Risk Analysis for Bridges

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Outline

- Importance of bridges
- Natural and man-made hazards
- Risk analysis procedures
- Target reliability
- Implementations

Bridges in USA

- Bridges are structures with span larger than 20 ft
- There are 584,000 highway bridges (4 million paved roadway)
- Interstate highway network consists of about 50,000 miles of highways and 54,800 bridges
- Traffic growth: number of vehicles and weight of trucks

National Bridge Inventory (NBI)

- NBI is maintained by the Federal Highway Administration (FHWA)
- Total number of bridges in NBI is 584,000
- NBI includes bridge location, structural type, material, number of spans, span length(s), width, and rating factors
- Federal Aid Highway Bridges – owned by State DOT’s (about 50%)
- Off System Highway Bridges – owned by Counties, Cities and private owners

Importance of Bridges

- Local and national economy (transportation)
- Considerable national investment
- Need to access affected regions during disasters (floods, hurricanes, earthquakes)
- Strategic importance for national defense, terrorist attacks
- Showcase for technological progress, signature bridges

General Problems

- Most bridges were built in 1950's and 1960's
- Bridges deteriorate due to aging, increased live loads, cracking, corrosion, environmental effects (freeze and thaw cycles), fatigue
- Many bridges (30%) are either structurally deficient or functionally obsolete. They need repair, rehabilitation or replacement
- Available funds are limited. How to use the limited resources in the most efficient way?

Needs

- Rational bridge design codes
- Efficient procedures for evaluation of existing bridges (actual loads, actual load carrying capacity)
- Efficient methods for repair and rehabilitation
- Rational protective and preventive measures (maintenance, monitoring, security devices)
- Methods for prediction of future changes

Current Trends

- Reliability-based design codes, load and resistance factor design (LRFD)
- Advanced finite element methods (FEM)
- Non-destructive evaluation techniques (NDT)
- Weigh-in-Motion (WIM) measurement of trucks
- Bridge management system (BMS)
- Focus on accelerated repair, rehabilitation and replacement

Future Developments

- Performance-based design
- Life-cycle optimization
- High-performance materials
- Computer-aided analysis and design
- Remote sensing and monitoring of structural performance
- Security considerations (protective design)
- Minimization of interference with traffic

Natural Hazards

- Wind (hurricanes, tornadoes)
- Snow and ice
- Floods (tsunami)
- Earthquakes
- Temperature effects
- Material degradation

Schoharie Creek Bridge

Depth of Scour

Damaged Plinth

Man-Made Hazards

- Inadequate maintenance (corrosion, cracking)
- Overloads (weight, height)
- Collisions – vehicles and vessels
- Acts o vandalism, intentional damage
- Terrorist attacks, explosions, fires

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Extreme Events

- Very small probability of occurrence
- Very severe consequences
- Approach:
  - Prevent, reduce probability of occurrence
  - Reduce consequences, contain the damage

Basic Questions

- How to measure probability of failure and reliability?
- What is the target reliability, or acceptable probability of failure?
- How to implement it in engineering practice?

Safety Measure

- Probability of failure, P_F
- Reliability index, β
- Simple formula
- Iterative procedures
- Monte Carlo simulations

