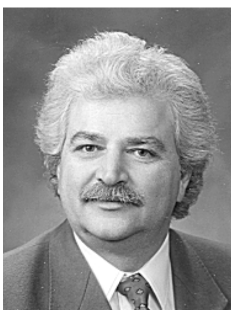
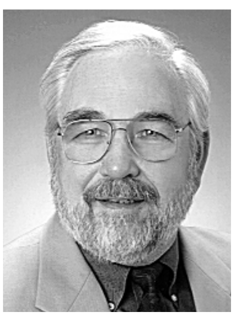
Rules of Thumb for Steel Design





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In earlier times *when computers were neither available nor essential, one objective of the structural design process was to discover a computational method, which was elegant, simple and appropriately accurate. When such a process was identified it was recorded as an expedient approach to solving a recurring structural design problem. Thus, quick "Rules of Thumb" became essential resources for the structural engineer. As computer software has proliferated, become very comprehensive, and been made very user friendly, the importance of "Rules of Thumb" and approximate methods has been diminished. It has been argued that, with the computational speed and ease of application of computer methods, the need for approximations and "Rules of Thumb" no longer exists. However, equally imposing arguments can be made for the value of these quick approaches such as:*

- *The structural engineer should have tools to make on-the-spot intelligent decisions,*
- *A reasonable solution is often required as computer input,*
- *The validity of the computer output should be verified with rational approximations.*

So, with the objective of fostering continued development, use and enthusiasm for "Rules of Thumb" and approximate methods, several steel framing "Rules of Thumb" are presented in this paper. In general, these rules of thumb are service-load based, which simplifies their application. Formal checks can then be made with factored loads and LRFD or service loads and ASD in the final design.

Structural Depths:

Inevitably, a question raised in a project concept meeting is what will be the structural depth? Regularly, the participants are impressed by the response of the structural engineer and that positive impression lasts if the actual depths designed fall within the range of these early predictions. Therefore, it is important to have established rules of thumb, which allow structural depth predictions. The depth of the structural system is influenced by the span of the elements as well as such variables as the spacing of elements, loads and loading conditions, continuity, etc. Nonetheless, ratios of span to depth can often be relied upon to provide a guide and a starting point from which further refinement can be made. With the caution that variables other than span need to be considered, the information in Table 1 is presented.

It is convenient to remember that serviceable steel section depths are in the range of ½" of depth for each foot of span (L/24). Some people might find it easier to remember the following simplified rule where the length is expressed in feet and the depth of the member in inches:

Depth of Roof Beams, Roof Joists = 0.5*Length

Depth of Floor Beams, Floor Joists = 0.6*Length

Depth of Composite Beams = 0.55*Length

Table 1: Structural Depths

System	L/d_s	Span Range
Steel Beam	20 to 28	0' to 75'
Steel Joist		
Floor Member	20	8' to 144'
Roof Member	24	
Plate Girder	15	40' to 100'
Joist Girder	12	20' to 100'
Steel Truss	12	40' to 300'
Space Frame	12 to 20	80' to 300'

Section Properties

Wide flange steel section properties can be estimated with reasonable accuracy when the member depth, width and foot-weight are known. Recalling that the density of steel is 490 pcf, the relationship between cross section area and foot-weight can readily be derived as:

$$A = \frac{Wt}{3.4}$$

The strong axis moment of inertia can be approximated using:

$$I_x \approx D^2 \frac{Wt}{20}$$

The radius of gyration is an important cross section property when considering column buckling. Both the strong axis and weak axis radius of gyration can be estimated using the member depth (D) and width (b) as:

$$r_y \approx 0.26\,b$$

$$r_x \approx 0.45\,D$$

Beams

The rapid determination of a steel section size can be made without reference to a steel manual using a very simple equation. If the moment capacity, depth and foot weight of the economy steel beams listed in the AISC Specification are tabulated with moment divided by the depth as the independent variable and foot weight as the dependent variable, a linear regression analysis results in a rather simple equation for F_y=36 ksi.

$$Wt \approx \frac{5\,M}{D}$$

The closest economy section of the depth used in the equation that has a foot weight greater than predicted by the equation indicates the beam that will sustain the moment. This equation was confirmed by the author using an alternate approach, coined "Visual Semi-rigorous Curve Fitting"3. If all the beam sections are included, a slope value in the linear equation of 5.2 yields closer approximations for **F_y=36 ksi**.

Consider a beam spanning 30 feet supporting a 10 foot width of floor with a total supported load of 140 psf, resulting in a moment of 157.5 foot-kips. For an 18" deep beam, the equation yields 43.75 pounds per foot. A W18x50 is the predicted section and the actual moment capacity is 176 foot-kips. If a beam depth of 21" is assumed, the equation yields 37.5 suggesting a W21x44, which has a moment capacity of 162 foot-kips.

A similar formulation for steel having **F_y = 50 ksi** produces:

$$Wt \approx \frac{3.5\,M}{D}$$

For an 18" deep beam, the equation yields 30.6 pounds per foot, therefore, a W18x35 is predicted. The actual capacity of a W18x35 beam with Fy=50 ksi is 158 foot kips.

