Technical Paper 4

Code Requirements for the Evaluation and Design of Rooftop Equipment Supports

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Abstract

Placing ammonia piping and equipment on the roof of a building presents additional loading challenges that the pipe designer may not typically address. General loading concerns including; service loads, gravity loading, and where applicable seismic loads, should be addressed for any above ground pipe system. However, wind loading on rooftop or exterior exposed piping can present a unique design challenge for the pipe systems and the support components. In the following we will discuss current code requirements specifically associated with wind and seismic loading on rooftop applications. While addressing this loading may be outside your scope of work, knowledge of the requirements can aid in better system coordination and design.

Introduction

Placing ammonia piping and other utility lines and equipment on the roof is common practice with many reasons and advantages. For projects involving retrofit or addition of new equipment, the roof is often the only place with adequate access and the clearest path to run mechanical, electrical, plumbing, and communication lines. However, rooftop installation exposes the equipment to other conditions that are not a factor when placed inside of the building envelope. Adopted codes and standards establish a minimum basis for the design and installation of building structures, components, and systems. Minimum requirements are a means to safeguard the public health, safety, and general welfare of building occupants and the community as a whole.

Currently, the most widely adopted code throughout the United States is the International Code Council's (ICC) International Code Family (2015). Many jurisdictions have adopted either the code family as a whole or have amended the code based on conditions within the jurisdiction. This paper intends to discuss the sections of the International Code Family that specifically address the requirements for supporting refrigeration equipment on the roof of a building and how the applicable loading requirements affect the design of the supporting elements. This paper is not intended to be an all-inclusive study of the many dynamic factors that affect the selection, design, and installation of refrigerant system piping. Some local amendments to the ICC code family will be discussed, but the design professional is responsible for ensuring all code requirements and guidelines for the applicable project and jurisdiction are met.

Trade or industry standards such as the ANSI/IIAR Standard 2-(2014), ASHRAE Standard 15-(2016), etc. identify standard practices that are then either referenced or specifically cited within the ICC codes. Often these industry standards contain more specific and stringent requirements for the design of the piping system and play a key role in the establishment and modification to adopted codes. As such the volume of literature referenced in the International Code Family can be overwhelming to any design professional. For the intent of this paper we will focus primarily on the following codes:

- 2015 International Mechanical Code (IMC),
- 2015 International Building Code (IBC),
- ASCE 7-10 (2010) "Minimum Design Loads for Buildings and Other Structures."

These three referenced documents are the most generally accepted and current codes containing the basis for the design for rooftop equipment supports.

2015 International Mechanical Code

Our journey will begin with the 2015 International Mechanical Code. Chapter 11 is dedicated to refrigeration, providing general requirements, system requirements, system classifications, application requirements, ventilation and detection requirements, refrigerant piping requirements, and testing/inspection requirements. Section 1107, "Refrigerant Piping," contains requirements for the type of pipe that can be used for refrigerant systems and where the pipe can or cannot be located, but the way to properly support the pipe is not discussed. For supporting requirements we need to jump back to Chapter 3, "General Regulations." Chapter 3 Section 301.1 begins with the blanket statement, "This chapter shall govern the approval and installation of all equipment and appliances that comprise parts of the building mechanical systems regulated by this code ….." Section 301 also contains specific requirement for other applicable loading conditions that are to be considered on mechanical systems. Section 301.15, "Wind Resistance," states that "Mechanical equipment, appliances and supports that are exposed to wind shall be designed and installed to resist the wind pressures determined in accordance with the International Building Code." The phrases "exposed to wind" and "shall be" are key. Is there ever a situation where a pipe on an open roof is not "exposed to wind"? Section 301.18, "Seismic Resistance," states "Where earthquake loads are applicable in accordance with the International Building Code, mechanical system supports shall be designed and installed for the seismic forces in accordance with the International Building Code." You will notice the difference in wording here as opposed to the wind loading requirements. The phrase "where earthquake loads are applicable" indicates that these forces may not apply where the wind loading phrase "that are exposed to wind shall be" does not leave any wiggle room. Finally, before we jump to the International Building Code, it is worth visiting Section 305, "Pipe Support." This section briefly covers pipe hanger and attachment methods and maximum support intervals. Section 305.4 and Table 305.4 list maximum horizontal and vertical spacing of supports for various piping materials. The maximum support spacing will later be factored into the design of the supports to resist the required wind and applicable seismic loading.

2015 International Building Code and ASCE 7-10

Now jumping into the 2015 International Building Code we will go directly to Chapter 16, "Structural Design." Some building parameters must first be established before subsequent loading requirements can be determined. If the project is new construction, the following parameters will be established by the project structural engineer of record. If your project deals with equipment on an existing building this information may not be as readily available. However, with a little information about the building's location, intended use, the height of the roof, an understanding of the roof cross-section, and information about the pipe or equipment to be supported, the applicable wind and seismic loading requirements can be established.

Building Risk Category

First we need to establish a risk category for the building. Table 1604.5 in Chapter 16 contains a list of building uses with the appropriate risk category. Four risk categories are based on the use and occupancy load of the building structure. Category I buildings have a low hazard to human life in the event of a failure. These are typically limited to agricultural facilities, temporary facilities, and storage facilities. Category II buildings are those that do not fall into one of the other three categories. Category III buildings pose a significant risk to human life in the event of a failure. These are typically buildings with high occupancies where groups of people gather; facilities where the occupants are confined or unable to exit the facility easily; and buildings that do not fall into Category IV but have a potential to cause significant disruption to daily civilian life, including economic loss or threat to public health and safety. Category IV structures are deemed essential facilities that need to remain open and functional. These facilities include emergency treatment facilities, first responder facilities, designated emergency shelters, critical government facilities, and facilities that contain significant quantities of hazardous materials.

Buildings utilizing ammonia refrigeration could be classified into any one of these categories. A cold storage facility based on very low occupancy load could fall into Category I, but when accounting for the volume of ammonia used in the refrigerant system, it could also be elevated to a Category IV structure by the local jurisdiction if a catastrophic failure of the system were determined to be a sufficient threat to public health and safety. The owner of the facility could also dictate that the building be designed to the elevated requirements of Category III or IV as a means to mitigate risk associated with failure. Systems that are not found to contain sufficient quantities of ammonia would be categorized based on use and occupancy guidelines per Table 1604.5 of the IBC.

