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Reinforced Concrete Design

EDUCATION MODULE

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Oregon State University

Guide for Instructors

Topic	Slide numbers	Approx. minutes
Introduction to Prevention through Design (PtD)	5–29	45
Elements, Activities, and Hazards	30–45	30
Mitigating Concrete Construction Hazards	46–78	50
Construction Case Study	79–82	20
Recap	83–84	5
References and Other Sources	85–95	—


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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.

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Overview

- PtD Concept
- Introduction to Reinforced Concrete
- Reinforced Concrete Design Process, Construction Activities, and Safety Hazards
- Reinforced Concrete PtD Examples
- Case Study

Photo courtesy of Thinkstock

PtD™

Prevention through Design

Introduction to Prevention through Design

EDUCATION MODULE

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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

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Construction Hazards

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

[BLS 2006; Lipscomb et al. 2006]

Graphic courtesy of OSHA

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Construction Accidents in the United States

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]

Photo courtesy of Thinkstock

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Design as a Risk Factor: Australian Study, 2000–2002

- 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]

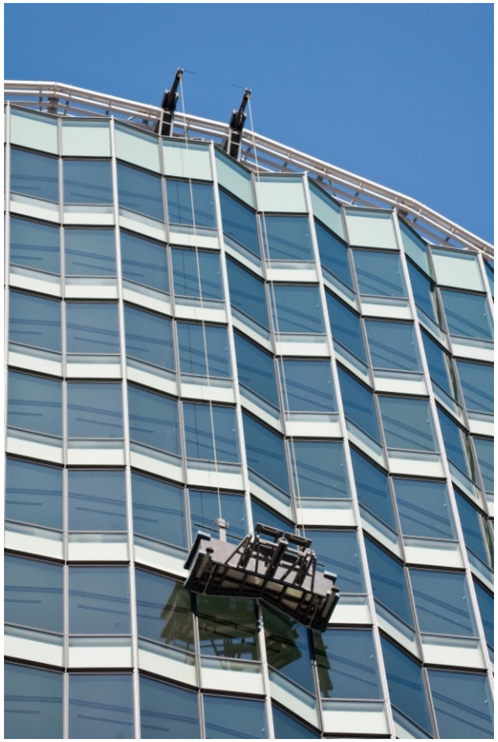

Photo courtesy of Thinkstock

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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]

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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

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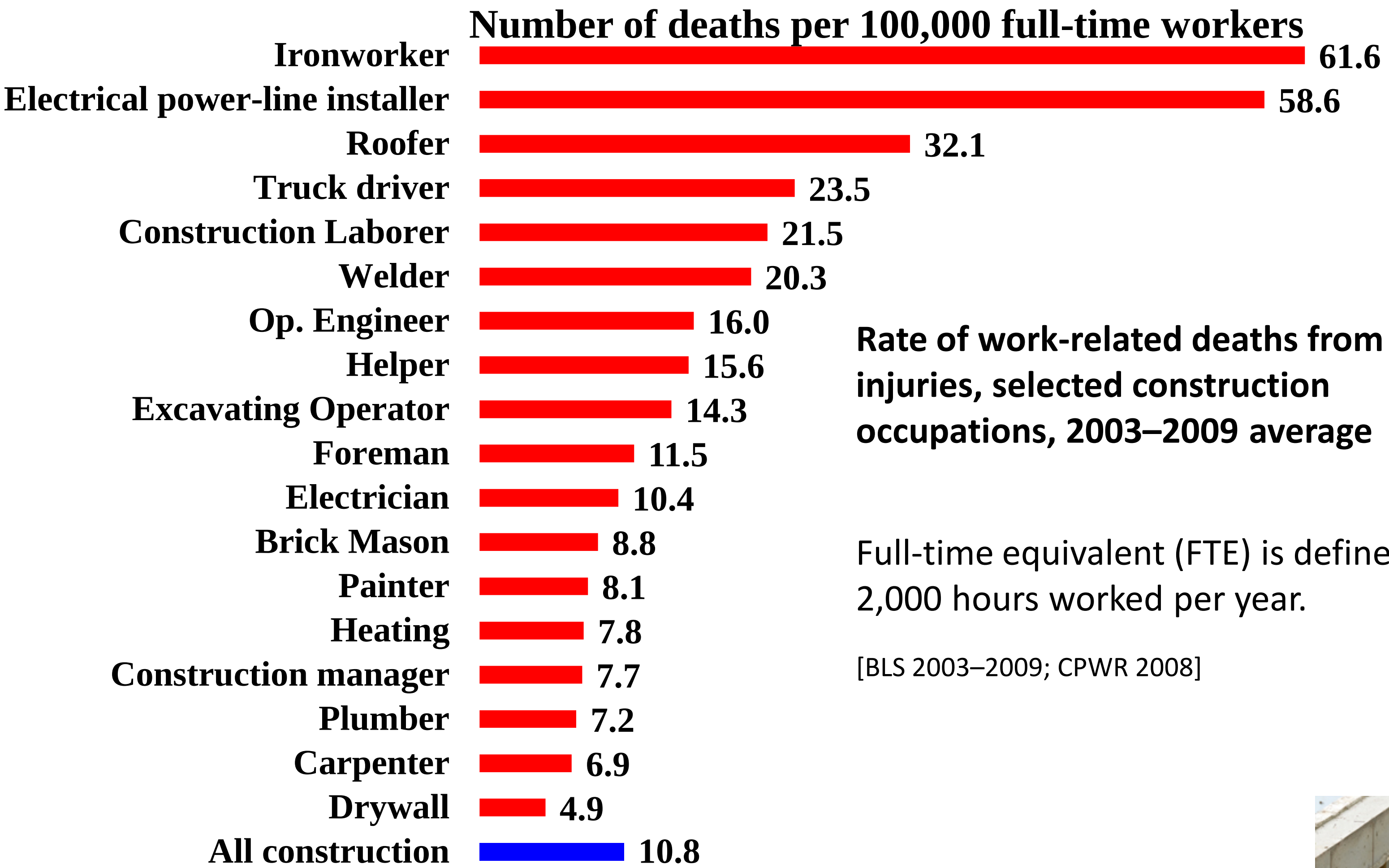
Death from Injury



