

Designing an Overhead Gantry Crane

Stress Analysis and Dynamics

ACMA5010

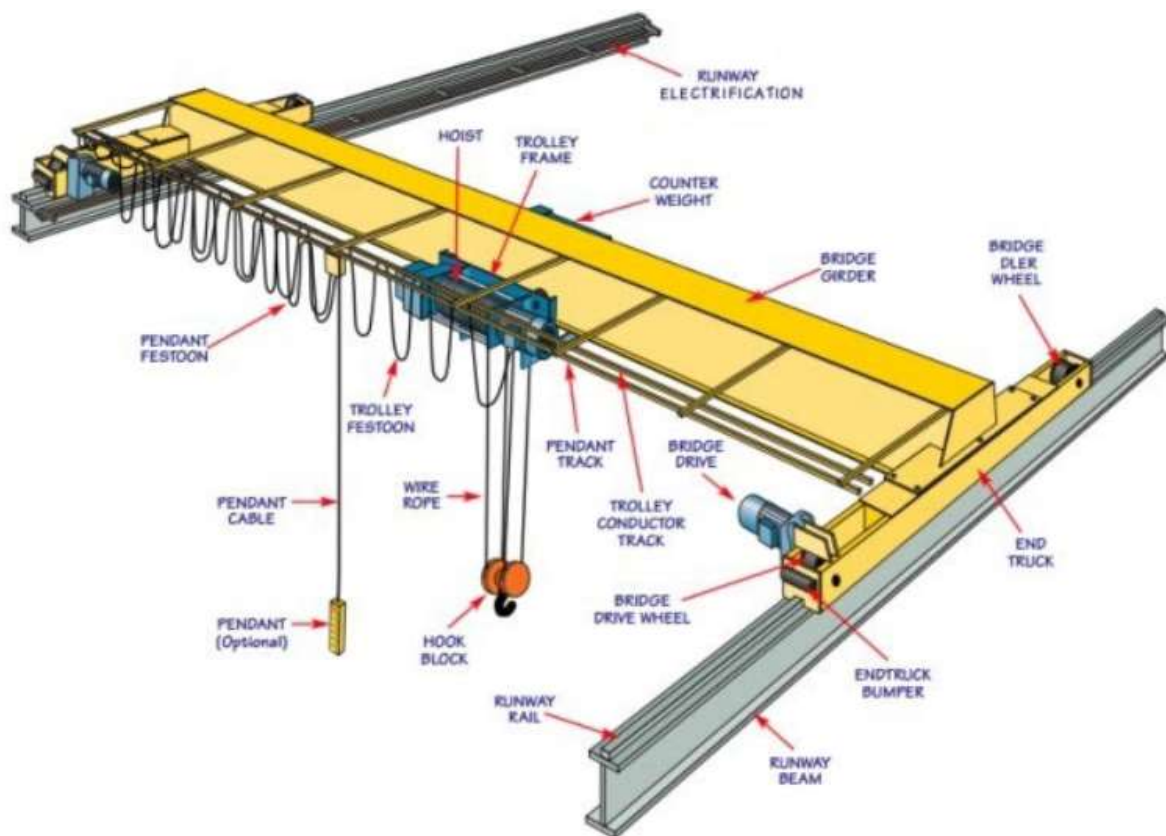
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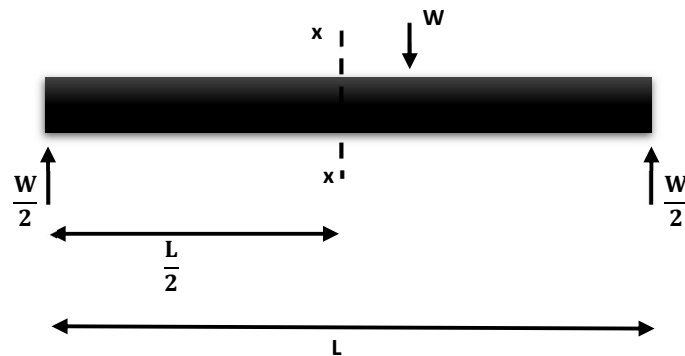
Introduction

In this assignment, I will be looking at the forces applied to a Steel Bridge Girder on a Gantry crane. I will be working out what is the most suitable type of beam section to use for the intended maximum operating mass. I will go over the types of strain gauges available and then recommend a strain gauge to be used on it.



