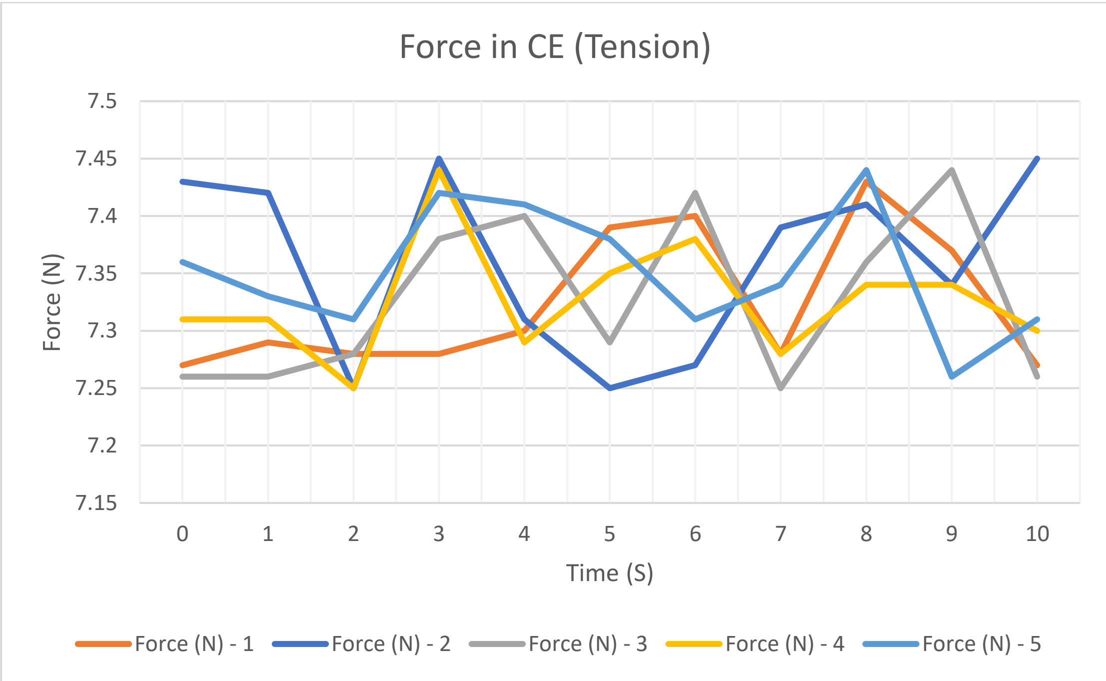


Figure 64 Warren Truss Cantilever Bridge Five Cell axial force acting in Beam CE

Beam DE												
Time (s)	0	1	2	3	4	5	6	7	8	9	10	Average
Force (N) - 1	-4.89	-4.87	-4.89	-4.82	-4.85	-4.83	-4.89	-4.82	-4.87	-4.89	-4.93	**-4.87**
Force (N) - 2	-4.92	-4.91	-4.92	-4.88	-4.8	-4.8	-4.87	-4.9	-4.8	-4.85	-4.87	**-4.87**
Force (N) - 3	-4.93	-4.87	-4.86	-4.8	-4.84	-4.89	-4.89	-4.87	-4.87	-4.95	-4.93	**-4.88**
Force (N) - 4	-4.95	-4.87	-4.83	-4.91	-4.82	-4.91	-4.91	-4.92	-4.93	-4.88	-4.93	**-4.90**
Force (N) - 5	-4.92	-4.84	-4.88	-4.87	-4.81	-4.82	-4.94	-4.89	-4.83	-4.83	-4.86	**-4.86**

Table 47 Warren Truss Cantilever Bridge Five Cell recorded data from PASCO for Beam DE

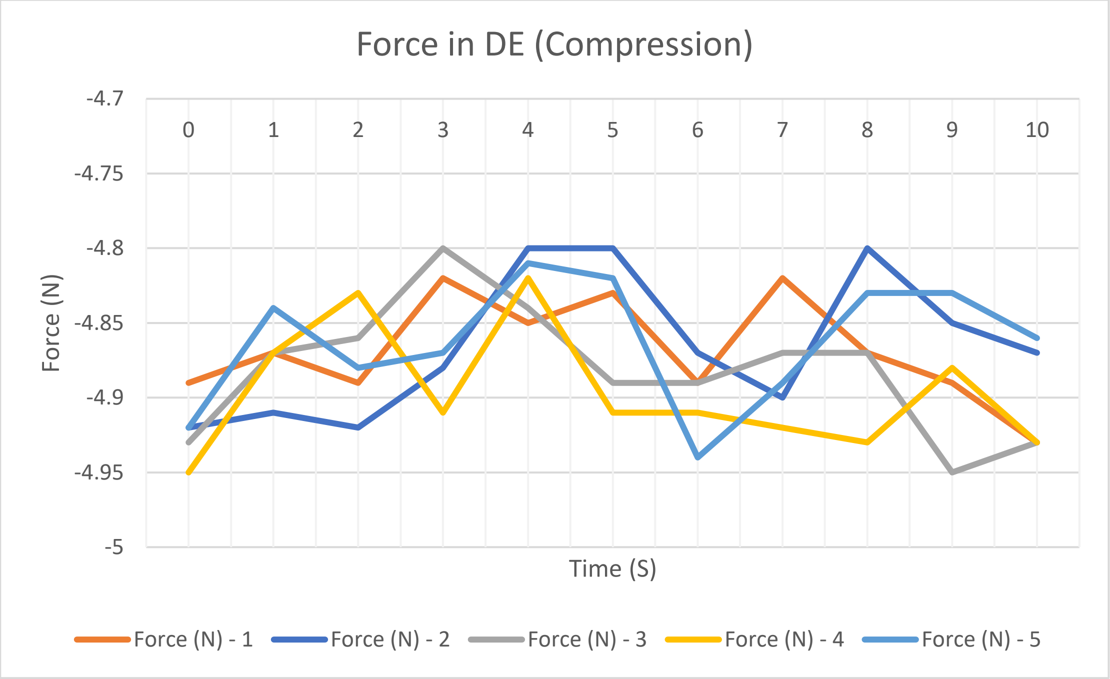


Figure 65 Warren Truss Cantilever Bridge Five Cell axial force acting in Beam DE

Beam DF												
Time (s)	0	1	2	3	4	5	6	7	8	9	10	Average
Force (N) - 1	-3.77	-3.62	-3.76	-3.6	-3.63	-3.73	-3.63	-3.73	-3.77	-3.62	-3.65	**-3.68**
Force (N) - 2	-3.78	-3.76	-3.76	-3.66	-3.6	-3.69	-3.71	-3.73	-3.67	-3.78	-3.67	**-3.71**
Force (N) - 3	-3.69	-3.72	-3.62	-3.62	-3.77	-3.73	-3.67	-3.6	-3.74	-3.61	-3.77	**-3.69**
Force (N) - 4	-3.74	-3.68	-3.66	-3.78	-3.68	-3.69	-3.6	-3.63	-3.71	-3.79	-3.68	**-3.69**
Force (N) - 5	-3.64	-3.63	-3.72	-3.63	-3.68	-3.62	-3.68	-3.8	-3.62	-3.71	-3.79	**-3.68**

Table 48 Warren Truss Cantilever Bridge Five Cell recorded data from PASCO for Beam DF

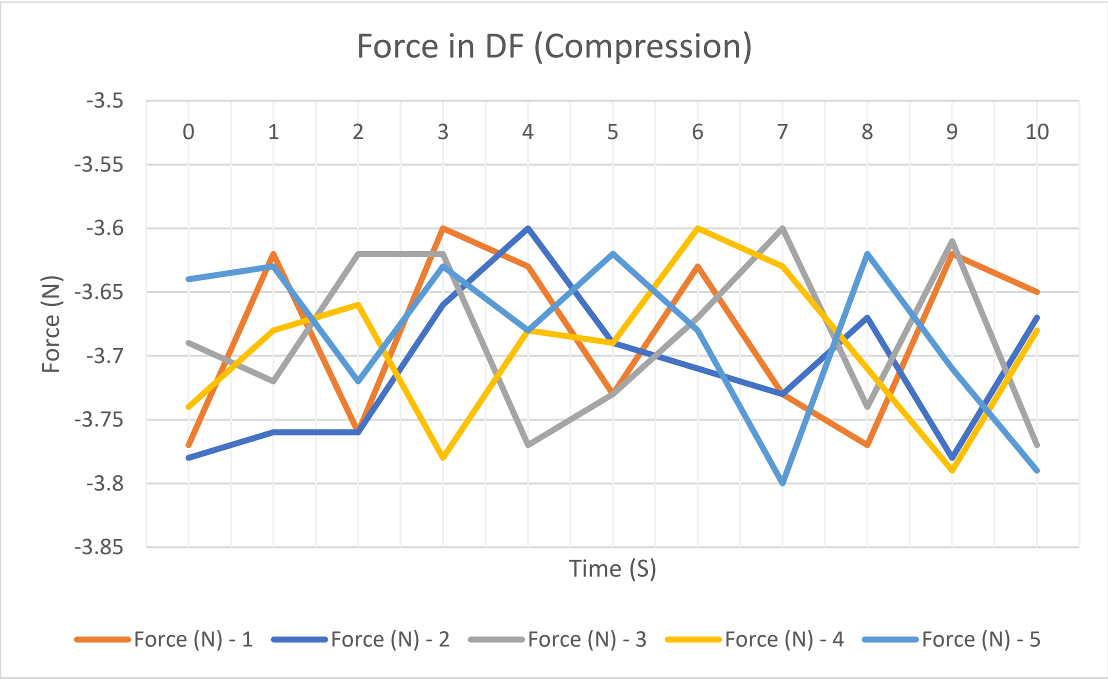


Figure 66 Warren Truss Cantilever Bridge Five Cell axial force acting in Beam DF

Beam EF												
Time (s)	0	1	2	3	4	5	6	7	8	9	10	**Average**
Force (N) - 1	0	0.04	0.05	0	0.04	0.05	0.02	0.03	0.04	0.01	0.03	**0.03**
Force (N) - 2	0.05	0.01	0.04	0.03	0.03	0.02	0.05	0.03	0	0.03	0	**0.03**
Force (N) - 3	0.05	0	0.02	0.01	0	0.02	0.05	0.01	0	0.01	0	**0.02**
Force (N) - 4	0.05	0.03	0.02	0.04	0.05	0.05	0.05	0.05	0.01	0	0.02	**0.03**
Force (N) - 5	0.01	0.03	0.05	0.02	0.05	0.05	0.02	0	0	0	0	**0.02**

Table 49 Warren Truss Cantilever Bridge Five Cell recorded data from PASCO for Beam EF

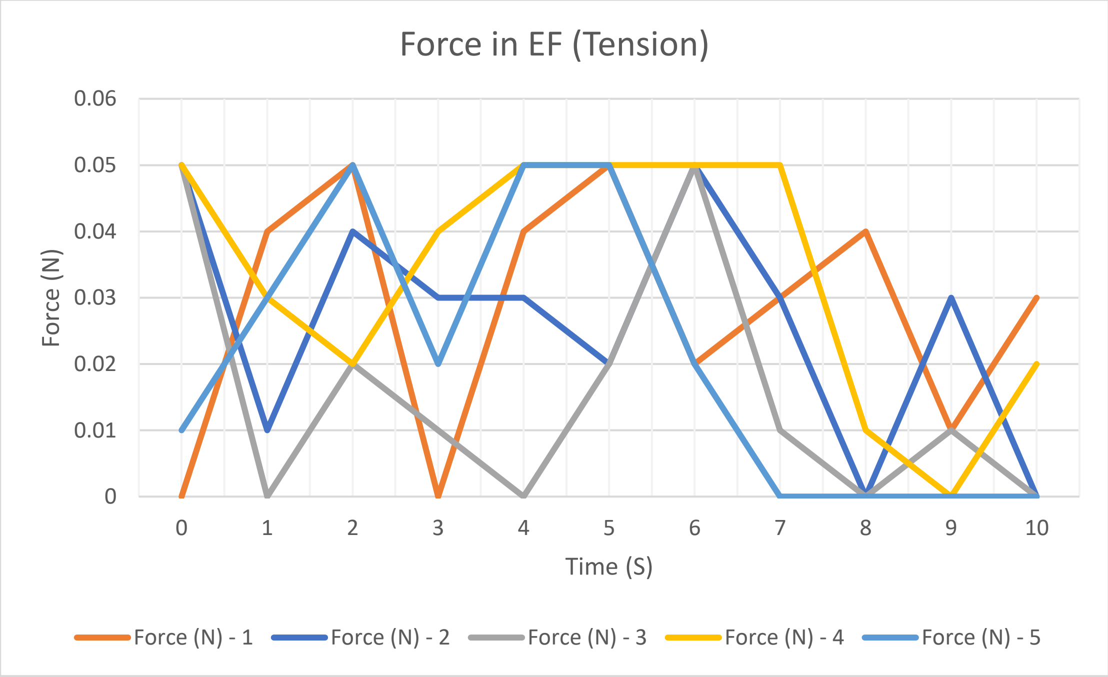


Figure 67 Warren Truss Cantilever Bridge Five Cell axial force acting in Beam EF

Beam EG												
Time (s)	0	1	2	3	4	5	6	7	8	9	10	Average
Force (N) - 1	4.63	4.77	4.72	4.7	4.72	4.76	4.6	4.64	4.78	4.79	4.78	**4.72**
Force (N) - 2	4.79	4.74	4.78	4.73	4.64	4.74	4.76	4.7	4.67	4.65	4.8	**4.73**
Force (N) - 3	4.73	4.74	4.66	4.71	4.78	4.79	4.79	4.6	4.72	4.79	4.77	**4.73**
Force (N) - 4	4.61	4.79	4.63	4.69	4.6	4.62	4.74	4.75	4.75	4.62	4.65	**4.68**
Force (N) - 5	4.68	4.77	4.69	4.66	4.71	4.77	4.76	4.7	4.69	4.61	4.63	**4.70**

Table 50 Warren Truss Cantilever Bridge Five Cell recorded data from PASCO for Beam EG

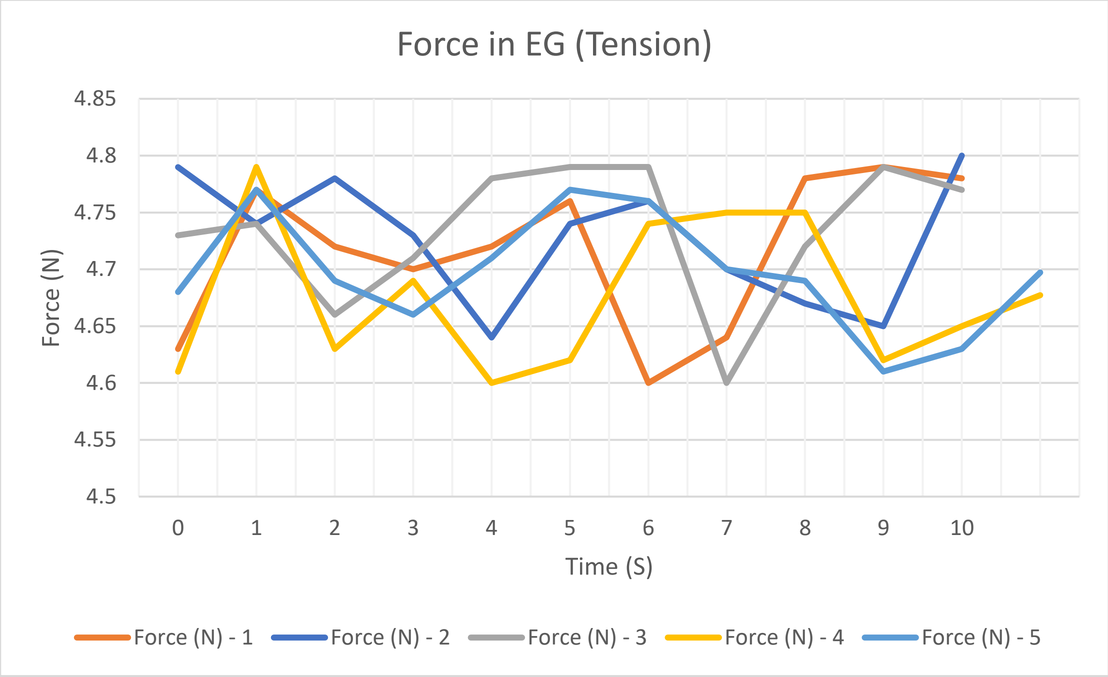


Figure 68 Warren Truss Cantilever Bridge Five Cell axial force acting in Beam EG

Beam FG												
Time (s)	0	1	2	3	4	5	6	7	8	9	10	**Average**
Force (N) - 1	-3.55	-3.64	-3.63	-3.66	-3.6	-3.57	-3.64	-3.67	-3.5	-3.56	-3.59	**-3.60**
Force (N) - 2	-3.54	-3.57	-3.51	-3.59	-3.64	-3.54	-3.63	-3.64	-3.51	-3.62	-3.64	**-3.58**
Force (N) - 3	-3.63	-3.66	-3.6	-3.7	-3.53	-3.51	-3.53	-3.6	-3.61	-3.58	-3.56	**-3.59**
Force (N) - 4	-3.63	-3.59	-3.7	-3.66	-3.61	-3.51	-3.54	-3.66	-3.7	-3.62	-3.52	**-3.61**
Force (N) - 5	-3.68	-3.66	-3.59	-3.54	-3.67	-3.59	-3.57	-3.55	-3.58	-3.66	-3.6	**-3.61**

Table 51 Warren Truss Cantilever Bridge Five Cell recorded data from PASCO for Beam FG

