American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-9, Issue-10, pp-46-51
www.ajer.org
Research Paper Open Access

Regional Variation in Steel Gable Construction

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ABSTRACT:*Variation in design of steel gable frames was found between regions in the US. The assumed explanation is the difference in loading conditions and different industries in each area. Cities of Santa Barbara, CA, Miami, FL, Detroit, MI, and St. Paul, MN were chosen for comparison since they represented a range of loading conditions. Each city has a unique trend of steel gable roof structures. Based on results, designers of these frames don't appear to be adjusting roof angles for optimum values.*

KEYWORDS: *Gable frames,Google Earth, Roof Angles.*

Date of Submission: 28-09-2020 Date of acceptance: 10-10-2020

I. INTRODUCTION

The objective is to study whether regional variation in roof slopes exists. Steel gable frames were studied since they are readily identifiable, and have easily measured slopes. External or photographic inspection enables the researchers to quickly determine whether local loading conditions are influencing regional design practices.

Previous researchers have shown that using Allowable Stress Design (ASD) and Load and Resistance Factor Design (LRFD) each produce differing designs of steel gable frames with LRFD generally producing more cost-efficient design [1]. The difference in designs based on the method is most severe in regions with high snow loading [2]. Gable frames are generally more cost efficient when they have foundation connections with a fixed base [3]. Also, it was found that the most efficient designs varied by region [4]. One of the significant findings was that a high slope should be preferred in regions with high snow. This is because above a certain roof slope, the unbalanced snow load is no longer required to be considered [5]. The hypothesis of this research is that engineers have an awareness of these factors so have been designing gable frames differently in regions across the US depending on controlling loads. If engineers have not been designing according to the most efficient methods, then there is much opportunity for savings in construction.

It has been shown previously that the optimum roof angle of gable frames depends upon the span to height ratio (L/H) [4]. Snow is a more significant loading as the span gets longer. However, wind load is primarily a function of the building height. Therefore, in each northern region, there is a tradeoff point where the snow load is a greater factor in design than wind. For southern regions, the roof slope is low to minimize the profile for wind, but may have a small roof slope to have more efficient distribution of loads in gables.

Balanced and unbalanced snow loads are the two different cases of snow load acting on sloped roofs in snowy regions. Balanced snow is placed uniformly on all the spans in roof, but unbalanced snow is not a uniform distribution of this load because of how wind loads move snow from the windward side to the leeward side of a roof. According to the code [5], unbalanced snow need not be considered for a roof angle less than 2.38 and greater than 30.2 degrees.

A typical gable building is shown in Figure 1. This photo was taken at 20601 Trolley Industrial Drive, Taylor, MI which is in the Detroit metropolitan area. The photo was near the position and height taken by Street View. In these frames, the whole floor plan is open for industrial operations. They often have only two columns per frame going to the foundation. The cross-sections of the steel members often are designed to vary linearly between the ends of the columns and the rafters. This is based on the moment diagrams from analyzing the load cases.

The cities chosen for comparison are Santa Barbara, CA, Miami, FL, Detroit, MI, and St. Paul, MN. The reason they were chosen is because previous researchers had compared them [4]. They also studied Berlin, NH because it has among the highest snow in an occupied US city. However, we ruled out studying that city because we identified no steel gable frame structures in or near the city. A small number of steel frames were found a few miles from the city, but the snow patterns are highly variable around that area.

Fig.1. Structure with a Gable Roof. (Author photo.)

II. METHODS

In order to compare roof slopes in many regions of the US, it would be necessary to either have design drawings provided by many engineers, or to inspect buildings in those regions. It would be extremely difficult to identify the engineers for many buildings. Therefore, inspecting the structures enables measurement of designs as-built.

Photographic analysis enables doing the inspection remotely. Google Earth has had Street View since 2008. Street View displays 360-degree panoramic photos of many cities. These are taken by a vehicle that drives through the area while photographing. Not all industrial buildings are visible from the street, but then a representative sample is expected to be found.

The angles of roofs as viewed from the photographs could be measured. However, photographs can distort angle measurement. For example, the perceived angle changes as the angle is rotated with respect to the viewer. A rotated angle looks shallower than it would directly on. This was corrected by trigonometric manipulation. Knowing the height of the camera on the Street View vehicle, and knowing its distance to the building as well as the rough building dimension, it is possible to calculated the true angle from the perceived angle.