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]

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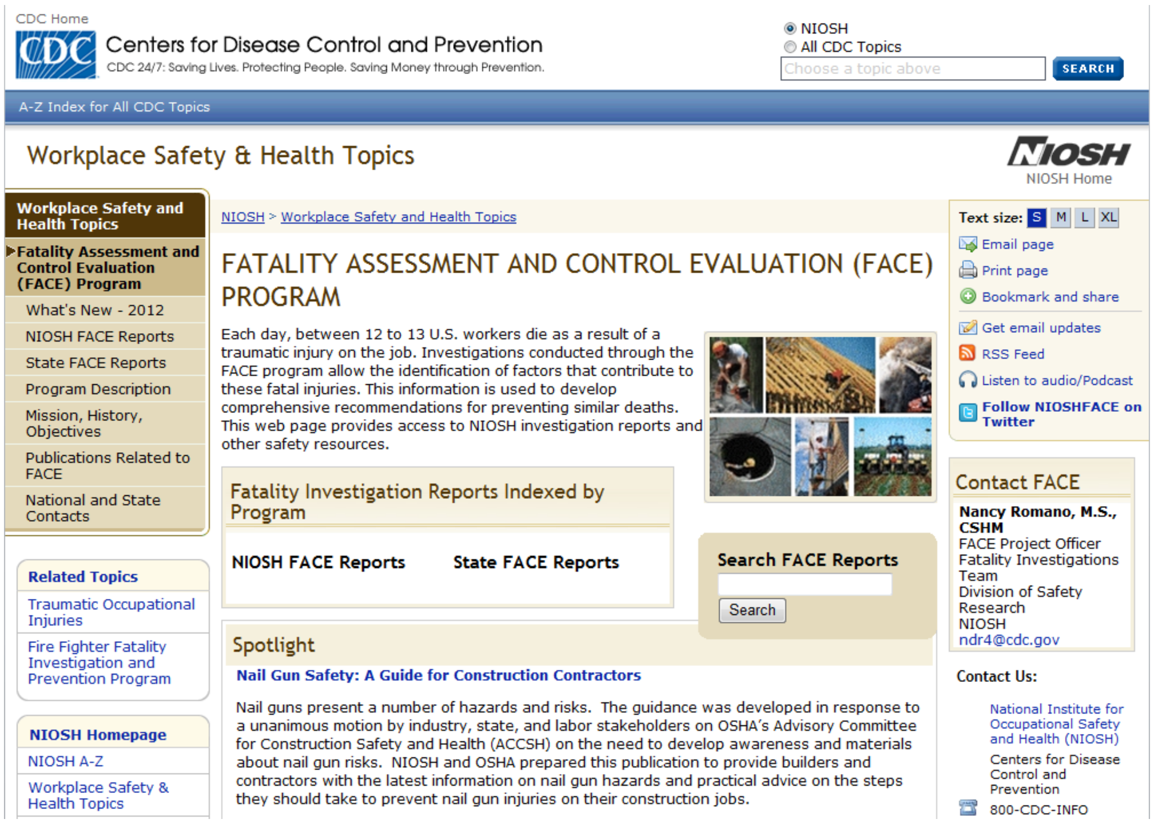
Fatality Assessment and Control Evaluation

