Do Structural Engineers Design for Rain Loads?

By Michael O'Rourke P.E., Ph.D., and Anthony Longabard

During its lifetime, a building roof is subjected to a number of different structural loads – roof dead loads and roof live loads (principally snow, wind, and rain). Depending upon the location, one of these will be the controlling roof live load. For a building in northern Vermont, snow is likely the controlling roof live load; in northern Mississippi, it may be rain. For locations such as northern Vermont where the snow load is generally larger than the rain or wind loads, one expects more snow-related structural problems. Similarly, one expects few snow-related structural problems in northern Mississippi where the snow load is small in comparison to wind or rain loads. That is, one expects more snow-related collapses in places where the snow load is comparatively large and fewer in places where the snow load is comparatively small.

The comparisons below show that building losses reported by FM Global for snow and wind hazards are consistent with the above expectation; for a specific hazard at locations where the magnitude of the hazard is large, more losses are generated. However, surprisingly, this expectation does not hold true for the rain load hazard.

Roof Live Load Losses

Across the United States, dollar losses due to rain, in the period from 2007 to 2017, were 58% of those due to snow. In the same period, dollar losses due to wind (primarily hurricanes) were about 470% of those due to snow. Although rain losses were the smaller of the three, they were not negligible. Rain losses in Texas and Arizona (excluding rainfall during hurricanes) were nearly equal to snow losses in New England. Note that the loss data presented herein was based on a review of losses reported by clients of commercial and industrial FM Global between 2007 and 2017. Dollar losses were indexed to 2017 to ensure comparisons were independent of inflation.

Losses due to Snow

As shown in the *Table*, states located in the northeast experienced the greatest snow-related losses followed by midwestern and western states, then southwestern and southeastern states. This is consistent with the ground snow load map in Chapter 7 of the American Society of Civil Engineer's ASCE 7-16, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*. That is, snow losses increased where the snow hazard was highest and decreased at locations where the hazard was smaller. Compared to the mean of the 2007 – 2017 period, snow losses fluctuated on an annual basis by +186%/-89% in terms of quantity and +222%/-95% in terms of total cost. As one might expect, snow losses were higher in particularly snowy winters.

Losses due to Wind

States bordering the Atlantic Ocean and the Gulf of Mexico are known to experience high wind speeds due to hurricanes. This is reflected in the Basic Wind Speed maps in Chapter 26 of ASCE 7-16. For most of the contiguous U.S., the basic wind speed for Risk Category II structures varies from roughly 95 miles per hour (mph) in California to roughly 110 mph in the upper Midwest. However, the wind contours range from 115 to 180 mph along the Atlantic and Gulf Coasts. Since the wind pressure is proportional to the square of the wind speed, the design wind pressure for the Florida Keys is roughly three times that for most other places in the contiguous U.S. Losses due to hurricanes in these states during the 2007 to 2017 time frame accounted for approximately 80% by total cost and 68% by total quantity compared to all wind losses experienced by FM Global insured locations throughout the United States. Losses due to hurricanes in Texas and Florida alone accounted for more than 58% by total cost and 32% by total quantity. Moreover, the average dollar loss for hurricanes in TX and FL was four times greater than the typical "straight line" wind loss averaged across all states. Hence, like the snow hazard, insured losses due to wind are highest where the wind hazard is most significant, and vice-versa.

Rain collapse at an FM Global insured location in the southern United States.

Losses due to Rain

The rain load hazard in ASCE 7-16 is a 15-minute duration, 100-year Mean Recurrence Interval (MRI) event. The area in the continental U.S. with the highest rain load hazard is the Southeast (Louisiana to North Carolina) with state average rain hazards ranging from roughly 6.6 to 8.2 inches/hour. The area with the next highest state average rain hazard (5.5 to 8.0 in/hr.) is the Midwest (Texas to the Dakotas). These are followed in order by the Northeast (Virginia to Maine, 5.1 to 6.4 in/hr.), the Southwest (New Mexico to Utah, 3.5 to 6.0 in/hr.) and the West.

