UNIVERSITY OF WOLLONGONG IN DUBAI

Laboratory Session 6 & 7:

Project 2A – Cantilever Beam Design

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Student Submitting			x	

Subject number and name:	ENGG102 - Fundamentals of Engineering Mechanics
Subject coordinator:	Dr. Umar Asghar
Title of Assignment:	Project 2A - Cantilever Beam Design
Date and time due:	29-02-2024, 23:59:59
Lab Number:	1.53
Tutor Name:	Mr. Ahmed Mohamed
Total number of pages:	14

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 (i.e., 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 can calculate and what you assumed	/4
Analysis and calculations for preliminary beam design AND predictions for deflection	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	To achieve top marks (30-36/36): Your report must demonstrate clear and insightful reflection considering your own solution and others in the class. Demonstrates further reading and critical analysis. Considers methods to optimize design. To achieve 20-30/36: Your report must describe the performance of your solution and some others. Itemization of knowledge gaps and some critique of designs to achieve 0-19/36: Describes own solution with limited reference to other beams. Adopts a poor design	/36
Teamwork reflection in report: Include at least one paragraph from each team member	Identifies models of teams e.g., from Smith (see e-reading) Compares own team with recognized models. Demonstrates awareness of how to perform better as a team	/5
Conclusion	1 or 2 paragraphs that draw appropriate conclusions from evidence presented in the report.	/5
Total		/100

Table of Contents

Statement of Purpose

The main purpose of this report is to design a cantilever beam made of balsa wood that can support a hanging mass of 1.5kg at a 500mm span. The design will be based on the computed values of cross-sectional area, second moment of area, Young's modulus, and maximum stress. The goal of the lab is to ensure that the chosen design adheres to specified deflection, length, and height requirements. The beam dimensions were found using trial and error techniques after finding the specific computational values. The beam must deflect within the given range, which is between 2 and 9 mm. Additionally, the maximum allowed height and width for the beam are 30 mm and 50 mm, respectively. Other restrictions include having a total length between 585 mm and 590 mm.

To sum up the ideas of the lab session, the theoretical values will be compared with the experimental outcomes obtained from testing the selected beam design. This comparison aims to evaluate the practicality of mathematical projections in real-world applications, offering crucial insights into the reliability of performance beam operations. While both the unequal flange and the T beam function as per the specifications, detailed analysis and mathematical computations concluded that the T beam is the best option. The lab provided insights into engineering decision-making, showcased problem-solving skills, and fostered collaboration in tackling intricate structural issues.

Preliminary Prediction Process

A free-body diagram for the preliminary design would be like in Figure 1.