Question 1

To get the formula needed to work out the inertia of the gantry girder, I will use the following steps to get the equation for a supported beam with a central concentrated load:



$$M_{xx} = \frac{W}{2} \left(\frac{L}{2} - x \right) = \frac{WL}{4} - \frac{Wx}{2} = EI \frac{d^2y}{dx^2}$$

$$EI \frac{dy}{dx} = \frac{WLx}{4} - \frac{Wx^2}{4} + A$$

$$EI y = \frac{WLx^2}{8} - \frac{Wx^3}{12} + Ax + B$$

$$\text{When } x = 0 \quad \frac{dy}{dx} = 0 \quad \therefore A = 0$$

$$\text{When } x = \frac{L}{2} \quad y = 0 \quad \therefore 0 = \frac{WL}{8} \left(\frac{L}{2} \right)^2 - \frac{W}{12} \left(\frac{L}{2} \right)^3 + B$$

$$\therefore B = \frac{WL^3}{96} - \frac{WL^3}{32}$$

$$\therefore B = -\frac{WL^3}{48}$$

$$\therefore y = \frac{1}{EI} \left[\frac{WLx^2}{8} - \frac{Wx^3}{12} - \frac{WL^3}{48} \right]$$

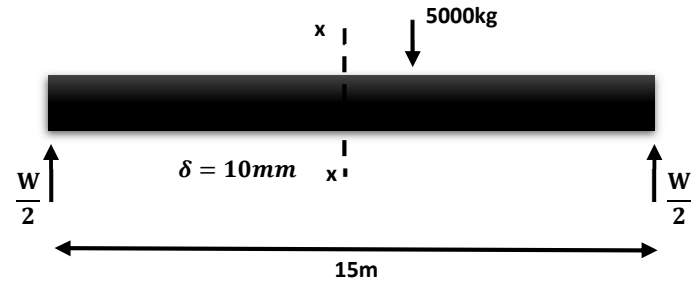
y_{max} is when $x = 0$

$$y_{max} = -\frac{WL^3}{48EI}$$

Using this equation, I can input the following data:

Steel E=210GPa Lifting Mass = 5000kg Deflection max = 10mm Length of beam = 15m

With this equation, I will be able to work out what the minimum second moment of area (Inertia) of the beam is.



Weight = 5000kg x 9.8 = 49kN

Steel E =210GPa

$$y_{max} = -\frac{WL^3}{48EI} \quad \therefore EI = -\frac{WL^3}{48y} = \frac{-49 \times 10^3 \times 15^3}{48 \times -10 \times 10^{-3}}$$

$$EI = 344,531,250Nm^2 \text{ or } 0.345GNm^2$$

$$I = 0.345/210$$

$$I = 0.0016406m^4 \text{ or } 0.164 \times 10^6cm^4$$

From the results of the equation above, I can use reference tables (APPENDIX 1) to review which types of beam section would be suitable for use on the gantry crane. The value gathered from the equation gave the I_{xx} a value of $164000mm^4$.

The three options for the beam section I am going to look at are: Universal Beam, Structural Tee and Gantry Girder. The factors to consider when choosing include: the strength of the beam, the mass of the beam and the size of the beam.

First thing to notice on the reference tables is that the Structural Tee does not have a size option that will allow for the inertia force previously calculated. Therefore, for this set of circumstances, the structural tee is not suitable for the task.

