Reinforced Concrete Design
EDUCATION MODULE

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# Guide for Instructors

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Learning Objectives

• Explain the Prevention through Design (PtD) concept.

• List reasons why project owners may wish to incorporate PtD in their projects.

• Identify workplace hazards and risks associated with design decisions and recommend design alternatives to alleviate or lessen those risks.
Overview

• PtD Concept

• Introduction to Reinforced Concrete

• Reinforced Concrete Design Process, Construction Activities, and Safety Hazards

• Reinforced Concrete PtD Examples

• Case Study
Occupational Safety and Health

- Occupational Safety and Health Administration (OSHA) [www.osha.gov](http://www.osha.gov)
  - Part of the Department of Labor
  - Assures safe and healthful workplaces
  - Sets and enforces standards
  - Provides training, outreach, education, and assistance
  - State regulations possibly more stringent

- National Institute for Occupational Safety and Health (NIOSH) [www.cdc.gov/niosh](http://www.cdc.gov/niosh)
  - Part of the Department of Health and Human Services, Centers for Disease Control and Prevention
  - Conducts research and makes recommendations for the prevention of work-related injury and illness
Construction Hazards

- Cuts
- Electrocution
- Falls
- Falling objects
- Heat/cold stress
- Musculoskeletal disease
- Tripping

[BLS 2006; Lipscomb et al. 2006]
Construction is one of the most hazardous occupations. This industry accounts for

- 8% of the U.S. workforce, but 20% of fatalities
- About 1,100 deaths annually
- About 170,000 serious injuries annually

[CPWR 2008]

- Main finding: design contributes significantly to work-related serious injury
- 37% of workplace fatalities are due to design-related issues
- In another 14% of fatalities, design-related issues may have played a role

[Driscoll et al. 2008]
Accidents Linked to Design

- 22% of 226 injuries that occurred from 2000 to 2002 in Oregon, Washington, and California were linked partly to design [Behm 2005]

- 42% of 224 fatalities in U.S. between 1990 and 2003 were linked to design [Behm 2005]

- In Europe, a 1991 study concluded that 60% of fatal accidents resulted in part from decisions made before site work began [European Foundation for the Improvement of Living and Working Conditions 1991]

- 63% of all fatalities and injuries could be attributed to design decisions or lack of planning [NOHSC 2001]
Falls

• Number one cause of construction fatalities
  – in 2010, 35% of 751 deaths
    www.bls.gov/news.release/cfoi.t02.htm

• Common situations include making connections, walking on beams or near openings such as floors or windows

• Fall protection is required at height of 6 feet above a surface [29 CFR 1926.760].

• Common causes: slippery surfaces, unexpected vibrations, misalignment, and unexpected loads
Death from Injury

Number of deaths per 100,000 full-time workers

- Ironworker: 61.6
- Electrical power-line installer: 58.6
- Roofer: 32.1
- Truck driver: 23.5
- Construction Laborer: 21.5
- Welder: 20.3
- Op. Engineer: 16.0
- Helper: 15.6
- Excavating Operator: 14.3
- Foreman: 11.5
- Electrician: 10.4
- Brick Mason: 8.8
- Painter: 8.1
- Heating: 7.8
- Construction manager: 7.7
- Plumber: 7.2
- Carpenter: 6.9
- Drywall: 4.9
- All construction: 10.8

Rate of work-related deaths from injuries, selected construction occupations, 2003–2009 average

Full-time equivalent (FTE) is defined as 2,000 hours worked per year.

[BLS 2003–2009; CPWR 2008]
What is Prevention through Design?

