Design of Steel Structures
According to AISC (13Edition)
Fourth Stage

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References

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2. Steel Design, William T. Segui, Sixth Edition, 2018
3. Structural Steel Design, Abi Aghayere and Jason Vigil, 2009
4. American Institute of Steel Construction (AISC),Thirteen Edition,2005
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Most Important Conversion factors

	To Convert	To	Multiply by
Length	ft	m	0.3048
	ft	in	12
	in	cm	2.54
	m	ft	3.28
Force	Kip	kN	4.448
	Ib	N	4.448
	kN	kip	0.2248
	ton	kip	2.2046
Stresses	Ksi	MPa(N/mm^2)	6.895
	Psi	MPa	0.006895
	MPa	Ksi	0.145
	MPa	psi	145
Moment	ft-kip	kN.m	1.356
	kN.m	ft. Kip	0.7376
Uniform Loading	Kip/ft	kN/m	14.59
	kN/m	kip/ft	0.06852
	kip/ft^2	kN/m^2	47.88
	psf	N/m^2	47.88
	kN/m^2	kip/ft^2	0.02089

Introduction of Steel Structures

Introduction

Steel as Structural structure is a structure which is made from the organized combination of custom-designed structural steel members to meet architecture and engineering requirements of users. This type of structure is widely used in construction projects of medium and large scale by useful features of steel. Steel is one of the most important structural materials. Properties of particular importance in structural usage are high strength, compared to any other available material, and ductility. Ductility is the ability to deform substantially in either tension or compression before failure. Other important considerations the use of steel includes widespread availability and durability, particularly with a modest amount of weather protection


Main Steel Structural Types:

A-based on their usage steel structure can be classified as:
1. Building Structures: residential, commercial, assembly, institutional, industrial.
2. Bridges: pedestrian, highway, railway.
3. Storage Structures: water towers, bins, silo pressure vessels.
4. Towers: radio and T.V transmission, lighting.
5. Special Structures: mine head frames, drilling structures, etc.




B-based on the load carrying system structure can be classified as:
1. Frames Structures: beam and columns.
2. Truss Structure: bar or truss members.
3. Tension Structures.
4. Arches and Surface Structures.



Advantages of Steel as a Structural Material:
The advantages of structural steel are discussing in detail in the following:
1. High Strength and light- weight
The high strength of steel per unit of weight means that structure weights will be small. This fact is of great importance for long-span bridges, tall buildings, and structures having poor foundation conditions.
2. Uniformity
The properties of steel do not change appreciably with time as do those of are in forced-concrete structure.
3. Elasticity
Steel behaves closer to design assumption than most materials because it follows Hooke's law up to high stresses. The moments of inertia of a steel structure can be definitely calculated,while the values obtained for a reinforced concrete structure are rather indefinite.
4. Permanence
Steel frames that are properly maintain will last indefinitely.

5. Ductility

The property of a material by which it can withstand Extensive deformation without failure under high tensile stresses is say to be its ductility. When a mild or low-carbon steel member is being testing in tension, a considerable reduction in cross section and a large amount of elongation will occur at the point of failure before the actual fracture occurs. In structural members under normal loads, high stress concentrations develop at various points.
The ductile nature of the usual structural steels enables them to yield locally at those points, thus preventing premature failures. A further advantage of ductile structures is that when overloaded their large deflections give visible evidence of impending failure.
6. Fracture Toughness
Structural steels are tough; that is, they have both strength and ductility. A steel member loaded until it has large deformations will still be able to withstand large forces. This is a very important characteristic because it means that steel members can be subjected to large deformations during fabrication and erection without fracture-thus allowing them to be bent, hammered, sheared, and have holes punched in them

without visible damage. The ability of a material to absorb energy in large amounts is calling toughness.

7. Miscellaneous

-Ability to be fastening together by several simple connection devices including welds, bolts, and rivets,
- Speed of erection,
-Ability to roll into a wide variety of sizes and shapes,
- Possible reuse after a structure is disassemble,
- Scrap value even though not reusable in its existing form,
- Ability to form built up section from standard sections.
- Steel structures are quite well suited to having additions made to them. New bays or even entire new wings can add to existing steel frame buildings, and steel bridges may often widen.

