Project 1B Report

Fundamentals of Engineering (University of Wollongong)

FACULTY OF ENGINEERING & INFORMATION SCIENCES | UNIVERSITY OF WOLLONGONG

ENGG102 Project 1B

Load-Bearing Beam Redesign

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Statement of Purpose:

The purpose of this report is to explain both planning of the design of Team G's balsa beam and the revised design of the beam. The report will identify flaws of the design and improvements which can be made for future designs. The report will also indicate the calculations and engineering theory used to develop the 1B design.

Description of preliminary beam:

The pieces we are given to work with are:

- 1 balsa sheet 1.5x75x900mm

A maximum of 8 of the following pieces:

- 6.5x6.5mm max 4
- 5x5mm max 4
- 3x3mm max 8

<u>Possible beam designs:</u>

I Beam:

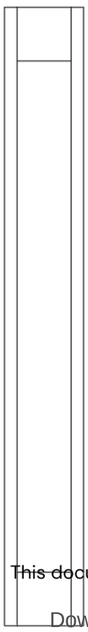
The I-beam has a thin central column with 4 protrusions, 2 at the top and 2 on the bottom such that it looks like the shape of the capital I letter. This type of beam works well because the I shape provides a stable base and a high ability to resist deflection, all while minimising volume and therefore increasing sustainability. *(Fig 1.1)*

Box Beam:

The box beam has two thin columns conjoined at the top and bottom by square beams, creating a rectangular shape with a void in the centre. This beam works well to resist deflections but using two columns is not as material efficient as doubling volume does not double the deflection resistance. *(Fig 1.2)*

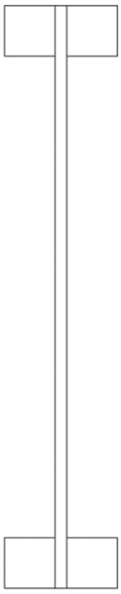
Channel Beam:

The channel beam or c-beam is similar to the I-beam, except that it does not have protrusions on one side of the beam. While this reduction improves material cost, it suffers in deflection resistance. The change also moves the centre of weight of the beam to a point outside of the beam, making it more unstable. *(Fig 1.3)*



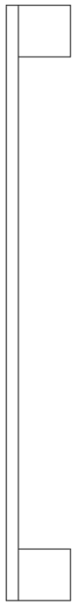
Double Box Beam:

The double box beam is similar to the box beam, except that the void in the centre of the beam contains another connection between the two columns. While this addition adds to the overall structural integrity of the beam, it increases the material footprint required to create it, and reduces the sustainability. *(Fig 1.4)*

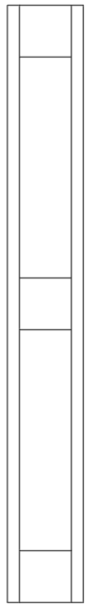


1.1

1.2



1.3



1.4

The final shape used will be the I-beam, since it is the most stable for the material cost, keeping the final beam sustainable and able to meet the requirements.

Results of preliminary design calculations:

I Section beam

Maximum bending moment = $\frac{pl}{4}$

p=24.5N

l=700mm

Max bending= 4287.5

$$I = \frac{bh^3 - (b - t_w)d^3}{12}$$

b=16mm
h=37.5mm
t_w=3mm
d=24.5mm

I=3038.91667

$$\delta = \frac{pl^3}{48EI}$$

P=24.5N
L=700

I=3038.91667

E=3GPa

$\delta = ¿$ 19.2

$$\sigma_{max} = \frac{(Maximum\, bend\, moment)\, h}{2I}$$

Maximum bend moment = 4287.5

h= 37.5mm

I=3038.91667

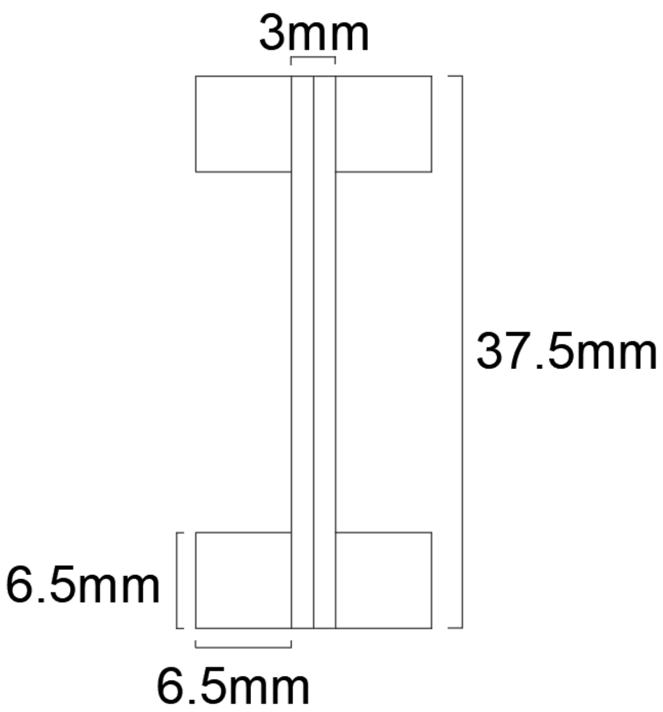
$\sigma_{max} = 26.45\ MPa$

Dimensions of preliminary beam:

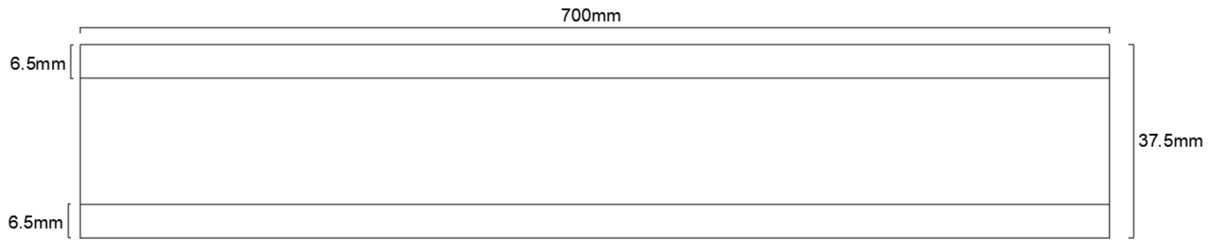
With the selected design being the I-beam, and using the given pieces of balsa wood, designing a beam and calculating its ability to deflect is simple.

Dimensions:
Since the maximum height is 75mm, and the width of the balsa wood is 75mm, it seems easy to use that as the column in the I-beam shape, but to prevent buckling of the 1.5mm thin beam, the team has decided to halve the beam to have a thickness of 3mm and a width of 37.5mm.
The length of the piece is 900mm, but the span is only 600mm. Therefore, in the name of material efficiency we can reduce the length to 700mm, to allow for a 50mm support on either side. This reduces the total volume by 22500mm^3. The total required volume for this beam is 37.5x3x700mm + 6.5x6.5x700x4mm = 197050mm^3.

Cross Section (not to scale):



Side view (not to scale):



Redesign in tutorial:

The new parameters for the beam to endure were:

- 640mm distance between supports
- 3kg weight at midpoint of beam

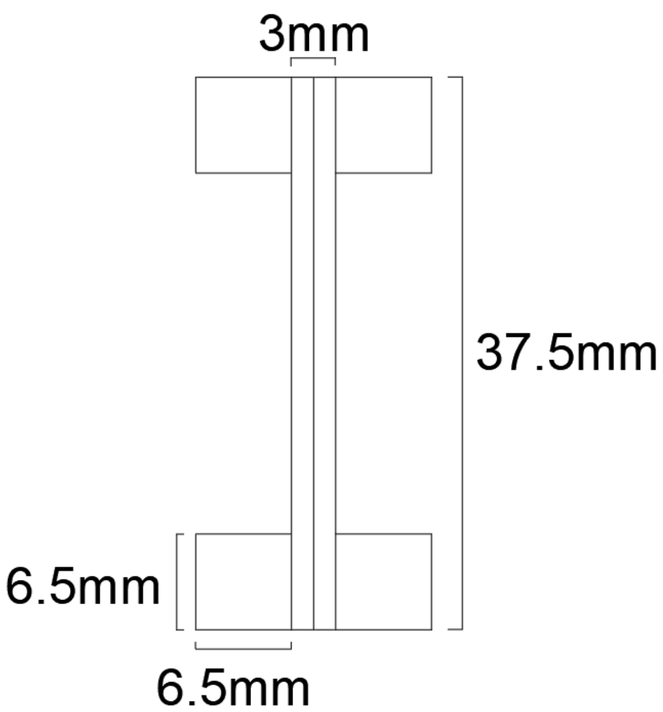
With these new parameters the predicted deflection is approximately 1mm, but since this is the deflection in the ideal case, it is safe to say the real deflection will be greater than 1mm and enter the range of 2mm to 5.5mm.