The two remaining options give the following recommended stats:

Universal beam:

Size: 762x266.7mm Mass per Metre: 173kg Inertia: 205177cm⁴

Gantry Girder:

Size: 630x432mm Mass Per Metre: 245kg Inertia: 206436cm⁴

The closest recommended beams that would be appropriate for the gantry crane both have similar inertia limits. However, the mass per metre for the recommended sizes have a difference of 72kg. Given that the beam is 15m in length, the total mass difference would be 1080 kg. This extra mass would translate to greater material costs. With the two options being sufficient to handle the operating mass of the crane, unnecessarily using more material to complete the job would not make sense economically. In conclusion, the most economical choice would have to be the Structural Tee.

Question 2

In the calculations for the Second Moment of area on the girder, I made the following assumptions:

The Beam is Symmetrical – They are produced to meet UK/EU manufacturing standards, so you would expect them to be symmetrical as designed.

The Beam is Uniform - The Beam is assumed to have no wear or imperfections; this makes it easier to calculate each of values.

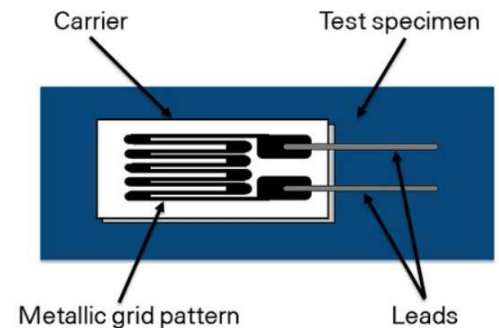
The ends of the beam are rigid – this is because the ends of the beam are held into place by the end truck onto the railway beams. The beams will only be able to travel along the x-axis of the railway and not the y-axis.

Question 3

Strain Gauge

A strain gauge is a form of sensor that acts as a variable resistor. The resistance that this gauge provides depends on the amount of Force being applied to it.

A strain gauge is made of a metal wire that weaves up and down the gauge body horizontally. At the bottom of the strain gauge there are two terminals which are used to connect the strain gauge to a circuit. The main body of the strain gauge is usually placed onto a structure that you want to measure for strain. Forces such as Weight, pressure and tension that act on the strain gauge will distort the shape of the metal wire as well as the gaps between each row. This change in length of the wire is directly proportional to the change in resistance that the strain gauge provides.

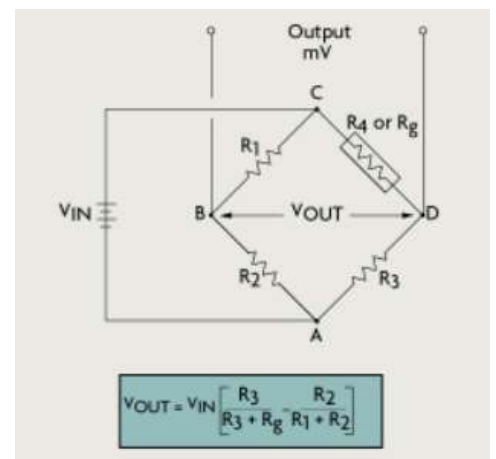


Wheatstone Bridge

The Wheatstone Bridge strain gauge is used to measure electrical resistances to determine the value of either a single resistance or the change of a resistance.

The Wheatstone bridge is typically made up of variable resistors and strain gauges. Set ups usually have either two or four strain gauges. The greater the number of strain gauges attached to the circuit, the more sensitive the overall Wheatstone bridge becomes.

As shown in the adjacent diagram, the layout has the resistors has two resistors place either side of each output. The theory suggests that if the resistance values on all four resistors are equal, the outputs will show no difference in voltage. However, if one of the resistors values changes it will cause an imbalance in the circuit and produce a voltage in the output.



So, if a strain gauge is included in the circuit and it experiences any forces, the strain gauges resistance value will change proportionately to this and thus cause an imbalance to the Wheatstone bridge circuit. This would then alert the system the change in stress value.