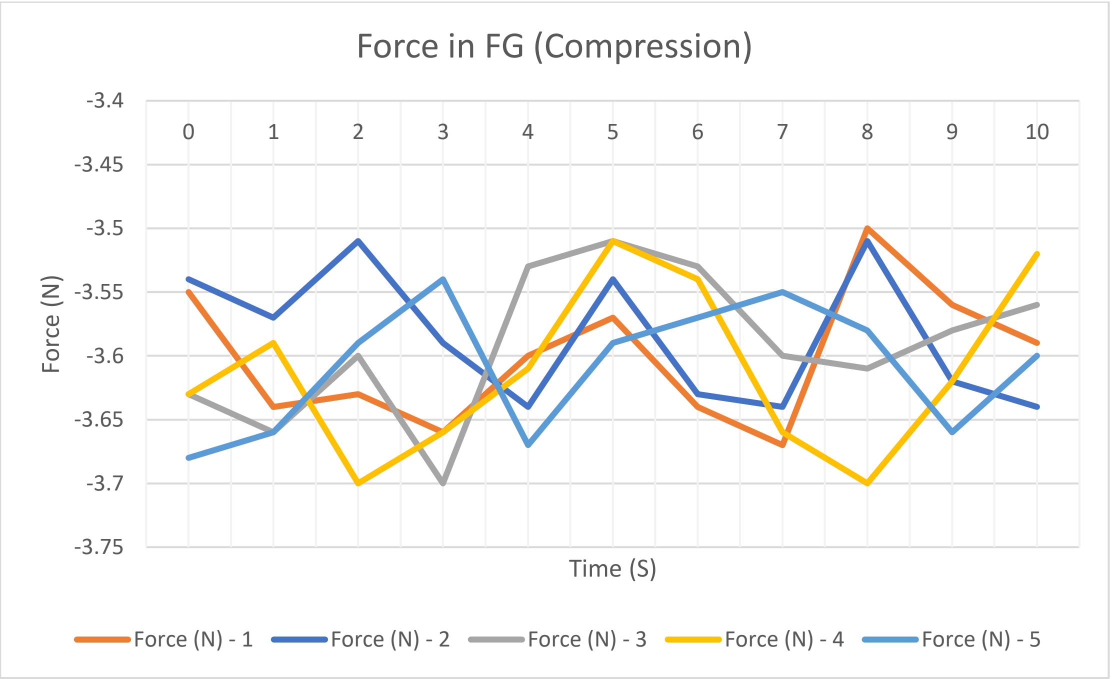


Figure 69 Warren Truss Cantilever Bridge Five Cell axial force acting in Beam FG

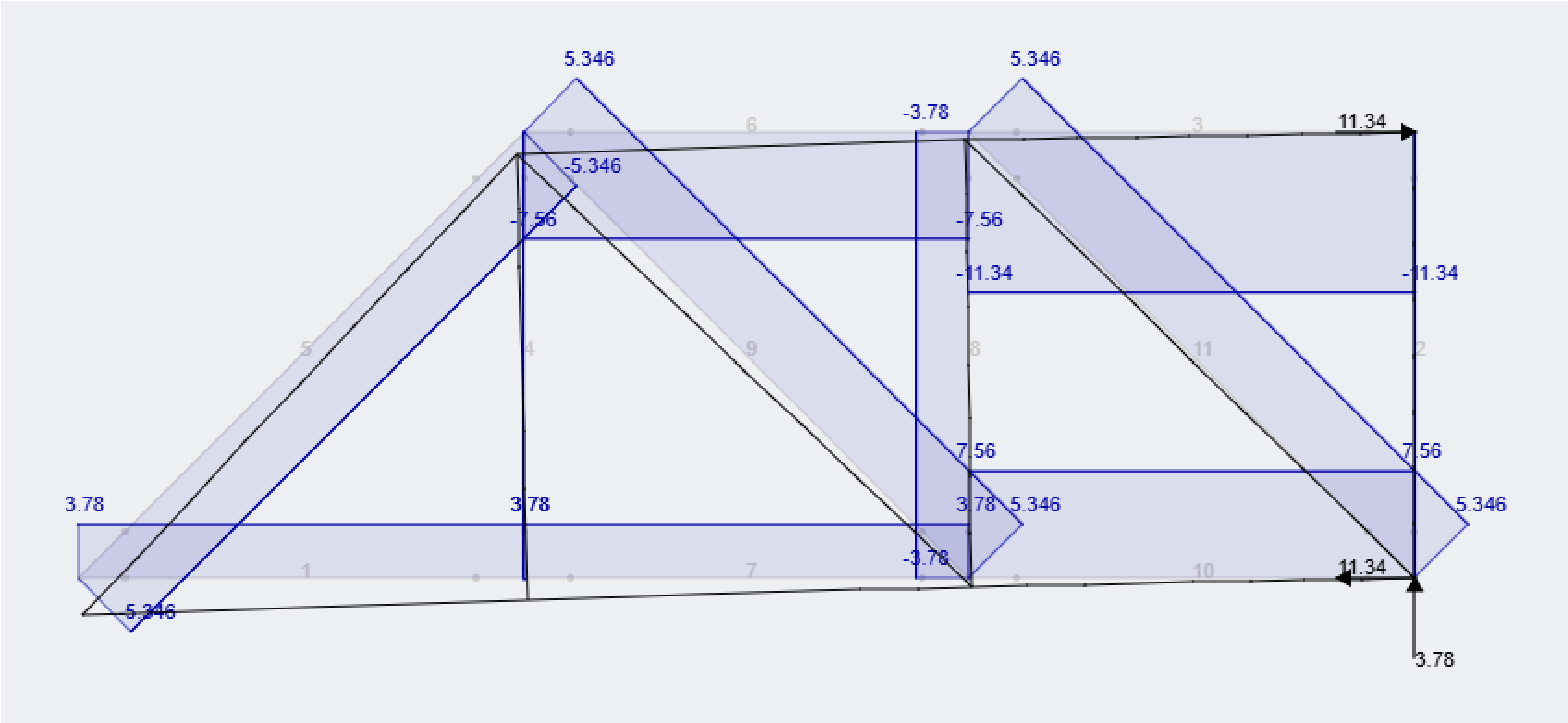


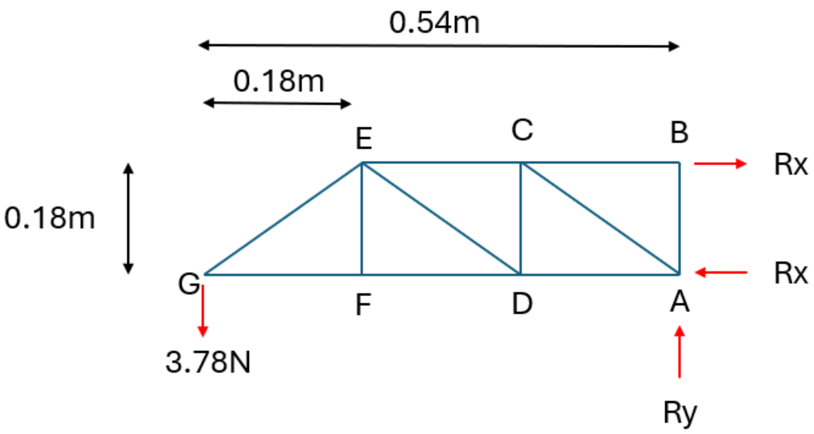
Figure 70 Warren Truss Cantilever Bridge Five Cell Ski Civ axial forces

Theoretical Data (Manual Calculations)

