



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

Thank you for joining our live  
webinar. We will begin shortly.  
Please standby.



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




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Stronger.  
Steel.**

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## AISC Live Webinars

### 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.



## AISC Live Webinars

### 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



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

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

Four Topics      Four Speakers



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



7.1 Pipe Racks

7.2 Equipment Supports



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



7.3 High Density Rack Storage

7.4 Steel Piles



## 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.



## 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)
- $T_m$  = (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.



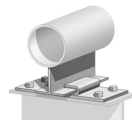
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## PIPE RACKS: THERMAL LOADS

Friction Forces at piping supports (PIP):

- Consider steel to steel friction  $\mu = .4$
- 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.

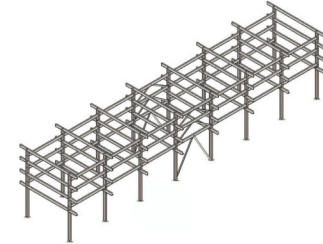


Fig. 2. Typical four-level pipe rack consisting of eight transverse frames connected by longitudinal struts.

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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

Redundancy:

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

- $\rho=1.0$

SDC D or higher:

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



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

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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 <sub>r</sub> + L (or .5W)	$1.2(D_s + D_o) + 1.2T_s + 1.0T_t + 1.6S + .5L$ $1.2(D_s + D_o) + 1.2T_s + 1.6S + .5W$

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

### Session 7: Non-building Structures, Part 1

- Section 7.2: Machine Supports



Bo Dowswell, PE, PhD, Arc International LLC



## 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

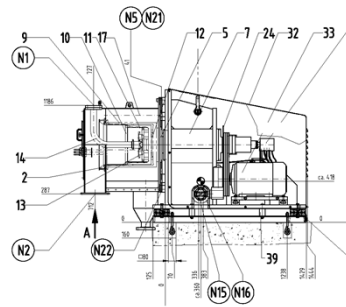


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### Introduction

#### 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*, 3<sup>rd</sup> Edition, Van Nostrand Reinhold



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### Machine Supports

### Design Objectives



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### 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



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## 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

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

$N$  = machine speed, rpm



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## Natural Frequencies

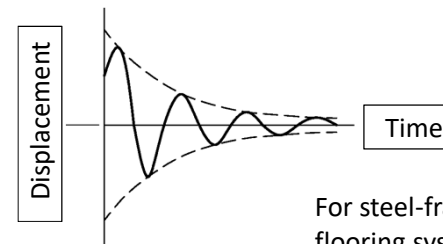
- The natural frequencies are the free (no external force) vibration frequencies of a system
- Usually, the fundamental (lowest) natural frequency is critical; however, the higher-mode natural frequencies can also be important
- Natural frequencies can be calculated using a modal analysis in a 3-D finite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



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## Damping

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



For steel-framed structures and flooring systems:  $\beta = 0.01$  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  $\Phi = \frac{1}{\sqrt{(1-r^2)^2 + (2\beta r)^2}}$

$F_o$  = free force of the machine

$r$  = ratio of the forcing frequency to the natural frequency of the system,  $\omega/\omega_n$  (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.

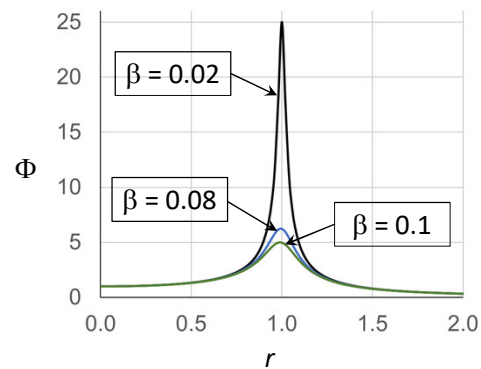
At resonance,  $r = 1$ , resulting in a dynamic magnification factor of

