TECHNOLOGY & RESEARCH

UNDERSTANDING DESIGN LOADS AND LOAD PATHS

Many important decisions must be considered before a reliable Post-Frame building can be constructed. This article presents some essential concepts and terms regarding design loads to be understood by all project stakeholders, followed by a discussion of commonly encountered situations and how they should be addressed during design and construction.

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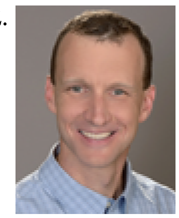

Essential Design Load Concepts and Decisions

Design Loads

Structural design loads are: "*forces or other actions that result from the weight of building materials, occupants and their possessions, environmental effects, …*"[1] Many decisions must be made to determine the minimum design loads to be used for the design of each building. While the building designer (often an engineer or architect) may be the project stakeholder most comfortable discussing the factors and variables involved, they should not be expected to make these decisions on their own. Other project stakeholders such as the building owner, the builder, financial investors, and insurance underwriter should be involved in this discussion and provide input on the design loads to be used.

The code and design standards include many adjustment factors which may reduce or increase the loads for a given project. If these adjustment factors are not understood and agreeable to all project stakeholders, the resulting design loads used in design may be inaccurate or based on a "best case scenario". In most cases, design loads should reflect the worst case conditions a building will reasonably be expected to encounter during its useful lifetime.

Required vs. Recommended vs. Desired

The minimum required design loads determined by the building code should be enforced by the Authority Having Jurisdiction (or "AHJ") for a particular project. Based upon experience or preference, a project stakeholder may have valid reasons to choose building design loads that exceed the minimum required loads in one or more ways. For example, the impacts of a building failure may be deemed more unacceptable than building code minimums, so the owner's more stringent desired values for wind and snow loads may be used instead of the minimum required design loads.

The builder or building design professional may also have recommended design loads for a particular project, having experiences and observations over many years leading to an understanding that certain code minimums may not be adequate for performance of the building throughout its useful life.

The design loads required are primarily a function of the building's:

1. Location (climate and which AHJ governs)
2. Size / shape / features of the building,
3. Risk Category

Risk Category – I, II, III, or IV

The building's Risk Category relates to the risk associated with unacceptable performance of a building and must be known to establish the minimum required design loads.

A brief overview of the four Risk Categories:

I. The lowest level allowed by codes and standards, intended for low importance buildings that represent a low risk due to very limited (or no) human occupancy. Certain temporary facilities and minor storage facilities may qualify for this category.

II. Default Category, this is for all buildings except those designated as I, III, and IV.

III. Buildings that represent a substantial hazard to human life including certain buildings with capacity for more than 250 occupants and other higher risk scenarios listed in the building code.

IV. Buildings designated as essential facilities including fire, rescue, ambulance, and police stations (and associated vehicle storage), emergency shelters, surgery centers, and other highest importance scenarios listed in the building code.

One option for achieving increased building performance is to assign a higher Risk Category for the building than required. For example, if Risk Category II would apply to a building, the owner or other stakeholder could elect to use Risk Category III or IV instead.

A Risk Category less than the highest applicable category should NEVER be used. For example, a Risk Category II building should never be designed as a Risk Category I building. Also, a building storing first responder vehicles should be a Risk Category IV building and nothing less.

Some Specific Design Load Decisions

Consideration must be given to the design loads from all potential sources, including wind, snow, ice, floods, and earthquakes. Since wind loads will govern lateral loads in most Post-Frame projects, and since snow loads are the source of maximum vertical loads in many regions, a few comments are provided for each of these sources.

Wind Loads

The Design Wind Speed, designated as V (Velocity) in units of miles per hour [mph], is determined based on the building's location and Risk Category. The building site Exposure Category (typically it should be "C" but may also be "B" or "D") and other variables will affect how the Design Wind Speed is converted to a velocity wind pressure (designated as q_h [psf]). This velocity pressure is used in the analysis of structural components and the main wind-force resisting system.

The Enclosure Classification could be: Enclosed, Partially Enclosed, Partially Open, or Open. Internal wind pressures for a Partially Enclosed building will be much higher than for buildings of other enclosure classifications and require stronger and/or stiffer primary and secondary framing members in the building to meet strength and serviceability requirements.

Snow Load

The Ground Snow Load (designated as p_G [psf]) will be assigned for the building location by ASCE

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7 or the AHJ. Risk Category may be "built-in" to the prescribed p_G value for ASCE 7 in the 2022 and future editions, or via a Snow Importance Factor applied in 2016 and prior editions. Ground Snow Load (p_G [psf]) is converted to Roof Snow Load (p_S [psf]) by several factors and this Roof Snow Load is used in structural analysis. Since both loads have the same units, it is particularly important to be clear about WHICH Snow Load value is being discussed (Ground or Roof).

