Designing a Structural Steel Beam

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Introduction

Have you ever looked at a building under construction and wondered how the structure was designed? What assumptions are made to determine what load a beam will be designed to support? This paper will demonstrate how to determine loading on a beam, how to draw the forces in the beam, and how to select a steel wide-flange shape from the AISC Steel Manual.

This task should take approximately two hours for someone who is just learning the process. It should be performed at a desk, where there is no risk of food or drinks being spilled on your calculations.

Definitions:

Construction: The way in which something is built or put together

Structure: The arrangement and interrelationship of parts in construction

Structural Member: A support that is a vital part of any building

Beam: A horizontal structural member that supports the structure above it

Column: A vertical upright used to support a structure

Girder: A large beam that frames into a column on each end and supports the beams framing into it

Wide-Flange: A steel beam or girder shaped like the letter I

Please reference Figure 1.

Figure 1: *Wide-Flange Shapes*

Structural Floor Plan: Drawing of the beam, girder, and column layout for a building

Please reference Figure 2.

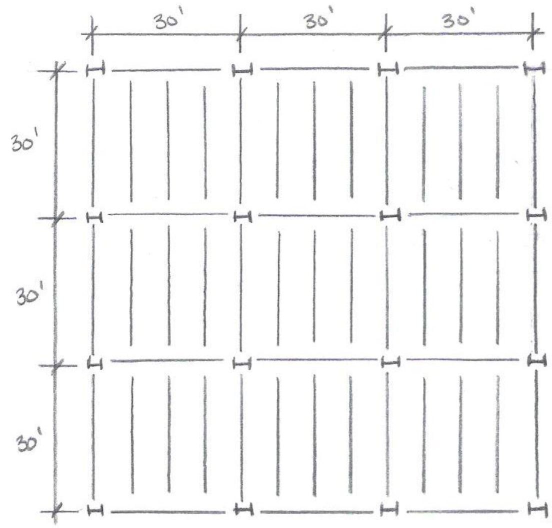


Figure 2: *Structural Floor Plan*

Tributary Width: Width of floor that contributes load to a structural member

Please reference Figure 3.

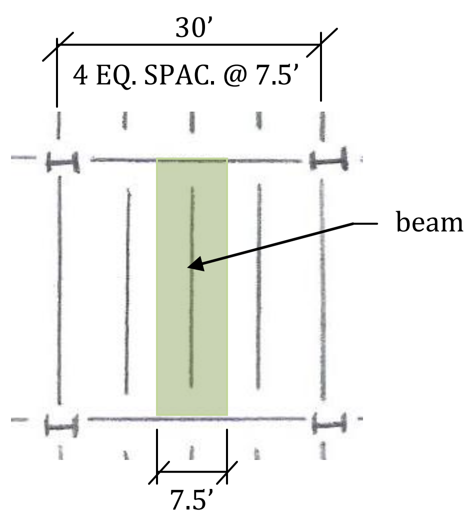


Figure 3: *Tributary Width*

Force: Strength or energy exerted

Load: Forces applied to a structure

Equilibrium: A state of balance among the forces acting on a structural member; the sum of all forces acting on a structural member are equal to zero

Reaction: A force exerted by a support

Shear: A stress generated in the beam during the transfer of applied loads from point of application to point of reaction

Moment: A measure of the tendency of a force to cause an object to rotate about a certain point

Dead Load: Loads resulting from objects permanently attached to the structure (i.e.- beam self weight, concrete slab weight, weight of floor finishing…)

Live Load: Loads resulting from items not permanently attached to the structure (i.e.- people, furniture, machinery…)

ASCE 7-05: A standard provided by the American Society of Civil Engineers that demonstrates how to obtain dead loads and live loads acting on a structural member

Please reference Figure 4.

Figure 4: *ASCE 7-05*

AISC Steel Manual: A design guide provided by the American Institute of Steel Construction for the design of steel structural members

Please reference Figure 5.

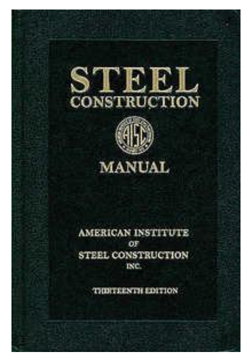


Figure 5: *AISC Steel Manual*

Caution:

Be sure to sit in a chair that provides proper back support. Sitting in a chair that causes you to slouch may result in muscle cramping and back pain.

If you feel yourself getting a headache, please stop and take a break. If you do not, you may risk making a mistake in your calculation. This mistake may lead to a structural failure during construction or even after the building is occupied!

