Laboratory Session 8 and 9L

Project 2A - Cantilever Beam Design

Part 1- Students' handouts

Students' learning outcomes: Part

This week's activities will focus on Learning Outcomes 1, 2, 4, 5, 6 as below

LO1- Describe the role of abstraction, simplification and the use of assumption and mathematical relationships in solving problems encountered by engineers
LO2- Construct free body diagrams to analyse the forces and moments acting on and within structural elements and structural systems
LO4- Solve engineering mechanics problems.
LO5- Undertake and present calculations and design in reports in a professional manner.
LO6- Work in a team to carry out design project work

Announcements:

1. *Must use your Excel/Matlab Design Worksheet in beam design in Project 2A Report.*

Task 1: Design Cantilever Beam for Project 2A - Week 6

Design your cantilever beam using an outstand length of 500mm to lift a hanging mass of 1500g so that it deflects more that 2mm and less than 6mm, using the engineering principles you have learned in this subject so far.

Also just like you did for Project 1B, an Excel Spreadsheet is to be developed, enabling fast design of your cantilever beam.

Please note that the new Cantilever Beam project is similar to the second simply supported Balsa Beam that was built and tested in last few weeks.

Refer to part 2 of this handout for details of this project.

These notes are based on originals developed by Richard Dwight and Cameron Lam They have been updated by Josip Horvat and Tim McCarthy They have been updated and are used by Khaled El-Akruti in 2017 and by Sana Amir in 2019.

Beam Free Length (outstand) (mm)	500mm
Hanging Mass (g)	1500g
Allowable End Point Deflection	2mm< Deflection <6mm

1. ***It is advised to use the Excel Design Worksheets to design the cantilever beam so trial and error for better designed is used to arrive at the design for the target deflection and it can be built today.***
2. ***In preparation, each Team must extend their Excel Design Worksheet to predict the deflection.***

Task 2: Build your designed Cantilever Beam for Project 2A - Week 7

Build your balsa Cantilever Beam that you designed in Task 1 above.

When ready, give your Tutor your written Material Request (a shopping list!) covering the Balsa sheet and square sections quantities they require. Use the standard form (See page 4)

Each team is allowed -

- 1 balsa sheet 4.7x101x900
- up to a maximum 6 of the 900mm long balsa square sections subject to the following restriction: 3.1x6.3mm max 4, 4.7x6.3mm max 4, and 1.5x6.3mm max 4.

For example the following materials list is valid: 1off 3.1x50.5x900, plus 2 of 3.1x6.3x900, plus 2 of 4.7x6.3x900, plus 2 of 1.5x6.3x900

Build your structure taking care when cutting as below -

1. Use the glue sparingly. ***Use up the already open glue bottles first.***
2. ***Wear safety glasses when using the glue and cutting balsa pieces.***
3. ***Wear plastic gloves when using the glue***
4. ***All cutting is done on the cutting boards provided***
5. You will need to share cutting resources with other teams.
6. Remember that you need some extra length at either end to go over the supports to provide adequate bearing strength to support your beam.
7. Take photos of the building process as you go - but do not waste time!

PLEASE MAKE SURE ALL CUTTING IS DONE ON THE CUTTING BOARDS PROVIDED (ONE PER TEAM), SO THAT THE FURNITURE IS NOT DAMAGED

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Task 3: Testing Your Beam and counterbalance mass predictions - do in class in Week 7

Testing Process is to be carried out through loading the cantilever beam by hanging a mass of 1500g and measuring the deflection.

NOTE:

1. **Teams are to clearly label their completed Cantilever Beams for testing.**

Classroom Health and Safety

Three safety risks are identified for this project -

1.) Handling of glue

Putting too much pressure on the glue tube results in the tube bursting, potentially ending up in the eyes of the handler of his/her team-mates. This can result in a serious eye injury. Such incidents typically happen when opening the new glue tube or when the nozzle gets blocked by the set glue (tube not closed properly). To avoid this happening -

NEVER apply excessive pressure to the glue tube. If the glue does not come out easily, consult the tutor.

- The Glue nozzle will be cut open for you. Inspect it before each use. If it is not open, ask your tutor.
- ALWAYS wear safety glasses and gloves when handling the glue.
- Be mindful of your team-mates. They may get injured by you handling the glue. Always point the nozzle away from people around you.