Wheatstone bridge strain gauges are used in a lot of civil and mechanical based monitoring. When placed on structures, they will allow someone to observe any changes to the acting forces it experiences. For example, a stone bridge may have been in operation for a long time, allowing cars to travel over it daily. To ensure the integrity of the bridge remains sound for safe passage across it, a person may place several of these gauges on key locations of the bridge. If the structure begins to degrade or show sign of deterioration, the strain gauges will pick up on this before any visible signs appear. Another example would be to place strain gauges on the walls of railway tunnels. Since they are underground and are not so easily accessible, the gauges provide an easier and safer method when taking these readings.

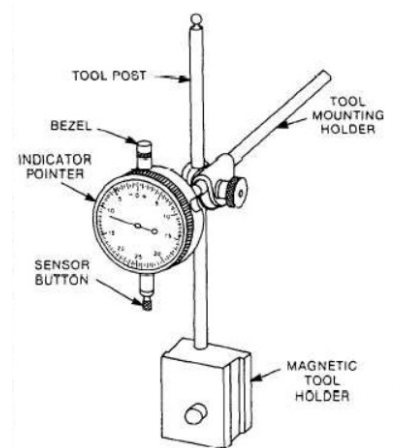
Mechanical Gauges

Mechanical gauges can come in a couple of forms, two of which are optical and mechanical Lever systems.

An example of an optical gauge is a Dial Test Indicator (DTI), these are used to measure displacement of a material. It is operated by applying pressure on the sensor button. As the Pressure increases against the sensor, the pressure transfers into the internal spring of the gauge. This then causes the indicator arm to turn until the dial face displays the amount of force being acted onto it.

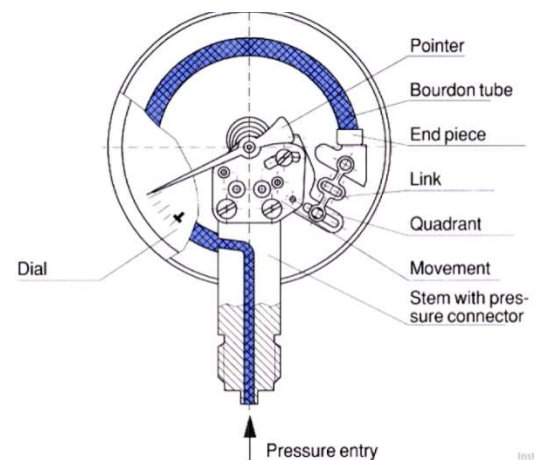
This method of gauging stress is suitable for smaller scale measurements. It is also more suited for project that do not require the highest level of accuracy. This is partly because the DTI is open to inaccuracies from multiple potential locations, specifically the internal spring and the tool holder. The spring will eventually give into fatigue over time and begin to make false readings. The other inaccuracies can come from the holder not being tightened effectively or being knocked by outside forces, this would lead to a false reading and the gauge will need to be reset.

This method also requires a longer set up time than other similar gauges. On top of that, it also requires the user to correctly zero the gauge before each use. A digital version of a DTI would be more efficient as it allows you to accurately zero the equipment as well as providing a read out of the result to the user, instead of reading the gauging by eye.



Pneumatic gauges

Pneumatic gauges work in a similar fashion to the DTI, the key difference is that it uses a Bourdon tube instead of a spring. As pressure builds up from the base of the gauge, the Bourdon tube fills up of the fluid or gas and then tries to straighten itself outwards. As it begins to do this, it pulls against a quadrant that is linked to the end piece. This then acts on the mechanical components that control the dial. As the pressure increases, the dial travels along the dial face until it is pointing at the correct pressure figure. There are also digital read out variations of this gauge available that can give a quick and accurate display of the pressure to the user.



This method of strain gauge is best used on vessels and pipework systems as they are typically filled with either liquids or gases of differentiating pressure levels. This method of gauge has the capability to measure high pressures at high accuracies whilst remaining safe for the user and the system.