NIOSH FACE Program www.cdc.gov/niosh/face



CDC Home

Centers for Disease Control and Prevention

CDC 24/7: Saving Lives. Protecting People. Saving Money through Prevention.

NIOSH
All CDC Topics
Choose a topic above
SEARCH

A-Z Index for All CDC Topics

Workplace Safety & Health Topics

NIOSH
NIOSH Home

Workplace Safety and Health Topics

- **Fatality Assessment and Control Evaluation (FACE) Program**
- What's New - 2012
- NIOSH FACE Reports
- State FACE Reports
- Program Description
- Mission, History, Objectives
- Publications Related to FACE
- National and State Contacts

Related Topics

- Traumatic Occupational Injuries
- Fire Fighter Fatality Investigation and Prevention Program

NIOSH Homepage

- NIOSH A-Z
- Workplace Safety & Health Topics

NIOSH > Workplace Safety and Health Topics

FATALITY ASSESSMENT AND CONTROL EVALUATION (FACE) PROGRAM

Each day, between 12 to 13 U.S. workers die as a result of a traumatic injury on the job. Investigations conducted through the FACE program allow the identification of factors that contribute to these fatal injuries. This information is used to develop comprehensive recommendations for preventing similar deaths. This web page provides access to NIOSH investigation reports and other safety resources.

Fatality Investigation Reports Indexed by Program

NIOSH FACE Reports **State FACE Reports**

Search FACE Reports

Search

Spotlight

Nail Gun Safety: A Guide for Construction Contractors

Nail guns present a number of hazards and risks. The guidance was developed in response to a unanimous motion by industry, state, and labor stakeholders on OSHA's Advisory Committee for Construction Safety and Health (ACCSH) on the need to develop awareness and materials about nail gun risks. NIOSH and OSHA prepared this publication to provide builders and contractors with the latest information on nail gun hazards and practical advice on the steps they should take to prevent nail gun injuries on their construction jobs.

Text size: S M L XL

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Contact FACE

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Contact Us:

National Institute for Occupational Safety and Health (NIOSH)

Centers for Disease Control and Prevention

800-CDC-INFO

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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

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Hierarchy of Controls per ANSI/AIHA Z10-2005

BEST ↑ Control effectiveness

ELIMINATION

Design it out

SUBSTITUTION

Use something else

ENGINEERING CONTROLS

Isolation and guarding

ADMINISTRATIVE CONTROLS

Training and work scheduling

PERSONAL PROTECTIVE EQUIPMENT

Last resort

BEST ↑ Business value

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Personal Protective Equipment (PPE)

