Steel Design Guide

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Industrial Buildings

Roofs to Anchor Rods

Second Edition

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Part 1

INDUSTRIAL BUILDINGS—GENERAL

1. INTRODUCTION

Although the basic structural and architectural components of industrial buildings are relatively simple, combining all of the elements into a functional economical building can be a complex task. General guidelines and criteria to accomplish this task can be stated. The purpose of this guide is to provide the industrial building designer with guidelines and design criteria for the design of buildings without cranes, or for buildings with light-to-medium duty cycle cranes. Part 1 deals with general topics on industrial buildings. Part 2 deals with structures containing cranes. Requirements for seismic detailing for industrial buildings have not been addressed in this guide. The designer must address any special detailing for seismic conditions.

Most industrial buildings primarily serve as an enclosure for production and/or storage. The design of industrial buildings may seem logically the province of the structural engineer. It is essential to realize that most industrial buildings involve much more than structural design. The designer may assume an expanded role and may be responsible for site planning, establishing grades, handling surface drainage, parking, on-site traffic, building aesthetics, and, perhaps, landscaping. Access to rail and the establishment of proper floor elevations (depending on whether direct fork truck entry to rail cars is required) are important considerations. Proper clearances to sidings and special attention to curved siding and truck grade limitations are also essential.

2. LOADING CONDITIONS AND LOADING COMBINATIONS

Loading conditions and load combinations for industrial buildings without cranes are well established by building codes.

Loading conditions are categorized as follows:

1. *Dead load:* This load represents the weight of the structure and its components, and is usually expressed in pounds per square foot. In an industrial building, the building use and industrial process usually involve permanent equipment that is supported by the structure. This equipment can sometimes be represented by a uniform load (known as a collateral load), but the points of attachment are usually subjected to concentrated loads that require a separate analysis to account for the localized effects.

2. *Live load:* This load represents the force imposed on the structure by the occupancy and use of the building. Building codes give minimum design live loads in pounds per square foot, which vary with the classification of occupancy and use. While live loads are expressed as uniform, as a practical matter any occupancy loading is inevitably nonuniform. The degree of nonuniformity that is acceptable is a matter of engineering judgment. Some building codes deal with nonuniformity of loading by specifying concentrated loads in addition to uniform loading for some occupancies. In an industrial building, often the use of the building may require a live load in excess of the code stated minimum. Often this value is specified by the owner or calculated by the engineer. Also, the loading may be in the form of significant concentrated loads as in the case of storage racks or machinery.

3. *Snow loads:* Most codes differentiate between roof live and snow loads. Snow loads are a function of local climate, roof slope, roof type, terrain, building internal temperature, and building geometry. These factors may be treated differently by various codes.

4. *Rain loads:* These loads are now recognized as a separate loading condition. In the past, rain was accounted for in live load. However, some codes have a more refined standard. Rain loading can be a function of storm intensity, roof slope, and roof drainage. There is also the potential for rain on snow in certain regions.

5. *Wind loads:* These are well codified, and are a function of local climate conditions, building height, building geometry and exposure as determined by the surrounding environment and terrain. Typically, they're based on a 50-year recurrence interval—maximum three-second gust. Building codes account for increases in local pressure at edges and corners, and often have stricter standards for individual components than for the gross building. Wind can apply both inward and outward forces to various surfaces on the building exterior and can be affected by size of wall openings. Where wind forces produce overturning or net upward forces, there must be an adequate counterbalancing structural dead weight or the structure must be anchored to an adequate foundation.

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6. *Earthquake loads:* Seismic loads are established by building codes and are based on:

   a. The degree of seismic risk
   b. The degree of potential damage
   c. The possibility of total collapse
   d. The feasibility of meeting a given level of protection

Earthquake loads in building codes are usually equivalent static loads. Seismic loads are generally a function of:

   a. The geographical and geological location of the building
   b. The use of the building
   c. The nature of the building structural system
   d. The dynamic properties of the building
   e. The dynamic properties of the site
   f. The weight of the building and the distribution of the weight

Load combinations are formed by adding the effects of loads from each of the load sources cited above. Codes or industry standards often give specific load combinations that must be satisfied. It is not always necessary to consider all loads at full intensity. Also, certain loads are not required to be combined at all. For example, wind need not be combined with seismic. In some cases only a portion of a load must be combined with other loads. When a combination does not include loads at full intensity it represents a judgment as to the probability of simultaneous occurrence with regard to time and intensity.