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



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### SDOF Systems



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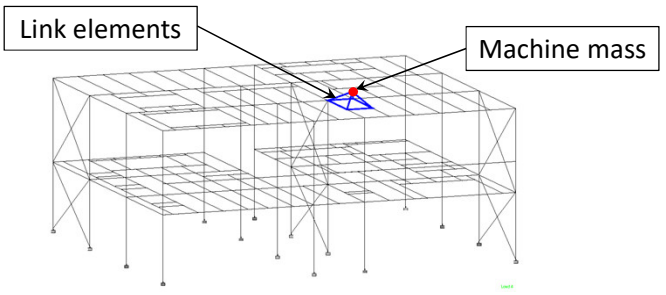
### Machine Supports Modeling Techniques



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### Modeling Techniques

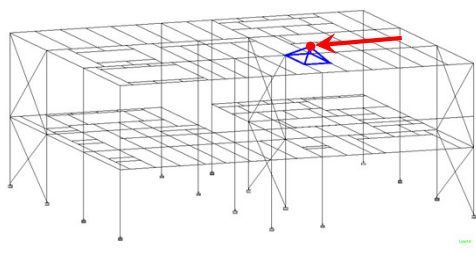
Link elements can be used to connect the machine mass to the structure



The diagram shows a 3D wireframe model of a steel frame structure. A blue triangular mass is positioned on the top surface of the frame. Two red lines, representing link elements, connect this mass to the structure. A callout box labeled "Link elements" points to these red lines, and another callout box labeled "Machine mass" points to the blue triangle. The AISC logo is in the bottom left, and the number 49 is in the bottom right.

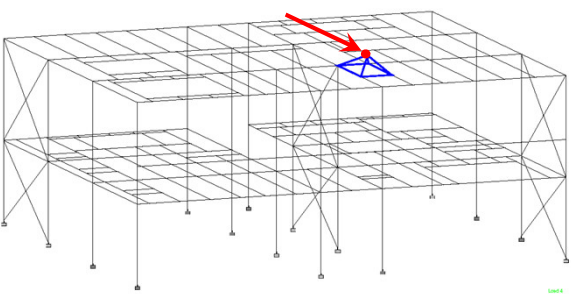
### Modeling Techniques

Machine forces are applied in the direction of interest



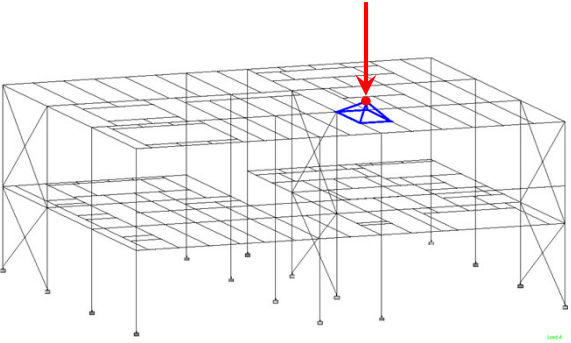
The diagram shows the same steel frame model as slide 49. A blue triangular mass is on the top surface. A red arrow points horizontally to the left from the mass, indicating the direction of an applied force. The AISC logo is in the bottom left, and the number 50 is in the bottom right.

### Modeling Techniques



The diagram shows the same steel frame model. A blue triangular mass is on the top surface. A red arrow points diagonally downwards and to the right from the mass, indicating the direction of an applied force. The AISC logo is in the bottom left, and the number 51 is in the bottom right.

### Modeling Techniques



The diagram shows the same steel frame model. A blue triangular mass is on the top surface. A red arrow points vertically downwards from the mass, indicating the direction of an applied force. The AISC logo is in the bottom left, and the number 52 is in the bottom right.

## 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.

The graph plots displacement  $\Phi$  on the y-axis (0 to 25) against frequency ratio  $r$  on the x-axis (0.0 to 2.0). A sharp resonance peak is centered at  $r = 1.0$ . A blue arrow labeled 'High-Tuned' points left towards  $r = 0.5$ , and another blue arrow labeled 'Low-Tuned' points right towards  $r = 1.5$ .