$$F = \text{mass} \times \text{accelectration}$$

$$F = 0.385\text{kg} \times 9.81\text{m}/s^2$$

$$F = 3.78N$$



$$\sum Fy = -3.78N + Ay$$

$$Ay = 3.78N$$

$$\sum Ma^+ = 3.78N \times 0.54m + Bx \times 0.18m$$

$$Gy = \frac{2.04N}{0.18m}$$

$$Bx = 11.34N$$

$$\sum Fx = Ax + Bx$$

$$0 = Ax + 11.34$$

$$Ax = -11.34N$$

Joint G

$$\sum Fy = -3.78 + EGsin(45°)$$

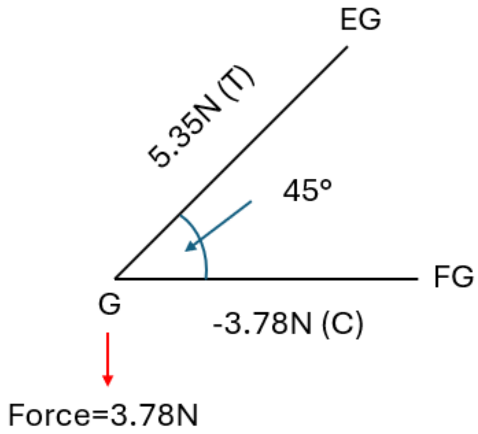
$$EG = \frac{3.78}{sin(45°)}$$

$$EG = 5.35N\ (T)$$

$$\sum Fx = 5.35cos(45°) - FG$$

$$FG = -5.35cos(45°)$$

$$FG = -3.78N$$



Joint E

$$\sum Fy = 5.35sin(45°) + DEsin(45°)$$

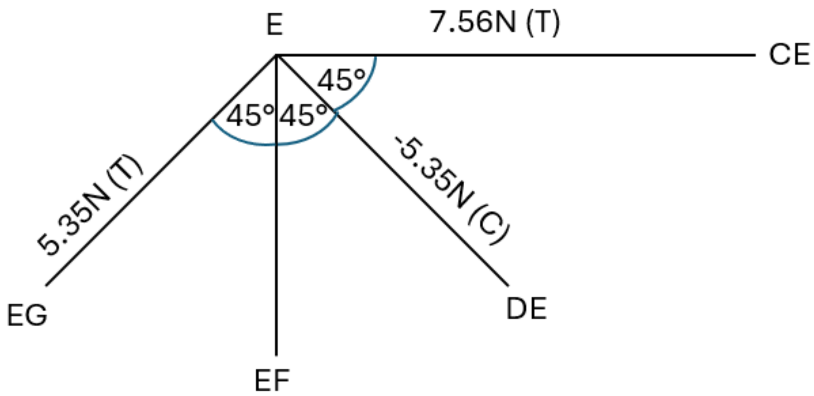
$$DE = -\frac{3.78}{sin(45°)}$$

$$DE = -5.35N\ (C)$$

$$\sum Fx = -5.35cos(45°) - 5.35\ cos(45°) + CE$$

$$CE = 5.35cos(45°) + 5.35\ cos(45°)$$

$$CE = 7.56N\ (T)$$



Joint F

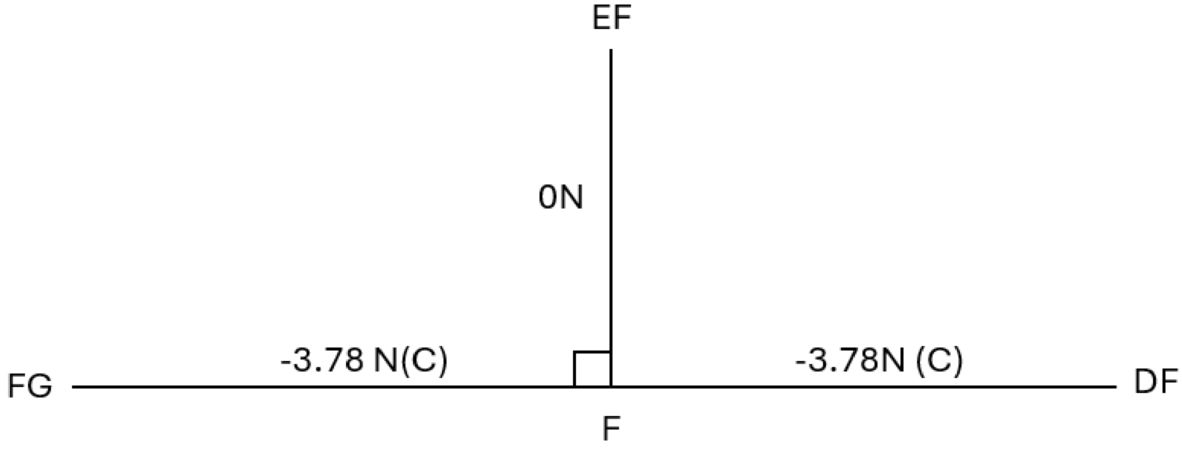
$$\sum Fy = 0$$

$$EF = 0$$

$$\sum Fx = 3.78cos(180°) + DF$$

$$DF = 3.78cos(180°)$$

$$DF = -3.78N\ (C)$$



Joint C

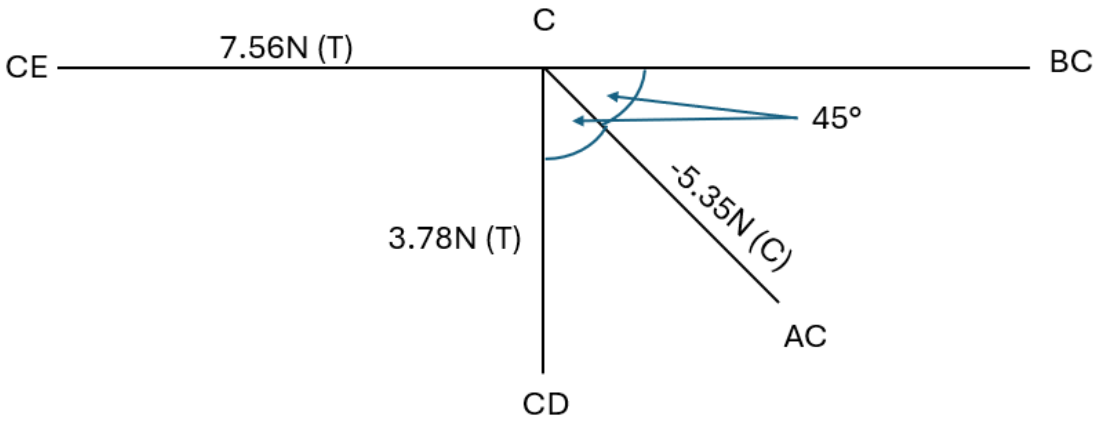
$$\sum Fy = CD - 5.35sin(45°)$$

$$CD = 3.78N\ (T)$$

$$\sum Fx = 11.34 - 7.56 + ACcos(45°)$$

$$AC = -\frac{3.78}{cos(45°)}$$

$$AC = -5.35N\ (C)$$

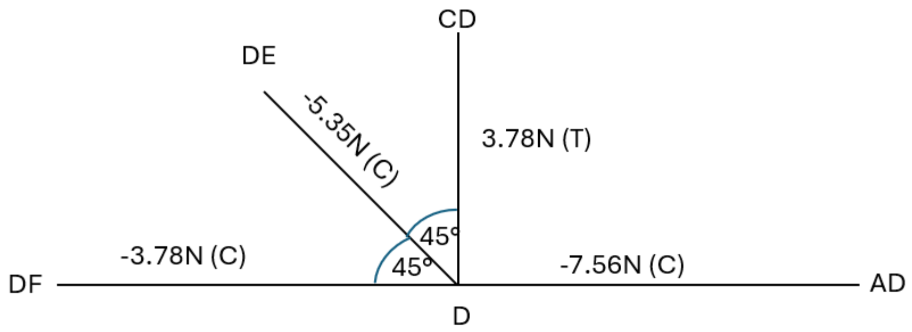


Joint D

$$\sum Fx = 3.78 + 5.35cos(45°) - AD$$

$$AD = -3.78 - 5.35cos(45°)$$

$$AD = -7.56N\ (C)$$



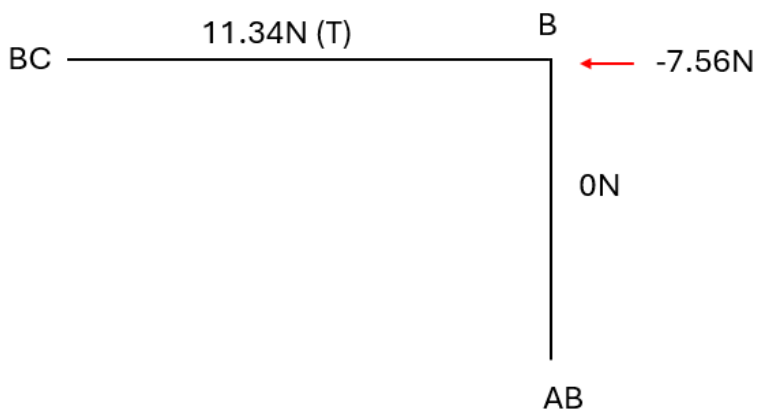
Joint B

$$\sum Fy = 0$$

$$AB = 0N$$

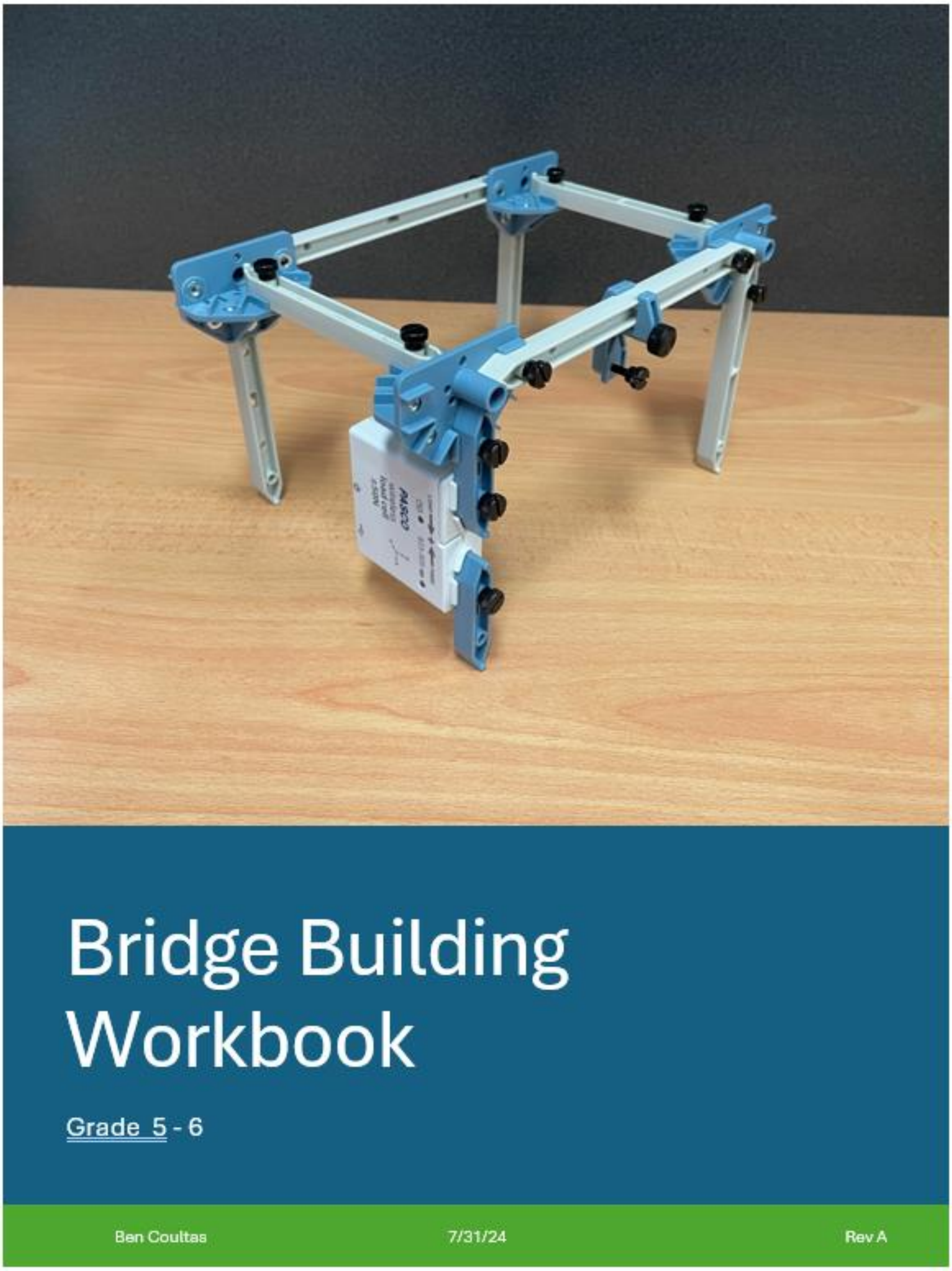
$$\sum Fx = 11.34 - BC$$

$$BC = 11.34$$



APPENDIX B

5 & 6 Work Book



Name: ____

Group Member: ____

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Part 1: What is a Bridge

1: Beam Bridges

See below a photo of simple beam bridges

2: Truss Bridge

See below a photo of a Truss Bridge

3: Cantilever Bridge

See below a photo of a Cantilever Bridge

4: Arch Bridge

Below is a picture of an arch Bridge

4: Suspension Bridge

Part 2: Forces acting on the beam

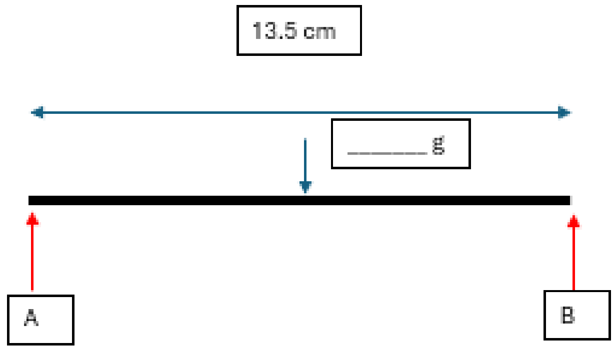
In this activity the group will be a model that represents a simple beam bridge using the provided materials (PASCO kit). Students will work out the theoretical based on the diagram below and compare to forces generated from the model kit using the accelerometer.

Theoretical data

See the diagram below to determine the forces reacting on the beam some information must be gathered

- Length of beam
- Force acting on the beam

For the theoretical calculations we will use beam length of 13.5cm and a weight of 380 grams.

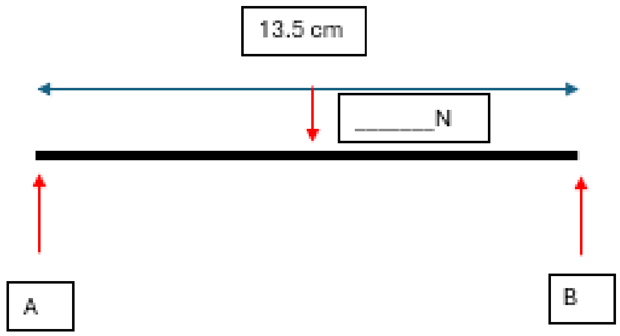


To convert the weight in a force (N), it must be multiplied by gravity of the earth which is $g = 9.81m/s^2$. Gravity is the measurement of acceleration that placed on the mass

$$F = \mathrm{ma}$$

$$F = \_\_\_\_\_ \mathrm{kg} \times 9.81 \mathrm{m}/s^2$$

$$F = \_\_\_\_\_\_\_\_\_\_ N$$



Now that we have worked out the force that will be placed in the beam, we can calculate the reaction forces acting on the support beams

Based on the diagram below calculate the force reacting at A and B

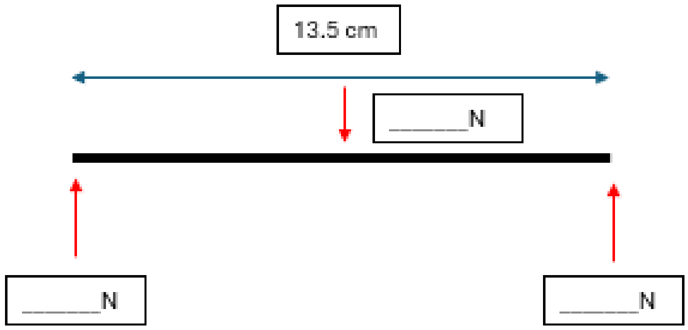
Reaction Force

Beam 1

$$A = \frac{\_\_\_\_\_N}{2}$$

$$A = \_\_\_\_\_N$$

$$B = A = \_\_\_\_\_\_N$$



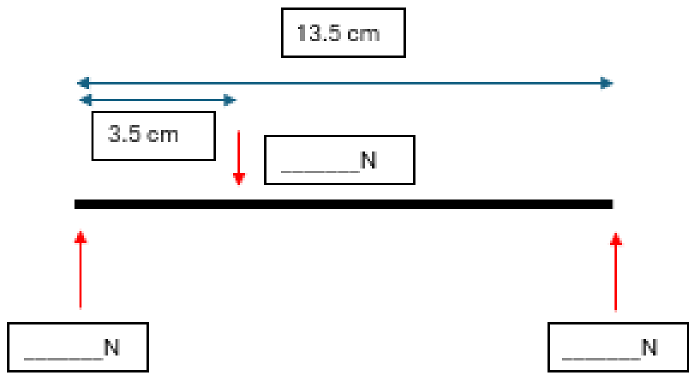
Beam 2

$$A = \frac{\_\_\_\_\_N \times \_\_\_cm}{13.5}$$

$$A = \_\_\_\_\_N$$

$$B = \frac{\_\_\_\_\_N \times 3.5}{13.5}$$

$$B = \_\_\_\_\_N$$



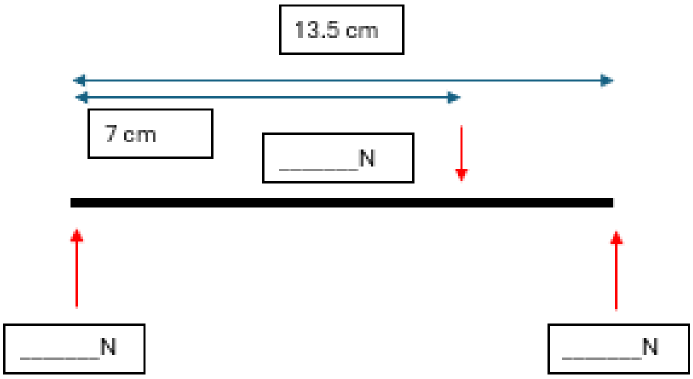
Beam 3

$$A = \frac{\_\_\_\_\_N \times \_\_\_\_\_cm}{13.5}$$

$$A = \_\_\_\_\_\_N$$

$$B = \frac{\_\_\_\_\_N \times \_\_\_\_\_cm}{13.5}$$

$$B = \_\_\_\_\_\_N$$



Part 3: Model Building

Now we that you understand the theoretical side of the forces and reactions its time to test it practically using the PASCO model kit. Following the steps below

Part 1 Loads

1. Select Senor data in SPEAKvue and connect your load sensor
2. From Quick start experiments, select Load Cell force
3. Insert a screw on each side of the load cell
4. Place all available washers on the weight hanger (380g)
5. Hold the Load Cell in one hand. Zero the sensor and start collecting data

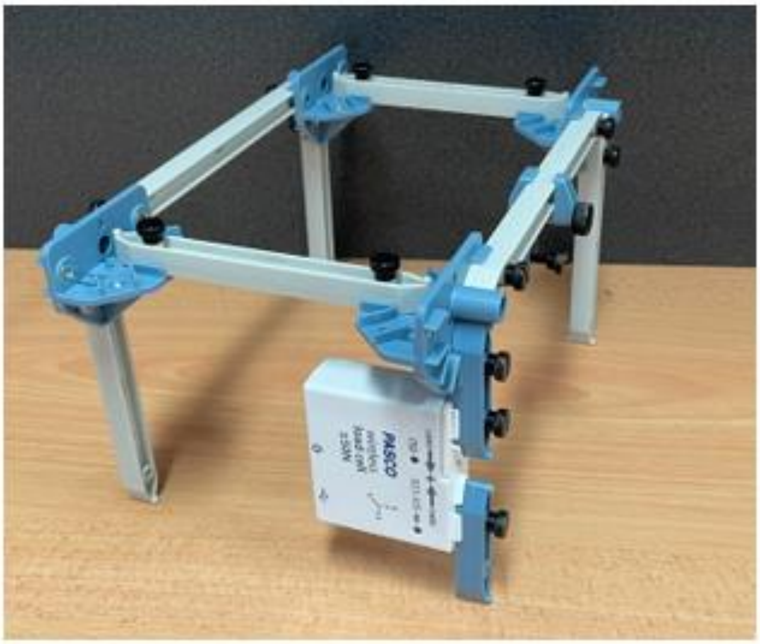
6. Hang the wights on the fixed side of the load cell
7. Stop recoding data and record the force in table 1
8. Repeat steps 5-7 for the load side of the sensor

Table 1 Force measured by Load Cell

Fixed (N)	Load (N)

Part 2

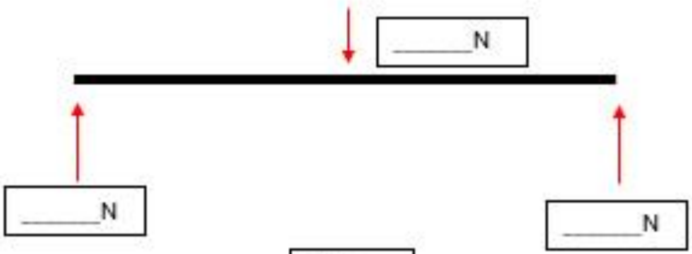
1. Build a simple bridge construction of a single beam supported on each end. Place the load cell in place of the of one of the supports

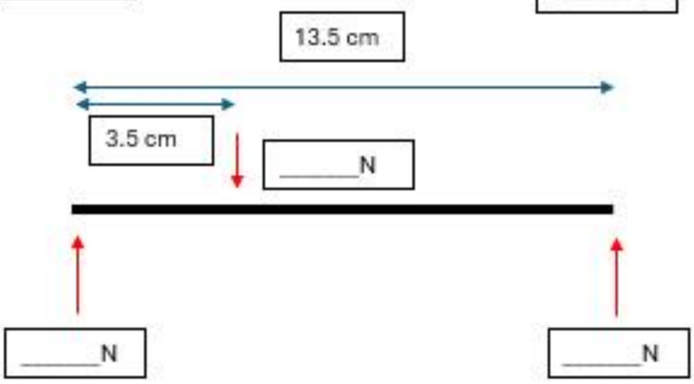


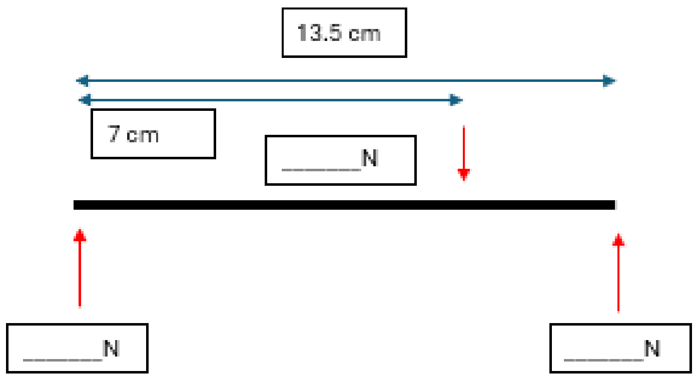
2. On the diagram below enter the load force from Part 1 onto the of each case. Remember for this activity only use positive integers by placing the load cell as per below picture.

3. Zero out the sensor and start collecting data
4. Hang the weight based on the same measurements used in Part 4, see diagrams below

5. Repeat steps 3-4 for each diagram noting the changes
6. Compare the results from Part 4







Results	Reaction A (N)	Reaction B (N)	Difference (N)
Beam 1			
Part 2			
Part 3			
Beam 2			
Part 2			
Part 3			
Beam 3			
Part 2			
Part 3			

Based on the tables above compare the differences between Part 2 and Part 3, explain what could affect the results

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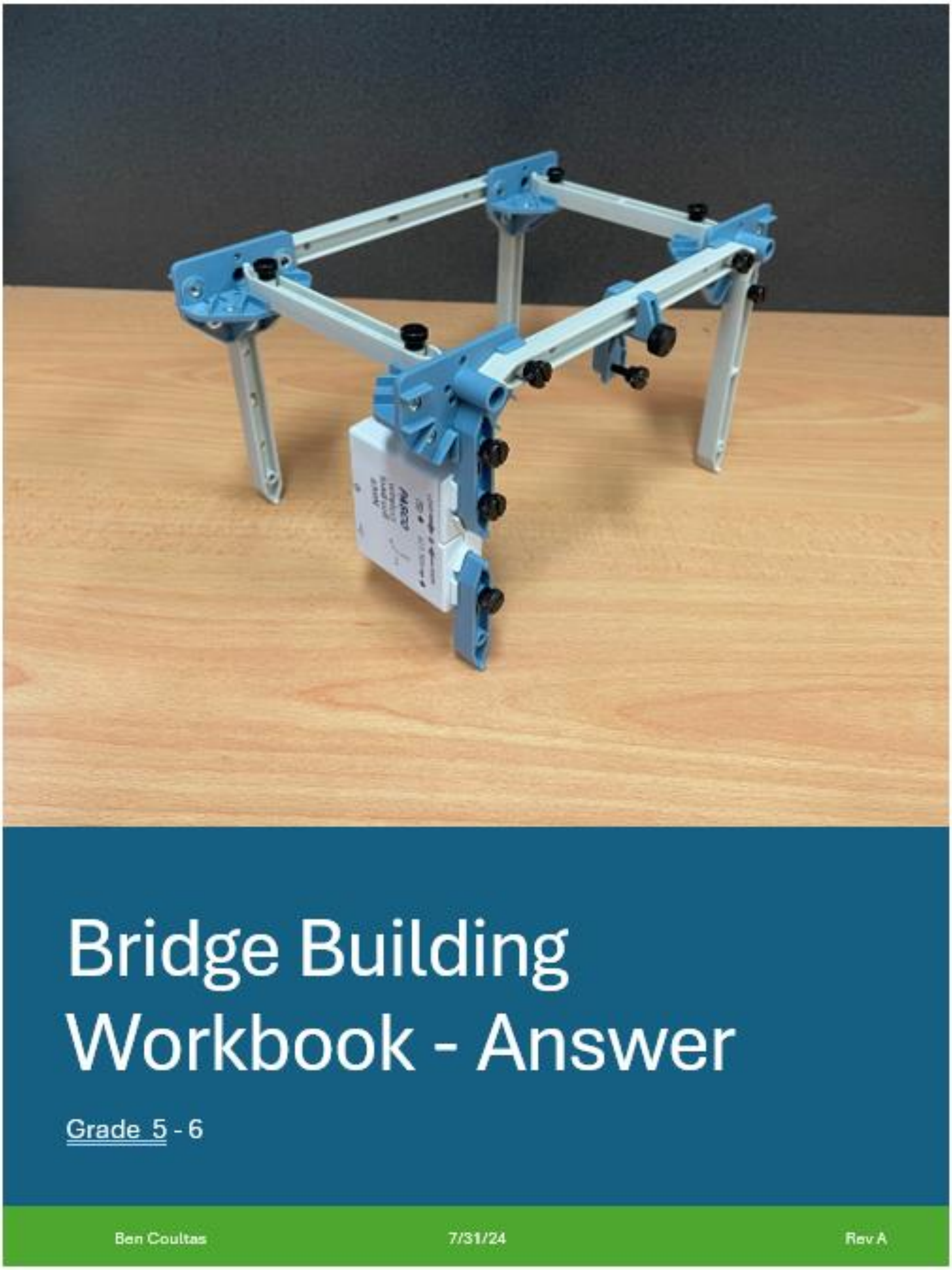
Answer Book for 5&6



Bridge Building Workbook - Answer

Grade 5 - 6

Ben Coultas 7/31/24 Rev A

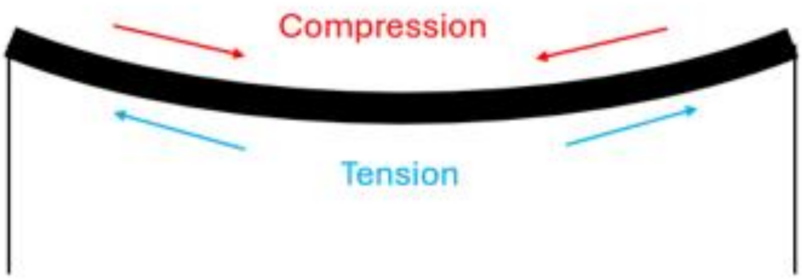
Part 1: What is a Bridge

1: Beam Bridges

See below a photo of simple beam bridges

Characteristics of a beam bridge

- Horizontal beam supported by vertical peris
- Horizontal beams under compression on top and tensions on bottom (axial forces)

