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Chapter 13 or Chapter 15?

Are You Using the Wrong Loads?

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The proper use and application of ASCE 7 seismic provisions for industrial structures (ASCE 7-05 Chapters 13 and 15) can be difficult to determine due to the complexity and individuality of these structures. Engineers are often left questioning how to properly apply the code to their unique situation. The objective of this article is to increase understanding of the code's application pertaining to industrial structures, and help clarify the use of ASCE 7-05 generated loads for nonbuilding structures and nonstructural components. With a stronger understanding, structural engineers can stay focused on what they do best, smart designs that are safe and economical.

Within this article several examples of commonly encountered design scenarios are presented, giving special emphasis to code application in industrial structures. The examples and associated commentary describe potential misapplications of code provisions pertaining to industrial structures. Procedures and flow charts are provided that are intended to provide engineers with a better understanding of how to use ASCE 7-05 generating loads, as defined within Chapter 13 and 15.

Classification

One of the first challenges facing engineers designing industrial structures is determining if an item is classified as a nonbuilding structure or a nonstructural component. This is an important first step to help establish which load generation method, as prescribed in ASCE 7-05 Chapter 13 or Chapter 15, is needed. ASCE 7-05 is not always straightforward but as a rule of thumb; if an item is self supporting (i.e. sits directly on its foundation) it is a nonbuilding structure, whereas most other items in industrial facilities are components. An article published in the July 2008 issue of STRUCTURE® magazine (Bachman, Dowty. (2008, July) Is It a Nonstructural Component or a Nonbuilding Structure?) did a thorough comparison of nonstructural components and nonbuilding structures and is a suggested read. Also recommended is the ASCE publication (ASCE Task Committee on Seismic Evaluation and Design of Petrochemical Facilities. (2011) *Guidelines for Seismic Evaluation and Design of Petrochemical Facilities*, Second Edition). Both of these publications provide valuable information, which can be related to most industrial designs.

The following are some examples of nonbuilding structures and nonstructural components commonly seen in industrial applications.

Nonbuilding Structures:

- Pipe Racks
- Large Field Erected Tanks
- Self Supporting Silos
- Chimneys
- Cooling Towers
- Large Fans
- Large Pumps

Nonstructural Components:

- Piping
- Large Ductwork
- Suspended Boilers
- Supported Turbines
- Supported Tanks

In general, these associations are typical but not always completely accurate. The use of nonbuilding structures similar to buildings to support other nonbuilding structures is common in industrial structures. To improve accuracy, the engineer needs to have a firm understanding of the physical makeup, construction and support of the industrial structure he/she is classifying. To achieve this understanding, the engineer may need to engage in important research and coordination with equipment vendors to better understand the structural behavior of the item being evaluated. This understanding can then be used to determine the three most important variables needed when classifying a structure accurately; relative weight, stiffness, and fundamental period. Sections 13.1.5 and 15.3 provide guidance for determining which path forward to take, once structural characteristics are understood. According to Sec. 15.3, three scenarios are possible (see the flowchart in *Figure 1, page 16*). The following are descriptions of these three potential scenarios:

W_{NB} = Weight of the supported nonbuilding structure
W_S = Weight of the supporting structure
T_{NB} = Fundamental period of the supported nonbuilding structure

Scenario 1 $W_{NB} \le 0.25(W_{NB} + W_S)$

The supported nonbuilding structure should be designed as a component using the provisions of ASCE 7-05 Chapter 13. The supporting structure should be designed as a nonbuilding structure similar to buildings using the provisions of ASCE 7-05 Chapter 15. The supported nonbuilding structure should be treated as an additional mass for the design of the supporting structure.

Scenario 2 $W_{NB} > 0.25(W_{NB} + W_S)$, $T_{NB} \le 0.06$s

The supported nonbuilding structure should be designed as a component using the provisions of ASCE 7-05 Chapter 13 with the following modifications: R_p=R taken from the appropriate entry in table 15.4-2 and a_p=1. The supporting structure should be designed as a nonbuilding

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structure similar to buildings using the provisions of ASCE 7-05 Chapter 15. The supported nonbuilding structure should be treated as an additional mass for the design of the supporting structure. It should be noted that $T_{NB} \leq 0.06$s is very rarely achieved given that the effect of support flexibility (such as floor beam deflections) must be included in the determination of T_{NB}.

