Reliability of Structures – Part 7

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Human Error

- Definition
- Control of causes
- Control of consequences

Uncertainties in the building process

- Human error: departure from acceptable practice
- Part of all human activities
- Considerable degree of uncertainty to design and construction activities
- From surveys, it is a dominating cause of structural failures in buildings and bridges
- Errors can be categorized according to causes and consequences. Structural reliability is determined by error control

Uncertainties in the building process

- The problem of error control can be approached from two directions:
  - reduce error frequency
  - minimize consequences
- Checking calculations and job inspections are used to control the error quantity.
- Sensitivity analyses can be performed to identify the severity of consequences.

Example Hyatt Regency Hotel in Kansas City

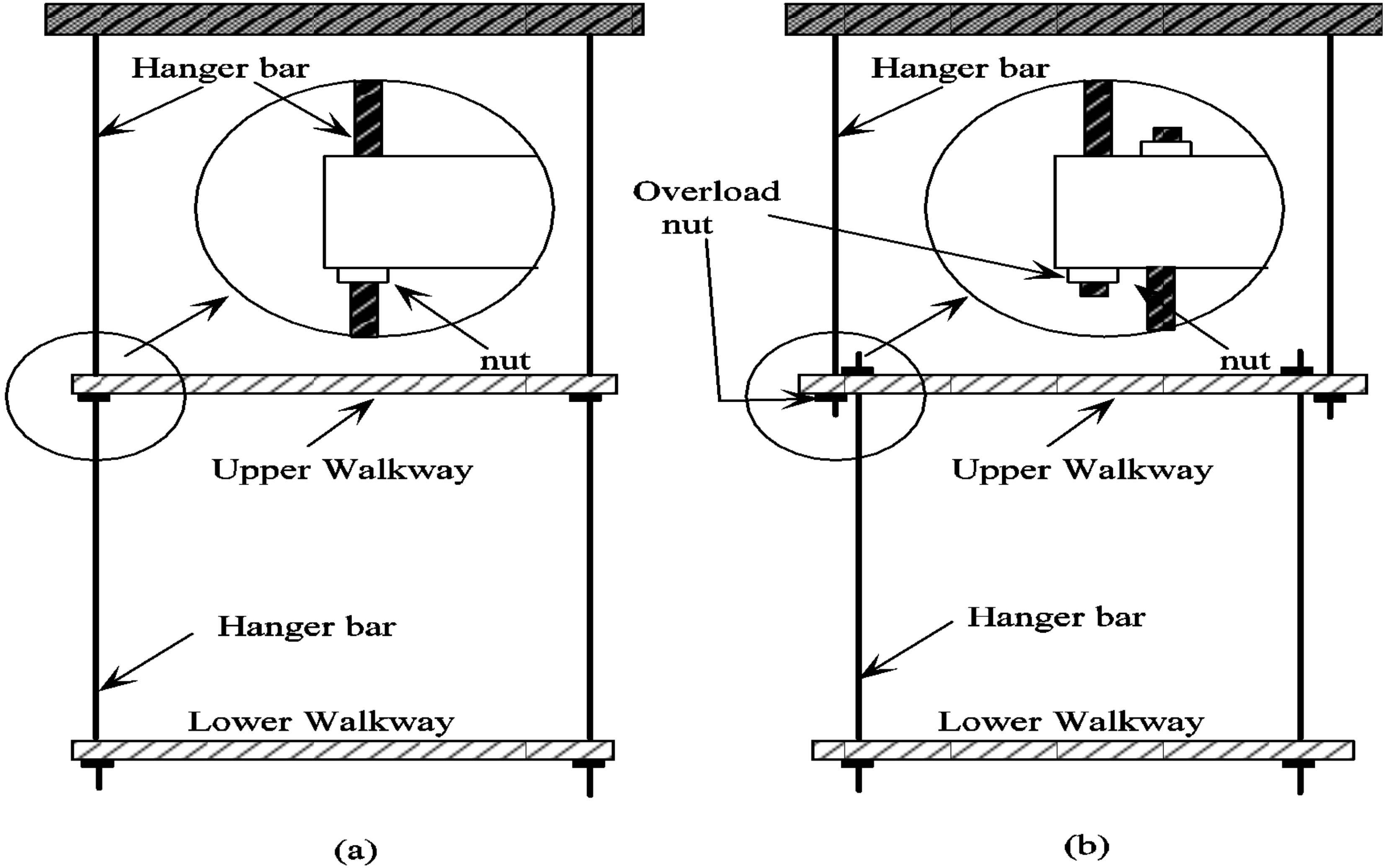


Figure 10-1 Details of Walkway Hanger Bar Connection
(a) Original Design
(b) As built.

Categories of uncertainty

Two major sources of uncertainty

- Natural hazards
- Man-made hazards

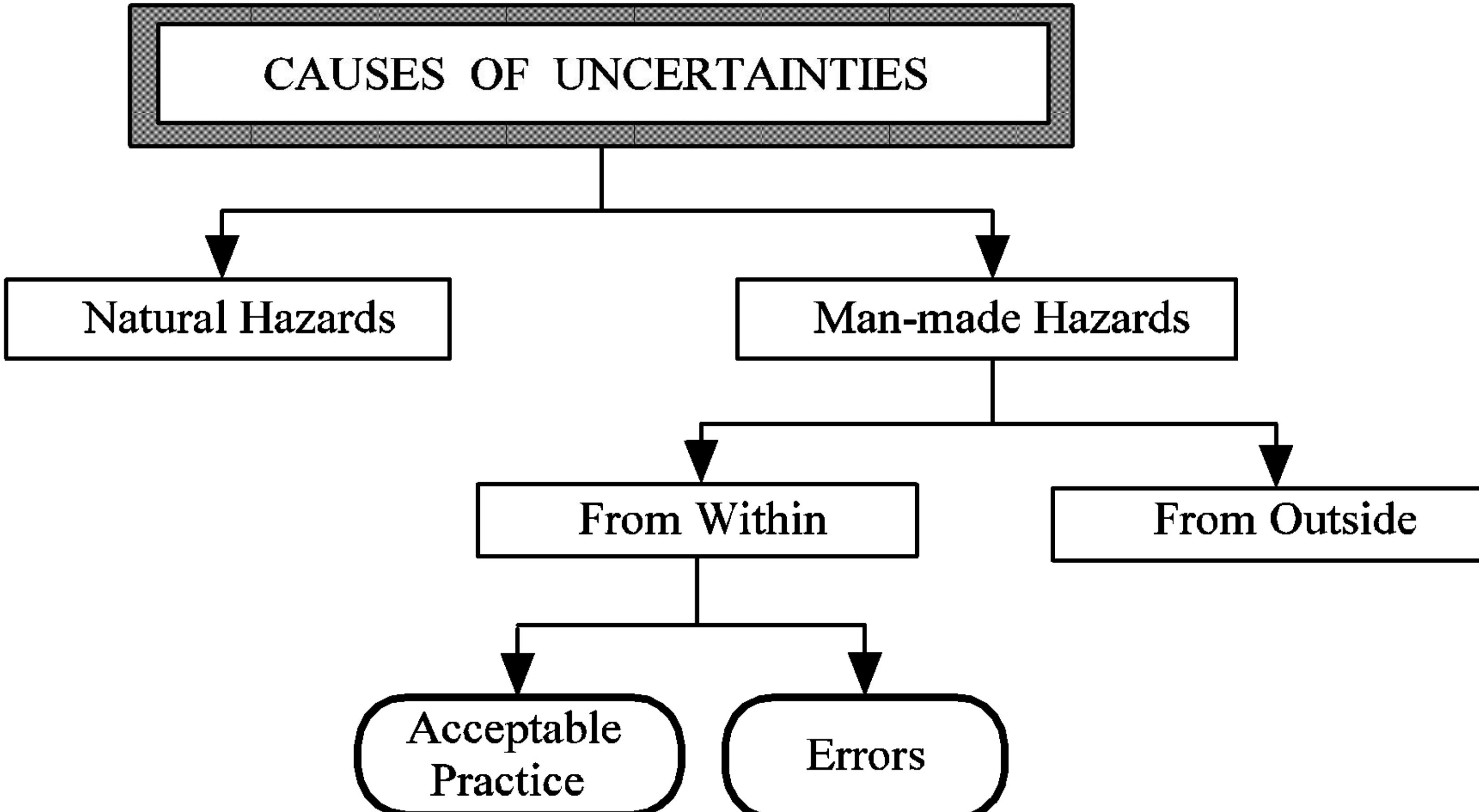
Categories of uncertainty

- Natural hazards
  - wind, earthquake, temperature differentials, snow load or ice accretion,
  - Natural variations of structural properties (strength, modulus of elasticity, dimensions)
  - Natural variations of loads (weight of people, furniture, or trucks on bridges)

Categories of uncertainty

- Man-made hazards (subdivided into two groups)
  - From within the building process (innovations, unique structures, use of new materials and new types of structures)
  - from outside the building process (fires, gas explosion, collisions…)

Categories of uncertainty



Error is a departure from acceptable practice

Figure 10-2 Causes of Uncertainty in the Building Process

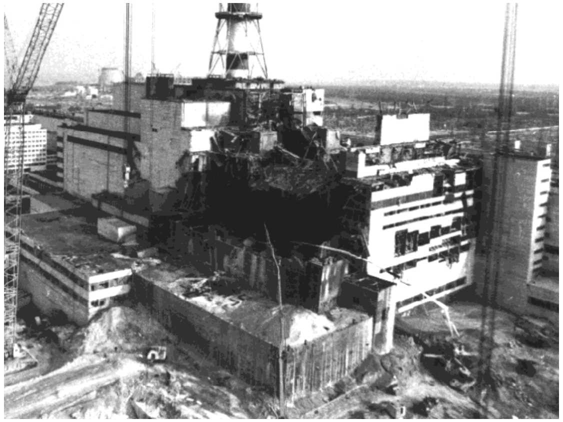
Categories of Uncertainty

- Practice is acceptable if no significant number of the most knowledgeable engineers find it unacceptable
- Common practice is not necessarily acceptable
- Acceptable practice is not necessarily common
- Departures from acceptable practice are human errors.

Theoretical and Actual Failure Rates

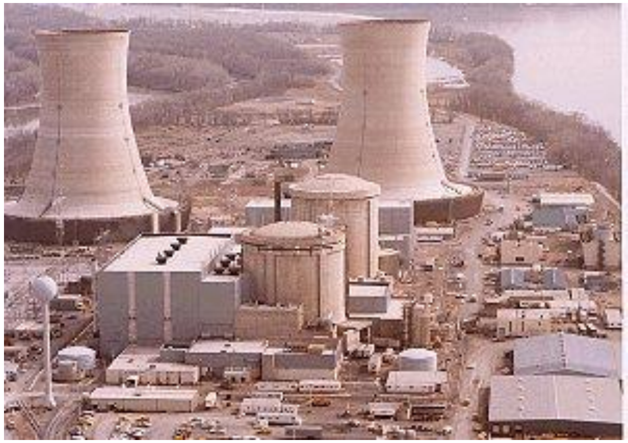
- Last 30 years : Large advances in structural reliability theory.
- Many applications to structural design standards and procedures.
- Optimize investment in that part of structural safety that is effectively controlled by traditional safety factors.
- However, a considerable discrepancy has been observed between the theoretical and actual failure rates.