Therefore, the group decided to not make any design changes to the beam and kept all the dimensions of the preliminary beam the same apart from the length of the beam.

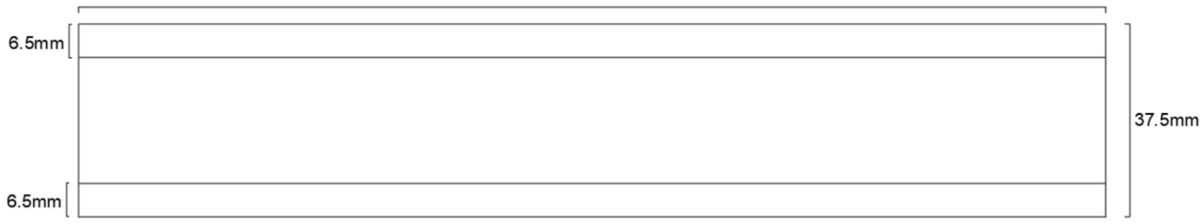
Since the wood came with a length of 900mm, and only the length over the supports with a small amount of overhang was necessary, the beam could be shortened in the interest of sustainability. The team did not make these offcuts because they would end up in the bin anyway and would not be used again. Because of this, it was decided that the beam was better intact since it required less construction effort.

Final design:

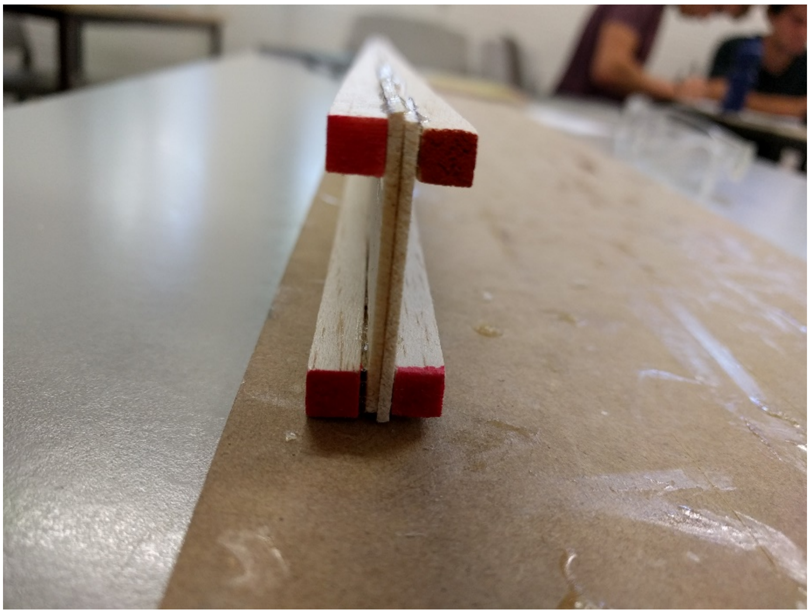
Cross section (not to scale):



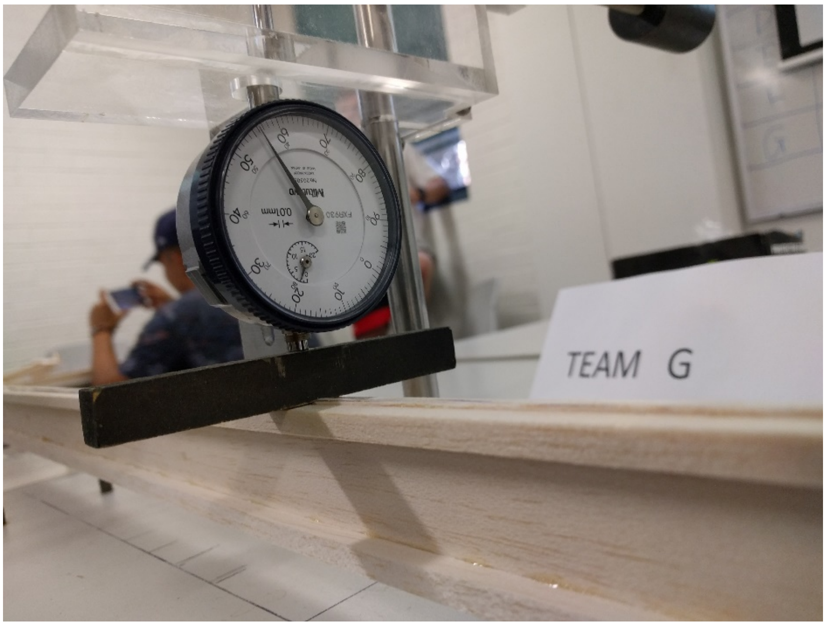
Side view (not to scale):