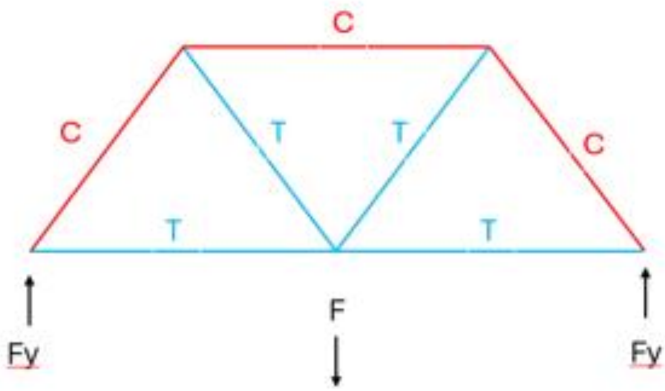


2: Truss Bridge

See below a photo of a Truss Bridge

Characteristics of a Truss bridge

- Beams can be either in Tension or Compression (axial forces) depending on where the forces are being applied
- Triangles are used as the main shape of a Truss bridge

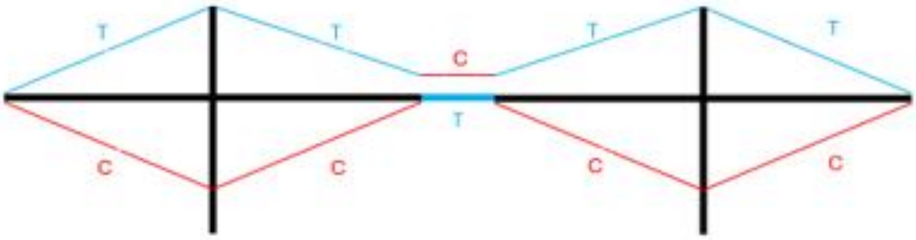


3: Cantilever Bridge

See below a photo of a Cantilever Bridge

Characteristics of a Cantilever bridge

- Generally made up of three spans with the outer spans are cantilevered



4: Arch Bridge

Below is a picture of an arch Bridge

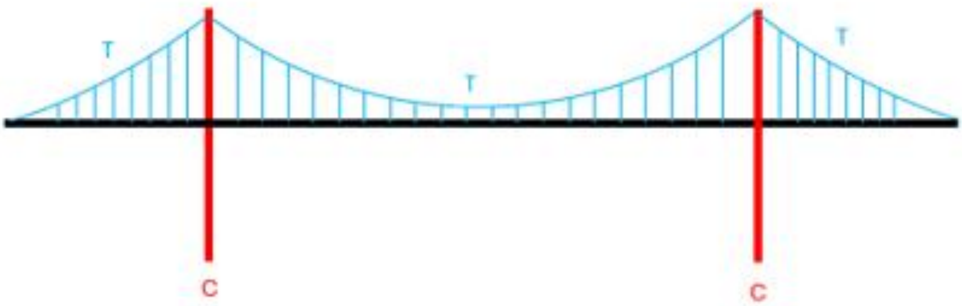
Characteristics of an Arch bridge

- The load is carried in the arch
- The foundations carry both vertical and horizontal forces, and they must be designed to prevent horizontal sliding and vertical settling

5: Suspension Bridge

Characteristics of an Arch bridge

- Made up of cables supporting deck/road
- Longest spanning bridge
- Vertical loads in cables tension which is transferred to the supports/towers which placed them in compression



Part 2: Forces acting on the beam

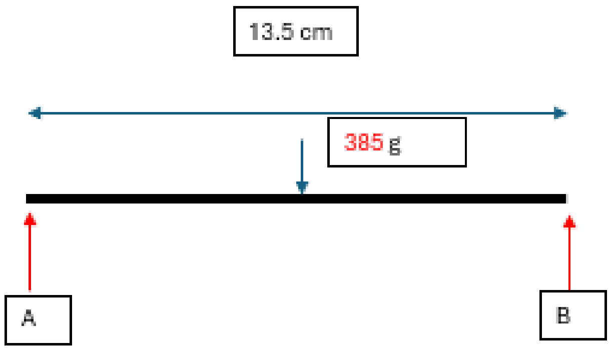
In this activity the group will be a model that represents a simple beam bridge using the provided materials (PASCO kit). Students will work out the theoretical based on the diagram below and compare to forces generated from the model kit using the accelerometer.

Theoretical data

See the diagram below to determine the forces reacting on the beam some information must be gathered

- Length of beam
- Force acting on the beam

For the theoretical calculations we will use beam length of 13.5cm and a weight of 385 grams.

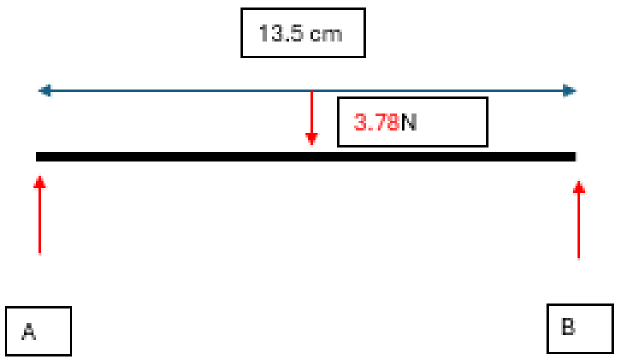


To convert the weight in a force (N), it must be multiplied by gravity of the earth which is $g = 9.81m/s^2$. Gravity is the measurement of acceleration that placed on the mass

$$F = \mathrm{ma}$$

$$F = 0.385\mathrm{kg} \times 9.81\mathrm{m}/s^2$$

$$F = 3.78N$$



Now that we have worked out the force that will be placed in the beam, we can calculate the reaction forces acting on the support beams

Based on the diagram below calculate the force reacting at A and B

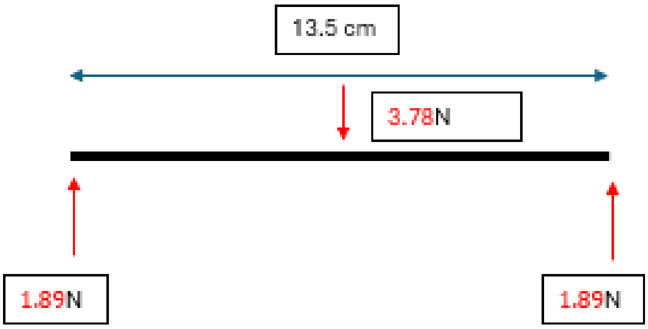
Reaction Force

Beam 1

$$A = \frac{3.78N}{2}$$

$$A = 1.89N$$

$$B = A = 1.89N$$



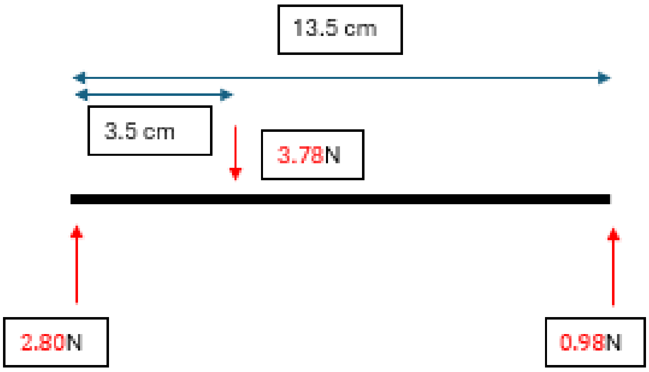
Beam 2

$$A = \frac{3.78N \times 10cm}{13.5}$$

$$A = 2.80N$$

$$B = \frac{3.78N \times 3.5}{13.5}$$

$$B = 0.98N$$



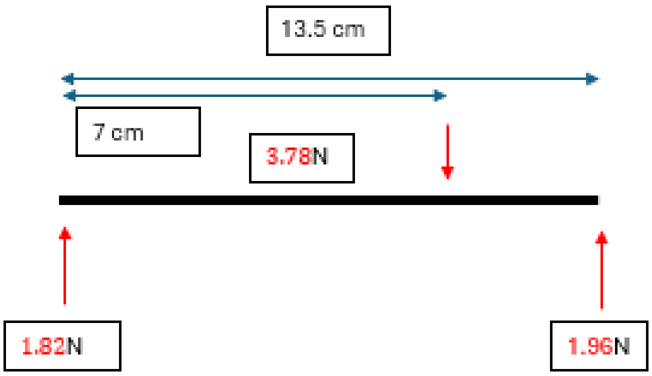
Beam 3

$$A = \frac{3.78N \times 6.5cm}{13.5}$$

$$A = 1.82N$$

$$B = \frac{3.78N \times 7cm}{13.5}$$

$$B = 1.96N$$



pg. 8

Part 3: Model Building

Now we that you understand the theoretical side of the forces and reactions its time to test it practically using the PASCO model kit. Following the steps below

Part 1 Loads

1. Select Senor data in SPEAKvue and connect your load sensor
2. From Quick start experiments, select Load Cell force
3. Insert a screw on each side of the load cell
4. Place all available washers on the weight hanger (385g)
5. Hold the Load Cell in one hand. Zero the sensor and start collecting data

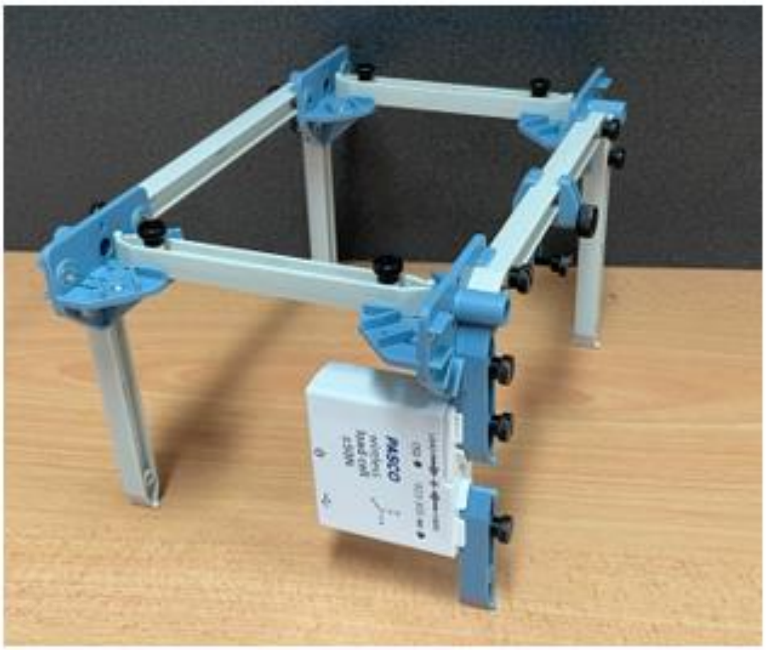
6. Hang the wights on the fixed side of the load cell
7. Stop recoding data and record the force in table 1
8. Repeat steps 5-7 for the load side of the sensor

Table 1 Force measured by Load Cell

Fixed (N)	Load (N)
0	3.78N

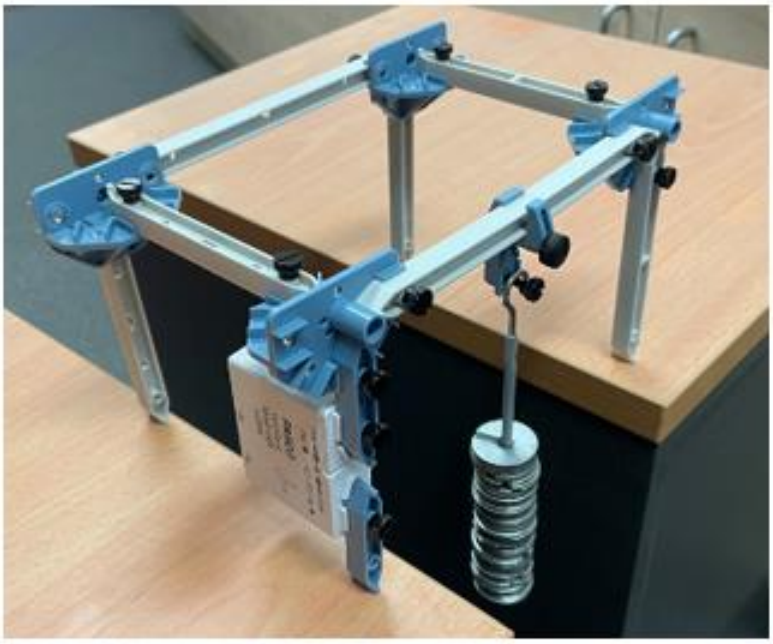
Part 2

1. Build a simple bridge construction of a single beam supported on each end. Place the load cell in place of the of one of the supports

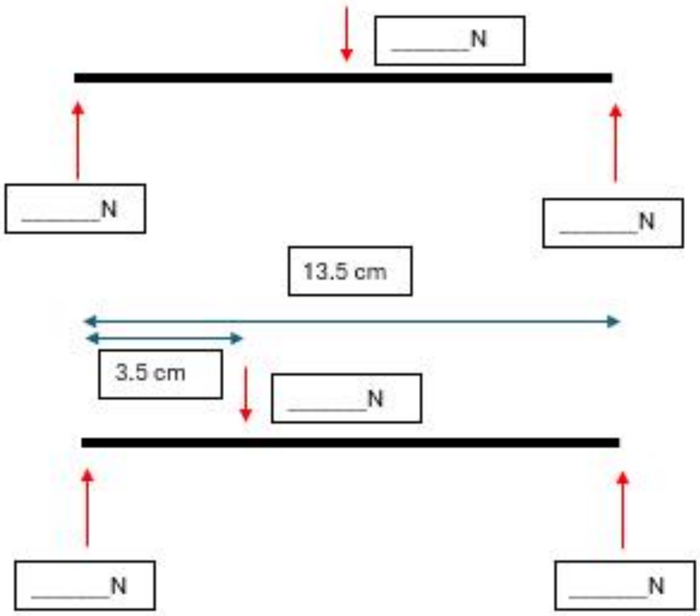


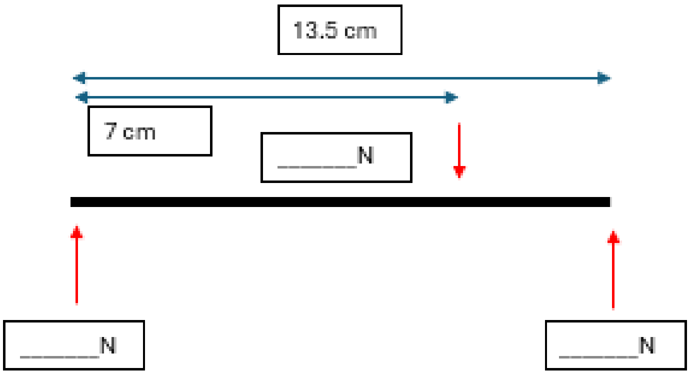
2. On the diagram below enter the load force from Part 1 onto the of each case. Remember for this activity only use positive integers by placing the load cell as per below picture.

