Cost-Benefit Analysis of PEMB vs. Conventional Steel Structure

Heath Todd Rose

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Cost-Benefit Analysis of PEMB VS. Conventional Steel Structure

by

Heath Todd Rose

An Honors Capstone

submitted in partial fulfillment of the requirements

for the Honors Diploma

to

The Honors College

of

The University of Alabama in Huntsville

April 6, 2020

Honors Capstone Director: Ms. Christine Robinson, PE

Instructor of Civil Engineering Design I & II

Heath Rose

4-6-20

Student Date

Christine C. Robinson

4-7-20

Digitally signed by William Wilkerson

Date: 2020.04.09 11:25:05 -05'00'

William Wilkerson

Digitally signed by William Wilkerson

Date: 2020.04.09 11:25:21 -05'00'

William Wilkerson

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Date: 2020.04.09 11:25:21 -05'00'

Honors College Dean Date
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Heath Rose

Student Name (printed)

Heath Rose

Student Signature

4-6-20

Date
Table of Contents

Abstract 2
Introduction 3
Chapter 1: PEMB Design 6
Chapter 2: Conventional Steel Design 11
Chapter 3: Comparison of Methods 20
Reference List 23
Conclusion 25
Design Drawings S0.0
Abstract

There are a variety of steel framing systems available and widely used in the construction industry. Each system has its own advantages and disadvantages. Therefore, it is often difficult to identify the appropriate framing system for each individual project. The following project will evaluate the two primary steel framing systems, PEMB (Pre-engineered metal building) and conventional steel structure, for a standard one-story commercial building. This manuscript will then compare several factors associated with both configurations which include but are not limited to steel tonnage, constructability, ability to modify, and customization.
Introduction

When designing a building, it is important to first determine what will be used to construct the building. This can influence design limitations, budget, schedule, and many other factors that are vital to the success of a project. Before these decisions can be properly made, it is important to fully understand the many alternatives that are available, and the pros/cons associated with each. Timber, masonry, concrete, and steel are some of the most common materials that are widely used in the construction industry here in the United States and abroad. Within each of these materials, there exist many methods of utilizing this material. In the United States, steel has become one of the most common construction materials in low-rise construction. It provides extreme versatility and is readily available in most markets.

Many framing methods have been developed for steel framed structures. However, this project will center on two of the primary methods: Pre-engineered Metal Building (PEMB) and conventional steel framing. The proposed Lamar Advertising Inc. building in Huntsville, AL, shown in Figures 0-1 and 0-2, will be used as a case study for this project. The building will be designed for both framing methods which will then be used to evaluate the effectiveness and feasibility of each method. The initial design calls for a mono-slope PEMB frame, and then the second design will be for a conventional “stick-frame” steel structure. Each design will be analyzed, and a thorough comparison will then be made for the designs.

The building will consist of approximately 6,800 square feet of office space and 8,200 square feet of warehouse space. There are several considerations that must be accounted for during the design process. It is important to maintain adequate clearance within the warehouse space to avoid interfering with the large trucks and equipment that will frequent the site. Additionally, minimal columns should be present within the interior of the warehouse space to
maximize the use of the area. This project will focus on identifying the framing method best suited to meet the owners needs and desires. It will consider the following factors for each method: material usage, constructability, ability to modify, and customization.

Figure 0-1: Exterior North & South Building Elevations
Figure 0-2: Exterior East & West Building Elevations
Chapter 1: PEMB Design

Overview

The initial design is for a PEMB (Pre-Engineered Metal Building) which consists of a series of frames, per Figure 1-1, equally spaced at 17’ O.C. (On Center). The frame was designed for the following load cases: dead, roof live, and wind loads. Seismic loading was not considered for this design due to the relatively low weight of one-story PEMB structures. This can be assumed because seismic design forces are controlled primarily by weight along with site conditions and location. Due to the proprietary nature of PEMB structures, this design will not be capable of incorporating tapered steel sections which are characteristic of common PEMB structures. Therefore, this design will be a conservative, but much less efficient design than would normally be encountered. This will require the final weight of the structure to be reduced significantly to account for this discrepancy.