Theoretical and Actual Failure Rates



Chernobyl

Exxon Valdez - Alaska



Three Mile Island

Bhopal

Theoretical and Actual Failure Rates

- Calculated Probabilities of failure for buildings and bridges

  10^{-6} to 10^{-8}

- Observed values are higher

- US bridges : 10^{-3} to 10^{-5}

- Failure rates are much higher for very large and unique structures (see examples)

Extreme Events and other Threats

- Natural disasters: hurricanes, floods, earthquakes, major storms
- Improper maintenance, negligence
- Collisions
- Vandalism
- Terrorist attacks

Ruins of Ponte Emilio-180 BC

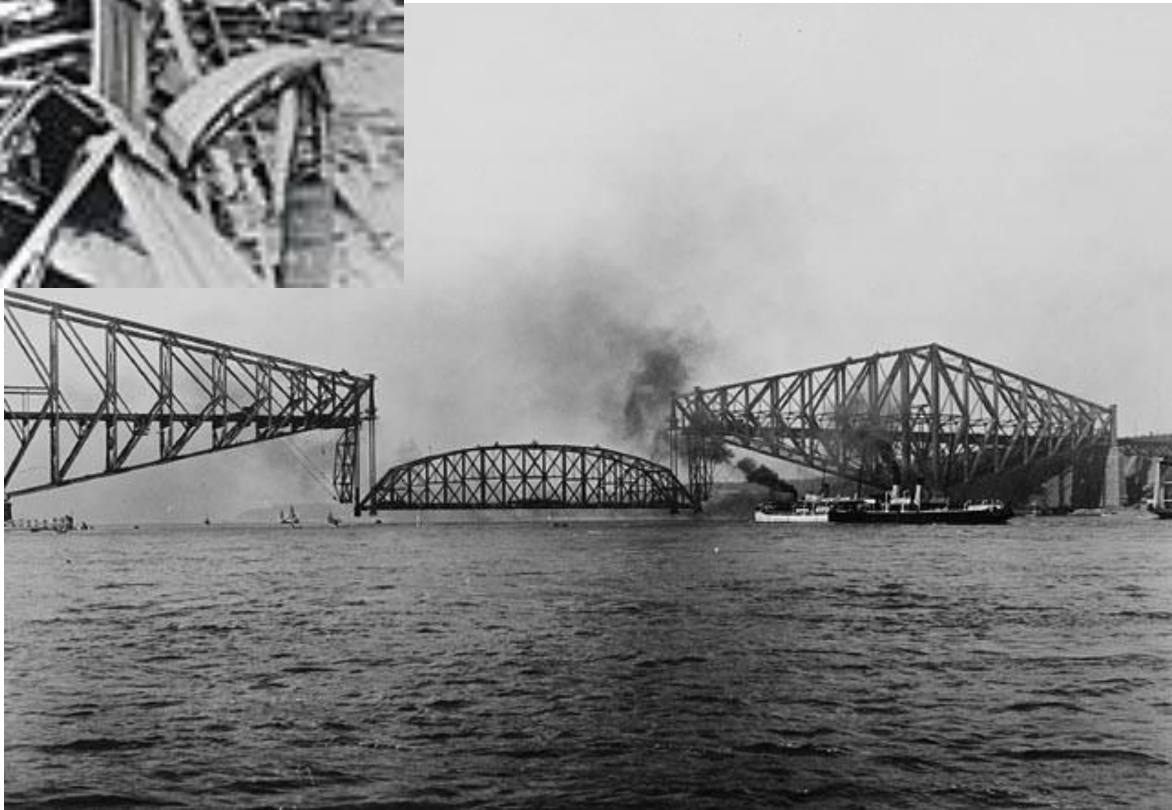
Schoharie Creek Bridge


Pier 3

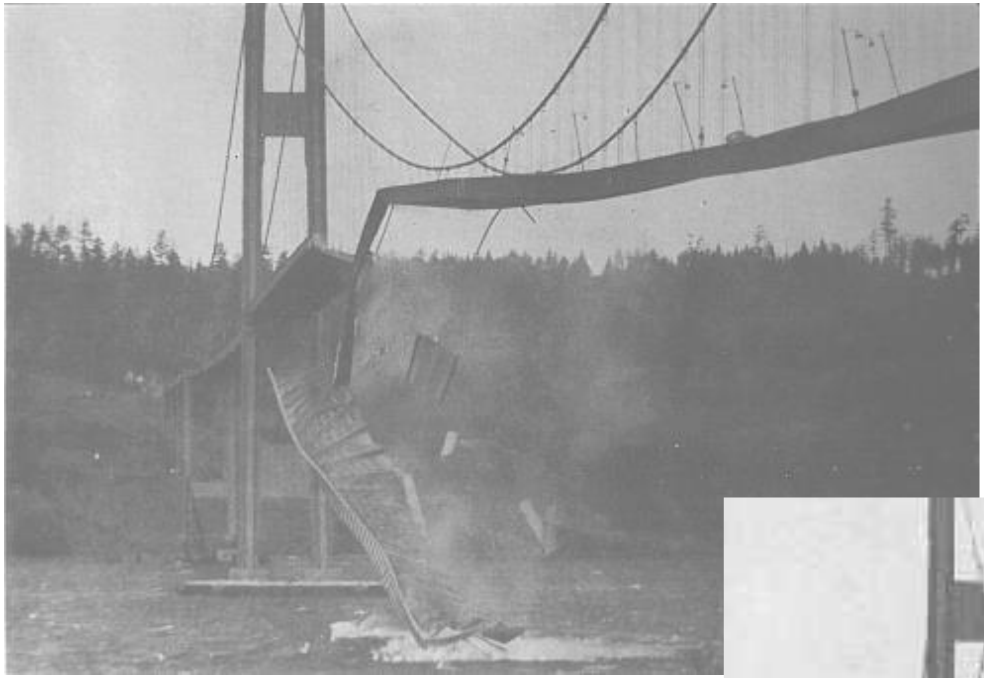
Depth of Scour

Damaged Plinth

Example: Quebec Bridge two collapses during construction



Example - Tacoma Narrows Bridge




ATSU
APR 13 2006
KOMATSU


APR 13 2006


HYUNDAI
02/14/2006


02/14/2006

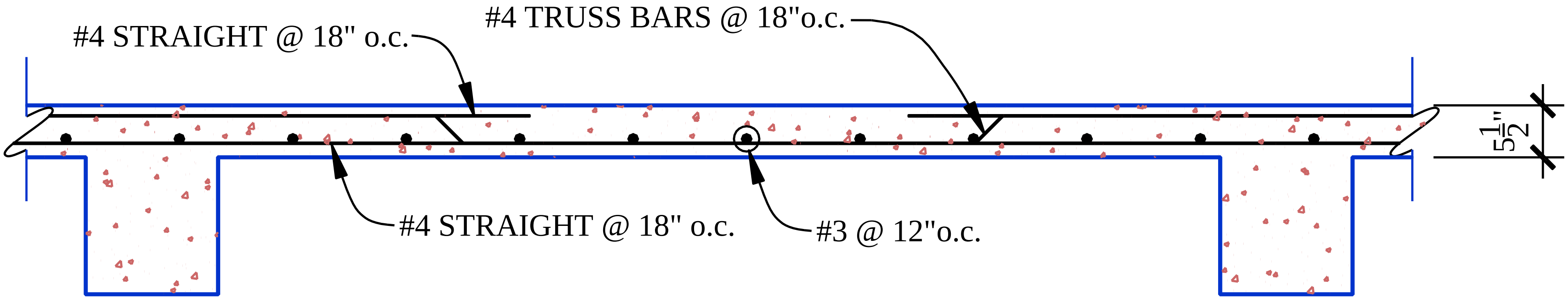
Before September 11

Security Camera Image 2

After Collapse

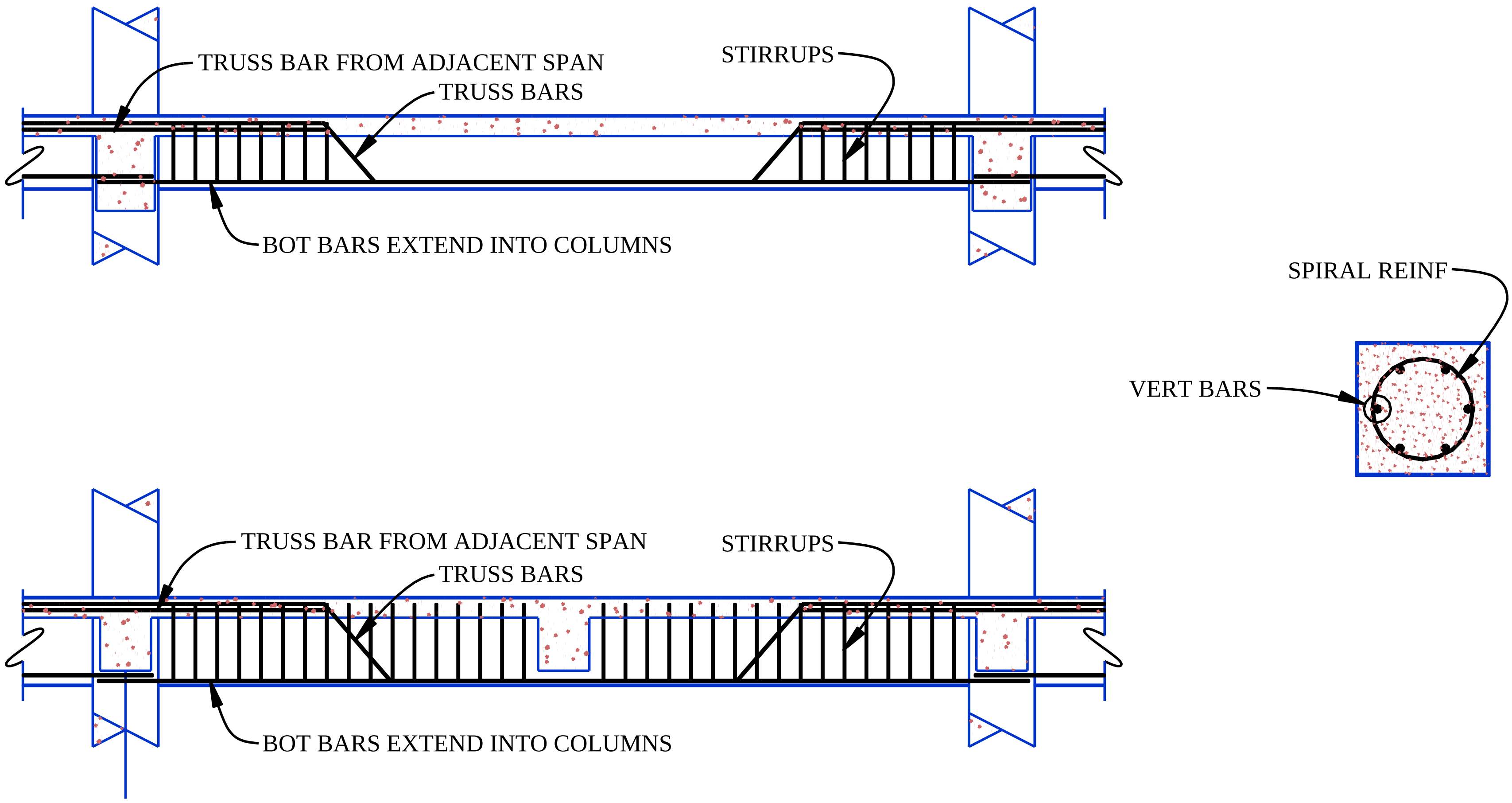
Exterior of Collapsed Portion

Typical Slab



- 1941 Design prompted by anticipated war
- Planned to become a storage facility
- Floor live load = 150 psf (7 kN/m^2)!

Typical Column, Girder, Beam



Before Shoring

Stripped Column

Beam Stripped from Slab

Protection of Infrastructure Facilities

- Major national investment; buildings, roads, bridges, industrial structures, pipelines, power lines
- These facilities are critical to the US economy
- And they are vulnerable to extreme events
- Protective design is a priority topic by various federal agencies, including Department of Homeland Security, Department of Defense, Federal Highway Administration

Theoretical and Actual Failure Rates

- Discrepancy between theoretical and actual failure rates is due to an incomplete theoretical model
- Most failures due to human errors, and errors are not included in the reliability analysis
- Reliability: calculated with random parameters that vary due to causes within the acceptable practice only.

Theoretical and Actual Failure Rates

- 1980 : human error recognized as a major issue in structural safety
- Since 1980 : studies in North America, Europe, Australia and Japan
- Perception of risk has been drawn to the importance through major incidents or disasters

Theoretical and Actual Failure Rates

- Control of errors : important part of the strategy to improve reliability of structures
- It involves :
    - Reduction of causes
    - Reduction of consequences
    - Inspections and checking
    - Sensitivity analysis

Major Contributions in Research Related to HE

- Pugsley (UK)
- Rackwitz (D)
- Schneider (CH)
- Knoll (CA)
- Blockley (UK)
- Lind (CA)
- Hadripriono (USA)

Allen (USA)
Matousek (CH)
Brown (USA)
Nowak (USA)
Melchers (AUS)
Turkstra (CA)

CLASSIFICATION OF ERRORS

- Useful in selection of the efficient control measures
- Categorized with regard to causes and consequences
- Analysis of causes : identification of occurrence of mechanisms
- Consequential errors can be prevented by additional control measures and by special design methods

CLASSIFICATION OF ERRORS

- Errors can be considered with regard to
  - Who ?
  - When ?
  - Where ?
  - When ?
  - How often ?

