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Comparison of LRFD and ASD for Pre-Fabricated Gable Frame Design

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ABSTRACT: *Pre-fabricated gable frames with tapered members of varying angles were designed for six locations using both Allowable Stress Design (ASD) and Load and Resistance Factor Design (LRFD). The locations were chosen to represent a range of local loading conditions as found in ASCE's Minimum Design Loads. Roof angles varied from 10 to 45 degrees and spans varied from 20 to 200 feet. The results demonstrate significant differences in the economies of ASD and LRFD. Each design basis had scenarios from one location to the next where it was more economical. The biggest differences were for steep roofs in areas with high wind. The differences were up to 30% with LRFD generally being favored. The biggest variations were LRFD gave up to 30% less stress in some situations, and ASD gave 10% less in others.*

KEYWORDS *Gable frame design, Pre-fabricated frames, Portal frames, LRFD, ASD, and Load Combinations.*

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I. INTRODUCTION

Gable pre-fabricated steel frames are common when the architectural purpose needs wide span without middle columns such as factories, warehouses, airplane hangars, stores, halls, and sports facilities. The frame sections are custom fabricated from plates because the required sections for these types frames are large [1].

Gable-prefabricated frames are usually designed with non-prismatic members that taper from one end to the other. This allows for efficient design because the section at every point more closely matches what is needed [1].

Previous researchers have compared design methods and found differences between Allowable Stress Design (ASD) and Load and Resistance Factor Design (LRFD)[2]. For the building frame examples considered, LRFD resulted in bigger members. However, that was based on previous versions of the codes.

II. PHILOSOPHIES OF DESIGN

Two philosophies for the design of steel structures are in current use: ASD and LRFD. These two approaches have differences such as how they handle safety factors. It will be shown that because of this the two methods give different results. Therefore, under varying loading conditions as found in different locations, either method could be preferred for apparent weight savings.

2.1 Allowable Stress Design

For the past 100 years, the ASD method was the most in-use approach for the design of steel structures [3]. This approach requires keeping stress in an elastic range by limiting working stress to an allowable stress which is below yielding. Inelastic behavior is not considered. Therefore, a bigger factor of safety may be needed in order to ensure a design in an elastic range. The relationship between design strength and applied load may be expressed as follows

$$\frac{\emptyset R_n}{\gamma_i} \geq \sum Q_i \qquad (1)$$

Where:
$\emptyset$ =Resistance factor
γ_i =Overload Factor
R_n =Nominal resistance

Q_i =Load

An assumption with this method is that all loads have the same variability. With this concept in mind, the entire variability of the loads, γ, is placed on the strength side of Equation 1.

Equation 2 shows this for stress design for bending in beams. In that equation, the left side would represent nominal beam strength, M_n, divided by factor of safety and the right side is the bending moment resulting from all types of loads. Thus, Equation 1 would become

$$\frac{M_n}{FS} \geq M \quad (2)$$

Or:

$$\frac{F_y}{FS} \geq \frac{M\,c}{I} \quad (3)$$

Where:
F_y = yield stress
FS = factor of safety
M = working moment
I = Moment of inertia about axis of bending
c= extreme fiber distance

In Equation 3, the left side represents the Allowable Stress Design and the right side would be computed as elastic stress under a full service load.

2.2Load and Resistance Factor Design

AISC adopted the LRFD as a design specification in 1986 [3]. This design procedure is based on limit states. The approach was developed and considered by several researchers. However, the leader of those groups is T.V. Galambos [3].

The safety requirement for the LRFD approach is as follows

$$\emptyset R_n \geq \sum \gamma_i Q_i \quad (4)$$

The simple statement of this equation would be, the design strength, ∅Rn, provided by the resulting design must be at least equal to the sum of the applied factored service loads, $\sum\gamma_i Q_i$. The subscript i refers to each type of load such as Dead, Live, Wind and etc. The term γi depends on the variability of the load. The factored load combinations (LC) of the 1982 ANSI code became ASCE 7 [4].

2.3Comparison between ASD and LRFD

Table 1 has the ASD and LRFD load combinations according to ASCE 7-16 [5]. The number of load combinations is different for each method. There is a correspondence between some of the load combinations with each method, but the ASD method requires more combinations. Also, the load factors are different. Those load combinations must be expanded in order to cover all possible loading situations like balanced and unbalanced snow load, wind suction or compression. The generalized load combinations according to ASCE7-16 are in Table 1.

Table 1. ASCE 7-16 General load combinations

LC	LRFD	ASD
1	*1.4D*	*D*
2	*1.2D +1.6L+0.5(L_r or S or R)*	*D+L*
3	*1.2D+1.6(L_r or S or R) + (L or 0.5W)*	*D+ (L_r or S or R)*
4	*1.2D +W+L+0.5(L_r or S or R)*	*D +0.75L+0.75(L_r or S or R)*
5	*0.9D+ W*	*D+0.6W*
6	*1.2D+E_v+E_h+L +0.2S*	*D +0.75L+0.75(0.6W) +0.75(L_r or S or R)*
7	*0.9D-E_v +E_h*	*0.6D+0.6W*
8		*D+0.7E_v+0.7E_h*
9		*D+0.525E_v+0.525E_h +0.75L +0.75S*
10		*0.6D-0.7E_v+0.7E_h*

Where:
D= Dead Load
L= Live Load
Lr= Roof Live Load
S= Snow Load
W= Wind Load
R= Rain Load

Ev & Eh= Vertical and Horizontal component of earthquake respectively

As shown in Table 1 some load combinations have no correspondence in other methods because the number of load cases is different. However, some combinations have similarities. For example, in Case 2 of ASD, dead load and live load together control serviceability. In Case 2 of LRFD, additional terms are given in addition to dead and live load.

Direct comparison between similar load combinations can be done by formulations. The second load combination for each is compared below assuming that no rain, snow or roof live load acts on the member under consideration. Also, assuming ∅=0.90 for a flexural example then we get the following:

$$1.2D + 1.6L = 0.90R_n \tag{5}$$

Dividing both sides by 0.90 gives:

$$1.33D + 1.78L = R_n \tag{6}$$

In ASD LC 2:

$$D + L = \frac{R_n}{FS} \tag{7}$$

For flexural design FS is 1.67. If both sides are multiplied by 1.67:

$$1.67D + 1.67L = R_n \tag{8}$$

Dividing Equation 7 by Equation 8 gives

$$\beta = \frac{{R_n}^{LRFD}}{{R_n}^{ASD}} = \frac{1.33\ D + 1.78\ L}{1.67\ D + 1.67\ L} = \frac{0.8+1.07(\frac{L}{D})}{1+\frac{L}{D}} \tag{9}$$

Where

β = ratio of strengths required for LRFD versus ASD.

Equation 9 is dependent on live load to dead load ratio. When (L/D) is about 3 the result of both methods is the same. For (L/D) less than 3, LRFD gives a more economical result and for (L/D) greater than 3, ASD is more economical. Deciding which is more economical in Equation 9 is easy because it depends on just a ratio of two loads. The comparison is more difficult when the relationship between LRFD and ASD contains a ratio of more types of loads such as (S/D) and (W/D) or (E/D). Consider a comparison between load combinations 1.2 D +W +0.5S for LRFD with D +0.45W +0.75S for ASD. This can be formulated as:

$$\beta = \frac{R_{n-LRFD}}{R_{n-ASD}} = \frac{1.33\ D + 1.11\ W + 0.56S}{1.67\ D + 0.75W + 1.25S} = \frac{0.8+0.66(\frac{W}{D})+0.33(\frac{S}{D})}{1+0.45(\frac{W}{D})+0.75(\frac{S}{D})} \tag{10}$$

Equation 10 is not as easy to use as Equation 9 for determining economical methods because Equation 10 has two ratios. It can't be said that a particular ratio will make one design method become preferred because the controlling ratio is influenced by the other ratio.

The direct solution becomes more complicated for real structures. Often multiple load combinations are near controlling. There may be non-corresponding load cases that control depending on whether ASD or LRFD is used. To see patterns on which method may be preferred, it is necessary to consider many scenarios and then compare them. In addition, the results will depend on the type of structure, so one at a time must be considered and this project will focus on pre-fabricated steel gable frames.

III. METHODS

It was determined that six locations would be necessary to illustrate how variation in commonly controlling loads influences whether ASD or LRFD would be preferred for design of pre-fabricated gable frames. Each location was selected because either it was typical or it had extreme loadings. See Table 2 for the list of the locations and loads used. In many cases the seismic load was not controlling (NC).