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

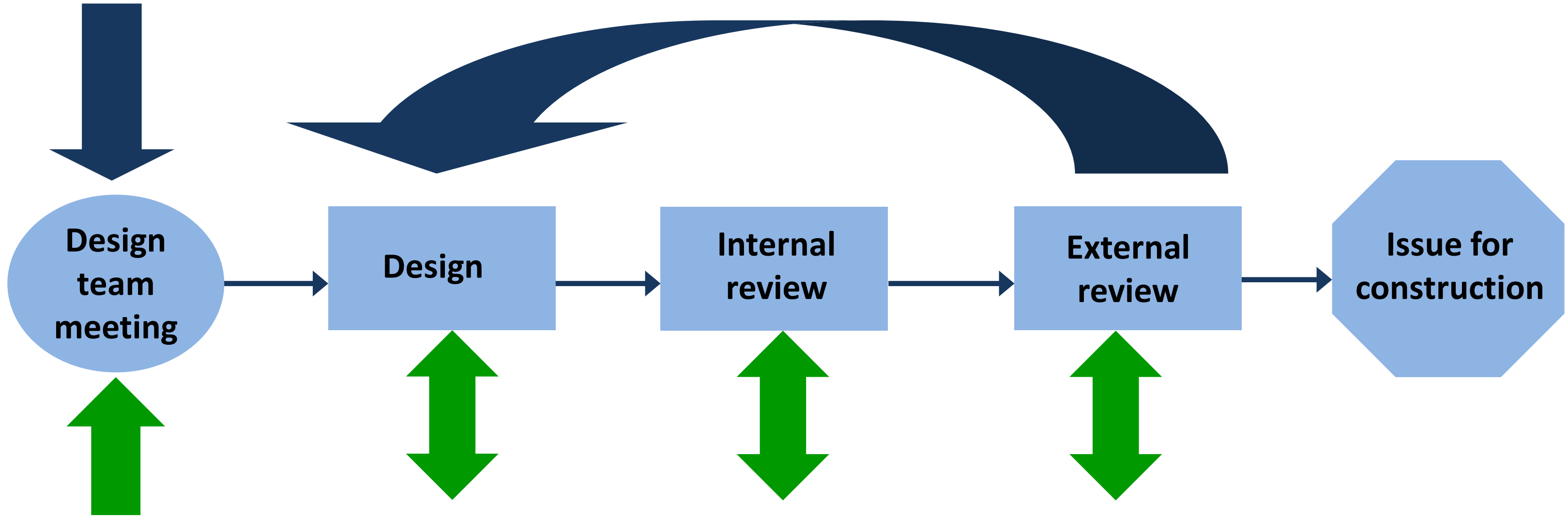
Photo courtesy of Thinkstock

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



- 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

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Integrating Occupational Safety and Health with the Design Process

Stage	Activities
Conceptual design	Establish occupational safety and health goals, identify occupational hazards
Preliminary design	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.
Detailed design	Select controls; conduct process hazard reviews
Procurement	Develop equipment specifications and include in procurements; develop “checks and tests” for factory acceptance testing and commissioning
Construction	Ensure construction site safety and contractor safety
Commissioning	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
Start up and occupancy	Educate; manage changes; modify SOPs


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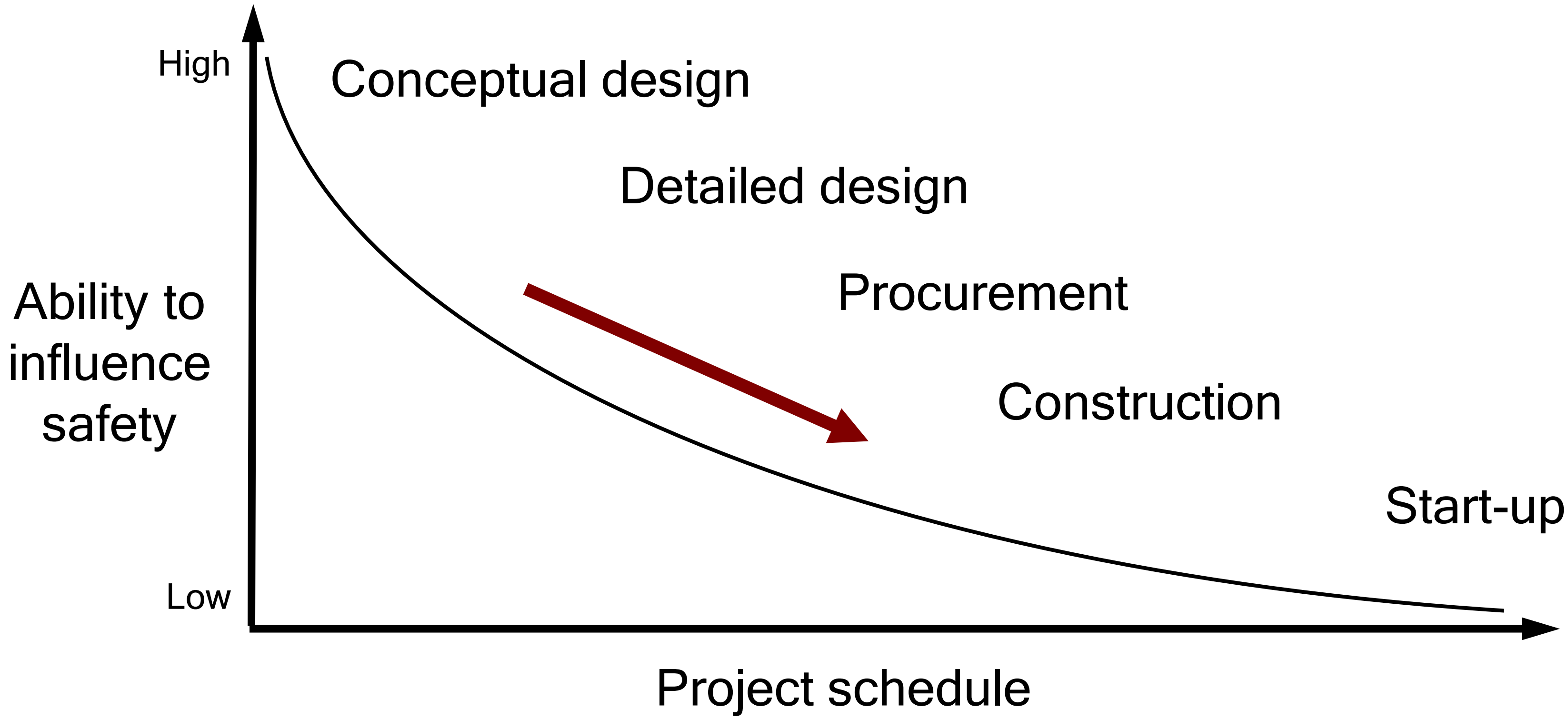
Safety Payoff During Design