Alternative Paths with regard to Acceptable Practice

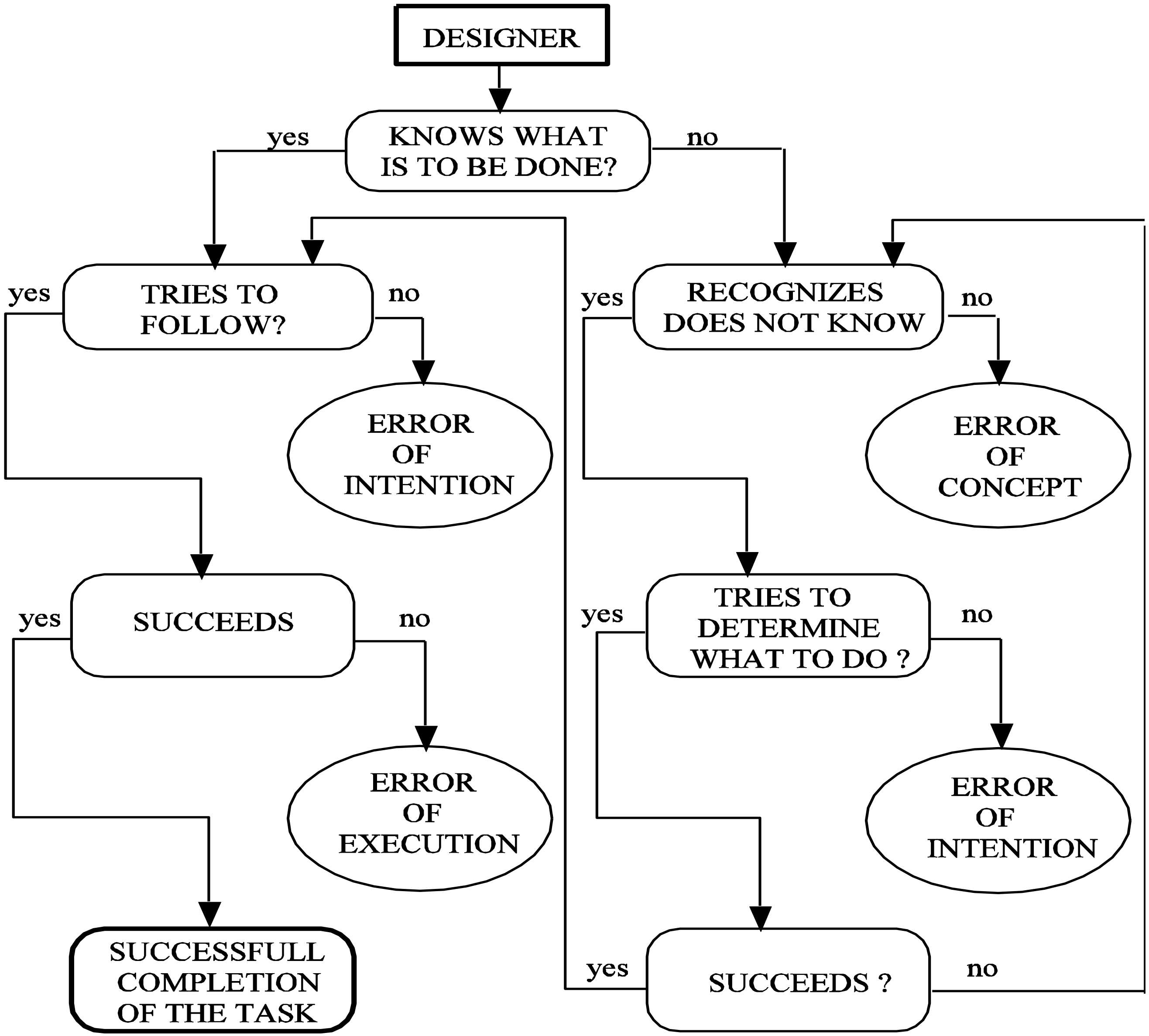


Figure 10-3 Alternative Paths with Regard to Acceptable Practice.

Errors of Execution

- Omitted, forgot, lost, left out
- Mis-understood, mis-read, mis-wrote, mis-drew, mis-hear, mis-operated, mis-placed, mis-interpreted
- Did not recognize
- Did not think of, did not hear, did not see
- Calculation errors

Conceptual Errors

- Not being aware of the most applicable method, model
- Not knowing which method was the most applicable
- Not knowing how to use the method or model
- Failing to do something because of lack of knowledge
- Not knowing the acceptable level of effort or care
- Not knowing the possible consequences
- Failing to understand assumptions or limitations
- Using simplifying assumptions which were not correct

Intentional errors

- Expediency
- To save time, money, energy or bother
- To avoid responsibility or liability
- To avoid embarrassing someone else
- Designer did not have the capability to do the work according to accepted practice
- Impossible to do the work under accepted practice
- Designer accepted risk which was recognized as unacceptable
- Designer chose to depart from common practice without acceptable reason

Example of a chain of errors

- Inexperienced engineer designing a reinforced concrete
  - Ignorance of the code
    - Wrong number of rebars
      - Poor strength
        - Failure causing damage
        - Failure causing injury to the users

Errors Surveys

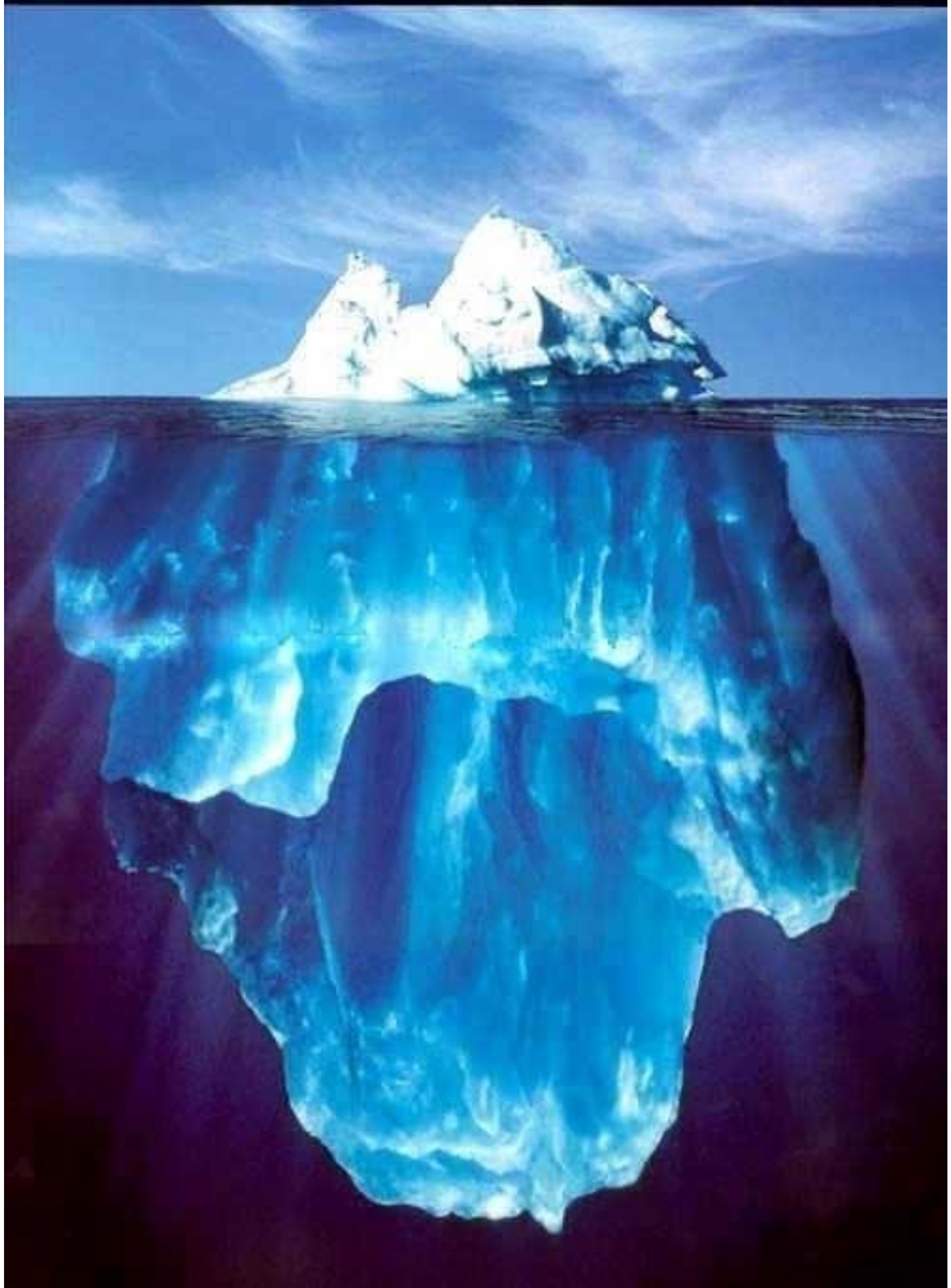
- Available data sources :
  - Failure surveys
    - North America (Fraczek 1979, Allen 1977)

      Survey on design and construction of concrete structures (90% of failures due to design and construction errors)

    - Europe (Matousek 1977)

      45% of failures due to defects in design

      49% of failures due to construction



Surveys of Errors

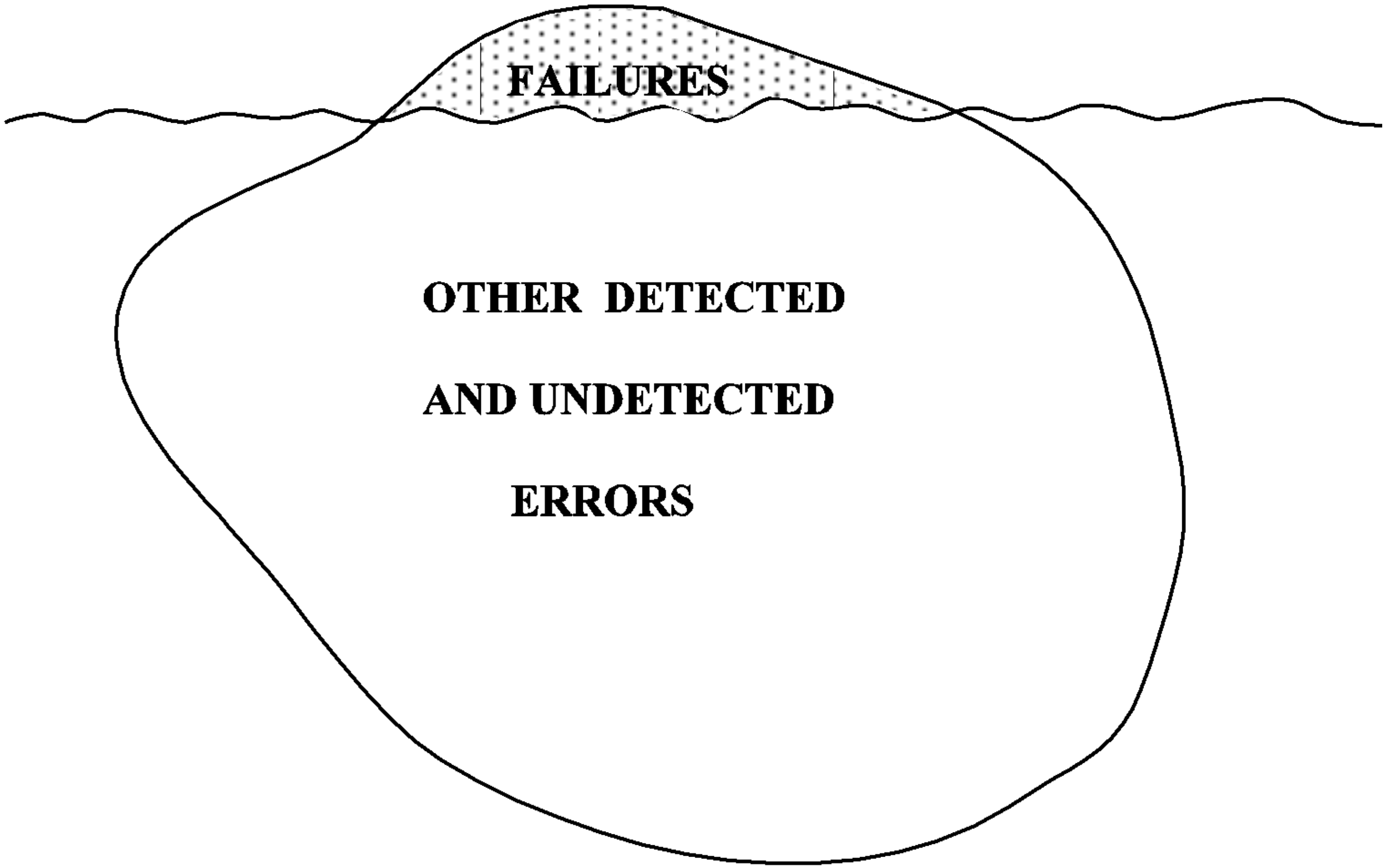


Figure 10-4 Detected and Undetected Human Errors.