Disadvantages of Steel Structural Material:

In general, steel has the following disadvantages:

1. High Maintenance & Capital Cost

When steel structures expose to severe or aggressive weather conditions, it may get corrode due to the action of steel with atmospheric oxygen or aggressive environment. For preventing such a problem expensive application of paints is required frequently.

2. Corrosion

Most steels are susceptible to corrosion when freely expose to air and water and must periodically paint. The use of weathering steels, in suitable design applications, tends to eliminate this cost.

3. **Fireproofing Costs**

The strength of steel depends primarily at temperature and steel is not flammable material.

Both the yield and tensile strength at (1000 f^o) are a about (60-70) percent of that at 70 f^0 (room Temp.), while at (1600 f^0) only 15 percent from yielding and ultimate strength remain as compared with room temperature.

So steel frames required fire protection to control the temperature for sufficient time by using material for protraction such as
-Gypsum products
-Light- weight concrete
-Fiber insulation boards
-expanded shale concrete

4. **Susceptibility to Buckling**

Longer and slenderer the compression members are the greater the danger of buckling. As previously indicated, steel has a high strength per unit of weight but when used for steel columns is sometimes not very economical because considerable material has to be used merely to stiffen the columns against buckling.

5. Fatigue

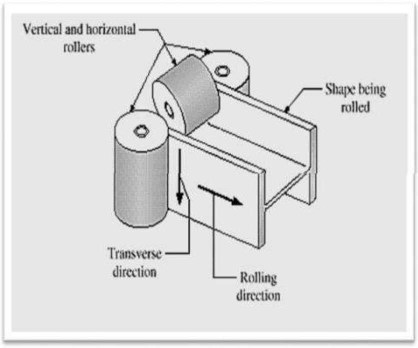
Another undesirable property of steel is that its strength may reduce if it subjected to a large number of stress reversals or even to a large number of variations of tensile stress. (We have fatigue problems only when tension is involved.) The present practice is to reduce the estimated strengths of such members if it is anticipate that they will have more than a prescribed number of cycles of stress variation.

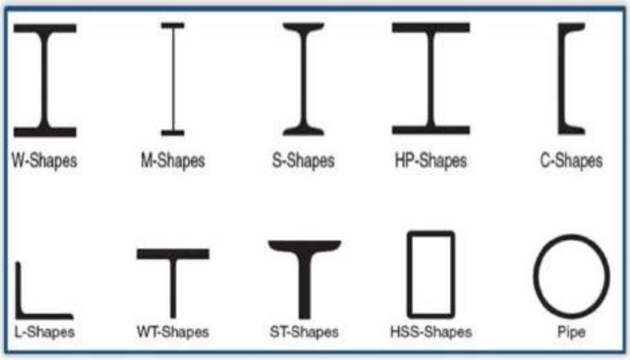
Structural Steel Shapes:

There are two types of steel shapes available:

1- Rolled Steel Sections

Steel ingots from the refining of pig Iron roll into plates of varying widths and thickness, several structural shapes: round, square, rectangular bars, and pipes as shown in figure. Several of the most common steel shape described in the following section:

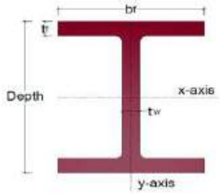




W-Shapes (Wide Flange Shapes)

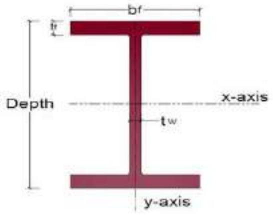
W-shapes commonly used as beams or columns in steel buildings, they are also used as the top and bottom chord members for trusses, and as diagonal braces in braced frames.

An example of their standard designation is W24 x 250. This indicates a W-shape that is nominally (approximately) 24 in deep from outside of flange to outside of flange and weighs 250 Ib/ft. The weight difference created by varying web thickness and flange width and thickness.



M-Shapes (Miscellaneous Shapes)

M-shapes are similar to the W-shapes, but they are not as readily available or widely used as W-shapes, and their sizes are also limited.