Load combinations

With the building risk category established we can move on to establishing required design loads. Rather than trying to group all loading together, multiple different load combinations are established. Two design methods are included in Section 1605, "Load Combinations." Strength design (or load and resistance factor design) and allowable stress design are the two most commonly used combinations. Either method can be used as long as the design is consistent throughout. Other items to consider in the design of any component include serviceability factors such as deflection limits or other visual or functional considerations. General loads included in the load combinations include dead loads (D), live loads (L), snow (S) or rain (R) loads, flood loads (F), lateral earth pressure loads (H), wind loads (W), seismic loads (E), and in some instances ice loading. Of all these loads, we will quickly discuss dead loads and dive more into the specifics of wind and seismic loading. Other loads may also contribute to the design of the pipe support racks, but dead, wind, and seismic loads are typically controlling factors. In regions prone to freezing rain or atmospheric ice loading, the potential for increased design consideration is also warranted.

Dead loads

Dead loads consist of the weight of all materials. Fixed service equipment typically falls into the dead load category as it is constant to the structure. For pipe loading, one may need to consider both wet and dry pipe conditions if the pipe is to be drained for any extended period of time. The weight of the support frame must also be factored into the design and specifically into the reactions that will need to be transferred through to the roof structure.

Wind loads

The International Building Code does not emphasize a requirement for wind loading on rooftop equipment, but some key requirements in Section 1609 of the IBC must be addressed.

The first paragraph of Section 1609.1, "Application," has the following requirement: "Decreases in wind loads shall not be made for the effect of shielding by other structures." Strictly interpreted, this blanket statement eliminates any potential to reduce or eliminate wind loading where applicable. Through the 2004 and 2005 hurricane seasons, significant damage was observed due to improper attachment of rooftop equipment. A study titled "Rooftop Equipment Wind Load and its Mitigation for Buildings in Hurricane Prone Regions" (2007) was completed in partnership with the International Hurricane Research Center and Florida International University. The study evaluated the potential reduction to wind loading on rooftop equipment via properly designed and installed wind screens. While the study reported significant reduction in wind loading on the shielded rooftop equipment, additional studies and revisions to the text of the code will be required before such reductions are allowed. In contrast, FEMA produced a document titled "Attachment of Rooftop Equipment in High-Wind Regions" with the findings of its Hurricane Katrina Recovery Assessment stating that "Equipment screens around rooftop equipment are frequently blown away. Equipment screens should be designed to resist the wind loads derived from ASCE 7. Note: The extent that screens may reduce increased wind loads on equipment is unknown. Therefore, the equipment behind screens should be designed to resist the loads previously noted." The FEMA report coincides with the requirement in the IBC that decreases in wind loads shall not be made for the effects of shielding by other structures.

Section 1609.1.1 of the IBC, "Determination of Wind Loads," states that "Wind loads on every building or structure shall be determined in accordance with Chapters 26 to 30 of ASCE 7 or provisions of the alternative all-heights method in Section 1609.6." However, the alternative all-heights method in Section 1609.6 requires certain conditions be met to qualify. Condition #5 specifically excludes this method for rooftop equipment, thus requiring the use of ASCE 7.

The wind loading chapters for the 2010 edition of ASCE 7 were reorganized and modified. This change had a fairly significant impact on wind loading to rooftop equipment. The two paragraphs in previous editions of the standard addressing wind loading on rooftop equipment are now better defined and addressed in Chapter 29, "Wind Loads on Other Structures and Building Appurtenances." The process for determining the basic wind speed changed significantly, and for the first time vertical wind uplift loading was included in the main body of the standard. Previously, uplift was mentioned in the commentary of the code with the note "The consensus of the committee is that uplift forces may be a significant fraction of the horizontal force. Hence, uplift load should also be considered by the designer." A few exemptions are also cited in subsequent paragraphs of the code but none apply to rooftop equipment or equipment supports.

With the building risk category previously determined, a basic wind speed, *V*, is determined based on Figures 1609.3(1, 2, or 3) of the IBC or Figures 26.5-1(A, B, or C) in ASCE 7. Most of the country falls within a basic wind speed range of 105 mph 3-s gust to 120 mph 3-s gust depending on the building risk category. Along the east coast and the gulf coast, wind speed can be as high as 200 mph 3-s gusts. A valuable tool in determining basic wind speeds was prepared by the Redwood City, California, based Applied Technology Council's (ATC) Windspeed by Location website (http://windspeed.atcouncil.org/). The site allows users to enter an address or latitude and longitude coordinates to determine the appropriate basic wind speed. Users are responsible for verifying that the information generated is valid, and in some "special wind regions" wind loads are to be provided by the authority having jurisdiction. The report generated by the ATC website is much more user friendly and easily verified by cross checking on the letter size maps presented in the IBC and ASCE 7.

With the basic design wind speed and some other site-specific parameters including wind directionality factor (K_d), velocity pressure exposure coefficient (K_z), and topographic factor (K_{zt}), which are pulled from tables in ASCE 7, the basic wind speed is converted to a velocity pressure via Equation 29.3-1,

$$q_z = 0.00256\, K_z K_{zt} K_d V^2\ (\mathrm{lb/ft^2}).$$

Finally, this pressure is converted to a force in Section 29.5 or 29.5.1. For buildings with a roof height above 60 ft Equation 29.5-1 is applied,

$$F = q_z G C_f A_f\ (\mathrm{lb}).$$

Where *G* is a gust effect factor that is allowed to be taken as 0.85 or manually determined based on frequency analysis of the component. The force coefficient factor, C_f, for rooftop equipment is based on Figure 29.5-1 of ASCE 7 and is dependent on the shape of the component, the surface roughness of the component, and a ratio of the height of the component off the roof to the diameter of a circular cross-section or the least horizontal dimension of any other section. A_f is the projected area normal to the wind.

