<table>
<thead>
<tr>
<th>Topic</th>
<th>Slide numbers</th>
<th>Approx. minutes</th>
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<tr>
<td>Introduction to Prevention through Design (PtD)</td>
<td>5–29</td>
<td>45</td>
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<tr>
<td>Design, Detailing, and Fabrication Process</td>
<td>30–36</td>
<td>10</td>
</tr>
<tr>
<td>Erection Process</td>
<td>37–41</td>
<td>10</td>
</tr>
<tr>
<td>Examples of Prevention through Design</td>
<td>42–77</td>
<td>50</td>
</tr>
<tr>
<td>Recap</td>
<td>78–79</td>
<td>5</td>
</tr>
<tr>
<td>References and Other Sources</td>
<td>80–86</td>
<td>—</td>
</tr>
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</table>
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
• Steel Design, Detailing, and Fabrication Process
• Steel Erection Process
• Specific Steel PtD Examples
Introduction to Prevention through Design
EDUCATION MODULE
Occupational Safety and Health

• Occupational Safety and Health Administration (OSHA)
  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
  – 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**

<table>
<thead>
<tr>
<th>Occupation</th>
<th>Number of deaths per 100,000 full-time workers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ironworker</td>
<td>61.6</td>
</tr>
<tr>
<td>Electrical power-line installer</td>
<td>58.6</td>
</tr>
<tr>
<td>Roofer</td>
<td>32.1</td>
</tr>
<tr>
<td>Truck driver</td>
<td>23.5</td>
</tr>
<tr>
<td>Construction Laborer</td>
<td>21.5</td>
</tr>
<tr>
<td>Welder</td>
<td>20.3</td>
</tr>
<tr>
<td>Op. Engineer</td>
<td>16.0</td>
</tr>
<tr>
<td>Helper</td>
<td>15.6</td>
</tr>
<tr>
<td>Excavating Operator</td>
<td>14.3</td>
</tr>
<tr>
<td>Foreman</td>
<td>11.5</td>
</tr>
<tr>
<td>Electrician</td>
<td>10.4</td>
</tr>
<tr>
<td>Brick Mason</td>
<td>8.8</td>
</tr>
<tr>
<td>Painter</td>
<td>8.1</td>
</tr>
<tr>
<td>Heating</td>
<td>7.8</td>
</tr>
<tr>
<td>Construction manager</td>
<td>7.7</td>
</tr>
<tr>
<td>Plumber</td>
<td>7.2</td>
</tr>
<tr>
<td>Carpenter</td>
<td>6.9</td>
</tr>
<tr>
<td>Drywall</td>
<td>4.9</td>
</tr>
<tr>
<td>All construction</td>
<td>10.8</td>
</tr>
</tbody>
</table>

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

- **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
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>
<thead>
<tr>
<th>Stage</th>
<th>Activities</th>
</tr>
</thead>
<tbody>
<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 project 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>Education; manage changes; modify SOPs</td>
</tr>
</tbody>
</table>
Safety Payoff During Design

[Adapted from Szymborski 1997]

- High Ability to influence safety
- Low Ability to influence safety

Conceptual design
- Detailed design
- Procurement
- Construction
- Start-up

Project schedule
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 Australia
  - Construction Hazard Assessment Implication Review, known as CHAIR [NOHSC 2001]
### Example Checklist

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1.0 Structural Framing</strong></td>
<td></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 Accessibility</strong></td>
<td></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>
</tbody>
</table>

Checklist courtesy of John Gambatese
OSHA Steel Erection eTool

Despite being covered since 1971 under the original steel erection standard, America’s 56,000 steel erectors continue to suffer 33 tool accidents per year, a rate of one death per 1,600 workers. OSHA estimates that 30 of those deaths, as well as nearly 1,150 annual lost-workday injuries, will be averted by compliance with provisions of the new standard, developed with industry and labor through negotiated rulemaking. To that end, this eTool* has been created to educate employers and workers about the revised standard (Subpart R).

* eTools are web-based training tools on occupational safety and health topics. They utilize graphical menus as well as expert system modules. As indicated in the disclaimer, eTools do not create new OSHA requirements.