Table 2. Locations and loads used

Location	Dead Load	Roof Live	Ground Snow	Wind	Earthquake			
	psf	psf	psf	mph	S_s	S_1	F_a	F_v
Boston, MA	20	20	40	120	NC	NC	NC	NC
Detroit, MI	20	20	20	108	NC	NC	NC	NC
Lake Tahoe area	20	20	120	115	1.576g	0.546g	1	1.7
Miami, FL	20	20	0	170	NC	NC	NC	NC
St. Paul, MN	20	20	50	109	NC	NC	NC	NC
Santa Barbara, CA	20	20	0	93	2.19g	0.79g	1	1.7

Miami, FL has the highest wind speed but the snow and seismic load is zero. The earthquake load is the highest in Santa Barbara, CA compared to other locations and also like Miami, snow load is zero. In the Lake Tahoe area, there is a wind load, an earthquake load and a very large snow load. In other locations, the wind load is similar; however, the snow load is different. In those locations we have a different ratio of snow to dead load with almost the same wind to dead load ratio. Assumptions about loads were made. In special wind zones that require a study, values were assumed. In order to determine the seismic weight of a structure, lateral walls were considered as masonry with weight 20 psf.

The gable spans were 20, 30, 40, 50, 60, 70, 80, 90, 100, 150, and 200 feet because wind load changes with the ratio of span to height and span to width. Roof angles varied between 10, 15, 20, 25, 30, 35 and 45 degrees because of changes in the wind and snow loads with angle. The column height and space between frames were a constant 20 feet for all cases. The column base support was hinged. For determining the unbraced length of the compression flange, the space between purlins was assumed to be 3 feet. See frame geometry in Figures 1 and 2. One typical frame in the middle was designed and is shaded in Figure 2. The total width of the structure needed to be set at a constant value for consistency. This building width influences the calculation of the leeward side wind load. There was no particular reason to pick one width over another so 20' was chosen which is the width of only one segment. A check found that the result only varied by about 1% when the width was changed, so in most cases the results are not significantly dependent on it.

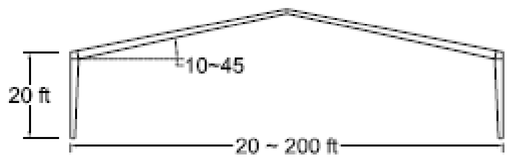

Fig.1. Typical Frame

Columns and rafters in gable frame are usually non-prismatic. Webs are assumed be linearly tapered and flanges are assumed be constant because that follows common fabrication practice. Therefore, the major axis moment of inertia will vary non-linearly in the column and rafter. Rafters and columns are defined as non-prismatic members and were the same for all locations and spans. Rather than redesigning members for each location, the stress utilization will be found even if it means the member would be overstressed. The following sections were defined for non-prismatic columns and rafters:

Column:
At base: Flange: 15×1" web: 14×0.375''
At top: Flange: 15×1" web: 30×0.375''
Rafter:
At eave: Flange: 15×1" web: 30×0.375''
At ridge: Flange: 15×1" web: 14×0.375''

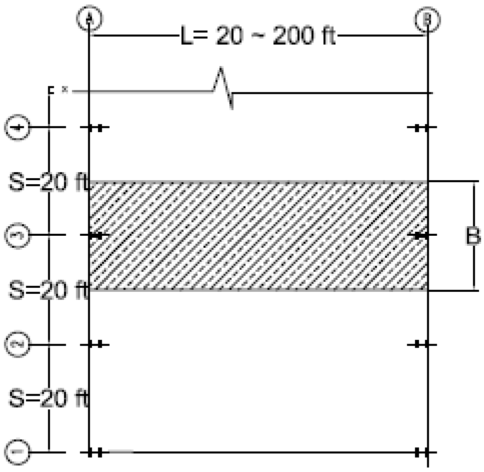

Fig.2. Plan View

For designing members AISC 360-16 was used [6]. Analysis and design has been done by ETABS 17. The load combinations in the codes are general, so a new set of combinations was created to consider each possibility in ETABS. These are shown in Table 3. There is no live load so ASD load combination number 2 is not considered.

Table 3. Expanded load combination as analyzed

LC	LRFD	LC	ASD
1	*1.4D*	1	*D*
2A	*1.2D +0.5L_r*	2	*D+L*
2B	*1.2D +0.5S_b*	3A	*D+L_r*
3A	*1.2D +1.6Lr +0.5W_s*	3B	*D+S_{ub}*
3B	*1.2D +1.6L_r +0.5W_c*	4A	*D +0.75L_r*
3C	*1.2D +1.6S_{ub} +0.5W_c*	4B	*D +0.75S_b*
4A	*1.2D +W_s +0.5L_r*	5A	*D+0.6W_s*
4B	*1.2D+ W_c +0.5L_r*	5B	*D+0.6W_c*
4C	*1.2D+ W_s +0.5S_b*	6A	*D +0.45W_s +0.75L_r*
4D	*1.2D +Wc +0.5S_b*	6B	*D +0.45W_c +0.75L_r*
5A	*0.9D +W_s*	6C	*D +0.45W_s +0.75S_b*
5B	*0.9D +W_c*	7A	*0.6D+0.6W_s*
6	*1.2D+E_h +0.2S_b*	7B	*0.6D+0.6W_c*
7	*0.9D+E_h*	8	*D+0.7E_h*
		9	*D+0.525E_h +0.75S_b*
		10	*0.6D+0.7 E_h*

Where:
S_b: Balanced Snow Load
S_{ub}: Unbalanced Snow Load
W_c: Wind Load when causes compression on windward roof
W_s: Wind Load when causes suction on windward roof

The moment frame considered was as an ordinary moment frame. The site class and seismic design category were assumed to be D. The importance factor was taken at 1. The surface roughness category was considered exposure C. The roof slope condition assumed was an unobstructed slippery surface and considered as a warm roof. For wind loading, the directional procedure was used from ASCE 7-16 [5].

Site Class D is used for each city so that comparisons between locations can be made. However, conditions at actual project sites may vary from the hypothetical. Additionally, Exposure C was used for wind, but that doesn't mean the predominant exposure in the area is that type.

The direct method was used in frame analysis. Moments in columns are expected to govern since the frames do not have significant axial loads from cranes or other attachments. Consequentially, axial analysis and determining the k factor bear little on the final result. The ASTM standard A 572 high- strength steel, grade 50 has been used for design members (F_y=50 ksi , F_u=65 ksi, F_{ye}=55 ksi, F_{ue}=71.5 ksi,E=29,000 ksi) .

Rather than redesigning members to find the actual optimal design, stress ratios will be reported. It is desirable to know the weight savings possible for each design method. However, if redesign was done, then rounding to practical values would bias the results. Instead stress ratios will be taken as an approximation for potential savings. Deflections were not considered since results were shown as stress ratios. Doing a fair comparison of whether weight savings are achievable would require ruling out deflection as controlling. However, that would require redesign. Preliminary estimates were that deflections did not control.

IV. RESULTS

Table 4 shows detailed results for Boston, MA for roof slope 20 degrees. Height is constant at 20'. Only the controlling load cases were shown. A total of 924 analyses were performed for the entire study, so this level of detail can't be shown for each. The variable β defined in Equations 9 and 10 is redefined to compare between whichever load combinations control. It is given here as a percentage of lower stress found in the preferred method.

Tables 5 to 10 represent controlling load combination for each location. The shaded load combination is the one that gives the lowest stress and the most likely lightest weight design. Tables 11 to 16 show which methods give the lowest stress and the difference.

According to Tables 5 to 9 and 11 to 15 there appears to be a dominance of LRFD for most situations. There is a pattern of ASD controlling with low spans that have high roof angles. However, even with that, no simple equation is obvious. Additionally, the complex patterns in Lake Tahoe seen in Tables 10 and 16 throw out the possibility any generalizations about ASD controlling only in those situations.

Looking at the controlling load case illustrates further levels of complexity. Miami as shown in Table 8 for roof slope of 35 degrees will be discussed to illustrate this. Initially, there are a few patterns visible. First, with lower spans ASD is preferred. Second, all of the controlling loadcases are controlled by cases with windward roof compression. Third, the roof live load is important in most spans. However, there are some complexities. First, both methods have differing load combinations controlling for shorter or longer spans, and the transition between those controlling combinations is different for each method. Second, the preference of one method over another is not immediately relatable to how these methods transition between controlling load combinations. For L/H from 2.5 to 5 at that roof angle in Miami, both methods are controlled consistently by the same cases. For ASD it is: D +0.45W_c +0.75L_r and for LRFD: 1.2D +W_c +0.5L_r. These load combinations account for the same loadings but differently. Not that within this range, for L/H equal to 2.5 and 3 ASD is preferred, but for L/H equal to 3.5 to 5 LRFD results in a lower stress ratio. Table 14 shows a continuous linear change in how each is preferred over that range. Therefore, it is apparent that results are more dependent on height to width ratios and slope than whether certain load combinations dominate.

Loads vary based on the geometry of the frame. For example, the amount of snow load depends on roof slope but is independent of the column's height. Snow load decreases for higher slopes. Wind load depends on both roof slope and span to height ratio and it may increase or decrease as those variables change.