Eliminating or reducing work-related hazards and illnesses and minimizing risks associated with

- Construction
- Manufacturing
- Maintenance
- Use, reuse, and disposal of facilities, materials, and equipment
Hierarchy of Controls per ANSI/AIHA Z10-2005

- **BEST**
  - **ELIMINATION**
    - Design it out
  - **SUBSTITUTION**
    - Use something else
  - **ENGINEERING CONTROLS**
    - Isolation and guarding
  - **ADMINISTRATIVE CONTROLS**
    - Training and work scheduling
  - **PERSONAL PROTECTIVE EQUIPMENT**
    - Last resort

- **Control effectiveness**
- **Business value**
Personal Protective Equipment (PPE)

• Last line of defense against injury
• Examples:
  – Hard hats
  – Steel-toed boots
  – Safety glasses
  – Gloves
  – Harnesses

OSHA [www.osha.gov/Publications/osha3151.html](http://www.osha.gov/Publications/osha3151.html)
PtD Process
[Hecker et al. 2005]

- Establish PtD expectations
- Include construction and operation perspective
- Identify PtD process and tools

Design team meeting

Design

Internal review

External review

Issue for construction

- Owner
- Architect
- Project Manager
- Health & Safety Professional

- Trade contractor
- Health & Safety review

- Quality Assurance/Quality Control
- Health & Safety review
- Value Engineering review

- Focused Health & Safety review
- Owner review
## Integrating Occupational Safety and Health with the Design Process

<table>
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<th>Activities</th>
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<tr>
<td>Conceptual design</td>
<td>Establish occupational safety and health goals, identify occupational hazards</td>
</tr>
<tr>
<td>Preliminary design</td>
<td>Eliminate hazards, if possible; substitute less hazardous agents/processes; establish risk minimization targets for remaining hazards; assess risk; and develop risk control alternatives. Write contract specifications.</td>
</tr>
<tr>
<td>Detailed design</td>
<td>Select controls; conduct process hazard reviews</td>
</tr>
<tr>
<td>Procurement</td>
<td>Develop equipment specifications and include in procurements; develop “checks and tests” for factory acceptance testing and commissioning</td>
</tr>
<tr>
<td>Construction</td>
<td>Ensure construction site safety and contractor safety</td>
</tr>
<tr>
<td>Commissioning</td>
<td>Conduct “checks and tests,” including factory acceptance; pre–start up safety reviews; development of standard operating procedures (SOPs); risk/exposure assessment; and management of residual risks</td>
</tr>
<tr>
<td>Start up and occupancy</td>
<td>Educate; manage changes; modify SOPs</td>
</tr>
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</table>
Safety Payoff During Design

[Adapted from Szymberski 1997]
PtD Process Tasks

[Adapted from Toole 2005; Hinze and Wiegand 1992]

- Perform a hazard analysis
- Incorporate safety into the design documents
- Make a CAD model for member labeling and erection sequencing

Photo courtesy of Thinkstock
Designer Tools

- Checklists for construction safety [Main and Ward 1992]
- Construction safety tools from the UK or Australia
  - Construction Hazard Assessment Implication Review (CHAIR) [NOHSC 2001]
## Example Checklist

<table>
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<th>Description</th>
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<tr>
<td><strong>1.0</strong></td>
<td><strong>Structural Framing</strong></td>
</tr>
<tr>
<td>1.1</td>
<td>Space slab and mat foundation top reinforcing steel at no more than 6 inches on center each way to provide a safe walking surface.</td>
</tr>
<tr>
<td>1.2</td>
<td>Design floor perimeter beams and beams above floor openings to support lanyards.</td>
</tr>
<tr>
<td>1.3</td>
<td>Design steel columns with holes at 21 and 42 inches above the floor level to support guardrail cables.</td>
</tr>
<tr>
<td><strong>2.0</strong></td>
<td><strong>Accessibility</strong></td>
</tr>
<tr>
<td>2.1</td>
<td>Provide adequate access to all valves and controls.</td>
</tr>
<tr>
<td>2.2</td>
<td>Orient equipment and controls so that they do not obstruct walkways and work areas.</td>
</tr>
<tr>
<td>2.3</td>
<td>Locate shutoff valves and switches in sight of the equipment which they control.</td>
</tr>
<tr>
<td>2.4</td>
<td>Provide adequate head room for access to equipment, electrical panels, and storage areas.</td>
</tr>
<tr>
<td>2.5</td>
<td>Design welded connections such that the weld locations can be safely accessed.</td>
</tr>
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</table>

[Checklist courtesy of John Gambatese]
OSHA silica eTool

OSHA www.osha.gov/dsg/etools/silica/index.html
Why Prevention through Design?