For buildings with a roof height less than or equal to 60 ft, the process has been standardized per Equation 29.5-2 for lateral loading,

$$F_h = q_h(GC_r)A_f \text{ (lb)}.$$

Where (GC_r) shall be 1.9 and A_f is the vertical projected area of the component. There is an allowance to reduce the factor of 1.9 down if specific conditions are met, but projects rarely meet the conditions for the reduction.

Also, on buildings with a roof height less than or equal to 60 ft, Section 29.5.1 contains equation 29.5.3 for uplift forces,

$$F_v = q_h(GC_r)A_r \text{ (lb)}.$$

Where (GC_r) shall be 1.5 and A_r is the horizontal projected area of the component. The reduction allowance for GC_r is allowed, but it will typically not apply to rooftop equipment. Again, this is the first time that vertical uplift forces for rooftop structures and equipment have been included in the main body of the code. Limited research is available on the effects of wind loading on rooftop equipment, so this will likely be one area of the code that will continue to evolve.

Earthquake loads

While wind loading (not necessarily the full design wind load) will be a daily, continuous occurrence, seismic events are typically infrequent, but the risks of damage to a piping system can be significant. There are known areas with high seismic activity, and those jurisdictions typically have higher or more stringent seismic design requirements. California is at the forefront of evaluating and developing seismic design standards across all construction trades and industries due to the high seismic risk in the region. However, other areas not known for seismic activity are not completely immune from the risk. A perfect example is the 2011 magnitude 5.8 quake initiated near Mineral, Virginia, as reported by the U.S. Geological Survey (USGS) that was felt by approximately one-third of the U.S. population. The total estimated economic loss from the earthquake was between \$200 and \$300 million. No reported damage was caused specifically by failed mechanical systems, but the event did raise awareness that seismic risk and design consideration should be considered for every project.

Chapter 16 of the IBC, Section 1613, deals with earthquake loading. Section 1613.1, “Scope,” states “Every structure, and portion thereof, including nonstructural components that are permanently attached to structures and their supports and attachments, shall be designed and constructed to resist the effects of earthquake motions in accordance with ASCE 7, excluding Chapter 14 and Appendix 11A. The seismic design category for a structure is permitted to be determined in accordance with Section 1613 or ASCE 7.” The remainder of Section 1613 of the IBC and the provisions in ASCE 7 are essentially identical, and while a structural engineer needs to understand the nuances of how and why a building is assigned to a seismic design category, we will forgo the discussion for the intent of this paper. The ATC’s Wind Speed by Location website is modeled very similarly to a long-established U.S. Geological Survey (USGS) site used to determine site-specific seismic design parameters. The USGS Earthquake Hazards Program (http://earthquake.usgs.gov/designmaps/us/application.php) allows users to enter a project’s longitude and latitude and specify the appropriate design code, building risk category, and site soil classification. The site soil classification is generally determined by a soils engineer, but such a report is not always available. The code allows the use of Class D site soil classification to be used as a default value where soil properties are not known. Once the values are entered, the USGS program will generate a report with the appropriate design values for the specific project. The two values in particular that we will need are S_{DS}, which is the short period design earthquake spectral response acceleration parameter, and the seismic design category for the building. With these two parameters we now turn back to ASCE 7 for seismic design requirements for nonstructural components, contained in Chapter 13.

Section 13.1.3 establishes a component importance factor, I_p, of either 1.0 or 1.5 based on the use or content of the component. Four conditions elevate the component to the 1.5 importance factor:

1. The component is required to function for life-safety purposes following a seismic event.
2. The component conveys, supports, or otherwise contains toxic or explosive content with sufficient quantities, established by the authority having jurisdiction, to pose a substantial threat to the public if released.
3. The component is in or attached to a Risk Category IV structure and is needed for continued operation of the facility, or its failure would affect the operation of the facility.
4. The component conveys, supports, or otherwise contains hazardous substances and is attached to a structure of portion thereof classified by the authority having jurisdiction as a hazardous occupancy.

If none of these conditions are met then the component is assigned to a component importance factor of 1.0.

The conditions requiring the 1.5 component importance factor, like the building risk category, are subject to engineering judgment and direction from the local jurisdiction. The building owner can also dictate that the elevated factor be used to mitigate risk further. The designer of ammonia refrigerant systems can also specify what design considerations need to be met for the design of the support frames.

Within Chapter 13 are detailed requirements for various mechanical and electrical component systems. Rather than going through each condition, we will cover some general requirements that must be met. Section 13.2.1 provides two methods to satisfy the seismic design requirements:

1. Project-specific design and documentation submitted for approval to the authority having jurisdiction after review and acceptance by a registered design professional.
2. Submittal of the manufacturer's certification that the component is seismically qualified by at least one of the following:
    a. Analysis, or
    b. Testing in accordance with the alternative set forth in Section 13.2.5, or
    c. Experience data in accordance with the alternative set forth in Section 13.2.6.

Qualifying a system can be difficult in that each building is unique in layout and construction. To meet or exceed design requirements for such a broad range of applications would require a worst-case scenario approach that would lead to uneconomic, overly conservative options. Subsequently, Section 13.2.7

requires that a project-specific design shall be shown in construction documents prepared by a registered design professional for use by the owner, authorities having jurisdiction, contractors, and inspectors.

The applicable seismic loading forces on nonstructural components are established in Section 13.3.1. Horizontal forces are determined according to Equation 13.3-1 through 3,

$$F_p = \frac{0.4 a_p S_{DS} W_p}{\left(\frac{R_p}{I_p}\right)}\left(1 + 2\frac{z}{h}\right)\ (13.3-1).$$

Where F_p is not required to be taken as greater than

$$F_p = 1.6 S_{DS} I_p W_p\ (13.3-2),$$

and F_p shall not be taken as less than

$$F_p = 0.3 S_{DS} I_p W_p\ (13.3-3).$$

Where

- F_p = seismic design force,
- S_{DS} = short period spectral acceleration,
- a_p = component amplification factor per Table 13.6-1,
- I_p = component importance factor,
- W_p = component operating weight,
- R_p = component response modification factor per Table 13.6-1,
- z = component attachment height from the base of the building structure, and
- h = average roof height of the structure from the base
    - The values of z/h need not exceed 1.0.