Materials

The materials you will need to complete this task are:

- Paper
- Pencil
- Eraser
- Calculator
- Ruler (or any straight edge)
- Structural Floor Plan
- ASCE 7-05
- AISC Steel Manual

Procedure

Determining Loads:

1. Estimate Dead Load acting on the beam.

w_{DL} = DEAD LOAD = 100 lb/ft² or psf

For an engineering project, this would be estimated based upon floor weight from the structural computer model. However, 100 psf is a good estimation to start a basic design.

2. Look up Live Load from ASCE 7-05 Table 4-1 on page 12.

We are assuming this is an office building. For an engineering project, this would be stated by the client.

TABLE 4-1 MINIMUM UNIFORMLY DISTRIBUTED LIVE LOADS, L_o, AND MINIMUM CONCENTRATED LIVE LOADS

Occupancy or Use	Uniform psf (kN/m^2)
Office Buildings	
File and computer rooms shall be designed for heavier loads based on anticipated occupancy	
Lobbies and first-floor corridors	100 (4.79)
Offices	50 (2.40)
Corridors above first floor	80 (3.83)

w_{LL} = LIVE LOAD = 50 lb/ft² or psf

3. Select load combination from ASCE 7-05 Section 2.3.2 on page 5.

2.3 COMBINING FACTORED LOADS USING STRENGTH DESIGN

2.3.1 Applicability. The load combinations and load factors given in Section 2.3.2 shall be used only in those cases in which they are specifically authorized by the applicable material design standard.

2.3.2 Basic Combinations. Structures, components, and foundations shall be designed so that their design strength equals or exceeds the effects of the factored loads in the following combinations:

1. $1.4(D + F)$
2. $1.2(D + F + T) + 1.6(L + H) + 0.5(L_r \text{ or } S \text{ or } R)$
3. $1.2D + 1.6(L_r \text{ or } S \text{ or } R) + (L \text{ or } 0.8W)$
4. $1.2D + 1.6W + L + 0.5(L_r \text{ or } S \text{ or } R)$
5. $1.2D + 1.0E + L + 0.2S$
6. $0.9D + 1.6W + 1.6H$
7. $0.9D + 1.0E + 1.6H$

EXCEPTIONS:

1. The load factor on L in combinations (3), (4), and (5) is permitted to equal 0.5 for all occupancies in which L_o in Table 4-1 is less than or equal to 100 psf, with the exception of garages or areas occupied as places of public assembly.
2. The load factor on H shall be set equal to zero in combinations (6) and (7) if the structural action due to H counteracts that due to W or E.

Minimum Design Loads for Buildings and Other Structures

We are designing the beam for gravity loads— dead load (D) and live load (L). Therefore, we can reduce the above combinations to include only these loads:

1. *1.4D*
2. ***1.2D + 1.6L***
3. *1.2D + L*
4. *1.2D + L*
5. *1.2D + L*
6. *0.9D*
7. *0.9D*

By inspection, load case 2 will create the largest load. This load case is selected as shown in the table above.

4. Determine the factored load by plugging in the dead and live loads into the load combination equation.

1.2 (DEAD LOAD) + 1.6 (LIVE LOAD) = FACTORED LOAD = w_u

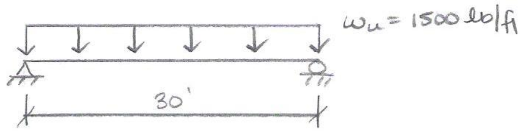
1.2 (100 psf) + 1.6 (50 psf) = 200 psf = w_u

5. Transform distributed load into a line load acting on the beam by multiplying the distributed load by the tributary width of the beam.

200 lb/ft² (TRIBUTARY WIDTH) = LINE LOAD

200 lb/ft² (7.5 ft) = 1500 lb/ft OR plf

6. Draw the line load on the beam for clarity of what we are designing.



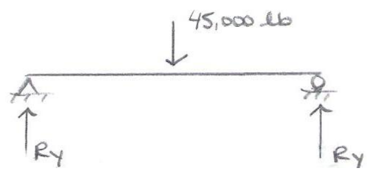
7. Transform line load on the beam into a point load in order to determine the reactions from the supports.

