# Ground Snow Loads for ASCE 7-22 – What Has Changed and Why?

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## Introduction

The forthcoming ground snow load maps target a uniform reliability rather than a uniform hazard – an important distinction – and are the first of their kind in ASCE 7 snow loads (Bean et al. 2021). Previously, the ASCE 7 snow loads used a uniform-hazard 50-year mean recurrence interval (MRI) with a 1.6 load factor, much like the current wind loads use an MRI of 700-years as risk-informed loads with a 1.0 load factor (McAllister et al. 2018). The site-specific ground snow load determination is no longer tied to a uniform hazard (i.e., X-year recurrence interval), but to the safety levels stipulated in Chapter 1 of ASCE 7. The result is a strength design level load that is to be used with a load factor of 1.0 as shown in Equation 1 and mapped in the new ASCE 7 Chapter 7 and in the online Hazard Tool.

$$\phi R_n = 1.2D_n + 1.0S_n \qquad \text{Equation 1}$$

In Equation 1, $\phi$ is the resistance factor, $R_n$ is the nominal resistance, $D_n$ is the nominal dead load, $S_n$ is the nominal roof snow load. The reliability-targeted ground snow loads take advantage of contemporary weather station data, computer processing, and mapping techniques to provide site-specific reliability targeted loads. Snow loading has significant site-to-site variability, both in mean, coefficient of variation, and shape of the statistical distribution of measurements.

## What are reliability targeted loads?

The compelling argument for using 50-year loads with a safety factor is that they are loads that have been observed (or exceeded) at many locations, which makes them easier to understand based on personal experience. The 1.6 load factor is intended to bridge the gap between observed loads and reliability-targeted loads which are almost never seen (for snow or other hazards). The 1.6 load factor was derived by Ellingwood et al. (1980) by taking the average behavior of ground snow load probability distributions defined for eight locations across the country. Averaging necessarily over-estimates reliability-targeted loads in some regions and under-estimates them in others but was necessary given the data availability and computational resources at the time and given the intent of the original calibration. When making comparisons between new and existing requirements, one must multiply the ASCE 7-16 loads by 1.6 for Risk Category II structures.

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The safety criteria outlined in ASCE Chapter 1 express safety as a reliability index of 3.0 for Risk Category II, corresponding to an annual probability of failure of 3 x $10^{-5}$, which results in an approximate mean failure interval of 30,000 years. Such a low probability of failure is difficult to contextualize for any single building. A different perspective on the 30,000-year interval is that out of perhaps 10,000 communities in the US, one would not want to see failures due to snow overload in more than about one of those 10,000 communities every three years.

This low failure rate requires the extrapolation of the statistical distributions describing all ASCE 7 considered hazards (snow, wind etc.) to events that exceed those observed in the period of record (which is well under 150 years and in many cases under 50 years). The resistance factor and the inherent conservatism in our design procedures deliver part of the safety, but the majority of the margin must be based on the source with the highest statistical variability, which in this case is the snow load.

The site-specific reliability analysis include consideration of both the uncertainty in the snow load and the uncertainty of the structural resistance. The reliability was assessed at 7,964 snow measurement locations in the US using Equations 1 through Equation 3.

$$G(R, D, S) = R - D - S \qquad \text{Equation 2}$$

$$S = G_r G_l \qquad \text{Equation 3}$$

In Equations 2 and 3, $R$ is the random resistance, $D$ is the random dead load, $S$ is the random roof load, $G_r$ is the random ground-to-roof conversion factor and $G_l$ is the random ground snow load at a specific site.

The targeted resistance member was the flexural yielding (i.e., $0.9Z_xF_y$) of a steel W-shape using new A992 steel statistical models (Bartlett et al., 2003). This resistance was combined with a flat roof condition and combined with a constant nominal dead load of 15 psf to be reasonably representative of a common roof construction. Uncertainty in the roof snow load made use of the compilation of data from North American measurements of $G_r$ (see Chapter 3 of Bean et al. 2021). Many stations do not report ground snow load, but only depth. Thus, a unified depth-to-weight conversion (effective density) that accurately estimates the ground snow load from depth, winter temperature, winter precipitation and distance to coastlines was validated and developed (see Chapter 5 of Bean et al. 2021). Site-specific snow load measurements were fit with a three-parameter Generalized Extreme Value distribution. This allows a detailed fitting of measured data and can model data that are symmetric (e.g., normal) or right skewed (e.g., lognormal, extreme), capturing the climatic variability in snow load patterns across the country (see Chapter 6 of Bean et al. 2021).