According to Equations 9 and 10 the main factor that could affect results of both methods is the ratio of loads to each other. For example, the ratio of wind to dead load or ratio of snow to dead load. Therefore, generalizations are made about under what conditions various loads control. This will be useful in understanding structures, but also in seeing how ASD and LRFD handle loadings differently.

Table 4. Boston, MA

L/H	Method	Stress Ratio and governing LC				Ave Stress	Preferred method	Less stress %
		Column	LC	Rafter	LC			
1	ASD	0.065	$D+0.6W_c$	0.061	$D+0.6\ W_c$	0.063	ASD	10.00
	LRFD	0.072	$1.2D+\ W_c+0.5S_b$	0.068	$1.2D+\ W_c+0.5S_b$	0.070		
1.5	ASD	0.087	$D+0.45\ W_c+0.75S_b$	0.082	$D+0.45\ W_c+0.75S_b$	0.085	ASD	1.17
	LRFD	0.087	$1.2D+\ W_c+0.5S_b$	0.084	$1.2D+\ W_c+0.5S_b$	0.086		
2	ASD	0.122	$D+0.45\ W_c+0.75S_b$	0.116	$D+0.45\ W_c+0.75S_b$	0.119	LRFD	7.56
	LRFD	0.113	$1.2D+0.5\ W_c+1.6L_r$	0.107	$1.2D+0.5\ W_c+1.6L_r$	0.110		
2.5	ASD	0.165	$D+0.45\ W_c+0.75S_b$	0.159	$D+0.45\ W_c+0.75S_b$	0.162	LRFD	5.56
	LRFD	0.156	$1.2D+0.5\ W_c+1.6L_r$	0.15	$1.2D+0.5\ W_c+1.6L_r$	0.153		
3	ASD	0.216	$D+0.45\ W_c+0.75S_b$	0.21	$D+0.45\ W_c+0.75S_b$	0.213	LRFD	4.23
	LRFD	0.207	$1.2D+0.5\ W_c+1.6L_r$	0.201	$1.2D+0.5\ W_c+1.6L_r$	0.204		
3.5	ASD	0.272	$D+0.45\ W_c+0.75S_b$	0.267	$D+0.45\ W_c+0.75S_b$	0.270	LRFD	3.53
	LRFD	0.263	$1.2D+0.5\ W_c+1.6L_r$	0.257	$1.2D+0.5\ W_c+1.6L_r$	0.260		
4	ASD	0.333	$D+0.45\ W_c+0.75S_b$	0.329	$D+0.45\ W_c+0.75S_b$	0.331	LRFD	2.42
	LRFD	0.326	$1.2D+0.5\ W_c+1.6\ S_{ub}$	0.32	$1.2D+0.5\ W_c+1.6S_{ub}$	0.323		
4.5	ASD	0.399	$D+0.45\ W_c+0.75S_b$	0.395	$D+0.45\ W_c+0.75S_b$	0.397	LRFD	2.39
	LRFD	0.39	$1.2D+0.5\ W_c+1.6S_{ub}$	0.385	$1.2D+0.5\ W_c+1.6S_{ub}$	0.388		
5	ASD	0.471	$D+\ S_{ub}$	0.466	$D+0.45\ W_c+0.75S_b$	0.469	LRFD	2.13
	LRFD	0.461	$1.2D+0.5\ W_c+1.6\ S_{ub}$	0.456	$1.2D+0.5\ W_c+1.6S_{ub}$	0.459		
7.5	ASD	0.891	$D+\ S_{ub}$	0.882	$D+\ S_{ub}$	0.887	LRFD	4.17
	LRFD	0.852	$1.2D+0.5\ W_c+1.6\ S_{ub}$	0.847	$1.2D+0.5\ W_c+1.6S_{ub}$	0.850		
10	ASD	1.36	$D+\ S_{ub}$	1.353	$D+\ S_{ub}$	1.357	LRFD	5.71
	LRFD	1.28	$1.2D+0.5\ W_c+1.6S_{ub}$	1.278	$1.2D+0.5\ W_c+1.6\ S_{ub}$	1.279		

Generally, the same patterns were found in Detroit, Boston and St. Paul. All three locations were chosen because they showed variations of loadings that are more common across the country. The fact that these have similar patterns makes application of this result easier for many designs. However, the extreme loadings in other regions all have unique patterns of how different methods control.

In Detroit, Boston and St. Paul, the wind compression on the windward roof is a significant factor most of the time. Wind is more dominant for higher roof angles, especially when the span is short. For smaller roof angles, especially for longer spans, snow is more dominant, and unbalanced snow is more dominant as the angles decrease and spans lengthen. This is because the snow load decreases with the roof angle, and unbalanced snow need not be considered for steep roof angles. However, windward roof compression from wind increases as the angle increases. A relationship was found to say which loading controls. When the ratio of maximum wind moment to dead moment was over 3.45, then ASD was preferred in all cities. Otherwise, LRFD was preferred. In the geometries and loadings, the maximum bending moment was found at the top of the column. For these locations, these ratios were found to be in these ranges: $0.00< (M_W/M_D)<11.00$ and $0.30< (M_S/M_D) <1.75$. Therefore, there are many conditions when either method is preferred.

The limit above 3.45 only applies when snow is not a dominant loading. When spans or roof angles cause the ratio of maximum moment from snow over moment from dead to exceed 1.70, then the processes for Lake Tahoe below should be followed to find the preferred method.

Miami is a unique situation since it has no snow load, but otherwise is very similar to Detroit, Boston and St. Paul. Instead of snow controlling for long shallow spans, the roof live load controls. However, the conclusion about the controlling method is the same in that a wind to dead moment ratio of 3.45 is the transition to preferring ASD. For Miami, the ratio of bending moment from wind to dead was found over this range: $0.00< (M_W/M_D)<19.5$. Since Miami has very high wind, it has a wider range where ASD is controlling.

Table 5. Controlling load cases for Boston, MA

L/H	method	θ = 10	θ = 15	θ = 20	θ = 25	θ = 30	θ = 35	θ = 45
1	ASD	D+0.6W_c	D+0.6W_c	D+0.6W_c	D+0.6W_c	D+0.6W_c	D+0.6W_c	D+0.6W_c
	LRFD	1.2D +W_c +0.5S_b	1.2D +W_c +0.5S_b	1.2D +W_c +0.5S_b	1.2D +W_c +0.5L_r	1.2D +W_c +0.5L_r	1.2D +W_c +0.5L_r	1.2D +W_c +0.5L_r
1.5	ASD	D +0.45W_c +0.75S_b	D +0.45W_c +0.75S_b	D +0.45W_c +0.75S_b	D +0.45W_c +0.75L_r	D +0.45W_c +0.75L_r	D +0.45W_c +0.75L_r	D+0.6W_c
	LRFD	1.2D +W_c +0.5S_b	1.2D +W_c +0.5S_b	1.2D +W_c +0.5S_b	1.2D +W_c +0.5L_r	1.2D +W_c +0.5L_r	1.2D +W_c +0.5L_r	1.2D +W_c +0.5L_r
2	ASD	D +0.45W_c +0.75S_b	D +0.45W_c +0.75S_b	D +0.45W_c +0.75S_b	D +0.45W_c +0.75L_r	D +0.45W_c +0.75L_r	D +0.45W_c +0.75L_r	D +0.45W_c +0.75L_r
	LRFD	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6L_r	1.2D +W_c +0.5L_r	1.2D +W_c +0.5L_r	1.2D +W_c +0.5L_r	1.2D +W_c +0.5L_r
2.5	ASD	D +0.45W_c +0.75S_b	D +0.45W_c +0.75S_b	D +0.45W_c +0.75S_b	D +0.45W_c +0.75L_r	D +0.45W_c +0.75L_r	D +0.45W_c +0.75L_r	D +0.45W_c +0.75L_r
	LRFD	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +W_c +0.5L_r	1.2D +W_c +0.5L_r
3	ASD	D +0.45W_c +0.75S_b	D +0.45W_c +0.75S_b	D +0.45W_c +0.75S_b	D +0.45W_c +0.75L_r	D +0.45W_c +0.75L_r	D +0.45W_c +0.75L_r	D +0.45W_c +0.75L_r
	LRFD	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +W_c +0.5L_r
3.5	ASD	D+S_{ub}	D+S_{ub}	D +0.45W_c +0.75S_b	D +0.45W_c +0.75L_r	D +0.45W_c +0.75L_r	D +0.45W_c +0.75L_r	D +0.45W_c +0.75L_r
	LRFD	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +W_c +0.5L_r
4	ASD	D+S_{ub}	D+S_{ub}	D +0.45W_c +0.75S_b	D +0.45W_c +0.75L_r	D +0.45W_c +0.75L_r	D +0.45W_c +0.75L_r	D +0.45W_c +0.75L_r
	LRFD	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +W_c +0.5L_r
4.5	ASD	D+S_{ub}	D+S_{ub}	D +0.45W_c +0.75S_b	D +0.45W_c +0.75L_r	D +0.45W_c +0.75L_r	D +0.45W_c +0.75L_r	D +0.45W_c +0.75L_r
	LRFD	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +W_c +0.5L_r
5	ASD	D+S_{ub}	D+S_{ub}	D+S_{ub}	D +0.45W_c +0.75L_r	D +0.45W_c +0.75L_r	D +0.45W_c +0.75L_r	D +0.45W_c +0.75L_r
	LRFD	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +W_c +0.5L_r
7.5	ASD	D+S_{ub}	D+S_{ub}	D+S_{ub}	D +0.45W_c +0.75L_r	D +0.45W_c +0.75L_r	D +0.45W_c +0.75L_r	D +0.45W_c +0.75L_r
	LRFD	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r
10	ASD	D+S_{ub}	D+S_{ub}	D+S_{ub}	D+L_r	D +0.45W_c +0.75L_r	D +0.45W_c +0.75L_r	D +0.45W_c +0.75L_r
	LRFD	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r