[Adapted from Szymberski 1997]

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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

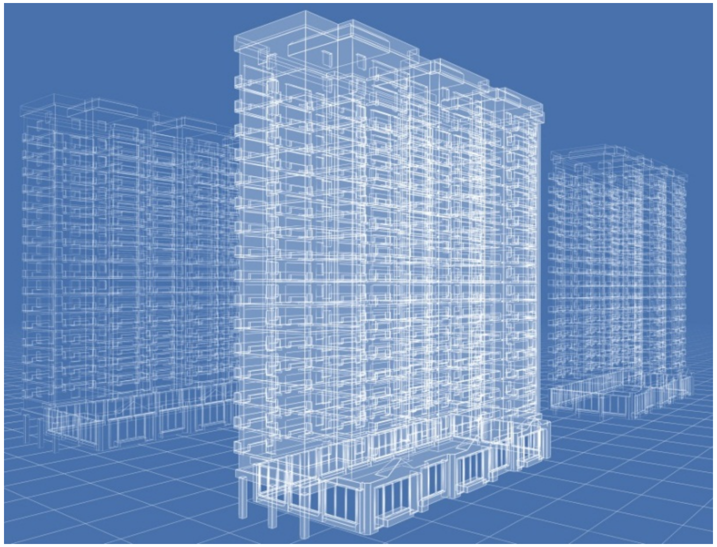

Photo courtesy of Thinkstock

Designer Tools

- Checklists for construction safety [Main and Ward 1992]
- Design for construction safety toolbox [Gambatese et al. 1997]
- Construction safety tools from the UK or Australia
  - Construction Hazard Assessment Implication Review (CHAIR) [NOHSC 2001]

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Example Checklist

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

[Checklist courtesy of John Gambatese]

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OSHA silica eTool

OSHA www.osha.gov/dsg/etools/silica/index.html

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Why Prevention through Design?

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

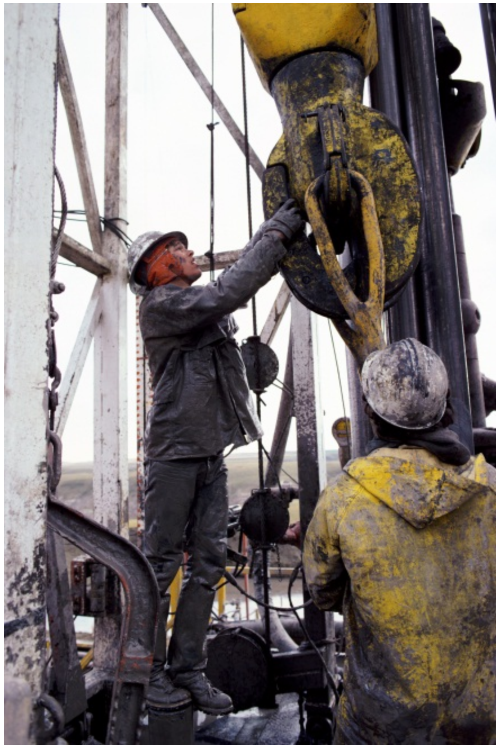

Photo courtesy of Thinkstock

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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