- Ethical reasons
- Construction dangers
- Design-related safety issues
- Financial and non-financial benefits
- Practical benefits

Photo courtesy of Thinkstock
Ethical Reasons for PtD

• National Society of Professional Engineers’ Code of Ethics:
  “Engineers shall hold paramount the safety, health, and welfare of the public...”

• American Society of Civil Engineers’ Code of Ethics:
  “Engineers shall recognize that the lives, safety, health and welfare of the general public are dependent upon engineering decisions...”

NSPE [www.nspe.org/ethics](http://www.nspe.org/ethics)

ASCE [www.asce.org/content.aspx?id=7231](http://www.asce.org/content.aspx?id=7231)
PtD Applies to Constructability

• How reasonable is the design?
  – Cost
  – Duration
  – Quality
  – Safety

Photo courtesy of the Cincinnati Museum Center www.cincymuseum.org
Business Value of PtD

- Anticipate worker exposures—be proactive
- Align health and safety goals with business goals
- Modify designs to reduce/eliminate workplace hazards in
  - Facilities
  - Equipment
  - Tools
  - Processes
  - Products
  - Work flows

  Improve business profitability!

AIHA [www.ihvalue.org](http://www.ihvalue.org)
Benefits of PtD

- Reduced site hazards and thus fewer injuries
- Reduced workers’ compensation insurance costs
- Increased productivity
- Fewer delays due to accidents
- Increased designer-constructor collaboration
- Reduced absenteeism
- Improved morale
- Reduced employee turnover
Industries Use PtD Successfully

- Construction companies
- Computer and communications corporations
- Design-build contractors
- Electrical power providers
- Engineering consulting firms
- Oil and gas industries
- Water utilities

And many others
Reinforced Concrete Elements, Activities, and Hazards

REINFORCED CONCRETE DESIGN
# Introduction to Reinforced Concrete

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Structural Collapses During Construction

Foundations

• Shallow
   – Mat
   – Floating
   – Strip Footings
   – Column Footings

• Deep
   – Piles
   – Piers
Reinforcement

- Concrete is about 90% weaker in tension than it is in compression.

- Steel has high tensile strength, has the same thermal expansion as concrete, and bonds well with concrete.

NIOSH [2010]. Reducing work-related musculoskeletal disorders among rodbusters.

Slabs

- On-Grade
  - Isolated
  - Stiffened
- Elevated Slabs
  - Beam-supported
  - Beamless
  - Extensive formwork

Photo courtesy of John Gambatese
Beams and Girders

• For simple spans:
  – Tension in bottom of beam
  – Compression in top of beam

• Precast elements tied into buildings with hooks, lap splices, or couplers
Columns

• Typically designed for compression, but must be able to resist bending

• Longitudinal rebar runs vertically and is held in place by ties
  – Longitudinal bars are typically about 4% of the gross column area; ties are usually #3 or #4 bars

Photo courtesy of John Gambatese
• Concrete walls resist compression forces.

• Walls are reinforced with a mesh of vertical and horizontal rebar in a layer on each wall face.

• Formwork and form ties are used to ensure proper wall thickness.
Pre-stressed Concrete

• Pre-tensioning
  – Cast over tensioned strands

• Post-tensioning
  – Cast over sleeves and tendons
  – Tendons are tensioned after slab cures

Photo courtesy of John Gambatese
Precast Concrete

- Cast off-site and transported
- Reduces formwork and allows for curing in a controlled environment
- Increased transportation and hoisting costs
Retaining Walls

• Walls made to withstand lateral earth pressure exerted by sloped soils

• Types
  – Gravity
  – Semi-gravity
  – Cantilever
  – Counterfort

Photo courtesy of Thinkstock
Reinforced Concrete Design Process

- Initial Design
- Shop Drawings
- Shop Drawing Submittal
- Shop Drawing Review
- Fabrication

Photo courtesy of John Gambatese
Concrete Construction Activities

- Layout
- Rebar Installation
- Formwork
- Concrete placement
  - Batching
  - Mixing
  - Transporting
  - Placing
- Vibration
- Curing
- Form stripping