For Santa Barbara seismic loading controls for short spans. However, for longer spans, the roof surface area increases the total wind and the roof live load. In nearly all situations, LRFD gives more efficient designs. ASD has substantial additional factors of safety requirements above LRFD for the loading combinations that are controlling. Further study is necessary to determine the threshold of how dominate seismic loading has to be in order for this preference to hold.

The Lake Tahoe results are very complex because of the changing effects of snow with the roof angle. Snow is a factor in all loading combinations for all frame geometries. The unbalanced snow load is controlling most of the time for roof angles up to 30 degrees. However, above 30.2 degrees, consideration of the unbalanced snow load it not required under the code. When that term suddenly drops, the balanced snow load suddenly predominates. The preference between ASD and LRFD also sharply changes at the same point. This occurs because based on the safety factors in the controlling load combinations, LRFD weights an unbalanced snow load more highly, but ASD weights a balanced snow more highly.

Table 6. Controlling load cases for Detroit, MI

L/H	method	θ = 10	θ = 15	θ = 20	θ = 25	θ = 30	θ = 35	θ = 45
1	ASD	$D+0.6W_c$	$D+0.6W_c$	$D+0.6W_c$	$D+0.6W_c$	$D+0.6W_c$	$D+0.6W_c$	$D+0.6W_c$
	LRFD	$1.2D+0.5L_r+W_c$	$1.2D+0.5L_r+W_c$	$1.2D+0.5L_r+W_c$	$1.2D+0.5L_r+W_c$	$1.2D+0.5L_r+W_c$	$1.2D+0.5L_r+W_c$	$1.2D+0.5L_r+W_c$
1.5	ASD	$D+0.75L_r+0.45W_c$	$D+0.75L_r+0.45W_c$	$D+0.75L_r+0.45W_c$	$D+0.75L_r+0.45W_c$	$D+0.75L_r+0.45W_c$	$D+0.75L_r+0.45W_c$	$D+0.75L_r+0.45W_c$
	LRFD	$1.2D+0.5L_r+W_c$	$1.2D+0.5L_r+W_c$	$1.2D+0.5L_r+W_c$	$1.2D+0.5L_r+W_c$	$1.2D+0.5L_r+W_c$	$1.2D+0.5L_r+W_c$	$1.2D+0.5L_r+W_c$
2	ASD	$D+0.75L_r+0.45W_c$	$D+0.75L_r+0.45W_c$	$D+0.75L_r+0.45W_c$	$D+0.75L_r+0.45W_c$	$D+0.75L_r+0.45W_c$	$D+0.75L_r+0.45W_c$	$D+0.75L_r+0.45W_c$
	LRFD	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$	$1.2D+0.5L_r+W_c$	$1.2D+0.5L_r+W_c$
2.5	ASD	$D+0.75L_r+0.45W_c$	$D+0.75L_r+0.45W_c$	$D+0.75L_r+0.45W_c$	$D+0.75L_r+0.45W_c$	$D+0.75L_r+0.45W_c$	$D+0.75L_r+0.45W_c$	$D+0.75L_r+0.45W_c$
	LRFD	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$	$1.2D+0.5L_r+W_c$
3	ASD	$D+L_r$	$D+L_r$	$D+0.75L_r+0.45W_c$	$D+0.75L_r+0.45W_c$	$D+0.75L_r+0.45W_c$	$D+0.75L_r+0.45W_c$	$D+0.75L_r+0.45W_c$
	LRFD	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$	$1.2D+0.5L_r+W_c$
3.5	ASD	$D+L_r$	$D+L_r$	$D+0.75L_r+0.45W_c$	$D+0.75L_r+0.45W_c$	$D+0.75L_r+0.45W_c$	$D+0.75L_r+0.45W_c$	$D+0.75L_r+0.45W_c$
	LRFD	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$
4	ASD	$D+L_r$	$D+L_r$	$D+L_r$	$D+0.75L_r+0.45W_c$	$D+0.75L_r+0.45W_c$	$D+0.75L_r+0.45W_c$	$D+0.75L_r+0.45W_c$
	LRFD	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$
4.5	ASD	$D+L_r$	$D+L_r$	$D+L_r$	$D+0.75L_r+0.45W_c$	$D+0.75L_r+0.45W_c$	$D+0.75L_r+0.45W_c$	$D+0.75L_r+0.45W_c$
	LRFD	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$
5	ASD	$D+L_r$	$D+L_r$	$D+L_r$	$D+0.75L_r+0.45W_c$	$D+0.75L_r+0.45W_c$	$D+0.75L_r+0.45W_c$	$D+0.75L_r+0.45W_c$
	LRFD	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$
7.5	ASD	$D+L_r$	$D+L_r$	$D+L_r$	$D+L_r$	$D+0.75L_r+0.45W_c$	$D+0.75L_r+0.45W_c$	$D+0.75L_r+0.45W_c$
	LRFD	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$
10	ASD	$D+L_r$	$D+L_r$	$D+L_r$	$D+L_r$	$D+L_r$	$D+0.75L_r+0.45W_c$	$D+0.75L_r+0.45W_c$
	LRFD	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$	$1.2D+1.6L_r+0.5W_c$

A simple general observation can be made for Lake Tahoe that above 30 degrees roof angle, most of the time a designer could use LRFD if they wanted the most lightweight design. Also, below a roof angle of 20 degrees, LRFD would be preferred with little consequence of slightly larger weights if ASD were actually better. From 20 to 30 degrees, ASD would be preferred. However, these observations only apply to the exact loadings that were picked for this location. The geometries for favoring one method over another would be different in other locations with other loadings even if snow is dominant.

Generalizations based on load ratios were given above for Detroit, Boston and St. Paul. As mentioned above for those cities, if the snow loading is high for particular geometries, then the formulation above needs tweaking. When the ratio of snow to dead bending moment is above 1.70 for any region with snow, then these additional rules can be used.

When snow increases to $1.70< (M_S/M_D)<2.40$, with$(M_W/M_D)>4.98$ ASD is preferred, but LRFD is preferred for lower than 4.98. With snow higher at $2.40< (M_S/M_D) < 3.25$ and with$(M_W/M_D)>0.21$ ASD is preferred, but LRFD otherwise. For $3.25< (M_S/M_D) <4.00$, ASD only is preferred in the range of $0.17< (M_W/M_D)<0.49$, but LRFD is preferred otherwise. With the highest snow $(M_S/M_D) >4.00$, LRFD is preferred. Differing frame geometries were found to have loads in all of these ranges in Lake Tahoe.

