Abstract

The Metal Building Manufacturers Association (MBMA) has sponsored the development of a comprehensive manual for the practical seismic design of metal building systems. The manual, entitled the “Seismic Design Guide for Metal Building Systems”, provides design approaches and procedures that are intended to be compliant with the seismic requirements of the 2000 International Building Code (IBC). The Guide, which is expected to be published and available in the second quarter of 2004, uses an example problem format and thereby provides interpretations about common design and analysis situations, which are common to metal buildings.

Guideline Style and Organization

MBMA has sponsored the development of a comprehensive manual for the practical seismic design of metal building systems. The manual, entitled the “Seismic Design Guide for Metal Building Systems”, provides design approaches and procedures that are intended to be compliant with the seismic requirements of the 2000 International Building Code. The Guide is expected to be published and available in the second quarter of 2004.

There are two primary parts to the Guide. In the relatively brief narrative first part of the guide, the background and organization are described. Also the technical basis is discussed and the approach used to establish a consensus on judgment issues is presented.

In the more lengthy second part of this guide, four design example problems are provided. The problems are in narrative form and are intended to illustrate acceptable approaches to deal with the most common seismic design issues encountered in the design of metal building systems. The problems were defined by the MBMA Seismic Design Guide Steering Committee with the desire for them to represent realistic design examples of metal building systems.

Throughout the design examples, commentary is provided as italicized notes, as shown in this sentence.

The comments are intended to provide the reader with discussion, which gives insights, background and perhaps potential future changes on the specific seismic requirements that are being utilized at that point in the design example. The four design examples that are provided in the second part are:

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1 Principal, Robert. E. Bachman Consulting Structural Engineer, Sacramento, California
2 Director of Research & Engineering, Metal Building Manufacturers Association, Cleveland, Ohio
• Design Example 1 - Determination of Seismic Design Forces. The seismic base shear forces are determined for a range of site locations and metal building system moment frame boundary conditions.

• Design Example 2 - Design of Frames, Columns, Bracing and other Elements of the Lateral Force Resisting System. The example specifically considers the design of end plate bolted moment frame connections.

• Design Example 3 - Determination of Seismic Design Forces and their distribution when a metal building contains a mezzanine with a concrete deck (rigid diaphragm).

• Design Example 4 - Determination of Seismic Design Forces and detailing associated with a metal building with hard walls (masonry or tilt-up).

**MBMA Seismic Guide Steering Committee Direction and Review**

The Metal Building Manufacturers Association (MBMA) commissioned the preparation of this document with the goal of providing a comprehensive manual for achieving practical metal building design systems that satisfy the 2000 IBC. To steer the development of the Guide, a steering committee was formed consisting of the following individuals:

- Buddy Oldner  
  Ruffin Building Systems
- James R. Miller  
  J.R. Miller & Associates
- Mike Pacey  
  Butler Research
- Scott Russell  
  Nucor Building Systems
- Don Tobler  
  Steelox Building Systems
- Steven J. Thomas  
  VP Buildings
- Dennis P. Watson  
  Star Building Systems

W. Lee Shoemaker of MBMA was advisor to the Committee and acted as the primary liaison between the committee and the consultants who were engaged to prepare the Guide.

The Steering Committee was involved in many ways on this project. They first defined the subjects that they wanted covered in the Guide. Secondly, they defined how they wanted the Guide to be organized (i.e. design examples). Thirdly, they provided the problem definitions for each of the design examples. Fourthly, they provided analysis support so that where needed, analysis results reflect actual industry analysis practice. And finally they provided a comprehensive review of this document so that it represented at least a majority view of the Committee. While full consensus was mostly achieved, in
some instances there was strong minority opinion on some issues or assumptions. These views are reflected in the document.

**Guideline Authors**

The Seismic Design Guide was authored by the following individuals:

- Robert Bachman, S.E.  Principal, R.E. Bachman Consulting  
  Structural Engineer
- Rick Drake, S.E.  Principal Structural Engineer, J.S. Dyer & Associates
- Martin Johnson, S.E.  Project Manager, ABS Consulting
- Thomas M. Murray, Ph.D., P.E.  Professor, Virginia Polytechnic Institute and State University

Each of these individuals provided special expertise to the guide document.

- Mr. Bachman provided expertise in IBC Seismic Requirements and served as the lead guideline author for coordinating the guide’s development among the guide’s authors.
- Mr. Drake provided expertise on the AISC Seismic Provisions and served as the publication consultant.
- Mr. Johnson provided expertise on seismic design issues associated with metal buildings.
- Dr. Murray provided expertise on the seismic design of beam column moment connections.

**Codes and Standards Used as the Technical Basis for the Guidelines**

The design basis of this guide is the 2000 International Building Code (IBC), the American Institute of Steel Construction (AISC) Seismic Provisions for Steel Buildings, April 15, 1997, including Supplement No. 1, February 15, 1999, and common industry practice. This guide focuses on Allowable Stress Design but points out differences and/or advantages of Load and Resistance Factor Design (LRFD) when appropriate. Where appropriate, revisions that have been accepted by ASCE 7-02 and AISC Seismic Provisions, Supplement No. 2, November 10, 2000, that have been incorporated into the IBC 2003 are discussed regarding the effect they will have on seismic design.

