Night School 23: Topics on Industrial Building Design and Design of Non-building Structures

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AISC Night School

Session 7 – Non-building Structures, Part 1

August 4, 2020

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Course Description

Non-building Structures, Part 1
August 4, 2020

In this session, various non-building structures will be introduced including pipe racks, machine support structures with an emphasis on vibration, storage racks, sheet piles and bearing piles. Design considerations, loads and references will be reviewed.

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Learning Objectives

- Describe design considerations for the design of pipe racks.
- List design considerations for mitigating vibration issues associated with machine support structures.
- Describe design considerations for the design of storage racks.
- Describe design considerations for the design of sheet piles and bearing piles.

Night School 23: Topics on Industrial Building Design and Design of Non-Building Structures

Session 7: Non-building Structures, Part 1
August 4, 2020

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Night School 23: Topics on Industrial Building Design and Design of Non-Building Structures

Session 7: Non-building Structures, Part 1

- **Section 7.1: Pipe Racks**

Jules Van de Pas, PE, SE
CSD Structural Engineers

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INTRODUCTION

SESSION 1 INTRODUCTION AND CODE PROVISIONS
SESSION 2 INDUSTRIAL BUILDINGS – PART 1
SESSION 3 INDUSTRIAL BUILDINGS – PART 2
SESSION 4 CRANE SUPPORTING STRUCTURES
SESSION 5 FATIGUE DESIGN FOR INDUSTRIAL STRUCTURES
SESSION 6 HIGH & LOW TEMPERATURE DESIGN FOR INDUSTRIAL STRUCTURES
SESSION 7 NON-BUILDING STRUCTURES –PART 1
SESSION 8 NON-BUILDING STRUCTURES –PART 2

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Session 7: Non-Building Structures, Part 1
August 4, 2020

Four Topics   Four Speakers

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7.1 Pipe Racks

7.2 Equipment Supports


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7.3 High Density Rack Storage

7.4 Steel Piles


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Session 7: Non-building Structures, Part 1
August 4, 2020
- 7.1: Pipe Racks

LEARNING OBJECTIVES:

- Review of typical pipe rack design loads, load combinations, and solutions used for pipe rack structures.

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PIPE RACKS

Structures that support process piping, equipment, cable trays, and potentially access catwalks in process facilities.

This presentation will focus mostly on larger ground supported pipe racks.

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PIPE RACKS: DEAD LOADS

Use the actual weight of the piping or reasonable uniform load allowance for each level of pipes and cable tray.

Allowances per PIP *Structural Design Criteria*:

- 40 psf for piping levels (eq. to 8" diameter pipes at 15" o/c.).
- 20 psf per cable tray level.

Note your allowances on your drawings!

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PIPE RACKS: DEAD LOADS

Dead Loads (D): Consider the dead loads as consisting of several categories.

D_s: The weight of the structure.

D_o : The full operating weight of supported piping, cable trays, etc.

D_e :empty dead load of piping ,often taken as 60% of $D_{o.}$

D_t :empty dead load of piping , plus the test medium.

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PIPE RACKS: THERMAL LOADS

Evaluation of thermal forces is appropriate.

Design Temperature T (Refer to Session 1)

$$T = T_w - T_m \quad \text{or} \quad T = T_m - T_c$$

- T_w= Either ambient or equipment operating temperature. (warm) consider adding 35 degrees F to the highest ambient temperature.
- T_c= Either ambient or equipment operating temperature. (cold)
- Tm = (mean) mean construction season temperature.

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PIPE RACKS: DESIGN LOADS

Consider breaking Thermal Loads (T) into two categories

- T_s: (Sustained) includes:
  - anchor and guide forces.
  - thermal expansion or contraction of the structure due to changes in ambient temperature.
  - Restrained dimensional changes at equipment.
- T_t: (Temporary) includes:
  - friction forces from start up and shut down temperature changes.
  - Differential thermal loading on the structure due to sunlight and shade.

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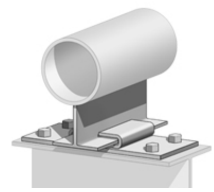
PIPE RACKS: THERMAL LOADS

Friction Forces at piping supports (PIP):

- Consider steel to steel friction μ=.4
- Consider reduction in the friction force from multiple pipes at a given beam or level.
- Consider these forces as resisted by the beam top flange only
- Use judgement when uneven size pipes are supported at a given beam.

# of pipes	Friction load as a % of pipe weight
1	40%
2, 3	30%
4, 5, 6	20%
> 6	10%



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PIPE RACKS: RISK CATEGORY (RC)

RC I: Low risk to human life

RC II: All buildings except I, III, IV

RC III:…Buildings and other structures…that contain…hazardous chemicals… where the quantity exceeds a threshold quantity established by the AHJ.

RC IV:…Buildings and other structures the failure of which could pose a substantial hazard…that contain…hazardous chemicals… where the quantity exceeds a threshold quantity established by the AHJ and is sufficient to pose a threat to the public if released.

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PIPE RACKS: WIND LOADS

Wind Loads (W):

- Apply wind load to all exposed piping and structure, neglect shielding.
- Do not consider an equivalent enclosed structure.

Drift Limits need to be considered carefully.

- h/100 for full wind load is typically considered acceptable.
- Coordinate frame drift limits at locations where the pipes attach to equipment with the piping designer. A proportional limit is not appropriate.

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PIPE RACKS

The typical lateral load resisting system consists of moment frames in the transverse direction and centrally located braced frames in the longitudinal direction.

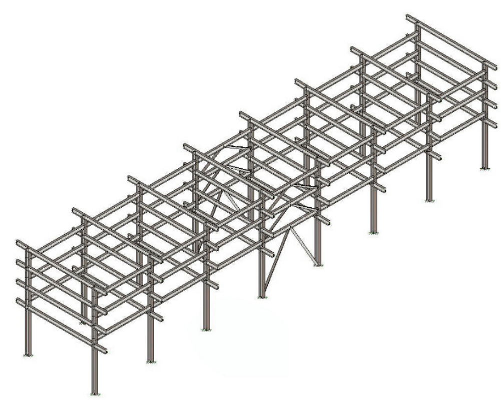

Fig. 2. Typical four-level pipe rack consisting of eight transverse frames connected by longitudinal struts.

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PIPE RACKS: SEISMIC LOAD

Select a system from Table 15.4-1 Seismic Coefficients for Nonbuilding Structures Similar to Buildings based on the Seismic Design Category and height of the structure.

For pipe racks using moment frame systems there are exceptions to the tabulated height limits.

Steel OMF and IMF are permitted in pipe racks up to 65 ft. where the moment joints are of field connections are constructed of bolted end plates.

Steel OMF and IMF are permitted in pipe racks up to 35 ft.

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PIPE RACKS: SEISMIC LOAD

Moment frame systems:

- SMF and IMF are allowed but the beam bracing requirements are problematic. The SMF beams require bracing for highly ductile members. The IMF beams require bracing for moderately ductile members.
- Since the pipes do not brace the beams, OMF systems are more commonly used.
- Bolted end plates are the preferred moment connection

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PIPE RACKS: SEISMIC LOAD

ASCE 7-16

- Refer to Section **15.5.2 Pipe Racks**
- Displacement of the pipe rack and the potential for interaction effects (pounding of the piping system) shall be considered using the amplified deflection obtained from the following equation:

$$\delta_x = \frac{C_d \delta_{xe}}{I_e}$$

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PIPE RACKS: SEISMIC LOAD

ASCE 7-16

- See Section 13.6.2 for the design of piping systems and their attachments. Friction resulting from gravity loads shall not be considered to provide resistance to seismic forces.

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PIPE RACKS: SEISMIC LOAD

T: Calculate the actual period of your structure. Do not use the approximate period equations. (15.4.4)

Avoid using highly conservative estimates of the supported dead loads when calculating the period.

$$T = 2\pi \sqrt{\frac{\sum_{i=1}^{n} w_i \delta_i^2}{g \sum_{i=1}^{n} f_i \delta_i}}$$

Consider decreasing the calculated period by 10% if the stiffness of the pipes leaving the rack is not included in the analysis.