OSHA www.osha.gov/SLTC/etools/steelerrection/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
ASCE 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
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
STRUCTURAL STEEL DESIGN

Design, Detailing, and Fabrication Process
Three Entities Associated with Design

- Engineer
- Detailer
- Fabricator

Photo courtesy of Thinkstock
Design Phase

- Owner establishes architectural/engineering requirements for building
- Designer runs analysis on design according to building codes
- Building is designed for safety, serviceability, constructability, and economy
- Client receives final design specifications and drawings
- Designer stores the calculations
Detailing

Fabricator programs engineer's drawings with software to visualize connections

[Daccarett and Mrozowski 2002]
While detailing, fabricator makes drawings containing specifics about how to fabricate each member

[Daccarett and Mrozowski 2002]
To achieve its final configuration, the steel may be
- Cut
- Sheared
- Punched
- Drilled
- Fit
- Welded

Each final member is labeled with a piece mark, length, and job number for identification.

[Daccarett and Mrozowski 2002]
Transportation

Members are transported via

• Flatbed truck
• Train
• Waterways

Photo courtesy Thinkstock
Unloading and Shake-out

- Steel members are unloaded and placed on blocking to allow space for chokers to be easily attached.
- Shake-out: members are sorted on the ground to allow for efficient erection.

[Daccarett and Mrozowski 2002]
Picking and Hoisting

- Cranes lift members into place
- Hole at end of each column
- After a choker is tied around the center of gravity, multiple beams can be lifted at once

[Daccarett and Mrozowski 2002]
Positioning and Initial Bolting

- Each beam is lowered into place, and a worker lines it up correctly with drift pins. At least two bolts are attached before the crane releases the load.

  — OSHA requirement

[Daccarett and Mrozowski 2002]
Final Bolting

• Once everything is in the correct position, the final bolting is performed with a torque wrench or similar tool.

[Daccarett and Mrozowski 2002]

Photo courtesy of Daccarett and Mrozowski
STRUCTURAL STEEL DESIGN

Examples of Prevention through Design
### Topics

<table>
<thead>
<tr>
<th>Topics</th>
<th>Slide numbers</th>
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<tbody>
<tr>
<td>Prefabrication</td>
<td>44–45</td>
</tr>
<tr>
<td>Access Help</td>
<td>46</td>
</tr>
<tr>
<td>Columns</td>
<td>47–50</td>
</tr>
<tr>
<td>Beams</td>
<td>51–54</td>
</tr>
<tr>
<td>Connections</td>
<td>55–67</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>68–77</td>
</tr>
</tbody>
</table>
Prefabrication

- Shop work is often faster than field work.
- Shop work is less expensive than field work.
- Shop work is more consistent because of the controlled environment.
- Shop work yields better quality than field work.
- With prefabrication, less work is done at high elevations, which reduces the risks of falls and falling objects.

[Toole and Gambatese 2008]
Example: Prefabricated Truss

- Fewer connections to make in the air
- Safer and faster

Photo courtesy of Thinkstock
Access Help

• Shop-installed vertical ladders

• Bolts on ladders and platforms can be removed later or kept for maintenance
Column Safety

- Column splices
- Tabs/Holes for safety lines
- Base plates
Column Splices

• Have column splice around 4 feet above the working floor
  – OSHA requirement

Photo courtesy of Bucknell University facilities
Holes for Safety Lines

- Include holes at 21 inches and 42 inches for guardrails
- Additional, higher holes can also be included for lifeline support

[Gambatese 1996; NISD and SEAA 2009]
Base Plates

- Column **base plates** should always have at least 4 anchor rods bolted in
  - OSHA Requirement

Beams and Girders

Workers walk on beams to get to connections or other columns, a common fall hazard. Increase safety by considering:

- Beam width
- Use of cantilevers
- Ability to support lifelines

Photo courtesy of Thinkstock
Beam Width

• For walking safely, use beams with a minimum beam width of 6 inches.