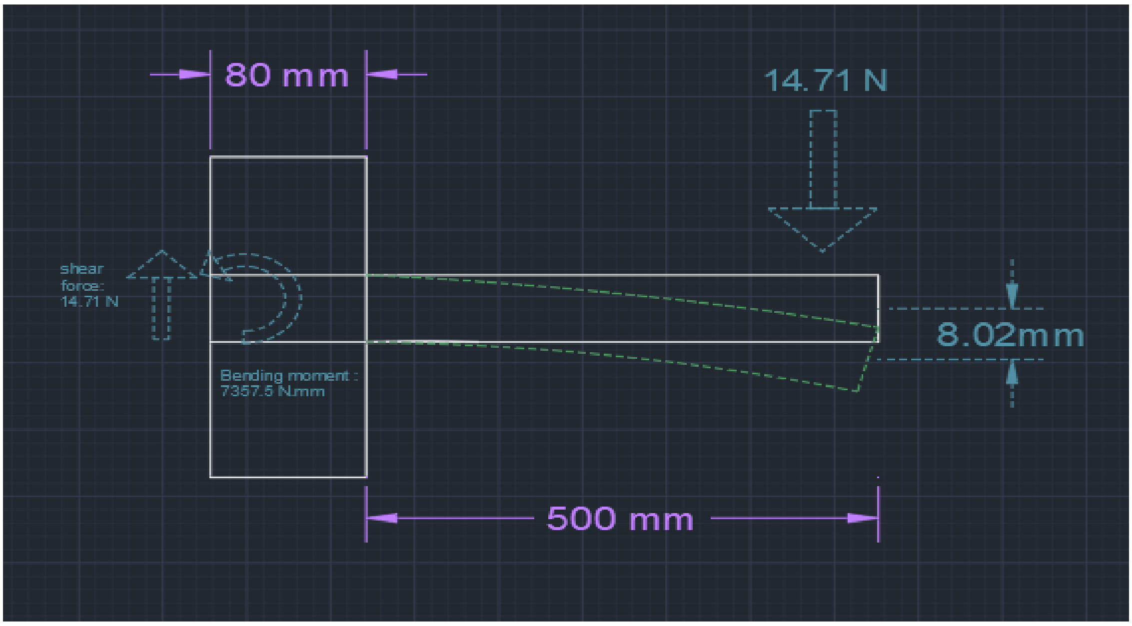

Figure 1: Free Body Diagram be of Preliminary Beam

This involves the external load applied downwards due to the hanging mass and the reaction forces opposite in direction acted by the fixed support (bending moment and shear force) that would resist bending. There is no reaction force on the x-axis as there are no axial forces applied.

Bending moment:

$$500 \times -14.715 = -7357.5\ N.mm\ (clockwise)$$

Preliminary Design Selection

When deciding on the best cross-sectional shape for the beam, the two options available were carefully examined: the unequal flange I beam and the T beam. After much debate, it was decided that a T beam would be better suited rather than the unequal flange I beam for a variety of convincing reasons. Taking these factors into account, the T beam proved to be superior to its substitute, the unequal flange I beam, in terms of volume requirements, ease of fabrication, and lower computational complexity in structural analysis.

The selected T beam configuration had a flange base measuring 30mm and a web base measuring 20mm. Additionally, both the flange and web heights were 15mm, thus maximizing the permissible height. It was determined that this arrangement would meet the project's structural needs while maximizing material utilization and production effectiveness.

After the design was complete, important structural factors were examined to guarantee the performance and dependability of the beam. The T beam's calculated area moment of inertia was 54,562.5mm^4, indicating resistance to bending forces. Furthermore, the computed deflection of the beam was 8.02mm, which is within the permissible range given by the design criteria.

Furthermore, the T beam encountered a maximum bending moment of -7357.5 N.mm, demonstrating its ability to tolerate considerable external stresses. In addition, the greatest stress magnitude detected within the beam was 2.023 MPa, demonstrating structural integrity under operational conditions.

Preliminary Design Calculations

PRELIMINARY													
	A	B						A	B				
Center	7.5	7.5					b	30	20	mm			
b	30	20	mm				h	15	15	mm			
h	15	15	mm	Total (H)	30		I	8437.5	5625	mm4	Total(I)	14062.5	mm4
Area	450	300	mm2	Total (A)	750	mm2	D from centroid	6	-9	mm			
Distance from reference (y)	22.5	7.5	mm				d^2	36	81	mm2			
Ay	10125	2250	mm3	Total(Ay)	12375	mm3	A x D^2	16200	24300	mm4	Total (AD^2)	40500	mm4
				Centroid	16.5	mm					Final I	54562.5	mm4
P	14.715	N		Deflection	8.026509573	mm							
L	500	mm		Max Bending Moment	-7357.5	N.mm							
E	1400	MPa		Max Stress	-2.022680412	MPa							

Table 1: Preliminary Design Results for Deflection, Maximum Bending Moment, and Maximum Stress

Preliminary Beam Description

To attain the desired structural integrity, the T beam must be carefully designed in terms of materials and dimensions. To start with, the beam should meet the criteria set. For this beam, the maximum height was set at 30mm, the maximum width was set at 75mm. The length was required to be between 585mm and 590mm. Deflection had to be between 2mm and 9mm.

In this scenario, the construction plan requires balsa wood with certain dimensions. The T beam's flange will be made from a big balsa sheet measuring 100 x 5 x 910mm. To obtain the desired 15mm height, the sheet will be cut into three strips of 30 x 5 x 590mm and layered on top of one another.

The beam's web will be made of two balsa wood rods measuring 10 x 10 x 1000mm each. These rods will be cut to a length of 590mm and then glued together to make a 20mm base.

In order to increase the web's height to 15mm, two sections measuring 10 x 5 x 590mm will be sliced from the large balsa sheet and glued beneath the 10 x 10mm rods.

Using this configuration, the T beam will have a cross-sectional area of 750mm^2 and a volume of 375,000mm^3. This fabrication procedure guarantees that the beam meets the prescribed dimensions and structural criteria while maximizing material efficiency.