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PIPE RACKS: SEISMIC LOAD

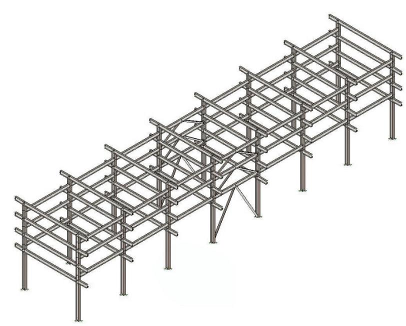

Fig. 2. Typical four-level pipe rack consisting of eight transverse frames connected by longitudinal struts.

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Redundancy:

SDC A, B, and C (transverse and long dir.)

- ρ=1.0

SDC D or higher:

- For the transverse direction with two columns ρ=1.3
- For the long direction ρ=1.3 unless two or more bays of bracing (4) braces are provided between expansion joints.

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LOAD COMBINATIONS: ASCE 7-16 expanded

(1)1.4D	$1.4(D_s + D_o)+1.2T_s$
	$1.4(D_s + D_t)+1.2T_s$
(2)1.2D+1.6L+.5S	$1.2(D_s + D_o)+1.2T_s+1.0T_t+1.6L+.5S$
	$1.2(D_s + D_t)+1.2T_s+1.0T_t+1.6L+.5S$
(3) $1.2D+1.6L_r+L$ (or.5W)	$1.2(D_s + D_o)+1.2Ts+1.0T_t+1.6S+.5L$
	$1.2(D_s + D_o)+1.2Ts+1.6S+.5W$

(Partial list from reference 5, see references 1 , 3, & 5 for additional suggested combinations.)

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REFERENCES

1. Drake, Richard M., Walter, Robert J. (2010), "Design of Structural Steel Pipe Racks" *AISC Engineering Journal.*

2. Arya, Suresh C., Feng, Edward, and Pincus, George (1979), "Optimum Design of Steel Pipe Racks" *AISC Engineering Journal.*

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REFERENCES

3. Seismic Evaluation and Design of Petrochemical and other Industrial Facilities Third Ed. *ASCE, Task Committee on Seismic Evaluation and Design of Petrochemical Facilities.*

4. ASCE/SEI 7-16 Minimum Design Loads and Associated Criteria for Buildings and Other Structures, ASCE

5. Process Industry Practices (PIP) STC01015 *Structural Design Criteria*

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PIPE RACKS: SUMMARY

Pipe Racks design requires consideration of:

- Thermal effects on the structure and piping.
- Careful application of load combinations.
- Coordination with the piping/process engineers.

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Session 7: Non-building Structures, Part 1

- Section 7.2: Machine Supports

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Session 7

Topic 2

Machine Supports

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Machine Supports

- Introduction
- Design objectives
- Fundamental behavior
- Modeling techniques
- Acceptance criteria
- Design

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Machine Supports

Introduction

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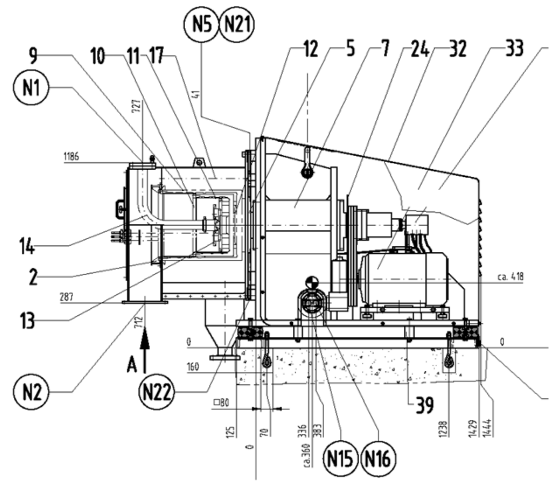
Introduction

The Machine Manufacturer Should Provide:

- Dynamic operating loads
- Operating speed, *N*
- Vibration limits



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Introduction

Vibration References

- Piersol, A.G. and Paez, T.L. (2010), *Harris' Shock and Vibration Handbook*, McGraw-Hill
- De Silva, C.W. (2005), *Vibration and Shock Handbook*, CRC Press
- Paz, M. (1991), *Structural Dynamics-Theory and Computation*, 3rd Edition, Van Nostrand Reinhold

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Machine Supports

Design Objectives

Design Objectives

- The support structure must be capable of resisting vibratory forces
  - Strength (dynamic loads)
  - Fatigue (cyclic loads)
- Vibration magnitudes must be limited based on the acceptance criteria

Machine Supports

Fundamental Behavior

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Machine Speed

Machine speeds are typically provided in revolutions per minute (rpm). The angular forcing (exciting, operating) frequency is

$$\omega = \frac{2\pi N}{60} \qquad \text{(radians/second)}$$

N = machine speed, rpm

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Natural Frequencies

- The natural frequencies are the free (no external force) vibration frequencies of a system
- Usually, the fundamental (lowest) natural frequency is critical; however, the higher-mode natural frequencies can also be important
- Natural frequencies can be calculated using a modal analysis in a 3-D finite element model

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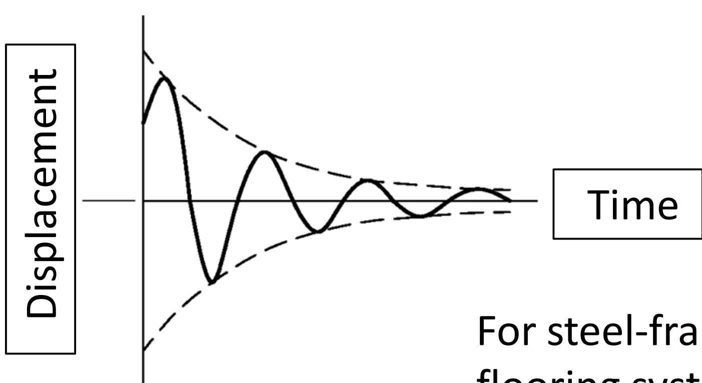
Damping

The damping ratio, β, is a measure of energy dissipation in a vibrating structure expressed as a portion of critical damping.



For steel-framed structures and flooring systems: β = 0.01 to 0.03

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SDOF Systems

For a single-degree-of-freedom (SDOF) system, the dynamic behavior can be expressed with an equivalent static force, $F_e = \Phi F_o$

The dynamic magnification factor is $\Phi = \dfrac{1}{\sqrt{\left(1-r^2\right)^2 + \left(2\beta r\right)^2}}$

F_o = free force of the machine

r = ratio of the forcing frequency to the natural frequency of the system, ω/ω_n (tuning ratio)

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SDOF Systems

Resonance

Resonance occurs when the forcing frequency equals the natural frequency for any significant vibration mode of the structure.