An example use of this would be to pressure test a valve. A Valve needs to be able to withstand certain test pressures before they can be accepted for use on a plant. These pneumatic gauges can easily withstand these high pressures and be able to provide the tester a clear visible display to take the readings from.

Acoustic Gauges

An Acoustic Gauge can measure changes in frequency. The Acoustic Gauge includes steel wire which is then put under tension between two supports. If there is any change in distance between these two points due to a shift in strain, it will affect the natural frequency. An electromagnet is set alongside the wire, the position of this magnet can set the movement. This wire movement generates the electrical signal that the gauge picks up.

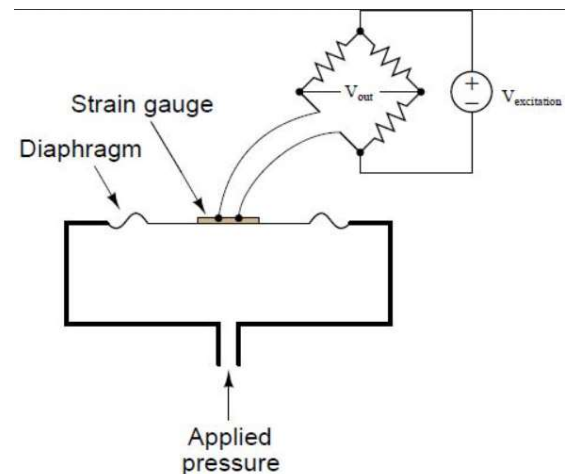


Semiconductor gauges

An example of a semiconductor strain gauge is the Piezoresistive gauge. This is a silicon-based strain gauge that picks up changes in resistance when a diaphragm is stretched or compressed.

As pressure is applied onto the diaphragm, it will begin to make the diaphragm deform and stretch. As this occurs, it causes the strain gauge that is installed on the surface to also stretch; causing the resistance of the gauge to fluctuate proportionally and thus sending a signal to the read-out.

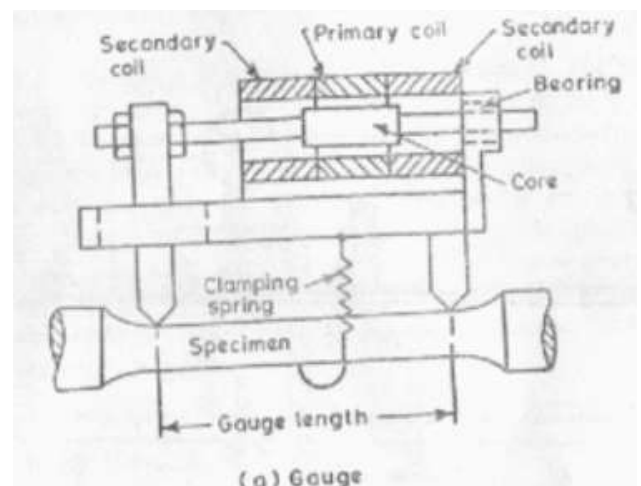
An example use for this type of strain gauge is that it can be used on mechanical systems including valves and pumps.



Inductance Gauge

Inductance Gauges measure the changes in inductance. The gauge consists of two coils and a magnetic core. The primary core will have power going through it which produces a magnetic field. If the core is moved at all, it will create a change in magnetic field which will cause either a positive or negative magnetic flux reaction with the secondary core. This will then send a signal to the inductance gauge that there has been a change.

A typical strain gauge will have a clamping spring and a pin that is connected to the secondary coil. It is when this moveable pin is pushed that the magnet is also pushed, thus causing the magnetic flux to occur.



The downside to using this form of strain gauge is that it cannot be used in an area where the magnets can be affected by external forces/materials. Unfortunately, magnets would be highly likely to cause false readings from the strain gauge.