Table 7. Controlling load cases for St. Paul, MN

L/H	method	θ = 10	θ = 15	θ = 20	θ = 25	θ = 30	θ = 35	θ = 45
1	ASD	D $+0.45W_c$ $+0.75S_b$	D $+0.45W_c$ $+0.75S_b$	D $+0.45W_c$ $+0.75S_b$	D$+0.6W_c$	D$+0.6W_c$	D$+0.6W_c$	D$+0.6W_c$
	LRFD	1.2D $+W_c$ $+0.5S_b$	1.2D $+W_c$ $+0.5S_b$	1.2D $+W_c$ $+0.5S_b$	1.2D $+0.5S_b$ $+W_c$	1.2D $+0.5S_b$ $+W_c$	1.2D $+0.5L_r$ $+W_c$	1.2D $+0.5L_r$ $+W_c$
1.5	ASD	D $+0.45W_c$ $+0.75S_b$	D $+0.45W_c$ $+0.75S_b$	D $+0.45W_c$ $+0.75S_b$	D $+0.75S_b$ $+0.45W_c$	D $+0.75S_b$ $+0.45W_c$	D $+0.75L_r$ $+0.45W_c$	D $+0.75L_r$ $+0.45W_c$
	LRFD	1.2D $+0.5W_c$ $+1.6S_{ub}$	1.2D $+0.5W_c$ $+1.6S_{ub}$	1.2D $+0.5W_c$ $+1.6S_{ub}$	1.2D +0.5S $+W_c$	1.2D +0.5S $+W_c$	1.2D $+0.5L_r$ $+W_c$	1.2D $+0.5L_r$ $+W_c$
2	ASD	D $+0.45W_c$ $+0.75S_b$	D $+0.45W_c$ $+0.75S_b$	D $+0.45W_c$ $+0.75S_b$	D $+0.75S_b$ $+0.45W_c$	D $+0.75S_b$ $+0.45W_c$	D $+0.75L_r$ $+0.45W_c$	D $+0.75L_r$ $+0.45W_c$
	LRFD	1.2D $+0.5W_c$ $+1.6S_{ub}$	1.2D $+0.5W_c$ $+1.6S_{ub}$	1.2D $+0.5W_c$ $+1.6S_{ub}$	1.2D $+1.6S_{ub}$ $+0.5W_c$	1.2D $+1.6S_{ub}$ $+0.5W_c$	1.2D $+0.5L_r$ $+W_c$	1.2D $+0.5L_r$ $+W_c$
2.5	ASD	D $+0.45W_c$ $+0.75S_b$	D $+0.45W_c$ $+0.75S_b$	D $+0.45W_c$ $+0.75S_b$	D $+0.75S_b$ $+0.45W_c$	D $+0.75S_b$ $+0.45W_c$	D $+0.75L_r$ $+0.45W_c$	D $+0.75L_r$ $+0.45W_c$
	LRFD	1.2D $+0.5W_c$ $+1.6S_{ub}$	1.2D $+0.5W_c$ $+1.6S_{ub}$	1.2D $+0.5W_c$ $+1.6S_{ub}$	1.2D $+1.6S_{ub}$ $+0.5W_c$	1.2D $+1.6S_{ub}$ $+0.5W_c$	1.2D $+1.6L_r$ $+0.5W_c$	1.2D $+0.5L_r$ $+W_c$
3	ASD	D $+0.45W_c$ $+0.75S_b$	D $+0.45W_c$ $+0.75S_b$	D $+0.45W_c$ $+0.75S_b$	D $+0.75S_b$ $+0.45W_c$	D $+0.75S_b$ $+0.45W_c$	D $+0.75L_r$ $+0.45W_c$	D $+0.75L_r$ $+0.45W_c$
	LRFD	1.2D $+0.5W_c$ $+1.6S_{ub}$	1.2D $+0.5W_c$ $+1.6S_{ub}$	1.2D $+0.5W_c$ $+1.6S_{ub}$	1.2D $+1.6S_{ub}$ $+0.5W_c$	1.2D $+1.6S_{ub}$ $+0.5W_c$	1.2D $+1.6L_r$ $+0.5W_c$	1.2D $+0.5L_r$ $+W_c$
3.5	ASD	D$+S_{ub}$	D$+S_{ub}$	D $+0.45W_c$ $+0.75S_b$	D $+0.75S_b$ $+0.45W_c$	D $+0.75S_b$ $+0.45W_c$	D $+0.75L_r$ $+0.45W_c$	D $+0.75L_r$ $+0.45W_c$
	LRFD	1.2D $+0.5W_c$ $+1.6S_{ub}$	1.2D $+0.5W_c$ $+1.6S_{ub}$	1.2D $+0.5W_c$ $+1.6S_{ub}$	1.2D $+1.6S_{ub}$ $+0.5W_c$	1.2D $+1.6S_{ub}$ $+0.5W_c$	1.2D $+1.6L_r$ $+0.5W_c$	1.2D $+1.6L_r$ $+0.5W_c$
4	ASD	D$+S_{ub}$	D$+S_{ub}$	D$+S_{ub}$	D $+0.75S_b$ $+0.45W_c$	D $+0.75S_b$ $+0.45W_c$	D $+0.75L_r$ $+0.45W_c$	D $+0.75L_r$ $+0.45W_c$
	LRFD	1.2D $+0.5W_c$ $+1.6S_{ub}$	1.2D $+0.5W_c$ $+1.6S_{ub}$	1.2D $+0.5W_c$ $+1.6S_{ub}$	1.2D $+1.6S_{ub}$ $+0.5W_c$	1.2D $+1.6S_{ub}$ $+0.5W_c$	1.2D $+1.6L_r$ $+0.5W_c$	1.2D $+1.6L_r$ $+0.5W_c$
4.5	ASD	D$+S_{ub}$	D$+S_{ub}$	D$+S_{ub}$	D $+0.75S_b$ $+0.45W_c$	D $+0.75S_b$ $+0.45W_c$	D $+0.75L_r$ $+0.45W_c$	D $+0.75L_r$ $+0.45W_c$
	LRFD	1.2D $+0.5W_c$ $+1.6S_{ub}$	1.2D $+0.5W_c$ $+1.6S_{ub}$	1.2D $+0.5W_c$ $+1.6S_{ub}$	1.2D $+1.6S_{ub}$ $+0.5W_c$	1.2D $+1.6S_{ub}$ $+0.5W_c$	1.2D $+1.6L_r$ $+0.5W_c$	1.2D $+1.6L_r$ $+0.5W_c$
5	ASD	D$+S_{ub}$	D$+S_{ub}$	D$+S_{ub}$	D $+0.75S_b$ $+0.45W_c$	D $+0.75S_b$ $+0.45W_c$	D $+0.75L_r$ $+0.45W_c$	D $+0.75L_r$ $+0.45W_c$
	LRFD	1.2D $+0.5W_c$ $+1.6S_{ub}$	1.2D $+0.5W_c$ $+1.6S_{ub}$	1.2D $+0.5W_c$ $+1.6S_{ub}$	1.2D $+1.6S_{ub}$ $+0.5W_c$	1.2D $+1.6S_{ub}$ $+0.5W_c$	1.2D $+1.6L_r$ $+0.5W_c$	1.2D $+1.6L_r$ $+0.5W_c$
7.5	ASD	D$+S_{ub}$	D$+S_{ub}$	D$+S_{ub}$	D$+S_{ub}$	D $+0.75S_b$ $+0.45W_c$	D $+0.75L_r$ $+0.45W_c$	D $+0.75L_r$ $+0.45W_c$
	LRFD	1.2D $+0.5W_c$ $+1.6S_{ub}$	1.2D $+0.5W_c$ $+1.6S_{ub}$	1.2D $+0.5W_c$ $+1.6S_{ub}$	1.2D $+1.6S_{ub}$ $+0.5W_c$	1.2D $+1.6S_{ub}$ $+0.5W_c$	1.2D $+1.6L_r$ $+0.5W_c$	1.2D $+1.6L_r$ $+0.5W_c$
10	ASD	D$+S_{ub}$	D$+S_{ub}$	D$+S_{ub}$	D$+S_{ub}$	D$+S_{ub}$	D $+0.75L_r$ $+0.45W_c$	D $+0.75L_r$ $+0.45W_c$
	LRFD	1.2D $+0.5W_c$ $+1.6S_{ub}$	1.2D $+0.5W_c$ $+1.6S_{ub}$	1.2D $+0.5W_c$ $+1.6S_{ub}$	1.2D $+1.6S_{ub}$ $+0.5W_c$	1.2D $+1.6S_{ub}$ $+0.5W_c$	1.2D $+1.6L_r$ $+0.5W_c$	1.2D $+1.6L_r$ $+0.5W_c$

V. CONCLUSION

Direct comparison between ASD and LRFD is not possible through formulation of equations because differing load cases might control for each. Results only make sense when looking at the application to real examples. This required modeling and loading with several cases which can be compared as stress ratios.

With current methods, generally LRFD produces more economical designs. However, there are some situations such as with steep roof angles, or with high snow loading where ASD can be preferred. Since ASD assumes constant variability of loads, if the loads are highly variable, it won't account for this and will give a lower weight design. Both design methods are allowed, but consideration should be given as to whether ASD is adequately accounting for extreme loads, and therefore whether it is ethical to use ASD in extreme situations. However, because LRFD more accurately models load variability, it more efficiently models structures in most situations. Decisions about that might qualify previous statements about which method is preferred. With a 30% difference in results between the methods for extreme situations, it brings up whether editing the load combinations is necessary.

Despite focusing on gable frames, the patterns seen here can be useful to designers of other steel structures. For example, gable frames and other moment frames share similarities.