At resonance, r = 1, resulting in a dynamic magnification factor of

$$\Phi = \frac{1}{2\beta}$$

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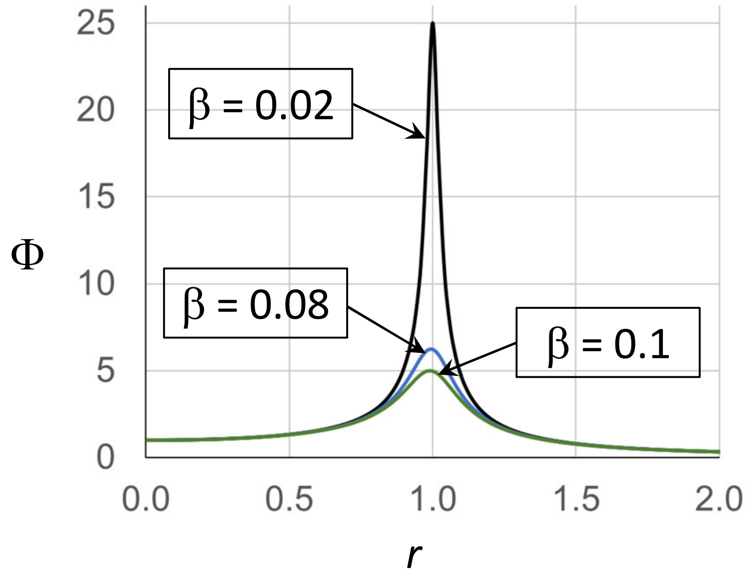
SDOF Systems



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Machine Supports

Modeling Techniques

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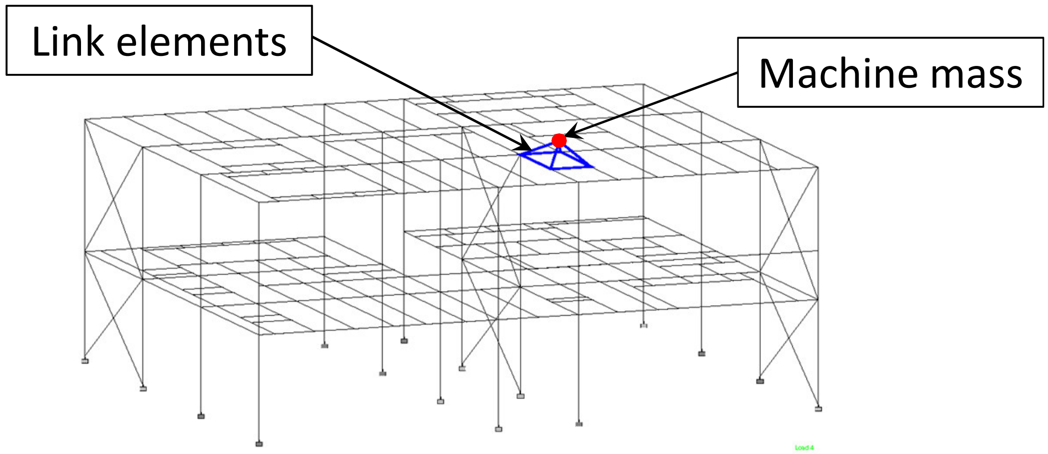
Modeling Techniques

Link elements can be used to connect the machine mass to the structure



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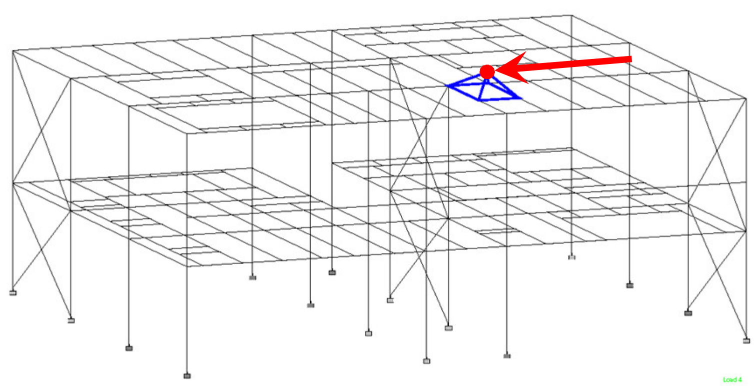
Modeling Techniques

Machine forces are applied in the direction of interest



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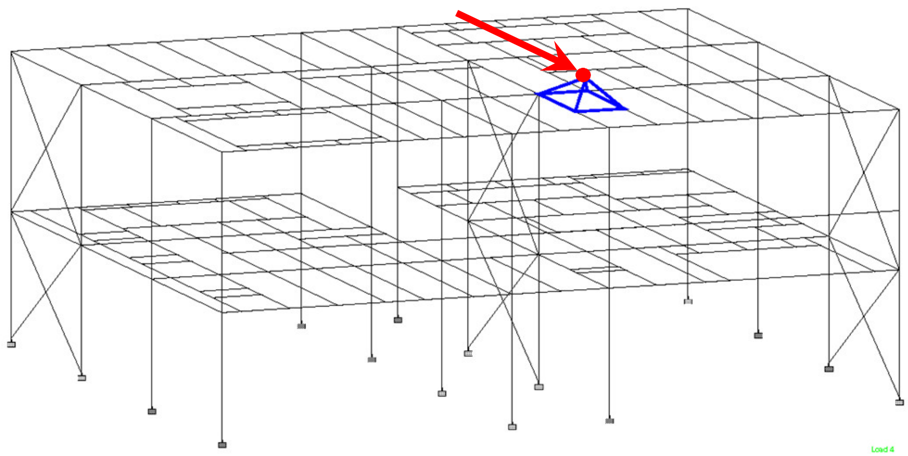
Modeling Techniques



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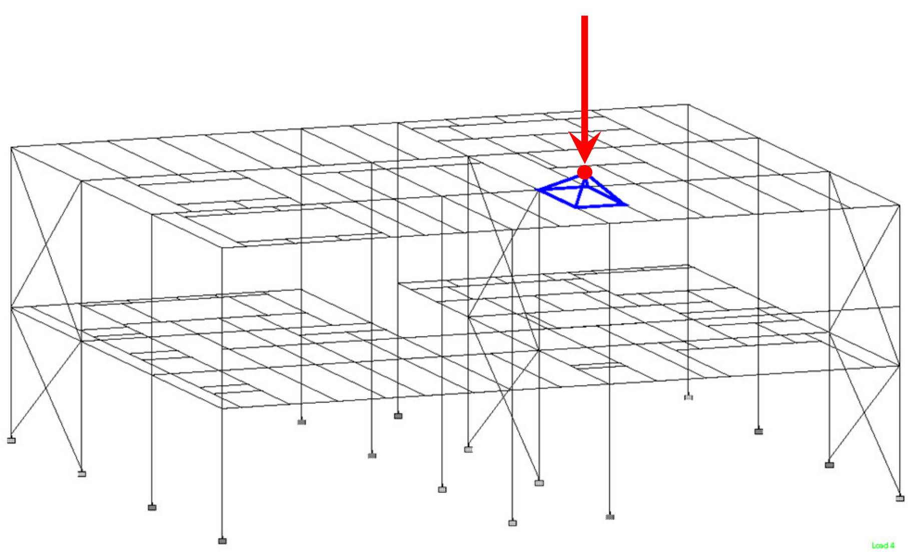
Modeling Techniques



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Machine Supports

Acceptance Criteria

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Acceptance Criteria

The acceptance criteria should consider:

- The risk of damage to the structure
- The risk of damage to non-structural elements
- The risk of damage to the machine
- Proper machine operation
- Production quality
- Human comfort

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Acceptance Criteria

Published criteria limit the amplitude of various vibration parameters.

- Displacement
- Velocity
- Acceleration
- Empirically-derived quantities

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Acceptance Criteria

Available Acceptance Criteria

- Structural damage
  - DIN 4150-3 (German Standard)
  - Bachmann, H. and Ammann, W. (1987), *Vibrations in Structures Induced by Man and Machines*, Structural Engineering Document 3e, International Association for Bridge and Structural Engineering

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Acceptance Criteria

- Machine operation/damage (dependent on the machine type)
  - Manufacturer's performance criteria
  - ISO 10816 (The International Organization for Standardization)
  - ISO 7919 (The International Organization for Standardization)

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Acceptance Criteria

- De Silva, C.W. (2005), *Vibration and Shock Handbook*, CRC Press
- Arya, S.C., O,Neill, M.W. and Pincus, G. (1979), *Design of Structures and Foundations for Vibrating Machines*, Gulf Publishing Company
- Jackson, C. (1979), *The Practical Vibration Primer*, Gulf Publishing Company
- PIP (2017), *Structural Design Criteria*, Document STC01015, Process Industry Practices.