Note that Equation 13.3-1, when applied to rooftop equipment where z/h is taken as 1.0, the design force can be as much as three times that at the ground level.

The component shall also be designed for a concurrent vertical force,

$$F_v = \pm 0.2 S_{DS} W_p.$$

Component displacements must also be considered, but detailed information about the building structure is required, which is beyond the scope of this paper. The intent of evaluating displacements is to prevent overstressing components, connection, or fittings, and consequential damage to components, supports, and adjacent elements. The risk of overstressing components, connections, and fittings will not typically be evaluated during the design of the component supports. However, the same procedures would be used to evaluate forces induced on connections and fittings. In the commentary of ASCE 7, the presence of insulation around piping can serve to protect the pipe from impact damage. The commentary also recognizes that piping systems are typically designed with a safety factor of 3 or more against pressure failure and are inherently robust enough to sustain minimal impact loading.

Finally, the last item of discussion for the intent of this paper is Section 13.4, which discusses component anchorage. The code specifically requires where seismic design is required that "Components attachments shall be bolted, welded or otherwise positively fastened without consideration of frictional resistance produced by the effects of gravity. A continuous load path of sufficient strength and stiffness between the component and the supporting structure shall be provided."

The requirement for a physical attachment to the structure eliminates any consideration for the use of ballasting to resist applicable seismic loading. While this requirement is not present in the wind loading section of the code, ballasting typically requires adding a substantial dead load, which can overload the building roof structure.

With rooftop applications, one must consider the capacities of the roof structure in the distribution of loading. Generally, roofs are designed to meet a minimum live and dead load as required in the code. For retrofit projects or additions where you are adding equipment to an existing roof or in new construction, where the additional roof loading was not considered in the design, the roof structure may not be adequate to accommodate the loading associated with rooftop equipment. For this reason, the building structural engineer of record should be included in the design process to ensure that applicable loading from rooftop equipment is adequately transferred through the building structure.

Example loading

With the general procedures used to establish gravity, wind, and seismic loading to rooftop equipment outlined, we can now examine the design forces that are applicable to rooftop pipe systems. For the purposes of illustration, let's consider a cold storage facility with the following design criteria:

- Adopted building codes: 2015 International Building Code and ASCE 7-10;
- Building risk category: I;
- Wind design criteria:
    - Mean roof height: 40 ft;
    - Basic wind speed, V: 110 mph 3-s gust; and
    - Wind exposure category: C;
- Seismic design criteria:
    - Site soil classification: D (assumed);
    - Short period spectral acceleration, S_{DS}: 1.643 g;
    - Seismic design category: D; and
    - Seismic component importance factor, I_e: 1.5;
- For the seismic component amplification factor, a_p, and component response modification factor, R_p, from Table 13.6-1 of ASCE 7, we will assume the pipe is designed in accordance with ASME B31 with welded joints;
- Component amplification factor, a_p: 2.5; and
- Component response modification factor, R_p: 12.

The facility owner has requested the rooftop pipe supports be designed to a 1.5 seismic component importance factor due to the moderate seismic risk for the area. The site conditions are for a location with moderate seismic risk and typical design wind speeds.

First, let's evaluate the required design loading applicable for 2–6 in. schedule 40 steel pipe carrying liquid ammonia with a density of 42.57 lb/ft^3. For consistency, we will assume a uniform pipe insulation thickness of 2 in. The height from the bottom of the insulated pipe to the finished roof deck will be 48 in. with an average roof height of 40 ft. Per Table 305.4 of the IMC, the horizontal distance between supports shall not exceed 12 ft on center. The design criteria are shown in Table 1, calculated applicable loading is shown in Table 2, and Figures 1 and 2 illustrate graphically how the loading varies with the size of the pipe. Figure 3 illustrates graphically how ASCE 7 factored load combinations for the applicable vertical forces will vary with the size of the pipe. Figures 4 and 5 illustrate potential pipe displacements for applicable ASCE 7 strength design load combinations and allowable stress design load combinations. The deflection illustrated is based on wind loads discussed in this paper. Deflection from thermal expansion and contraction and hammer forces for start-up and fatigue should also be considered when evaluating stresses on pipe connections and joints.

Table 1. Design criteria summary.

ASCE 7-10 Wind Loading per Section 29.5.1 for Buildings with h ≤ 60 ft

Rooftop Structures and Equipment for Buildings with h ≤ 60 ft.

Building Risk Category:	IV	K_z =	1.04	(Table 29.3-1)
Mean Roof Height (h):	40 ft	K_{zt} =	1	(No Topographic Effects)
Roof Insulation Thickness:	4 in	K_d =	0.95	(Table 26.6-1)
Exposure Category:	C			
Design Wind Speed (V):	120 mph 3 sec gust			
Velocity Pressure (q_h):	$q_h = 0.00256 K_z K_{zt} K_d V^2$ = 36.42 psf			

Wind Design Load per Section 29.5.1

Lateral Force:	$F_h = q_h(GC_f)A_f$	Vertical Uplift Froce:	$F_v = q_h(GC_r)A_r$
G_{cf}:	1.9	G_{cr}:	1.5

ASCE 7-05 Seismic Design Loading per Chapter 13

Seismic Design Parameters:

Seismic Design Category:	D	
Spectral acceleration - S_{DS}:	1.643	
Component Importance Factor - I_p :	1.5	(Section 13.1.3)
Redundancy Factor, ρ:	1.3	(Section 12.3.4)

Seismic Design must be considered

Horizontal Seismic Design Factors:

a_p :	2.5	Component amplification factor (Table 13.6-1)
R_p :	12	Component response modification factor (Table 13.6-1)
z:	Avover Roof	Height in structure of point of attachment for component from the base.
h:	40 ft	Average roof height o f structure from the base.
z/h :	1	(Need Not Exceed 1.0)

Horizontal Force Component:

$$F_P = \frac{0.4 * a_p * S_{DS} * W_p}{\frac{R_p}{I_p}}\left(1 + 2\left(\frac{z}{h}\right)\right)$$

F_p shall not be taken greater than: $F_P = 1.6 * S_{DS} * I_P * W_p$

F_p shall not be taken less than: $F_P = 0.3 * S_{DS} * I_P * W_p$

Vertical Force Component:

$$F_{VP} = \pm 0.2 * S_{DS} * W_p$$

Table 2. Applicable rooftop equipment loading on schedule 40 steel pipe with 2 in. insulation.