The *Table* also shows the rank ordering of regions by rain load losses. The region with the largest rain losses is the Southeast – a photograph on one such loss is presented in the *Figure*. This is not unexpected since this region has the highest rain load hazard. However, the rest of the ranking (i.e., ranking numbers 2 through 5) does not make sense. The Southwest and West regions have lower rain hazard values than the Northeast and the Midwest, yet they experience higher losses.

Note that the Southeast and Southwest regions, which make up approximately 30% of the land mass of the country, accounted for nearly 60% of all rain losses. As noted above, this is reasonable for the Southeast, which experiences the highest rain intensities in the United States; however, it is neither logical nor straightforward that Southwestern states followed as the region with next greatest rain-related losses. Furthermore, many losses in the Southeast that involved hurricanes, which typically bring a significant amount of rainfall, were filtered and categorized as wind losses. Losses were categorized in this manner because the wind associated with the tropical cyclone functioned as the initiating factor by way of breaching portions of waterproofing elements of the components and cladding. Secondary to a breach, rainwater directly entered the building envelope. This secondary rainwater likely would not have led to a loss without the damage from wind.

Also, rain-related losses occurred 50% more frequently than snow-related losses, and non-collapse liquid damage (i.e., from snow or rain) losses occurred 4 times more frequently for rain than for snow (i.e., a leaky roof versus an eave ice dam). An analysis of loss variation caused by rain compared to the mean of the 2007 – 2017 period showed collapses fluctuated on an annual basis by +83%/-71% in terms of quantity and +76%/-51% in terms of dollars. This shows less annual variability compared to snow losses. That is, the year-to-year rain losses are more consistent, while snow losses peak in particularly snowy winters.

Table of snow and rain losses by region. (Rank #1 means highest losses).

Rank	Snow Hazard	Rain Hazard
1	Northeast	Southeast
2	Midwest	Southwest
3	West	West
4	Southwest	Northeast
5	Southeast	Midwest

Rain Loads in Building Design

In summary, the above analysis showed rain losses to be the outlier among the natural hazards discussed. Unlike snow and wind losses, rain losses occurred with more frequency and consistency in portions of the country where the hazard is not necessarily the highest.

So, why did the entire southern United States experience the majority of rain losses when the midwest, north-central, and portions of the north have a comparable rain hazard?

The authors contend that, unlike snow and wind loads, structural engineers do not adequately consider rain loads in building design. As discussed in more detail below, either rain loads are ignored by the structural engineer or the rain hazard level used by the structural engineer is too low. Note that, in this regard, the relative lack of rain load losses in the Northeast and Midwest is likely due to the comparatively large design snow load for these regions. The robust structural resistance due to wintertime snow loads, which structural engineers routinely consider, is available in the spring and summer to accommodate rain loads which structural engineers apparently routinely neglect.

There is also limited anecdotal evidence that the authors' contention is correct. The authors asked a principal of a medium sized structural engineering firm in the Northeast if the firm designed for rain loads. The principal responded, "Yes, if we think it is needed." This suggests that they do not routinely determine rain load values, but rely upon snow loads as the "surrogate" for the uncalculated rain loads. In a discussion of rain loads with a principal at a large prominent structural engineering firm headquartered in the Northeast, the principal indicated that, in an impromptu internal survey of 10 to 20 people, the majority said that rain loads were not routinely considered in their building designs in heavy snow load areas. Finally, when asked how frequently buildings are designed for rain loads, a retired public sector structural engineer in upstate New York responded, "never."

Possible Reasons

There are three possible reasons or explanations for the apparent lack of consideration of rain loads in United States structural engineering practice.

Hazard Level: Rain loads have always been part of the ASCE 7 Load Standard. However, until recently, the actual hazard level (storm

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duration and return period) has not been specified. In ASCE 7-88 (the first edition of ASCE 7), the roof drainage system was required to meet the provisions of the "code having jurisdiction." The *Commentary* mentions the 1982 Building BOCA (Building Officials and Code Administrators International) *Basic Plumbing Code* and its required hazard level of a one-hour duration, 100-year return period event. Also mentioned is the 1975 *National Building Code of Canada* which used a 15-minute duration, 10-year return period event.