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Acceptance Criteria

- Human response
  - ISO 2631 (The International Organization for Standardization)
  - DIN 4150 -2 (German Standard)
  - AA (2007), *Design of Steel Structures*, Specification 114001, Anglo American
  - AISC Design Guide 11

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Machine Supports

Design

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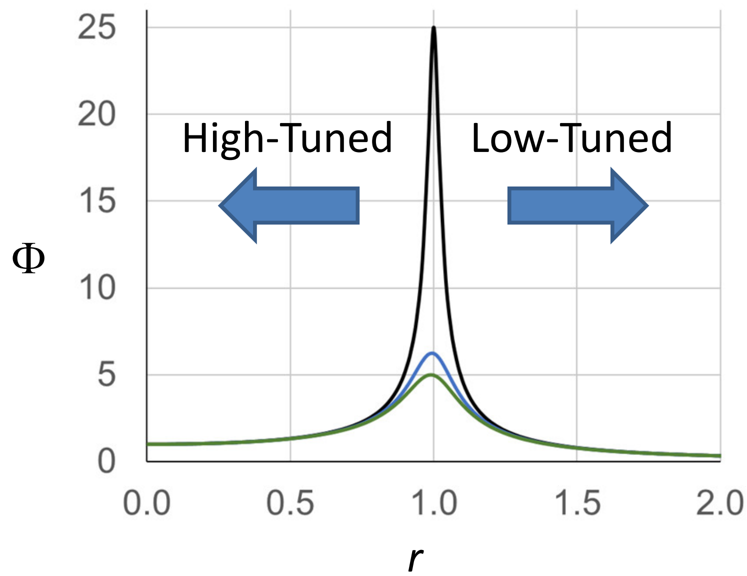
Design

Frequency Tuning

Frequency tuning is used to avoid resonance at operating frequencies.



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Design

High-Tuned Structures

High-tuning is preferred because resonance can be avoided.

Low-Tuned Structures

Resonance cannot be avoided in low-tuned structures because the forcing frequency will pass through the natural frequency during startup and shutdown of the machine.

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Design

Tuning Ratios

To reduce the effects of resonance during operation of the machine, the forcing frequency must be sufficiently separated from the natural frequency.

- High-tuned structures: $r \leq 0.5$ to 0.8
- Low-tuned structures: $r \geq 1.2$ to 4

AA (2007), Design of Steel Structures, Specification 114001, Anglo American, February 12.

Wolf, C.D. (1983), "Structural Design Aspects of Materials Handling Plant," *Proceedings of the Metal Structures Conference*, Brisbane, May 18-20.

End

Machine Supports

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Session 7: Non-building Structures, Part 1

- Section 7.3: Industrial Rack Structures

John Rolfes, PE, SE, CSD Structural Engineers

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SESSION 7: TOPIC 3 - INDUSTRIAL RACK STRUCTURES

LEARNING OBJECTIVES:

- Introduction to Industrial Rack Structures
- Introduction to Typical Rack Framing Systems
- Introduction to the RMI Specification

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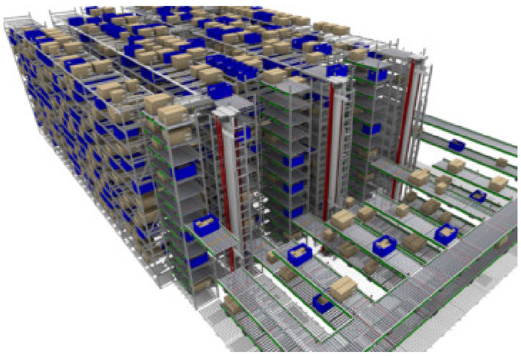
WHAT ARE INDUSTRIAL RACK STRUCTURES?

- Modular steel structure designed for high-density storage of prepackaged pallets, totes or manufactured product.



Focus of our discussion is going to be on ASRS Rack Structures

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ASRS SYSTEMS

ASRS Systems – Automated Storage and Retrieval Systems

- A rack structure in which loading and unloading of the racks is accomplished by a stacker crane, or similar vehicle, without the aid of an on-board operator

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FREESTANDING RACK VS. RACK BUILDNG

Freestanding Rack:
Rack structure located within a separate building structure.

- Commonly Used for ASRS up to 30 ft. tall

Rack Supported Building Structure:
Rack structure that also supports roof and wall cladding

- Commonly Used for ASRS over 30 ft. tall

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ASRS STACKER CRANE

Single Mast
Stacker Crane

Double Mast
Stacker Crane

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ASRS RACK SIZES (Rack Module Sizes)

- Function of Material Stored
  - Pallet Storage - Unit Load (e.g. 4 ft. x 5 ft. palleted material)
    - Rack Frames spaced at 4.5 ft. to 5 ft. centers
    - Double-Wide Racks – store two pallets in one module (rack frames 8 to 9 ft. o.c.)
  - Very Large Items (e.g. auto bodies or boat storage)
    - Module sizes and rack frame spacing significantly larger due to large elements stored
  - Mini Storage Racks (store totes or trays of material)
    - Tote sizes are small, rack frame spacing may be as small as 2 ft. or less on center

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SESSION 7 – TOPIC 3: INDUSTRIAL RACK STRUCTURES

LEARNING OBJECTIVES:

- Introduction to Industrial Rack Structures
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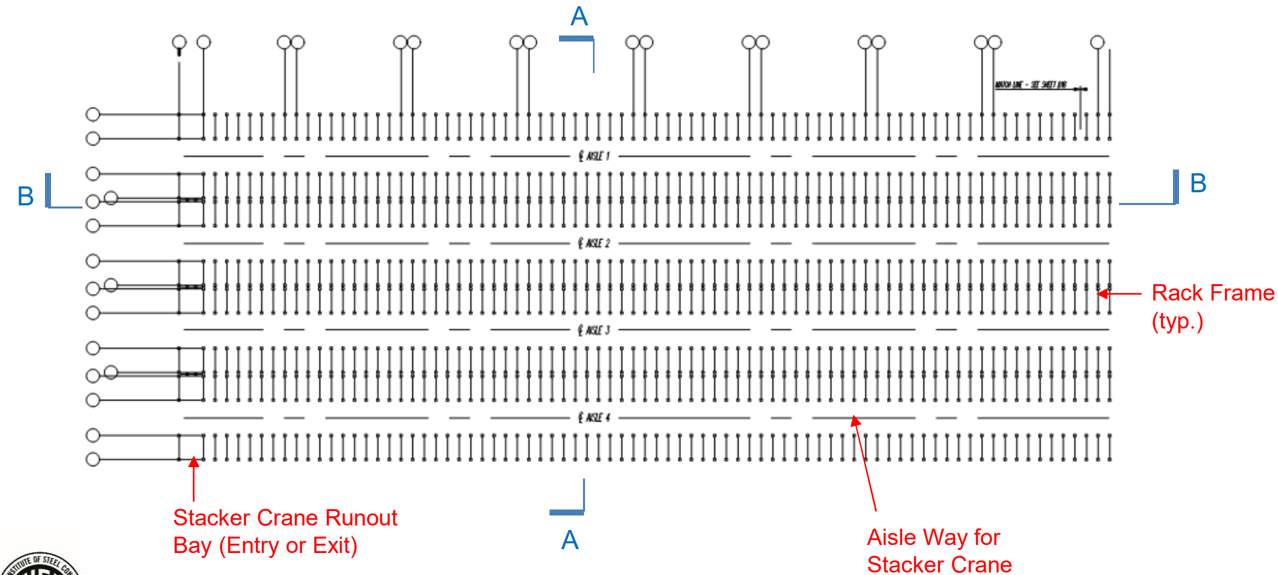
GENERAL ARRANGEMENT – ASRS RACK