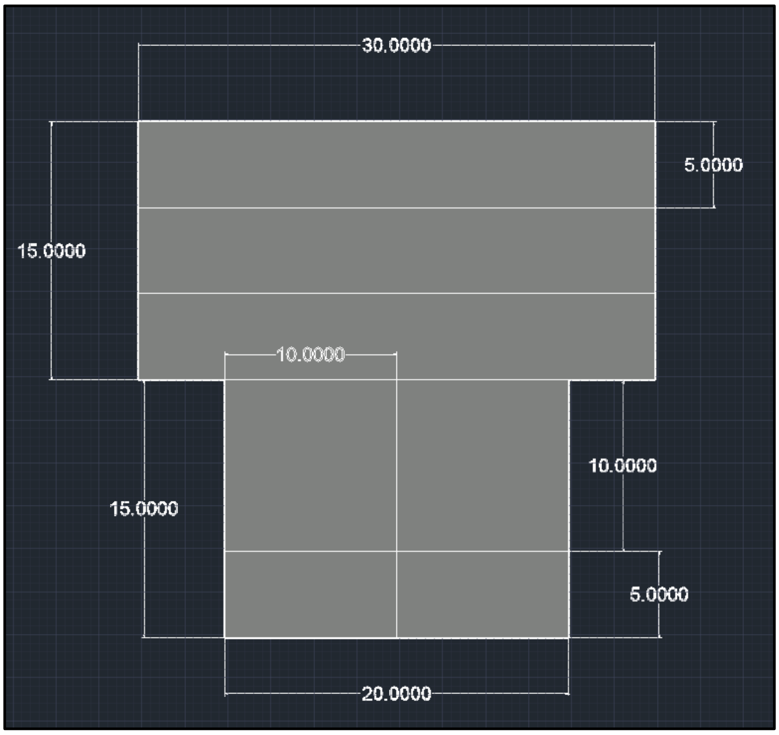

Figure 2: Cross-sectional view of Preliminary Beam

Optimized Beam Predictions

The free body diagram of the optimal beam is expected to have similar parameters for internal and external forces compared to the preliminary design, as the cross-sectional area is not considered in the diagram. However, different dimensions would correspond to different deflection expectations.

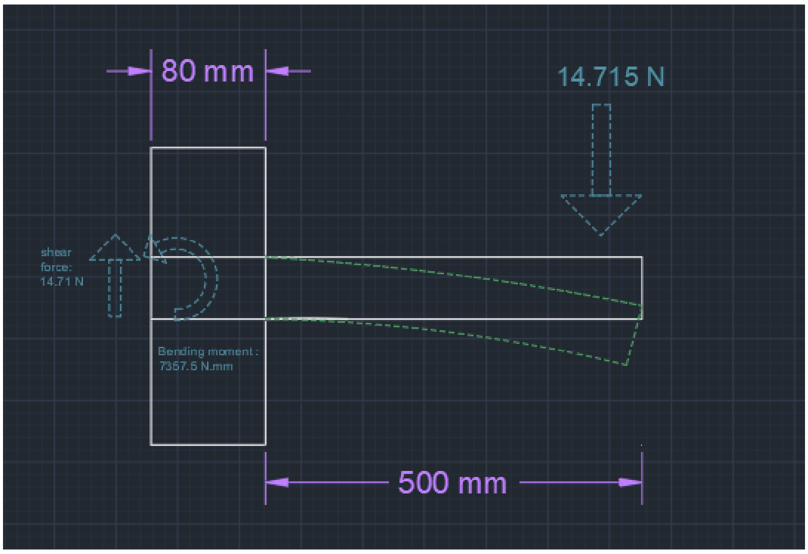

Figure 3: Free Body Diagram of Optimized Beam

Theoretically:

$$\delta = \frac{PL^3}{3EI}$$

$$P = 1.5 \times 9.81 = 14.715\ N$$

$$L = 500\ mm$$

$$E = 1400\ MPa$$

$$I = 50476.19\ mm^4$$

$$\Rightarrow \delta = \frac{14.715 \times 500^3}{3 \times 1400 \times 50476.19} = 8.676\ mm$$

The optimization of the beam has reduced the cross-sectional area from 750 mm^2 to 700 mm^2. This decrease in cross-sectional area also translates to a lower volume requirement, from 442,500 mm^3 to 413,000 mm^3. This means that the beam is easier to fabricate and is also more sustainable than the preliminary beam. Additionally, the decrease in cross-sectional area has also decreased the area moment of inertia. Despite the increase in the theoretical deflection, the beam still meets the deflection criteria set, which states that the deflection must be within 2mm and 9mm.