Design Wind and Seismic Loads

Pipe Content:	Liquid Ammonia		Insulation Thickness:	2 in
Content Density:	42.61 pcf	@ -28^{o}F	Support Spacing:	12 ft
Pipe Type:	Steel Pipe - Schedule 40		Height off Roof:	48 in
Youngs Modulus, E:	29000000 psi			

Trade Pipe Size:	2 in	2-1/2 in	3 in	3-1/2 in	4 in	5 in	6 in
Pipe ID:	2.067 in	2.469 in	3.068 in	3.548 in	4.026 in	5.047 in	6.065 in
Pipe OD:	2.375 in	2.875 in	3.5 in	4 in	4.5 in	5.563 in	6.625 in
Total OD:	6.375 in	6.875 in	7.5 in	8 in	8.5 in	9.563 in	10.625 in
Section Modulus, I (in^4):	0.627	1.45 in	2.85 in	4.52 in	6.82 in	14.3 in	26.5 in
Center Line Height:	51.1875 in	51.4375 in	51.75 in	52 in	52.25 in	52.7815 in	53.3125 in
Pipe Weight:	4.65 lb/ft	7.22 lb/ft	9.77 lb/ft	12.04 lb/ft	14.57 lb/ft	20.55 lb/ft	27.54 lb/ft
$A_f = A_r$ =	6.38 sf	6.88 sf	7.50 sf	8.00 sf	8.50 sf	9.56 sf	10.63 sf
Dead Load =	**55.791 lbs**	**86.582 lbs**	**117.245 lbs**	**144.520 lbs**	**174.808 lbs**	**246.613 lbs**	**330.487 lbs**
Horizontal Wind - F_h =	**441.157 lbs**	**475.758 lbs**	**519.008 lbs**	**553.609 lbs**	**588.209 lbs**	**661.770 lbs**	**735.262 lbs**
Wind Uplift - F_v =	**348.282 lbs**	**375.598 lbs**	**409.743 lbs**	**437.060 lbs**	**464.376 lbs**	**522.450 lbs**	**580.470 lbs**
Horizontal Seismic - F_P =	34.374 lbs	53.345 lbs	72.237 lbs	89.042 lbs	107.704 lbs	151.944 lbs	203.621 lbs
Max Horizontal - $F_{P,MAX}$ =	219.996 lbs	341.409 lbs	462.319 lbs	569.870 lbs	689.304 lbs	972.444 lbs	1303.175 lbs
Min Horizontal - $F_{P,MIN}$ =	**41.249 lbs**	**64.014 lbs**	**86.685 lbs**	**106.851 lbs**	**129.245 lbs**	**182.333 lbs**	**244.345 lbs**
Vertical Seismic - F_{VP} =	**18.333 lbs**	**28.451 lbs**	**38.527 lbs**	**47.489 lbs**	**57.442 lbs**	**81.037 lbs**	**108.598 lbs**

ASCE 7 Section 2.3 - Strength Design Load Combinations - Vertical Loading

Trade Pipe Size:	2 in	2-1/2 in	3 in	3-1/2 in	4 in	5 in	6 in
LC 1. -1.4D	-78.108 lbs	-121.214 lbs	-164.143 lbs	-202.327 lbs	-244.732 lbs	-345.258 lbs	-462.681 lbs
LC 4. -1.2D + 1.0W_y	281.332 lbs	271.700 lbs	269.050 lbs	263.636 lbs	254.606 lbs	226.515 lbs	183.886 lbs
LC 5. -(1.2+0.2S_{DS})D + ρQ_E	-40.596 lbs	-63.000 lbs	-85.312 lbs	-105.158 lbs	-127.197 lbs	-179.445 lbs	-240.475 lbs
LC 6. -0.9D + 1.0W_y	298.070 lbs	297.675 lbs	304.223 lbs	306.992 lbs	307.048 lbs	300.498 lbs	283.032 lbs
LC 7. -(0.9-0.2S_{DS})D + ρQ_E	12.808 lbs	19.876 lbs	26.915 lbs	33.176 lbs	40.129 lbs	56.613 lbs	75.867 lbs
Governing Downward Load:	-78.108 lbs	-121.214 lbs	-164.143 lbs	-202.327 lbs	-244.732 lbs	-345.258 lbs	-462.681 lbs
Governing Uplift Load:	298.070 lbs	297.675 lbs	304.223 lbs	306.992 lbs	307.048 lbs	300.498 lbs	283.032 lbs
Horizontal Wind Deflection:	0.9433 in	0.4399 in	0.2442 in	0.1642 in	0.1156 in	0.0620 in	0.0372 in
Horizontal Seismic Deflection:	0.0735 in	0.0493 in	0.0340 in	0.0264 in	0.0212 in	0.0142 in	0.0103 in
Vertical Uplift Deflection:	0.6374 in	0.2752 in	0.1431 in	0.0911 in	0.0604 in	0.0282 in	0.0143 in
Vertical Downward Deflection:	0.1670 in	0.1121 in	0.0772 in	0.0600 in	0.0481 in	0.0324 in	0.0234 in

ASCE 7 Section 2.4 - Allowable Stress Design Load Combinations - Vertical Loading