Errors Surveys

- To increase the data base for study of errors, a survey was conducted by a research team at the University of Michigan.
- Survey: detected errors and near-failure cases.
- Projects: office buildings, parking structures, nuclear power plants, bridges and others.
- Natural aversion to admit commission of errors: an important barrier
- Solution: identities not revealed

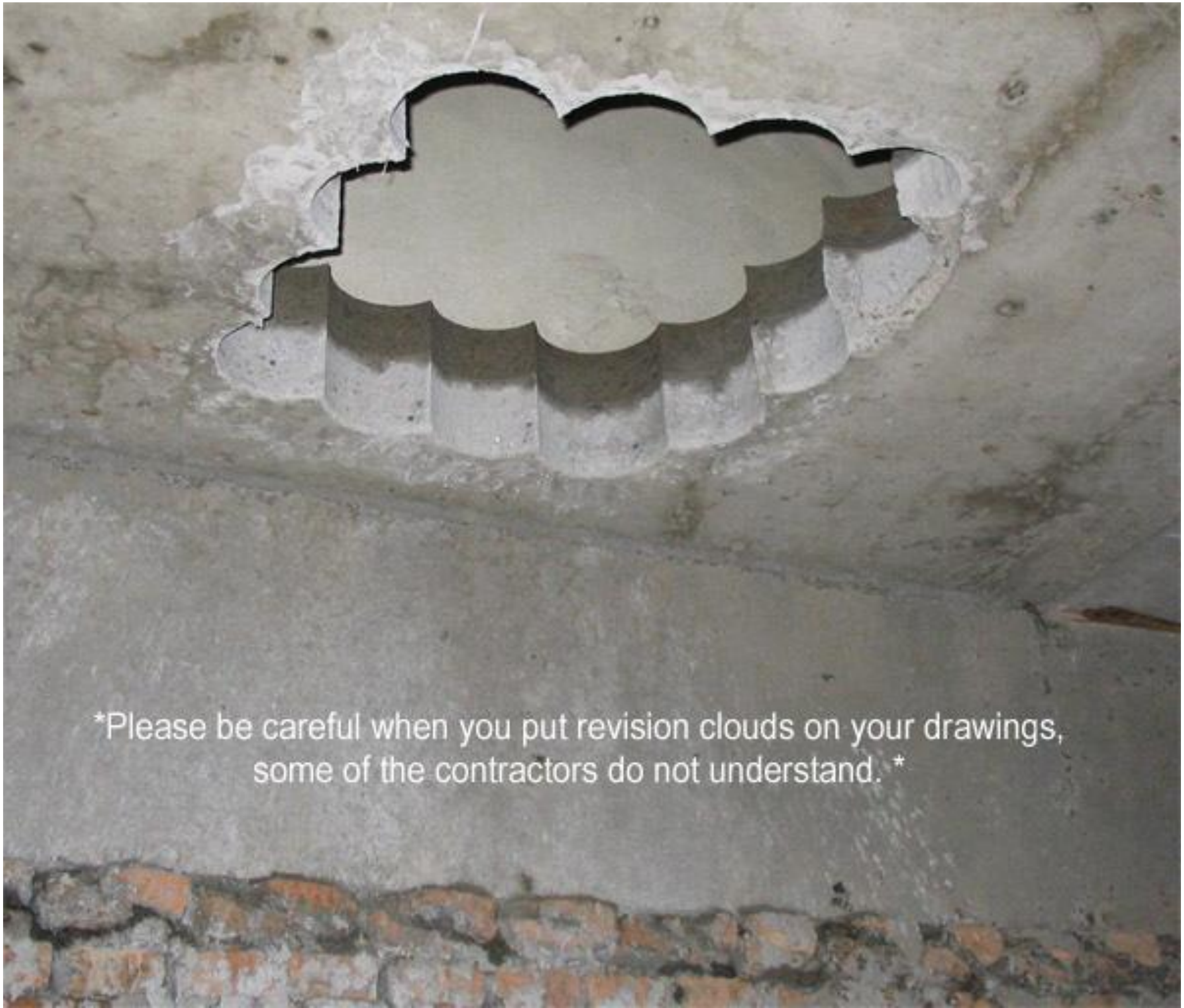
Errors Surveys (Results)

- Incomplete understanding of the behavior of the structure
- Poor judgment and overlooking the problem
- Calculation errors are not detected
- Change of use is a frequent error
- Contractor interprets the design and drawings to his own advantage
- Organizational problems; lack of continuity
- Trying to fit numbers in wrong formulas
- Errors often occur when information is copied from different sources without understanding

Errors Surveys (Results -continued)

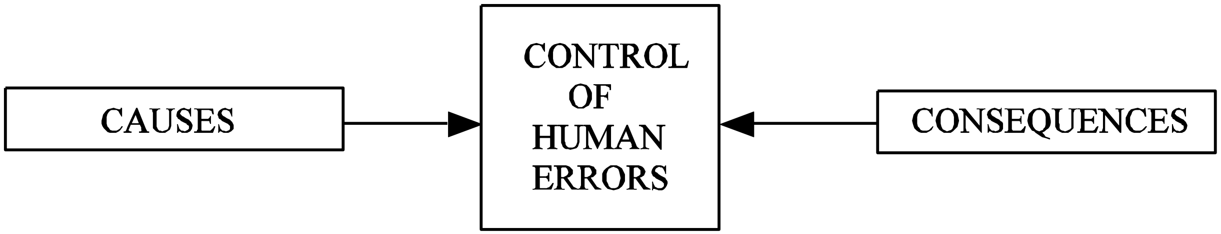
- Specification ambiguity
- Errors caused by inexperienced engineers, designers and inspectors
- Poor inspection or no regulations to provide good inspectors
- Lack of coordination between field engineers
- Communication problems
- Undefined goals so that a change of use may be expected
- little attention given to the boundary conditions and supports
- incomplete design and ignorance of some important forces such as torsion or buckling…

Human Error?


*Please be careful when you put revision clouds on your drawings,
some of the contractors do not understand. *

APPROACH TO ERRORS

Probability of failure depends mostly on the control of causes and consequences of errors



- The causes cover frequencies of occurrence and reasons. They can be controlled (reduced) by inspections, checking, improvement of working, or use of special design and construction techniques

Approach to errors

- Error frequency can be reduced by reducing or eliminating opportunity
- Consequences of errors can be controlled through identification of the consequential errors using the sensitivity analysis. Sensitivity analysis determine relation between error magnitude and structural reliability. Human errors may affect parameters or modes of structural behavior.

Sensitivity analysis - Example

- Simply supported beam designed to resist a uniformly distributed load.

- Calculated reliability index $\beta = 3.5$

- It is often the case that during construction or use the load can be piled in the central portion of the beam , rather than spread over the whole length.

- 3 cases taken into account

Sensitivity analysis – Example

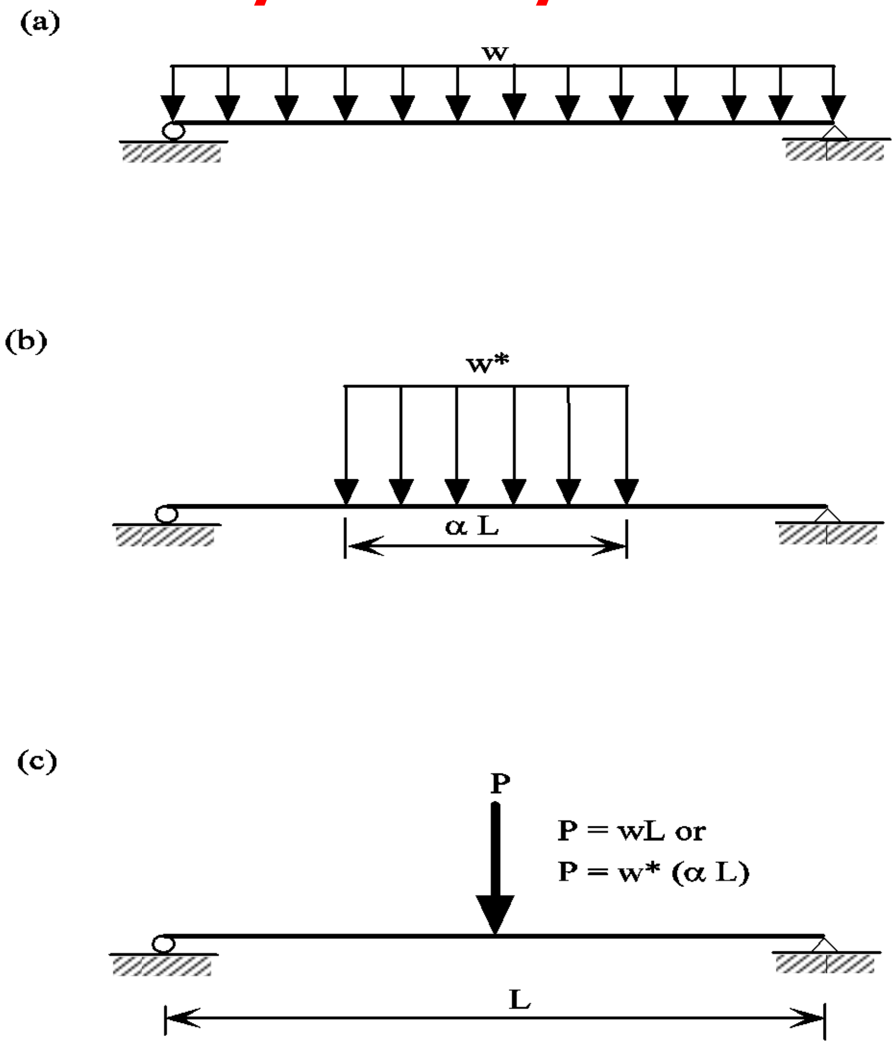
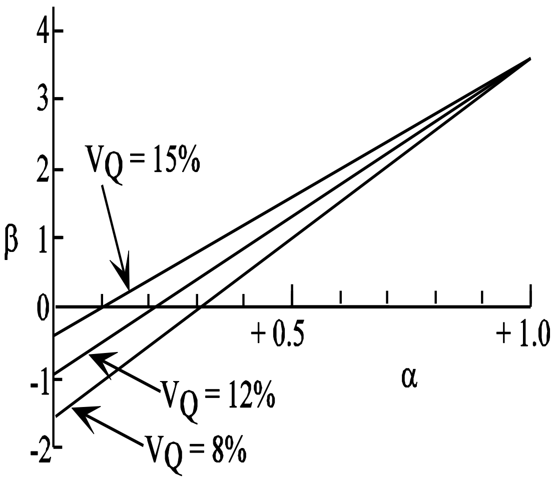


Figure 10-6 Simple Beam with (a) Uniformly Distributed Load on the Whole Span,
(b) Uniformly Distributed Load on the Middle Portion of the Span, and
(c) Concentrated Force at Midspan.

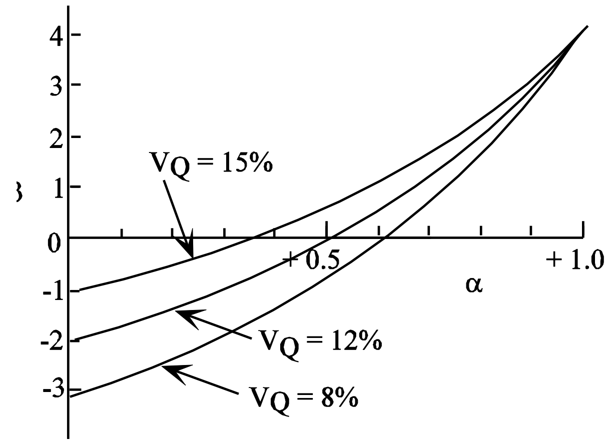
Sensitivity analysis – Example



STEEL BEAM

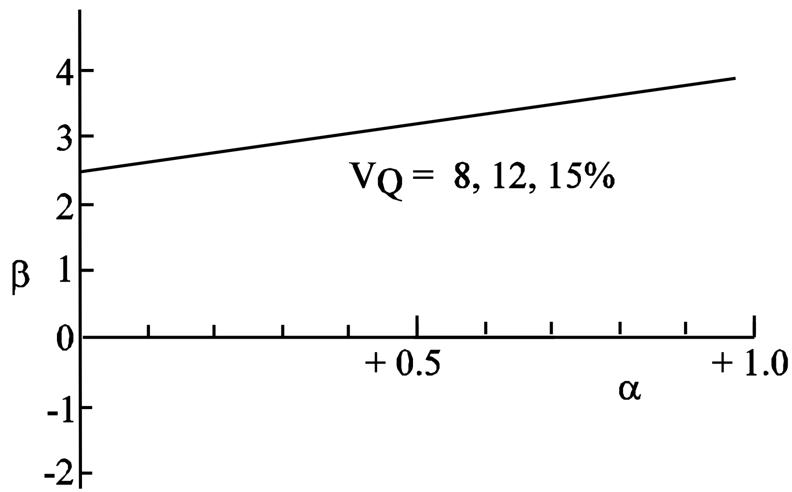
V_R = 10.5%

(Flexure Compact Section)



PRESTRESSED CONCRETE BEAM

V_R = 6.5%
(Bridge Girder)



TIMBER BEAM
DOUGLAS-FIR
6 x 16 inch
(150 x 400 mm)

V_R = 22.5%

Sensitivity Analysis

Procedure

1. Develop a structural model: identify parameters and limit states functions
2. Generate possible scenarios for errors
3. Calculate the reliability for each scenario
4. Calculate overall reliability
5. Identify most sensitive parameters