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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  $4$

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### End

#### Machine Supports

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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 7.3: Industrial Rack Structures



John Rolfes, PE, SE, CSD Structural Engineers



## SESSION 7: TOPIC 3 - INDUSTRIAL RACK STRUCTURES

### LEARNING OBJECTIVES:

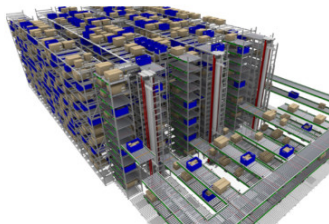
- Introduction to Industrial Rack Structures
- Introduction to Typical Rack Framing Systems
- Introduction to the RMI Specification



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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 BUILDING



**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



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Double Mast  
Stacker Crane

### ASRS RACK SIZES (Rack Module Sizes)

- Function of Material Stored
  - Pallet Storage - Unit Load (e.g. 4 ft. x 5 ft. palletized 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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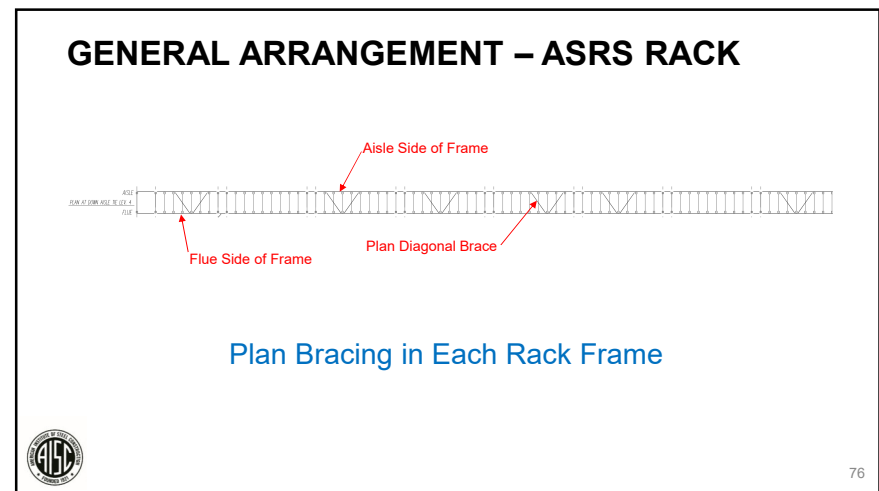
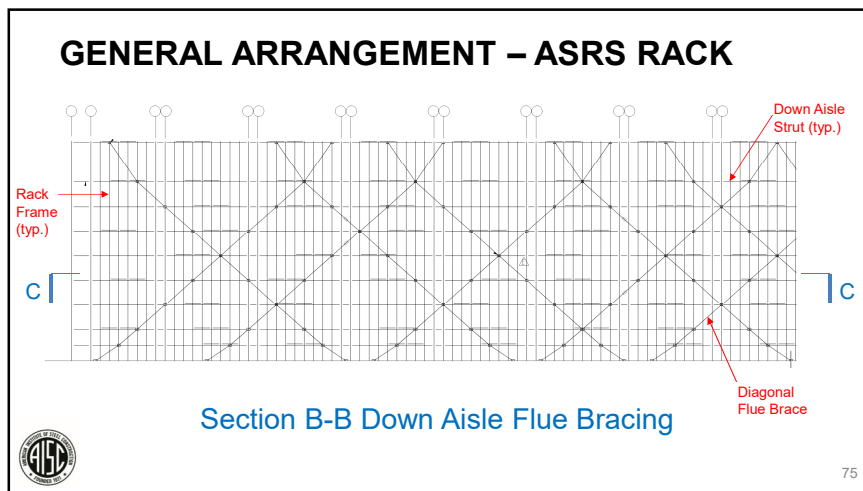
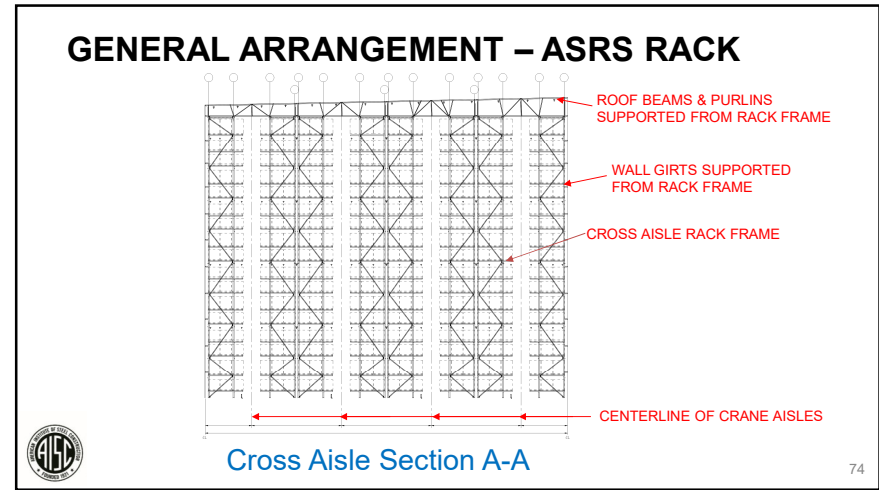
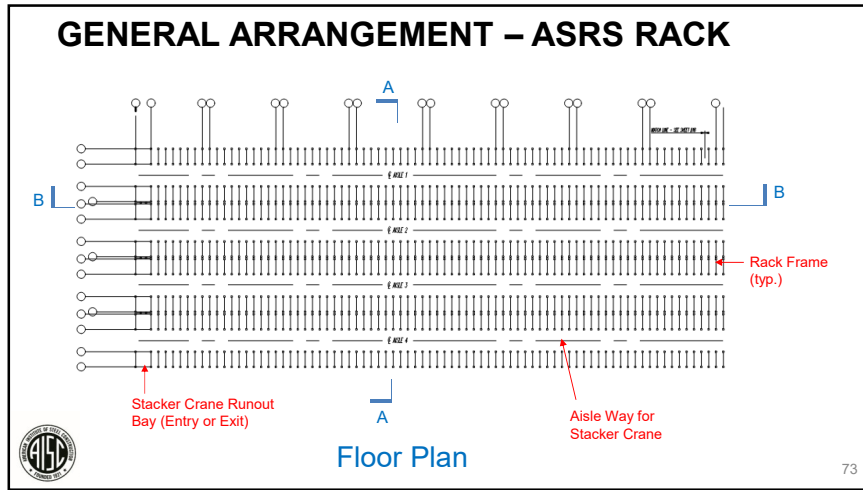
### SESSION 7 – TOPIC 3: INDUSTRIAL RACK STRUCTURES