2.) Cutting balsa pieces

Use the small saws where possible. A sharp blade can also be used for cutting balsa pieces. Fingers can get cut and blade may snap, potentially resulting in eye injury. To avoid this -

- Always use the safety rule when cutting the balsa sheet, keeping your fingers in the groove to protect them from the blade.
- Keep your fingers well away from the blade at all times (at least the length of the blade).
- ALWAYS wear safety glasses when cutting.
- Make sure your team-mates are at safe distance (at least a metre) to prevent injuring them.
- Always cut in a direction away from your fingers.

3.) Testing

A mass of 1500 g will be used to apply a force on the beam may fall from the beam, potentially hurting your feet. This may cause serious injury or damage. To avoid this -

- Wear sturdy closed-type shoes.

- Keep your feet away from the potential falling path of the weights at all times.
- ALWAYS wear safety glasses when testing the system.

Recap

1. *WHAT happened and suggest some reasons WHY.* Identify and share the learning with the *design and Building of their Cantilever Beam for Project 2A.* Good Reflections Fodder!
2. *What they need to have calculations via their Design Worksheet.*
3. *The continuing need* to hold *regular Team Meetings and to keep minutes:*

ATTACHMENT 1:

Material Request List

Task 4: Project 2A: Beam Design - Building

Tutorial Number..... **Team Number**..... **Tutor's Name**..... **Date**.....

Please supply the following Balsa Beam construction materials -

1. Balsa Sheet

Section dimensions and length -.....
Quantity -.....

2. Balsa rectangular Sections

Section dimensions and length -.....
Quantity -.....

Section dimensions and length -.....
Quantity -.....

Section dimensions and length -.....
Quantity -.....

Materials collected by -.....

Please note -

1. Material supplies are limited so please do not delay in collecting your order.
2. It is your responsibility to choose your materials wisely. Returns or refunds will not be considered.
3. Replacements for breakages and any additional Material Requests will be considered only at the discretion of the management.

Part 2 - Students' handoutshandouts

Project 2A: Design of a cantilevered beam structure under a static point applied load

A: Design of 500mm cantilever beam structure- Week 6

Design the cantilever beam using an outstand length of 500mm to lift a hanging mass of 1500g so that it deflects more that 2mm and less than 6mm, using the engineering principles you have learned in this subject so far.

This **Project 2A Design part of the Report** needs to include developing an **Excel Design Spreadsheet to show how to improve the design.** Such improvement should allow to modify design parameters in particular (cross section area and second moment of area) to achieve a design that **will meet the target deflection and minimize the used material.** Such spreadsheet should allow trial and error **for varying the design parameters in particular (cross section area and second moment of area) to result in the target deflection.**

The Final Design and Reflection Report of Project 2A is worth 5**%** of the overall mark.

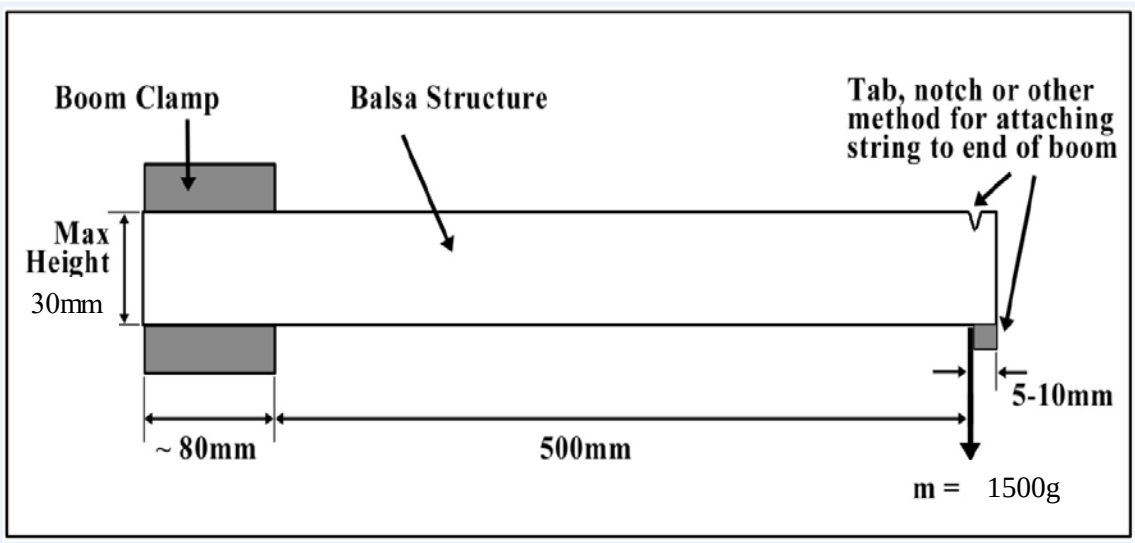


Figure 1: Side View of New Cantilever Beam. (Can be used as shown or inverted)