Figure 1-1: Frame Layout and Supports
Analysis

In order to mimic the design of a PEMB structure, 2-D finite element analysis was utilized by inputting the frame into RAM Elements and STAAD Pro, both by Bentley Systems. These programs require loads to be manually generated and inputted into the system. The loads were calculated per ASCE 7-10, as detailed below. Member sizes were generated using the provisions of the AISC 15th Edition. LRFD, Load Resistance Factored Design, was used throughout the entirety of the analysis.

The frame was analyzed using the following assumptions and design considerations:

- Bracing at 10’ O.C. (steel angle kickers will be used to brace the flanges).
  - Therefore, the unbraced length is reduced to 10’.
- A maximum deflection of L/240 was considered for each member.
- Pinned connections were used at each support, as illustrated in Figure 1-1.
- The frame is assumed to be braced against translation in the z-direction by repetitive framing members.
- Second order, P-Delta, analysis was performed for the frame.
- A tributary width of 17’ was used for all calculations.
- Wind Loads were used per the worst-case wind loading, calculated per ASCE 7-10.
  - These same loads were applied for wind in both directions (see figures 1-4 and 1-5 below for clarification).

Material Properties:

A992 Gr. 50 Steel (Fy=50 ksi)
Load Cases:

- Dead Load (DL):
  - 8 psf + Member Self-Weight

- Roof Live Load (LLR):
  - 20 psf per ASCE 7-10

- Wind Loading:

  ![Diagram of wind loads](image)

**Figure 1-3: Wind Loads across High Eave**

**Figure 1-4: Wind Loads across Low Eave**
After the load cases were inputted into the programs, the following LRFD load combinations were generated. These combinations were used to generate the worst-case loading condition on the frame.

1. 1.4DL
2. 1.2DL+0.5LLR
3. 1.2DL+1.6LLR
4. 1.2DL+0.5Wind
5. 1.2DL+1.6LLR+0.5Wind
6. 1.2DL+Wind
7. 1.2DL+Wind+0.5LLR
8. 0.9DL+Wind

Global Restraints at Nodes:

![Sign Convention](image)

Figure 1-5: Sign Convention

Maximum Reactions:

<table>
<thead>
<tr>
<th>Node</th>
<th>-Fx</th>
<th>+Fx</th>
<th>-Fy (uplift)</th>
<th>+Fy (downward)</th>
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</thead>
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<td>4</td>
<td>-8.59 K</td>
<td>2.90 K</td>
<td>-12.09 K</td>
<td>35.13 K</td>
</tr>
</tbody>
</table>
Design Summary:

Frame Design:

Figure 1-6: Frame Design

LFRS (Lateral Force Resisting System):

PEMB structures commonly rely on rods used as x-bracing or portal frames to resist the lateral forces imparted by wind and seismic events. For consistency and minimal steel usage, x-bracing rods are assumed to be used for this design.
Chapter 2: Conventional Steel Design

Overview

The secondary design is for a conventional steel frame structure which consists of wide-flange columns and girders, and steel joists, as illustrated in Figure 2-1. The frame was designed for the following load cases: dead, roof live, seismic, and wind loads. Seismic loading was considered for this design because conventional steel structures typically weigh enough to necessitate its inclusion. Therefore, seismic loading could potentially control the lateral design as opposed to wind loading. Additionally, a column layout was chosen that provided the least viable impact to the architectural layout of the structure.

Figure 2-1: Framing Layout
Analysis

In order to design the structure, RAM Structural Systems by Bentley Systems, Inc. was used to perform a 3-D analysis of the structure. The program requires the input of dead and roof live loads and then self-calculates wind and seismic loading based on the user input of the necessary variables. The loads were calculated per ASCE 7-10, as detailed below. Member sizes were generated using the provisions of the AISC 15th Edition. LRFD, Load Resistance Factored Design, was used throughout the entirety of the analysis.