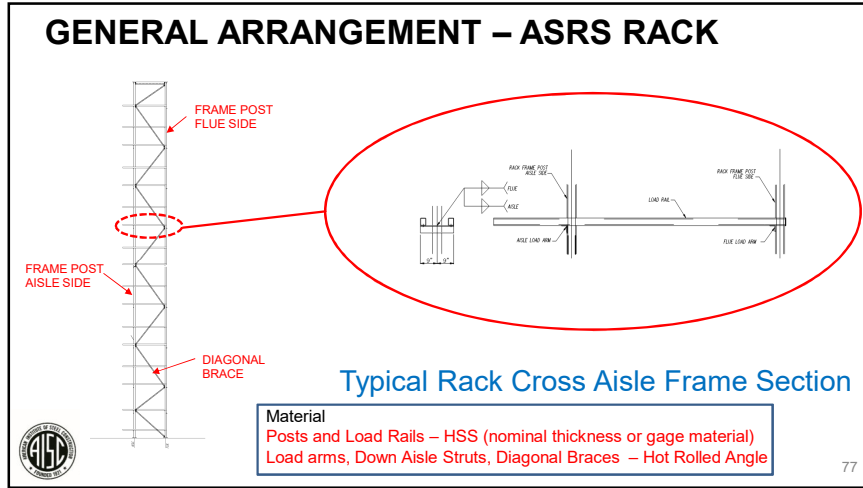
#### LEARNING OBJECTIVES:

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



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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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### 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 ANSIRMI 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
      - $I_p = 1.0$  for unoccupied rack storage areas. If open to the general public,  $I_p = 1.5$
      - 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