3. OWNER-ESTABLISHED CRITERIA

Every industrial building is unique. Each is planned and constructed to requirements relating to building usage, the process involved, specific owner requirements and preferences, site constraints, cost, and building regulations. The process of design must balance all of these factors. The owner must play an active role in passing on to the designer all requirements specific to the building such as:

1. Area, bay size, plan layout, aisle location, future expansion provisions.

2. Clear heights.

3. Relations between functional areas, production flow, acoustical considerations.

4. Exterior appearance.

5. Materials and finishes, etc.

6. Machinery, equipment and storage method.

7. Loads.

There are instances where loads in excess of code minimums are required. Such cases call for owner involvement. The establishment of loading conditions provides for a structure of adequate strength. A related set of criteria are needed to establish the serviceability behavior of the structure. Serviceability design considers such topics as deflection, drift, vibration and the relation of the primary and secondary structural systems and elements to the performance of nonstructural components such as roofing, cladding, equipment, etc. Serviceability issues are not strength issues but maintenance and human response considerations. Serviceability criteria are discussed in detail in *Serviceability Design Considerations for Steel Buildings* that is part of the AISC Steel Design Guide Series (Fisher, 2003). Criteria taken from the Design Guide are presented in this text as appropriate.

As can be seen from this discussion, the design of an industrial building requires active owner involvement. This is also illustrated by the following topics: slab-on-grade design, jib cranes, interior vehicular traffic, and future expansion.

3.1 Slab-on-Grade Design

One important aspect to be determined is the specific loading to which the floor slab will be subjected. Forklift trucks, rack storage systems, or wood dunnage supporting heavy manufactured items cause concentrated loads in industrial structures. The important point here is that these loadings are nonuniform. The slab-on-grade is thus often designed as a plate on an elastic foundation subject to concentrated loads.

It is common for owners to specify that slabs-on-grade be designed for a specific uniform loading (for example, 500 psf). If a slab-on-grade is subjected to a uniform load, it will develop no bending moments. Minimum thickness and no reinforcement would be required. The frequency with which the author has encountered the requirement of design for a uniform load and the general lack of appreciation of the inadequacy of such criteria by many owners and plant engineers has prompted the inclusion of this topic in this guide. Real loads are not uniform, and an analysis using an assumed nonuniform load or the specific concentrated loading for the slab is required. An excellent reference for the design of slabs-on-grade is *Designing Floor Slabs on Grade* by Ringo and Anderson (Ringo, 1996). In addition, the designer of slabs-on-grade should be familiar with the ACI *Guide for Concrete Floor and Slab Construction* (ACI, 1997), the ACI *Design of Slabs on Grade* (ACI, 1992).

3.2 Jib Cranes

Another loading condition that should be considered is the installation of jib cranes. Often the owner has plans to

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install such cranes at some future date. But since they are a purchased item—often installed by plant engineering personnel or the crane manufacturer—the owner may inadvertently neglect them during the design phase.

Jib cranes, which are simply added to a structure, can create a myriad of problems, including column distortion and misalignment, column bending failures, crane runway and crane rail misalignment, and excessive column base shear. It is essential to know the location and size of jib cranes in advance, so that columns can be properly designed and proper bracing can be installed if needed. Columns supporting jib cranes should be designed to limit the deflection at the end of the jib boom to boom length divided by 225.

3.3 Interior Vehicular Traffic

The designer must establish the exact usage to which the structure will be subjected. Interior vehicular traffic is a major source of problems in structures. Forklift trucks can accidentally buckle the flanges of a column, shear off anchor rods in column bases, and damage walls.

Proper consideration and handling of the forklift truck problem may include some or all of the following:

1. Use of masonry or concrete exterior walls in lieu of metal panels. (Often the lowest section of walls is made of masonry or concrete with metal panels used for the higher section.)

2. Installation of fender posts (bollards) for columns and walls may be required where speed and size of fork trucks are such that a column or load-bearing wall could be severely damaged or collapsed upon impact.

3. Use of metal guardrails or steel plate adjacent to wall elements may be in order.

4. Curbs.

Lines defining traffic lanes painted on factory floors have never been successful in preventing structural damage from interior vehicular operations. The only realistic approach for solving this problem is to anticipate potential impact and damage and to install barriers and/or materials that can withstand such abuse.

3.4 Future Expansion

Except where no additional land is available, every industrial structure is a candidate for future expansion. Lack of planning for such expansion can result in considerable expense.

When consideration is given to future expansion, there are a number of practical considerations that require evaluation.