SENSITIVITY ANALYSIS
Bridge slab

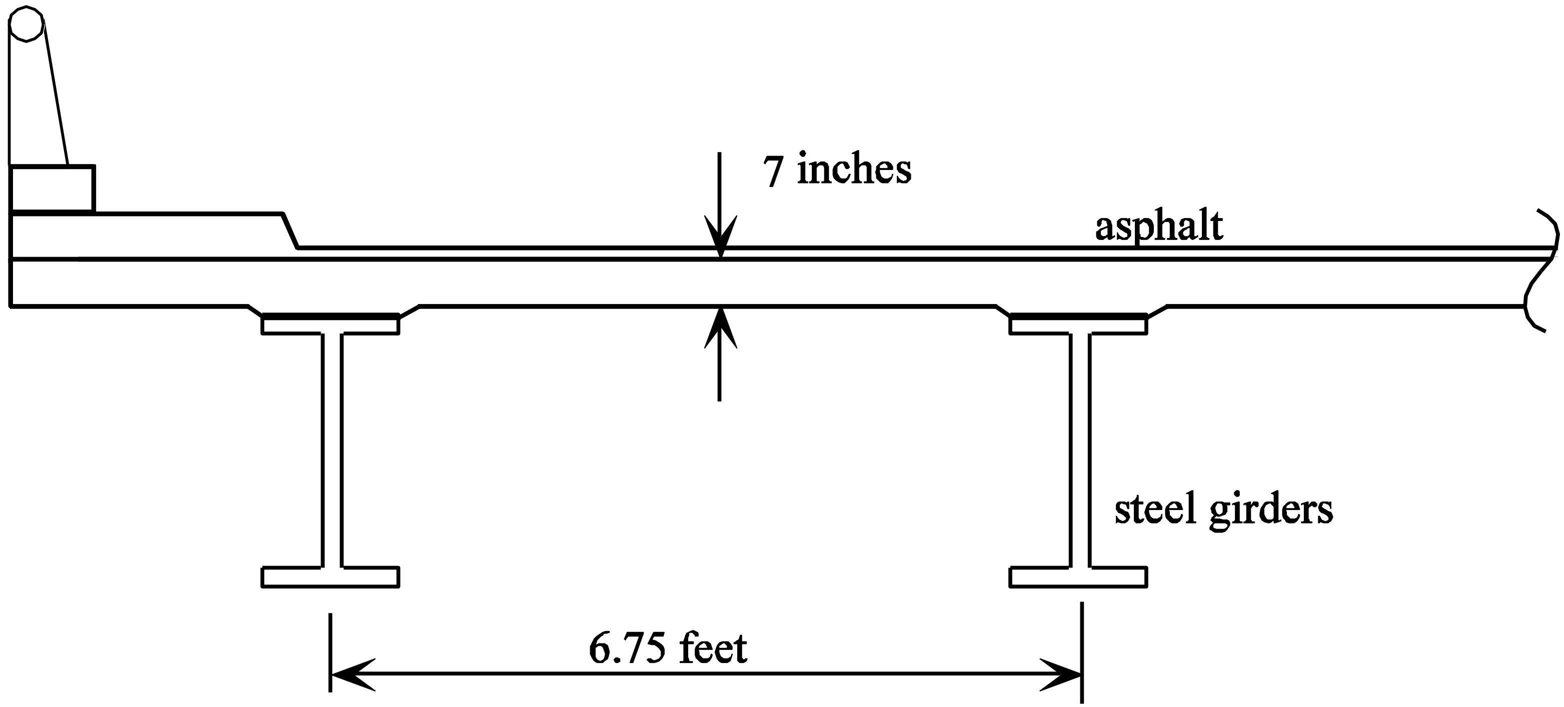


Figure 10-8 Bridge Slab.

SENSITIVITY ANALYSIS Bridge slab

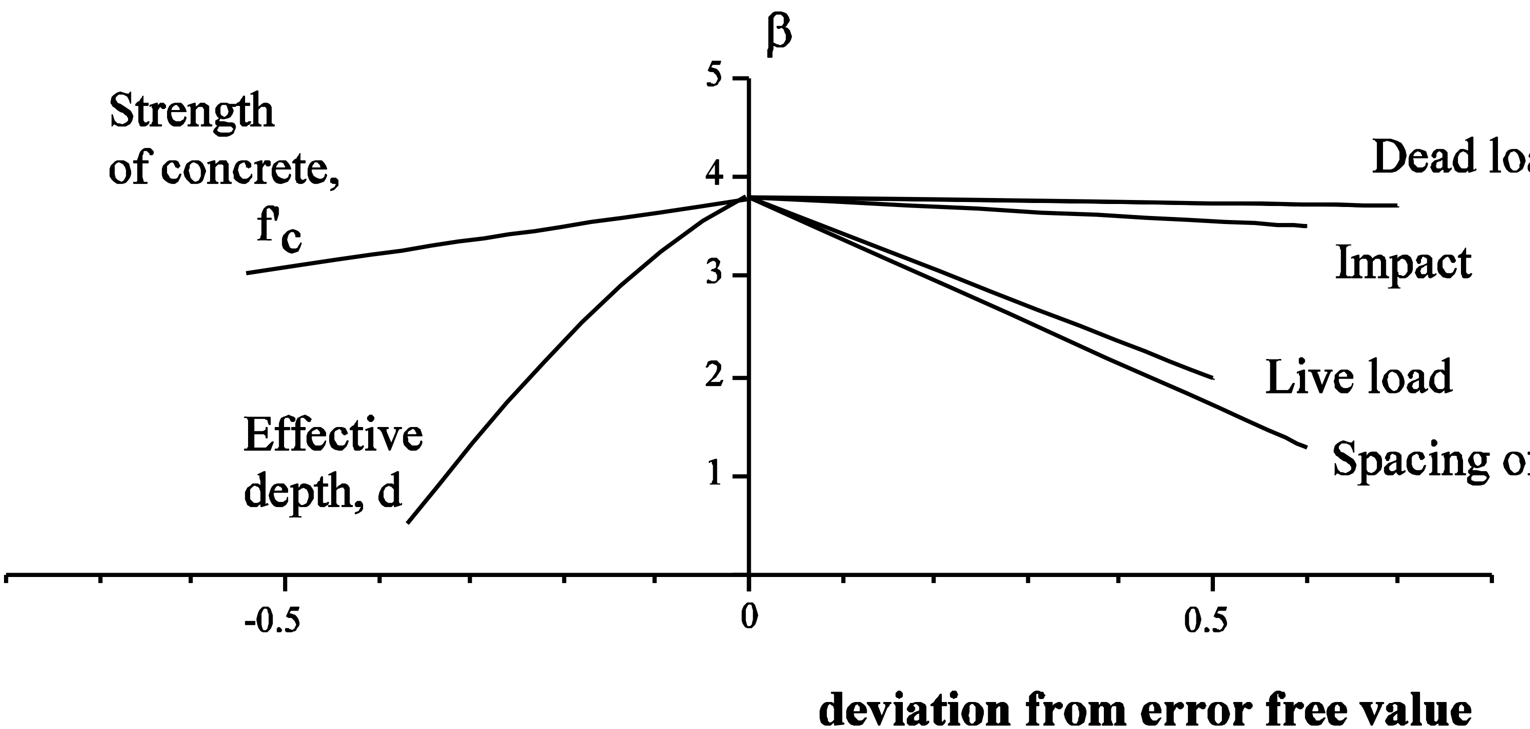


Figure 10-9 Sensitivity Functions for Bridge Slab.

SENSITIVITY ANALYSIS Beam-to-Column Connection

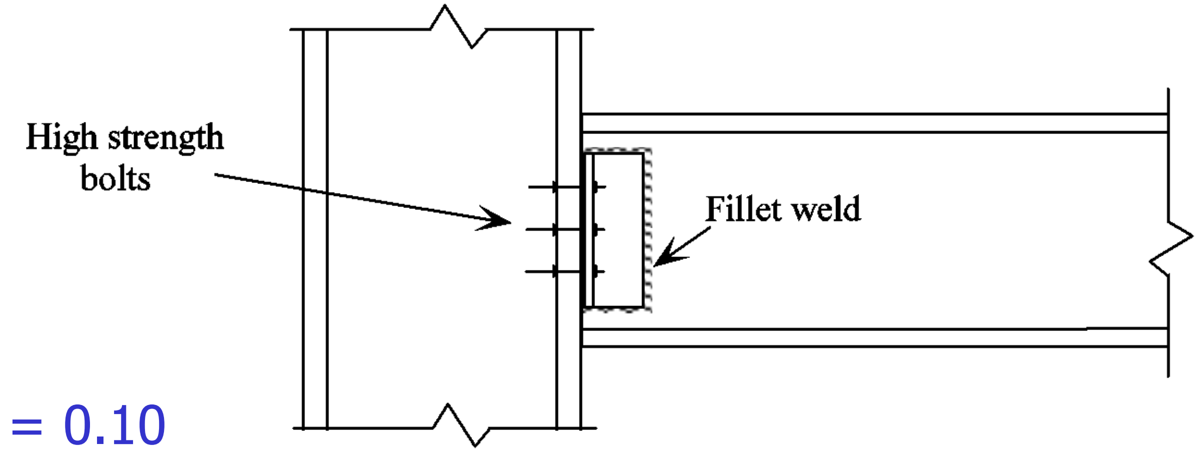
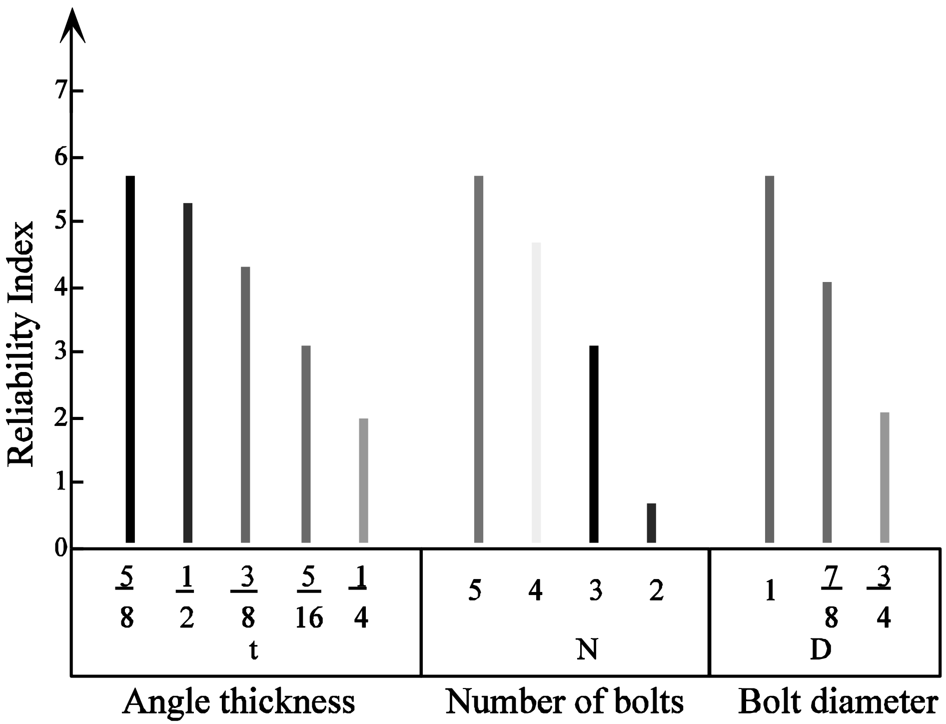


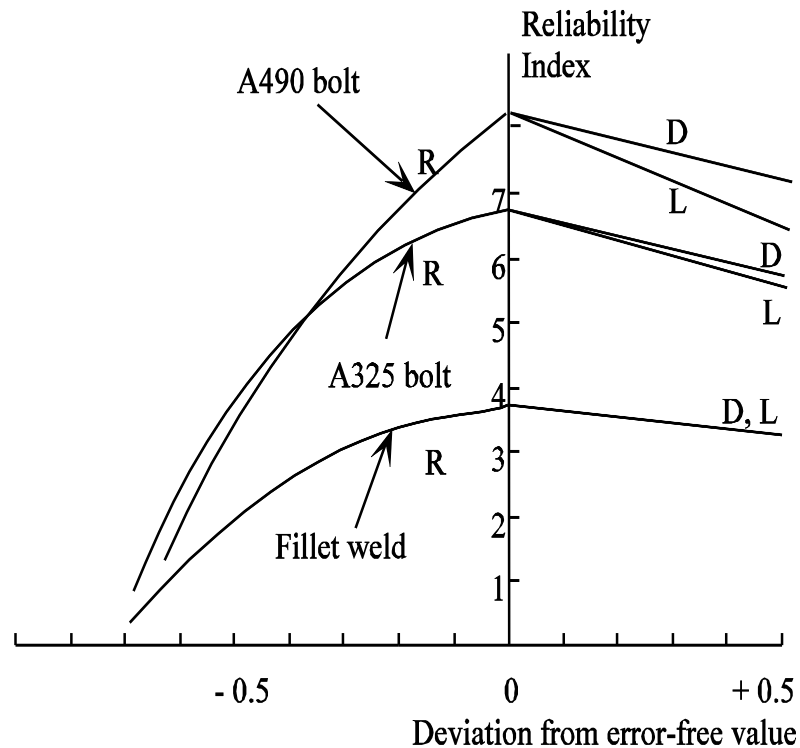
Figure 10-10 Steel Beam-to-Column Connection.