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## 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. $1.2D + 1.4P + 1.6L + 0.5(L \text{ or } S \text{ or } R)$	Gravity Load
3. $1.2D + 0.85P + (0.5L \text{ or } 0.5W) + 1.6(L \text{ or } S \text{ or } R)$	Snow/Rain
4. $1.2D + 0.85P + 0.5L + 1.0W + 0.5(L \text{ or } S \text{ or } R)$	Wind load
5. $(1.2 + 0.2S_{se})D + (1.2 + 0.2S_{se})BP + 0.5L + pE + 0.2S$	Seismic Load
6. $0.9D + 0.9P_{se} + 1.0W$	Wind Uplift
7. $(0.9 - 0.2S_{se})D + (0.9 - 0.2S_{se})BP_{se} + pE$	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. $D + P + (L \text{ or } S \text{ or } R)$	Snow/Rain Load
4. $D + 0.75P + L + (L \text{ or } S \text{ or } R)$	Gravity + Snow/Rain Load
5. $(1 + 0.105S_{se})D + 0.75(1.4 + 0.14S_{se})BP + L + (L \text{ or } S \text{ or } R) + 0.7pE$	Gravity + Seismic
6. $(1 + 0.14S_{se})D + (0.85 + 0.14S_{se})BP + 0.7pE$	Gravity + Seismic
7. $D + 0.75P + L + (L \text{ or } S \text{ or } R) + 0.6W$	Gravity + Wind
8. $0.9D + 0.9P_{se} + 0.6W$	Wind Uplift
9. $(0.8 - 0.14S_{se})D + (0.6 - 0.14S_{se})BP_{se} + 0.7pE$	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<sub>r</sub> = Roof live load as determined in accordance with ASCE 7 [4] Section 4.8  
 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<sub>se</sub> = Maximum load from pallets or products stored on the racks.  
 P<sub>se</sub> = 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<sub>se</sub>. P<sub>se</sub>



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## 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.



## Introduction

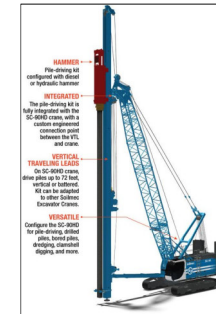
- This presentation is meant to address applications of structural steel to:
- Deep Foundations
- Retaining Structures



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## Deep Foundations

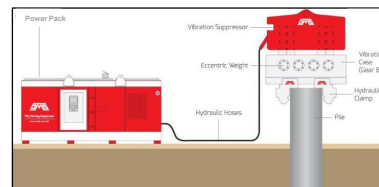
- Driven pile-supported foundations
- There are different types of hammers
- There are different pile sections to consider; H, pipe



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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.*

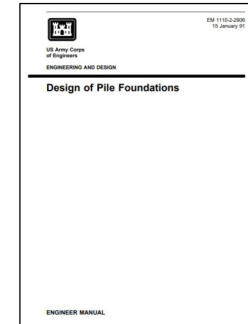
This Standard includes information on applicable standards from ASTM, AWWA, and ACI, as well as an appendix on partial factors of safety.



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## Codes and Standards cont'd

- USACE



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## Useful References

- AASHTO
- Pile Buck
- Nucor Skyline

<p>SPW101 Sheet Pile Design Software \$24.00 - \$109.99 SELECT OPTIONS</p>	<p>Sheet Pile Design (PDF Download) \$24.00 ADD TO CART</p>	<p>Pile Driving (PDF Download) \$24.00 ADD TO CART</p>	<p>Basics of Foundation Design (Book) \$24.00 ADD TO CART</p>
<p>Soil Mechanics Vol. 1 (Book) \$24.00 ADD TO CART</p>	<p>Marine Construction (CD-ROM) \$24.00 - \$109.99 SELECT OPTIONS</p>	<p>Coastal Protection (PDF Download) \$24.00 ADD TO CART</p>	<p>THE BUCK™ LISTING \$24.00 ADD TO CART</p>



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## Geotechnical Considerations

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

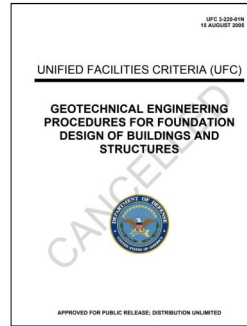
- Suitable pile sections
- Resistance to axial (including uplift) and horizontal loads
- Settlement potential
- Special considerations for end bearing
- Need for load testing
- Corrosion considerations