According to the reliability targets of ASCE 7 Chapter 1, Monte Carlo simulations were performed for each risk category and target reliability index, β, thus eliminating the need for separate snow importance factors. Careful examination of the values from the four maps for each Risk Category will show that the ratio of load between risk categories is not constant; the ratio depends upon the site-specific climate, as represented in historical data for snow accumulation. This fact is an illustration of why the use of a single load factor of 1.6 applied to 50-year MRI loads results in inconsistent levels of safety (see Chapter 2 of Bean et al. 2021).

Since the original calibration of the 1.6 safety factor, there has been more than 40 years of additional snow load data collected, including greater spatial coverage (see Chapter 4 of Bean et al. 2021). This additional information makes it possible to perform site-specific reliability analyses and significantly reduce Case Study regions in the west. The Case Study regions have been reduced by more than 90% from what they were in ASCE 7-10 and 7-16, prior to the adoption of state-specific studies into the standard (see Chapter 7 of Bean et al. 2021).

## Why did loads change?

Local snow load histograms and the resulting distribution fits for Minneapolis, Boston, and Baltimore are presented in Figure 1. Notice that Boston, Minneapolis, and Baltimore all have very similar maximum measured loads (within 10% of each other), even though Minneapolis typically receives more snow than Baltimore or Boston. Interestingly, the proposed loads are also similar for the cities in this example. Generally, cities like Minneapolis in the upper Midwest or others in Northern New England that regularly receive moderately high snow loads may see loads decrease. This is because there is less difference between the *typical* annual maximum load and *extreme* annual maximum load.

One major theme of the region-specific, reliability-target approach was that mid-latitude locations (Baltimore, Chicago, Denver, Portland, etc.) needed a larger margin between the design load and a 50-year MRI load than other parts of the country to achieve reliability targets. These places all tend to see intermittent snow melt throughout the snow season, but also had recorded annual peak loads from substantial accumulations of snow in very short periods of time. In short, these locations *typically* did not receive large accumulations of snow, but they all had the *capacity* for extreme accumulations of snow under the right extreme conditions.

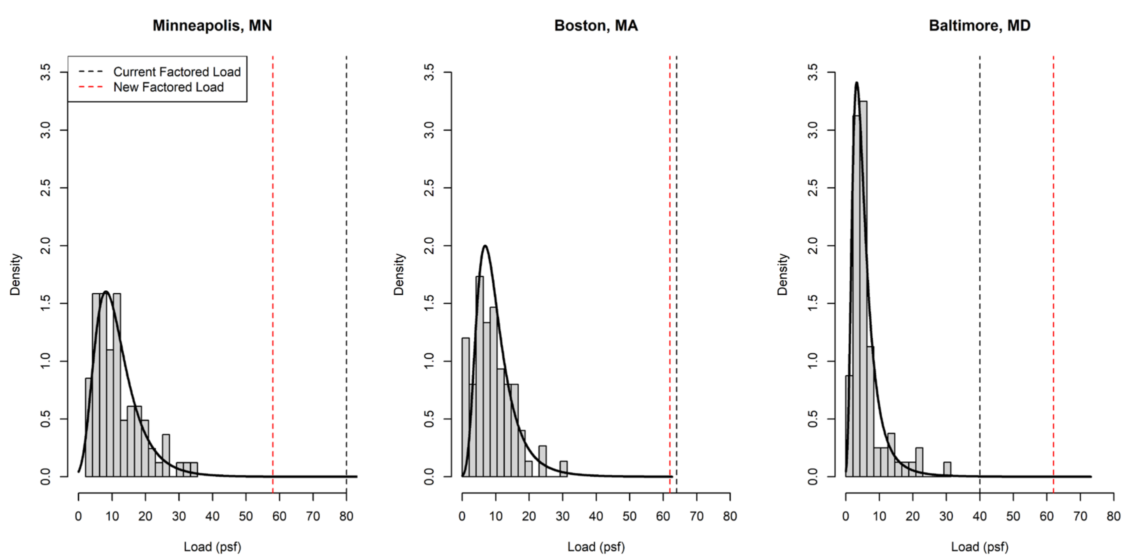


*Figure 1. Histograms, Fitted Distributions and Factored Loads for Select Cities*

It is the extreme behavior that drives the reliability-targeted loads (the red lines in Figure 1), specifically the potential for extreme deviation from typical behavior. Table 1 shows that Minneapolis receives substantially less precipitation than Baltimore on average, but Minneapolis *almost always receives that precipitation as snow because of consistently colder temperatures.* However, the temperatures are cold enough that Baltimore has the *capacity* to receive substantial amounts of precipitation as snow *in the right, extreme* conditions even though it would normally be received as rain or quickly melted snow events. The legendary, but atypical, snow events in the mid-Atlantic foreshadow the potential for large amounts of snow in this region. The reliability-targeted loads reflect *what might happen* if the mid-Atlantic were to receive a series of super-heavy storms with unusually cold temperatures that prevent the snow from melting between storms. The chance that such an event happens within one building's lifetime is small, but so is the probability of failure ASCE 7 charges us to design against.