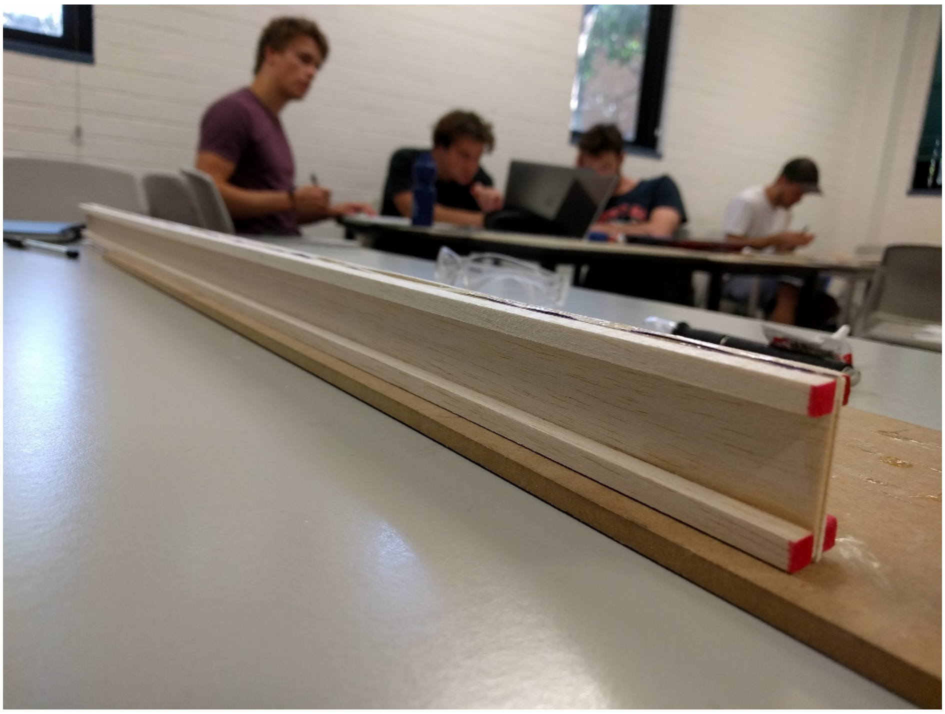
Cross-section:



Under load:



Beam:



Dimensions:

The centre of the I-beam is made from the 75x1.5x900mm sheet, cut in half lengthways and glued to itself, creating a 37.5x3x900mm block. Each corner of this block has a 6.5x6.5x900mm piece glued to it to create the shape of the I-beam. The total structure is 37.5mm tall, 16mm wide and 900mm long with 24.5x6.5mm voids on either side.

The volume of wood required for this beam is:

37.5x16x900mm-2x 24.5x6.5x900mm

$=253350mm^3$

This volume could be reduced with length to provide the same deflection.

Results:

Team	Beam type	Calculated deflection(mm)	Measured deflection(mm)	Met criteria	Materials used (mm) all materials are made of balsa	Volume (mm^3)	Fabrication	comments
A	I	2.83	10	No	4x(5x5x650) lengths 4x(6.5x6.5x650) square lengths 1x(5x75x680) sheet	95440	Medium	Not enough supports
B	I	1.04	0.2	No	1x(1.5x75x680) sheet 4x(5x5x680) square lengths	144500	Low	Was significantly stiffer than G despite same design with thinner lengths
C	I	2.8-3.4	3.4	Yes	2x(1.5x28x680) sheet 4x(5x5x680) square lengths	90820	Low	Beam worked as calculated and kept volume low
D	Double box	2.5	5.6	No	3x(5x5x700) square lengths 2x(1.5x30x700) sheet	93150	Medium	Didn't test range of values for Yong's modulus in calculations
E	I	1.0	1.9	No	1x(1.5x75x900) sheet 4x(6.5x6.5x900) square lengths	197050	Medium	Allow too much error resulted in enough deflection
F	I	1.2	2.56	Yes	4x(6.5x6.5x900) square lengths 4x(5x5x900) square lengths	242100	Low	N/A
G	I	1.0	2.55	Yes	1x(1.5x75x900) sheet 4x6.5x6.5x900) square lengths	25350	Medium	Calculated deflection is never right