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PtD Applies to Constructability

- How reasonable is the design?
  - Cost
  - Duration
  - Quality
  - Safety

Photo courtesy of the Cincinnati Museum Center www.cincymuseum.org

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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

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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

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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

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REINFORCED CONCRETE DESIGN

Elements, Activities, and Hazards

Introduction to Reinforced Concrete

Topic	Slides
Elements	32–40
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Construction Activities	42
Construction Hazards	43–44

Structural Collapses During Construction

Adobe Acrobat Document

Structure Magazine www.structuremag.org/article.aspx?articleID=1177

Foundations

- Shallow
  - Mat
  - Floating
  - Strip Footings
  - Column Footings
- Deep
  - Piles
  - Piers

Photo courtesy of John Gambatese

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

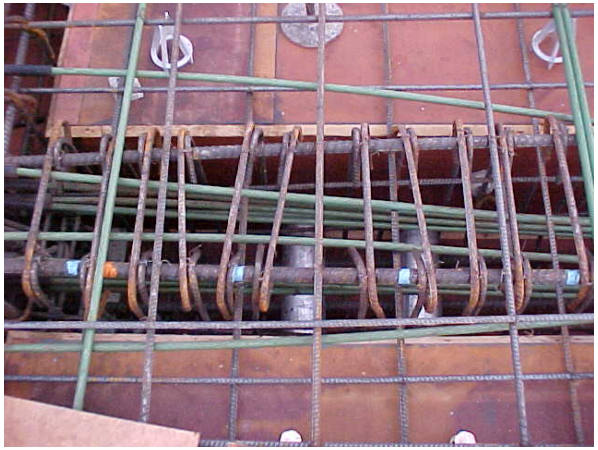

Photo courtesy of John Gambatese

NIOSH [2010]. Reducing work-related musculoskeletal disorders among rodbusters www.cdc.gov/niosh/docs/wp-solutions/2010-103.

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

Photo courtesy of Thinkstock

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

Walls

- 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.

Photo courtesy of John Gambatese

Pre-stressed Concrete

- Pre-tensioning
  - Cast over tensioned strands
- Post-tensioning
  - Cast over sleeves and tendons
  - Tendons are tensioned after slab cures

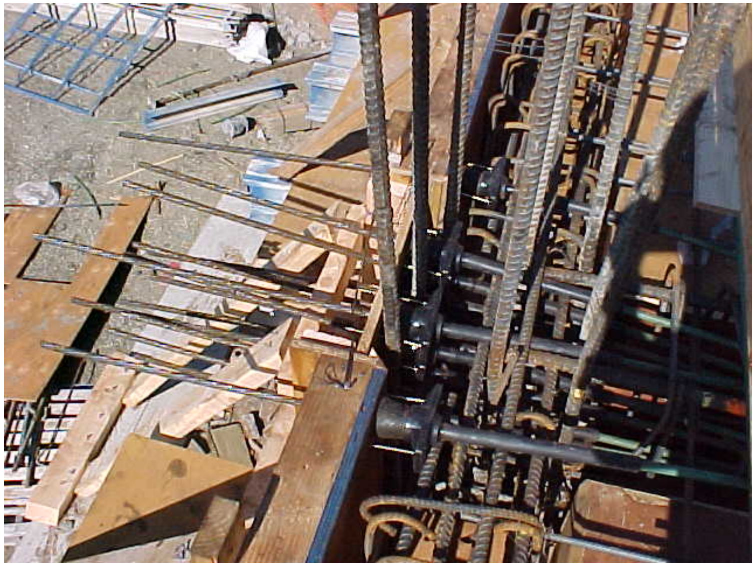

Photo courtesy of John Gambatese

Precast Concrete

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

Photo courtesy of Thinkstock

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Retaining Walls

- Walls made to withstand lateral earth pressure exerted by sloped soils
- Types
  - Gravity
  - Semi-gravity
  - Cantilever
  - Counterfort

Photo courtesy of Thinkstock

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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

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Concrete Construction Hazards