A second method was also considered to measure roof slopes. Google Earth also has 3D building models for most structures in the same regions. These buildings are autogenerated by Google Earth [6]. The 3D building models are created from flyover images from planes. Photos are collected from the cardinal directions. Then photogrammetry is used to construct the 3D models. The only difficulty with structures is if they are obscured, but this was found to be uncommon for steel gables. Therefore, this represents independent measurement of the structure geometry. To measure the roof angle, the researcher aligned their view of the building with the end of the ridge of the gable. This should be free of distortion, but it was noticed that the images are often rough, so imprecise.

For the structure in Figure 1, the two methods were compared. By both methods, this structure was found to have a roof slope of 5 degrees. The precision of the analysis was to the nearest degree. Trigonometric correction of the Street View photo accounted for about a half of a degree correction in the angle. This was typical; therefore, it was determined that in most cases the correction wasn’t necessary. Additionally, the two methods were found to continuously give the same result within a degree. The roof angles of gables were expected to vary from 5 degrees to more than 30 degrees, so it was decided that any of the discussed methods was sufficiently accurate to find variations in roof angles between regions.

The steel gable frame structures were identified through Google Earth. In each of the four cities, industrial areas were found. Often, they followed rail lines or were around airports, freeways or rivers. Steel gable frame buildings were simple structures with corrugated steel siding and roofs.

Some frames could be made from timbers. Wood frame industrial structures have short span length because the material can't hold the high loads of longer spans. Also, timber gables have steeper slopes because structurally they are trusses that can't be made with small slopes. Therefore, short-span industrial structures with high roof slopes were not included in the analysis. However, the results are statistical, so having a few structures misidentified does not affect the results. The goal for each city was to find 100 sample structures.

III. RESULTS

Each city had a large number of gable frame structures. All cities had airports, and hangers were found to be steel gable frames.

The type of industry in the area was a secondary factor in frames types. Santa Barbara had the fewest gable frames, since it is not a heavily industrial area, so a larger share of its structures are hangers. Likewise, Miami was not heavily industrial, so many of the frames were hangers. Detroit is more industrial so gable frames were easily found, but some were large and not built with the same construction methods assumed here. St. Paul had a mix of uses.

Figures 2 to 5 show the histograms for frames found in the four cities. First, only the shape of the histogram is discussed. The shape is the frequency of various roof slopes. For Santa Barbara, most commonly, gables had a slope of five degrees plus or minus a couple degrees. This agrees with the work of Katanbafnezhad [4] that in regions with high earthquake, but no snow, the optimum slopes are low. Katanbafnezhad [4] didn't consider roof slopes of less than ten degrees, but industrial roofs are commonly made with lower slopes. The minimum slope for using corrugated steel roofing is a couple percent. Miami also has mostly roofs with lower slope. That matches predictions for regions with high wind. Detroit has a mix of roof slopes with some that have higher slopes. That mostly matches predictions for areas with low snow.