Table 8. Controlling load cases for Miami, FL

L/H	method	θ = 10	θ = 15	θ = 20	θ = 25	θ = 30	θ = 35	θ = 45
1	ASD	$D+0.6W_c$	$D+0.6W_c$	$D+0.6W_c$	$D+0.6W_c$	$D+0.6W_c$	$D+0.6W_c$	$D+0.6W_c$
	LRFD	$1.2D +0.5L_r +W_c$	$1.2D +0.5L_r +W_c$	$1.2D +0.5L_r +W_c$	$1.2D +W_c +0.5L_r$	$1.2D +W_c +0.5L_r$	$1.2D +W_c +0.5L_r$	$1.2D +W_c +0.5L_r$
1.5	ASD	$D+0.6W_c$	$D+0.6W_c$	$D+0.6W_c$	$D+0.6W_c$	$D+0.6W_c$	$D+0.6W_c$	$D+0.6W_c$
	LRFD	$1.2D +0.5L_r +W_c$	$1.2D +0.5L_r +W_c$	$1.2D +0.5L_r +W_c$	$1.2D +W_c +0.5L_r$	$1.2D +W_c +0.5L_r$	$1.2D +W_c +0.5L_r$	$1.2D +W_c +0.5L_r$
2	ASD	$D +0.75L_r +0.45W_c$	$D +0.75L_r +0.45W_c$	$D +0.75L_r +0.45W_c$	$D +0.45W_c +0.75L_r$	$D +0.45W_c +0.75L_r$	$D+0.6W_c$	$D+0.6W_c$
	LRFD	$1.2D +0.5L_r +W_c$	$1.2D +0.5L_r +W_c$	$1.2D +0.5L_r +W_c$	$1.2D +W_c +0.5L_r$	$1.2D +W_c +0.5L_r$	$1.2D +W_c +0.5L_r$	$1.2D +W_c +0.5L_r$
2.5	ASD	$D +0.75L_r +0.45W_c$	$D +0.75L_r +0.45W_c$	$D +0.75L_r +0.45W_c$	$D +0.45W_c +0.75L_r$	$D +0.45W_c +0.75L_r$	$D +0.45W_c +0.75L_r$	$D+0.6W_c$
	LRFD	$1.2D +1.6L_r +0.5W_c$	$1.2D +1.6L_r +0.5W_c$	$1.2D +1.6L_r +0.5W_c$	$1.2D +W_c +0.5L_r$	$1.2D +W_c +0.5L_r$	$1.2D +W_c +0.5L_r$	$1.2D +W_c +0.5L_r$
3	ASD	$D +0.75L_r +0.45W_c$	$D +0.75L_r +0.45W_c$	$D +0.75L_r +0.45W_c$	$D +0.45W_c +0.75L_r$	$D +0.45W_c +0.75L_r$	$D +0.45W_c +0.75L_r$	$D+0.6W_c$
	LRFD	$1.2D +1.6L_r +0.5W_c$	$1.2D +1.6L_r +0.5W_c$	$1.2D +1.6L_r +0.5W_c$	$1.2D +W_c +0.5L_r$	$1.2D +W_c +0.5L_r$	$1.2D +W_c +0.5L_r$	$1.2D +W_c +0.5L_r$
3.5	ASD	$D+L_r$	$D +0.75L_r +0.45W_c$	$D +0.75L_r +0.45W_c$	$D +0.45W_c +0.75L_r$	$D +0.45W_c +0.75L_r$	$D +0.45W_c +0.75L_r$	$D +0.45W_c +0.75L_r$
	LRFD	$1.2D +1.6L_r +0.5W_c$	$1.2D +1.6L_r +0.5W_c$	$1.2D +1.6L_r +0.5W_c$	$1.2D +0.5W_c +1.6L_r$	$1.2D +W_c +0.5L_r$	$1.2D +W_c +0.5L_r$	$1.2D +W_c +0.5L_r$
4	ASD	$D+L_r$	$D+L_r$	$D +0.75L_r +0.45W_c$	$D +0.45W_c +0.75L_r$	$D +0.45W_c +0.75L_r$	$D +0.45W_c +0.75L_r$	$D +0.45W_c +0.75L_r$
	LRFD	$1.2D +1.6L_r +0.5W_c$	$1.2D +1.6L_r +0.5W_c$	$1.2D +1.6L_r +0.5W_c$	$1.2D +0.5W_c +1.6L_r$	$1.2D +0.5W_c +1.6L_r$	$1.2D +W_c +0.5L_r$	$1.2D +W_c +0.5L_r$
4.5	ASD	$D+L_r$	$D+L_r$	$D +0.75L_r +0.45W_c$	$D +0.45W_c +0.75L_r$	$D +0.45W_c +0.75L_r$	$D +0.45W_c +0.75L_r$	$D +0.45W_c +0.75L_r$
	LRFD	$1.2D +1.6L_r +0.5W_c$	$1.2D +1.6L_r +0.5W_c$	$1.2D +1.6L_r +0.5W_c$	$1.2D +0.5W_c +1.6L_r$	$1.2D +0.5W_c +1.6L_r$	$1.2D +W_c +0.5L_r$	$1.2D +W_c +0.5L_r$
5	ASD	$D+L_r$	$D+L_r$	$D +0.75L_r +0.45W_c$	$D +0.45W_c +0.75L_r$	$D +0.45W_c +0.75L_r$	$D +0.45W_c +0.75L_r$	$D +0.45W_c +0.75L_r$
	LRFD	$1.2D +1.6L_r +0.5W_c$	$1.2D +1.6L_r +0.5W_c$	$1.2D +1.6L_r +0.5W_c$	$1.2D +0.5W_c +1.6L_r$	$1.2D +0.5W_c +1.6L_r$	$1.2D +W_c +0.5L_r$	$1.2D +W_c +0.5L_r$
7.5	ASD	$D+L_r$	$D+L_r$	$D+L_r$	$D +0.45W_c +0.75L_r$	$D +0.45W_c +0.75L_r$	$D +0.45W_c +0.75L_r$	$D +0.45W_c +0.75L_r$
	LRFD	$1.2D +1.6L_r +0.5W_c$	$1.2D +1.6L_r +0.5W_c$	$1.2D +1.6L_r +0.5W_c$	$1.2D +0.5W_c +1.6L_r$	$1.2D +0.5W_c +1.6L_r$	$1.2D +0.5W_c +1.6L_r$	$1.2D +W_c +0.5L_r$
10	ASD	$D+L_r$	$D+L_r$	$D+L_r$	$D +0.45W_c +0.75L_r$	$D +0.45W_c +0.75L_r$	$D +0.45W_c +0.75L_r$	$D +0.45W_c +0.75L_r$
	LRFD	$1.2D +1.6L_r +0.5W_c$	$1.2D +1.6L_r +0.5W_c$	$1.2D +1.6L_r +0.5W_c$	$1.2D +0.5W_c +1.6L_r$	$1.2D +0.5W_c +1.6L_r$	$1.2D +0.5W_c +1.6L_r$	$1.2D +W_c +0.5L_r$

REFERENCES

[1]. Kaehler, R. C., White, D. W., & Kim, Y. D.: Frame design using web-tapered members. American Institute of Steel Construction. Design Guide 25, (2011).

[2]. Ftoeder, C. W.: Comparison of LRFD and allowable stress design methods for steel structures, (1990).

[3]. Salmon, C. G., & Johnson, J. E.:Steel Structures: Design and Behavior. 4th Edition, (1997)

[4]. Ellingwood, B., MacGregor, J. G., Galambos, T. V., & Cornell, C. A.:Probability based load criteria: load factors and load combinations. Journal of the Structural Division, 108(5), 978-997, (1982).

[5]. American Society of Civil Engineers: ASCE 7-16- Minimum design loads and associated criteria for buildings and other structures, (2016).

[6]. American Institute of Steel Construction: Specification for Structural Steel Buildings, ANSI/AISC 360-16, Chicago, IL, (2017).

[7]. Forero, N., Hernández, J., Gordillo, G.: Development of a monitoring system for a PV solar plant. Energy Conversion and Management 47(15-16), 2329–2336 (2006).

[8]. Jorge, A., Guerreiro, J., Pereira, P., Martins, J., Gomes, L.: Energy Consumption Monitoring System for Large Complexes. In: Camarinha-Matos, L.M., Pereira, P., Ribeiro, L. (eds.) DoCEIS 2010. IFIP AICT, vol. 314, pp. 22–24. Springer, Heidelberg (2010).