Floor Plan

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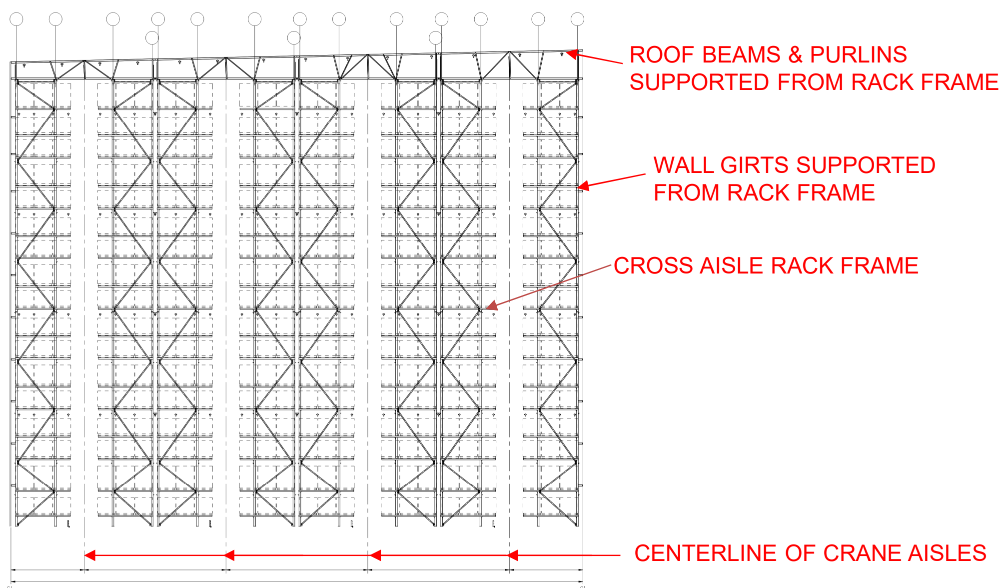
GENERAL ARRANGEMENT – ASRS RACK



Cross Aisle Section A-A

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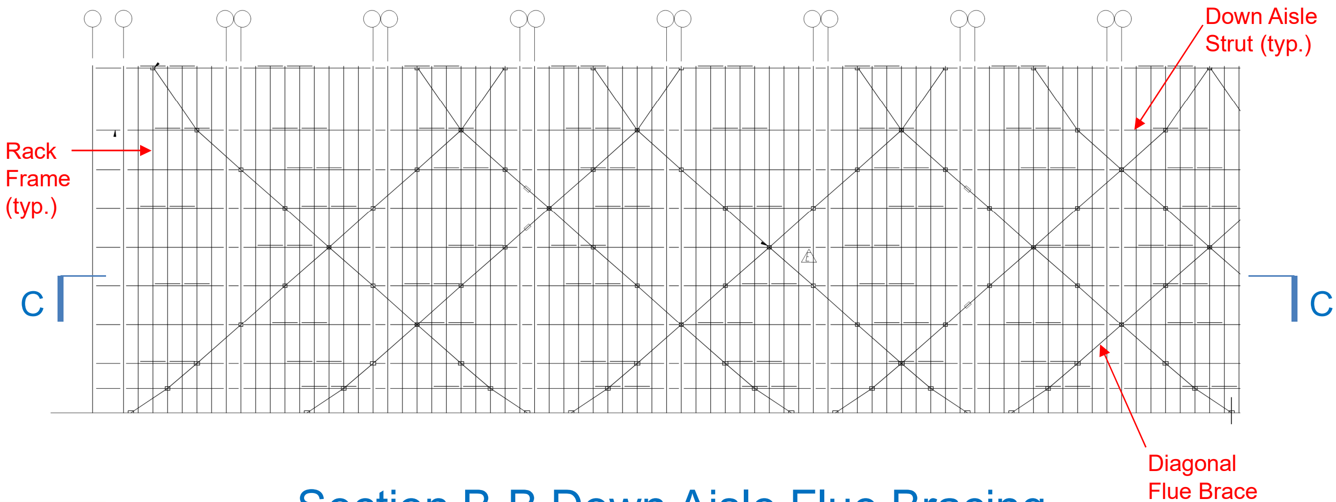
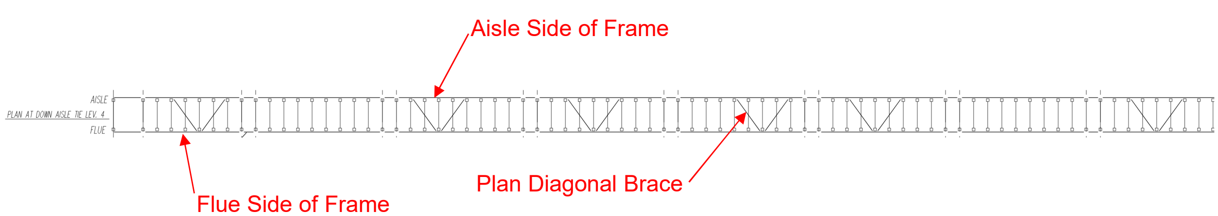
GENERAL ARRANGEMENT – ASRS RACK



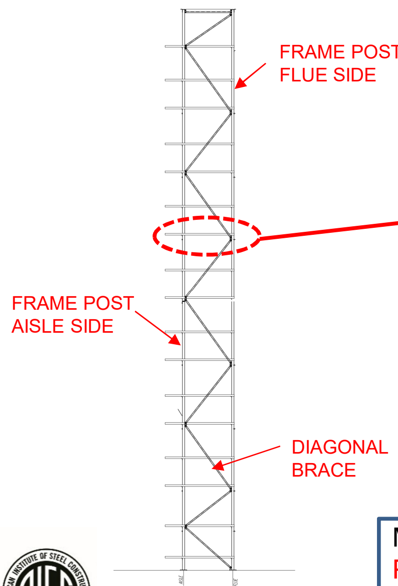
Section B-B Down Aisle Flue Bracing

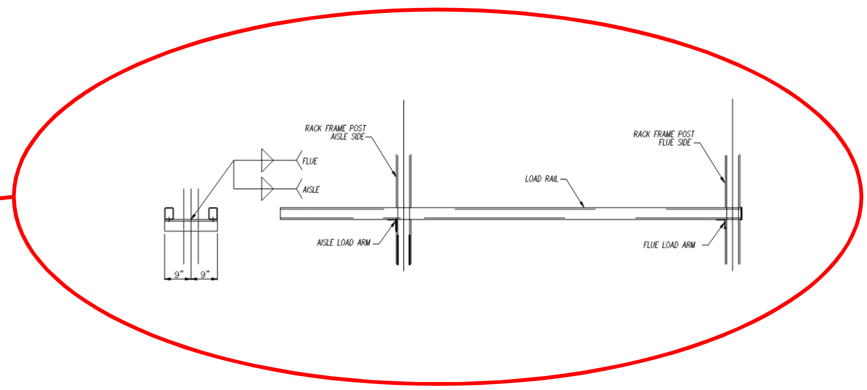
GENERAL ARRANGEMENT – ASRS RACK



Plan Bracing in Each Rack Frame

GENERAL ARRANGEMENT – ASRS RACK





Typical Rack Cross Aisle Frame Section

Material
Posts and Load Rails – HSS (nominal thickness or gage material)
Load arms, Down Aisle Struts, Diagonal Braces – Hot Rolled Angle

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SESSION 7 – TOPIC 3: INDUSTRIAL RACK STRUCTURES

LEARNING OBJECTIVES:

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- Introduction to Typical Rack Framing Systems
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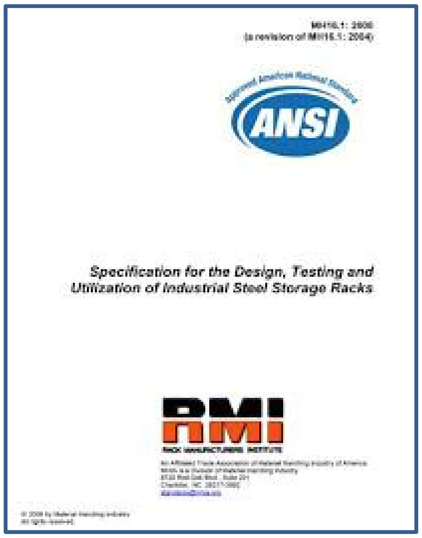
RMI SPECIFICATION



- Rack Manufacturers Institute (RMI) is an independent incorporated trade association affiliated with the Material Handling Industry of America
- First RMI Spec generated in 1964
- Current Edition – 2012
- ANSI Standard MH16.1 first issued in 1974
- Specification has evolved over time with a significant amount of testing and research, much of it done at Cornell University (Professor's Winter and Pekoz)
- RMI Specification is Permissive – Not Mandatory

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RMI SPECIFICATION

- 1997 Edition was expanded to include complete treatment of seismic design considerations so that this specification could be more easily incorporated by reference into various model building codes (including IBC)
- IBC 2018, Section 2209 Steel Storage Racks:

2209.1 Storage racks. The design, testing and utilization of *storage racks* made of cold-formed or hot-rolled steel structural members shall be in accordance with RMI ANSI/MH 16.1. Where required by ASCE 7, the seismic design of *storage racks* shall be in accordance with Section 15.5.3 of ASCE 7.

