BUILDING CODE REQUIREMENTS

FOR

ROOFTOP EQUIPMENT AND SUPPORTS

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INTRODUCTION

The International Code Family, published by the International Code Council (ICC) is the most widely adopted code in the United States. One element in the code that I believe has been overlooked, or gone unenforced, is the loading requirements for equipment and supply/distribution lines that are installed on building rooftops. The placement of ammonia piping, as well as other utility lines and equipment on the roof or within the building, will be exposed to loading other than gravity loading. Current codes have requirements for evaluating a variety of loads that a mechanical system will be exposed to and establish minimum design and installation requirements for these systems.

There are many reasons and advantages to running service lines on the roof of a building. Often, on retrofit projects or remodels, the roof is the only place with adequate access and a clear path to run mechanical, electrical, plumbing and communication lines. However, there are conditions that a roof install exposes the equipment to that are not a factor when placed inside of the building envelope. Historically, codes and standards have contained a minimum basis for the design and installation of mechanical equipment and supports located on roofs, but how often are the provisions for rooftop equipment addressed?

The intent of this paper is to discuss the evolution of the International Codes and sections of the codes that specifically addresses the requirements for supporting refrigeration equipment located on the roof of a building, and how the applicable loading requirements affect the design of the supporting elements. Some local code amendments will be discussed, but it is the responsibility of the design professional to ensure code requirements for the applicable jurisdiction are met.

BUILDING CODE PURPOSE AND HISTORY

As a refrigeration professional, you are likely familiar with trade or industry standard (IIAR 2 and ASHRAE 15) that establishes standard practices for specific systems or equipment. These standards play a significant role in the development of adopted building codes and are then either referenced or specifically cited within the ICC Codes. As such, the volume of literature referenced in the International Code Family can be overwhelming. For simplicity in this paper, we will focus primarily on the following codes;

- 2015 International Mechanical Code (IMC)
- 2015 International Building Code (IBC)
- ASCE 7-10 “Minimum Design Loads for Buildings and Other Structures”

ASCE 7 is a standard produced by The American Society of Engineers and the Structural Engineering Institute to provide minimum loading requirements for the design of building and other structures that are subject to building code requirements. These three referenced documents are the most current codes and standard containing the basis for the design and loading requirements for rooftop equipment and supports.

The intent of building codes and design standards is to provide uniform minimum criteria for buildings, components and systems to safeguard the health, safety and welfare of occupants, the surrounding community and to mitigate risk. In addition to the safety of personnel, building owners may also consider economic loss associated with downtime or disruption of service. Codes, as a minimum standard, are generally written to ensure safe evacuation of occupants rather than to maintain the operation of the building and systems. To some owners, the code minimum design requirements may not suffice and they may specify more strict requirements than what we will discuss.

Building codes have evolved over time largely in reaction to disasters and perceived threats (natural or man-made.) The first building code enforced in the U.S. was adopted in Boston, Massachusetts in 1872. The code was written and adopted in response to fire hazards associated with wooden chimneys and thatched roofs. Three more broadly adopted model codes were established between 1915 and 1940;

- Building Officials and Code Administration (BOCA) – National Building Code
- International Congress of Building Officials (ICBO) – Uniform Building Code
- Southern Building Code Congress International (SBCCI) – Standard Building Code

In 1994, the three organizations combined forming the International Code Council (ICC) to develop a uniform standard to be applied throughout the United States. The new organization released its first I-Codes in 2000. The ICC I-Codes are on a 3-year code cycle with the 2015 I-Codes being the most current. Evaluation and revisions to the codes between each code cycle provides a democratic consensus process where public input submissions are considered, reviewed, proposed revisions/edits are prepared and voted on by ICC members for implementation. This process is done in collaboration with the Federal Emergency Management Agency (FEMA), other federal, state, local and private authorities and professional organizations.