Trade Pipe Size:	2 in	2-1/2 in	3 in	3-1/2 in	4 in	5 in	6 in
LC 1. -1.0D	-55.791 lbs	-86.582 lbs	-117.245 lbs	-144.520 lbs	-174.808 lbs	-246.613 lbs	-330.487 lbs
LC 5. -D + 0.6W_y	153.178 lbs	138.777 lbs	128.601 lbs	117.716 lbs	103.817 lbs	66.857 lbs	17.795 lbs
LC 5. -(1.0+0.14S_{DS})D + 0.7ρQ_E	-37.344 lbs	-57.953 lbs	-78.477 lbs	-96.734 lbs	-117.007 lbs	-165.069 lbs	-221.210 lbs
LC 6a. -D + 0.45W_y	100.936 lbs	82.437 lbs	67.140 lbs	52.157 lbs	34.161 lbs	-11.510 lbs	-69.275 lbs
LC 6b. -(1+0.1S_{DS})D + 0.525ρQ_E	-41.497 lbs	-64.399 lbs	-87.206 lbs	-107.493 lbs	-130.021 lbs	-183.429 lbs	-245.814 lbs
LC 7. -0.6D + 0.6W_y	175.494 lbs	173.410 lbs	175.499 lbs	175.524 lbs	173.741 lbs	165.502 lbs	149.990 lbs
LC 8. -(0.6-0.14S_{DS})D + 0.7ρQ_E	10.639 lbs	16.511 lbs	22.358 lbs	27.559 lbs	33.335 lbs	47.028 lbs	63.022 lbs
Governing Downward Load:	-55.791 lbs	-86.582 lbs	-117.245 lbs	-144.520 lbs	-174.808 lbs	-246.613 lbs	-330.487 lbs
Governing Uplift Load:	175.494 lbs	173.410 lbs	175.499 lbs	175.524 lbs	173.741 lbs	165.502 lbs	149.990 lbs
Horizontal Wind Deflection:	0.9433 in	0.4399 in	0.2442 in	0.1642 in	0.1156 in	0.0620 in	0.0372 in
Horizontal Seismic Deflection:	0.0735 in	0.0493 in	0.0340 in	0.0264 in	0.0212 in	0.0142 in	0.0103 in
Vertical Uplift Deflection:	0.3753 in	0.1603 in	0.0826 in	0.0521 in	0.0342 in	0.0155 in	0.0076 in
Vertical Downward Deflection:	0.1193 in	0.0801 in	0.0552 in	0.0429 in	0.0344 in	0.0231 in	0.0167 in

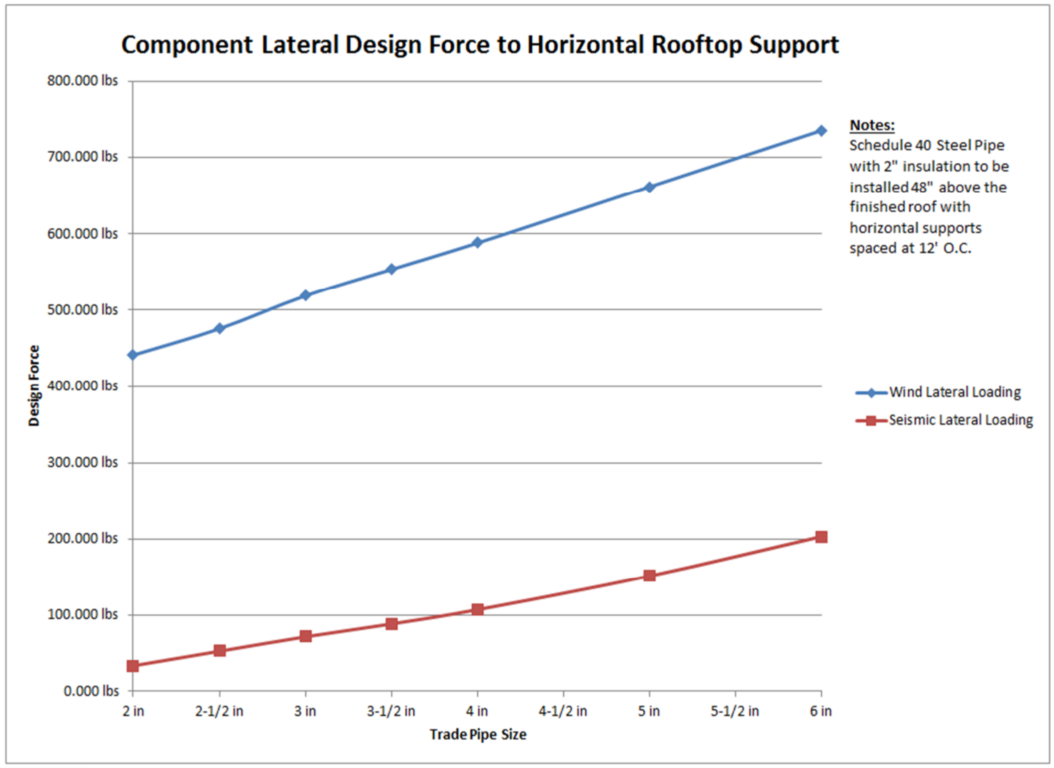

Figure 1. Design lateral loading on schedule 40 steel pipe with 2 in. insulation.