Photo courtesy of Walter Heckel
Concrete Construction Hazards

- Tripping
- Muscle strain caused by repeated lifting
- Structural collapse
- Falling materials
- Manipulation and erection of reinforcing steel and formwork
- Silicosis

Silicosis is caused from inhaling silica dust during concrete mixing, grinding, polishing or cutting

More Construction Hazards

- Falls
- Obstructions
- Cave-in during foundation construction
- Lung or skin irritation from exposure to cement or admixtures [NIOSH 2008, 2009]
- Jack, cable, or fitting failure during tensioning

Photo courtesy of John Gambatese
## Construction Industry Statistics [BLS 2011]

<table>
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<tr>
<th>Industry</th>
<th>2008 Annual average employment (thousands)</th>
<th>Total recordable cases*</th>
<th>Cases* with days away from work</th>
<th>Cases with job transfer or restriction</th>
<th>Other recordable cases*</th>
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<tr>
<td>Construction</td>
<td>7597.2</td>
<td>4.7</td>
<td>2.5</td>
<td>1.7</td>
<td>0.7</td>
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<tr>
<td>Poured concrete foundation and structure contractors</td>
<td>235.6</td>
<td>6</td>
<td>3.3</td>
<td>2.3</td>
<td>1</td>
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<tr>
<td>Structural steel and precast and concrete contractors</td>
<td>105.1</td>
<td>6.4</td>
<td>3.9</td>
<td>2.5</td>
<td>1.4</td>
</tr>
<tr>
<td>Framing contractors</td>
<td>114.5</td>
<td>6.9</td>
<td>4.3</td>
<td>3.1</td>
<td>1.2</td>
</tr>
<tr>
<td>Masonry contractors</td>
<td>231.3</td>
<td>4.6</td>
<td>3.1</td>
<td>2.3</td>
<td>0.8</td>
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<tr>
<td>Glass and glazing contractors</td>
<td>64.8</td>
<td>7.6</td>
<td>3.4</td>
<td>2.1</td>
<td>1.3</td>
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<tr>
<td>Roofing contractors</td>
<td>196.2</td>
<td>6.3</td>
<td>3.8</td>
<td>2.7</td>
<td>1.1</td>
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<tr>
<td>Siding contractors</td>
<td>45.6</td>
<td>5.1</td>
<td>2.5</td>
<td>2.1</td>
<td>0.5</td>
</tr>
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*Cases per 100 FTE workers
REINFORCED CONCRETE DESIGN

Mitigating Concrete Construction Hazards
## PtD Examples

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Site Activities

• Use alternative methods for pouring concrete below or next to overhead power lines
  – Pumping truck

• Consider using onsite batch plant, with inspections performed if required
  – Minimizes transportation hazards
Site Activities

Photo courtesy of John Gambatese
Site Activities

• Allow flexibility in concrete mixes. Designate slump and air content ranges and do not preclude adding water at the site.
  – Give the contractor a window of tolerance for less than ideal site conditions such as in poor weather

• Require the constructor to locate and mark existing reinforcing steel prior to cutting into the concrete
  – Preserve the structural integrity of existing reinforced concrete members
Cranes and Derricks

• Erection and disassembly must be carefully planned.

• Site layout affects crane maneuverability.

• Show site utilities on plans.

• Comply with OSHA standards.

Foundations

• Do not use driven piles in deep excavations in areas of loose or backfilled soil
  – Prevent cave-ins

• Avoid designing piles at angles flatter than 4:12 (horizontal: vertical)

• When developing a plot plan, group footings in a way that permits proper drainage of mass excavations
  – Avoid water build-up on site
Foundations

• Use 4" × 4" mat mesh or welded wire fabric (WWF) on top of more widely spaced top rebar
  – Provides walking surface

• Review clearances between forms, anchor bolts, sleeves, and rebar at congested pier locations
  – Ensure sufficient room for equipment

• Standardize anchor bolts to several different diameters, types, and lengths
  – Prevent confusion about placement
Foundations

Photo courtesy of John Gambatese
Foundations

- Design placement directly against earth, instead of forming, where conditions permit
  - Prevent formwork blowouts
- Design small foundations and slabs-on-grade without haunches
  - Irregular, small excavated areas can be tripping hazards
- Eliminate offsets, tapered sections, and other complicated shapes
  - Cave-in hazards
Foundations

• Design-in adequate embedment in concrete foundations, piers, and walls
  – Allows easy attachment of platforms, stairs, light fixtures, etc.