[Gambatese 1996]
Use of Cantilevers

Minimize the use of cantilevers, which

- are not good for tying off
- pose connection difficulties

[Gambatese 1996]
Ability to Support Lifelines

• Design beams near or above openings to be able to support lifelines

• Contract drawings should make clear how many lifelines each beam can support, and at what locations they can be attached

Connections are very important but can be very difficult to install. There are two main tools for making connections:

- Bolts
- Welds
Bolts

For safe bolted connections, consider:

- Self-supporting connections
- Double connections
- Erection aid: “dummy holes”
- Bolt sizes
- Minimum number of bolts
- Awkward or dangerous connection locations
Self-Supporting Connections

- Avoid hanging connections
- Consider using beam seats

[Gambatese 1996; NISD and SEAA 2009]
Double Connections

• Avoid beams of common depth connecting into the column web at the same location.

• If double connections are necessary, design them to have full support during the connection process.
  – OSHA requirement

Alternate Double Connection

Photos courtesy of AISC
Erection Aids: “Dummy Holes”

• Provide an extra “dummy hole” in the connection, where a spud wrench can be inserted

• This is most appropriate when there are only two bolts

[Gambatese 1996]

Photo courtesy Bucknell University facilities
Bolt Sizes

• Use as few bolt sizes as possible

[Gambatese 1996]
Minimum Number of Bolts

• Use a minimum of two bolts per connection
  – OSHA requirement

[Gambatese 1996]
Immediate Stability

Provide pin-holed or bolted connections to provide immediate stability after placement of members

[Gambatese 1996]
Avoid Awkward or Dangerous Connection Locations

• Time-consuming and dangerous
• Can cause strain

[Gambatese 1996; NISD and SEAA 2009]
Welds

For safer welded connections:

- Avoid awkward or dangerous connection locations
- Immediate stability
- Welding location
- Welding material
Welding Locations

• Specify shop welding rather than field welding

• If field welds are necessary, design them in convenient locations

[Gambatese 1996]
Welding can be a fire hazard and can emit toxic fumes. Always be aware of what material is being welded.

[Gambatese 1996; Sperko Engineering Services 1999]
Other Methods for Safer Construction

Address these factors:

• Sharp corners
• Access problems
• Temporary bracing
• Crane safety
• Member placement
• Tripping hazards
Avoid Sharp Corners

- Corners can cause clothing or wires to snag, resulting in falling objects or tripping hazards
- Corners can cause scratches or cuts

[NISD and SEAA 2009]
Access Problems

Complicated connections take time to complete and are dangerous if they require awkward positioning, so consider

- Adequacy of space for making connections
- Small column size access
- Hand trap danger
Provide Enough Space for Connections

• There may not be enough space for common tools
• These connections can be made better by clipping away portions or increasing distances

[NISD and SEAA 2009]
Small Column Size Access

- Small column depth can make connections difficult
- Access to bolts can be blocked by the column flanges
- Attach a tab to the column

[NISD and SEAA 2009]
Hand Trap

- The situation shown can create a dangerous hand trap
- A solution is to cut out a section of the flange to allow access to the bolts

[NISD and SEAA 2009]
“Knuckle-busting” – workers’ knuckles get damaged from trying to fit their hands into a tight space

[NISD and SEAA 2009]
Cranes and Derricks

- Erection and disassembly must be carefully planned.
- Site layout affects crane maneuverability.
- Show site utilities on plans.
- Comply with OSHA standards.

Member Placement

- Members need sufficient space to fit between columns
- Members without enough space could cause columns to tilt

[NISD and SEAA 2009]
Tripping Hazards

Avoid having connections on top of beams and joists.

[NISD and SEAA 2009; OSHA 29 CFR 1926-754]

Image courtesy of Thinkstock
Recap

• **Prevention through Design (PtD)** is an emerging 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 the ethical duty to create drawings with good constructability.

• There are tools and examples to facilitate PtD.
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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References

References


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References


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  www.cdc.gov/niosh/topics/PtD
  www.cdc.gov/niosh/programs/PtDesign
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  www.setonresourcecenter.com/MSDS_Hazcom/FatalFacts/index.htm
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- OSHA comprehensive crane standard
- OSHA crane regulation text is available at
- A press release for the crane standard can be found:
- OSHA PPE publications
  [www.osha.gov/Publications/osha3151.html](http://www.osha.gov/Publications/osha3151.html)
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