ASCE 7 follows a similar development process as the I-Codes via a consensus standard process. "The consensus process includes balloting by a balanced standards committee made up of Society members and non-members, balloting by the membership of the Society as a whole and balloting by the public." ASCE 7 has been on a 5 year review cycle, but it is now going to a 6 year cycle that will coincide more with the I-Code Cycle.

Adoption of the codes is left to state and local jurisdictions. Many states now adopt the I-Codes with minimal amendments, while other states heavily amend the I-codes to meet increased perceived threats in their jurisdiction. For instance, California and Florida both have state specific codes based on the format and general content found in the I-Codes, but contain significant amendments to justify publication of a state specific code. A handful of other states, counties and cities have taken this same approach.

Once a jurisdiction adopts a building code, it is typically up to local building officials, inspectors and plan reviews who ensure the provisions in the code are followed in construction documents and the systems are properly installed. Design professionals must stay current on applicable codes and consider how to specify code compliant systems that are also constructible. Contractors, installers and end users should also be aware of code requirements to also ensure compliance. The ultimate goal of building codes, with proper understanding, adherence and enforcement, is to establish a safer, more resilient and sustainable built environment by learning from errors from the past and other perceived risks.

2015 INTERNATIONAL MECHANICAL CODE (IMC)

Our code review will begin in the 2015 International Mechanical Code. Chapters 1 and 2 of each of the I-Codes are devoted to general scope, definitions, administration and enforcement. Familiarity with these chapters is recommended to understand how the codes are to be applied and enforced by local officials, and what responsibility designers, installers and end users have with respect to building systems.

Chapter 3 – General Regulations, gets into specific requirements for mechanical systems. *Section 301.1- Scope,* 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 critical. Is there ever a situation where a piece of equipment, pipe, duct, etc. ran 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 seismic design consideration may not apply. In contrast, the wind loading phrase "that are exposed to wind shall be designed" does not leave any exception.

Section 305 – Pipe Support, covers pipe hanger strength requirements and attachment methods, as well as 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 is later used in the design of the supports to resist all applicable loading.

Worth mentioning, but not directly related to rooftop supports, is *Section 306 – Access and Service Space*. In particular, *Section 306.5 - Equipment and Appliances on Roofs or Elevated Structures*, requires that where personnel have to climb higher than 16 feet above grade to access equipment there shall be a permanent means to access the equipment. This section also includes a requirement for a level walking/working surface for roofs having a slope greater than 4 units vertical in 12 units horizontal (33-percent slope). Additionally the access shall not require climbing over any obstructions greater than 30 inches in height and the use of a portable ladder for the access is prohibited. The requirements for access are similar to the requirements found in *OSHA 1910 Subpart D – Walking and Working Surfaces*.

Chapter 11 of the IMC is dedicated to refrigeration systems with 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 specifically cannot be located, but leaves the requirements of Chapter 3 for support and external load design requirements.

2015 INTERNATIONAL BUILDING CODE (IBC)

Now jumping into the International Building Code, we will go directly to Chapter 16, Structural Design. There are some building parameters that must first be established before loading requirements can be determined. If the project is new construction the following parameters will have been established by the buildings structural engineer of record and will be included in the structural general notes. 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 location, use of the building and the construction materials and methods used, applicable loading requirements can be determined with minimal conservative assumptions required.

- ***Building Risk Category***

First off, we need to establish a Risk Category of the building. *Table 1604.5* in chapter 16 contains a list of building uses with the appropriate Risk Category. There are (4) Risk Categories 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. Category III can also be assigned to buildings that 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 those that are deemed essential facilities. Essential facilities are those buildings 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.

• *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 have been established. The load combinations apply factors to the various loads being considered to provide more realistic loads. For instance, it is not practical to design a structure for the worst case wind and seismic load simultaneously. The code also requires consideration for other serviceability factors such as deflection limits or other visual or functional considerations. The load combination include: Dead Loads (D), Live Loads (L), Snow (S) or Rain (R) Loads, Flood Loads (F), Lateral Earth Pressure Loads (H), Wind Loads (W) and Seismic Loads (E). There are also combinations in ASCE 7 for atmospheric ice loading and wind on ice loading that we will discuss later. Of all these loads, we will quickly discuss dead loads and dive more into the specifics of wind and seismic loading. Other loads may contribute to the design of the pipe support racks, but dead, wind and seismic loading are typically controlling factors.