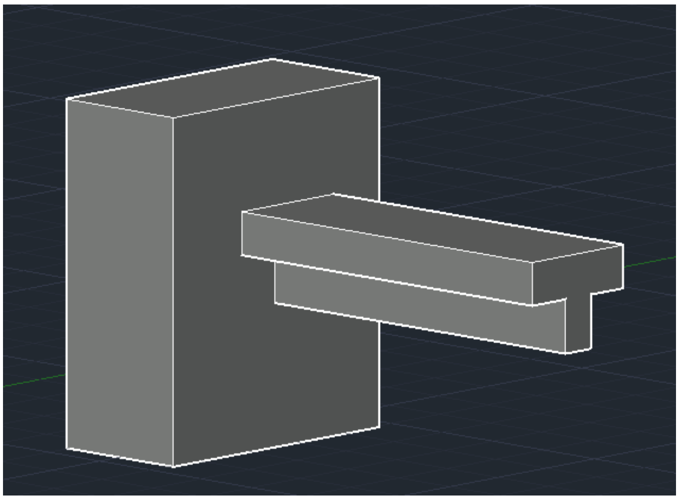

Figure 4: 3-D view of the cantilever (T-beam, fixed support)

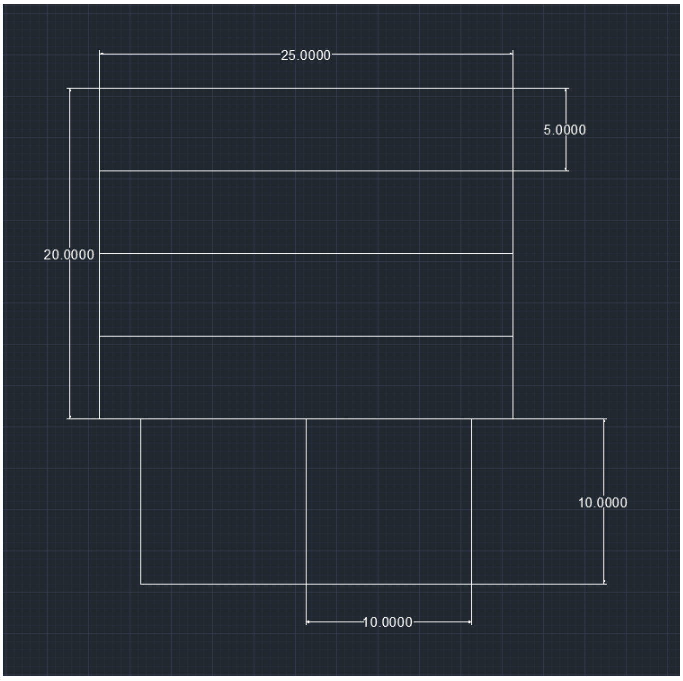

Figure 5: Cross-sectional view of optimized beam

Figure 6: Cross-sectional view of fabricated beam

Optimized Beam Description

Optimized Dimensions

The optimized beam is a T-shaped section with a 25mm wide base flange, a 20 mm wide base web, and a total height of 30 mm made from a 20mm flange height and a 10mm web height. These dimensions are consistent across the entire 590mm length of the beam. The total cross-sectional area of the beam is 700 mm^2, and total volume of the beam is 413,000mm^3.

Optimization Calculations

OPTIMIZED													
	A	B						A	B				
Center	10	5					b	25	20	mm			
b	25	20	mm				h	20	10	mm			
h	20	10	mm	Total (H)	30		I	16666.66667	1666.666667	mm4	Total(I)	18333.33333	mm4
Area	500	200	mm2	Total (A)	700	mm2	D from centroid	4.285714286	-10.71428571	mm			
Distance from reference (y)	20	5	mm				d^2	18.36734694	114.7959184	mm2			
Ay	10000	1000	mm3	Total(Ay)	11000	mm3	A x D^2	9183.673469	22959.18367	mm4	Total (AD^2)	32142.85714	mm4
				Centroid	15.71428571	mm					Final I	50476.19048	mm4
P	14.715	N		Deflection	8.67629717	mm							
L	500	mm		Max Bending Moment	-7357.5	N.mm							
E	1400	MPa		Max Stress	-2.186426887	MPa							

Table 2: Optimized Design Results for Deflection, Maximum Bending Moment, and Maximum Stress

Fabrication Parts

The parts were fabricated from a large balsa sheet measuring 100 x 5mm with a length of 910mm and two 10 x 10mm balsa rods, each 1000mm long. The final dimensions are as follows: all segments of the beam share a length of 590mm. The 10mm x 10mm rods were cut down to length with a saw, and the sheet was sawed into four equal 5mm x 25mm pieces. This resulted in two 590mm long, 10 x 10mm pieces and four 5 x 25mm pieces.