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

Photo courtesy of John Gambatese

Silicosis is caused from inhaling silica dust during concrete mixing, grinding, polishing or cutting
www.cdc.gov/niosh/docs/wp-solutions/2009-115/; www.cdc.gov/niosh/docs/wp-solutions/2008-127

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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]

Industry	2008 Annual average employment (thousands)	Total recordable cases*	Cases* with days away from work, job transfer, or restriction			Other recordable cases*
			Total	Cases with days away from work	Cases with job transfer or restriction	
Construction	7597.2	4.7	2.5	1.7	0.7	2.2
Poured concrete foundation and structure contractors	235.6	6	3.3	2.3	1	2.8
Structural steel and precast and concrete contractors	105.1	6.4	3.9	2.5	1.4	2.5
Framing contractors	114.5	6.9	4.3	3.1	1.2	2.6
Masonry contractors	231.3	4.6	3.1	2.3	0.8	1.5
Glass and glazing contractors	64.8	7.6	3.4	2.1	1.3	4.1
Roofing contractors	196.2	6.3	3.8	2.7	1.1	2.5
Siding contractors	45.6	5.1	2.5	2.1	0.5	2.6

*Cases per 100 FTE workers


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PtD Prevention through Design™

REINFORCED CONCRETE DESIGN

Mitigating Concrete Construction Hazards

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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

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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

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Cranes and Derricks

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

Photo courtesy of Walter Heckel

The OSHA comprehensive crane standard: www.osha.gov/FedReg_osha_pdf/FED20100809.pdf.
Regulation text: www.osha.gov/cranes-derricks/index.html.

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

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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

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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


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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

Photo courtesy of Thinkstock

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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

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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

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Concrete Floor Surfaces

Photo courtesy of John Gambatese

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

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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.

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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

Photo courtesy of Thinkstock

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.

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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

Photo courtesy of Thinkstock

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

Photo courtesy of John Gambatese

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.

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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

Reinforced Concrete

Concrete Columns

- Design columns with holes (sleeves) or embedded attachment points for guardrails and lifelines
- Specify long rebar lengths to minimize rebar splices

Photo courtesy of Thinkstock

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

Reinforced Concrete

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.

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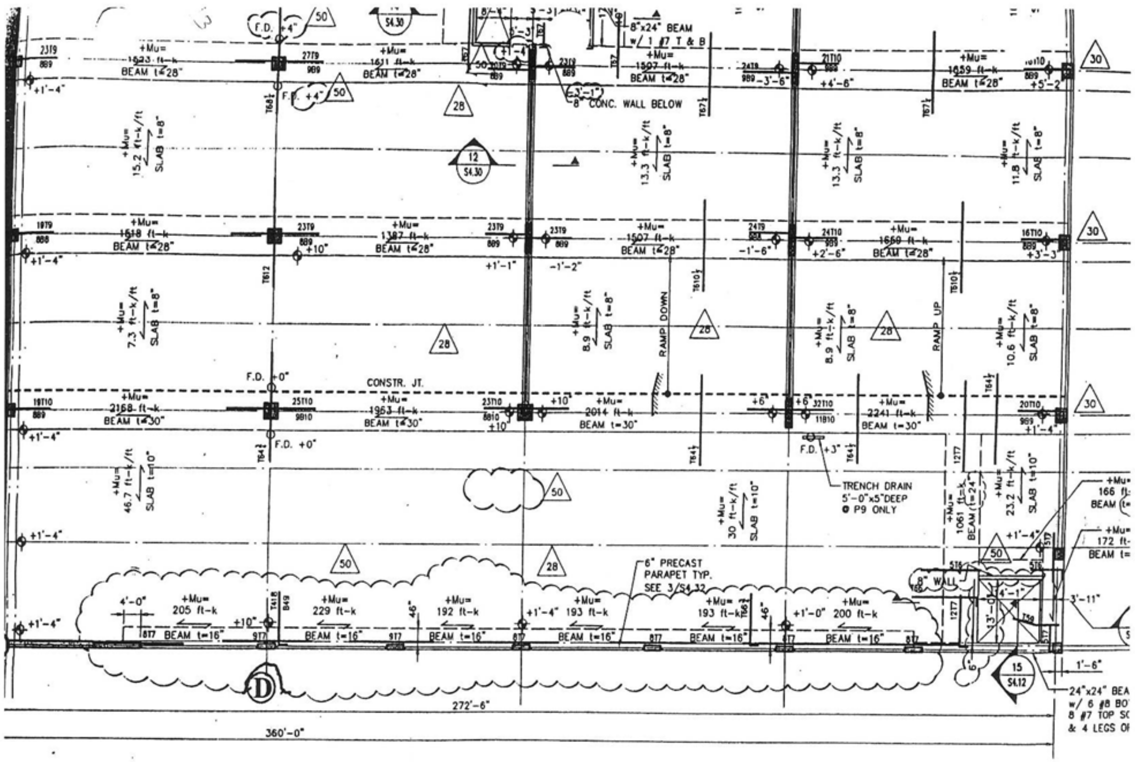
Prevention through Design