Scenario 3 $W_{NB} > 0.25(W_{NB} + W_S)$, $T_{NB} \geq 0.06$s

The supported nonbuilding structure and the supporting structure should be analyzed as a single composite structure. This combined analysis should accurately capture the mass distribution and stiffness of both the supported nonbuilding structure and the supporting structure. Both the supported nonbuilding structure and the supporting structure should be designed for the forces determined in the combined analysis in accordance with ASCE 7-05 Chapter 15. The R value used should be the lesser value of the supported structure or the supporting structure.

Please note that for non building structures that have significantly different full and empty weights, the case that maximizes the weight of the non building structure should be used to determine the applicable scenario.

Once the engineer has accurately classified the structure, and determined which portion of the code is applicable, execution of load generation can begin. The following are summarized procedures for Chapter 13 and Chapter 15, as outlined within ASCE 7-05.

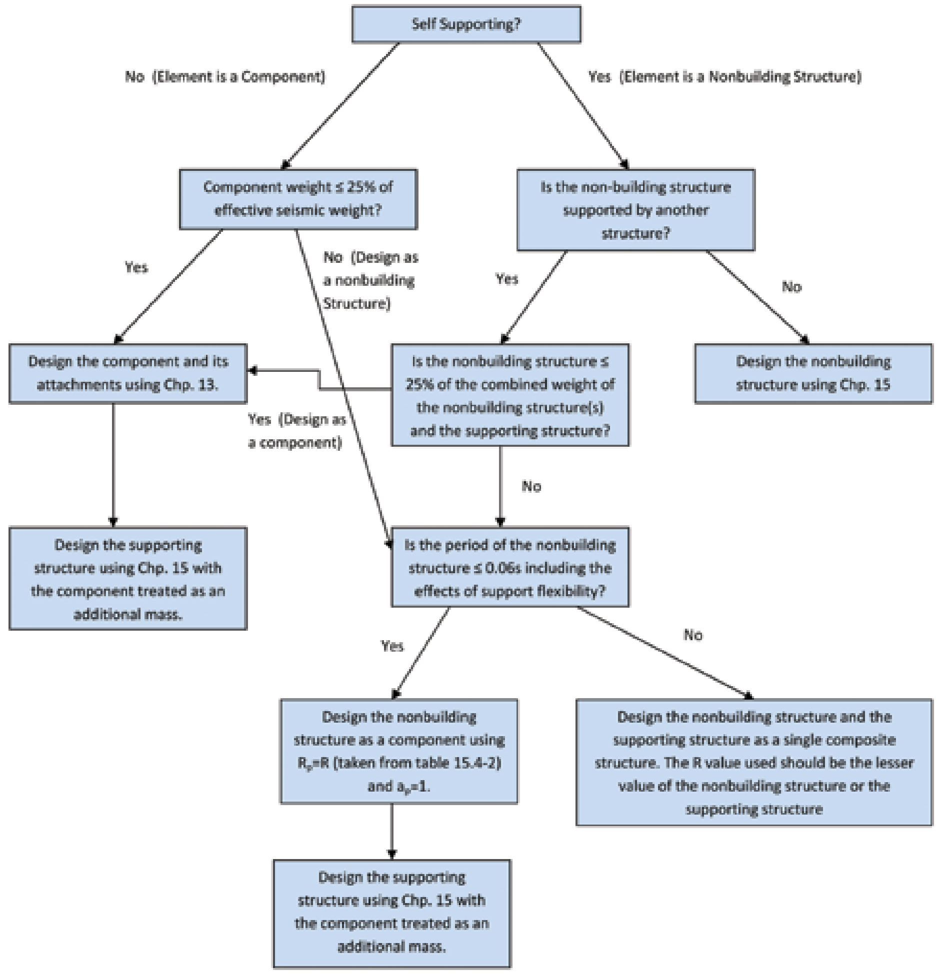


Figure 1: Design Flowchart for Nonstructural Components and Nonbuilding Structures in Industrial Facilities (ASCE 7-05).

Chapter 13 Procedures

The ASCE 7-05 Chapter 13 procedure to determine seismic loading on nonstructural components is a method that is independent of the supporting structure, with most parameters contained within the chapter. The procedure described herein will be limited to the typical case used for mechanical and electrical components.