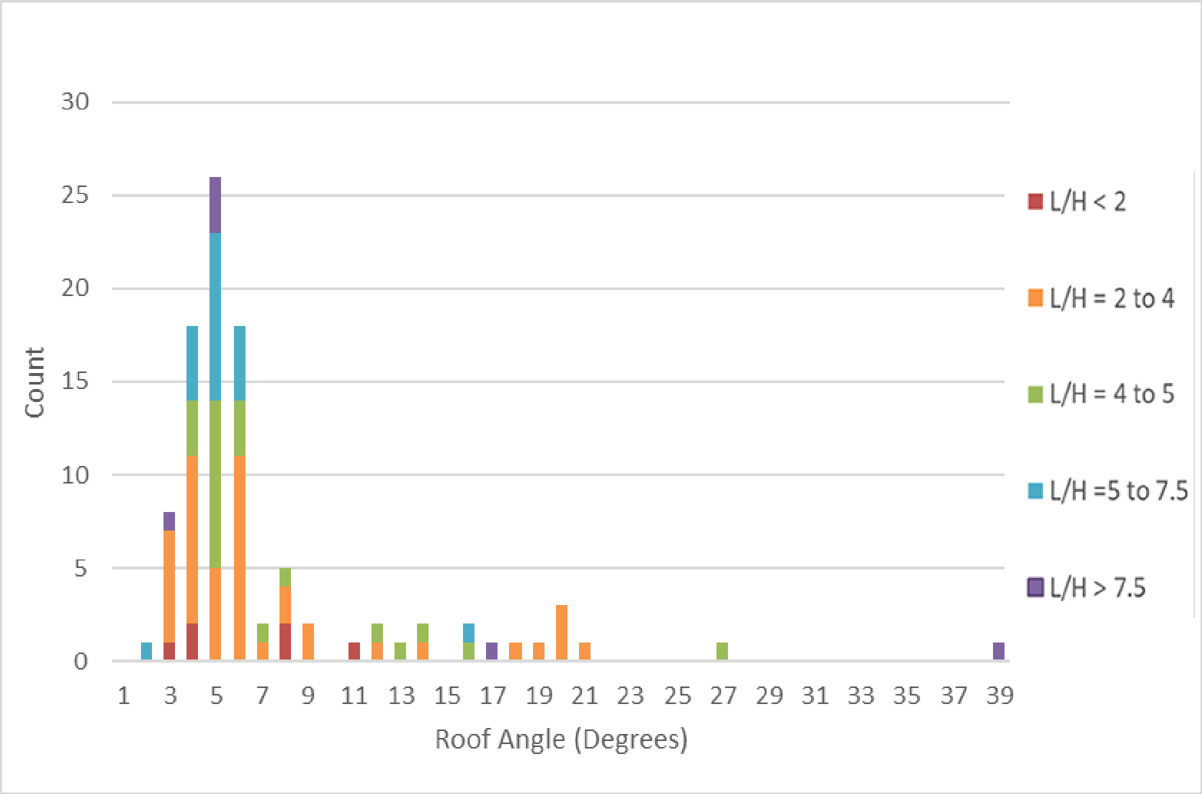

Fig.2. Count of roof angles by L/H for Santa Barbara

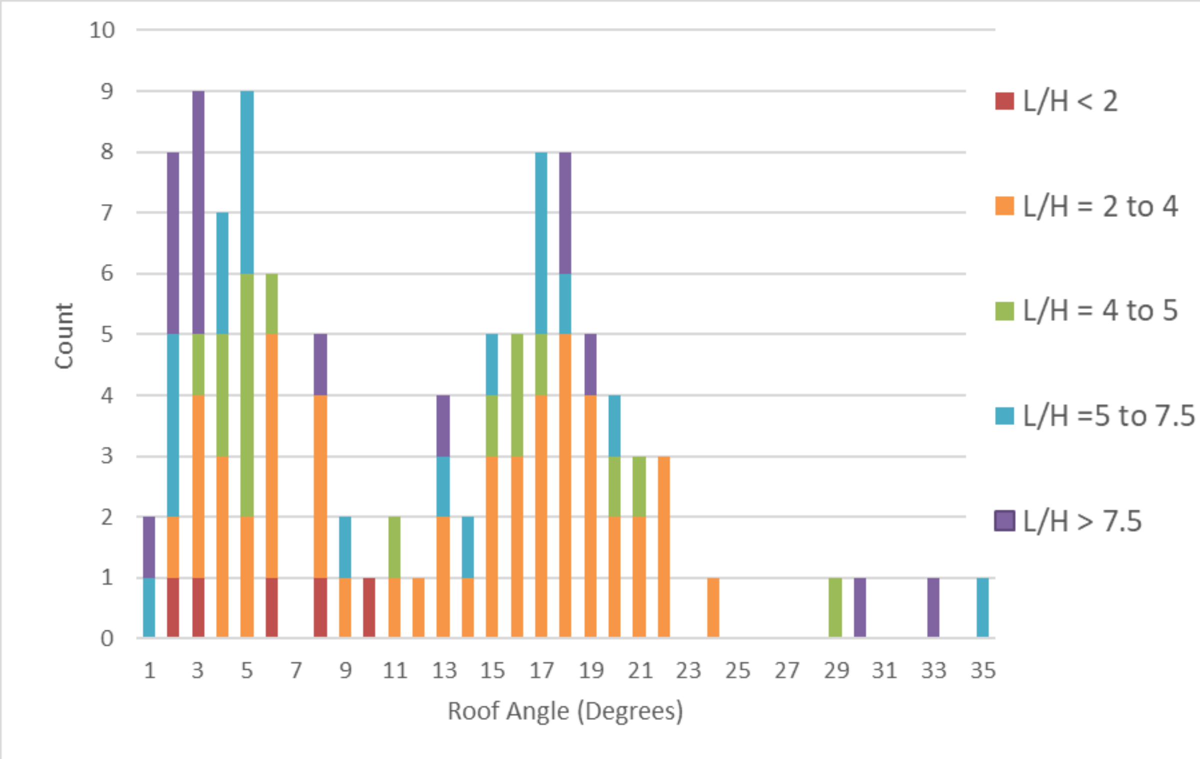

Fig.3. Count of roof angles by L/H for St. Paul

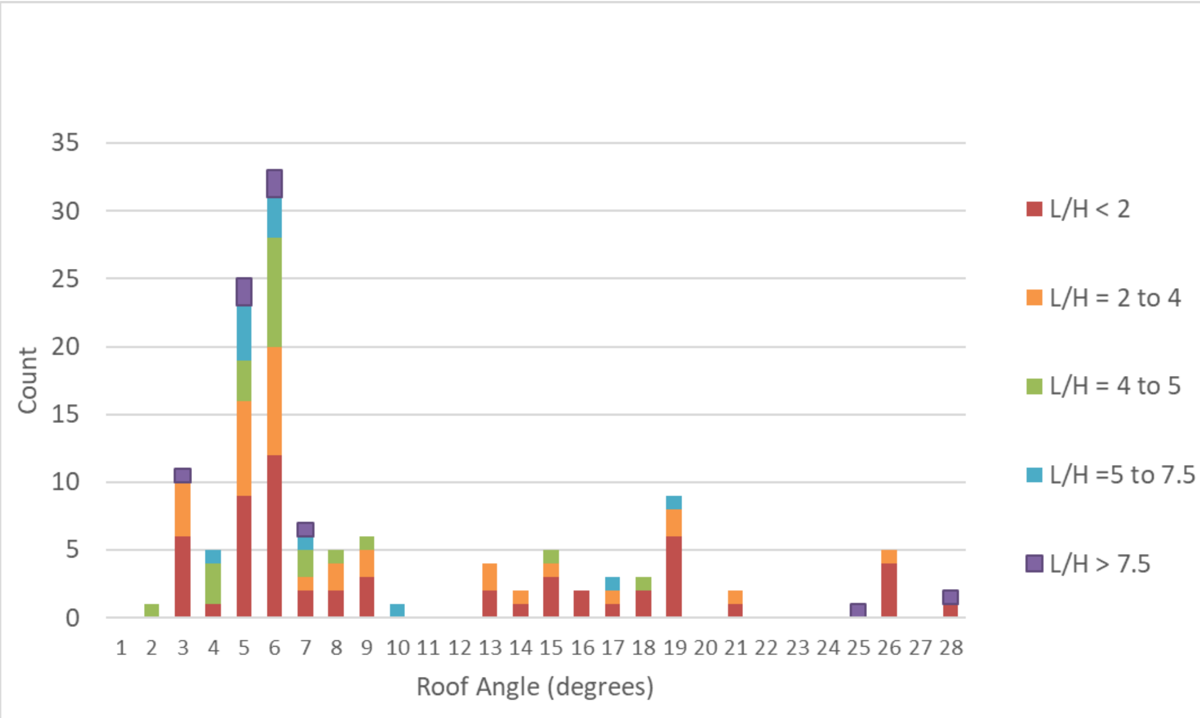

Fig.4. Count of roof angles by L/H for Detroit

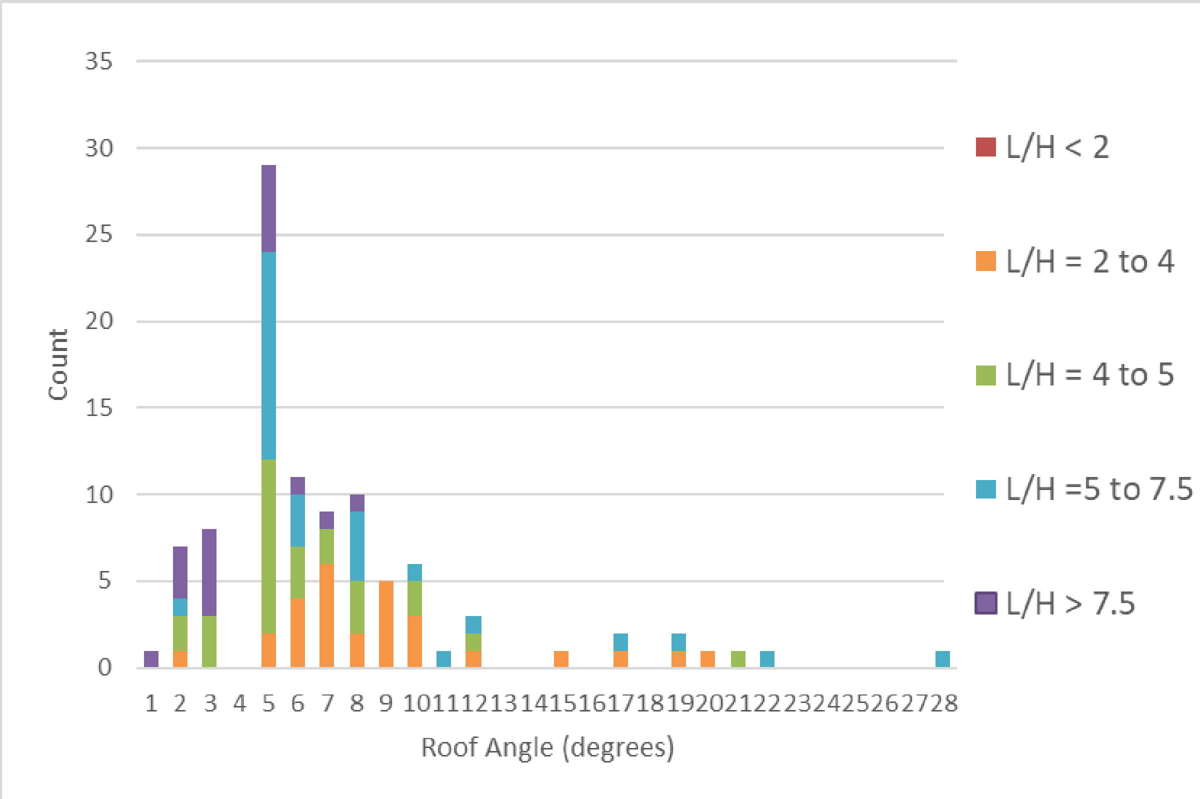

Fig.5. Count of roof angles by L/H for Miami

St. Paul has higher snow loads. It was found that a larger number of structures there have high higher slopes. However, only two structures out of 100 in St. Paul were found to have slopes above 30.3 degrees where unbalanced snow load doesn't need consideration. Therefore, it is clear that designers working on structures for St. Paul have not been optimizing the gable frames by sloping them to limit unbalanced snow load. Yet, the higher number of sloped roofs shows that other factors are influencing the choice of slopes. The balanced snow load is reduced as roof slopes increase. Additionally, with high load, arching of the structure is considered to be more efficient. Those were possible influences in choosing roof slopes in St. Paul.

Katanbafnezhad [4] predicted that the optimum roof angle would change based on the span to height ratio. Higher spans would have higher slopes. The detail within the histograms will help to evaluate whether the expected trends exist.

Patterns are visible in the span to height (L/H) ratios of gables. The ratio of L/H is indicated in each figure for each city. Detroit has the highest number of roofs with small L/H. Red is L/H less than 2. This might be explained by the fact that manufacturing requires many different sorts of suppliers of varying sizes, so each would have a building of its own size. St. Paul has the greatest variety of buildings. However, Miami and Santa Barbara consist of mainly airport hangers so those tend to be more median in L/H.