Table 9. Controlling load cases for Santa Barbara, CA

L/H	Method	θ = 10	θ = 15	θ = 20	θ = 25	θ = 30	θ = 35	θ = 45
1	ASD	D+0.7E	D+0.7E	D+0.7E	D+0.7E	D+0.7E	D+0.7E	D+0.7E
	LRFD	1.2D+E +0.2S_b	1.2D+E +0.2S_b	1.2D+E +0.2S_b	1.2D+E +0.2S_b	1.2D+E +0.2S_b1	1.2D +W_c +0.5L_r	1.2D +W_c +0.5L_r
1.5	ASD	D+0.7E	D+0.7E	D+0.7E	D+0.7E	D+0.7E	D+0.7E	D +0.45W_c +0.75L_r
	LRFD	1.2D+E +0.2S_b	1.2D+E +0.2S_b	1.2D+E +0.2S_b	1.2D+E +0.2S_b	1.2D+E +0.2S_b1	1.2D +W_c +0.5L_r	1.2D +W_c +0.5L_r
2	ASD	D+0.7E	D+0.7E	D+0.7E	D+0.7E	D +0.45W_c +0.75L_r	D +0.45W_c +0.75L_r	D +0.45W_c +0.75L_r
	LRFD	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +W_c +0.5L_r
2.5	ASD	D+L_r	D+L_r	D +0.45W_c +0.75L_r	D +0.45W_c +0.75L_r	D +0.45W_c +0.75L_r	D +0.45W_c +0.75L_r	D +0.45W_c +0.75L_r
	LRFD	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r
3	ASD	D+L_r	D+L_r	D+L_r	D +0.45W_c +0.75L_r	D +0.45W_c +0.75L_r	D +0.45W_c +0.75L_r	D +0.45W_c +0.75L_r
	LRFD	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r
3.5	ASD	D+L_r	D+0.7E	D+L_r	D +0.45W_c +0.75L_r	D +0.45W_c +0.75L_r	D +0.45W_c +0.75L_r	D +0.45W_c +0.75L_r
	LRFD	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r
4	ASD	D+L_r	D+L_r	D+L_r	D+L_r	D +0.45W_c +0.75L_r	D +0.45W_c +0.75L_r	D +0.45W_c +0.75L_r
	LRFD	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r
4.5	ASD	D+L_r	D+L_r	D+L_r	D+L_r	D +0.45W_c +0.75L_r	D +0.45W_c +0.75L_r	D +0.45W_c +0.75L_r
	LRFD	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r
5	ASD	D+L_r	D+L_r	D+L_r	D+L_r	D+L_r	D +0.45W_c +0.75L_r	D +0.45W_c +0.75L_r
	LRFD	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r
7.5	ASD	D+L_r	D+L_r	D+L_r	D+L_r	D+L_r	D +0.45W_c +0.75L_r	D +0.45W_c +0.75L_r
	LRFD	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r
10	ASD	D+L_r	D+L_r	D+L_r	D+L_r	D+L_r	D +0.45W_c +0.75L_r	D +0.45W_c +0.75L_r
	LRFD	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r	1.2D +0.5W_c +1.6L_r

Table 10. Controlling load cases for Lake Tahoe, NV

L/H	method	θ = 10	θ = 15	θ = 20	θ = 25	θ = 30	θ = 35	θ = 45
1	ASD	D+0.525E +0.75S_b	D+0.525E +0.75S_b	D+0.525E +0.75S_b	D +0.45W_c +0.75S_b	D +0.45W_c +0.75S_b	D +0.45W_c +0.75S_b	D +0.45W_c +0.75S_b
	LRFD	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +W_c +0.5S	1.2D +W_c +0.5S
1.5	ASD	D+0.525E +0.75S_b	D+0.525E +0.75S_b	D+0.525E +0.75S_b	D +0.45W_c +0.75S_b	D +0.45W_c +0.75S_b	D +0.45W_c +0.75S_b	D +0.45W_c +0.75S_b
	LRFD	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +W_c +0.5S	1.2D +W_c +0.5S
2	ASD	D+0.525E +0.75S_b	D+0.525E +0.75S_b	D+0.525E +0.75S_b	D+0.525E +0.75S_b	D +0.45Wc +0.75S_b	D +0.45Wc +0.75S_b	D +0.45Wc +0.75S_b
	LRFD	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +W_c +0.5S	1.2D +W_c +0.5S
2.5	ASD	D+0.525E +0.75S_b	D+0.525E +0.75S_b	D+0.525E +0.75S_b	D+0.525E +0.75S_b	D +0.45W_c +0.75S_b	D +0.45W_c +0.75S_b	D +0.45W_c +0.75S_b
	LRFD	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +W_c +0.5S	1.2D +W_c +0.5S
3	ASD	D+0.525E +0.75S_b	D+S_{ub}	D+0.525E +0.75S_b	D+S_{ub}	D+S_{ub}	D +0.45W_c +0.75S_b	D +0.45W_c +0.75S_b
	LRFD	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +W_c +0.5S	1.2D +W_c +0.5S
3.5	ASD	D+0.525E +0.75S_b	D+S_{ub}	D+S_{ub}	D+S_{ub}	D+S_{ub}	D +0.45W_c +0.75S_b	D +0.45W_c +0.75S_b
	LRFD	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +W_c +0.5S	1.2D +W_c +0.5S
4	ASD	D+S_{ub}	D+S_{ub}	D+S_{ub}	D+S_{ub}	D+S_{ub}	D +0.45W_c +0.75S_b	D +0.45W_c +0.75S_b
	LRFD	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +W_c +0.5S	1.2D +W_c +0.5S
4.5	ASD	D+S_{ub}	D+S_{ub}	D+S_{ub}	D+S_{ub}	D+S_{ub}	D +0.45W_c +0.75S_b	D +0.45W_c +0.75S_b
	LRFD	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +W_c +0.5S	1.2D +W_c +0.5S
5	ASD	D+S_{ub}	D+S_{ub}	D+S_{ub}	D+S_{ub}	D+S_{ub}	D +0.45W_c +0.75S_b	D +0.45W_c +0.75S_b
	LRFD	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +W_c +0.5S	1.2D +W_c +0.5S
7.5	ASD	D+S_{ub}	D+S_{ub}	D+S_{ub}	D+S_{ub}	D+S_{ub}	D +0.45W_c +0.75S_b	D +0.45W_c +0.75S_b
	LRFD	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +W_c +0.5S	1.2D +W_c +0.5S
10	ASD	D+S_{ub}	D+S_{ub}	D+S_{ub}	D+S_{ub}	D+S_{ub}	D +0.45W_c +0.75S_b	D +0.45W_c +0.75S_b
	LRFD	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +0.5W_c +1.6S_{ub}	1.2D +W_c +0.5S	1.2D +W_c +0.5S

Table 11. Preferred Method and Percentage Stress Difference for Boston, MA

L/H	θ = 10	θ = 15	θ = 20	θ = 25	θ = 30	θ = 35	θ = 45
1	ASD 10.26	ASD 9.02	ASD 10.00	ASD 9.21	ASD 9.41	ASD 9.34	ASD 9.17
1.5	LRFD 3.42	LRFD 0.68	ASD 1.17	ASD 4.71	ASD 6.57	ASD 7.76	ASD 9.06
2	LRFD 9.43	LRFD 9.62	LRFD 7.56	LRFD 5.45	LRFD 1.84	ASD 0.68	ASD 5.18
2.5	LRFD 6.31	LRFD 6.51	LRFD 5.56	LRFD 5.25	LRFD 6.27	LRFD 4.39	ASD 1.73
3	LRFD 4.66	LRFD 3.89	LRFD 4.23	LRFD 4.06	LRFD 4.80	LRFD 6.13	LRFD 0.71
3.5	LRFD 4.97	LRFD 3.02	LRFD 3.53	LRFD 2.90	LRFD 4.06	LRFD 5.50	LRFD 2.91
4	LRFD 6.27	LRFD 4.45	LRFD 2.42	LRFD 2.90	LRFD 3.24	LRFD 4.62	LRFD 4.32
4.5	LRFD 7.27	LRFD 5.51	LRFD 2.39	LRFD 1.52	LRFD 2.75	LRFD 4.30	LRFD 5.53
5	LRFD 7.91	LRFD 6.35	LRFD 2.13	LRFD 1.19	LRFD 2.38	LRFD 3.95	LRFD 6.43
7.5	LRFD 9.69	LRFD 8.14	LRFD 4.17	LRFD 0.73	LRFD 1.94	LRFD 3.09	LRFD 6.01
10	LRFD 10.37	LRFD 10.12	LRFD 5.71	LRFD 1.80	LRFD 0.48	LRFD 2.72	LRFD 5.75