ASCE 7-10 also defers to the code having jurisdiction, while the *Commentary* mentions a 1-hour/100-year event from BOCA 1993 and Factory Mutual Engineering (1991), a 15-minute/100-year event for secondary drains in the 1991 *Southern Building Code*, and a 15-minute/10-year event in the 1980 *National Building Code*. This ambiguity in required rain loads hazard level was thankfully eliminated in the ASCE 7-16 Load Standard. The code language identifies a 15-minute/100-year event as the design basis for secondary drains, while the *Commentary* clarifies the difference between requirements of the 2012 *International Plumbing Code* (1-hour/100-year) for primary roof drains and those in ASCE 7 (15-minute/100-year) for secondary roof drains.

Hence, prior to local adoption of ASCE 7-16, a practicing structural engineer may well have assumed that rain loads should be based on a 1-hour/100-year event or a 15-minute/10-year event. Note that rainfall intensity (in inches per hour) for the 15-minute/100-year event is typically 2 to 2.5 times larger than that for the 1-hour/100-year event. The corresponding ratio for the 15-minute/10-year event is roughly 1.5.

The rain load is comprised of two parts, the static head and the hydraulic head. Since the hydraulic head is nominally proportional to the design rain intensity, if the static head is low and the hydraulic head was based on a 1-hour/100-year event, structural collapse of a roof experiencing the 15-minute/100-year event would not be unexpected. That is, design for an unrealistically low rain hazard would appear in an insurance loss compilation as a design lacking consideration of the rain hazard.

Out of Sight, Out of Mind: For the past 40 or 50 years, it has been considered good practice to list the structural design loads on building plans. For example, since its inception in 2000, the *International Building Code* (IBC), Section 1603, has required that structural design loads be clearly indicated on the construction documents. Until recently, floor live load, roof live load, roof snow load, wind load, earthquake design data, and flood loads were required to be listed on the construction documents. Note that although rain loads are covered in IBC section 1611, they were not required to be listed on the construction documents. In this sense, rain loads seemed to be in a special category of loads, not important enough to be listed on building plans. It is possible that structural engineers may have mistakenly assumed that, since rain loads did not need to be listed, their inclusion in the structural design process was somehow optional. Also, since design rain loads were not required to be listed, it was difficult for the local building official to confirm whether the structural engineer properly considered them.

Fortunately, this potential misunderstanding has been rectified. The 2018 version of IBC will require rain loads to be listed, along with the other structural loads, on the construction documents.

Bad Timing: Rain loads are unique in that the magnitude of the load is a function of decisions made by other building professionals. That is, the rain load is a function of the size of the drainage area for a given secondary drain or outlet, as well as the location of the secondary outlet within its drainage area. Also, unless a schedule for the architect/plumbing decisions is made at an early-on project meeting, the structural design of the roof may occur before the drainage area and secondary outlet information is available.

In such cases, the structural engineer may assume that the "plumbing engineer will handle it." Alternately, the structural engineer may place a note on the structural plans indicating that the roof was designed for a rain load of xx psf. In the first case, the plumbing engineer may not realize that the hazard level for the secondary roof outlets is higher than that for the primary roof outlets. Also, it is highly unlikely that the plumbing engineer would properly check for ponding instability. In the second case, the structural engineer is relying on the architect to read the "cover your backside" note and appreciate its import. In either case, the potential for inadequate secondary drainage system design and resulting structural collapse is generally consistent with the apparent lack of consideration of rain loads in U.S. structural engineering practice.

In relation to roof drainage information needed to calculate rain loads, it is best practice to discuss the issue at an early-on project meeting. A deadline for the roof drainage information to be sent to the structural engineer should be agreed upon. It is the authors' opinion that the structural engineer is best positioned to actually perform the rain load calculations and subsequent evaluation of potential ponding instability.▪

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