3. Zero out the sensor and start collecting data
4. Hang the weight based on the same measurements used in Part 4, see diagrams below



5. Repeat steps 3-4 for each diagram noting the changes
6. Compare the results from Part 4

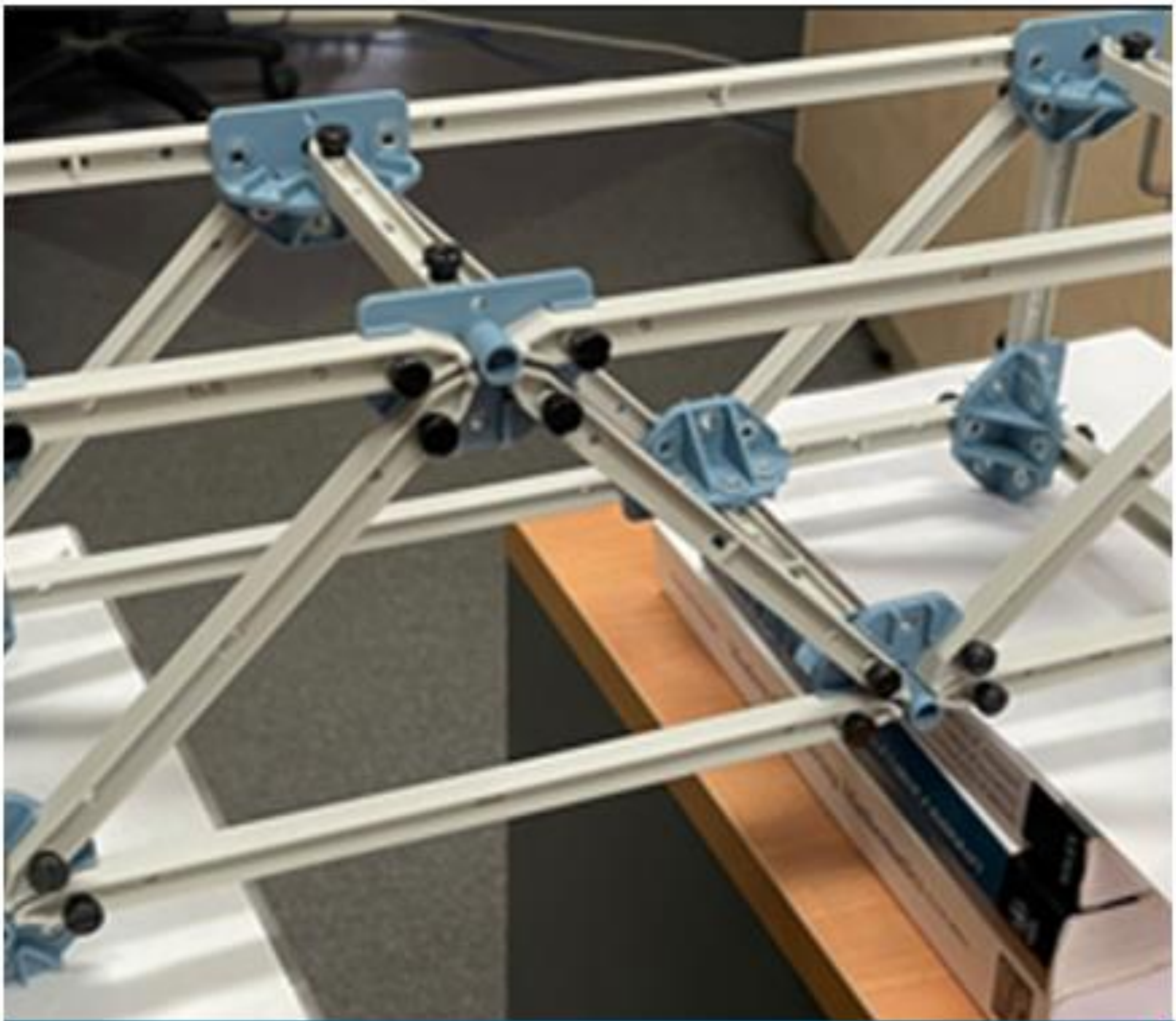




Results	Reaction A (N)	Reaction B (N)	Difference (N)
Beam 1			
Part 2			
Part 3			
Beam 2			
Part 2			
Part 3			
Beam 3			
Part 2			
Part 3			

Based on the tables above compare the differences between Part 2 and Part 3, explain what could affect the results

9 & 10



Bridge Building Workbook

Grade 9 - 10

Ben Coultas 7/31/24 Rev A

Name: ____

Group Member: ______________________________________

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Part 1: What is a Bridge

1: Beam Bridges

See below a photo of simple beam bridges

2: Truss Bridge

See below a photo of a Truss Bridge

3: Cantilever Bridge

See below a photo of a Cantilever Bridge

4: Arch Bridge

Below is a picture of an arch Bridge

4: Suspension Bridge

Part 2: Forces acting on Asymmetrical Bridge

In this activity a Bridge design has been completed for a project, but it has been determined that the bridge in to short. The bridge can be only extended on one end. To make it cost effect you need to limit the amount of materials but also aim to have the least amount of joints with no forces acting on them.

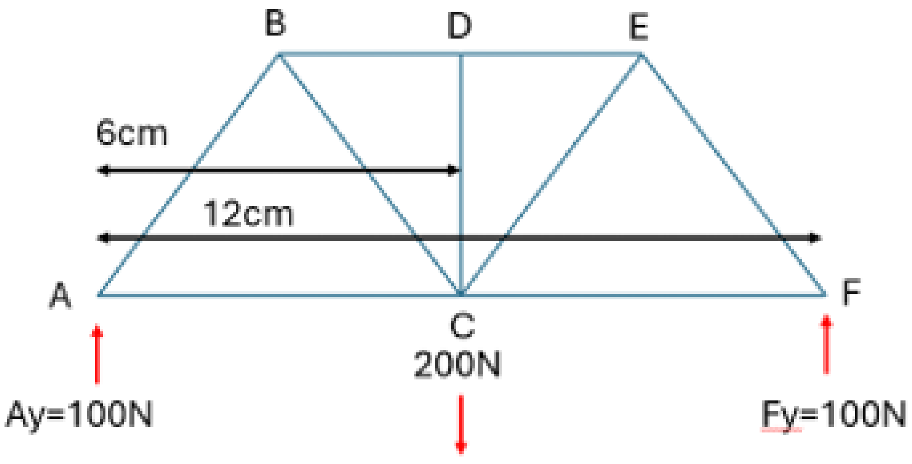
Objectives

- To extend bridge to meet the project requirements using the materials provided.
- Determine the magnitude of force in a truss member by determining the force on a truss joint
- Most cost-effective design and limited use of materials.
- Limit the amount of beams with no forces acting on them

Theoretical data

Understanding the forces that act in the truss is important and will help you understand what the changes are when adding and removing joint and beams

See below the diagram of a Truss Bridge and a force of 200N acting of point C



From this it can be determined the forces acting of the Point A and C as shown above.

$$\sum Fy = -200N + Ay + Fy$$

$$\sum Ma^{+} = -200N \times 6cm + Fy \times 12cm$$

$$Fy = \frac{1200N}{12cm}$$

$$Fy = 100N$$

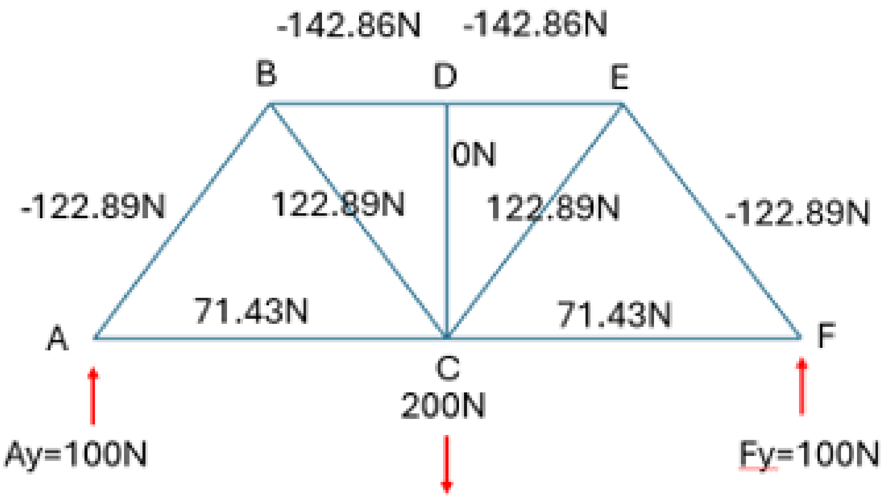
$$\sum Fy = 200N + Ay + 100N$$

$$Ay = 200N - 100N$$

$$Ay = 100N$$

From this the joints can be assessed and weather the beams are acting with compression or tension.

Compression is negative and positive



pg. 6

Below is an example calculation of how the forces are determined

Joint B

$$\sum Fy = 100N + ABsin(45°)$$

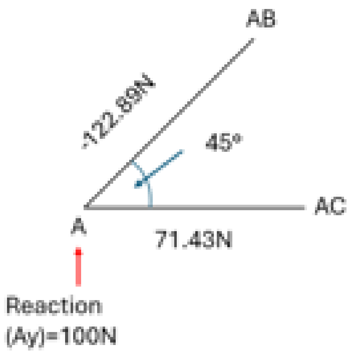
$$AB = \frac{-100N}{sin(45°)}$$

$$AB = -122.89N\ (Compression)$$

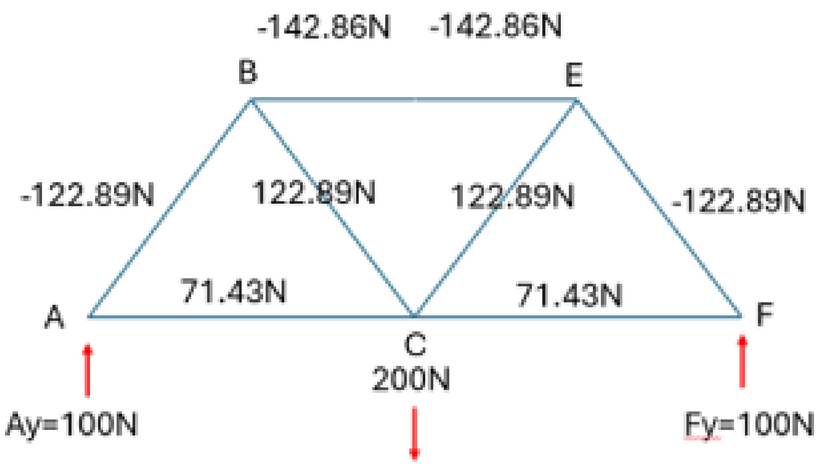
$$\sum Fx = -122.89N + ACcos(45°)$$

$$AC = \frac{122.89N}{cos(45°)}$$

$$AC = 71.43N\ \ (Tension)$$



As you can see that all beams expect DC have forces running though it. If DC was reomved from the design it would have no effect on the surrounding forces based on where the force is acting. See the diagram below to show the differenc when reomving the beam.



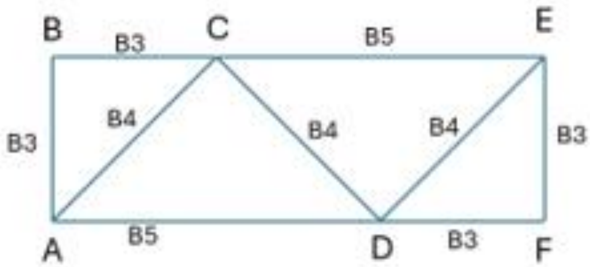
Now it always a good idea to remove beams as it could have other effect in the bridge structure. Such as the length between B and E is greater which is placing more stress on the member as there is not support holding it up. For this exercise we will not consider that.

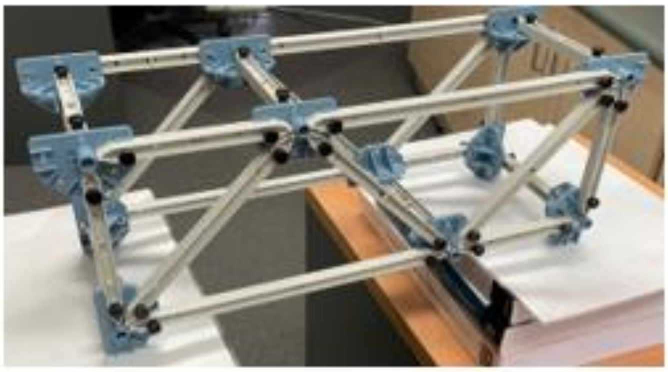
Part 3: Model Building

Part 1 Loads

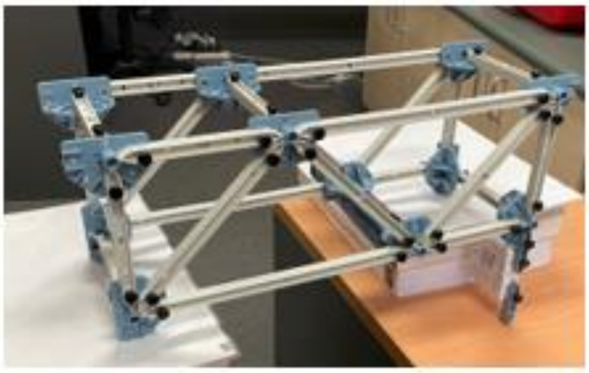
1. Place all the weight on the senor and record the force like the picture below

2. Record the data on the diagram below
3. Build the model same as the picture below.

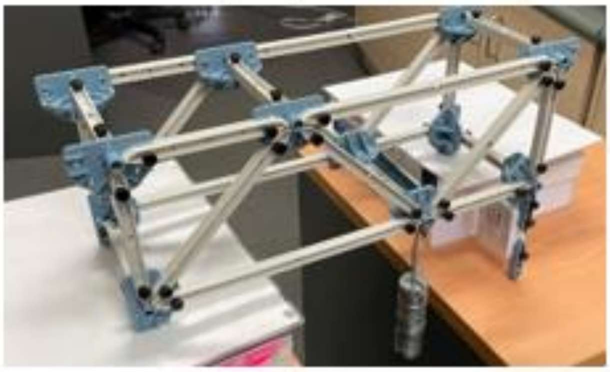




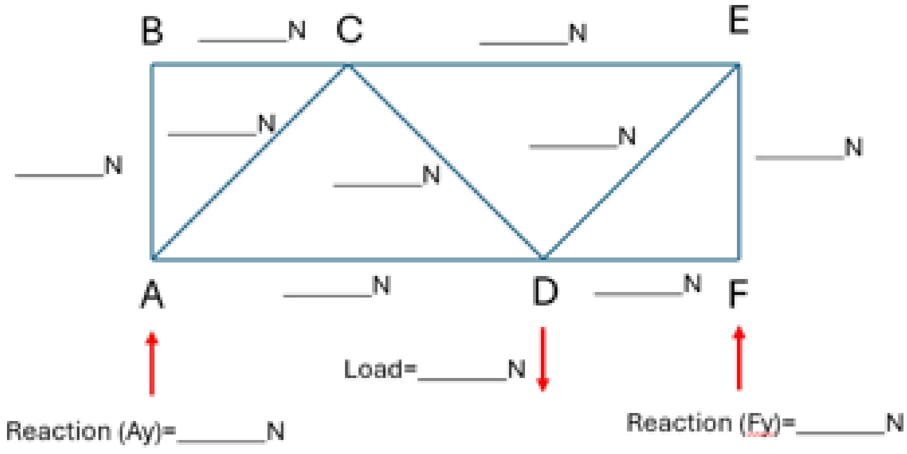
4. Attached the load Cell to the support F



5. Open the Sparkvue app
6. From Quick start experiments, select Load Cell force
7. Zero out the load sensor
8. Attach the weight to joint D as shown in the picture



9. Record the data on the diagram below
10. Repeat steps 5 to 7 only moving the load sensor, you will need to remove the weight and then zero out the load sensor



Part 2

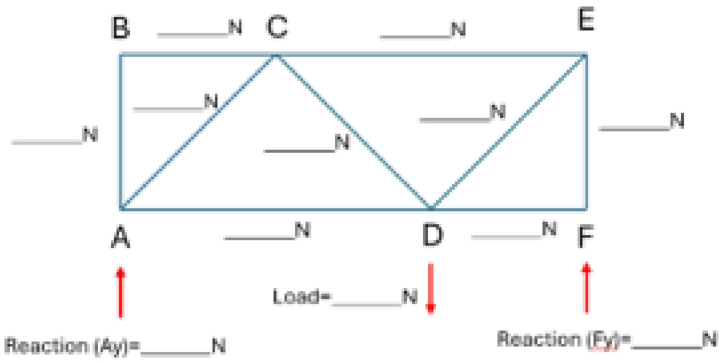
With the left-over materials provided to you, the bridge must be extended in one direction only. No materials can be removed from the existing bridge. The maximum length the bridge can be extended in 2.1m and minimum is 0.85m. The model is at a scale of 1cm:1m

- Beam 5 = 21cm
- Beam 4 = 13.5cm
- Beam 3 = 8.5cm

See the table below for the left-over materials and cost

Materials	Quantity	Cost
Beam 5	3	$150
Beam 4	3	$80
Beam 3	3	$50

Draw on the diagram below the extra materials and record the changes in the forces acting on the structure. The weight is to stay on the same joint D when remeasuring with the load cell. Following the same steps as part two

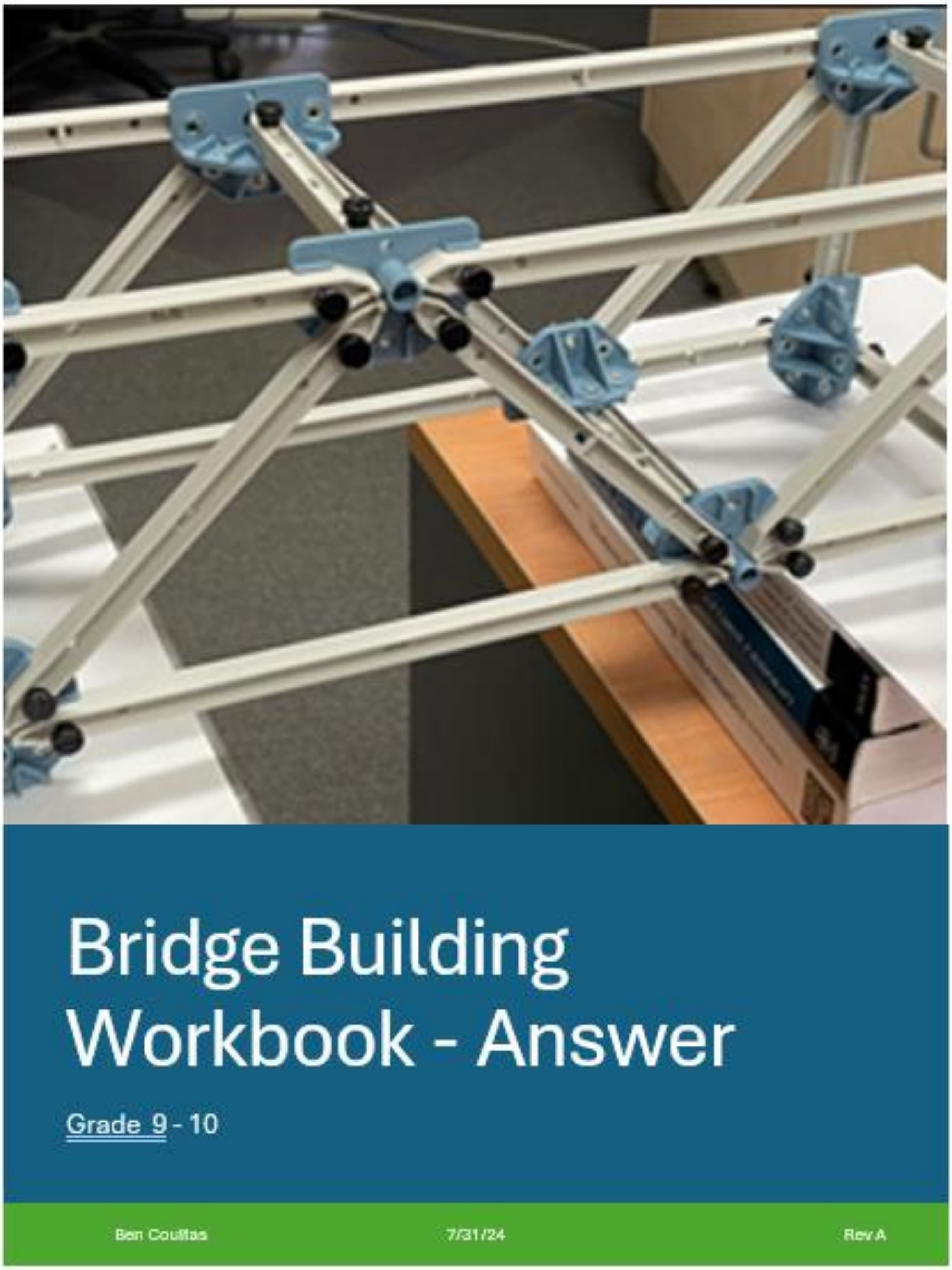


Results	Original Bridge	New Design	Difference (N)
Ay			
Fy			
Load			
Member			
AB			
AC			
BC			
CE			
CD			
DE			
DF			
EF			