**Basic Concept of Seismic Code Reduced Forces**

The 2000 IBC requires that all structures in most parts of the United States be designed to resist design earthquake ground motions. As currently defined, these design earthquake
motions have average return periods of between 300 and 800 years and are quite severe. If the forces resulting from these motions were designed to be resisted elastically by the structure (like what is done for wind loads), the resulting designs would be impractical for most building in the higher seismic regions of the United States.

To provide a practical way to accommodate these motions, the practice of earthquake engineering has evolved to permit the elastic forces associated with severe earthquake ground motions to be reduced to design earthquake force levels. This reduction has been based on observed performance of certain types of structures to inelastically absorb earthquake motions without collapse. The codes have recognized this inherent performance with seismic force reduction factors “R”. The more inelastic absorption capacity, the larger the value of R and the lower the design earthquake forces. However, the larger the value the more detailing requirements are imposed on the design to assure that the structure will perform inelastically as intended. Also, with larger values of R, more restrictions are imposed on proportioning of members and their limitations on the types of systems that can have high R values. In higher seismic areas, many structural systems that have low R values are not permitted because they have low earthquake resistance reliability. It should be noted that the reduction of seismic forces by R is a function of period. At periods less than one fifth of velocity transition period, the ground motion acceleration reduces proportionately to the period while the base shear force remains constant.

In the guideline document, seismic force reduction factors are used which are consistent with the structural systems found in metal buildings. Because reduced forces are used, special design and detailing is required for some members and connections. The design examples illustrate where these special connection forces are required and how they should be applied. The user is cautioned that application of reduced seismic forces in design without the corresponding application of seismic detailing will likely result in a design that is not in compliance with the 2000 IBC.

**Metal Building Standard Design and Analysis Practice/Economy**

The metal building industry is very unique. The primary cornerstone of the metal building design is to minimize building cost through optimization of steel weight and the fabrication process. The industry takes advantage of all allowed code exceptions and options that frequently result in lighter structures than are normally found in other types of building construction.

Special custom computer systems have been developed by metal building suppliers that are tailored specifically for metal building design. This results in a very efficient design process. The analysis approach typically used in the design of most metal buildings is to analyze each line of resistance as a 2-D model. The typical practice is to analyze the building assuming a flexible diaphragm and to assign loads to each line of resistance using a tributary area approach. Code prescribed exceptions to drift limits are sometimes invoked by demonstrating that the detailing of non-structural attached items can accommodate the excess drift.
Typically (but not always) the metal building supplier designs only the building. Others do the foundation design and construction. Seismic design presents a unique challenge to the metal building industry because of the many special seismic detailing requirements that are not necessary for any other loadings.

**Approach to Metal Building Roof Diaphragm Rigidity (Flexible vs. Rigid)**

The way that applied forces are distributed within any building is directly related to the rigidity of the structural elements of that building. A significant factor is the rigidity of structure elements that transfer forces horizontally, relative to elements that transfer force vertically. Engineers have developed simplified design approaches to determine force distributions based upon assumptions anchored at either extreme of this relative rigidity between horizontal and vertical elements. The two extremes are defined as follows:

- **Flexible Diaphragm.** The rigidity of the horizontal diaphragm is very small relative to the rigidity of the vertical systems.

- **Rigid Diaphragm.** The rigidity of the horizontal diaphragm is very large compared to the rigidity of the vertical systems.

Analysis using either of these bounding assumptions produces results that vary in accuracy depending upon how closely the actual structure matches the simplifying assumptions. Although many (perhaps most) structures fall somewhere between these extremes, more accurate analysis can only be done by using complex finite-element models that are generally not practical to use for ordinary building designs.

IBC Sec. 1602.1 defines a flexible diaphragm as having a lateral deflection of more than two times the average story drift of the vertical elements supporting the diaphragm, and a rigid diaphragm as everything else. This definition requires calculation of diaphragm deflection, which is complex and imprecise for many types of diaphragm construction. Therefore, it is important to be able to select and use appropriate simplified assumptions to obtain rapid structural design solutions.

Diaphragm deflection varies depending upon the materials used, the type and spacing of fasteners used in the construction, the depth of the diaphragm in the direction of deformation, and the width or span of the diaphragm transverse to the direction of deformation. Horizontal diaphragm systems in metal buildings might consist of either the metal cladding of the roof itself or of separate horizontal bracing systems installed beneath the roof.

Metal roof cladding in metal buildings typically consists of either standing seam type metal panels or through-fastened roof panels.

- In Standing Seam Roof (SSR) systems, the formed roof sheets are restrained against uplift but are free to slide against each other (float) along the length of
the joining seams. The resulting roof systems vary in the strength and stiffness required to transfer horizontal forces and in general they are considered to be flexible for any type of construction. Therefore, separate horizontal bracing systems usually need to be provided that are designed to resist the full wind and earthquake demands. Friction caused by sliding of panels along seams probably provides energy dissipation (damping) to the structure that is beneficial to earthquake response, but is usually ignored in the design. There are exceptions to this typical presumed behavior. Standing seam roof systems with documented strength and stiffness values may be sufficient to act as sub-diaphragms for the distribution of portions of the lateral forces to the main diaphragm cross-ties.