Capacitance Gauge

Capacitance Gauges measure the changes in Capacitance. Capacitance gauges are used to notice changes in position, displacement or in fluid levels of a system. This form of gauge is used in modern technology included touchscreens.

The sensor does this by picking up the change of charges in the atmosphere around itself. The sensor consists of a metal plate which acts as a sensing surface, this is then connected to an oscillator circuit which produces a continuous waveform. If an object gets closer to the surface, it will begin to disrupt the area and cause shifts to the electrostatic field. This causes the waveform to change which the gauge picks up. Once the object has moved away from the sensor, the waveform will revert to the way it was before.

A benefit of using this technology is that they are simple to build and require small amounts of power to function. They are also extremely sensitive and thus does not require a great amount of force to pick up changes. On the other hand, if the sensitivity is turned up too high, they will also register changes in temperature and pressure from the environment. Meaning that the gauge will constantly be mis-reading inputs. They are also not the most accurate of sensor types and are not recommended for taking precise readings.

Question 4

From the strain gauges discussed on the previous section, I would suggest that the Wheatstone Bridge Strain Gauge would be the most suitable method of measurement on the gantry crane beam. When placing the strain gauges on the beam, it would be sensible to locate them where the greatest risk of deflection would occur. I would recommend that a sensor is placed on the top and underside of the central area of the beam. This is where the most deflection is likely to appear. I would also recommend putting a gauge one quarter and three quarter of the beam length. As the single point load of the crane will move positions for each lift, it is important to check that deflection does not occur in other areas of the beam.

When looking at how to receive the data from the strain gauge, it is possible to have the data transferred to a mobile device. Looking at a product from appmeas.co.uk (*How to get strain gauge readings instantly to your phone or tablet, 2021*), they offer a Bluetooth strain transmitter that allows instant readings to be sent to a tablet or mobile device. The device can be used to send alerts and constant updates from the strain gauges. This makes it easy to know if any abnormalities occur with the beam. The operator of the crane could also use the device to gain live readings when conducting lifts.

An alternative option is to have an illuminated readout on the crane itself. As the crane begins to lift an object, the weight of it will act on the beam and the strain gauge will give a reading which the readout will display. This would allow the operator to check that they are not subjecting the gantry crane to excess forces. This would help extend the working life of the crane.

Conclusion

From this Assignment, I have come to the decision that the crane should use the Universal beam as the choice of structural section. Also, Wheatstone Bridge strain gauges are the most optimal choice for collecting strain readings during and outside of general operations.

References

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Appendices

APPENDIX 1 – Beam Section Tables

Size $D \times B$ (mm)	Mass per metre (kg)	Thickness		I_{xx} (cm ⁴)	I_{yy} (cm ⁴)	Z_{xx} (cm ³)	Z_{yy} (cm ³)
		Web t (mm)	Flange T (mm)				
910.3 x 304.1	222	15.9	23.9	375 924	11 223	8259	738.1
840.7 x 292.4	194	14.7	21.7	279 450	9069	6648	620.4
762.0 x 266.7	173	14.3	21.6	205 177	6846	5385	513.4
677.9 x 253.0	125	11.7	16.2	118 003	4379	3481	346.1
617.5 x 307.0	113	14.1	23.6	151 631	11 412	4911	743.3
533.1 x 209.3	92	10.2	15.6	55 353	2392	2076	228.6
467.4 x 192.8	98	11.4	19.6	45 717	2343	1956	243.0
457.2 x 151.9	67	9.1	15.0	28 577	878	1250	115.5
402.3 x 142.4	46	6.9	11.2	15 647	539	777.8	75.7
364.0 x 173.2	67	9.1	15.7	19 522	1362	1073	157.3
352.8 x 126.0	39	6.5	10.7	10 087	357	571.8	56.6
310.9 x 166.8	54	7.7	13.7	11 710	1061	753.3	127.3
312.7 x 102.4	33	6.6	10.8	6487	193	415.0	37.8
254.0 x 101.6	22	5.8	6.8	2867	120	225.7	23.6
203.2 x 133.4	25	5.8	7.8	2356	310	231.9	46.4