• *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 piping, it is appropriate to consider both wet and dry pipe conditions.

- ***Wind Loads***

Requirements for wind loading on rooftop equipment has not had a very large presence in the International Building Code, but there are some key requirements specifically addressed in *Section 1609 – Wind Loads*.

The first paragraph of the section, *1609.1 – Application*, states "Decreases in wind loads shall not be made for the effect of shielding by other structures." Strictly interpreted, this statement eliminates any potential to reduce or eliminate wind loading rooftop equipment. Wind screens or other architectural elements placed around rooftop equipment, theoretically, will shield or reduce wind loading on the equipment, but currently no reduction is allowed. A FEMA report titled "Attachment of Rooftop Equipment in High-Wind Regions" reinforces this requirement with the findings of the Hurricane Katrina Recovery assessment. The report states "Equipment screens around rooftop equipment are frequently blown away. Equipment screens should be designed to resist the wind loads derived from ASEC 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." Conversely, a study prepared in August 2007 titled "Rooftop Equipment Wind Load and its Mitigation for Buildings in Hurricane Prone Regions" was completed in partnership with the International Hurricane Research Center, Florida International University. The study evaluated the potential reduction to wind loading on rooftop equipment via properly designed and installed wind screens. While significant reduction in wind loading on the shielded rooftop equipment were reported in the findings, additional studies and revisions to the text of the code will be required before any reductions are are allowed.

Section 1609.1.1 – 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 of the IBC requires certain conditions be meet to qualify. Condition #5 specifically excludes this method for rooftop equipment thus requiring the use of ASCE 7.

In both the IBC and ASCE 7 the design wind speed to be applied is based on wind contour maps of the U.S. The design wind speed is based on the location and the Building Risk Category previously discussed. Design wind speeds range from 100 to 200 mile-per-hour 3-second gusts. A significant portion of the country falls into a 115 to 120 range with higher values being required along the Atlantic and Gulf coast and the Alaskan coastline. Once the proper design wind speed is selected, equations in Chapter 29, *Wind Loads on Other Structures and Building Appurtenances,* are used to convert the wind speed to lateral and vertical uplift forces that are then applied to the pipe or other equipment.

A valuable tool in determining basic wind speeds had been prepared by the Applied Technology Council's (ATC) Windspeed by Location web site, (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 to verify the information generated is valid. There are also some "Special Wind Regions" where wind loads are to be provided by the authority having jurisdiction. However, in my opinion, the report generated is much more user friendly for obtaining a design wind speed, and easily verified by cross checking on the letter size maps presented in the IBC and ASCE 7.

- ***Earthquake Loads***

If you provide services in high risk seismic zones, it is very likely that you have had to deal with meeting seismic requirements for ammonia systems, regardless if the pipe and equipment are being installed on the roof or within the building. The equations used to determine applicable seismic loading have not changed significantly over the last 15 years. Some of the factors used in the equations are revised in each code cycle as more data becomes available. The codes pay specific attention to components that contain or convey hazardous materials. Larger ammonia systems would generally fall under this increased scrutiny. Where wind loads were dependent more on the projected (surface) area of the component, seismic loading is more dependent upon the weight of the component.

Back in 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 consistent, and while it is important for a structural engineer to understand the nuances of how a building is assigned a seismic design category, we will forgo for the intent of this paper. Another very useful tool in determining the seismic design requirements for structures and equipment is available through the United States Geological Survey (USGS) and their Earthquake Hazards Program (http://earthquake.usgs.gov/designmaps/us/application.php). The program requires the user to enter in a project's site longitude and latitude, specify the appropriate design code, building risk category and a site soil classification. From this information, the program generates a report that contains the seismic design parameters that are used to determine if seismic design will be required and site specific values that are used in the equations to determine the applicable loading. The IBC contains the process used to determine the same information obtained from the USGS Seismic Hazards Program, but for how to use this information to determine seismic loading on the mechanical equipment we must go to ASCE 7, *Chapter 13 – Seismic Design Requirements for Nonstructural Components*.