- Through-Fastened Roof (TFR) systems come in many types. Some systems use screws that fasten through only one sheet of adjoining roof panels, while an overlapping rib holds down the adjacent sheet from the fastened sheet. This roofing type, like a standing seam roof, is considered to be flexible for all types of construction. Other TFR systems use concealed or exposed screws that fasten through both metal sheets along an overlapping edge. The rigidity of these systems varies depending upon the type and spacing of fasteners, the profile and thickness of the joining metal roofing sheets, and the overall depth and width of the diaphragm.

It has been a traditional metal building design practice to assume that diaphragms of all types are flexible, regardless of the size or shape of the building or the type and relative rigidity of the vertical structural elements. For the most part, this assumption is reasonably correct and appropriate. A typical metal building which is relatively square in plan dimensions, with either a SSR or TFR system, a series of moment frames in the transverse directions, and several bays of tension-rod bracing in the longitudinal direction would be expected to meet the deflection check as a flexible diaphragm system. However, the design engineer should be aware that some structural geometries might be better classified as having rigid diaphragms:

- As an example, a warehouse building with a TFR system that has a series of moment frames instead of bracing along the walls of the longitudinal axis, in order to provide a continuous line of loading docks along the walls of the building. The relatively flexible moment frames are likely to experience deflections equal to or greater than the TFR system. Note that an SSR system would still be considered flexible for this building.

- Structures using relatively flexible cable bracing systems as vertical bracing, in conjunction with relatively more rigid tension-rod horizontal bracing or a TFR system might be considered as having rigid diaphragms.

Where structure conditions warrant that the diaphragm is not flexible, and yet it is not clear that rigid diaphragm assumptions are appropriate, it is always conservative to “bound” the analysis problem by distributing forces using both a flexible and rigid diaphragm assumption, and then use the worst-case forces for the design of each element.
This approach is referred to as the “envelope” diaphragm analysis method. Design Example 3 provides a procedure for performing a rigid diaphragm torsional analysis for a mezzanine (presumed to be rigid) attached to a metal building. A similar approach could be used for a roof system.

**Accidental Torsion**

IBC Sec. 1617.4.4.3 requires for diaphragms which are rigid (i.e. not flexible), that the distribution of base shear forces should consider the actual torsional moment caused by difference in location between the center of mass and center of stiffness of the structure. In addition, IBC Sec. 1617.4.4.4 requires for rigid diaphragms that an additional “accidental” torsional moment be added to the actual torsion defined by Sec. 1617.4.4.3. Further, IBC Sec. 1617.4.4.5 requires that in some instances the combined actual and accidental torsional moment must be multiplied by a dynamic amplification factor.

**Unique Structure Geometries and Diaphragm Force Distribution**

Many buildings have geometries that complicate the picture when considering horizontal force distribution. A common instance is for buildings that contain partial mezzanine floor levels. These floors might be clearly rigid by inspection, such as when consisting of concrete-topped metal decking supported by steel beams, or they might be of more questionable rigidity, such as when plywood floor sheathing is used. In either instance, the design of the overall building would need to include the forces generated by the weight of the floor system, and appropriate structural elements would need to be provided to resist these forces. The method used to distribute these forces to the building system, whether flexible, rigid or envelope, would be determined based on comparison of the relative rigidity of the horizontal floor system versus the rigidity of the resisting vertical elements.

It is not inappropriate or uncommon that flexible diaphragm assumptions might be used to distribute roof forces while also using rigid diaphragm assumptions to distribute forces from an interior mezzanine system. This is the approach that is used in Design Example 3.

**Minority Opinions**

In the process of developing the guidelines, there were some subjects upon which a full consensus could not be obtained. Where this occurred the *italics* discussion explains both points of view and cautions the user that the approach taken in this guide may not be accepted by the authority having jurisdiction. However, it is the opinion of the authors that the approaches provided are in literal compliance with the 2000 IBC.

**Lower Seismic Area Design Alternative**

The approach provided in this guideline document assumes that the design will utilize the largest R value that is permitted for the structural system being utilized resulting in the
lowest seismic design forces. This means that specific and somewhat stringent detailing requirements of the AISC Seismic Provisions are imposed. In the lower areas of seismicity for structures which are classified as Seismic Design Category B or C, the steel building design engineer has the option to design for somewhat higher seismic forces assuming an $R = 3$ but ignoring the special detailing requirements. There are several special requirements embedded in the 2000 IBC. These are discussed in Design Example 1. The advantage of the $R = 3$ option might be that other loads (such as wind) may govern the design. The $R = 3$ option may perhaps result in much simpler design and analysis for such cases without any reduction in economy.

Concluding Remarks

This paper has provided a brief overview of the new MBMA Seismic Design Guide for Metal Building Systems. It is the hope of MBMA and Guide authors that the Guide will achieve its goal of providing a comprehensive manual for achieving practical metal building design systems that satisfy the seismic requirements of the 2000 IBC.

References