Snow drifting over ridges and at roof steps (high/low conditions) is a SIGNIFICANT factor in many areas and can cause accumulation of snow in great excess of the normal snow load for a gable roof. Snow drifting potential must be considered carefully from multiple sources: new tall buildings may create snow drift potential on lower structures nearby, existing tall structures may result in snow drifts on new buildings, and even silos, industrial towers or tall trees may result in snow drifts that should be considered.

Much like the discussion of choosing a more conservative Risk Category, project stakeholders can and should be given the opportunity to specify values that exceed the code minimum requirements for any or all of these: Design Wind Speed (V [mph]), velocity wind pressure (q_h [psf]), Ground Snow Load (p_G [psf]), or Roof Snow Load (p_S [psf]).

Common Post-Frame Challenges

A key concept in structural design is to consider an entire load path, or the continuous chain of structural elements that an external load goes through from the source to the foundation. Loads or forces must be successfully transferred along the entire load path and this chain will only be as strong as the weakest link.

Some challenges based on the authors' experiences are presented as a resource for the reader to consider in current and future building projects. These examples are admittedly very brief and simplified but remember that each building and all load paths within it must be designed for the proper design loads.

1. Partially Enclosed Buildings

Partially enclosed buildings can provide economical, roof-covered areas for applications where ventilation is desirable such as livestock shelters (Figure 1) or vehicle storage (Figure 2), but these buildings will generally have larger roof uplift forces, fewer shear walls for lateral load path design, and more horizontal pressure on the wall components where walls are present (Figure 3). Extra attention to connection capacities is required to resist these loads which will be higher than for a similarly sized building that is fully enclosed: roof panels to purlins, purlins to trusses, trusses to columns, trusses to headers, headers to columns, and columns to foundation.

Figure 1 An example of a Partially Enclosed Building

Figure 2 Vehicle Storage - Partially Enclosed

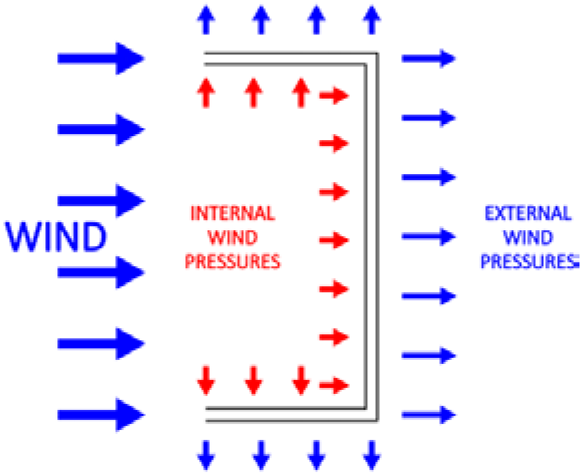

Figure 3 Plan View of a Partially Enclosed Building showing internal pressurization35

2. Increased Wind Pressure at Roof Edges and Corners

Roof edges and corners must be designed for increased wind uplift load based on the physics of wind flowing over the edges and surfaces of a building (Figure 4). One method to address this wind uplift is to add additional screws to fasten the purlin to the truss top chord, perhaps one screw in each of the first three purlins at the eave and the upper three purlins at the ridge. Additional fasteners may also be needed between purlins and trusses at the gable and/or near the eave. An alternative detail to adding screws is to add an uplift strap or twist clip to each purlin in regions in or near the increased wind uplift zones.

3. Slender Buildings

Buildings that are long and narrow (Figure 5) present a specific load path issue. Roofing and siding material often provide lateral strength and stiffness to resist lateral loads in Post-Frame buildings from wind and seismic sources. Gable walls (shear walls) and the roof (diaphragm) must be designed to provide this resistance, referred to as "diaphragm action"; however, diaphragm action can run into limitations in buildings with high length to width ratios (typically greater than 2.5). When diaphragm action is inadequate, additional shear walls, interior bracing or exterior buttresses may be required to fortify such buildings.

Figure 5 Long buildings relative to span create challenges

4. Roof Truss to Column Connection

Like roof edge uplift, trusses or rafters must be tied to the header or post with enough strength to resist the uplift load path from the roof system (Figure 6). This connection may involve the truss to post, truss to header, or header to post. Uplift forces in this connection will be larger if the building is partially enclosed.