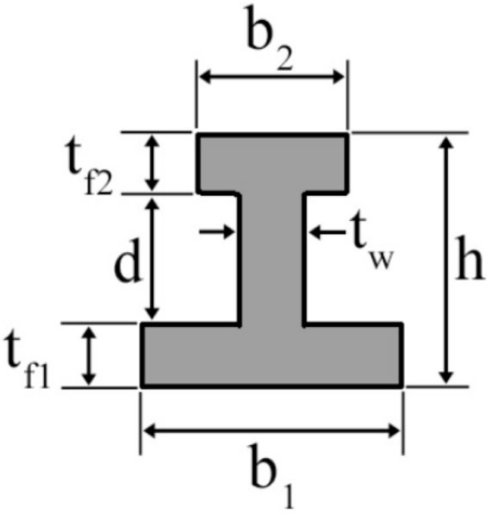
Procedure - Part A: Preliminary design

1. You must use one of the cross section shapes given in Figure 2. You must justify your shape selection in your report.
2. Begin by guessing the overall dimensions from the available material sizes. Calculate the cross sectional area and the second moment of area for the full cross section using the Parallel Axis Method.

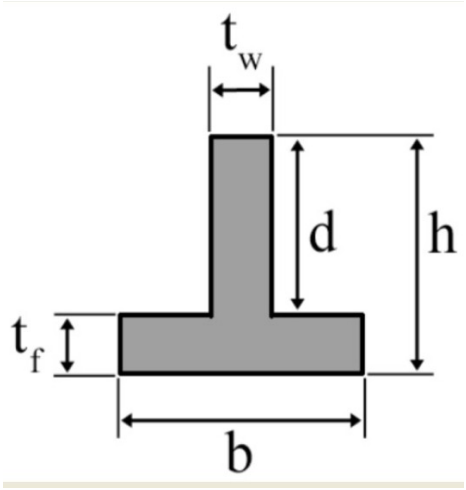
3. Use an estimate of Young's modulus of the balsa results based your experiments in week 3: (use E= 1.40 GPa) and check published data to compare (e.g. Encyclopaedia Britannica Online).
4. Calculate the deflection at the free end of the beam using the formula $\delta = PL^3/(3EI)$, where L is the effective length, P is the load in newtons, E is Young's modulus and I is the second moment of area.
5. Check for the maximum stress at the free end of the beam. This occurs on the top and bottom surfaces of the beam directly under the load. Find the maximum bending moment ($M_{max}= -PL$) and the stress, $\sigma_{max}=M_{max}*h/(2*I)$, where h is the overall height of the section.
6. Sketch this preliminary design showing all details so it can be built.
7. Check your Excel Design Worksheet by doing test runs with similar but different loads, spans and deflection requirements. Do this by doing some calculations on paper using a calculator and correct the Worksheet as necessary.
8. Document all of the above in your Design Report. You should also add your title page, Contents, and Purpose statement.
9. Assumptions: The above formulae work only for beams of **constant cross section** (i.e. beams that have the same cross section along their entire length). The maximum bending moment and deflection equations are true for an end point load on a cantilever beam as shown in Figure 1. The maximum stress equation is true for symmetrical cross section (e.g. T, I, Box, Channel) structures.
10. We are restricted to using mathematical models that we understand and formulae that have been justified by experiment or research in literature.

Choose your basic beam design from the shapes given below -

Design 1: Unequal Flange I Beam



Design 2: T Beam



NOTE:

1. **Beams can be designed and used as shown or inverted.**
2. **Beams MUST be stiffened for the first 80mm where they are held by the Clamp to stop crushing.**
3. **To optimize this structure, you must set up an Excel Design Spreadsheet to calculate the second moment of area and deflections.**
4. **By varying the height of the vertical web and using different size square sections you can find the lowest value for cross sectional area while meeting the deflection criterion.**
5. **You have to avoid buckling by limiting h/tw ratios to about < 25**

B: Final design of nominal 500mm cantilever beam - Week 6 homework

During week 6 as homework, your Team will have to complete your final end loaded cantilever balsa beam design.