The original cost of the of bridge is shown in the table below. For every beam that has a zero-force acting on it a cost of $100 will be added

		Bridge Original Cost	$1,000
Extra Members used	Quantity	Rate	
Beam 5		$150	
Beam 4		$80	
Beam 3		$50	
Zero Force		$100	
		Total Amount	

9& 10 answer


Bridge Building
Workbook - Answer
Grade 9 - 10
Ben Coulitas
7/31/24
Rev A

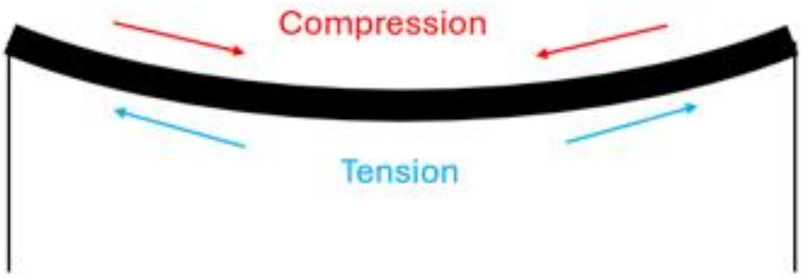
Part 1: What is a Bridge

1: Beam Bridges

See below a photo of simple beam bridges

Characteristics of a beam bridge

- Horizontal beam supported by vertical peris
- Horizontal beams under compression on top and tensions on bottom (axial forces)

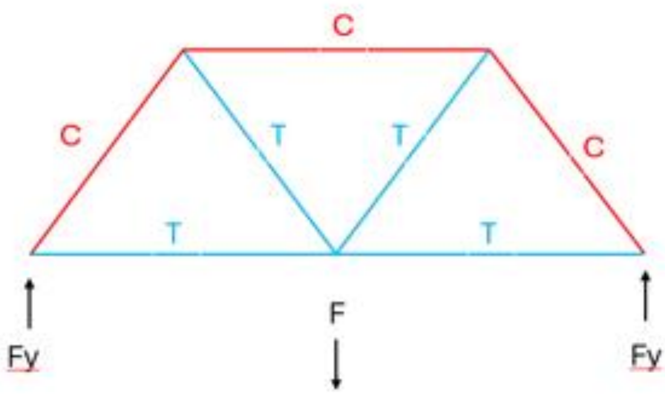


2: Truss Bridge

See below a photo of a Truss Bridge

Characteristics of a Truss bridge

- Beams can be either in Tension or Compression (axial forces) depending on where the forces are being applied
- Triangles are used as the main shape of a Truss bridge

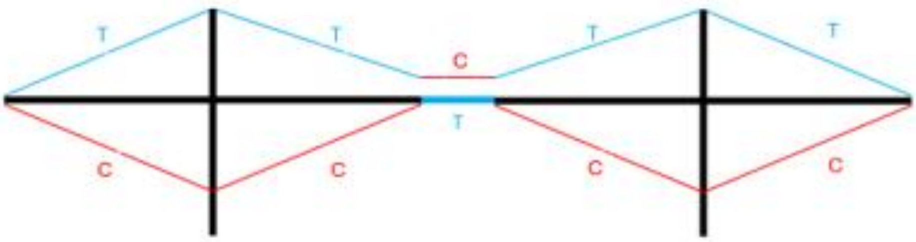


3: Cantilever Bridge

See below a photo of a Cantilever Bridge

Characteristics of a Cantilever bridge

- Generally made up of three spans with the outer spans are cantilevered



4: Arch Bridge

Below is a picture of an arch Bridge

Characteristics of an Arch bridge

- The load is carried in the arch
- The foundations carry both vertical and horizontal forces, and they must be designed to prevent horizontal sliding and vertical settling

Part 2: Forces acting on Bridge

In this activity a Bridge design has been completed for a project, but it has been determined that the bridge in to short. The bridge can be only extended on one end. To make it cost effect you need to limit the amount of materials but also aim to have the least amount of joints with no forces acting on them.

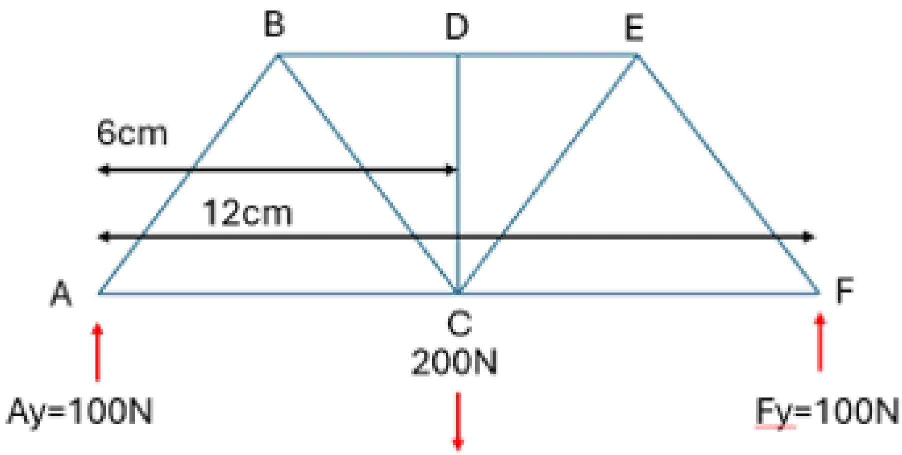
Objectives

- To extend bridge to meet the project requirements using the materials provided.
- Determine the magnitude of force in a truss member by determining the force on a truss joint
- Most cost-effective design and limited use of materials.
- Limit the number of beams with no forces acting on them

Theoretical data

Understanding the forces that act in the truss is important and will help you understand what the changes are when adding and removing joint and beams

See below the diagram of a Truss Bridge and a force of 200N acting of point C



From this it can be determined the forces acting of the Point A and C as shown above.

$$\sum Fy = -200N\ + Ay + Fy$$

$$\sum Ma^{+} = -200N \times 6cm + Fy \times 12cm$$

$$Fy = \frac{1200N}{12cm}$$

$$Fy = 100N$$

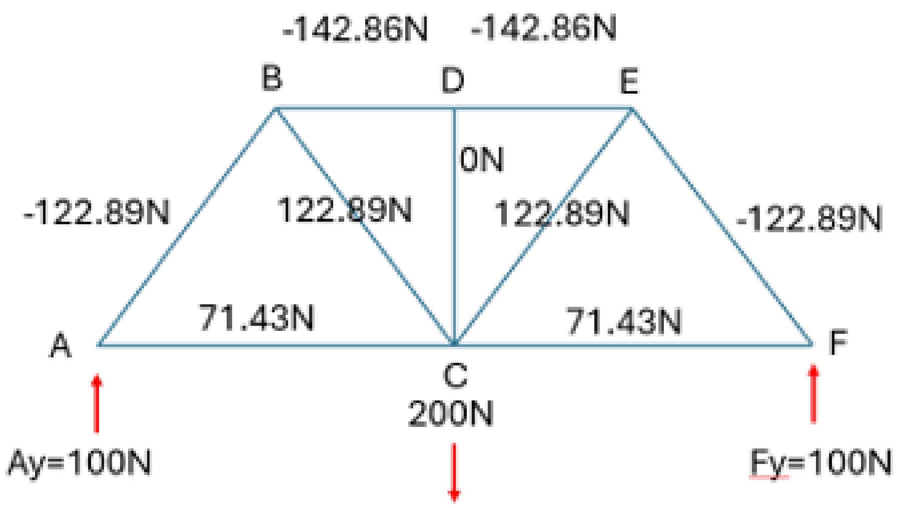
$$\sum Fy = 200N + Ay + 100N$$

$$Ay = 200N - 100N$$

$$Ay = 100N$$

From this the joints can be assessed and weather the beams are acting with compression or tension.

Compression is negative and positive



pg. 7

Below is an example calculation of how the forces are determined

Joint B

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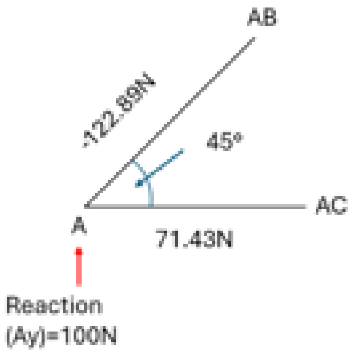

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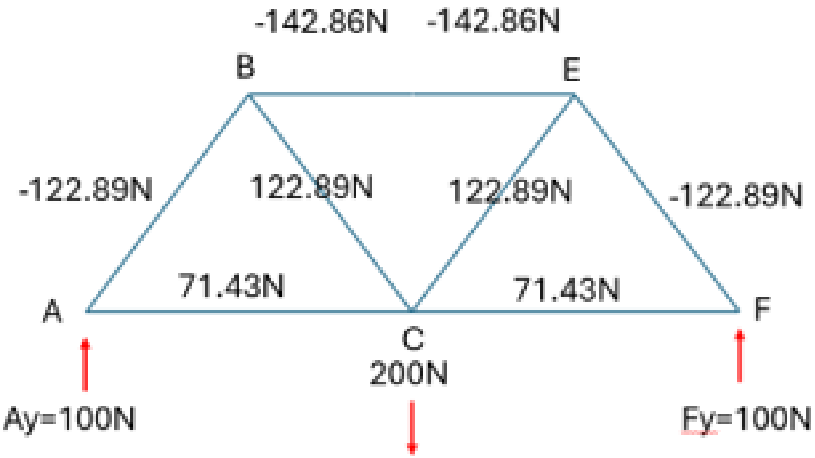

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Part 1 Loads

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2. Record the data on the diagram below
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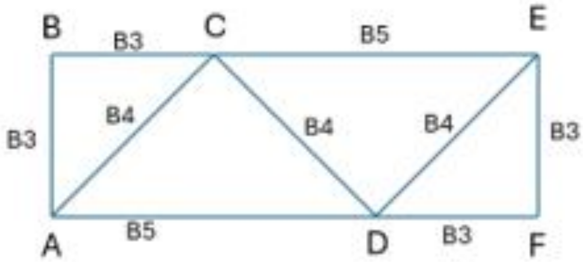

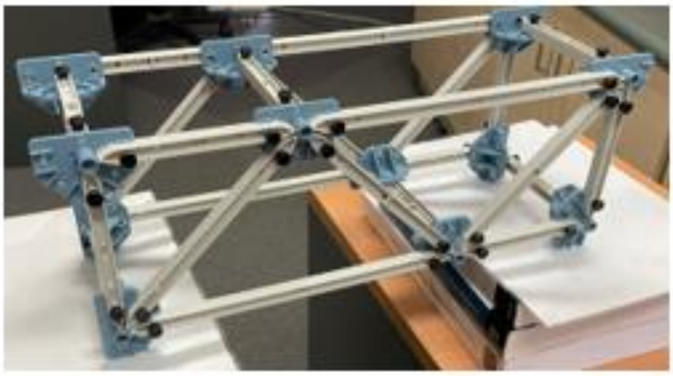

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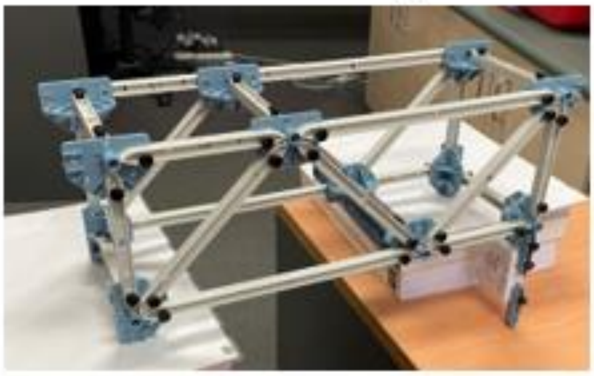
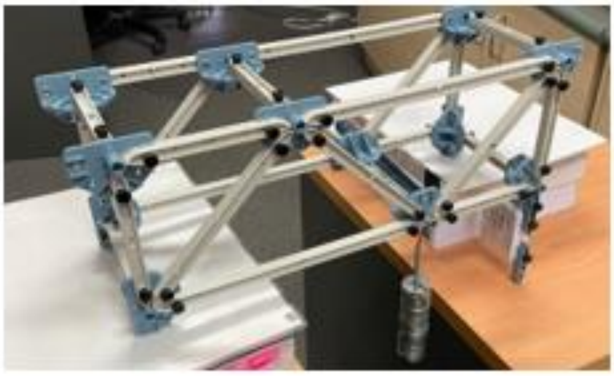


5. Open the Sparkvue app
6. From Quick start experiments, select Load Cell force
7. Zero out the load sensor
8. Attach the weight to joint D as shown in the picture



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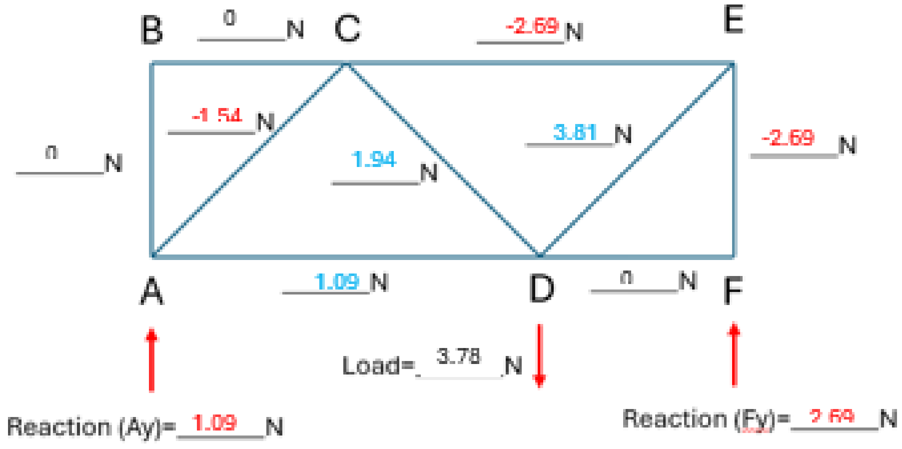
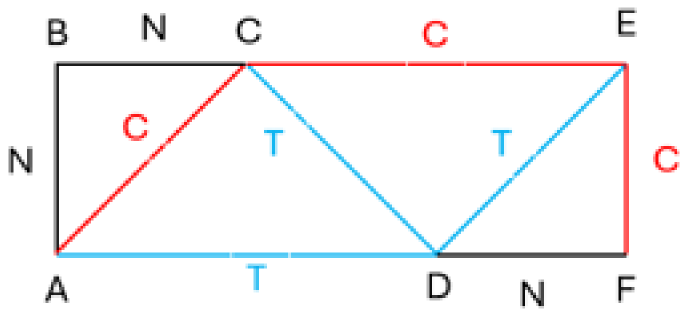
10. Repeat steps 5 to 7 only moving the load sensor, you will need to remove the weight and then zero out the load sensor



The number produced in the experiment maybe be slightly different if wireless load cell is not setup correctly or vibrations affect the results by hitting the table or moving the model when loading. The axial forces should still be the same as the figure below.