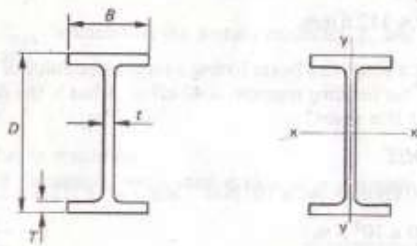


Fig. 2.31 Universal beam

Size $D \times B$ (mm)	Mass per metre (kg)	Extreme fibre distance		I_{xx} (cm ⁴)	Z_{xx} (cm ³)
		y_1 (cm)	y_2 (cm)		
939 x 432	355	39.20	54.68	644 504	11 797
853 x 432	260	32.92	52.37	384 673	7345
774 x 432	239	29.16	48.26	288 718	5982
700 x 432	218	25.58	44.40	215 582	4856
630 x 432	245	24.11	38.86	206 436	5313
627 x 381	195	23.60	39.14	155 882	3982
622 x 381	180	22.74	39.49	140 490	3558
618 x 305	155	23.53	38.22	120 871	3163
555 x 381	177	20.27	35.23	108 879	3091
550 x 305	151	20.84	34.13	92 644	2715
478 x 305	140	17.77	29.98	64 431	2149
472 x 254	117	18.67	28.50	54 593	1916
465 x 229	93	17.57	28.91	39 916	1381
423 x 305	116	14.67	27.62	40 572	1469
418 x 254	95	15.52	26.23	34 059	1298

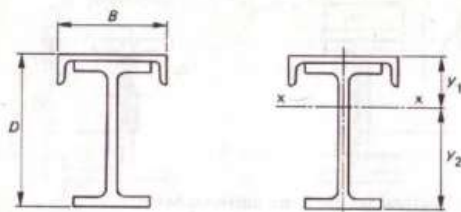


Fig. 2.33 Gantry girder

Size $B \times A$ (mm)	Mass per metre (kg)	Thickness		I_{xx} (cm ⁴)	Z_{xx} (cm ³)	Extreme fibre distance	
		Web t (mm)	Flange T (mm)			y_f (cm)	y_t (cm)
304.1 x 455.2	112	15.9	23.9	29 036	869.8	12.1	33.42
292.4 x 420.4	97	14.7	21.7	21 381	690.9	11.1	30.94
266.7 x 381.0	87	14.3	21.6	15 495	551.3	9.99	28.11
253.0 x 339.0	63	11.7	16.2	8997	359.5	8.87	25.03
307.0 x 308.7	90	14.1	23.6	8949	369.5	6.65	24.22
209.3 x 266.6	46	10.2	15.6	3905	194.4	6.56	20.10
192.8 x 233.7	49	11.4	19.6	2978	167.2	5.55	17.82
151.9 x 228.6	34	9.1	15.0	2128	126.1	5.99	16.87
142.4 x 201.2	23	6.9	11.2	1130	75.0	5.05	15.07
173.2 x 182.0	34	9.1	15.7	1158	81.6	4.01	14.19
126.0 x 176.4	20	6.5	10.7	719.6	54.4	4.41	13.23
166.8 x 155.4	27	7.7	13.7	636.4	51.5	3.19	12.35
102.4 x 156.3	17	6.6	10.8	486.7	42.4	4.14	11.49
101.6 x 127.0	11	5.8	6.8	227.2	24.7	3.49	9.21
133.4 x 101.6	13	5.8	7.8	133.7	16.6	2.12	8.04

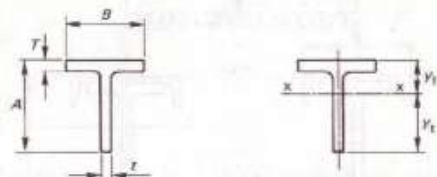


Fig. 2.32 Structural tee cut from universal beam