The procedure consists of the following steps:

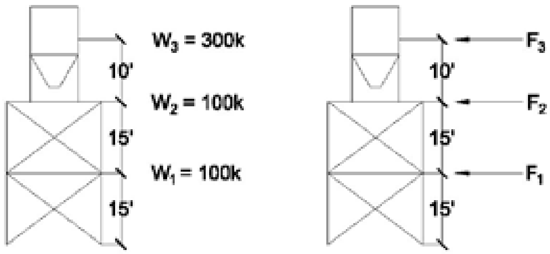
1) Evaluate the applicability of section 13.1.5.
2) Determine component factor I_p as defined in 13.1.3.
3) Determine the appropriate seismic coefficients R_p and a_p, per table 13.6-1.
4) Where a modal analysis is used, see equation and associated parameters 13.3.4.
5) Determine the component operating weight W_p per section 13.3.
6) The period can be determined using 13.6.1 but this value is not a direct variable needed for load generation.
7) The component design forces (F_p) should be determined per section 13.3.1 using the associated boundary limits.

ASCE 7-05 Sec. 13.6 contains several design provisions for specific nonstructural components. While beyond the scope of this article, these provisions should always be checked.

Section 13.4 instructs that the force F_p be used to design the component and its attachments. It is important to note that forces determined in accordance with Chapter 13 should not be used to design the supporting structure (*Figure 2, page 18*). It is common for equipment vendors to provide earthquake loads calculated in accordance with Chapter 13. These loads can sometimes be misinterpreted as supporting structure design loads, which is not the case. Chapter 13 loads should be used to design the equipment and its attachment to the supporting structure. In most cases, for commercial type buildings these loads are conservative (in some cases extremely conservative). In industrial structures, however, it is common to use low R factors (1.5 or 1) selected from table 15.4-1 in order to avoid special detailing requirements. This decision can result in loads that are calculated using Chapter 13, which are not conservative when used to design the supporting structure.

Chapter 15 Procedures

Most support structures and certain pieces of equipment in industrial structures are considered "Nonbuilding Structures" by ASCE 7-05. Seismic design of nonbuilding structures is governed by Chapter 15 of ASCE 7-05. Chapter 15 divides nonbuilding structures into two primary groups, those



Design Parameters

Occupancy Cat. II

Site Class D

S_S=1.6

S_1=0.6

F_a=1.0

F_v=1.5

S_{DS}=1.07

S_{D1}=0.6

T_L=8 s

SDC D

I=1.0

Supporting Structure Period T=0.5 s

Ash Hopper Period T≤0.06 s

Note: Per ASCE 7-05 Table 12.6-1 a modal analysis should be used in lieu of the ELF procedure. The ELF procedure was used for demonstration only.

As depicted above, the following example consists of an Ash Hopper on unbraced legs supported by a steel braced frame. This example illustrates the difference between the component design force and the supporting structure design force. The first example uses a special braced frame with an R=6 for the supporting structure and the second example uses an ordinary braced frame with an R=1.5.

Special Braced Frame (R=6)

$$C_s = \frac{S_{DS}}{\frac{R}{I}} = \frac{1.07}{\frac{6}{1}} = 0.178\ (Controls)$$

$$C_{smax} = \frac{S_{D1}}{T\frac{R}{I}} = \frac{0.6}{(0.5)\left(\frac{6}{1}\right)} = 0.2$$

$$C_{smin} = \frac{0.8S_1}{\frac{R}{I}} = \frac{(0.8)(0.6)}{\left(\frac{6}{1}\right)} = 0.08\ or\ 0.03$$

$$V = C_sW = (0.178)\big(300 + (2)(100)\big) = 89k$$

$$T = 0.5s\,, k = 1$$

$$F_x = \frac{w_x h_x^k}{\sum_{i=1}^{n} w_i h_i^k} V$$

$$F_1 = \left(\frac{(100)(15)}{(100)(15+30) + (300)(40)}\right)(89) = 8.1k$$

$$F_2 = \left(\frac{(100)(30)}{(100)(15+30) + (300)(40)}\right)(89) = 16.2k$$

$$F_3 = \left(\frac{(300)(40)}{(100)(15+30) + (300)(40)}\right)(89) = 64.7k$$

$R_p = 2$ (Ash Hopper, unbraced legs), $I_p = 1.0,\ a_p = 1$

$$F_p = \frac{0.4a_pS_{DS}W_p}{\frac{R_p}{I_p}}\left(1 + 2\frac{z}{h}\right) = \frac{(0.4)(1)(1.07)(300)}{\frac{2}{1}}(3)$$
$$= 192k\ (Controls)$$

$$F_{pmax} = (1.6)(1.07)(1)(300) = 514k$$

$$F_{pmin} = (0.3)(1.07)(1)(300) = 96.3k$$

As this example shows using the component force (F_p=192k) to design the supporting structure would result in overestimating the design force (F_3=64.7k) by a factor of 3.