Fabrication Process

Assembly of the first beam: Take the four 5mm x 25mm x 590mm sheets and glue them together directly on top of each other using a hot glue gun. This creates a section with dimensions 20mm x 25mm x 590mm.

Assembly of the second beam: Glue the two 10mm x 10mm x 590mm rods side-by-side using a hot glue gun. This forms a section with dimensions 10mm x 20mm x 590mm.

Attachment of the first and second beams: Draw a line across the center of the wider (25mm) face of the first section (20mm x 25mm x 590mm). Use this line as a guide to position the second section (10mm x 20mm x 590mm) with its 20mm face centered on the marked line on the first section. This produces the final T beam with the dimensions above.

Results

Team	Type	Reflection	Met Criteria	Area (mm^2)	Fabrication effort
1	T-Beam	>10mm	No	650	High
2	T-Beam	>10mm	No	700	High
3	T-Beam	>10mm	No	600	High
4	T-Beam	>10mm	No	700	High
5	T-Beam	>10mm	No	300	Medium
6	T-Beam	>10mm	No	300	Medium

Test Results and Comparison

Team's Results

The designed beam did not meet the required deflection range (2mm to 9mm) as the experimental deflection was higher than the theoretically predicted value. This shows the importance of combining both theoretical analysis and real-world testing to examine external factors that may affect results beforehand.

Comparison with Other Teams

All six teams used **T-beams**. None of the beams met the required deflection criteria. There is a correlation between fabrication effort and cross-sectional area of beams, where the larger the area, the higher the effort of fabrication.

Possible Factors of Failure

Adding more glue and increasing the cross-sectional area could have improved the beam's stiffness and deflection performance. From the previous labs, where criteria may have not been met potentially from the excessive use of hot glue, less glue was used in hopes of meeting deflection. This resulted in over deflection as the experiment's requirements did not match that of the previous one.

Fabrication imperfections may have caused the deflection to exceed, as some pieces were not precisely cut during fabrication or may have been damaged by the hot glue gun, which in turn decreases the experimental cross-sectional area. An example of this can be seen in the bottom left rod of the web in Figure 6, where the cross-section shows a diagonal fracture.

Another factor could be the value of the **Young's Modulus** provided to calculate the theoretical value of deflection. Research shows that the approximate Young's Modulus for balsa wood is around 3 GPa [1], whereas the Young's Modulus used for theoretical calculations was 1.4 GPa.

Other factors can include testing conditions, human error, and issues within material itself, where moisture or manufacturing conditions may have affected the Young's Modulus value used for the theoretical calculations.

Reflection

Generalizing Beam Design

The approach to Project 1A and 1B to 2A changed significantly from initial assumptions and methodologies to more accurate calculations and decision-making. Accurate computations of cross-sectional area, second moment of inertia, and deflection helped narrow options and theoretically predict performance, enabling informed decisions. However, experimental deflection did not follow expectations, indicating the need for experimental testing and verification in real life. Teams can enhance design processes by incorporating test and verification activities like prototyping and physical testing, resulting in more reliable designs. This involves a systematic methodology and fundamental engineering principles.

Learning Outcomes

The evolution of beam design principles and conceptual approach from Lab 1A and 1B to Lab 2A involves fundamental parameters and testing. Area and second moment of area along the beam determine the beam capacity in carrying a load in a cantilever, while endurance to load and resistance to bending are determined by boundary conditions and load distribution. These factors significantly influence the cantilever beam's efficiency and resistance to bending, ensuring the structure's integrity. A balance between theoretical calculations and practical restrictions was necessary for optimal dimensions, material distribution, and minimizing bending stress. Future challenges in beam design include using computational tools for analysis and optimization, standardizing procedures, incorporating empirical data, and collaborating across disciplines to streamline the process and ensure efficient designs meet performance criteria.