• Provide railing or grating on top of sumps
  – Prevents falls into the sump pit
Foundations

- Standardize foundation sizes for pumps, pipe racks, structures, and miscellaneous supports
  - Standard, regular work environment helps workers
- Dimension concrete foundations and structures to maximize use of commercial form sizes
  - Custom forms may be under-designed or difficult to install
Concrete Floor Surfaces

- Keep steps, curbs, blockouts, slab depressions, and other similar floor features away from window openings, exterior edges, and floor openings.

- Design the covers over sumps, outlet boxes, drains, etc., to be flush with the finished floor.

- Provide a non-slip walking surface on walkways and platforms that are adjacent to open water or exposed to the weather.
Concrete Floor Surfaces

- For access doors through floors, use doors which immediately provide guarded entry around the whole perimeter when the door is opened.
- Locate floor openings away from passageways, work areas, and the structure perimeter.
- Eliminate tripping hazards (changes in elevation, curbs, etc.) around floor openings.
Concrete Floor Surfaces

- Specify broom finish (non-slip walking surfaces) on floors adjacent to open water or exposed to the weather.

- For slabs-on-grade, specify the compaction requirements of the backfill around foundations. Schedule backfilling completion as soon as possible.
Elevated Slabs

• Provide drainage for all floor areas, especially around elevated equipment pads.

• Prohibit the manual placement of metal decking or forms, especially on elevated structures, if wind speeds exceed 25 mph.

• Provide permanent guardrails around floor openings.
Elevated Slabs

• Note on the contract drawings the existing and new floor design loads
  – Help the constructor in determining material stockpile locations and heavy equipment maneuverability

• For elevated floors, use permanent metal-formed decking with concrete fill to eliminate temporary formwork
Elevated Slabs

• When showing pipe sleeves on drawings, consider whether the sleeves will be installed before or after the concrete is placed
  – Prevent unnecessary rework at elevated locations after the concrete is in place
• When specifying a top-of-concrete elevation, consider the combined steel and concrete tolerance (including deflection)
  – This may influence the beam size, composite design of floor, and $F_f$ and $F_l$ numbers for floor flatness and levelness.
Elevated Slabs

Photo courtesy of John Gambatese
Elevated Slabs

- Design concrete members to be of similar size and regularly spaced to facilitate the use, and re-use, of pre-fabricated forms.
- Minimize the number of details to reduce costs and construction errors.
- Consider using bent steel-form plate around the edges of concrete slabs at large openings and around the perimeter.
  - Keep rebar installers away from exposed edges.
- Specify composite steel-form deck.
  - Eliminate formwork and minimize rebar in elevated slabs.
Post-tensioning Cables

- Align or locate post-tensioning cables such that if failure of a jack, cable, or fitting occurs during tensioning, the cable is not directed towards an active work area.
Rebar

- Show splice location and splice lengths on the drawings
- Standardize use of a few sizes of rebar such as #5, #7, and #10
  - Between bars that are of similar size
  - Two smaller sizes can substitute for one larger size if field conditions warrant
- Where practical, show vertical wall and pier dowels extending to 6' height instead of using vertical bars spliced to the dowels
Rebar

- Use one grade of rebar throughout the whole job
- Prefabricate column and wall cages when feasible
- Utilize welded wire fabric (WWF) (flat sheets) for area paving reinforcement
- Specify carbon microfibers where design allows
Formwork

• It is customary to prohibit forming work by hand if wind speed exceeds 25 mph

• Limit the lift height of concrete pours to minimize the load on formwork and the risk of collapse of fresh concrete during pouring operations
Formwork

- For complicated and large formwork designs, specify that formwork calculations and drawings must be reviewed and stamped by a licensed engineer.