You will need to use your Excel Design Worksheet to check that your design will meet the criteria. If it does not meet the criteria according to your Design Worksheet, you will need to change the design. You could consider -

- Changing the height
- Changing the width
- Using different sized balsa sections
- Using the discarded design shape from above - the one you did not use initially

C: Building Your Beam -- to be done in class in Week 7

By Sunday start of week 7, give your Tutor your written Material Request (a shopping list!) covering the Balsa sheet and square sections quantities they require. Use the standard form in the Student's - (in Word form on Moodle)

Each team is allowed -

- 1 balsa sheet 3.1x50.5x900
- up to a maximum 8 of the 900mm long balsa square sections subject to the following restriction: 3.1x6.3mm max 4, 4.7x6.3mm max 4, and 4.7x10mm max 4.

For example the following materials list is valid: 1off 3.1x50.5x900, plus 2 of 3.1x6.3x900, plus 2 of 4.7x6.3x900, plus 4 of 4.7x10x900

Procedure - Part C:

Build your structure taking care when cutting as below -

1. Use the glue sparingly. ***Use up the already open glue bottles first.***
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4. ***All cutting is done on the cutting boards provided***
5. You will need to share cutting resources with other teams.
6. Remember that you need some extra length at either end to go over the supports to provide adequate bearing strength to support your beam.
7. Take photos of the building process as you go - but do not waste time!

D: Testing Your Beam and counterbalance mass predictions - Week 7

Testing Process is to be carried out through loading the cantilever beam by hanging a mass of 1500g and measuring the deflection.

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- The Glue nozzle will be cut open for you. Inspect it before each use. If it is not open, ask your tutor.
- ALWAYS wear safety glasses and gloves when handling the glue.
- Be mindful of your team-mates. They may get injured by you handling the glue. Always point the nozzle away from people around you.

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- Keep your fingers well away from the blade at all times (at least the length of the blade).
- ALWAYS wear safety glasses when cutting.
- Make sure your team-mates are at safe distance (at least a metre) to prevent injuring them.
- Always cut in a direction away from your fingers.

3.) Testing

A mass of 1500 g will be used to apply a force on the beam may fall from the beam, potentially hurting your feet. This may cause serious injury or damage. To avoid this -

- Wear sturdy closed-type shoes. **You are not allowed to be in the class in thongs or similar shoes.**
- Keep your feet away from the potential falling path of the weights at all times.
- ALWAYS wear safety glasses when testing the system.

Guidelines for preparing your Project 2A Report

You are required to submit **Project 2A report on time. Final Design Report** on the final design and performance including your reflections (see below). Make sure that you record the details and performance of each beam including the other teams in your week 10 tutorial. **This project 2A report is worth 5% of the total mark for this subject.** You will **submit** this report as a word **file** through **Moodle**. **Make sure you complete the assignment cover sheet and give the name and student number of each team member. One student per team is to submit the report. That student will receive the feedback and must share it with other teammates.** All assignments that are required to be uploaded to the assignment link on ENGG102 Moodle Site **before 11:59 pm** on the day they are due. A link will be provided on moodle for submission.

Since you are submitting the report as a team, your team leader will take the responsibility of completing the cover sheet, uploading on moodle and collecting it back from Moodle.

The Project 2A Final Design and Reflection Report should contain the following -

1. Coversheet signed by each team member. You will need to write your tutors name.
2. Project 2A Assessment Marking Sheet with Team information include Team number and names, place, time and date of design exercise. Use the PDF version provided in Moodle. Please note if you are in a different team to the one you were in for the first attempt.
3. Title page and Contents page
4. Statement of purpose
5. Your prediction process, with appropriate FBDs and all calculations to develop a design to achieve the target deflection. Make sure you define the problem first.
6. Description of the beam design completed and should include alternative shapes considered and the reasons for selecting the final shape.
7. Results of all design calculations to predict the deflection of the beam.
8. Brief description of your beam, including a drawing with dimensions and volume of wood.

NOTE: Items 1 - 8 above plus Excel Design Spreadsheet.

9. Repeat your prediction process, with appropriate FBDs and all calculations to achieve the deflection.
10. Description of the designed beam done including modified drawing with dimensions and volume of wood needed.
11. Test results for your final designed beam and results for the rest of the teams found during week 10 including a comparison of results. (WHAT happened)
12. Reflection on process and outcomes including teamwork performance. (WHY it happened)
13. Conclusion
14. References
15. Appendices:
    - A: Minutes of team meetings and team on-line discussions.
    - B: Results
    - C: Excel Design Worksheet covering Beam AND design calculations