The frame was analyzed using the following assumptions and design considerations:

- All connections are pinned.
- X-bracing is used for lateral support. Locations are shown on the roof framing plan, Figures 2-4A and 2-4B.
- Compression flange of girders are braced at 5’-0” O.C. by joists.

Material Properties:

- Wide Flange Sections: A992 Gr. 50 Steel (Fy=50 ksi)
- HSS X-bracing: A500 Gr. C (Fy=46 ksi)

Load Cases:

- Dead Load (DL):
  - 20 psf (includes member self-weight)
- Roof Live Load (LLR):
  - 20 psf per ASCE 7-10
o Wind Loading:

▪ Occupancy Category = II

▪ Basic Wind Speed ($V_{ult}$) = 115 mph

▪ Building Category = Enclosed

▪ Exposure Category = B

▪ Internal Pressure Coefficient ($GC_{pi}$) = +/- 0.18

o Seismic Loading, From U.S. Seismic Design Maps:

▪ Occupancy Category = II

▪ Seismic Importance Factor ($I_E$) = 1.0

▪ Spectral Response Accelerations:
  
  $S_S=0.251$  $S_I=0.12$
  $S_{DS}=0.267$  $S_{D1}=0.185$

▪ Soil Site Class: Assumed D

▪ Seismic Design Category: C

Global Restraints at Nodes:

Figure 2-2: Sign Convention
Maximum Reactions:

<table>
<thead>
<tr>
<th>Location</th>
<th>-Fx</th>
<th>+Fx</th>
<th>-Fy (uplift)</th>
<th>+Fy (downward)</th>
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<td>Exterior</td>
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<td>None</td>
<td>None</td>
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</tbody>
</table>
Design Summary

Framing Design

Figure 2-3A: Column Layout & Size – Part A
Figure 2-3B: Column Layout & Size – Part B
Figure 2-4B: Roof Framing Layout & Sizes – Part B
LFRS (Lateral Force Resisting System):

X-Braces were used to resist the lateral forces exerted by wind and seismic loading. The locations of these braces are designated by BRACED BAY in Figure 2-4A and 2-4B. Figure 2-5 demonstrates how they function when lateral forces are applied. A scale factor of 1000 was used to illustrate the movement of the braces.

Figure 2-5: LFRS X-Brace Design
Chapter 3: Comparison of Methods

Steel Takeoff – Material Usage

One of the chief factors in the cost of a structure is the amount of material needed to construct it. Materials cost money to form in the manufacturing plant, ship to the site, and erect during construction. Additionally, environmental sustainability efforts such as LEED, Leadership in Energy and Environmental Design, have brought additional attention to the usage and conservation of materials during construction. For instance, LEED v4.1 introduced a credit for the sourcing of raw materials that encourages designers to utilize responsibly sourced materials. Therefore, it is important to maximize the reduction of materials to meet these requirements. As a result, this is an important factor to consider when choosing a framing system. Estimated steel weights were calculated for each of the framing systems. For easy comparison, the purlins and steel deck were not considered in the total weights.

PEMB (estimated based on 40% of the conservative design):

Estimated Total: **62,280 lb**

Conventional Steel Structure:

Columns: 23,940 lb
Beams: 16,755 lb
Braces: 6316 lb
Joists: 20658 lb
Total: **67,669 lb**

Although the PEMB weight is difficult to accurately predict without the required software, the estimated weight provides a good comparison between the two structures. PEMB structures generally weigh less than conventional steel structures with some manufacturers even
claiming up to 30% less steel usage ("PEMB vs. Conventional"). As a result, a PEMB structure would likely minimize the steel usage.

**Constructability**

In addition to material cost, labor costs are the second major factor in the overall cost of a structure. Naturally, the easier a building is to construct, the cheaper it will be. The two framing methods differ significantly in this area. The PEMB frame is constructed in a manufacturing plant, and then erected and bolted together when it reaches the site. Because a large part of the manufacturing takes place inside, weather has little impact on the construction schedule. Additionally, the relatively few segments and modest field work required save time and ultimately money.