REINFORCED CONCRETE DESIGN

Construction Case Study

Reinforced Concrete

Construction Case Study

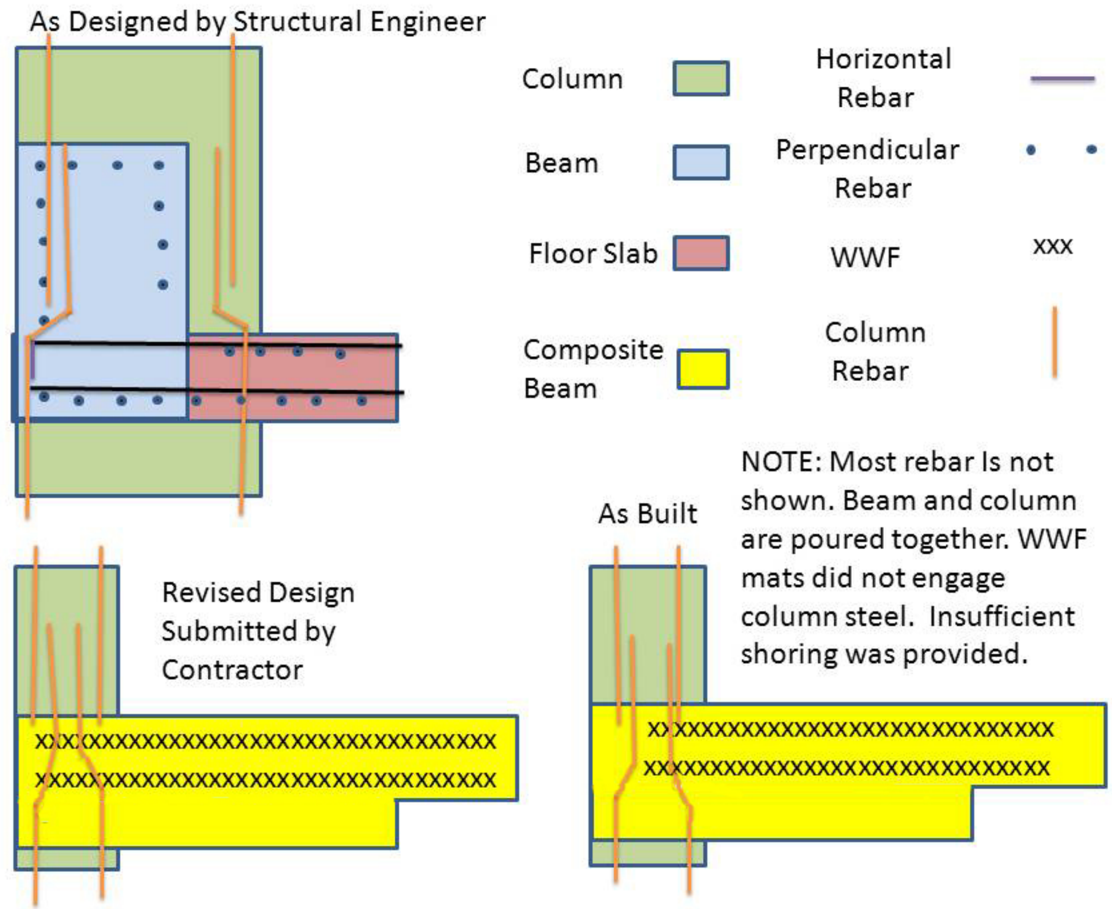


PARTIAL P6 TO P9 FRAMING PLAN (CONTRACT DRAWING S-1.36, REV. 50)
(NTS)

Drawing courtesy of OSHA

Reinforced Concrete

Comparison of Design and As-Built



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

Sketch courtesy of Pamela Heckel

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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

www.cdc.gov/niosh/programs/PtDesign

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