S-Shapes (American Standard Beams)

Also known as American Standard Beams, they are similar to W-shapes except that the inside flange surfaces are sloped. The inside face of the flanges usually have a slope of 1:6, with the larger flange thickness closest to the web.

These sections commonly used as hoist beams for the support of monorails.

HP-Shapes (Bearing Pile Shapes)

HP-shapes are similar to W-shapes and are commonly used in bearing pile foundations, they may also be used occasionally as beams and columns but they are generally less efficient (more costly) for these applications.

HP-shapes have thicker flanges and webs, the cross section of them are rather square with flanges and webs of nearly the same thickness (in order that the web will withstand pile-driving hammer blows).

C-Shapes &M.C-Shapes (Channels)

C-shapes are the American Standard Channels, while MC-shapes are miscellaneous channels. Channels are C-shaped members with the inside faces of the channel flanges sloped. As the M-shapes, the MC-shapes are generally less readily available and produced by only a limited number of mills.

The channel shapes commonly used as beams to support light loads, such as in catwalks or as stair stringers, and they used to frame the edges of roof openings. Examples of their designation are C12 X30 and MC12 X 50, where the first number indicates the depth in inches and the second number indicates the weight in pounds per foot.

L-Shapes (Angle Shapes)

Angles are L-shaped members with equal or unequal length legs, they used as lintels to support brick cladding and block wall cladding and as web member in trusses, and they are also used as X-braces, chevron braces, or knee-braces in braced frames, and could be used as single angles or as double angles placed back-to-back.

Example of their designation L8 x 4 x ½ indicate an angle with a long leg length of 8 in., and short leg length of 4 in., and a thickness of ½ in..

Note that the designation does not provides the unit weight of the angle as has been the case with all shapes discussed thus far, for that reason the weight in pounds per foot is tabulated.

WT, MT and ST Shapes (Structural Tees)

Structural tees made by cutting a W-shape, M-shape or S-shape in half. For example, if a W14 x 120 is horizontally cut in half, the resulting shapes will be WT7 x 60, where the nominal depth is 7 in., and the self-weight of each piece is 60 Ib/ft. WT-shapes are commonly used as braced members and as top and bottom chords of trusses. They also used to strengthen existing steel beams where a greater moment capacity is required. Similarly, ST- and MT-shapes made from S- and M-shapes, respectively.

Hollow Structural Sections (HSS)

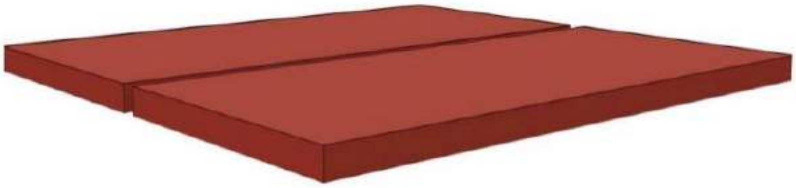
HSS members are rectangular, square, or round tubular members that commonly used as columns, hangers, and braced-frame members. HSS members are not as susceptible to lateral torsional buckling and torsion as W-shapes or other sections.

Structural Pipes (P)

Pipes are round structural tubes similar to round HSS members that sometimes used as columns. They are available in three strength categories: standard (STD), extra strong (X-strong), and double-extra strong (XX-strong).

Flat Bars and Plates (PL)

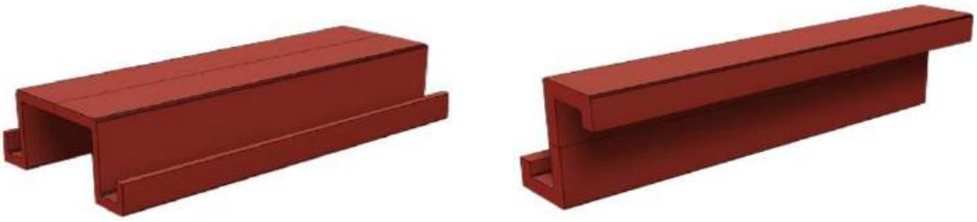
Flat bars, plates, stripes, and sheets, rectangular in cross section, come in many width and thicknesses. A flat shapes has historically been classified as a bar if its width is less than or equal to 8 in. and as plate if its width is greater than8 in. A flat bar is usually designated with the width given before the thickness, for example, a 6 x ⅝ bar. Conversely, a plate is usually designated with the thickness first, as in a ½ x 9 plate.