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KEY REQUIREMENTS OF RMI SPECIFICATION

- **Section 1.3 Applicable Design Specifications**
  - Defers to AISC Specification for Steel Buildings (AISC 360) for design of hot-rolled members
  - Defers to North American Specification for the Design of Cold-Formed Steel Structural Members (AISI S100) for design of cold-formed steel members
- **Section 1.4 Integrity of Rack Installations**
  - The owner shall maintain the structural integrity of the installed rack system by assuring proper operational, housekeeping, and maintenance procedures …
  - Plaque: Owner is responsible for displaying plaque in prominent area that states
    - Maximum Permissible unit load
    - Average Unit Load
    - Maximum Total Load Per Bay
  - Out-of-plumb and Out-of-Straight Limit (top to bottom of post – L/240 (1/2 in. per 10 feet))

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KEY REQUIREMENTS OF RMI SPECIFICATION

- **Section 2. Loadings**
  - Vertical Impact Loads
    - Load Rails, Load Arms and Load Supporting Beams to be designed for vertical impact load equal to 25% of the unit load in the most unfavorable position on the element.
    - Need not be considered for beam deflection checks. Need not be applied to upright frames.
  - Horizontal Loads
    - Rack to be designed for horizontal forces associated with
      - Earthquake Loads
      - Wind Loads
      - Notional Loads (1.5%D + 1.5%P) applied separately in the principal directions of rack framing
      - Lateral forces from the stacker crane (supplied by the crane supplier)
  - Wind Loads
    - Wind loads per ASCE 7
    - Consideration of wind loads during construction on exposed framing using ASCE 37 - may control due to density of framing

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KEY REQUIREMENTS OF RMI SPECIFICATION

- **Section 2. Loadings**
  - Earthquake Loads
    - ASCE 7 Requirements

15.5.3 Storage Racks. Storage racks constructed from steel supported at or below grade shall be designed in accordance with Sections 15.5.3.1 or 15.5.3.2, as applicable, and the requirements in Section 15.5.3.3.

15.5.3.1 Steel Storage Racks. Steel storage racks supported at or below grade shall be designed in accordance with ANSI/RMI MH 16.1 and its force and displacement requirements, except as follows.

- R = 4
- Seismic Mass for cross aisle frame based on maximum unit loads
- Seismic Mass for down aisle bracing based on average unit loads
- Use 67% of the pallet weight in determining seismic mass in recognition that pallets are not positively attached to framing. This is in recognition of friction induced energy dissipation due to relative movement between the rack and pallet during seismic motions. 67% of load is referred to as "dynamically active" portion of the load
- I_e = 1.0 for unoccupied rack storage areas. If open to the general public, I_e =1.5
- Vertical distribution of seismic base shear per Section 12.8.3 of ASCE 7, treating each pallet level as a story level in the structure, exponent "k" = 1.0

KEY REQUIREMENTS OF RMI SPECIFICATION

- **Section 2. Loadings**
  - Load Combinations

LRFD

When the LRFD design method is used, all load factors and combinations shall be as stated in the ASCE 7 [4] except as modified below for racks:

For all rack members:	Critical Limit State
1. $1.4D + 1.2P$	Dead Load
2. $1.2D + 1.4P + 1.6L + 0.5(L_r \text{ or } S \text{ or } R)$	Gravity Load
3. $1.2D + 0.85P + (0.5L \text{ or } 0.5W) + 1.6(L_r \text{ or } S \text{ or } R)$	Snow/Rain
4. $1.2D + 0.85P + 0.5L + 1.0W + 0.5(L_r \text{ or } S \text{ or } R)$	Wind load
5. $(1.2 + 0.2S_{DS})D + (1.2 + 0.2S_{DS})\beta P + 0.5L + \rho E + 0.2S$	Seismic Load
6. $0.9D + 0.9P_{app} + 1.0W$	Wind Uplift
7. $(0.9 - 0.2S_{DS})D + (0.9 - 0.2S_{DS})\beta P_{app} + \rho E$	Seismic Uplift
For load support beams and their connections only:	
8. $1.2D + 1.6L + 0.5(S \text{ or } R) + 1.4P + 1.4I$	Product/Live/Impact

ASD

When the ASD design method is used, all load combinations shall be as stated in the ASCE 7 [4] as modified below for racks.

For all rack members	Critical Limit State
1. $D + P$	Dead Load
2. $D + P + L$	Gravity Load
3. $D + P + (L_r \text{ or } S \text{ or } R)$	Snow/Rain Load
4. $D + 0.75(P + L + (L_r \text{ or } S \text{ or } R))$	Gravity + Snow/Rain Load
5. $(1 + 0.105S_{DS})D + 0.75[(1.4 + 0.14S_{DS})\beta P + L + (L_r \text{ or } S \text{ or } R) + 0.7\rho E]$	Gravity + Seismic
6. $(1 + 0.14S_{DS})D + (0.85 + 0.14S_{DS})\beta P + 0.7\rho E$	Gravity + Seismic
7. $D + 0.75(P + L + (L_r \text{ or } S \text{ or } R) + 0.6W)$	Gravity + Wind
8. $0.6D + 0.6P_{app} + 0.6W$	Wind Uplift
9. $(0.6 - 0.14S_{DS})D + (0.6 - 0.14S_{DS})\beta P_{app} + 0.7\rho E$	Seismic Uplift
For load support beams and their connections only:	
10. $D + L + 0.5(S \text{ or } R) + 0.88P + I$	Shelf + Impact

where:

D = Dead load
L = Live load other than the pallets or products stored on the racks. (Example: floor loading from rack supported platforms)
L_r = Roof live load as determined in accordance with ASCE 7 [4] Section 4.9
S = Snow load as determined in accordance with ASCE 7 [4] Chapter 7
R = Rain load as determined in accordance with ASCE 7 [4] Chapter 8
W = Wind load
E = Earthquake load
I = Impact loading on a shelf (Section 2.3)
P = Maximum load from pallets or products stored on the racks.
P_{app} = for seismic uplift, the portion of pallet or product load that is used to compute the seismic base shear.

for uplift due to wind, only pallet loads that must be present to develop the lateral wind forces shall be considered in P_{app}. P_{app}

RACK DAMAGE

Rack damage is generally associated with:

1. Collision between the stacker crane and/or pallet load and the rack structure due to miscalibration of the automated stacker crane with the geometry of the "as built" rack structure. (Due to poor fabrication/erection tolerances or foundation settlement)
2. Collision between forklift trucks and lower posts of rack structure
3. Fatigue
4. Poor design – not acknowledging eccentricities in connected rack structure
5. Loosening of bolts

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RACK DAMAGE

Periodic inspection and maintenance is required

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SESSION 7 – TOPIC 3: INDUSTRIAL RACK STRUCTURES

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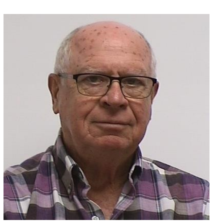
Night School 23: Topics on Industrial Building Design and Design of Non-Building Structures

Session 7: Non-building Structures, Part 1

- Section 7.4: Steel Piles



Robert (Bob) MacCrimmon, P.Eng.
Senior Civil/Structural Specialist
Hatch Ltd.