- D = L
  λ_D = 1.0; V_D = 0.10
  λ_L = 0.85; V_L = 0.20

μ_R = 2.93 (D+L) V_R = 0.185 for fillet weld
μ_R = 3.00 (D+L) V_R = 0.10 for A325 bolts
μ_R = 2.51 (D+L) V_R = 0.07 for A490 bolts

SENSITIVITY ANALYSIS Beam-to-Column Connection





SENSITIVITY ANALYSIS Bridge Timber Deck

- Major parameters considered
  - MOR = Modulus of Rupture
  - MOE = Modulus of Elasticity
- Reliability analysis : Monte Carlo

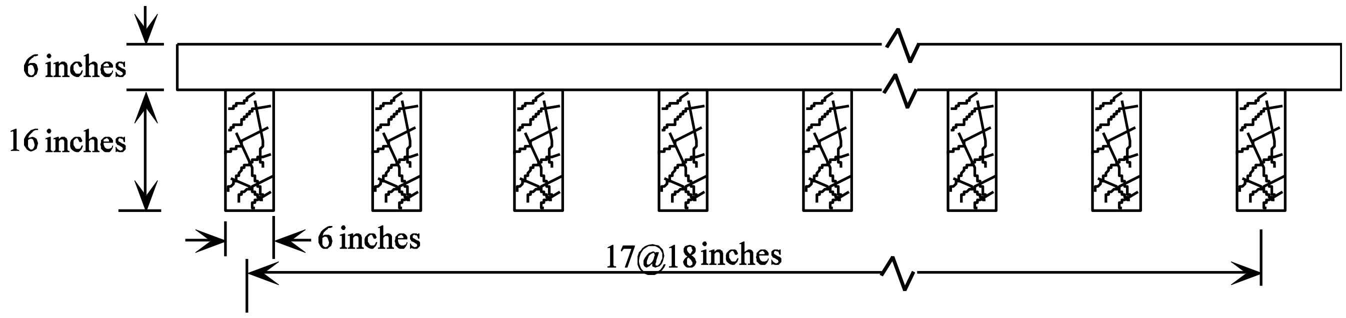


Figure 10-13 Bridge Timber Deck.

SENSITIVITY ANALYSIS Bridge Timber Deck

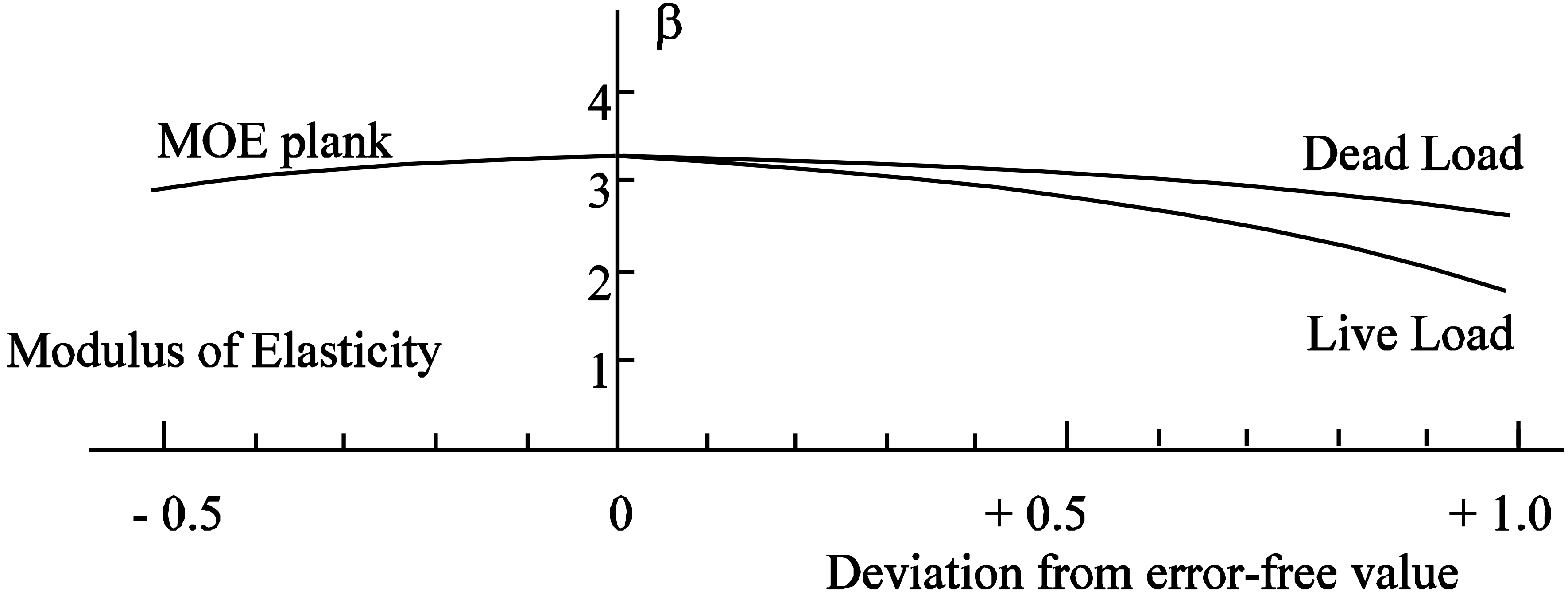


Figure 10-14 Sensitivity Functions for Bridge Timber Deck.

SENSITIVITY ANALYSIS
Partially Rigid Frame Structure

- Fully fixed support A,
  $\beta = 2.7$

- Partially fixed support A,
  $\beta = 2.0$

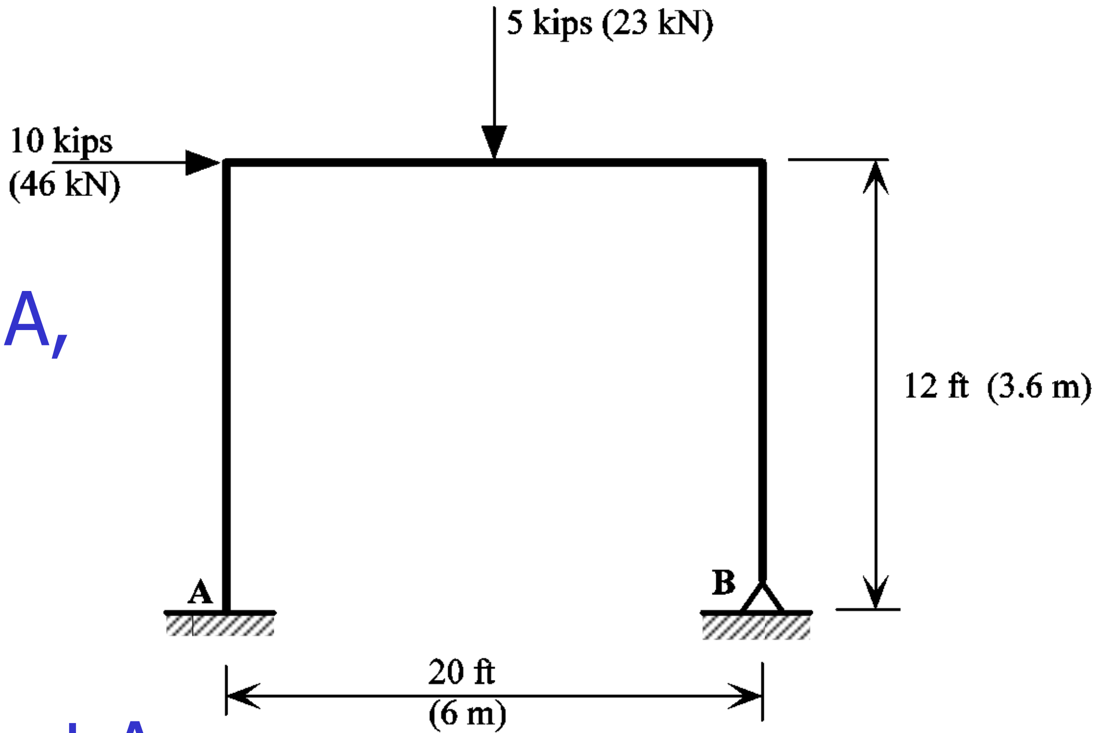


Figure 10-15 Partially Rigid Frame Structure.

SENSITIVITY ANALYSIS
Rigid Frame Structure

Parameters	Bias	Coefficient of Variation	PDF
Material properties, M_P	1.1	0.11	Log-normal
Gravity load P	0.6	0.20	Normal
Horizontal load H	0.8	0.25	Extreme Type I

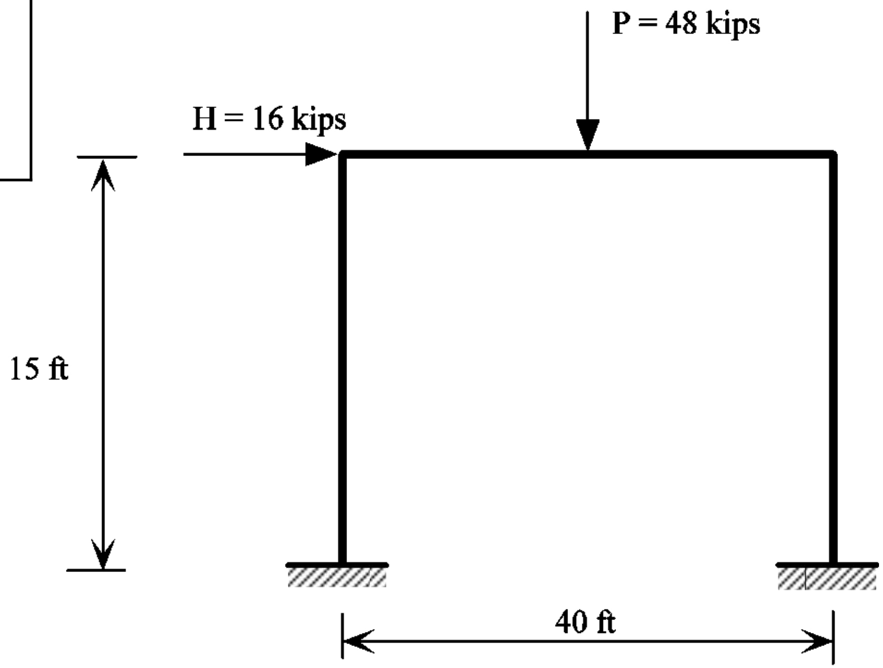
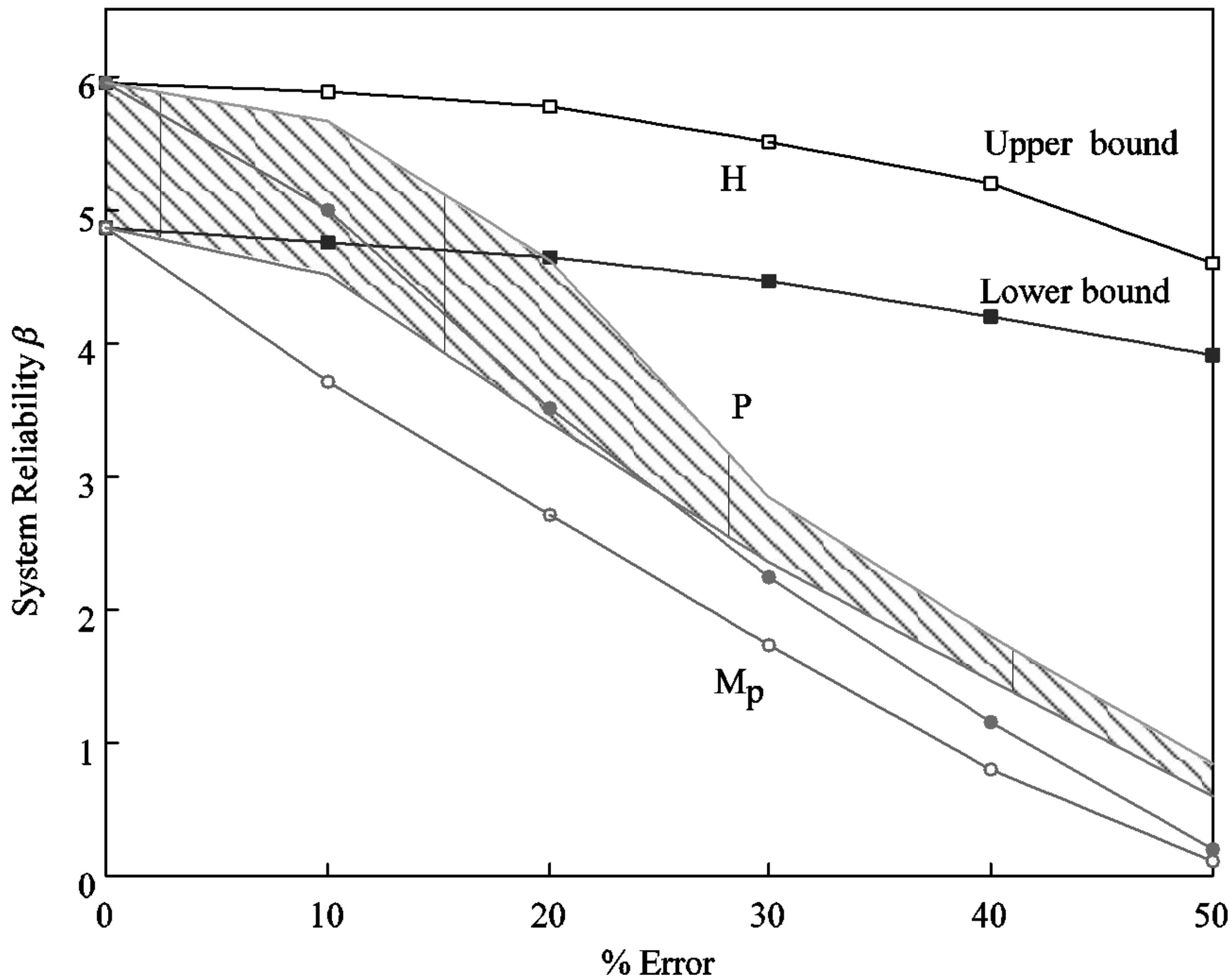