Ordinary Braced Frame (R=1.5)

$$C_s = \frac{S_{DS}}{\frac{R}{I}} = \frac{1.07}{\frac{1.5}{1}} = 0.713\ (Controls)$$

$$C_{smax} = \frac{S_{D1}}{T\frac{R}{I}} = \frac{0.6}{(0.5)\left(\frac{1.5}{1}\right)} = 0.8$$

$$C_{smin} = \frac{0.8S_1}{\frac{R}{I}} = \frac{(0.8)(0.6)}{\left(\frac{1.5}{1}\right)} = 0.32\ or\ 0.03$$

$$V = C_sW = (0.713)\big(300 + (2)(100)\big) = 357k$$

$$T = 0.5s\,, k = 1$$

$$F_x = \frac{w_x h_x^k}{\sum_{i=1}^{n} w_i h_i^k} V$$

$$F_1 = \left(\frac{(100)(15)}{(100)(15+30) + (300)(40)}\right)(356.5) = 32.4k$$

$$F_2 = \left(\frac{(100)(30)}{(100)(15+30) + (300)(40)}\right)(356.5) = 64.8k$$

$$F_3 = \left(\frac{(300)(40)}{(100)(15+30) + (300)(40)}\right)(356.5) = 259k$$

$R_p = 2$ (Ash Hopper, unbraced legs), $I_p = 1.0,\ a_p = 1$

$$F_p = \frac{0.4a_pS_{DS}W_p}{\frac{R_p}{I_p}}\left(1 + 2\frac{z}{h}\right) = \frac{(0.4)(1)(1.07)(300)}{\frac{2}{1}}(3)$$
$$= 192k\ (Controls)$$

$$F_{pmax} = (1.6)(1.07)(1)(300) = 514k$$

$$F_{pmin} = (0.3)(1.07)(1)(300) = 96.3k$$

As this example shows using the component force (F_p=192k) to design the supporting structure would result in underestimating the design force (F_3=259k) by a factor of 0.74.

Figure 2: Steel Braced Frame Design Example.

structures similar to buildings and those not similar to buildings. This article will focus on nonbuilding structures similar to buildings.

The ASCE 7-05 Chapter 15 procedure to determine seismic loading on nonbuilding structures similar to buildings is very similar to that for buildings. In general, the procedure consists of the following steps:

1) Select a structural system from either table 15.4-1 or table 12.2-1. Determine the following variables: R, Ω_0, and C_d.
2) Determine I from table 11.5-1
3) Determine the effective seismic weight in accordance with ASCE 7-05 Sec. 12.7.2. This weight should include any components or nonbuilding structures supported by the structure under consideration. The use of the full or empty weight should be in agreement with the gravity loads in the same combination (i.e. if the contents of a tank are not included in the gravity loads of a combination they should not be included in the seismic weight and vice versa).
4) Determine the period of the structure using one of the procedures outlined in Sec. 15.4.4. It is not acceptable to use the approximate fundamental period for a nonbuilding structure.
5) Determine C_s from the procedure outlined in ASCE 7-05 Sec. 12.8.1.1.
6) Determine the base shear V using Eq. 12.8-1.
7) Distribute the base shear per ASCE 7-05 Sec. 12.8.3.

ASCE 7-05 Sec. 15.5 contains several design provisions for specific nonbuilding structures. While beyond the scope of this article, these provisions should always be checked.

To better reinforce the goals of this article, a typical industrial scenario has been included that demonstrates the divergence that can occur between Chapter 13 and Chapter 15 load generation. The examples shown in *Figure 2* illustrate scenario 2, discussed earlier. Both examples consist of a steel braced frame supporting a large ash hopper. The first example uses a large R factor and highlights the common situation in which the Chapter 13 component loads are much greater than the supporting structure design loads. The second example uses a small R factor and highlights the less common situation in which the reverse is true. These examples highlight a potential misunderstanding that can occur when the ASCE 7 code is not accurately applied to a common industrial design scenario. Even though the seismic variables are accurately defined and calculated, the method chosen will yield substantially different results.

The provided commentary, external references, flowchart, and examples have been assembled in an attempt to raise awareness in those engineers who face similar design challenges on industrial projects. Tooled with an increased awareness, future industrial projects can be designed with greater safety, smarter framing, and fewer material quantities.▪