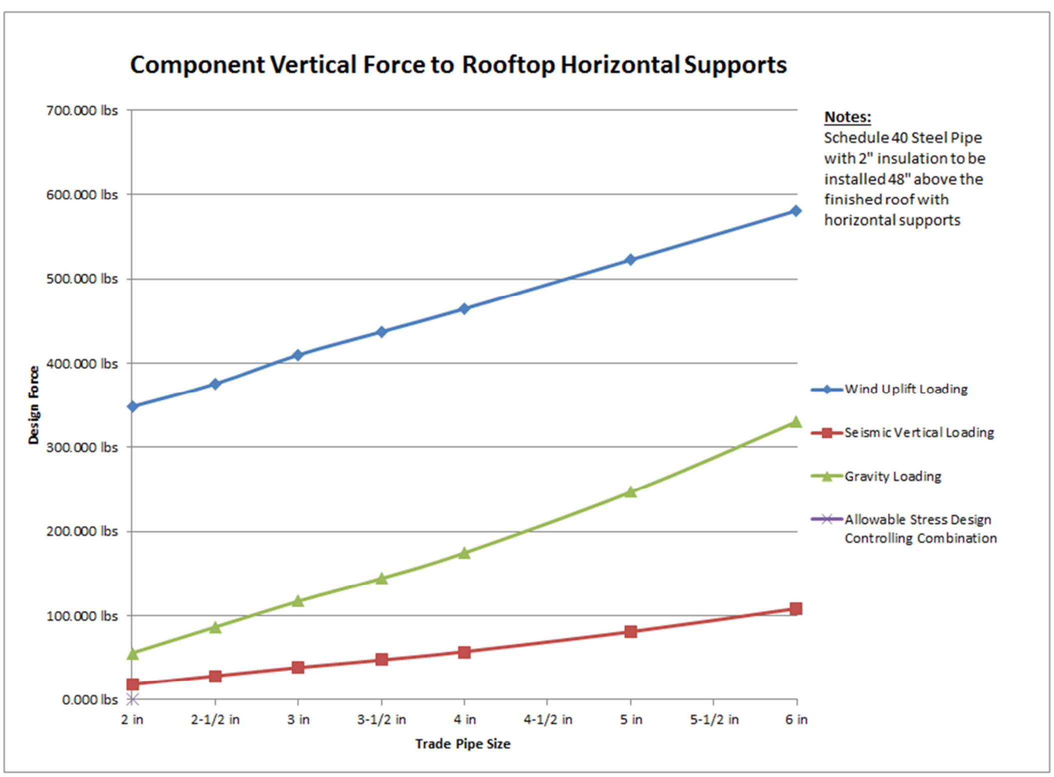

Figure 2. Design vertical loading on schedule 40 steel pipe with 2 in. insulation.

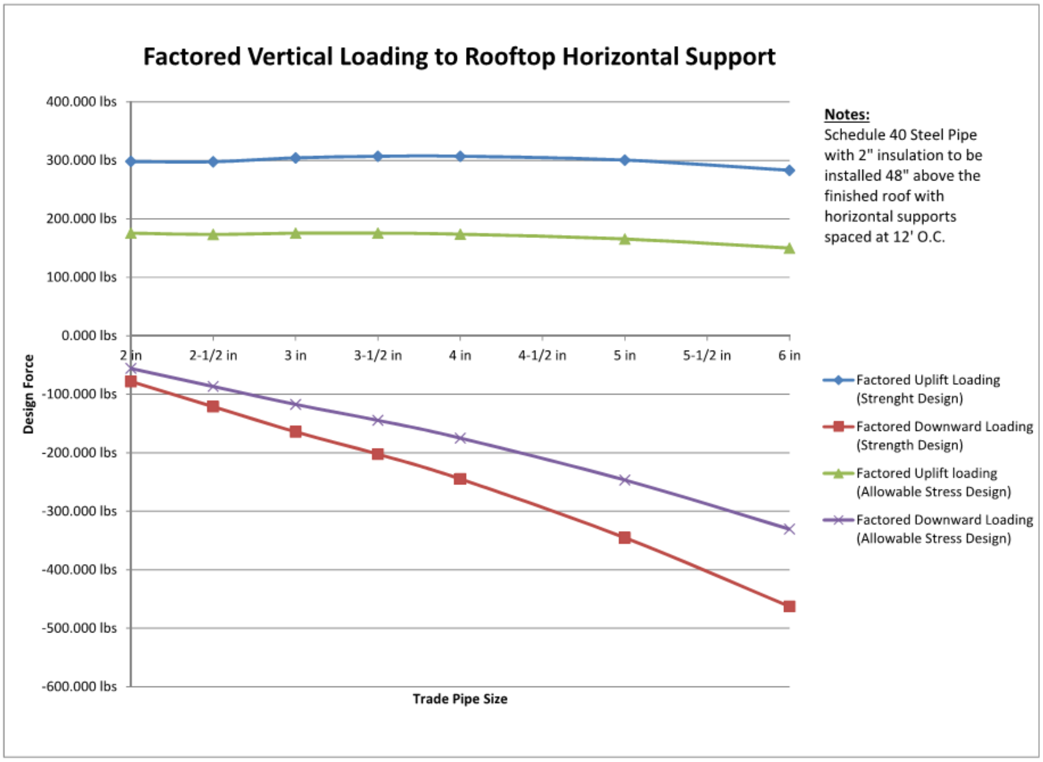

Figure 3. ASCE 7 factored vertical loading on schedule 40 steel pipe with 2 in. insulation.

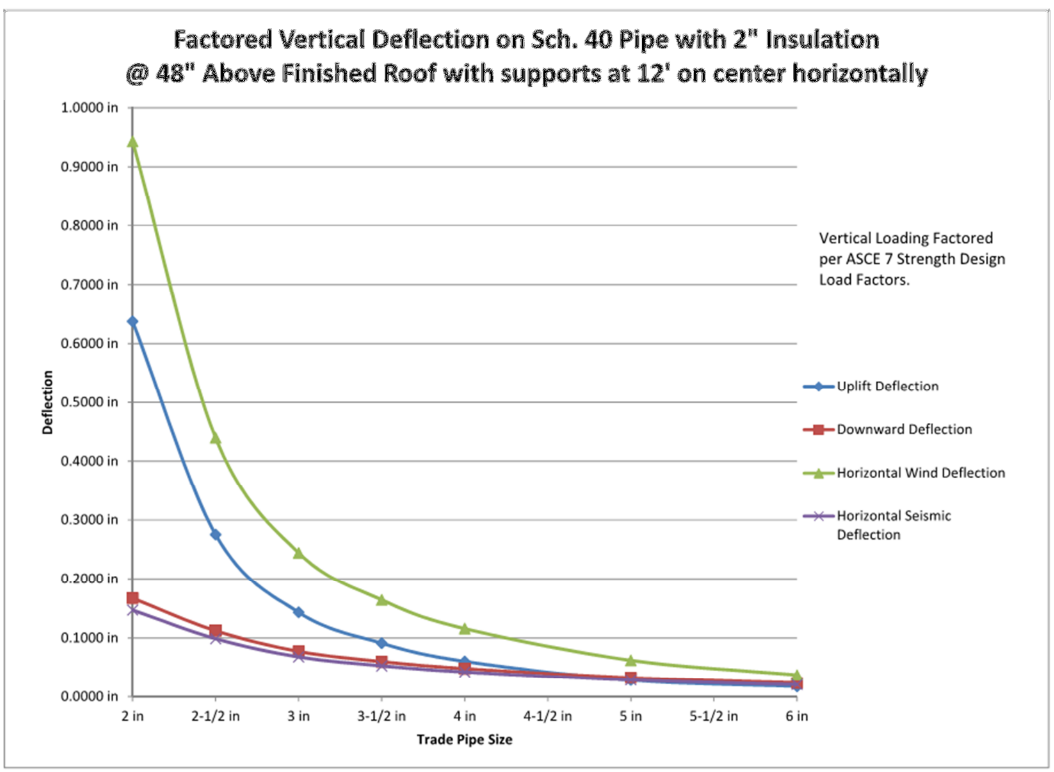

Figure 4. ASCE 7 strength design deflections on schedule 40 steel pipe with 2 in. insulation.