2 Cold-Formed Steel shapes

Cold formed structural steel shapes produced by passing sheet or strip steel at room temperature through rolls or press brakes and then bending the steel into desired shapes. In addition, it can divided into two types:

- Framing members: have the general outline of well-established hot-rolled shapes, such as channels, zees, and hat shapes. I-shapes made by spot -welding together two channels or a channel and two angles. They extensively used as purlins, girts, wall studs, chord member of open-web steel joists, and so on.

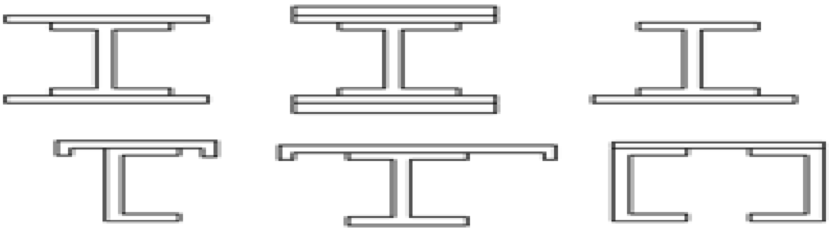


- Surface Members: are load-resisting shapes, which also provide useful surface. They extensively used in roof, floor, wall, and, partition constructions due to their favorable weight-strength and weight-stiffness ratios.

3 Built-Up Sections

Built-up sections include welded plate girders and plates welded to the top or bottom flanges of W-sections. Plate girders used to support heavy loads where the listed standard steel sections are inadequate to support the loads. Built-up sections used as lintels and as reinforcement for existing beams and columns.

Other built-up shapes include double angles (2L) and double channels (2C) placed back-to-back in contact with each other or separated by spacers, and W- and M-shapes with cap channels that used to increase the bending capacity of W- and S-shapes about their weaker (y-y) axis.



Steel Properties:

1- Material of constriction (chemical components)

The strength of steel depends on its consistency of [carbon, alloys, silicon, manganese, copper, molybdenum, nickel, phosphors, vanadium, zirconium, chromium, columbium…etc.

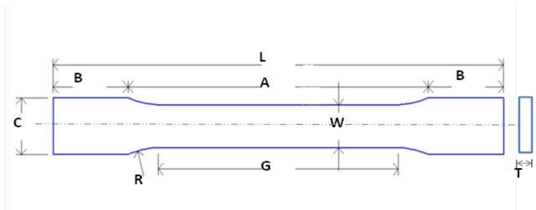
Carbon & manganese are the mean element to increase the strength.

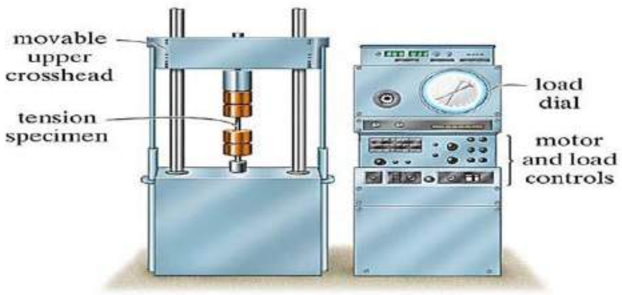
Product Analysis Tolerances		
Element	**Symbols**	**Max. specified value %**
Iron	**Fe**	**96.08**
Carbon	**C**	**0.15**
Manganese	**Mn**	**0.6**
Phosphorus	**P**	**0.04**
Sulfur	**S**	**0.05**
Silicon	**Si**	**0.3**

2- Mechanical properties of steel alloy

The stress strain curve of the mild steel is obtained from the standard tension test as shown in the Fig. below and is characterized by the following

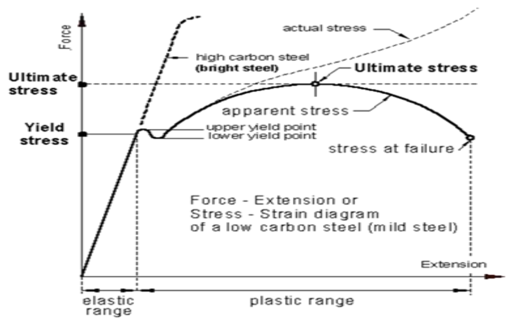
- An initial linear relation between the stress and the strain, which defined the young's modulus of the steel within this zone the material, is perfectly elastic.
- A yield point at which the material starts to behave in plastic manner.
- Tensile strength defined as a maximum value for the stress.