Roof angles versus span to height ratios were plotted for structures in Figure 6. It is seen that as the L/H increases, the roof angle decreases. From the histogram for Detroit in Figure 4, you can see that frames with a low L/H are distributed with many angles, but then frames with a high L/H have roof slopes mostly near 5 degrees. This is the opposite of what is predicted by Katanbafnezhad [4]. The correlation coefficient is only 0.14, so it has no predictive value. However, we can rule out that designers are increasing the roof angle with larger spans.

For St. Paul, a similar plot was attempted. This would be the city that should show the greatest variation in roof slopes according to Katanbafnezhad [4]. However, the correlation was 0.02. Therefore, any trend is not statistically valid.

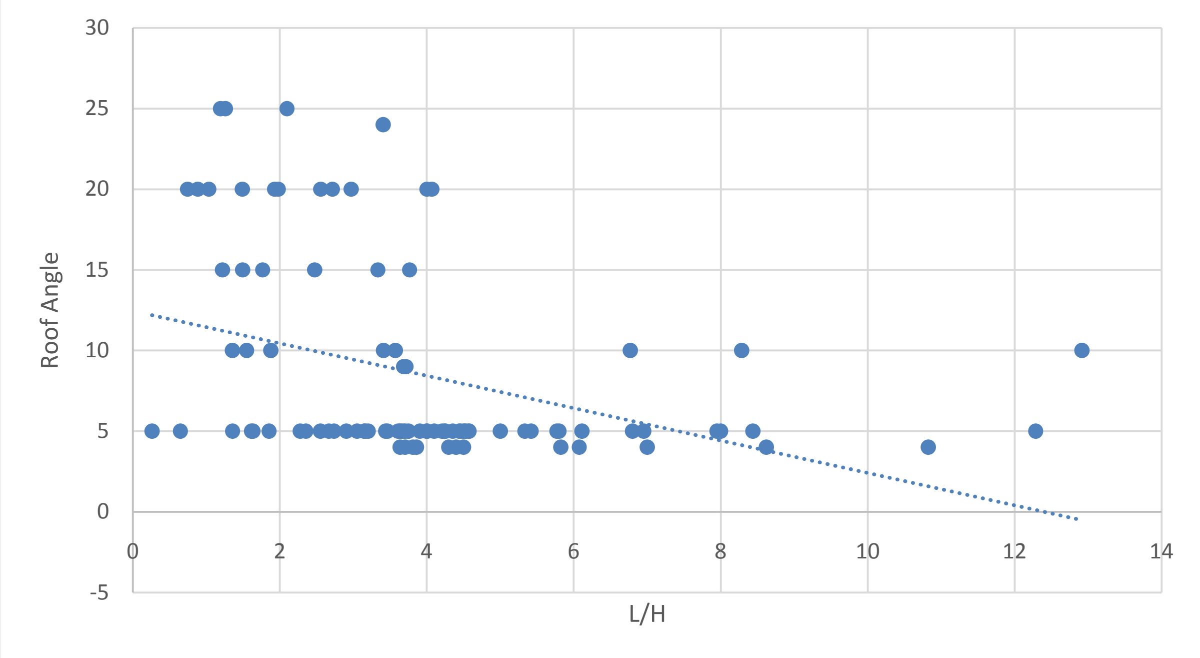

Fig.6. Relation between L/H and Roof Angle for Detroit

IV. CONCLUSION

Great variety in roof designs were found across regions and regions with higher snow were found to have steeper roof. This supported one of the hypotheses. This shows that local designers generally produce structures that are more efficient with snow loading.

The hypothesis was not supported that steel gables with lower spans have lower roof slopes than roofs with higher spans. Span and the span to height ratio (L/H) were nearly synonymous since many structure heights were nearly the same.

There are several possible explanations for engineers not following predicted optimal designs. The first is that the engineers are not aware of the advantage of higher roof slopes in reducing snow load. Designers are probably just following local tradition in their designs. A second explanation might be that designers don't want tall roofs for aesthetic reasons. A tall building may look ominous. A third explanation could partly be that there has been a change in the code methods over time. For example, flat roofs are not required to account for unbalanced snow loads, and the definition of flat has changed in versions of the code. Also related to time, materials and methods of design may have changed over time and that could have affected what is considered optimal.

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