For common composite beam floor systems (e.g. 5½" slabs with 3" composite deck, 4½" slab with 2" composite deck, etc.), the simplified equations yield relatively accurate foot weights if 70% to 75% of the simple span moment is used for M. Following are two more “Rules of Thumb” relating to composite construction and Fy=36:

In ASD Number of shear studs required for Full Composite Action = 1.1*Wt

In LRFD Number of shear studs required for Full Composite Action = 1.25*Wt

COLUMNS

When the column axial capacity is plotted as a function of Kl/r, an approximate linear relation can be observed. Certainly, the column curve is not linear, however an accurate approximation of column capacity for Fy=36 ksi can be calculated using:

$$\mathbf{P \approx A\left(22.0 - 0.10\,\frac{Kl}{r}\right)}$$

A similar formulation for steel having $\mathbf{F_y}$ **= 50 ksi** produces:

$$\mathbf{P \approx A\left(30.0 - 0.15\,\frac{Kl}{r}\right)}$$

Thus, using the section property approximations in conjunction with a member foot-weight, width, depth and unsupported length, the capacity of a column can be approximated.

Roof Systems

A common approach to economy in steel roof systems of single story buildings is to cantilever girders over the columns. The ends of the cantilever support a reduced span beam. When this system is subjected to a uniform load and multiple equal spans are available, a cantilever length approximately equal to 15% (0.146) of the span length will result in the maximum moment in any span being equal to 1/16 wL2. For end spans, negative and positive moments can be balanced using a cantilever length equal to 25% of the first interior span.

Another approach to economical roof systems is the use of plastic analysis. Although not as critical for this system, splice locations in the plastically designed continuous beams are usually chosen so that they are close to the point of zero moment.

Hinge or splice location for cantilever or continuous roof systems is 15% to 25% of span length

Trusses

The foot weight of trusses utilizing Fy=36 ksi steel can be calculated by assuming Fa=22 ksi. The Chord Force (Fch) is then equal to the moment (M) in foot-kips divided by de (center of top chord to center of bottom chord) in feet, resulting in a chord area of M/22de. By recognizing that Wt = A*3.4, converting de to inches and assuming that de = 0.9D and that the total truss weight is equal to 3.5 times the chord weight then:

$$\mathbf{Wt \approx \frac{6\,M}{D}}$$

The same formulation using steel with Fy=50 ksi produces the following approximation:

$$Wt \approx \frac{4.5\,M}{D}$$

These weight approximations include truss joint connection material weight.

Rigid Frame Analysis Approximations:

The following "Rules of Thumb" are useful in determining preliminary sizes for Rigid Moment Frames resisting Lateral loads. They are based on the traditional "Portal Frame" approach modified from the authors' experiences with "real" frames.

$$M_{col} \approx \frac{1.2H}{2} \bullet \frac{V_{story}}{n_{col}}$$

$M_{beam} \approx {}^{M_{col}}\!/_{2}$ ***Interior Columns at Roof***

$M_{beam} \approx M_{col}$ ***Interior Columns Not at Roof***

The moments in beams framing into exterior columns are half of the above values

Steel Weight Estimates

Cost is generally the basis for confirming a structural system since safety and functions are essential for any options considered. Economy is related to the weight of the structural steel although costs are influenced by many other parameters. Yet, weight can be a valuable indicator of cost and Rules of Thumb are useful in establishing an expectation for steel weight. A quick assessment of anticipated weight serves as a check of the reliability of the weight determined by more involved investigations.

Bracing is a cost-effective means of providing lateral load resistance for low to medium rise buildings. As the building height increases, the unit steel weight increases since columns are subjected to larger loading at the lower floors and lateral load resisting components are subjected to greater loads for greater heights. Thus, one parameter influencing the steel weight is building height. A rough approximation for steel weight per square foot in a braced building using steel with Fy = 50 ksi is:

Wt(psf) = stories/3 + 7

A three-story building would have a steel weight in the range of 8 psf and a 27-story building would require 16 psf. Certainly, this relationship is an over simplification. Yet, it provides a value, which can be used to confirm that the results of a more detailed analysis are reasonable.

Tall Building Structural Systems

The late Fazlur Khan hypothesized that the appropriate structural system to resist lateral loads was directly related to building height. He predicted that structural economy could be realized using the appropriate system shown in Table 2.

Table 2: Tall Building Structural Systems	
Stories	**Lateral Load Resisting System**
<30	Rigid frame
30 to 40	Frame – shear truss
41 to 60	Belt truss
61 to 80	Framed tube
81 to 100	Truss – tube w/ interior columns
101 to 110	Bundled tube
111 to 140	Truss – tube without interior columns

Miscellaneous

End rotation of a simple beam = 0.2 radians

Deflection of simple span beam (reduction due to connections) = 80% of calculated

Roof Framing Systems

For Cantilevered or continuous roof beams :

- Run beams in short direction
- Optimum bay size is 30' x 40'

For Truss Joist and Joist roof systems:

- Run Girders in Long direction
- Optimum bay size is 40' x 40'

Nomenclature

A = Area (in^2)

b = Nominal member width (inches)

D = Nominal member depth (inches)

d_s = System depth (ft)

F_y = Yield strength of steel

H = Story Height

I = Moment of Inertia (in^4)

l = Column Length (inches)

L = Length (ft)

M = Bending moment (foot-kips)

M_{beam} = Design Moment for Beam

M_{col} = Design Moment for Column

n_{col} = Number of Columns (not bays) in the story of the Frame

P = Column Axial Capacity

r_x = Strong Axis Radius of Gyration (inches)

r_y = Weak Axis Radius of Gyration (inches)

S = Elastic Section Modulus (in3)

V_{story} = Total Story Shear for the Frame

Wt = Foot weight of the steel beam (pounds per foot)

Wt(psf) = Weight of steel structure (psf)