1. The directions of principal and secondary framing members require study. In some cases it may prove economical to have a principal frame line along a building edge where expansion is anticipated and to design edge beams, columns and foundations for the future loads. If the structure is large and any future expansion would require creation of an expansion joint at a juncture of existing and future construction, it may be prudent to have that edge of the building consist of nonload-bearing elements. Obviously, foundation design must also include provision for expansion.

2. *Roof Drainage*: An addition which is constructed with low points at the junction of the roofs can present serious problems in terms of water, ice and snow piling effects.

3. Lateral stability to resist wind and seismic loadings is often provided by X-bracing in walls or by shear walls. Future expansion may require removal of such bracing. The structural drawings should indicate the critical nature of wall bracing, and its location, to prevent accidental removal. In this context, bracing can interfere with many plant production activities and the importance of such bracing cannot be overemphasized to the owner and plant engineering personnel. Obviously, the location of bracing to provide the capability for future expansion without its removal should be the goal of the designer.

3.5 Dust Control/Ease of Maintenance

In certain buildings (for example, food processing plants) dust control is essential. Ideally there should be no horizontal surfaces on which dust can accumulate. HSS as purlins reduce the number of horizontal surfaces as compared to C's, Z's, or joists. If horizontal surfaces can be tolerated in conjunction with a regular cleaning program, C's or Z's may be preferable to joists. The same thinking should be applied to the selection of main framing members (in other words, HSS or box sections may be preferable to wide-flange sections or trusses).

4. ROOF SYSTEMS

The roof system is often the most expensive part of an industrial building (even though walls are more costly per square foot). Designing for a 20-psf mechanical surcharge load when only 10 psf is required adds cost over a large area.

Often the premise guiding the design is that the owner will always be hanging new piping or installing additional equipment, and a prudent designer will allow for this in the

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Table 4.1 Steel Deck Institute Recommended Spans (38)				
Recommended Maximum Spans for Construction and Maintenance Loads Standard 1-1/2 in. and 3 in. Roof Deck				
	Type	**Span Condition**	**Span Ft -In.**	**Maximum Recommended Spans Roof Deck Cantilever**
Narrow Rib Deck (Old Type A)	NR22 NR22	1 2 or more	3′-10″ 4′-9″	1′-0″
	NR20 NR20	1 2 or more	4′-10″ 5′-11″	1′-2″
	NR18 NR18	1 2 or more	5′-11″ 6′-11″	1′-7″
Intermediate Rib Deck (Old Type F)	IR22 IR22	1 2 or more	4′-6″ 5′-6″	1′-2″
	IR20 IR20	1 2 or more	5′-3″ 6′-3″	1′-5″
	IR18 IR18	1 2 or more	6′-2″ 7′-4″	1′-10″
Wide Rib (Old Type B)	WR22 WR22	1 2 or more	5′-6″ 6′-6″	1′-11″
	WR20 WR20	1 2 or more	6′-3″ 7′-5″	2′-4″
	WR18 WR18	1 2 or more	7′-6″ 8′-10″	2′-10″
Deep Rib Deck	3DR22 3DR22	1 2 or more	11′-0″ 13′-0″	3′-5″
	3DR20 3DR20	1 2 or more	12′-6″ 14′-8″	3′-11″
	3DR18 3DR18	1 2 or more	15′-0″ 17′-8″	4′-9″

NOTE: SEE SDI LOAD TABLES FOR ACTUAL DECK CAPACITIES

system. If this practice is followed, the owner should be consulted, and the decision to provide excess capacity should be that of the owner. The design live loads and collateral (equipment) loads should be noted on the structural plans.

4.1 Steel Deck for Built-up or Membrane Roofs

Decks are commonly 1½ in. deep, but deeper units are also available. The Steel Deck Institute (SDI, 2001) has identified three standard profiles for 1½ in. steel deck, (narrow rib, intermediate rib and wide rib) and has published load tables for each profile for thicknesses varying from 0.0299 to 0.0478 in. These three profiles, (shown in Table 4.1) NR, IR, and WR, correspond to the manufacturers' designations A, F, and B, respectively. The Steel Deck Institute identifies the standard profile for 3 in. deck as 3DR. A comparison of weights for each profile in various gages shows that strength-to-weight ratio is most favorable for wide rib and least favorable for narrow rib deck. In general, the deck selection that results in the least weight per ft^2 may be the most economical. However, consideration must also be given to the flute width because the insulation must span the flutes. In the northern areas of the U.S., high roof loads and thick insulation generally make the wide rib (B) profile predominant. In the South, low roof loads and thinner insulation make the intermediate profile common. Where very thin insulation is used narrow rib deck may be required, although this is not a common profile. In general the lightest weight deck consistent with insulation thickness and span should be used.

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