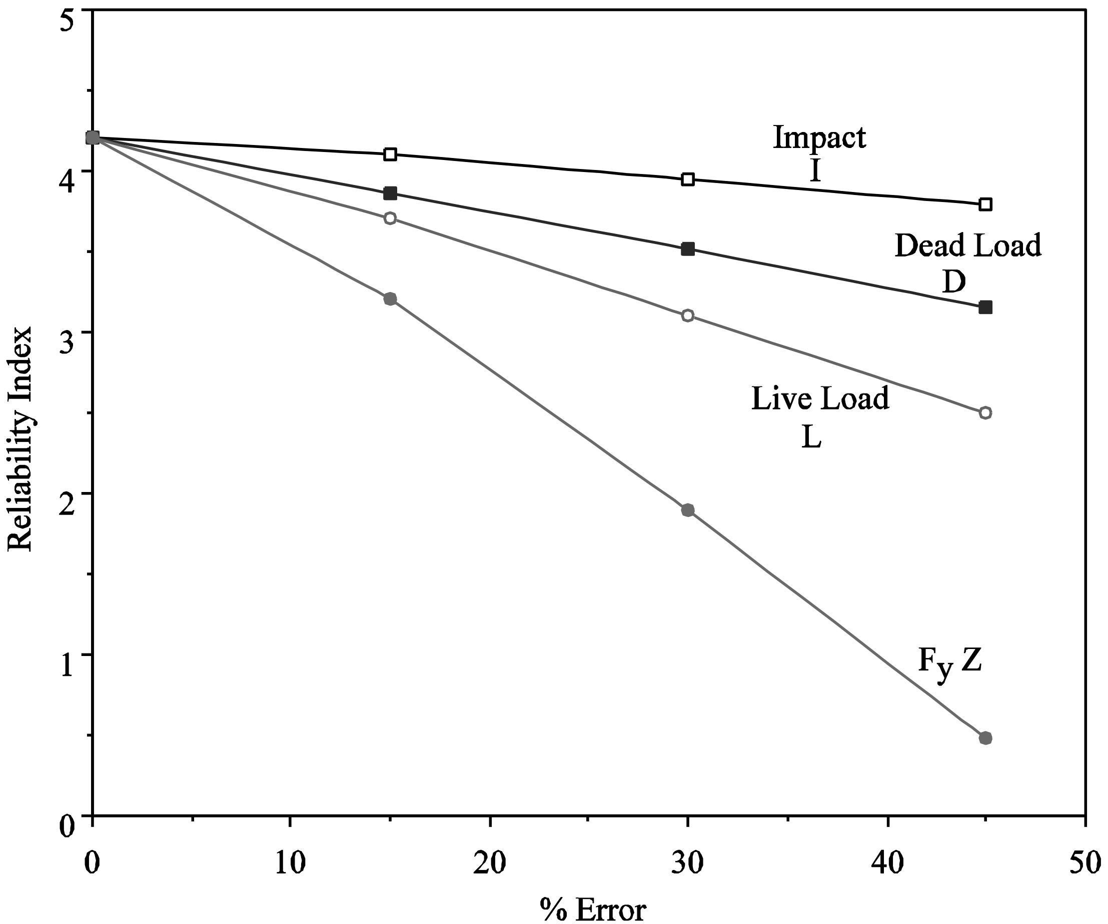
Figure 10-16 Rigid Frame Structure.

SENSITIVITY ANALYSIS
Rigid Frame Structure



SENSITIVITY ANALYSIS
Non-Composite Steel Bridge Girder

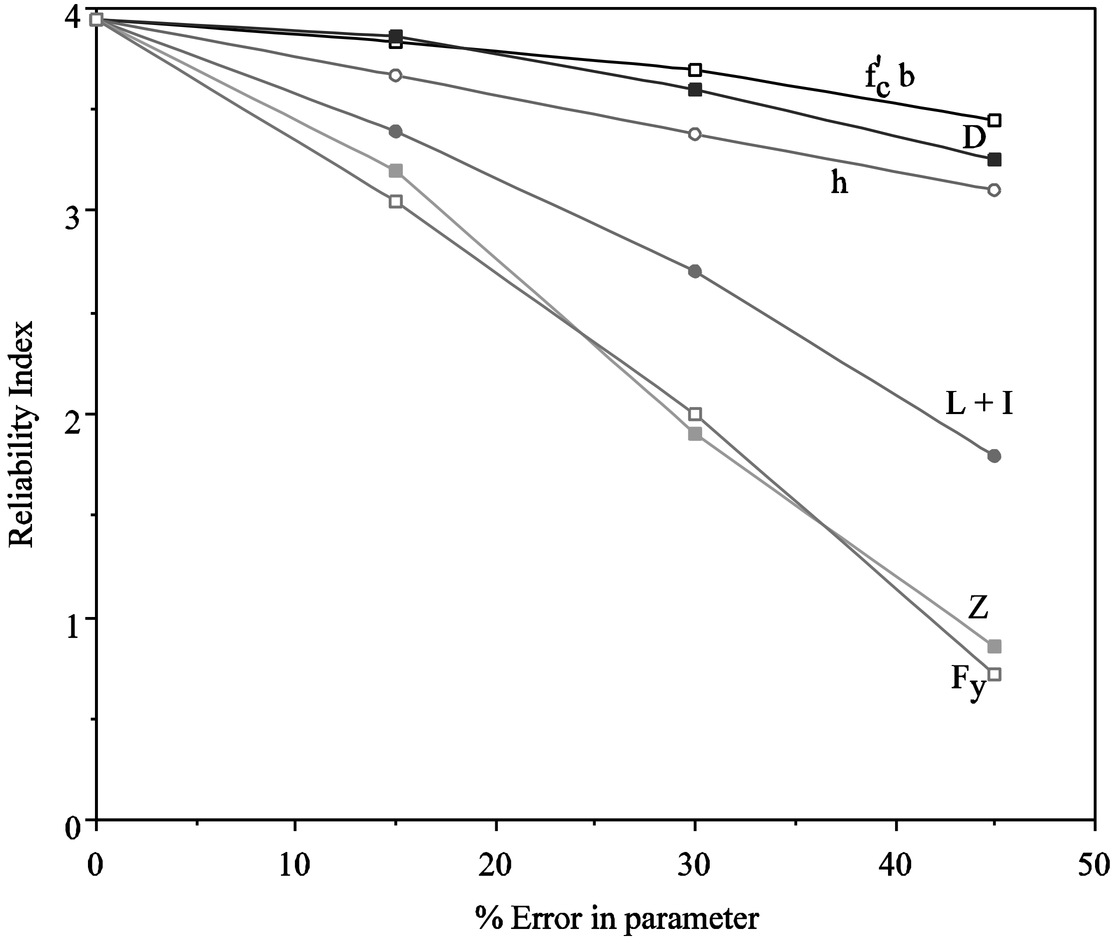
- Span = 18 m
- Girders : W36 x 210
  Spacing 2.4 m
- Fy = 250 MPa
- Slab thickness = 180 mm
- Concrete Slab f'c = 21 MPa



SENSITIVITY ANALYSIS
Composite Steel Bridge Girder

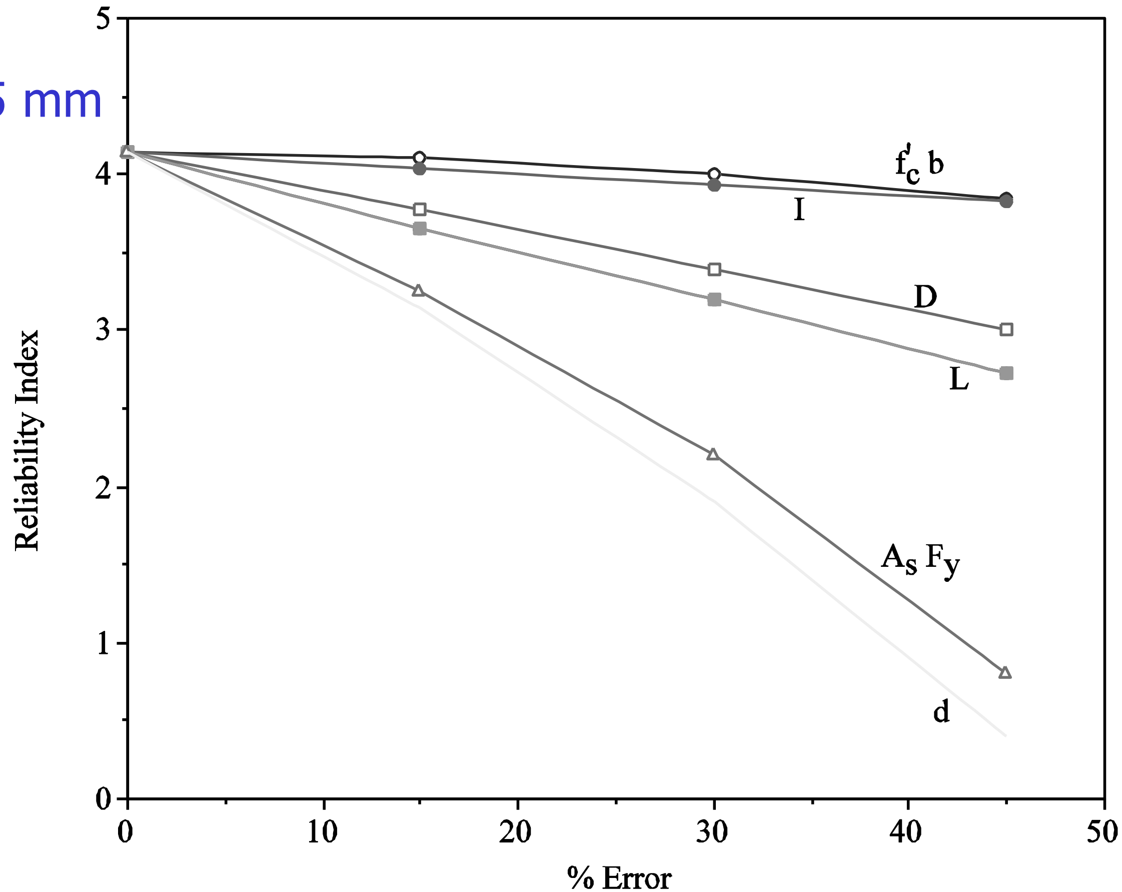
- Span = 18 m
- Girders : W33 x 130

  Spacing 2.4 m
- Fy = 250 MPa
- Slab thickness = 180 mm
- Concrete Slab f'c = 21 MPa



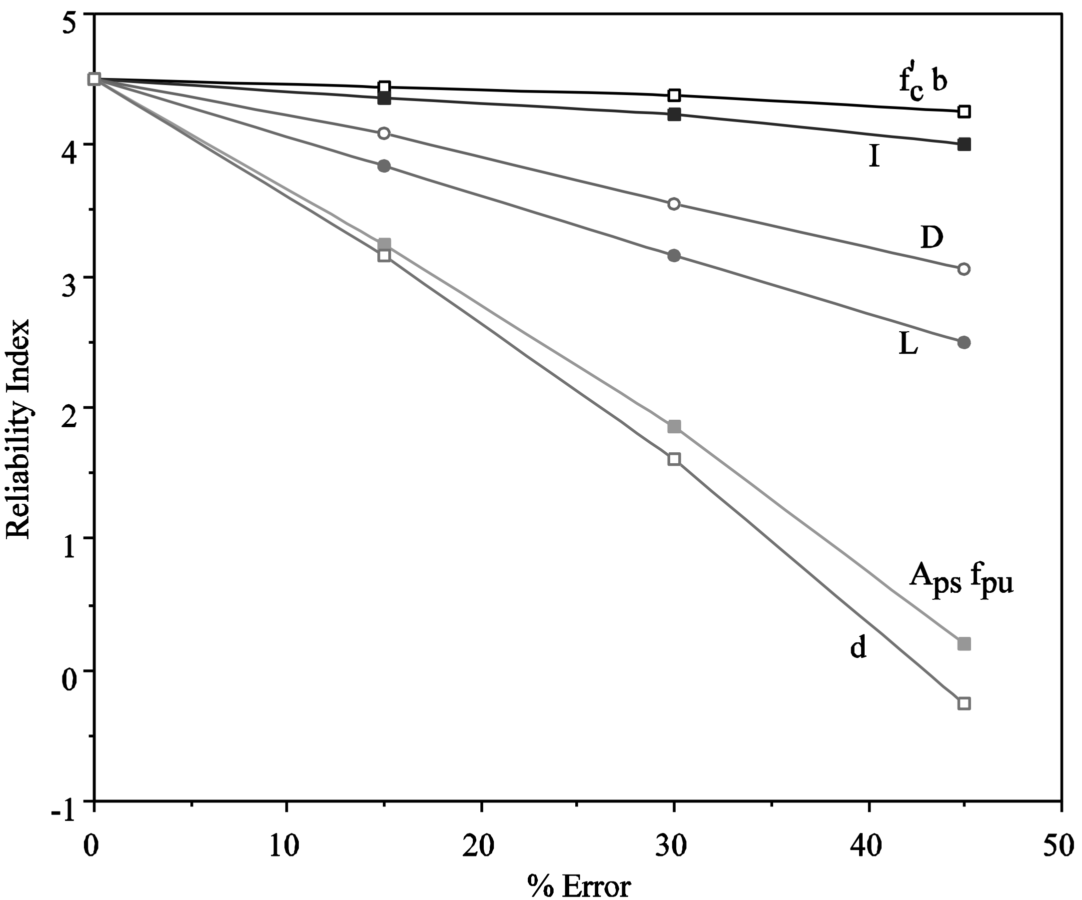
SENSITIVITY ANALYSIS Reinforced Concrete T-Beam