NOTE: Items 9-15 are to be included in the report

Your reflection might contain the following -

1. Consider your initial response to Beam design problem in reports of project 1A and 1B and how your new design calculations have helped you or hindered you in producing a new design. You should consider how you have generalised your method to allow you to rapidly produce a new design to meet new performance criteria. How could we generalise these approaches to allow us to tackle any new engineering design problem?
2. In your first attempt you may have had difficulties understanding how the cross section area and second moment of area affected the performance of beams. And, how all these factors affected the required of design of this cantilever beam. What were the most difficult parts of the calculations that took most time? How did you avoid this in any future beam design?
3. Reflection on the performance of your beam relative to the others. What things made some Teams perform better with respect to the deflection acheived? What improvements would you make if you were to repeat the design one more time? Did you adopt a conservative approach or try to push the envelope? Both are valid!
4. Compare how your team's understanding of beam design and beam behaviour has changed since the first attempt. Try to identify the relevant knowledge you gained during the last number of weeks. Are there still gaps in your understanding? What can you do about filling those gaps during your degree studies?
5. What did you learn from the relative performance of the beams?
6. Reflection on your team's performance in relation to the models of teamwork discussed in the e-reading by Smith or the reference text Engineering Your Future by Dowling et al. and the lecture in week 7.

Each team member should write an individual paragraph for this part of the reflection.

Keeping your reports

Each team is required to keep the original marked reports for all team activities in a Team folder. This may be requested at any time during the session for quality assurance and academic review. Copies of a sample of portfolios are required to be retained by the Faculty for Engineering Australia accreditation purposes.

Keep your personal portfolio up to date. It can be useful to show prospective employers examples of your work when applying for work experience. If you maintain an e-portfolio, you can give employers access to it electronically.

ENGG102 Project 2A – Final attempt – Design and Reflection report: Self Assessment sheet

Tutorial number:_____ Tutors name:_____

Team Number:_____ Date and time of exercise:_____

Names and ID Numbers: _____

_____

_____

Aspect	Comment	Mark
ENGG102 Project 2A Beam Design and Reflection Report: Assessment sheet.	**Minus 3 marks if this Assessment Sheet is not included with the Project 2A Design and Reflection Report. Use word version from Moodle**	
Appendix A: Minutes of Team Meetings (evidence of teamwork)	**Minus 5 marks if Minutes of Team Meetings (more than one!) are not included with this Report**	
Appendix C: Cantilever Beam Design Spreadsheet	**Minus 2 marks if Excel Design Worksheet not included with this Report.**	
Structure of report, team information etc (as per "what report should contain" above)	5.0 marks for including all items 3 - 13 (ie; nominal 0.5 marks per item). (see Report structure provided above)	/5
Overall Presentation	Neatness Spelling Grammar Diagrams Professionalism	/4
Problem definition	Define the problem. Identify concepts involved. What you are able to calculate and what you assumed.	/4
Analysis and calculations for **preliminary beam design** AND predictions for deflectiont.	Clearly present all calculations using the 6-step method. Include all appropriate FBDs with calculations to predict the beam deflection	/10
Reasons for design of **preliminary beam.** Description of 500 mm beam with drawing/sketches and dimensions	Describe the principle behind the design. Accurate line drawings with all important dimensions (should enable tutor to build the same structure)	/8
Redesign calculations done covering predicted deflection	Demonstrates the generic nature of the theory and model. Can be a modified and simplified version of original preliminary 500mm design calculations including appropriate FBDs to predict the beam deflection	/8
Description of **re-designed beam** with drawing/sketches dimensions	Describe the principle behind the design. Accurate line drawings with all important dimensions (should enable tutor to build the same structure)	/5
Results of final designs and testing including comparison with other team(s)	Table of all results. Commentary on table and main factual findings. Describe main failure mechanisms and performance achievements. Include a comparison of results and identify the best designs.	/10
Reflections – identified WHY for performance (yours and other teams). Considered the various aspects of the task (problem definition, effect of design, FBD's, calculations, beam fabrication, material use), discussed how might be improved, what knowledge might be needed..	<u>To achieve top marks(30-36/36):</u> Your report must demonstrate clear and insightful reflection considering own solution and others in the class. Demonstrates further reading and critical analysis. Considers methods to optimise design. <u>To achieve 20-30/36:</u> Your report must describe the performances of your solution and some others. Itemisation of knowledge gaps and some critique of designs <u>To achieve 0-19/36:</u> Describes own solution with limited reference to other beams. Adopts a poor design.	/36
Teamwork reflection in report: <u>Include at least one paragraph</u> from each team member.	Identifies models of teams e.g. from Smith (see e-reading) Compares own team with recognised models. Demonstrates awareness of how to perform better as a team.	/5
Conclusion	1 or 2 paragraphs that draws appropriate conclusions from evidence presented in report.	/5
Total		/100