POINT LOAD = $P_u = w_u$ (LENGTH OF BEAM)

$P_u = 1500\ \text{lb/ft}\ (30\ \text{ft})$

$P_u = 45{,}000\ \text{lb}$

8. Draw the point load and reaction forces on the beam for clarity.



9. Find reactions from the supports by using equilibrium.

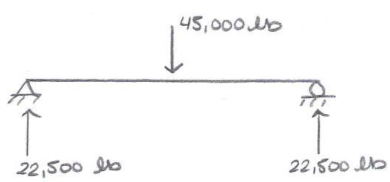
$+\uparrow \Sigma F_y = 0$

$R_y + R_y - 45{,}000 = 0$

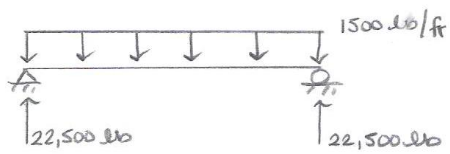
$2R_y = 45{,}000$

$R_y = 22{,}500\ \text{lb}$

10. Draw the point load and corresponding reactions on the beam.



11. Draw the line load and corresponding reactions on the beam.



This is what the actual loading looks like on the beam. The only reason we transformed this load into a point load, as shown in step 10, was to solve for the reactions from the supports.

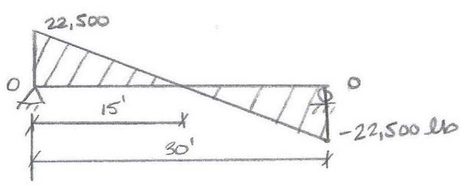
Drawing Forces in the Beam:

12. Draw a diagram of the shear force in the beam.

The shear in the end of the beam starts out at 0 lbs. However, since there is a reaction of 22,500 lbs on the left side of the beam, it will create that much shear in that location. The line load will cause this shear to decrease along the length of the beam as demonstrated:

$$22{,}500\,\text{lb} - 1500\,\text{lb/ft}\,(30\,\text{ft}) = -22{,}500\,\text{lb}$$

This shear of -22,500 lbs will be brought back up to 0 lbs due to the reaction from the support on the right side of the beam as shown below.



13. Draw the diagram of the moment in the beam.

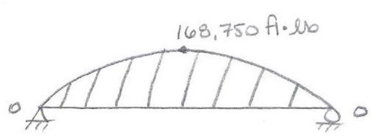
The moment in the end of the beam starts out at 0 ft-lbs. The moment along the length of the beam is found by calculating the area of the shear diagram. The shear diagram is the shape of a triangle; therefore the area is calculated as shown:

$$22{,}500\,\text{lb}\,(1/2)(15\,\text{ft}) = 168{,}750\,\text{ft}\cdot\text{lb}$$

The moment goes back to zero on the right side of the beam because the area of the triangle for the shear diagram on the right side of the beam is negative:

$$-22{,}500\,\text{lb}\,(1/2)(15\,\text{ft}) = -168{,}750\,\text{ft}\cdot\text{lb}$$

The design moment (maximum moment) in a beam is found where the shear is equal to zero. In this case, that location would be at the center of the beam.



Selecting a Wide-Flange Steel Shape:

14. Convert the moment into kilo pound-feet.

168,750 ft·lb × (1 kilo pound / 1000 lb) = 168,750 ft·k ≈ 169 ft·k

15. Select a wide-flange shape from Table 3-2 in the AISC Steel Manual that has a ΦM_n (moment capacity) value greater than the moment found on the beam.

FROM TABLE 3-2:

TRY A W14×30 —

Table 3–2 (continued)