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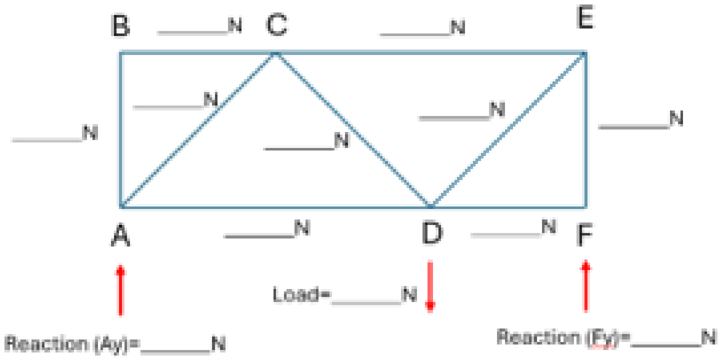
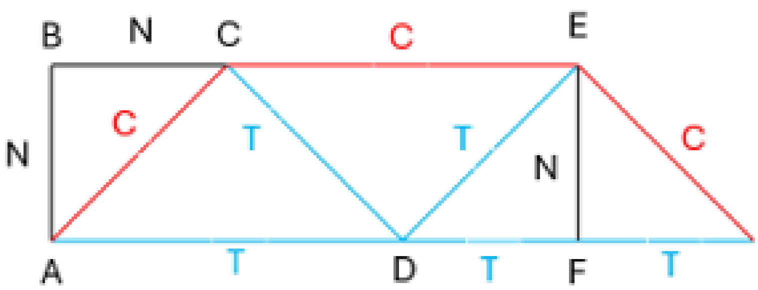
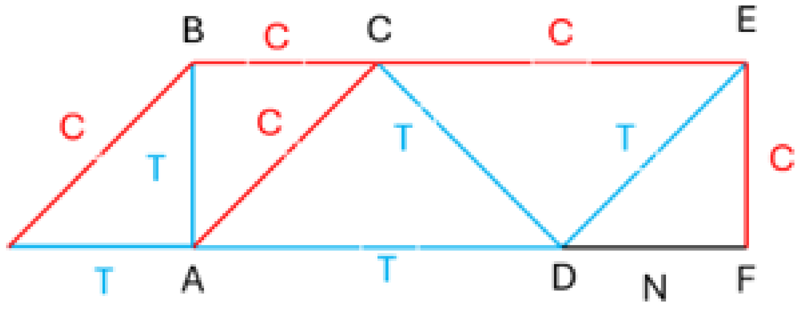


Option 1



Option 2 (Correct)



Results	Part 2	Part 3	Difference (N)
Ay			
Ey			
Load			
Member			
AB			
AC			
BC			
CE			
CD			
DE			
DF			
EF			

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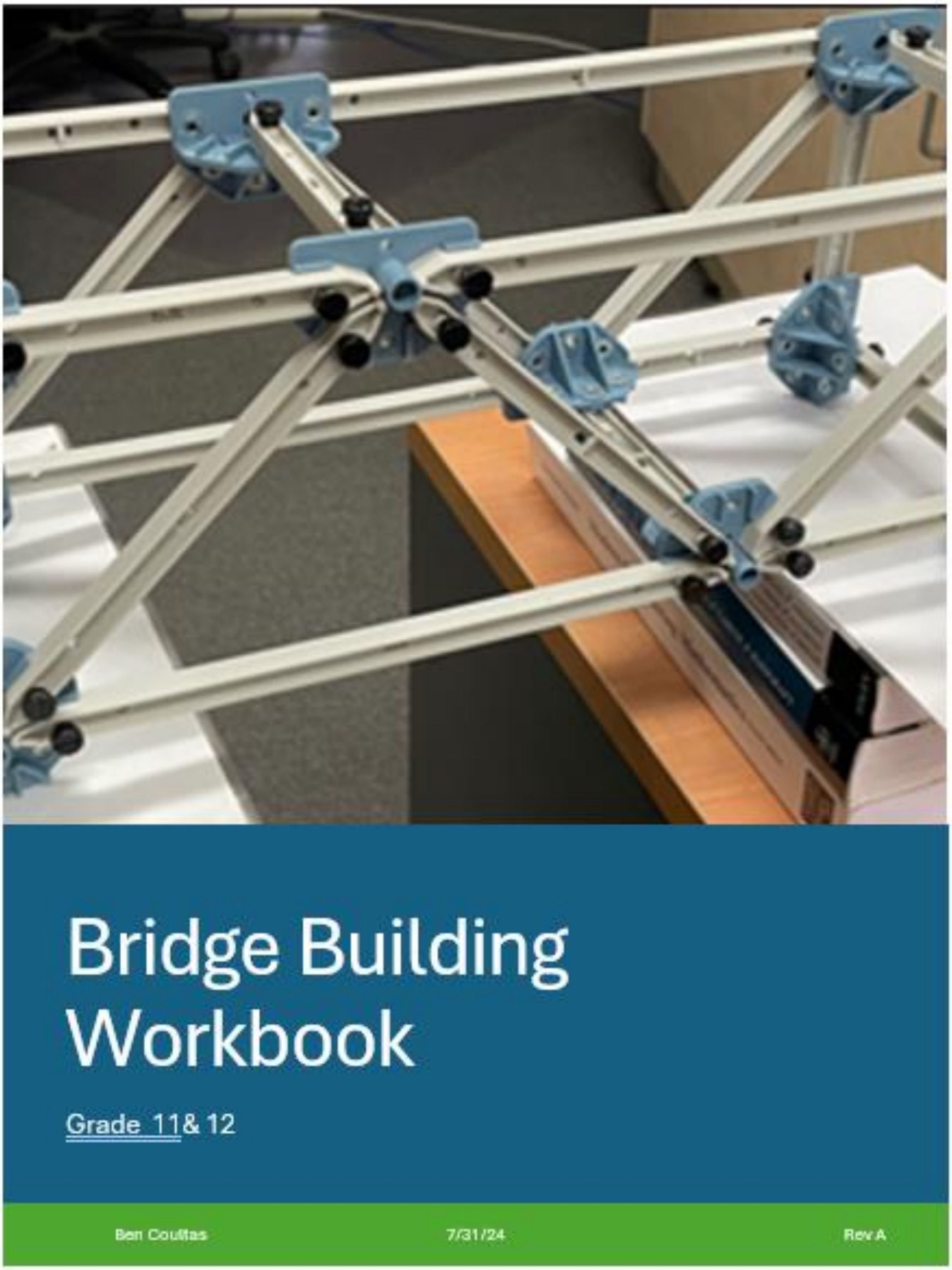
		Total Amount	

11&12


Bridge Building Workbook
Grade 11& 12
Ben Coultas
7/31/24
Rev A

Name: ____

Group Member: ____

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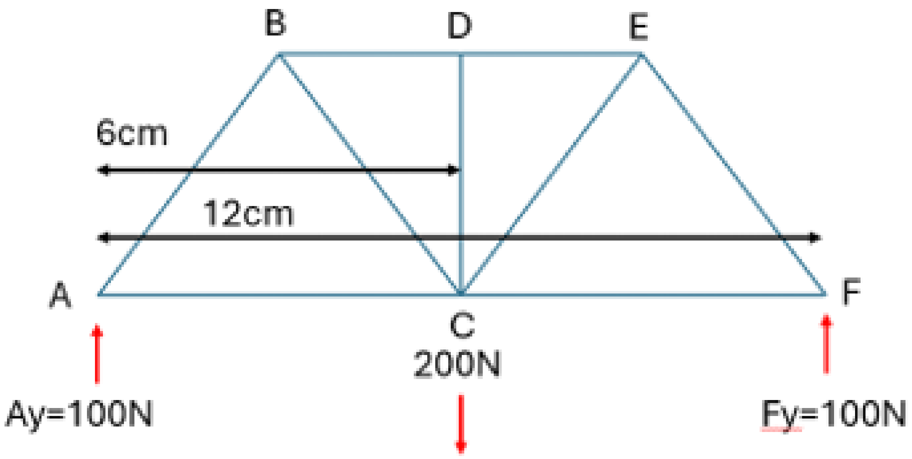

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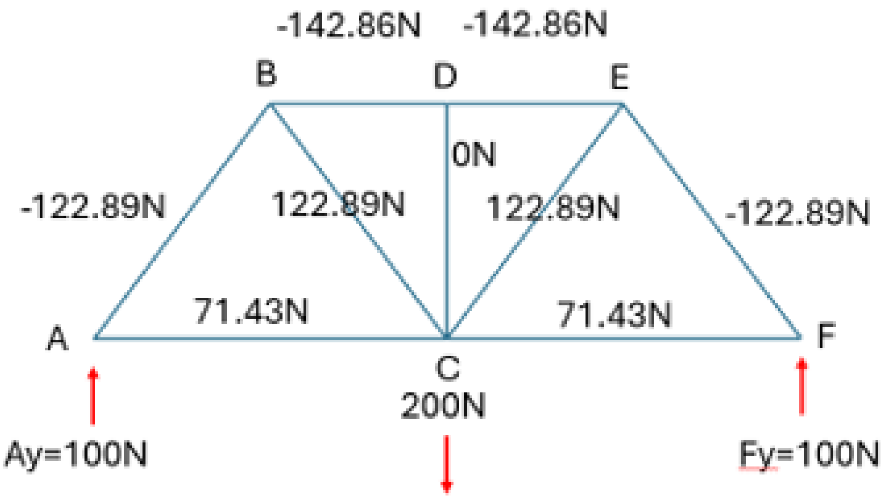
Compression is negative and positive



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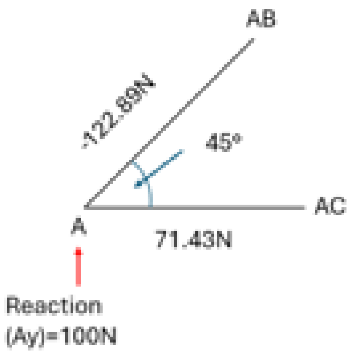

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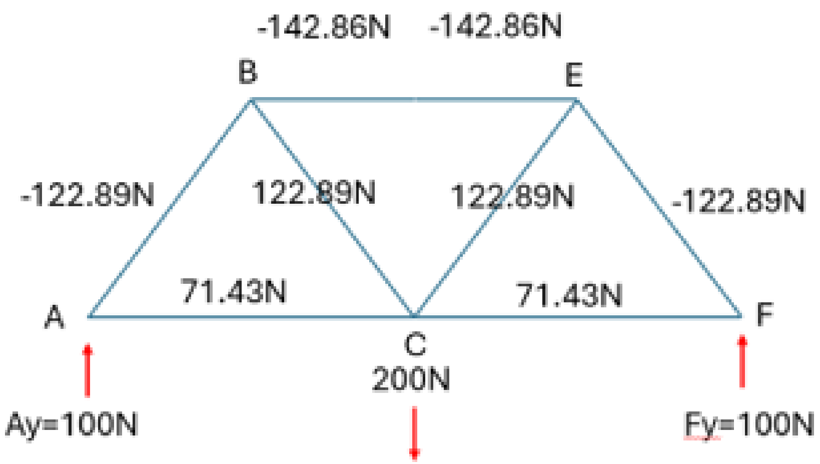

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2. Record the data on the diagram below
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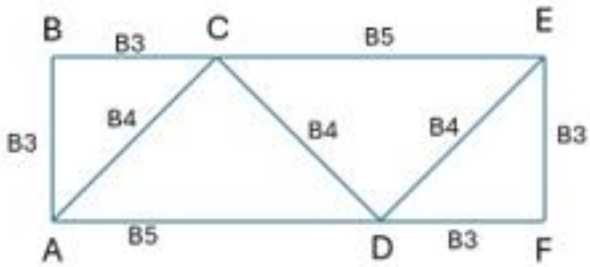

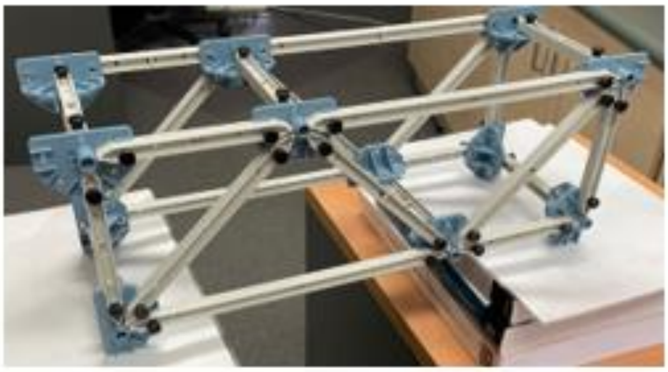

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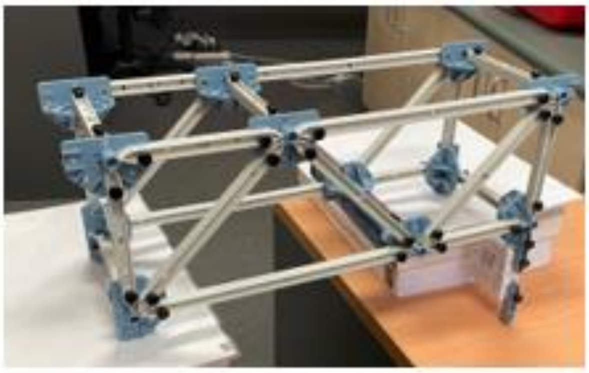
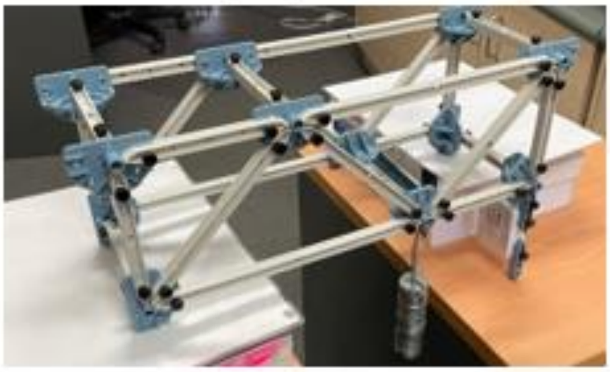
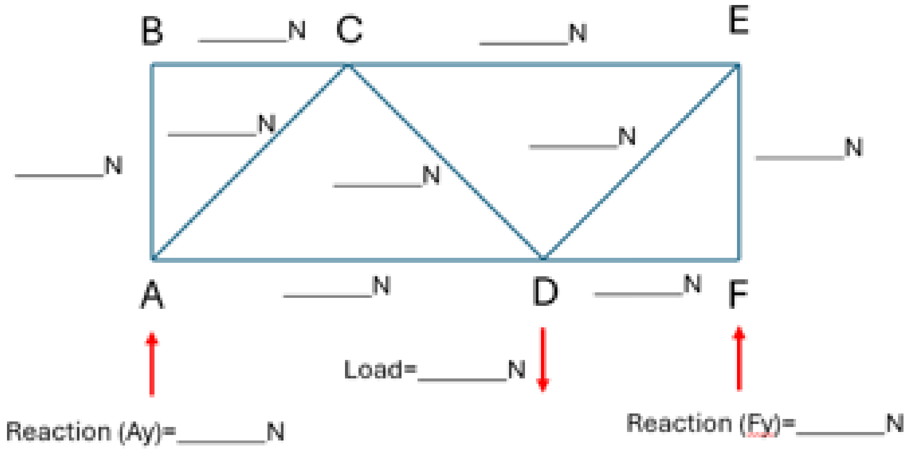


5. Open the Sparkvue app
6. From Quick start experiments, select Load Cell force
7. Zero out the load sensor
8. Attach the weight to joint D as shown in the picture



9. Record the data on the diagram below
10. Repeat steps 5 to 7 only moving the load sensor, you will need to remove the weight and then zero out the load sensor



Part 2

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- Beam 4 = 13.5cm
- Beam 3 = 8.5cm

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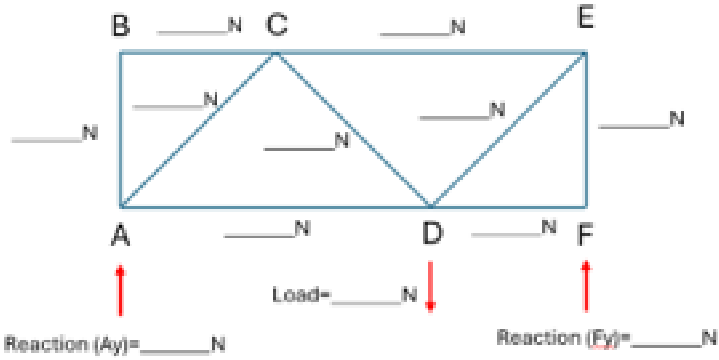
Draw on the diagram below the extra materials and record the changes in the forces acting on the structure. The weight is to stay on the same joint D when remeasuring with the load cell. Following the same steps as part two



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Ay			
Fy			
Load			
Member			
AB			
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The original cost of the of bridge is shown in the table below. For every beam that has a zero-force acting on it a cost of $100 will be added

		Bridge Original Cost	$1,000
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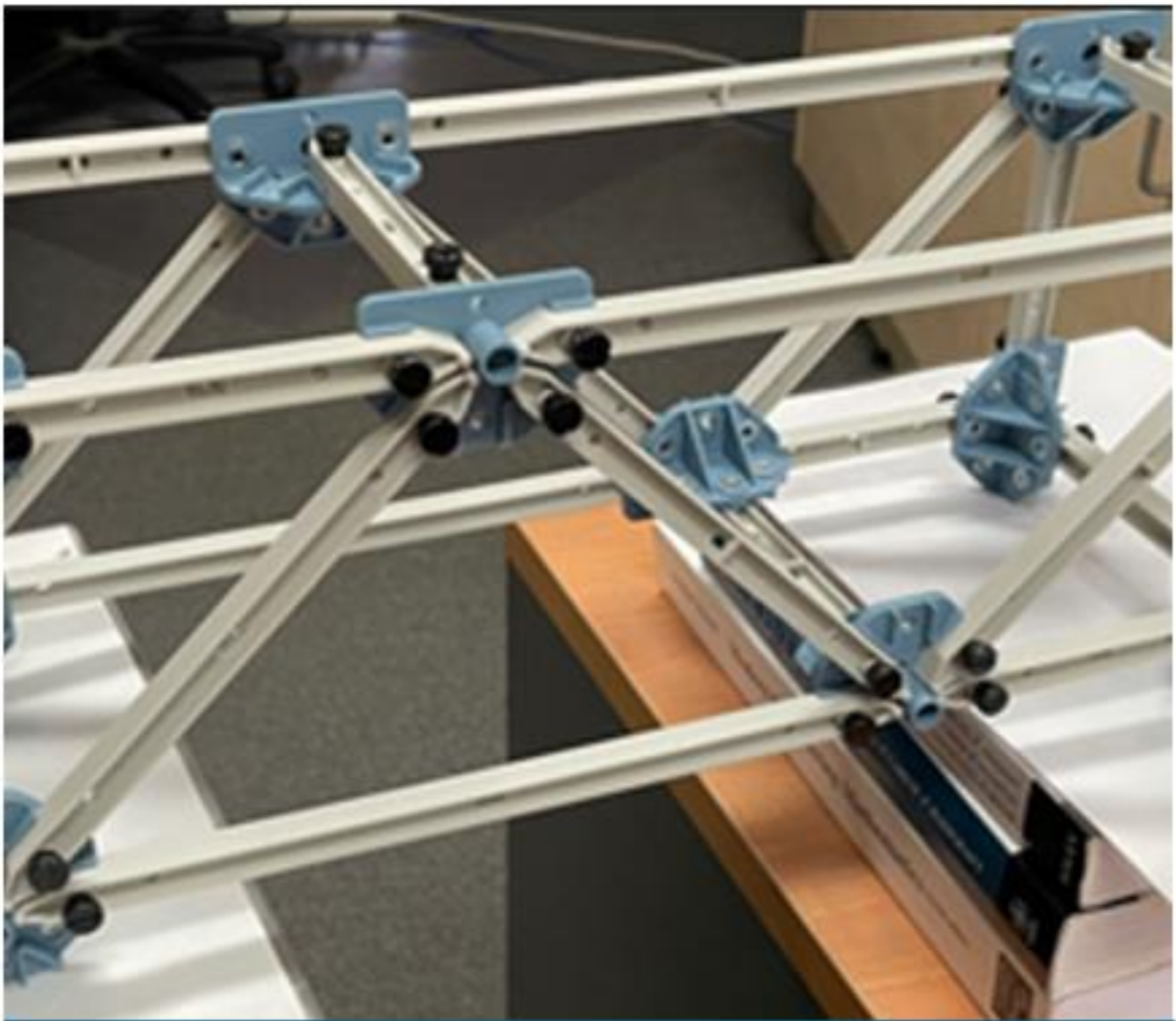
Zero Force		$100	
		Total Amount	