No.	Measure	Nominal (mm)
1	G-Gage length	200
2	W-Width	40
3	T-Thickness	5
4	R-Radius of fillet ,Min.	13
5	L-Overall length, Min.	450
6	A-Length of reduced section, Min.	225
7	B-length of grips section, Min	75

Dimension of steel plate coupons



Typical stress-strain curve of steel plate specimens

Stress = $\sigma t = P / A$
Strain = $\varepsilon = \Delta \ell / \ell o$
Where
σt = Computed tensile stress
P = Applied tensile load
A= Cross-sectional area of the tensile specimen: is value assumed constant throughout the test; decrease in cross sectional area neglected.
E = Unit strain elongation
$\Delta\ell$ = Elongation or the change in length between two reference points on the tensile specimen
ℓ_o= Original length between two reference points (may be two punch marks) placed longitudinally on the tensile specimen before loading.

Some of the important structural properties of steel are listed in this Table

Item	Symbols	Specified value
Young's Modulus	**E**	**29000 ksi**
Yield Strength	**fy**	**Table 2-3 / page 2-39 in AISC Manual show the strength of steel according to its type**
Ultimate Strength	**fu**	
Poisson`s Ratio	**μ**	**0.3**
Shear Modulus	**G**	**11000 ksi.**
Weight of Steel	**γ**	**490 lb / ft^3**

Table 2–3
Applicable ASTM Specifications for Various Structural Shapes

Steel Type	ASTM Designation		F_y Min. Yield Stress (ksi)	F_u Tensile Stress[a] (ksi)	Applicable Shape Series: W	M	S	HP	C	MC	L	HSS Rect.	HSS Round	Pipe
Carbon	A36		36	58-80[b]	▦	■	■	▦	■	■	■			
	A53 Gr. B		35	60										■
	A500	Gr. B	42	58									■	
			46	58								■		
		Gr. C	46	62									▦	
			50	62								▦		
	A501		36	58								▦	▦	
	A529[c]	Gr. 50	50	65-100	▦	▦	▦	▦	▦	▦	▦			
		Gr. 55	55	70-100	▦	▦	▦	▦	▦	▦	▦			
High-Strength Low-Alloy	A572	Gr. 42	42	60	▦	▦	▦	▦	▦	▦	▦			
		Gr. 50	50	65[d]	▦	▦	▦	■	▦	▦	▦			
		Gr. 55	55	70	▦	▦	▦	▦	▦	▦	▦			
		Gr. 60[e]	60	75	▦	▦	▦	▦	▦	▦	▦			
		Gr. 65[e]	65	80	▦	▦	▦	▦	▦	▦	▦			
	A618[f]	Gr. I & II	50[g]	70[g]								▦	▦	
		Gr. III	50	65								▦	▦	
	A913	50	50[h]	60[h]	▦	▦	▦	▦	▦	▦	▦			
		60	60	75	▦	▦	▦	▦	▦	▦	▦			
		65	65	80	▦	▦	▦	▦	▦	▦	▦			
		70	70	90	▦	▦	▦	▦	▦	▦	▦			
	A992		50-65[i]	65[i]	■	▦	▦	▦	▦	▦	▦			
Corrosion Resistant High-Strength Low-Alloy	A242		42[j]	63[j]	▦									
			46[k]	67[k]	▦			▦			▦			
			50[l]	70[l]	▦	▦	▦	▦	▦	▦	▦			
	A588		50	70	▦	▦	▦	▦	▦	▦	▦			
	A847		50	70								▦	▦	

■ = Preferred material specification.
▦ = Other applicable material specification, the availability of which should be confirmed prior to specification.
□ = Material specification does not apply.