Comparative Analysis of Beams

When the produced beam's performance was compared to that of other teams, all six groups constructed T beams, but none of them succeeded in meeting the required deflection (2mm to 9mm). The main cause of performance differences was mainly due to the variation in the cross-sectional area of the beams. Although the group was cautious with its design for the 700 mm^2 beam, it failed to fulfill the experimental deflection requirements, even though it had satisfied theoretical requirements and was built based on careful computations before fabrication. If given the chance to redo the design, the team would increase the beam's structural support by increasing the cross-sectional area of the beam and adding more glue to the beam. This would add more stiffness to the beam, thereby reaching the required deflection criteria. This demonstrates how crucial it is for design projects to combine theoretical analysis with real-world testing.

Understanding of Beam Designs

The team has made significant progress in understanding beam design and behavior, overcoming challenges in understanding factors like cross-sectional area and second moment of area. strong skills were developed in structural analysis techniques and design optimization modifications. By utilizing data from experiments and computing techniques, the team has ascertained material behavior and structural performance, enabling spatial decision-making and iterative design processes. However, there are still some gaps in the knowledge gained, particularly in complex aspects of structural engineering and beam behavior. To bridge these gaps, the team plans to participate in internships and research experiences, providing practicality in solving real-life engineering problems.

Relative Beam Performance

Based on the relative performance of the beams, it is evident that the choice of beam shape and load distribution plays a major role in the efficiency and efficiency of the beams. The results demonstrated the inequalities between teams as each of them was using a different form of optimization and manufacturing technique. It can be observed with the change in beam volume relationships – this demonstrates the great significance of design and plans to optimize the use of materials while still meeting the project's demanded performance. Finally, the beams' overall relative performances reaffirm the crucial impact of the selected design decisions, manufacturing technique, and material choice in attaining a purpose-driven structural system.

Teamwork Evaluation

Ahmed: Looking back, our team's communication was a strong point. We set clear goals and kept each other updated throughout. Compared to Lab 1B, task allocation and conflict resolution improved, leading to increased efficiency. However, reflecting on the points we discussed in class, I would like to further explore how we can actively listen to each other's perspectives and identify potential areas to further enhance our collaborative flow. All in all, the task was completed efficiently within the time limit and without missing key points.

Karam: With each successive lab session, our team continues to demonstrate noticeable advancement in our collective capacity to tackle intricate design challenges. Effective communication has emerged as the bedrock of our collaborative efforts, enabling coordinated strategizing and planning during the preparatory stages of every lab. By thoughtfully considering the unique talents and preferences of each member, we are able to efficiently allocate responsibilities in a manner that plays to individual strengths while upholding shared accountability. This thoughtful approach to task distribution has empowered our team to achieve an admirable integration of skill sets, allowing us to produce comprehensive solutions that would likely overwhelm any single member.

Razan: Through our team's performance in Lab 2A, I would pinpoint adaptability as our greatest strength. Through our prompt use of calculations and testing, we were able to rapidly adjust our design strategies, therefore we overcame difficult situations and improved our beam designs more efficiently. Communication was also a vital part of it: we had our goals set and we were always in the loop which helped us with task delegation and conflict resolution a lot more than before. Even then, there is space for our own mistakes in the form of active listening to different perspectives that we covered in class. We accomplished everything we had set our minds to within the specified time frame, and we didn't leave out any critical details.

Taha: When I review our performance, I notice striking resemblances to teamwork ideals from the course materials. Our communication stood out: we established clear targets and offered regular updates. Mutual respect allowed each member to leverage their particular talents for efficient collaboration. In comparison to Lab 1B, improved efficiency was achieved through better task allocation and dispute resolution procedures, and I endorse the continuation of this dynamic. Our combination of individual commitment and collaborative group work toward common goals generates confidence in future endeavors.

Conclusion

In Lab 2A, the focus was on the beam design, where the main topics were principles and testing experiments. Beam actions and measures of performance were calculated, resulting in optimized designs for them. The approach was improving along the way through standardizations methodology, but in the end, challenges were still encountered. Teamwork and cooperation within the group supported overcoming these difficulties. The main objective is the research and application of new ideas in present engineering techniques that help in dealing with future problems. On the other hand, it is also essential to demonstrate that putting the results of the theoretical analysis through practical testing will not only validate the analyses but also guarantee the reliability of the design solutions (During the project, there was a significant issue with obtaining theoretically valid data that was not experimentally accurate). Further, highlighting the repetitive aspect of the design process and the data borrowed from the analysis can be a big boost to the effectiveness of structural engineering initiatives. Focusing on interdisciplinary collaboration and adaptability, implementing scalable and effective approaches was mandatory to facilitate technological progress and make engineering more robust, leading to a better field development.