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Introduction

- This presentation is meant to address applications of structural steel to:
- Deep Foundations
- Retaining Structures

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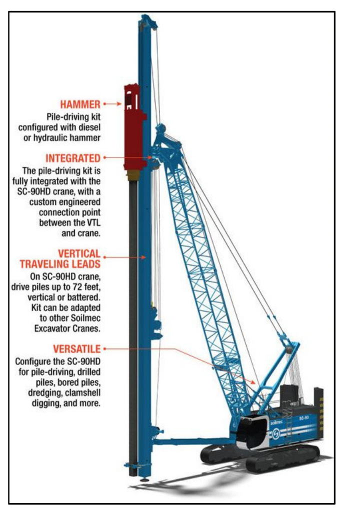
Deep Foundations

- Driven pile-supported foundations
- There are different types of hammers
- There are different pile sections to consider; H, pipe



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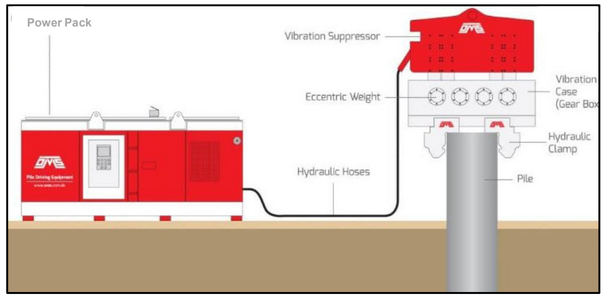
Deep Foundations cont'd

- Non-driven pile supported foundations



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Codes and Standards

- Your local building code
- ASCE 7 for loads, information on seismic, liquefaction

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Codes and Standards cont'd

- ASCE

Standard Guidelines for the Design and Installation of Pile Foundations

ASCE

DOWNLOAD TOOLS SHARE

Standard Guidelines for the Design and Installation of Pile Foundations provides a guideline for an engineering approach to the design and subsequent installation of pile foundations. The purpose is to furnish a rational basis for this process, taking into account published model building codes and general standards of practice. Topics include: administrative requirements; pile shaft strength requirements: soil\-pile interface strength requirements and capacity; design loads; design stresses; construction and layout guidelines for pile design; and installation guidelines for pile construction.

This Standard includes information on applicable standards from ASTM, AWPA, and ACI, as well as an appendix on partial factors of safety.

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Codes and Standards cont'd

- USACE

EM 1110-2-2906
15 January 91

US Army Corps of Engineers

ENGINEERING AND DESIGN

Design of Pile Foundations

ENGINEER MANUAL

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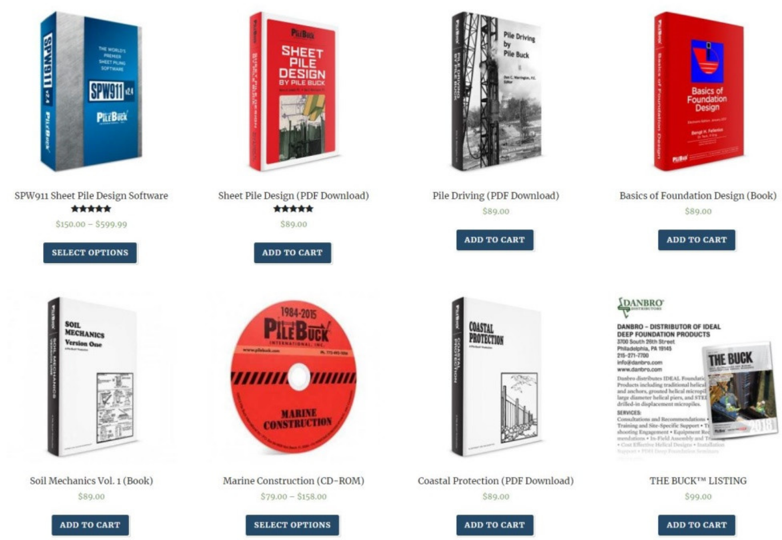
Useful References

- AASHTO
- Pile Buck
- Nucor Skyline



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Geotechnical Considerations

You will need a Geotechnical Report with recommendations including but not limited to:

- Suitable pile sections
- Resistance to axial (including uplift) and horizontal loads
- Settlement potential
- Special considerations for end bearing
- Need for load testing
- Corrosion considerations

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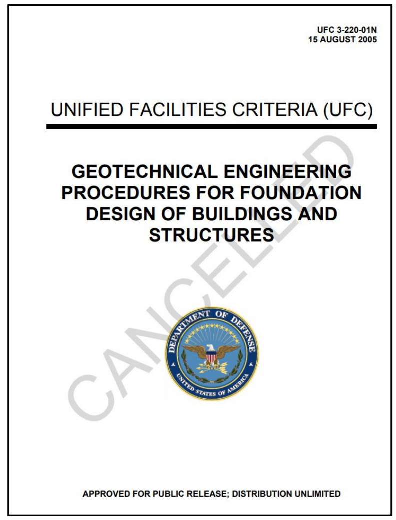
Geotechnical Considerations cont'd

- Pile driving criteria (set)
- Unusual conditions such as potential for liquefaction, downdrag
- USACE is a useful reference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GEOTECHNICAL ENGINEERING PROCEDURES FOR FOUNDATION DESIGN OF BUILDINGS AND STRUCTURES

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Useful Tips

- Most any soil will prevent buckling (beware liquefaction)
- Batter piles frowned on for seismic events
- Consider full structural capacity of the pile after suitable corrosion allowance (check building code)
- Corrosion not usually a consideration where buried
- Pile tip reinforcing at rock surface
- Pile caps not usually desirable or necessary if embedded 6 inches or more-see AASHTO and other available info
- Consideration of repeated loads

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That’s it for Deep Foundations

- Now we’ll discuss Retaining Structures

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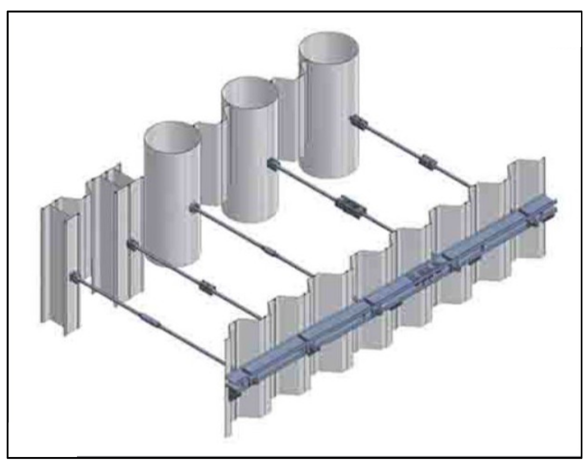
Tied Back Retaining Walls

- Commonly used for waterfront structures
- Wall (embedded)
- Ties
- Anchor Wall
- Wales (walers)
- Shapes may be hot rolled, formed, welded



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Typical Waterfront Structure

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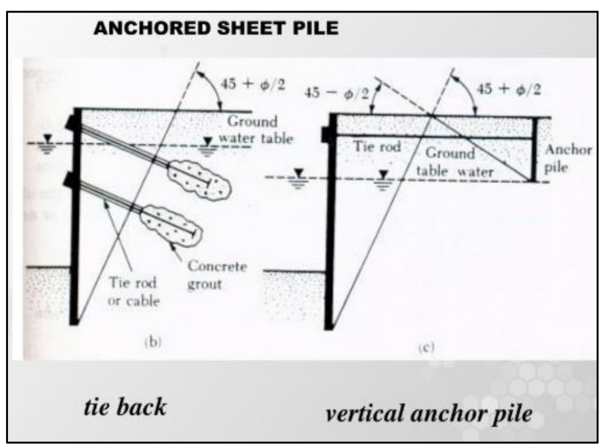
Tied Back Retaining Walls cont'd

- Typical Cross Section



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Soldier Piles

- May be cantilever or tied back
- Occasionally sheet pile sections spanning horizontally have been used instead of timbers