*Table 1. Comparison of 1981-2010 Average Winter Precipitation and Coldest Month Temperatures (PRISM Climate Group 2015).*

| City | Winter Precipitation (Dec – Feb) | Coldest Month Temperature (ºF) |
|---|---|---|
| Baltimore | 9.6 | 33.9 |
| Boston | 10.9 | 28.4 |
| Minneapolis | 2.9 | 15.9 |

This is not to say that many of these changes are unexpected. For instance, many local jurisdictions had superseded ASCE 7-16 loads. Among these, state/local ordinances in Portland (SEAO 2013), Denver (DeBock et al. 2016), and Baltimore (Baltimore County Building Code, 2015) had already superseded ASCE 7 loads with requirements that are like those in the new maps.

DeBock et al. (2016) demonstrated the non-uniform reliability of the ASCE 7 snow loads in Colorado and introduced the concept of reliability targeted snow loads. Engineers and building officials in Colorado had long recognized the potential for extreme loads in excess of the published ASCE 7 values in Denver and the eastern plains of the State. This study identified the differences between locations that obtain annual maximum snow loads from single or a few events (plains locations) and those that accumulate snow from many events (mountainous locations).

## What is the Cost Impact?

Figure 2 presents a box plot of the ratio of the new factored flat *roof* load to the factored ASCE 7-16 uniform risk loads for 80 locations in the United States. This plot indicates that while some locations changed drastically, the majority of structures have a roof load 0.95 to 1.15 with an average ratio of 1.05.

One of the more significant changes in design Ground Snow Load values occurred in Baltimore, MD. In ASCE 7-16, $p_g$ is 25 psf (x 1.6 load factor). The reliability targeted value of $p_g$ for Risk Category II for this location is 60 psf (x 1.0 load factor). The change calculated to the roof Total Load (using a uniform roof dead load of 15 psf) is an increase of 30%. In order to assess the cost on a snow-sensitive metal building, two buildings were analyzed for these loads (along with changes to the minimum roof snow load) as shown in Table 2. There is a about 1% total cost increase with the new loads vs. ASCE 7-16. However, recall that Baltimore County had already superseded requirements presented in ASCE 7-16 by requiring a minimum *roof* snow load of 30 psf (or 48 psf factored roof load), exceeding the design roof snow load resulting from the reliability targeted load.

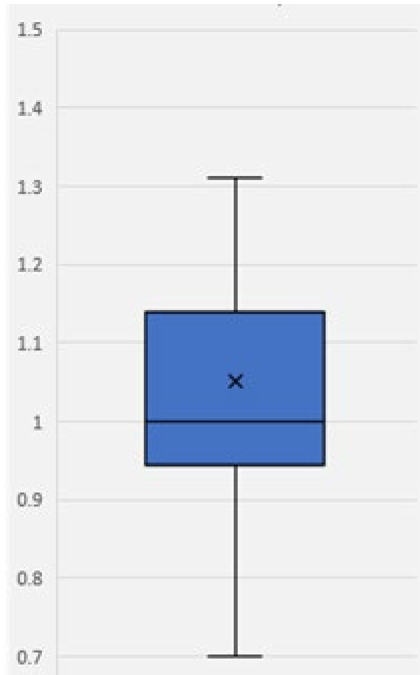


*Figure 2. Box plot of the ratio of proposed factored loads to previous factored loads. Average ratio: 1.05, Standard Deviation: 0.21.*

*Table 2. Baltimore Maryland Cost Comparison for Metal Building, comparing ASCE 7-16 and the proposed reliability-targeted load*

| Metal Building Structure | Weight Impact | Building Cost Impact | Total Cost Impact |
|---|---|---|---|
| 70'w x 125'l x 15'h 2:12 | +6.5% | +4.5% | +0.8% |
| 200'w x 550'l x 18'h 3:12 | +8.7% | +6.4% | +0.9% |

## What is the Mean Recurrence Interval now?

In past iterations of ASCE 7, snow loads have been uniform hazard. In other words, there was a single recurrence interval pre-determined for each load. The mean-recurrence interval for snow load in the reliability targeted scenario is no longer constant because the shape of the snow load distribution changes in a site-specific manner. To illustrate this, a reliability analysis with several simplifying assumptions is illustrated in Figure *3*. For this illustration only, the ground to roof conversion is assumed non-random, dead load is not considered and both the resistance and snow load are assumed normally distributed. If the coefficient of variation of the snow load is changed, the corresponding shape of the load and resistance distributions are plotted in Figure *3* and the load that results in a reliability of 3.0 is indicated by the vertical dashed line.