- Span = 18 m
- Beam effective Depth = 915 mm
  Spacing = 2.4m
- Concrete Slab f'c = 21 MPa



SENSITIVITY ANALYSIS Prestressed Concrete Girder

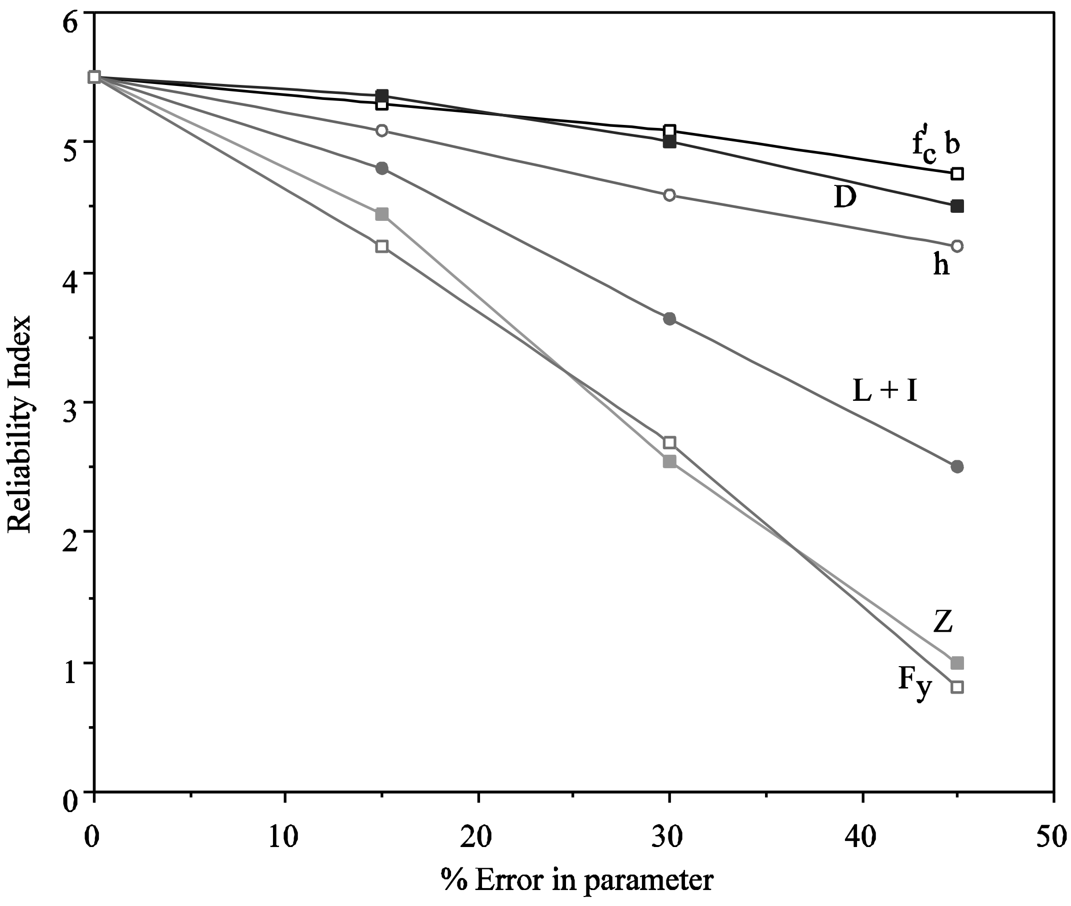
- Span = 18 m
- fpu =1860 MPa
- Slab Thickness = 180 mm
- Concrete girder = 28 MPa
- Concrete Slab f'c = 21 MPa



SENSITIVITY ANALYSIS
Composite Steel Bridge System

- Span = 18 m
- Girders : W33 x 130

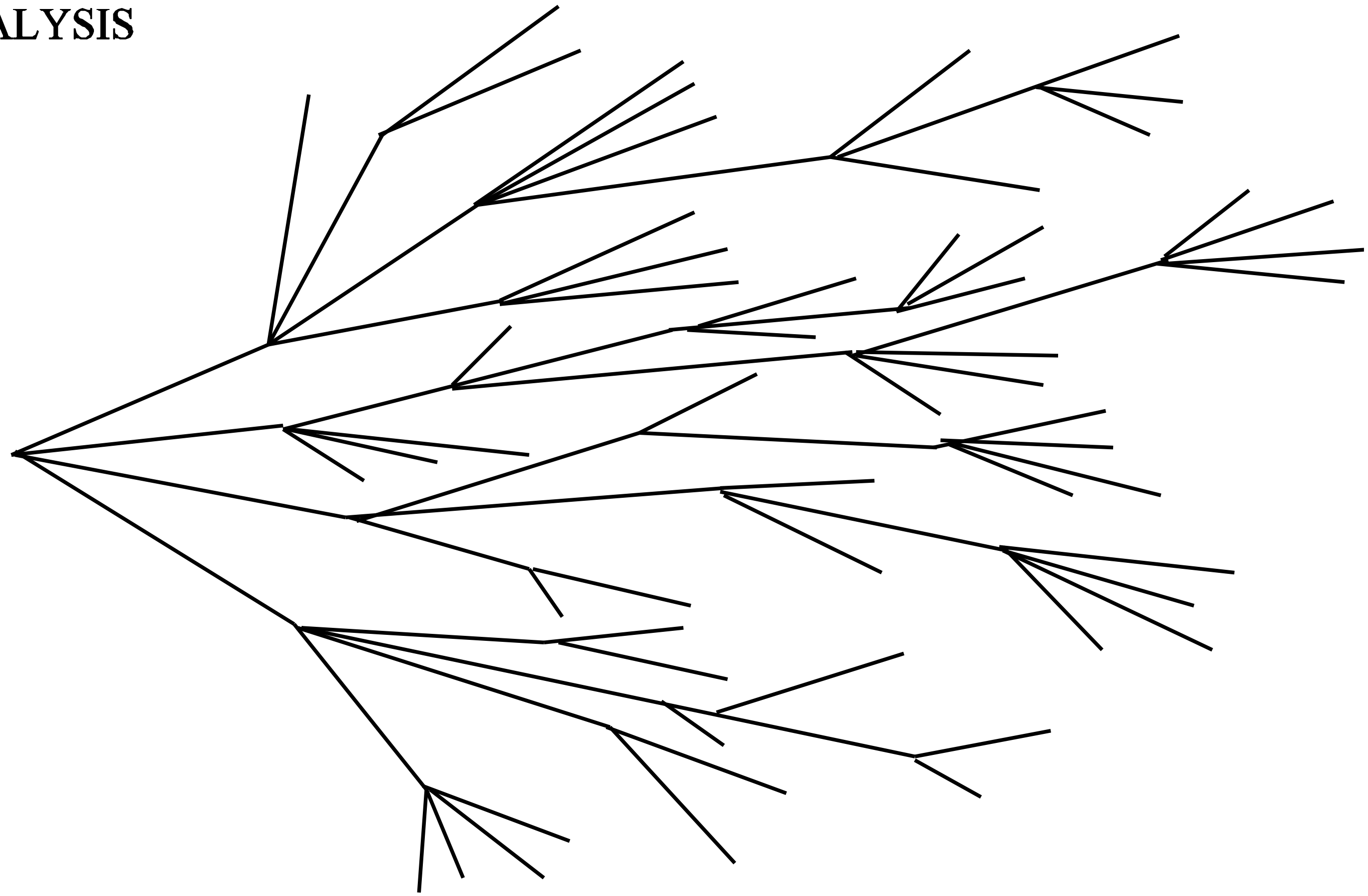
  Spacing 2.4 m
- Fy = 250 MPa
- Slab thickness = 180 mm
- Concrete Slab f'c = 21 MPa



OTHER APPROACHES

- Failure Tree Analysis

FAILURE TREE (EVENT TREE) ANALYSIS



OTHER APPROACHES

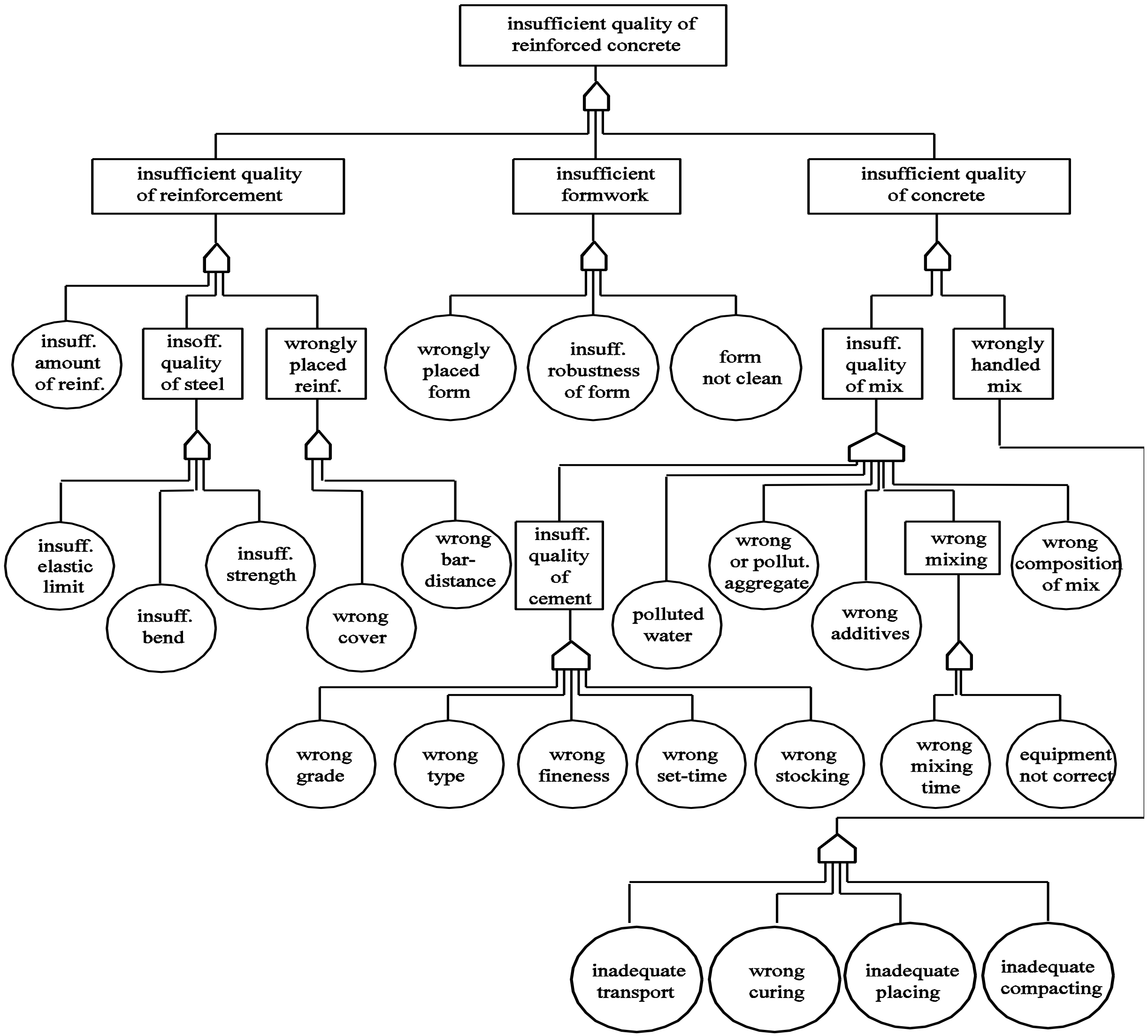


Figure 10-24 Fault Tree for Reinforced Concrete Structure (Task Group I, CEB 1983).

Human Errors - Conclusions

- Major cause of structural failures
- Reliability depends on the control of errors, their causes and consequences
- Optimization of error control :
  - Identification of the most frequent errors (error surveys)
  - Identification of consequential errors (sensitivity analysis)
- Methods of control (inspection, checking, monitoring, fool-proof design, proof loading)