Comparison:

Team G was able to successfully meet the criteria as well with teams C and F. Every team chose the I section beam apart from team D who used a double box approach. Relative to the other teams, team G had the highest volume. If there was further attempts on this project, team G would aim for a lower volume in order to conserve materials used. Fabrication ranged between low-medium in this project. Measured deflections ranged between 0.2mm and 10mm. Every teams' measured deflection was greater than the calculated deflection apart from team B which was 0.8mm lower than its calculated value. Team B also had an identical design to team G except team B used thinner selections yet had a much lower deflection than team G which was an anomaly. Team C had the most efficient beam as they had the lowest volume of all teams and still met the criteria. Although team G met the criteria in this attempt improvements cans till be made to the volume.

Reflection:

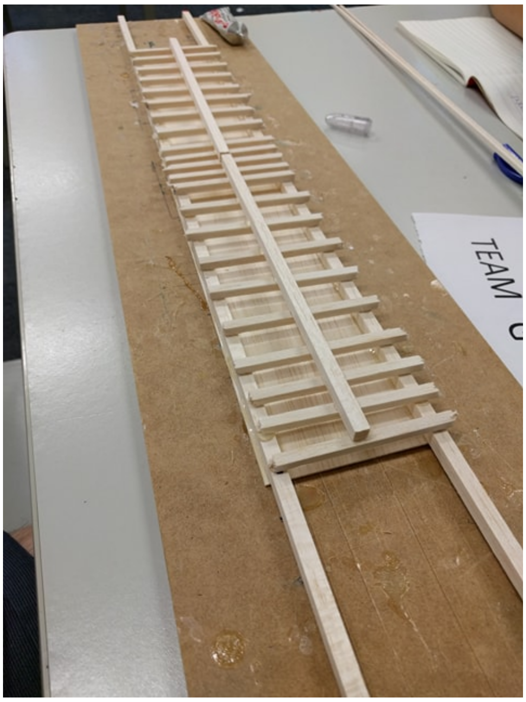
The team's initial response to the 400mm problem was to create a bridge-like structure based loosely on what can be seen around the world and attempt to emulate the design of these large structures by miniaturising the basic shapes involved. Also, with basic and non-mathematical ideas about how the beam's deflection could be predicted, it was assumed that the structure could withstand the force. This was of course, not the case.

For the second attempt, the team had learned the mathematics behind a single point load in the midpoint of a beam and were able to apply that knowledge to the design of the beam. Since the mathematics for calculating the second moment of area, a main factor in predicting deflection, required a cross-sectional area, it would make the mathematics simpler if the beam had a uniform cross-section along its entire length. It was partly for this reason the team chose to use an I-beam for the second attempt.

Using a generalised shape like an I-beam makes it easier to tackle new engineering problems since it is easily reproduced, the calculations are simple, and the structure itself is a sturdy shape.

The first attempt proved to be a struggle since the team needed to divide a long piece into 23 equally sized small pieces, which was difficult since the cutting tool was not sharp enough to make a clean cut and the wood was easily compressed rather than sliced, leaving the ends of the pieces frayed and uneven. Gluing these individual pieces was also a challenge since they slightly rested on two long rails, meaning they only had a small dab of glue to hold them in place, and under time pressure some pieces were not fully attached by the time the beam was tested, either by not being dry or by not having enough glue.

First attempt:



In the second attempt the team wanted to negate things like this and minimise the number of cuts needed to create the structure. Also, with the parts needing gluing the team wanted to attach pieces with long lines of glue rather than precise gluing of small sections. The I-beam was perfect for this, since it consists of a middle column with protrusions on the corners that are all glued along the entire length of the beam. Without failing the first time, succeeding the second time would have been harder, since the failing mechanisms of our initial beam were shining examples of what not to replicate.