References

[1] "(PDF) A review of factors that affect the static Load-Bearing Capacity of Urban trees," ResearchGate, Jan. 01, 2014. Available: https://www.researchgate.net/publication/317215849_A_review_of_factors_that_affect_the_static_load-_bearing_capacity_of_urban_trees

Appendix

Appendix A: Minutes of team meetings

Meeting 1

Date: 20.02.2024

Time: 17:00 – 18:00

Purpose: Discuss roles of each member for upcoming Lab 2A and possible dimensions for fabrication of the beam

Tasks Done:

- Distribute sections of the reports.
- Switch word processing software.
- Redo document style from ground up.

Attendance

Member	Present	Late	Absent
Ahmed I.	x		
Mohamad Karam	x		
Razan A.	x		
Taha Parker	x		

Follow up: Majority of tasks been completed without any issues occurring after switching the documents style.

Meeting 2

Date: 26.02.2024

Time: 17:00 – 18:00

Purpose: Reviewing and proof-reading report to meet assessment sheet requirements. Additionally, adding the finishing touches such as pictures or diagrams.

Tasks Done:

- Proofreading the report.
- Give feedback on various parts of the report.
- Recheck whether all parts have met the assessment sheet guidelines.

Attendance

Member	Present	Late	Absent
Ahmed I.	x		
Mohamad Karam	x		
Razan A.	x		
Taha Parker	x		

Follow up: Pictures have been placed where they are most appropriate.

Team Rules:

- Come to class and team meetings on time with assignments and other necessary preparations done.
- Respect one another.
- Help each other when the need arises and participate equally.
- Communicate through designated channels.
- Maintain a consistent format for fonts and writing style.
- Commit to timeline and submit within deadline.
- Give constructive feedback and assist fellow members.
- Record references used and where they are used.
- Follow safety rules and wear gloves whilst using equipment.

Appendix B: Excel Design Worksheet

PRELIMINARY													
	A	B						A	B				
Center	7.5	7.5					**b**	30	20	mm			
b	30	20	mm				**h**	15	15	mm			
h	15	15	mm	**Total (H)**	30		**I**	8437.5	5625	mm4	**Total(I)**	14062.5	mm4
Area	450	300	mm2	**Total (A)**	750	mm2	**D from centroid**	6	-9	mm			
Distance from reference (y)	22.5	7.5	mm				**d^2**	36	81	mm2			
Ay	10125	2250	mm3	**Total(Ay)**	12375	mm3	**A x D^2**	16200	24300	mm4	**Total (AD^2)**	40500	mm4
				Centroid	16.5	mm					**Final I**	54562.5	mm4
P	14.715	N		**Deflection**	8.026509573	mm							
L	500	mm		**Max Bending Moment**	-7357.5	N.mm							
E	1400	MPa		**Max Stress**	-2.022680412	MPa							

Table 1: Preliminary Design Results for Deflection, Maximum Bending Moment, and Maximum Stress

OPTIMIZED													
	A	B						A	B				
Center	10	5					**b**	25	20	mm			
b	25	20	mm				**h**	20	10	mm			
h	20	10	mm	**Total (H)**	30		**I**	16666.66667	1666.666667	mm4	**Total(I)**	18333.33333	mm4
Area	500	200	mm2	**Total (A)**	700	mm2	**D from centroid**	4.285714286	-10.71428571	mm			
Distance from reference (y)	20	5	mm				**d^2**	18.36734694	114.7959184	mm2			
Ay	10000	1000	mm3	**Total(Ay)**	11000	mm3	**A x D^2**	9183.673469	22959.18367	mm4	**Total (AD^2)**	32142.85714	mm4
				Centroid	15.71428571	mm					**Final I**	50476.19048	mm4
P	14.715	N		**Deflection**	8.67629717	mm							
L	500	mm		**Max Bending Moment**	-7357.5	N.mm							
E	1400	MPa		**Max Stress**	-2.186426887	MPa							

Table 2: Optimized Design Results for Deflection, Maximum Bending Moment, and Maximum Stress