- Specify the minimum compressive strength for removal of elevated forms if different than the design compressive strength of the concrete:
  - Prevents collapse of the structure due to early removal of the forms.
Concrete Walls

- Use one or more curtains of WWF for reinforced concrete walls and columns
  - Allows placement of large sections rather than many small pieces

Photo courtesy of John Gambatese
Concrete Beams and Girders

• Design members of consistent size and shape
  – Standardize the work environment

• Specify a minimum beam width of 6 inches
  – Provides a wide walking surface

• Minimize the use of cantilevers, which can be hard to form and finish.

• Design pre-fabricated members to be of one size and shape, or make them easily distinguishable to avoid incorrect placement.
Concrete Beams and Girders

• Design concrete members to be of similar size and regularly spaced
  – Facilitates the use, and reuse, of prefabricated forms

• Consider using shotcrete instead of poured concrete
  – Does not require a form on one side of the member

• Design member depths to allow adequate head room clearance around stairs, platforms, valves, and all areas of egress.

American Concrete Institute
www.shotcrete.org
Concrete Columns

• Design columns with holes (sleeves) or embedded attachment points for guardrails and lifelines

• Specify long rebar lengths to minimize rebar splices
Precast Concrete

- Maximize the use of pre-cast manholes, pull boxes, and other miscellaneous concrete items.
- For precast concrete members, provide inserts or other devices to attach lines or lanyards for fall protection.
Precast Concrete

Photo courtesy of John Gambatese
Safe Work Procedures

• Specify that the device must be embedded in concrete members when testing strength before form removal.

• Design scaffolding tie-off points into exterior walls of buildings for construction purposes.

• Design special attachments or holes in structural members at elevated work areas to provide permanent, stable connections for supports, lifelines, guardrails, scaffolding, or lanyards.
Construction Case Study

Drawing courtesy of OSHA
Comparison of Design and As-Built

As Designed by Structural Engineer

Column
Beam
Floor Slab
Composite Beam

Horizontal Rebar
Perpendicular Rebar
WWF
Column Rebar

Revised Design Submitted by Contractor

As Built

NOTE: Most rebar is not shown. Beam and column are poured together. WWF mats did not engage column steel. Incomplete shoring was provided.

Sketch courtesy of Pamela Heckel
Case Study—Construction Failure

Photo courtesy of OSHA
Recap

• Prevention through Design (PtD) is an emerging design process for saving lives, time, and money.

• PtD is the smart thing to do and the right thing to do.

• Although site safety is the contractor’s responsibility, the designer has an ethical duty to create drawings with good constructability.

• There are tools and examples available to facilitate PtD in reinforced concrete design.
Help make the workplace safer...

Include *Prevention through Design* concepts in your projects.

For more information, please contact the National Institute for Occupational Safety and Health (NIOSH) at

**Telephone:** (513) 533–8302  
**E-mail:** preventionthroughdesign@cdc.gov

Visit these NIOSH Prevention through Design Web sites:

[www.cdc.gov/niosh/topics/PtD](http://www.cdc.gov/niosh/topics/PtD)  
[www.cdc.gov/niosh/programs/PtDesign](http://www.cdc.gov/niosh/programs/PtDesign)
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Other Sources

- NIOSH Fatality Assessment and Control Evaluation Program
  [www.cdc.gov/niosh/face](http://www.cdc.gov/niosh/face)

- National Society of Professional Engineers [NSPE]
  [www.nspe.org/ethics](http://www.nspe.org/ethics)

- NIOSH Prevention through Design web sites:
  [www.cdc.gov/niosh/topics/PtD](http://www.cdc.gov/niosh/topics/PtD)
  [www.cdc.gov/niosh/programs/PtDesign](http://www.cdc.gov/niosh/programs/PtDesign)

- OSHA Fatal Facts
Other Sources

- OSHA home page
  www.osha.gov/pls/oshaweb/owastand.display_standard_group?p_toc_level=1&p_part_number=1926

- OSHA PPE publications
  www.osha.gov/Publications/osha3151.html
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