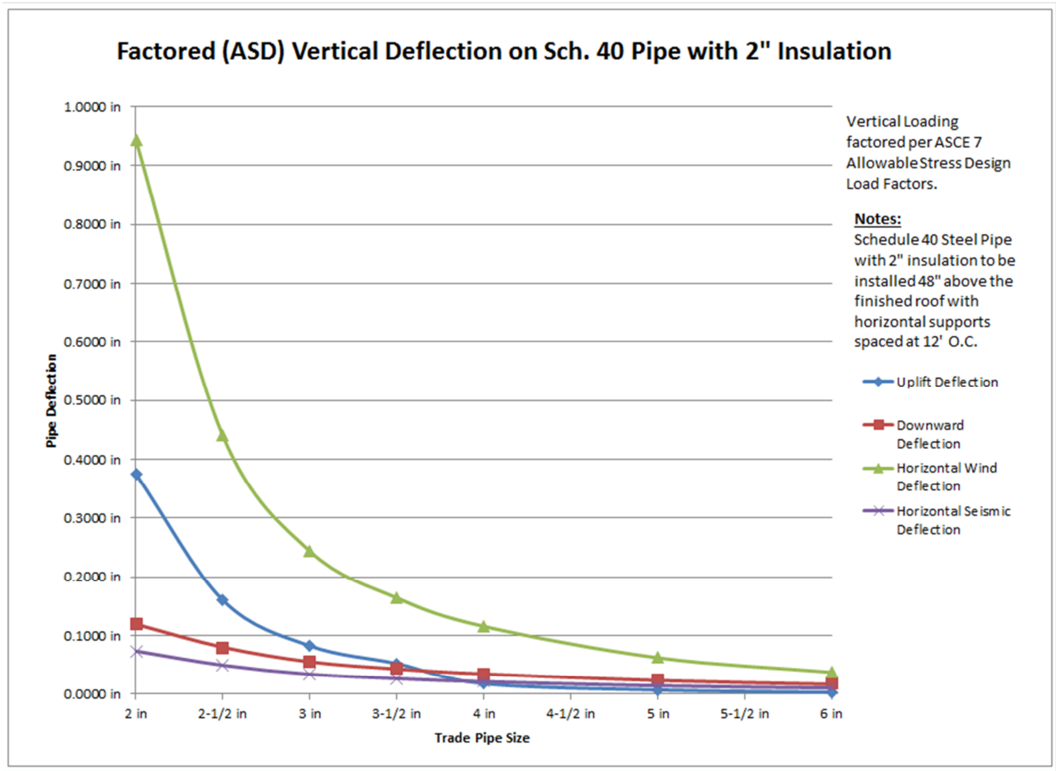

Figure 5. ASCE 7 stress design deflections on schedule 40 steel pipe with 2 in. insulation.

From these figures you can see how wind loading in both the lateral and uplift direction will generally control the design of the support frames. Some conditions in the seismic portion of the code will still need to be met where seismic evaluation is required, but generally, the design to accommodate the wind loading requirements will also meet or exceed the seismic design requirements.

Another factor that can significantly affect wind loading on a pipe is insulation thickness. The added weight will not significantly affect gravity or seismic loading, but going from 2 in. of insulation to 4 in. of insulation will nearly double the applicable lateral and uplift wind loading on a piped system.

Application

Once the applicable loading to the pipe has been determined, the support frame system can be designed accordingly. After applying the various load combinations, the worst case or governing case for downward, uplift, and lateral loading will be accounted for in the design of the support frame. Note also that frames supporting multiple pipes will need to be evaluated with the applicable loading from each pipe being transferred to the support frame. Due to the complexity of evaluating the various load combinations with placement of loading at various locations and magnitudes on a support using design software such as RISA 3D or other software packages to design the support frames is common. The design software provides an accelerated method to evaluate the support frames and make changes or modifications where required to optimize the members used in the construction of the frame and find the reactions from the frame that will need to be transferred to the building structure.

The final design and installation of properly designed rooftop piping support frames will require coordination among the building owner, the mechanical engineer, the building structural engineer of record, the mechanical contractor, a roofer, and the support supplier. The support supplier will likely also be working with an engineer who will be running the calculations for the support frames and providing the sealed submittal package for the frames.

Summary

The ammonia refrigeration industry is by no means lacking in established design procedures, regulations, and oversight, and justifiably so. The risk associated with the failure of an ammonia distribution line or associated equipment can have serious health and economic consequences. Code requirements and industry standards are established and maintained with the primary goal of protecting the health, safety, and general welfare of the community. The requirement to address wind and seismic loading on rooftop equipment, which includes piping and other distribution lines and their supports, is included in the International Code Council's family of codes and other adopted state/local codes and standards, industry standards, and insurance standards. The codes and standards will evolve and adapt as more research is conducted and through the involvement of those with a vested interest in how the codes are written and interoperated.

Current codes are written in a manner that will generally require a site-specific design of support frames to meet applicable loading requirements. Rooftop equipment and supports exposed to wind shall be determined for each pipe or component being supported per the requirements found in the International Building Code and ASCE 7. Where earthquake loading is applicable, rooftop equipment and supports shall be designed in accordance with the International Building Code and ASCE 7. Other environmental loading considerations may also require evaluation based on the requirements of the local building official. Coordination between trades and professions is essential to ensure a properly designed and installed system that will meet both code requirements and customer expectations. Early consideration and coordination between trades in the design phase of a project can also ease financial and project completion consequences.

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