[a] Minimum unless a range is shown.
[b] For shapes over 426 lb/ft, only the minimum of 58 ksi applies.
[c] For shapes with a flange thickness less than or equal to $1\frac{1}{2}$ in. only. To improve weldability a maximum carbon equivalent can be specified (per ASTM Supplementary Requirement S78). If desired, maximum tensile stress of 90 ksi can be specified (per ASTM Supplementary Requirement S79).
[d] If desired, maximum tensile stress of 70 ksi can be specified (per ASTM Supplementary Requirement S91).
[e] For shapes with a flange thickness less than or equal to 2 in. only.
[f] ASTM A618 can also be specified as corrosion-resistant; see ASTM A618.
[g] Minimum applies for walls nominally $\frac{3}{4}$-in. thick and under. For wall thicknesses over $\frac{3}{4}$ in., $F_y = 46$ ksi and $F_u = 67$ ksi.
[h] If desired, maximum yield stress of 65 ksi and maximum yield-to-tensile strength ratio of 0.85 can be specified (per ASTM Supplementary

Specification, Loads and Method of Design philosophies:

The AISC specifications provide two acceptable methods for design steel structural member and their connection.
These are **Load and Resistance Factor Design (LRFD)** and **Allowable Strength Design (ASD).** Both methods based on the limit state design principle, which provided the boundaries of structural usefulness.

Allowable Strength Design (ASD)
In the allowable strength design (ASD) method, member is selected, so that allowable strength is greater than or equal to the applied service load (load effect, or the required strength) (Ra). The allowable strength is the nominal strength divided by a safety factor that is depending on the limit state will be considered.

$$Rn/\Omega \geq Ra$$

Where:-
Rn/Ω = Allowable Strength
Ra= Required allowable strength, or applied service load or load effect determined by using the ASD load combination.
Ω = safety factor (usually less greater than 1.0)

Load and Resistance Factor Design Method (LRFD)

In the Load and Resistance Factor Design (LRFD) method, the safety margin is realize by using load factors and resistance factor that are determine from probabilistic analysis based on a survey of the reliability indices. The load factors vary depending on the type of load because of the different degree of certainty in predicting each load type and the resistance factors prescribed in the AISC specification vary depending on the load effects.
The LRFD method use a limit state design method (a limit state is the point at which a structures or structure member reach its limits of usefulness). The basic LRFD, limit state design equation required that the design strength (θRn) be greater than or equal to the sum of the factored loads or load effects mathematically, this can be written as

$$\theta Rn \geq Ru$$

Where:-
Rn= theoretical or nominal strength or resistance of the member determined by using AISC specification
Ru= required strength or sum of the factored loads or load effects by using the LRFD load combination
θ = resistance or strength reduction factor (usually less than 1.0)

Computation of loads for LRFD & ASD methods

Based on AISC Specification Sections B3.3 and B3.4, the required strength (either Pu, Mu Vu, etc. for LRFD or Pa, Ma, Va, etc. for ASD) is determined for the appropriate load magnitudes, load factors and load combinations given in the applicable building code. These are usually based on ASCE/SEI 7, which may be used when there is no :applicable building code. The common loads found in building structures are

D = Dead load
L = Live load due to occupancy
Lr = Roof live load
S = Snow load
R = Nominal load due to initial rainwater or ice exclusive of the ponding contribution
W = Wind load
E = Earthquake load

Load and Resistance Factor Design

For LRFD, the required strength is determined from the following factored combinations, which are based on ASCE/SEI 7 Section 2.3:

1.4 D

1.2 .D + 1.6L + 0.5(Lr or S or R)

1.2 D + 1.6 (Lr or S or R) + (0.5L or 0.8W)

1.2 D + 1.6W + 0.5L + 0.5(Lr or S or R)

1.2D ± 1.0 E+ 0.5L +0.2S

0.9D ± (1.6W or 1.0E)

Allowable Strength Design

For ASD, the required strength is determined from the following combinations, which are also based on ASCE/SEI 7 Section 2.4:

D

D+L

D + (Lr or S or R)

D + 0.75L + 0.75(Lr or S or R)