The beam performed very well, being the beam in the tutorial with the smallest deflection in the given range of 2mm to 5.5mm. The beam had a relatively high volume, however, our beam produced no scrap material and used all of the wood ordered, whereas most other beams made cut-offs and excluded them from volume calculations. Beams that followed the general given shapes such as I-beam, box beam, and double box beam were the most successful at being in the given deflection range, and beams that had unique designs were less reliable. This could be because formula for the general shaped were available for use, whereas unique shapes had to create their own, which could have had errors.

The general theme of the designs in the tutorial were that the recorded deflection was greater than the predicted deflection which is understandable since the predicted beam deflection does not account for inconsistencies in the material or slight positional changes of pieces glued together compared to the perfect design groups are following. However, one team's recorded deflection was lower than their predicted deflection. This could just be an error while testing, or they could have used an amount of glue that dramatically increased the young's modulus of the beam.

If the project was to be repeated once more, perhaps the team could look into strong shapes that could produce the same deflection results with a reduced total volume of wood used, increasing the sustainability of the beam. Also, the amount of glue used to fabricate the beam could be reduced in the interest of sustainability.

The team took a relatively conservative approach to ensure the success of the beam by choosing to use a common beam shape that is almost guaranteed to succeed. The only risk taken was assuming that the real deflection was going to be slightly greater than the predicted deflection of 1mm.

The knowledge which the team was a significant factor in meeting the project criteria in this attempt. In the first attempt the team had no knowledge on calculating the deflection of the beam, during ENGG102 tutorials and lectures from weeks 2-5 members of the team were able to learn the required formula and engineering theory in calculating the deflection of the beam to ensure the criteria was met. Also, the restrictions placed on the selections of beam-models was also a factor in ensuring the design was successful.

Unlike in the first attempt at this project where there was an infinite amount of designs available to choose, in this attempt the team was limited to a choice between four designs. This was a beneficial factor for the team as it shortened time to brainstorm a design for the beam as the team was only limited to four options.

In the week 2 lecture the team was able to learn Yong's modulus which gives a measurement (pascals) of the stiffness of the material. With the Yong's modulus, this allowed the team to use the deflection at mid-span formula $\delta=\frac{p l^3}{48 EI}$ to calculate the length required for the beam. Also, the deflection data gathered through given values in the week 2 tutorial allowed the team to choose a Yong's modulus to use for the second attempt. The data gathered in the week 2 tutorial showed how the beam can be placed to obtain the largest possible Yong's modulus as shown in the two tables in the references. As shown in the tables below placing the beam sideways had the highest probability of achieving the criteria.

The team also learned about the second inertial area through the week 2 lecture. The second moment of area which measures how much material is far away from the centroid. The second moment of area is also an element in the deflection at mid-point formula (I). In this project the team was given the formula for the second moment of area with each formula different pending on which beam-model variant was chosen from available selections. In team G's case the formula was $I=\frac{b h^3-(b-t_w) d^3}{12}$ as the team opted for the I section design.

With the data analysed in the week 2 tutorial and the formula learnt in the lectures and requirements of the project, the team was able to calculate the deflection of the beam and adjust dimensions to ensure the beam met the criteria.

Although team G pre-emptively thought the deflection would be greater than anticipated as a conservative approach and met the criteria. The team still does not fully understand why the deflection value from the test was double the deflection value calculated. A factor which has not currently covered in the course was the effect of fabrication on the deflection. Further studies on the effect of fabrications on the material will help achieve a better estimation of deflection. The team can also improve its understanding of second moment of area which will be further covered in ENGG102 week 9 lectures. The team also needs to improve resource management as the team had used the highest amount of materials comparing to other teams.

From the performance results of the beam in this attempt, the team learnt that pre-testing calculations are essential in achieving the criteria. The team also can't be too reliant on the calculations as there was a significant difference between calculated deflection and actual deflection. This was evident as every team had at least a 0.6mm difference between calculated results and test results. Team G's difference between calculations and test results was 1.55mm in deflection.