We won't get into this section too deeply, but there are some elements of the section that can help us understand what equipment needs to be evaluated.

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. There are (4) conditions that 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 impact the operation of the facility.
4. The component conveys, supports or otherwise contains hazardous substances and is attached to a structure or 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. Unless directed otherwise I will typically assume an ammonia pipe system contains sufficient quantities of hazardous material to justify a seismic importance factor of 1.5.

Section 13.1.4 – Exemptions presents six scenarios where seismic forces don't need to be considered. Four of the six cases pertain to mechanical equipment. If the project is located in a low seismic risk area (Seismic Design Category A or B) seismic design requirements are exempted, but in higher seismic risk areas seismic consideration will be required (Seismic Design Category C, D, E or F.)

If seismic consideration is required, ASCE 7 Chapter 13 contains detailed requirements for various mechanical and electrical component systems. Rather than going through each conditions we will cover some general requirements that must be met. *Section 13.2.1 – Applicable Requirements for Architectural, Mechanical and Electrical Components, Supports and Attachments* 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 pipe support 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, which would lead to uneconomic, overly conservative options. Subsequently, *Section 13.2.7- Construction Documents* requires that 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.

In addition to the evaluating the pipe and supports for the design forces, component displacements must also be considered. The intent of evaluating displacements is to prevent overstressing component connection or fittings and consequential damage to adjacent elements. In the commentary of ASCE 7, the presence of insulation around piping can serve to protect piping 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 – Nonstructural Component Anchorage*. The code specifically requires where seismic design is required that "Component 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 substantial dead load which can overload the building roof structure.

• *Force Transfer and Other Load Considerations*

With rooftop applications, the capacity of the roof structure and other building structural elements must be able to handle the additional loading. Generally, roofs are designed to meet a minimum live and dead load as required in the code. For retrofit projects 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 additional load required to resist design 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.

Other loading that may be applicable to rooftop equipment that is not specifically called out in the Mechanical Code but is addressed in the Building Code and ASCE 7 includes snow loading, and atmospheric ice loading. Snow can accumulate on piping and other equipment adding additional loading. Including snow loading on large horizontal surfaces of equipment is understandable. However, an argument can be made that snow loading on smooth round pipe would be short term and will not pose a significant or sustained increase in loading. Ice loading on the other hand can be a significant concern on both rooftop equipment and piping. Design requirements for Ice loading in ASCE 7 identify areas of the country where 1-1/2 inch of ice buildup can occur. In addition to the added weight of the ice, there is also consideration given for wind on the ice covered component. When ice loading is factored into the design, alternate load combinations are used that account for the weight of the ice and wind on ice factors.

SUMMARY

The ammonia refrigeration industry is by no means lacking in established design procedures, regulations and oversight, and justifiably so. The "prevent them all or stop them small" approach to ammonia release as taught by the Ammonia Safety and Training Institute is directly in-line with the goal of the I-codes to protect the health, safety and general welfare of the community. The requirement to design rooftop equipment, which includes piping and other distributions lines, and their supports, has been include in the I-Codes since the first edition and will remain. There will likely be changes as the codes evolve, more research is available and through the involvement of those with a vested interest in how the codes are written and interpreted.

Current codes are written in a manner that will generally require a site-specific design of rooftop support frames in order to meet applicable loading requirements. Rooftop equipment and supports exposed to wind must 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 also be designed in accordance with the International Building Code and ASCE 7. Other environmental loading considerations may also need to be considered base on the requirements of the local building official or the building owner. Coordination between trades, design professions, maintenance personnel and building owners/managers is essential to ensure properly designed, installed and maintained rooftop equipment, supports.

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