5. Snow Drifts and Sliding Snow

Load path for snow loads must consider areas of increased load due

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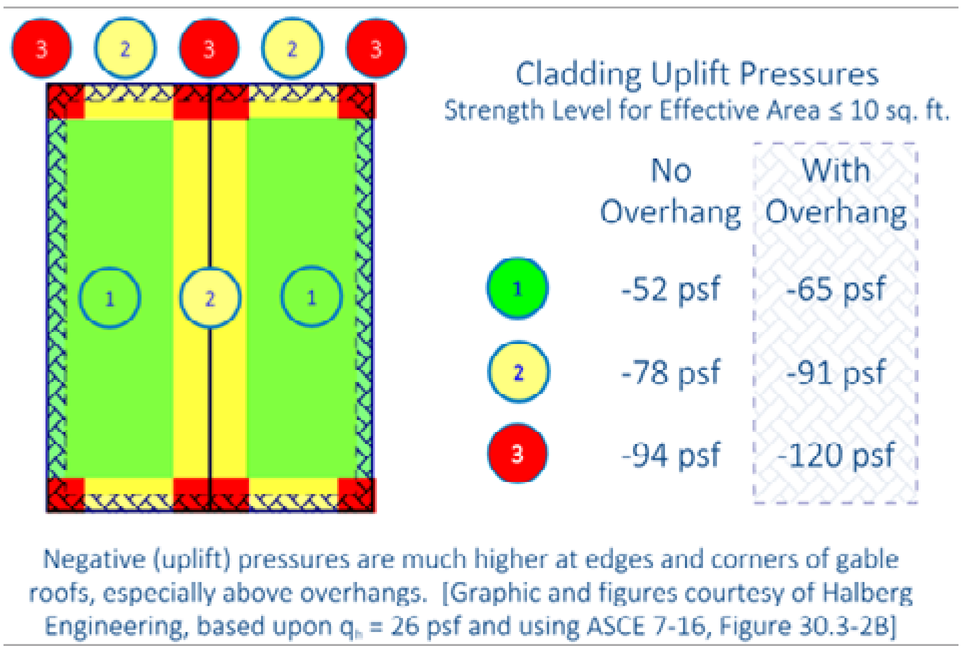

Figure 4 Plan View of Gable Roof Zones with example uplift pressures.

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Figure 6 Truss to Column, Truss to Header, and Header to Column Connections: all Critical

to drifting, unbalanced, and sliding snow (Figure 7). The derivations for these special snow loads are detailed in ASCE 7. The demand on structural elements in affected areas will be significantly higher than they would be for balanced snow loads alone. Reinforcing the load path in this area may involve an increased number of trusses, closer spaced purlins, increased header or beam sizes, stronger connections, larger posts and footings. Inaccurate analysis of the increased loads for any of these elements could create a weak link in the load path (Figure 8).

6. Knee Braces

Another method of resisting lateral loads in post-

Figure 7 Snow Drift illustration and variables at a generic roof step condition
(ASCE 7-16 Figure 7.7-2)

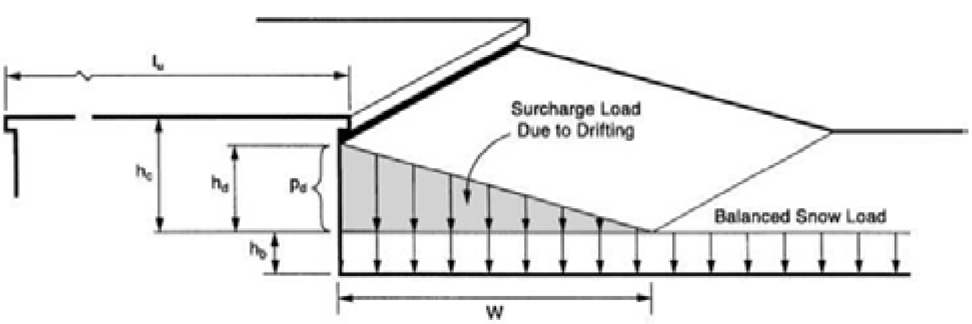

Figure 8 Accumulated Snow drifts at Roof Steps accumulate SIGNIFICANT snow weight on a building

frame buildings is with knee braces (Figure 9). A knee brace is a structural member that connects to the post and extends to the roof line and connects to the roof truss top chord. In most buildings that utilize diaphragm action to resist lateral loads knee braces are not required. However, in open or partially open buildings knee braces may be the primary

Figure 9 An open-sided building utilizing Knee Braces for Lateral Resistance

method to resist lateral loads. Knee braces can attract large forces in tension or compression and must be able to transfer these loads between the roof truss and the post. Part of this load path is the design of the truss for the load that is in the knee brace. The connection of the knee brace to truss, knee brace to post, and truss to post are critical. To complete the load path, the post and truss must also be designed to resist the knee brace forces. Missing any one of these elements will result in a weak link within the load path. NFBA recently published the "Non-Diaphragm Post-Frame Building Design Guide" to address knee brace design as part of the lateral force resisting system.

Conclusion

There are many issues which may present challenges during the design and construction of a reliable Post-Frame building and only some of the potential challenges were discussed in this article. It is important to establish the right design loads at the beginning of the project by ensuring the recommended and desired loads are satisfied, as well as the code required minimum design loads, and ensure the entire load path can withstand these design loads.

[1]From the 2021 International Building Code, International Code Council. Online at iccsafe.org

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