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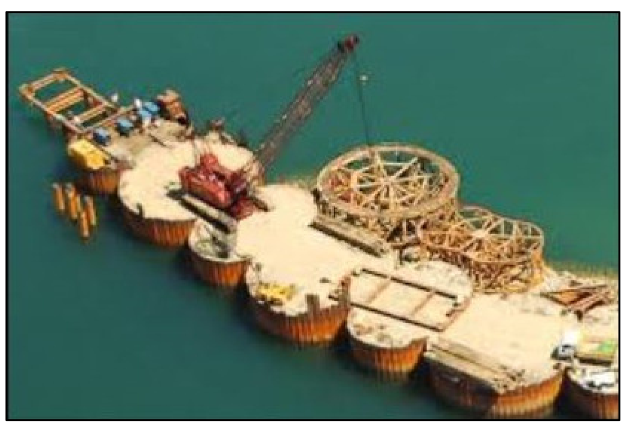
Cellular Cofferdam

- Interlocking flat sheets
- Templates are used



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Codes and Standards

- Check your local building code but since these structures are not "buildings" they are not likely to be covered
- If it is associated with a bridge, consult AASHTO
- ASCE 61-14 is a Standard for Seismic Design of Piers and Wharves

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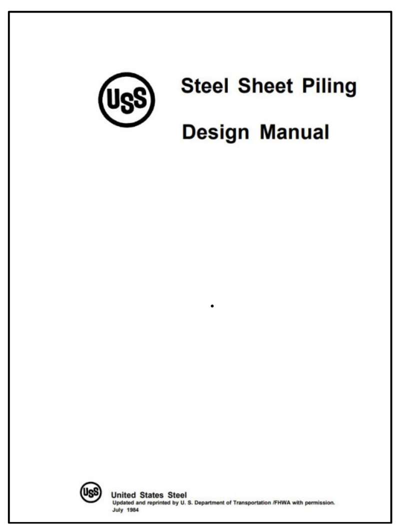
Codes and Standards cont'd

- The USS Steel Sheet Piling Manual has been around for many years



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USACE Manuals

EM 1110-2-2504
31 March 1994

US Army Corps
of Engineers

ENGINEERING AND DESIGN

Design of Sheet Pile Walls

ENGINEER MANUAL

EM 1110-2-2503
29 September 1989

US Army Corps
of Engineers

ENGINEERING AND DESIGN

Design of Sheet Pile Cellular Structures

ENGINEER MANUAL

107

Codes and Standards, cont'd

- Technical Supplement 14R published by the United States Dept of Agriculture

Technical Supplement 14R

Design and Use of Sheet Pile Walls in Stream Restoration and Stabilization Projects

(210-VI-NEH, August 2007)

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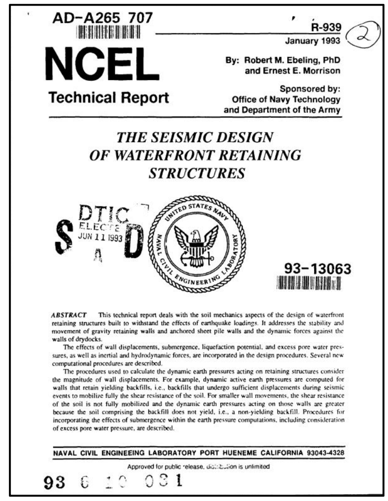
Seismic Design Reference

- NCEL AD-A265 707 by Ebeling and Morrison is a useful reference and has worked examples



AD-A265 707

R-939

January 1993

NCEL
Technical Report

By: Robert M. Ebeling, PhD
and Ernest E. Morrison

Sponsored by:
Office of Navy Technology
and Department of the Army

THE SEISMIC DESIGN OF WATERFRONT RETAINING STRUCTURES

DTIC ELECTE JUN 11 1993

93-13063

ABSTRACT This technical report deals with the soil mechanics aspects of the design of waterfront retaining structures built to withstand the effects of earthquake loadings. It addresses the stability and movement of gravity retaining walls and anchored sheet pile walls and the dynamic forces against the walls of drydocks.

The effects of wall displacements, submergence, liquefaction potential, and excess pore water pressures, as well as inertial and hydrodynamic forces, are incorporated in the design procedures. Several new computational procedures are described.

The procedures used to calculate the dynamic earth pressures acting on retaining structures consider the magnitude of wall displacements. For example, dynamic active earth pressures are computed for walls that retain yielding backfills, i.e., backfills that undergo sufficient displacements during seismic events to mobilize fully the shear resistance of the soil. For smaller wall movements, the shear resistance of the soil is not fully mobilized and the dynamic earth pressures acting on those walls are greater because the soil comprising the backfill does not yield, i.e., a non-yielding backfill. Procedures for incorporating the effects of submergence within the earth pressure computations, including consideration of excess pore water pressure, are described.

NAVAL CIVIL ENGINEEING LABORATORY PORT HUENEME CALIFORNIA 93043-4328

Approved for public release, distribution is unlimited

93 6 10 031

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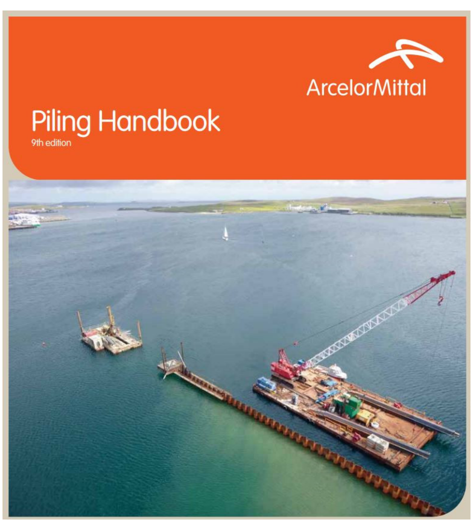
Useful references and Design Aids



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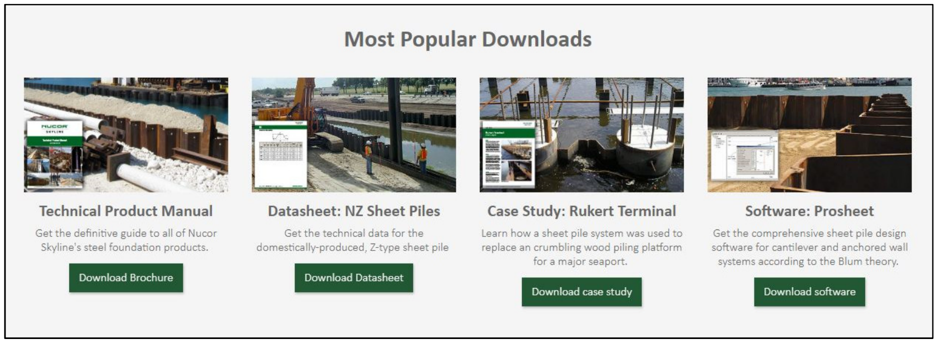
Useful References cont'd

- Nucor Skyline



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Geotechnical Considerations

You will need a Geotechnical Report with recommendations including but not limited to:

- Soils properties
- Settlement potential
- Seismic design criteria
- Potential for liquefaction
- Corrosion considerations during life of the structure

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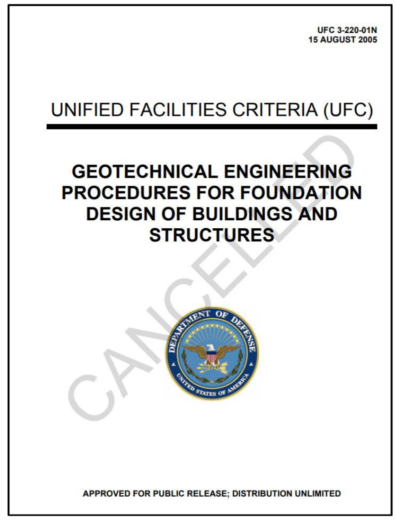
Geotechnical Considerations cont'd

- Pile driving methods
- USACE is a useful reference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Design Criteria

- Every project should have a design criteria document agreed to by all
- Some important topics are listed on the right

- Design description
- Useful life
- Type of construction
- Codes and Standards
- Environmental conditions
- Materials of construction
- Design methodology

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Construction Specifications

- There are lots of model specifications available on the web including USACE and State Department of Transportation documents

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The End

- Thank you for tuning in!

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