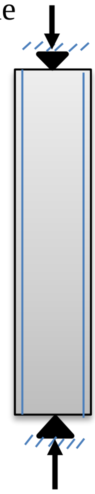
D ± (W or 0.7 E)

D ± 0.75(W or 0.7 E) +0.75 L+0.75 (Lr or S or R)

0.6D± (W or 0.7E)

Example

A column (compression member) in the upper story of a building is subject to the following loads:



Dead load: 109 kips compression
Floor live load: 46 kips compression
Roof live load: 19 kips compression
Snow: 20 kips compression

Determine the controlling load combination for LRFD and the corresponding factored load (Pu)

Solution:-

Combination 1:
1.4D = 1.4(109) = 152.6 kips

Combination 2:
1.2D + 1.6L + 0.5(Lr or S or R)
Because S is larger than Lr and R = 0, we need to evaluate this combination, only once, using S
1.2D + 1.6L + 0.5S = 1.2(109) + 1.6(46) + 0.5(20) =214.4 kips

Combination 3:
1.2D + 1.6(Lr or S or R) + (0.5L or 0.5W)
In this combination we use S instead of Lr, and both R and W are zero
1.2D + 1.6S + 0.5L = 1.2(109) + 1.6(20) + 0.5(46) =185.8 kips

Combination 4:
1.2D + 1.0W+ 0.5L + 0.5(Lr or S or R)
This expression reduces to 1.2D + 0.5L + 0.5S,
1.2x109 +0.5x46 +0.5x20 =163.8 kips

Combination 5:
1.2D ± 1.0E + 0.5L + 0.2S
As E = 0, this expression reduces to 1.2D + 0.5L + 0.2S
1.2x109 +0.5x46+0.2x20 = 157.8 kip

Combinations 6:
0.9D ± (1.0W or 1.0E)
These combinations do not apply in this example, because there are no wind or Earthquake loads to counteract the dead load
0.9x109 =98.1 kip

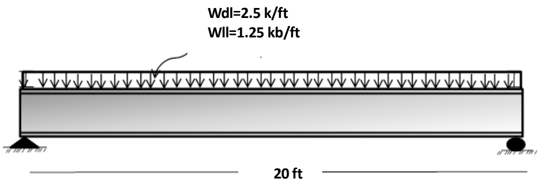
Therefore the combination .2 controls, and the factored load (Pu) is 214.4 kips

Homework

For the above example, determine the controlling load combination for ASD and the corresponding required service load strength

Example

A simple supported floor beam with 20 ft long is used to support a service (working) loads ($W_{d.l}$= 2.5 k/ft, $W_{l.l}$ = 1.25 k/ft) calculated the working load (ASD) and ultimate load (LRFD)



1- by ASD method (working load)

W_a= W $_{d.l}$ +W $_{l.l}$

=2.5+ 1.25 = 3.75 /ft

2- by LRFD method (ultimate load)

W_u= 1.2W $_{d.l}$ +1.6 W $_{l.l}$

=1.2x2.5+ 1.6x 1.25 = 5 /ft

Example

Determine the required moment capacity acting on the beam if the calculated service moment acting on the beam as follows

M $_{d.l}$ = 55 ft. Kip and M $_{l.l}$ = 30 ft. Kip

1-by ASD method (working moment)

M_a= M $_{d.l}$ +M $_{l.l}$

=55+ 30 = 85 ft. kip

2-by LRFD method (ultimate moment)

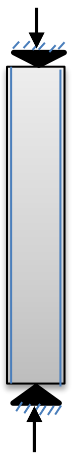
M_u= 1.2M $_{d.l}$ +1.6 M $_{l.l}$

=1.2x55+ 1.6x 30 = 114 ft. kip

Example

Determine the required factored load acting on the column if the calculated service loads as follows

P $_{d.l}$ = 50 kip and P $_{l.l}$ = 100 Kip



1-by ASD method (Working load)

P_a= P $_{d.l}$ +P $_{l.l}$

=50+ 100 = 150 kip

2-by LRFD method (Ultimate load)

P_u= 1.2P $_{d.l}$ +1.6 P $_{l.l}$

=1.2x50+ 1.6x 100 = 240 kip