11&12 answer



Bridge Building Workbook - Answer

Grade 11&12

Ben Coultas 7/31/24 Rev A

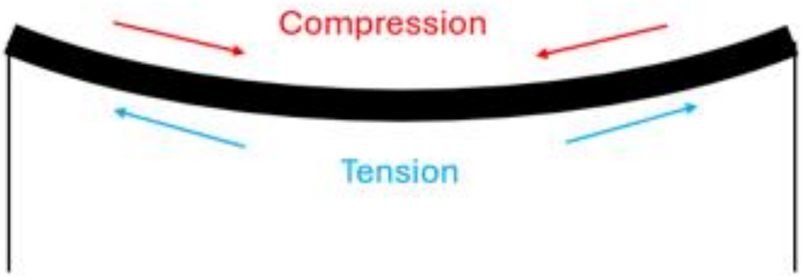
Part 1: What is a Bridge

1: Beam Bridges

See below a photo of simple beam bridges

Characteristics of a beam bridge

- Horizontal beam supported by vertical peris
- Horizontal beams under compression on top and tensions on bottom (axial forces)

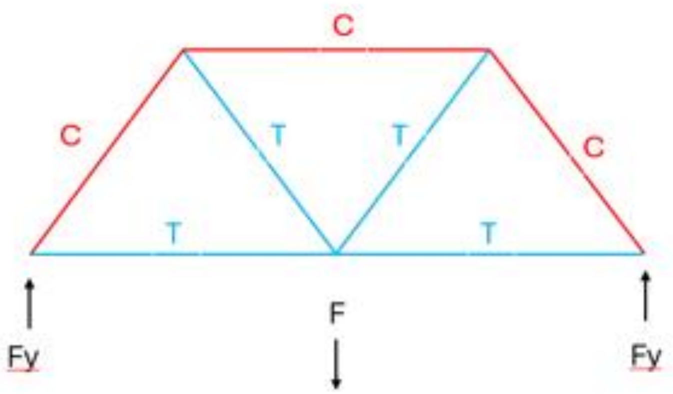


2: Truss Bridge

See below a photo of a Truss Bridge

Characteristics of a Truss bridge

- Beams can be either in Tension or Compression (axial forces) depending on where the forces are being applied
- Triangles are used as the main shape of a Truss bridge

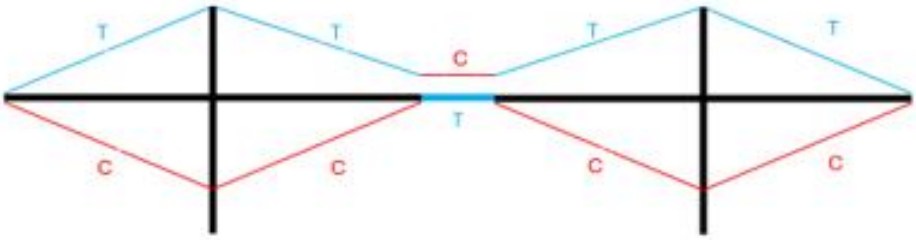


3: Cantilever Bridge

See below a photo of a Cantilever Bridge

Characteristics of a Cantilever bridge

- Generally made up of three spans with the outer spans are cantilevered



4: Arch Bridge

Below is a picture of an arch Bridge

Characteristics of an Arch bridge

- The load is carried in the arch
- The foundations carry both vertical and horizontal forces, and they must be designed to prevent horizontal sliding and vertical settling

Part 2: Forces acting on Bridge

In this activity a Bridge design has been completed for a project, but it has been determined that the bridge in to short. The bridge can be only extended on one end. To make it cost effect you need to limit the amount of materials but also aim to have the least amount of joints with no forces acting on them.

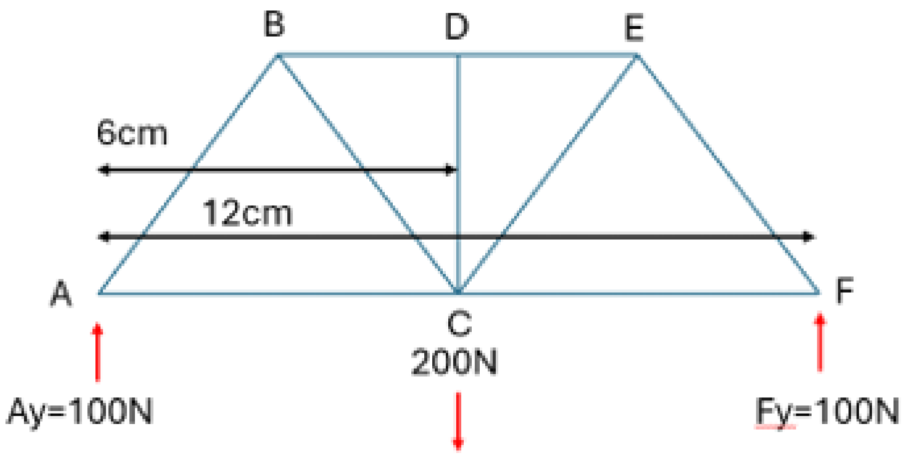
Objectives

- To extend bridge to meet the project requirements using the materials provided.
- Determine the magnitude of force in a truss member by determining the force on a truss joint
- Most cost-effective design and limited use of materials.
- Limit the number of beams with no forces acting on them

Theoretical data

Understanding the forces that act in the truss is important and will help you understand what the changes are when adding and removing joint and beams

See below the diagram of a Truss Bridge and a force of 200N acting of point C



From this it can be determined the forces acting of the Point A and C as shown above.

$$\sum Fy = -200N + Ay + Fy$$

$$\sum Ma^{+} = -200N \times 6cm + Fy \times 12cm$$

$$Fy = \frac{1200N}{12cm}$$

$$Fy = 100N$$

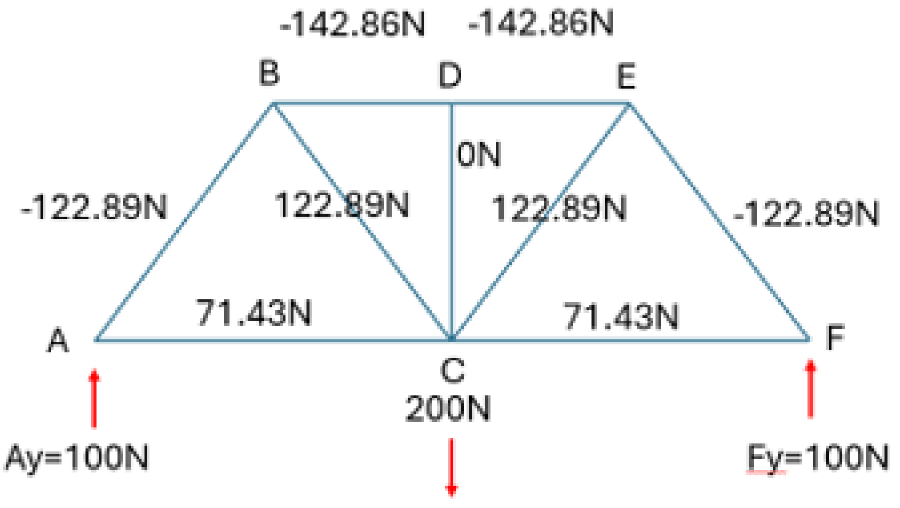
$$\sum Fy = 200N + Ay + 100N$$

$$Ay = 200N - 100N$$

$$Ay = 100N$$

From this the joints can be assessed and weather the beams are acting with compression or tension.

Compression is negative and positive



pg. 7

Below is an example calculation of how the forces are determined

Joint B

$$\sum Fy = 100N + ABsin(45°)$$

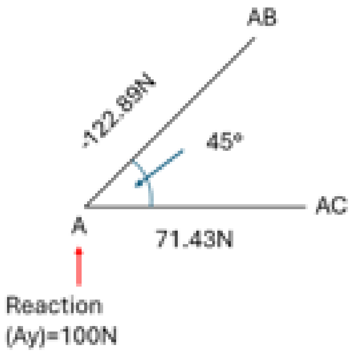
$$AB = \frac{-100N}{sin(45°)}$$

$$AB = -122.89N\ (Compression)$$

$$\sum Fx = -122.89N + ACcos(45°)$$

$$AC = \frac{122.89N}{cos(45°)}$$

$$AC = 71.43N\ \ (Tension)$$



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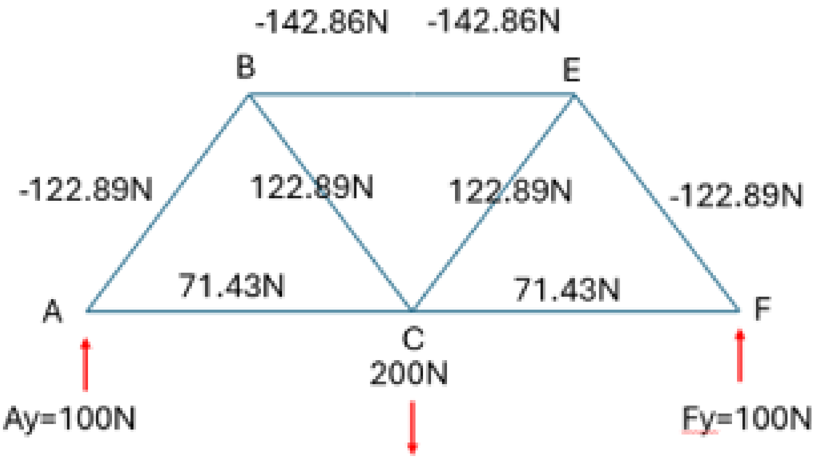

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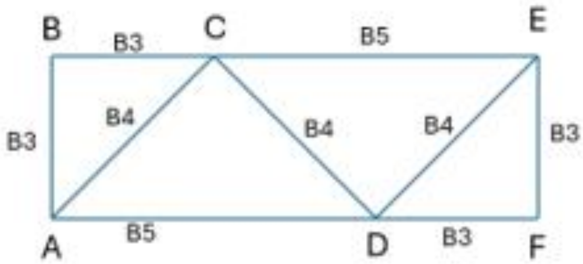

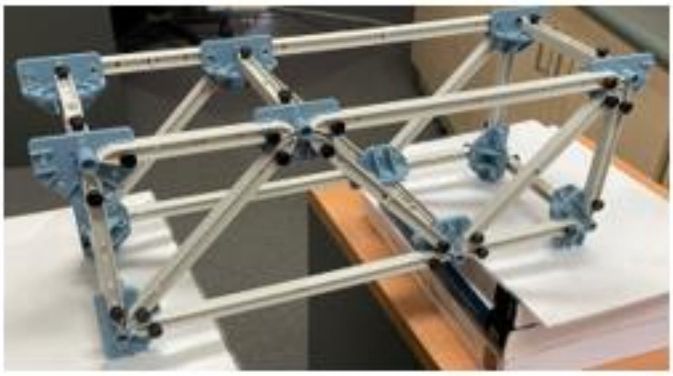

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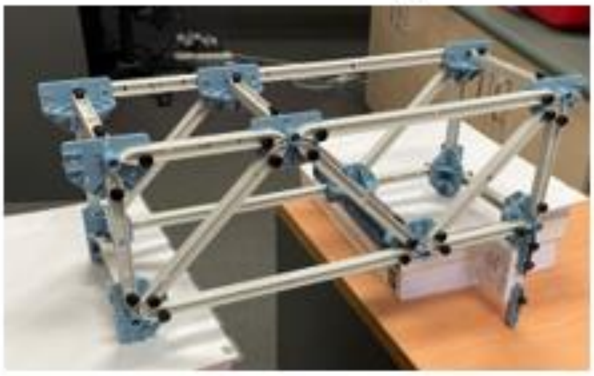

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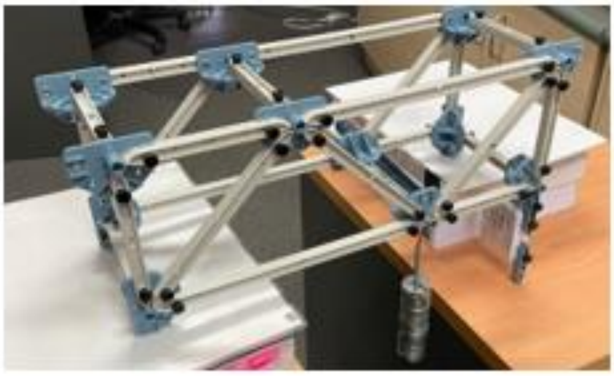

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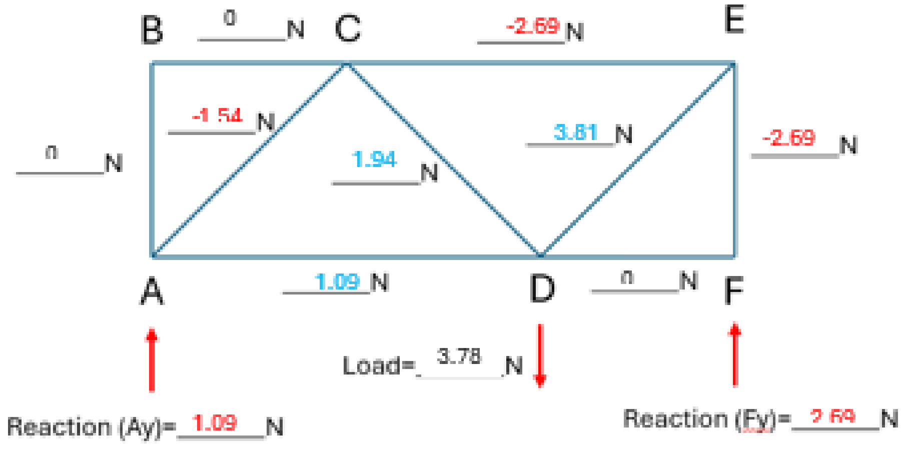
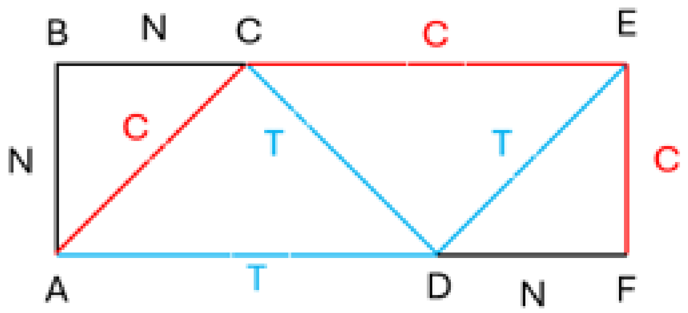


The number produced in the experiment maybe be slightly different if wireless load cell is not setup correctly or vibrations affect the results by hitting the table or moving the model when loading. The axial forces should still be the same as the figure below.



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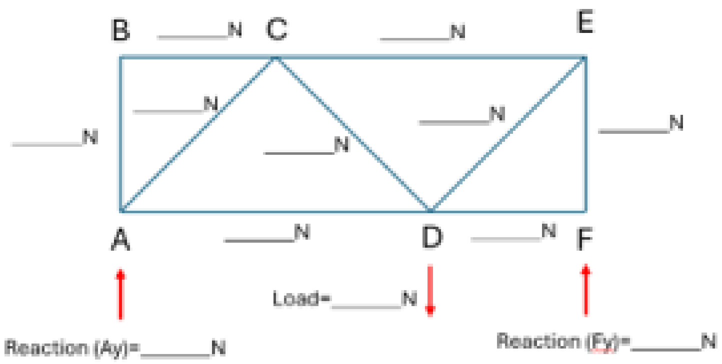
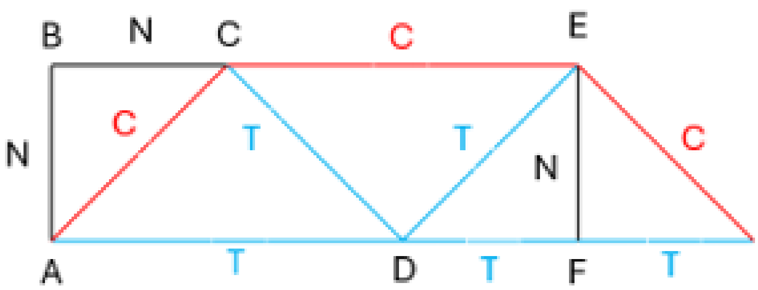
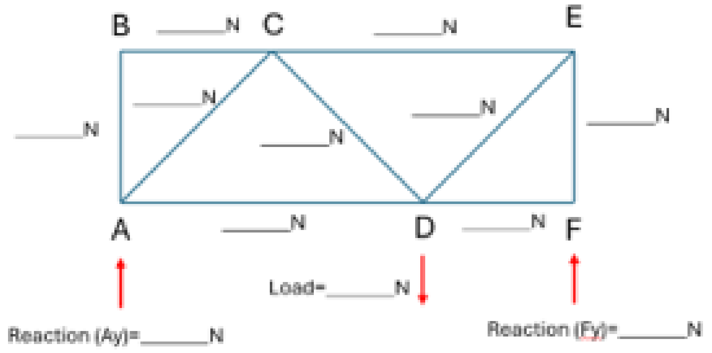


Option 1





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