On the other hand, conventional steel structures must first be detailed by a steel detailer and then a fabricator constructs each individual column, beam, etc. before being shipped to the site. Once on the site, a significant amount of work must be done in the field. For instance, many of the connections must be welded on the site which also requires extra laborers on the site. As a result, conventional steel structures are much more susceptible to weather delays and other scheduling conflicts. Therefore, conventional steel structures are estimated to require 33% more time on average to erect ("15 Reasons").

**Ability to Modify**

Both types of structures easily provide for future additions and renovations. Due to loadbearing walls not being required for either method, walls can easily be removed to accommodate any future renovations. However, the conventional steel structure has many interior columns which affects the potential usability of the interior space. Conversely, the
PEMB structure does not have interior columns which provides for easy modification of the floor plan.

In contrast, the conventional steel structure is superior for accommodating mechanical equipment. For instance, if the owner later decides to add an air conditioning unit on the roof, only a few of the roof joists must be reinforced to accommodate the additional loading. In a PEMB structure, however, the entire frame must be reinforced across the full length of the building which is often not feasible. Therefore, the smaller segmentation of the roof framing in the conventional steel structure provides more future flexibility because a much smaller area of framing is impacted when changes are necessitated.

**Customization**

Some buildings place a focus on the architectural uniqueness of the structure while others are simply designed to be functional. This is an important consideration when determining a framing system. PEMB structures largely come in predetermined sizes and are generally limited to a rectangular shape. For some buildings, this is sufficient for the use of the building. For instance, buildings located in industrial districts such as the structure at hand, are not focused on the “curb appeal” of the building.

Alternatively, a conventional steel structure presents almost limitless possibilities for the architectural design of the building. Almost any shape can be achieved, and unique nuances can be added to the building. As a result, a conventional steel structure would be more appropriate for a commercial building that will be highly visible to the general public.
Reference List


*RAM Elements*. Bentley Systems, Inc.

*RAM Structural Systems*. Bentley Systems, Inc.

*STAAD Pro*. Bentley Systems, Inc.


“U.S. Seismic Design Maps.” *U.S. Seismic Design Maps*, seismicmaps.org/.
Conclusion

Based on the findings of this project, I recommend the usage of a Pre-Engineered Metal Building for Lamar Advertising Inc.’s new Huntsville facility. Firstly, it appears to be the most cost-effective framing method for the current layout of the building. Next, it maximizes the available space within the warehouse area of the building. The lack of interior columns is a big upside of the PEMB design. Additionally, it provides for a much faster delivery of the completed building to the owner. This comes with a large financial benefit to the owner with a sooner move-in date as well as decreased labor costs. With the building being located in an existing industrial park, architectural features are not a high priority which would not necessitate a more expensive conventionally framed steel structure. As a result, a PEMB serves as the most economical and ultimately best-suited framing method for the facility.
STRUCTURAL FRAMING PLANS
FOR
LAMAR ADVERTISING COMPANY
260 ELECTRONICS BLVD SW HUNTSVILLE, AL 35824
APRIL, 2020

VICINITY MAP
(NOT TO SCALE)

SECTION 32, TOWNSHIP 4 SOUTH, RANGE 2 WEST
HUNTSVILLE MERIDIAN, MADISON COUNTY, ALABAMA
NEW FACILITY FOR:
LAMAR ADVERTISING COMPANY

DRAWN BY: HEATH ROSE
CHECKED BY:
DATE: 04/06/2020

SEE SHEET 260 ELECTRONICS BLVD HUNTSVILLE, AL 35824

ROOF FRAMING PLAN

SCALE: 1/8" = 1'-0"

CONV. ROOF FRAMING PLAN

S1.2A
TYPICAL FRAME DETAIL

W14x38

W30x173

W12x30