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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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## 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

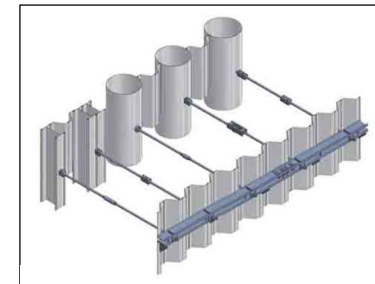
- Now we'll discuss Retaining Structures



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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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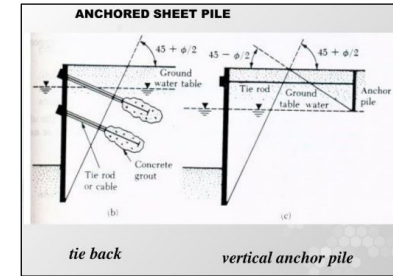
### Typical Waterfront Structure



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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

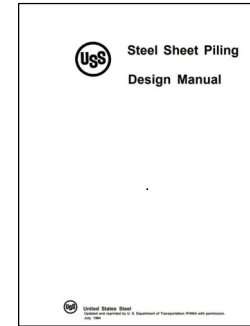
- Check your local building code but since these structures are not “buildings” they are not likely to be covered
- If it is associated with a bridge, consult AASHTO
- ASCE 61-14 is a Standard for Seismic Design of Piers and Wharves



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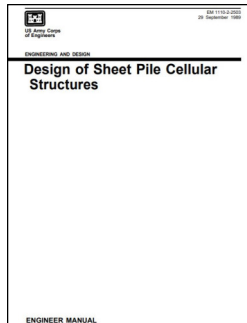
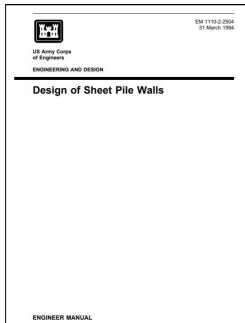
### Codes and Standards cont'd

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



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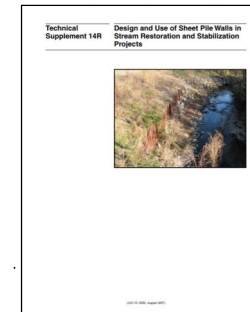
### USACE Manuals



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### Codes and Standards, cont'd

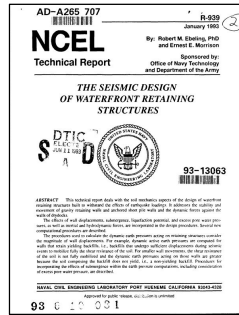
- Technical Supplement 14R published by the United States Dept of Agriculture



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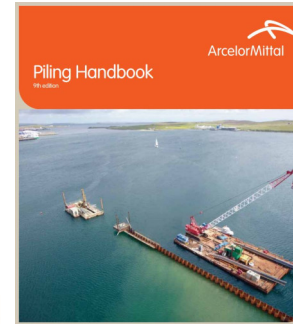
## Seismic Design Reference

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



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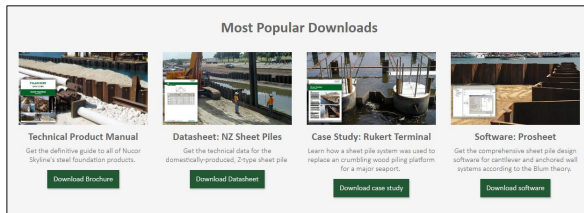
## Useful references and Design Aids



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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:

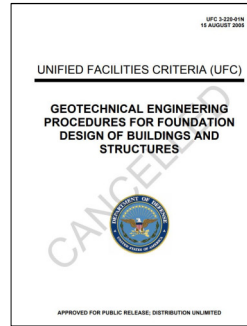
- Soils properties
- Settlement potential
- Seismic design criteria
- Potential for liquefaction
- Corrosion considerations during life of the structure



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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!