Being a team of two, more pressure was on team G as there was more workload for the team members comparing to other teams in the tutorial. Although some may see it as a disadvantage, the members of team G saw it as their advantage. The members saw this as an advantage as it was easier for members to see the rate of pace of each other as well as the contributions of each member. Team G also believes that having a third member it was likely that tensions will rise due to conflicting ideas or an introduction of a dominant personality which will break the team dynamics. Team dynamics was great amongst team G as both members helped each other in completing their sections as well as constant communication amongst both members. The main reason to team G's success was due to the complimenting personalities of both members which ensured maximum efficiency.

Being in a team of two, it was easy to divide the workload down the middle and give each member a fair part of the work. It would also be very obvious if the other member was not pulling their weight, as the member doing the work would only see their own work. Luckily, this team was able to be responsible and punctual about completing the task on the schedule. The team of two works better than three since there is only one other person in the group, which means that no members can be slack about completing the task. Also, in a team of three, two of the members can choose a scapegoat as the reason for failure, whereas in a group of two any failures are shared. The team achieved success by being respectful of each other, constructive, and equal.

Teamwork performance:

Unlike other teams in the tutorial team G was the only two-member team. This had both advantages and disadvantages. Advantages of a two-member team is that decisions can be made faster, distributing workloads will be easier and conflicts in the time schedule also significantly decreased. Also, contribution of a single member to a team is much clearer in a two-member team compared to larger teams. Disadvantages of a two-member team is that each team member has to take a larger load of work compared to a three-member team, also a three-member team can work much more effectively in practical activities.

Personality of the team members is an essential factor in determining whether a two-member team can be successful. In team G's case a two-member team was the best scenario as both team-members did not have a dominant personality which allowed both members to easily collaborate on designs and avoid conflict. Also, communications were clear amongst both sides and members were able to complete their required tasks efficiently. There were no disagreements amongst members of the team. Through mutual respect and clear understanding the concepts of teamwork, the team was able to design and construct a beam to the required criteria despite having less members as well as completing this report.

Conclusion:

From the first attempt to the second, the team was able to make huge improvements in both the design and construction of the beam. The design of the beam was improved since the team gained knowledge about the engineering principles behind the beam and applied them to create a design that was almost guaranteed to succeed. The construction of the beam was improved by learning from the mistakes made during the fabrication of the first beam. Each member of the team has demonstrated self-directed learning to apply logical engineering design practices and learned important engineering calculations while working actively as a member of a team.

References:

Fundamentals of Engineering Mechanics for ENGG102 and ENGG100, compiled by Tim McCarthy, Pearson, 2014

Weeks 2-7 ENGG102 lecture slides

Appendix B (Young's Modulus Experiment)

Upright:

L (mm)	L^3 (mm^3)	b (mm)	h (mm)	I (mm^4)	M (kg)	P (N)	Deflection (mm)
150	3375000	5	10	416.7	0.2	1.962	0.73
150	3375000	5	10	416.7	0.3	2.934	0.91
150	3375000	5	10	416.7	0.4	3.924	0.98
150	3375000	5	10	416.7	0.5	4.905	1.12
150	3375000	5	10	416.7	0.6	5.886	1.19
150	3375000	5	10	416.7	0.7	6.867	1.28

Value for young's modulus, found from line of best fit: 1.655 GPa

Sideways:

L (mm)	L^3 (mm^3)	b (mm)	h (mm)	I (mm^4)	M (kg)	P (N)	Deflection (mm)
150	3375000	10	5	104.2	0.2	1.962	0.1
150	3375000	10	5	104.2	0.3	2.934	0.32
150	3375000	10	5	104.2	0.4	3.924	0.46
150	3375000	10	5	104.2	0.5	4.905	0.59
150	3375000	10	5	104.2	0.6	5.886	0.76
150	3375000	10	5	104.2	0.7	6.867	0.91

Value for young's modulus, found from line of best fit: 4.413 GPa

Young's modulus value we will use in calculations: 3 GPa

Appendix C (Displacement Excel Worksheet)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1														
2		Height(mm)		Width(mm)		I(mm^4)			Void Height(mm)		Void Width(mm)		Void I(mm^4)	
3		37.5		16		70312.5			24.5		13		15931.64	
4														
5		Actual I (mm^4)												
6		54380.86												
7														
8		E(Mpa)		Force Applied(N)		Length(mm)								
9		3000		29.4		640								
10														
11		Displacement(mm)			Target displacement:									
12		0.984189			2mm<d<5.5mm									
13														