Table 12. Preferred Method and Percentage Stress Difference for Detroit, MI

L/H	θ = 10	θ = 15	θ = 20	θ = 25	θ = 30	θ = 35	θ = 45
1	ASD 9.47	ASD 9.00	ASD 8.70	ASD 8.73	ASD 9.29	ASD 8.72	ASD 8.43
1.5	LRFD 3.28	LRFD 3.13	LRFD 3.31	LRFD 0.01	ASD 2.21	ASD 3.55	ASD 6.64
2	LRFD 3.31	LRFD 3.21	LRFD 4.13	LRFD 5.96	LRFD 6.02	LRFD 4.49	ASD 0.95
2.5	LRFD 0.39	LRFD 1.53	LRFD 1.99	LRFD 3.43	LRFD 4.78	LRFD 5.88	LRFD 3.16
3	LRFD 3.01	LRFD 1.12	LRFD 1.00	LRFD 2.39	LRFD 3.48	LRFD 4.62	LRFD 5.60
3.5	LRFD 5.26	LRFD 3.14	LRFD 0.39	LRFD 1.71	LRFD 2.61	LRFD 4.09	LRFD 6.35
4	LRFD 6.88	LRFD 4.75	LRFD 1.56	LRFD 1.09	LRFD 2.16	LRFD 3.56	LRFD 5.89
4.5	LRFD 7.63	LRFD 5.83	LRFD 2.55	LRFD 0.78	LRFD 1.83	LRFD 3.03	LRFD 5.64
5	LRFD 8.32	LRFD 6.38	LRFD 3.43	LRFD 0.34	LRFD 1.46	LRFD 2.74	LRFD 5.23
7.5	LRFD 9.87	LRFD 8.67	LRFD 5.48	LRFD 1.96	LRFD 1.04	LRFD 2.07	LRFD 4.57
10	LRFD 10.76	LRFD 9.68	LRFD 4.64	LRFD 2.94	LRFD 0.04	LRFD 1.67	LRFD 4.21

Table 13. Preferred Method and Percentage Stress Difference for St. Paul, MN

L/H	θ = 10	θ = 15	θ = 20	θ = 25	θ = 30	θ = 35	θ = 45
1	ASD 7.14	ASD 8.74	ASD 9.32	ASD 10.94	ASD 9.29	ASD 8.72	ASD 8.43
1.5	LRFD 6.94	LRFD 5.63	LRFD 5.49	LRFD 2.34	ASD 1.09	ASD 3.55	ASD 6.64
2	LRFD 6.76	LRFD 5.66	LRFD 5.42	LRFD 6.05	LRFD 7.11	LRFD 4.49	ASD 0.95
2.5	LRFD 3.74	LRFD 3.63	LRFD 2.69	LRFD 3.80	LRFD 4.42	LRFD 5.88	LRFD 2.92
3	LRFD 2.26	LRFD 1.95	LRFD 1.12	LRFD 2.01	LRFD 2.52	LRFD 4.62	LRFD 5.61
3.5	LRFD 4.46	LRFD 3.11	LRFD 0.01	LRFD 0.89	LRFD 1.65	LRFD 4.09	LRFD 6.37
4	LRFD 5.62	LRFD 4.29	LRFD 0.85	LRFD 1.16	LRFD 1.67	LRFD 3.56	LRFD 5.92
4.5	LRFD 6.12	LRFD 5.06	LRFD 1.85	LRFD 0.12	LRFD 0.64	LRFD 3.03	LRFD 5.57
5	LRFD 6.70	LRFD 5.62	LRFD 2.41	LRFD 0.42	LRFD 0.89	LRFD 2.74	LRFD 5.19
7.5	LRFD 6.99	LRFD 6.80	LRFD 3.77	LRFD 0.97	LRFD 0.38	LRFD 2.07	LRFD 4.57
10	LRFD 7.56	LRFD 7.61	LRFD 4.87	LRFD 2.74	LRFD 0.04	LRFD 1.67	LRFD 4.28

Table 14. Preferred Method and Percentage Stress Difference for Miami, FL

L/H	θ = 10	θ = 15	θ = 20	θ = 25	θ = 30	θ = 35	θ = 45
1	ASD 9.29	ASD 9.38	ASD 9.17	ASD 9.58	ASD 9.26	ASD 9.06	ASD 9.77
1.5	ASD 8.72	ASD 8.65	ASD 8.94	ASD 8.57	ASD 8.81	ASD 8.91	ASD 9.17
2	LRFD 3.56	LRFD 1.69	ASD 0.70	ASD 5.37	ASD 7.98	ASD 8.51	ASD 8.84
2.5	LRFD 3.72	LRFD 5.19	LRFD 6.54	LRFD 0.95	ASD 2.22	ASD 5.81	ASD 8.68
3	LRFD 1.56	LRFD 2.78	LRFD 4.71	LRFD 5.62	LRFD 2.20	ASD 2.60	ASD 8.74
3.5	LRFD 1.82	LRFD 1.21	LRFD 3.29	LRFD 5.56	LRFD 5.30	LRFD 0.14	ASD 7.36
4	LRFD 4.84	LRFD 1.14	LRFD 2.43	LRFD 4.79	LRFD 6.26	LRFD 2.23	ASD 6.12
4.5	LRFD 6.76	LRFD 2.78	LRFD 1.69	LRFD 4.20	LRFD 5.59	LRFD 3.64	ASD 5.06
5	LRFD 8.22	LRFD 4.18	LRFD 1.14	LRFD 3.54	LRFD 5.25	LRFD 4.78	ASD 4.07
7.5	LRFD 12.13	LRFD 9.32	LRFD 1.57	LRFD 2.29	LRFD 3.80	LRFD 6.12	ASD 2.06
10	LRFD 13.59	LRFD 11.39	LRFD 4.12	LRFD 1.40	LRFD 3.13	LRFD 5.56	ASD 0.79

Table 15. Preferred Method and Percentage Stress Difference for Santa Barbara, CA

L/H	θ = 10	θ = 15	θ = 20	θ = 25	θ = 30	θ = 35	θ = 45
1	LRFD 8.74	LRFD 7.77	LRFD 9.01	LRFD 8.93	LRFD 9.65	LRFD 5.22	ASD 6.98
1.5	LRFD 10.34	LRFD 10.27	LRFD 10.97	LRFD 10.83	LRFD 10.69	LRFD 4.97	LRFD 1.61
2	LRFD 10.50	LRFD 10.00	LRFD 7.58	LRFD 4.69	LRFD 4.52	LRFD 5.15	LRFD 6.74
2.5	LRFD 2.93	LRFD 1.49	LRFD 1.06	LRFD 2.03	LRFD 2.63	LRFD 3.45	LRFD 5.04
3	LRFD 5.41	LRFD 3.72	LRFD 1.80	LRFD 1.02	LRFD 1.76	LRFD 2.43	LRFD 4.41
3.5	LRFD 6.55	LRFD 8.02	LRFD 2.95	LRFD 0.20	LRFD 1.00	LRFD 2.14	LRFD 3.95
4	LRFD 7.50	LRFD 6.46	LRFD 3.91	LRFD 1.30	LRFD 0.66	LRFD 1.77	LRFD 3.48
4.5	LRFD 8.06	LRFD 7.03	LRFD 4.60	LRFD 2.14	LRFD 0.14	LRFD 1.23	LRFD 3.25
5	LRFD 8.46	LRFD 7.46	LRFD 5.16	LRFD 2.71	LRFD 0.59	LRFD 1.07	LRFD 2.96
7.5	LRFD 9.61	LRFD 8.73	LRFD 6.48	LRFD 4.17	LRFD 2.37	LRFD 0.48	LRFD 2.41
10	LRFD 9.99	LRFD 9.28	LRFD 7.22	LRFD 5.00	LRFD 3.13	LRFD 0.24	LRFD 0.72

Table 16. Preferred Method and Percentage Stress Difference for Lake Tahoe, NV

L/H	θ = 10	θ = 15	θ = 20	θ = 25	θ = 30	θ = 35	θ = 45
1	LRFD 5.04	LRFD 0.01	ASD 5.67	ASD 8.39	ASD 5.81	ASD 5.00	ASD 9.78
1.5	LRFD 5.79	LRFD 0.80	ASD 3.23	ASD 7.51	ASD 7.91	LRFD 8.75	LRFD 0.01
2	LRFD 6.64	LRFD 3.24	ASD 0.79	ASD 5.26	ASD 7.03	LRFD 16.33	LRFD 6.70
2.5	LRFD 4.02	LRFD 1.37	ASD 2.16	ASD 6.23	ASD 7.41	LRFD 20.71	LRFD 10.27
3	LRFD 2.10	ASD 2.12	ASD 3.56	ASD 6.50	ASD 8.07	LRFD 23.30	LRFD 12.60
3.5	LRFD 1.15	ASD 1.23	ASD 2.74	ASD 5.17	ASD 6.69	LRFD 25.16	LRFD 14.52
4	LRFD 0.13	ASD 0.52	ASD 2.19	ASD 4.17	ASD 5.63	LRFD 26.45	LRFD 15.68
4.5	LRFD 0.28	ASD 0.06	ASD 1.53	ASD 3.44	ASD 5.01	LRFD 27.35	LRFD 16.44
5	LRFD 0.60	LRFD 0.25	ASD 1.23	ASD 3.03	ASD 4.41	LRFD 28.03	LRFD 17.13
7.5	LRFD 1.34	LRFD 1.32	ASD 0.36	ASD 2.44	ASD 3.48	LRFD 29.85	LRFD 19.25
10	LRFD 2.05	LRFD 3.40	LRFD 5.58	ASD 1.05	ASD 1.28	LRFD 30.28	LRFD 19.73

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