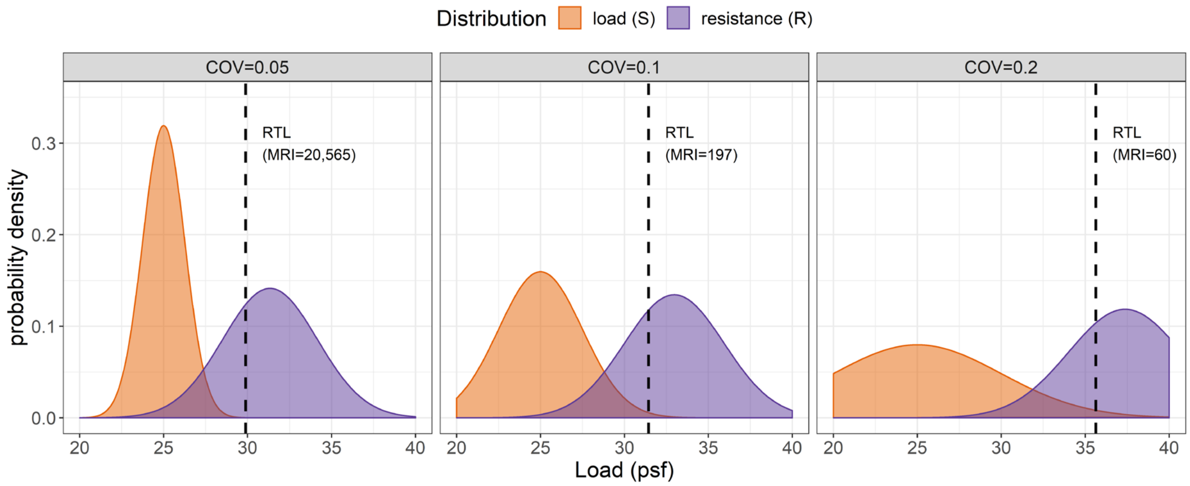


*Figure 3. Illustration of the increase in reliability-targeted ground snow loads (RTL) due to increases in the coefficient of variation (COV) of the ground snow load distribution while the mean remains constant. These increases are associated with a reduction in the mean recurrence interval (MRI) of the nominal ground snow load, as indicated by the increasing area under the orange curve to the right of the dashed line.*

In this simplified scenario, the reliability-targeted load (as indicated by the black, dashed line) increases as the COV of the ground snow load distribution increases. However, this increase is associated with a reduction in the MRI, as indicated by the increasing area to the right of the black dashed line in the upper tail of the ground snow load (orange) distribution. The reason for the change in the MRI is that the increase in the COV changes the relative variability of the resistance and the load. When the COV of the ground snow load distribution is small, the reliability-targeted load is pushed higher by the variability of the resistance, causing the resulting ground snow MRI to be high. However, when the COV of the ground snow load distribution is large, the variability of the resistance loses its influence, and the MRI of the ground snow load starts to converge towards the failure MRI (which, in this case is 50-years).

The key takeaway is that the value being held constant is the probability of failure, not the probability of the hazard. To preserve a constant probability of failure, the MRI of the nominal ground snow load must be allowed to vary to accommodate changes in the variability of the hazard relative to the variability of the resistance. When other uncertainties are included in the analysis, or when different distribution fit the data, the MRI can change in ways not demonstrated in this figure. This property is not unique to snow and would hold true for all site-specific hazard reliability analyses for which the hazard statistics change with location indicated by McAllister et al. (2018) and DeBock et al. (2016).

## Final Thoughts

The changes to the ASCE 7 ground snow loads proposed for the 2022 Edition represent a significant step forward: Case Study regions are dramatically reduced, 40-years of additional data is incorporated, and calibration statistics are updated. Most importantly, this represents a shift away from uniform hazard to uniform risk for an environmental load in ASCE 7, a move which should provide engineers and owners comfort and ultimately reduce the need for superseding ASCE 7 locally. While changes in some locations may seem significant, the average total cost impact should be minimal based on the above analysis.

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