W Shapes

Selection by Z_x

Z_x — F_y = 50 ksi

Shape	Z_x	M_{px}/Ω_b	$\phi_b M_{px}$	M_{rx}/Ω_b	$\phi_b M_{rx}$	BF	BF	L_p	L_r	I_x	V_{nx}/Ω_v	$\phi_v V_{nx}$
		kip-ft	kip-ft	kip-ft	kip-ft	kips	kips				kips	kips
	in.³	ASD	LRFD	ASD	LRFD	ASD	LRFD	ft	ft	in.⁴	ASD	LRFD
W18×35	66.5	166	249	101	151	8.07	12.1	4.31	12.4	510	106	159
W12×45	64.2	160	241	101	151	3.83	5.75	6.89	22.4	348	80.8	121
W16×36	64.0	160	240	98.7	148	6.19	9.31	5.37	15.2	448	93.6	140
W14×38	61.5	153	231	95.4	143	5.39	8.10	5.47	16.2	385	87.4	131
W10×49	60.4	151	227	95.4	143	2.44	3.67	8.97	31.6	272	68.0	102
W8×58	59.8	149	224	90.8	137	1.70	2.56	7.42	41.7	228	89.3	134
W12×40	57.0	142	214	89.9	135	3.66	5.50	6.85	21.1	307	70.4	106
W10×45	54.9	137	206	85.8	129	2.59	3.89	7.10	26.9	248	70.7	106
W14×34	54.6	136	205	84.9	128	5.05	7.59	5.40	15.6	340	79.7	120
W16×31	54.0	135	203	82.4	124	6.76	10.2	4.13	11.9	375	87.3	131
W12×35	51.2	128	192	79.6	120	4.28	6.43	5.44	16.7	285	75.0	113
W8×48	49.0	122	184	75.4	113	1.68	2.53	7.35	35.2	184	68.0	102
W14×30	47.3	118	177	73.4	110	4.65	6.99	5.26	14.9	291	74.7	112
W10×39	46.8	117	[illegible]	73.5	111	2.51	3.77	6.99	24.2	209	62.5	93.7
W16×26ᵛ	44.2	110	166	67.1	101	5.96	8.96	3.96	11.2	301	70.5	106
W12×30	43.1	108	162	67.4	101	3.92	5.89	5.37	15.6	238	64.2	96.3
W14×26	40.2	100	151	61.7	92.7	5.32	7.99	3.81	11.1	245	70.9	106
W8×40	39.8	99.3	149	62.0	93.2	1.64	2.47	7.21	29.9	146	59.4	89.1
W10×33	38.8	96.8	146	61.1	91.9	2.39	3.59	6.85	21.8	171	56.4	84.7
W12×26	37.2	92.8	140	58.3	87.7	3.61	5.42	5.33	14.9	204	56.2	84.3
W10×30	36.6	91.3	137	56.6	85.0	3.08	4.62	4.84	16.1	170	62.8	94.2
W8×35	34.7	86.6	130	54.5	81.9	1.62	2.43	7.17	27.0	127	50.3	75.5
W14×22	33.2	82.8	125	50.6	76.1	4.75	7.14	3.67	10.4	199	63.2	94.8
W10×26	31.3	78.1	117	48.7	73.2	2.90	4.36	4.80	14.9	144	53.7	80.6
W8×31ᶠ	30.4	75.8	114	48.0	72.2	1.58	2.37	7.18	24.8	110	45.6	68.4
W12×22	29.3	73.1	110	44.4	66.7	4.65	6.99	3.00	9.17	156	64.0	96.0
W8×28	27.2	67.9	102	42.4	63.8	1.66	2.50	5.72	21.0	98.0	45.9	68.9
W10×22	26.0	64.9	97.5	40.5	60.9	2.68	4.02	4.70	13.8	118	48.8	73.2
W12×19	24.7	61.6	92.6	37.2	55.9	4.27	6.43	2.90	8.62	130	57.2	85.7
W8x24	23.1	57.6	86.6	36.5	54.9	1.59	2.39	5.69	19.0	82.7	38.9	58.3
W10×19	21.6	53.9	81.0	32.8	49.3	3.17	4.77	3.09	9.72	96.3	51.2	76.8
W8×21	20.4	50.9	76.5	31.8	47.8	1.86	2.79	4.45	14.8	75.3	41.4	62.1

ASD	LRFD
$\Omega_b = 1.67$	$\phi_b = 0.90$
$\Omega_v = 1.50$	$\phi_v = 1.00$

ᶠ Shape exceeds compact limit for flexure with F_y = 50 ksi.

ᵛ Shape does not meet the h/t_w limit for shear in Specification Section G2.1a with F_y = 50 ksi, Ω_v = 1.67, ϕ_v = 0.90.

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16. Ensure that the moment capacity is larger than the moment found on the beam.

ϕM_n = MOMENT CAPACITY OF THIS SHAPE = 177 ft·k
M_u = 169 ft·k (FOUND ABOVE)

SHAPE CAPACITY > LOAD ON SHAPE
177 ft·k > 169 ft·k ✓ OK

Conclusion

This instruction set describes how to design a structural steel beam in an attempt to satisfy the curiosity of the reader. In order to complete this goal, all steps were listed and explained in logical order.

We started by determining the loads acting on the beam based upon the building's use. Next, we determined the factored load acting on the beam based on the controlling load combination from ASCE 7-05. We then calculated the shear and moment acting on the beam resulting from this loading. Based on the maximum moment acting on the beam, we were able to select a steel wide-flange shape with adequate moment capacity from the AISC Steel Manual.

You will no longer have to wonder how engineers design structural elements of a building. Everything is based off the principle of equilibrium, as seen in this instruction set.