Reliability Index, β

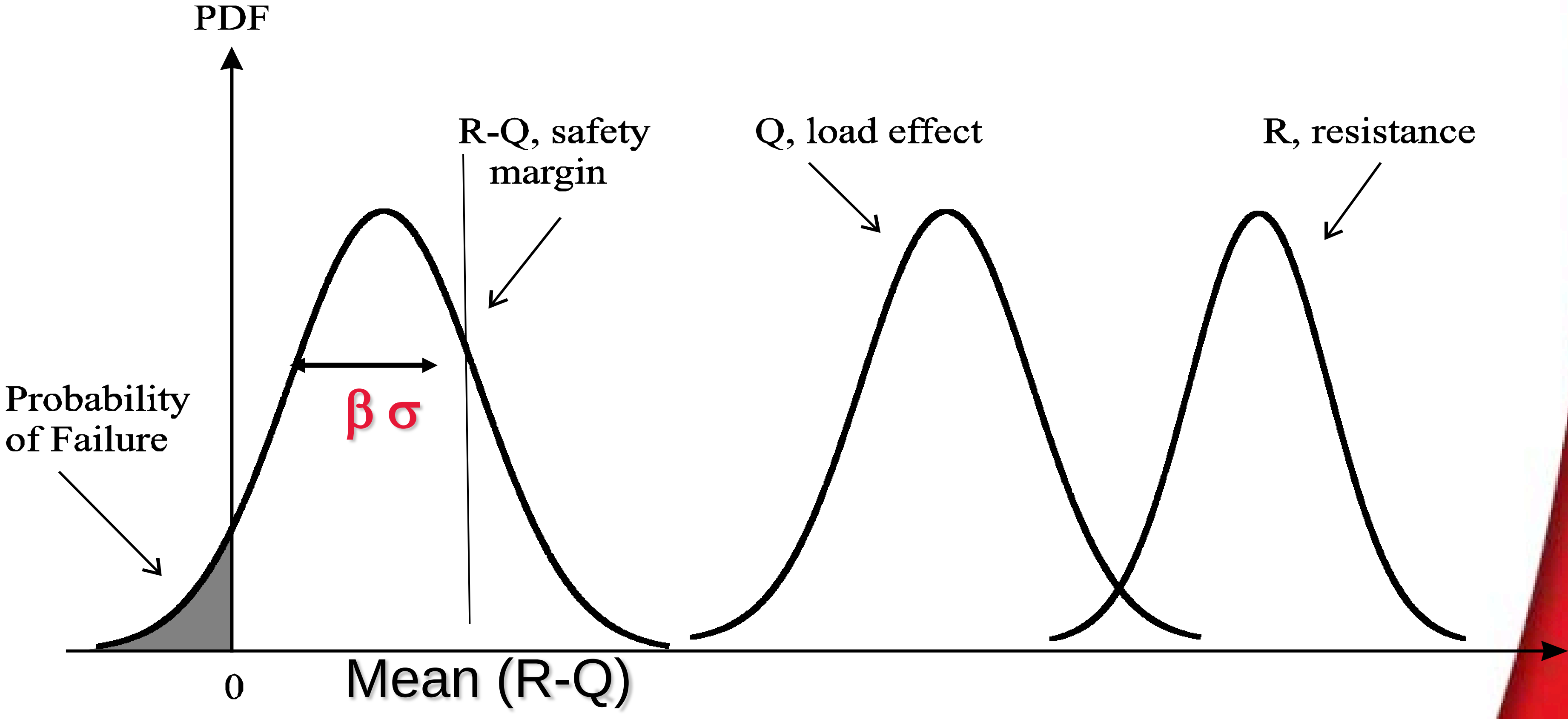


Figure 5-8 PDFs of load, resistance, and safety margin.

Reliability Index, β

For a linear limit state function, and R and Q both being normal random variables

$$\beta = \frac{(\mu_R - \mu_Q)}{\sqrt{\sigma_R^2 + \sigma_Q^2}}$$

μ_R = mean resistance
μ_Q = mean load
σ_R = standard deviation of resistance
σ_Q = standard deviation of load

Reliability index and probability of failure

P_F	β
10^{-1}	1.28
10^{-2}	2.33
10^{-3}	3.09
10^{-4}	3.71
10^{-5}	4.26
10^{-6}	4.75
10^{-7}	5.19
10^{-8}	5.62
10^{-9}	5.99

Target Reliability Index

- If reliability index is too small – there are problems, even structural failures
- If reliability index is too large – the structures are too expensive

Historical Perspective

- Trial and error, past experience, judgment
- Allowable stress design, central safety factor
- Partial safety factors (limit state design, or load and resistance factor design)
- Life-cycle analysis, optimization of the total cost, cost-benefits ratio

Selection Criteria for the Target Reliability Index

- Consequences of failure
- Economic analysis (costs)
- Past practice
- Human perception
- Political decisions

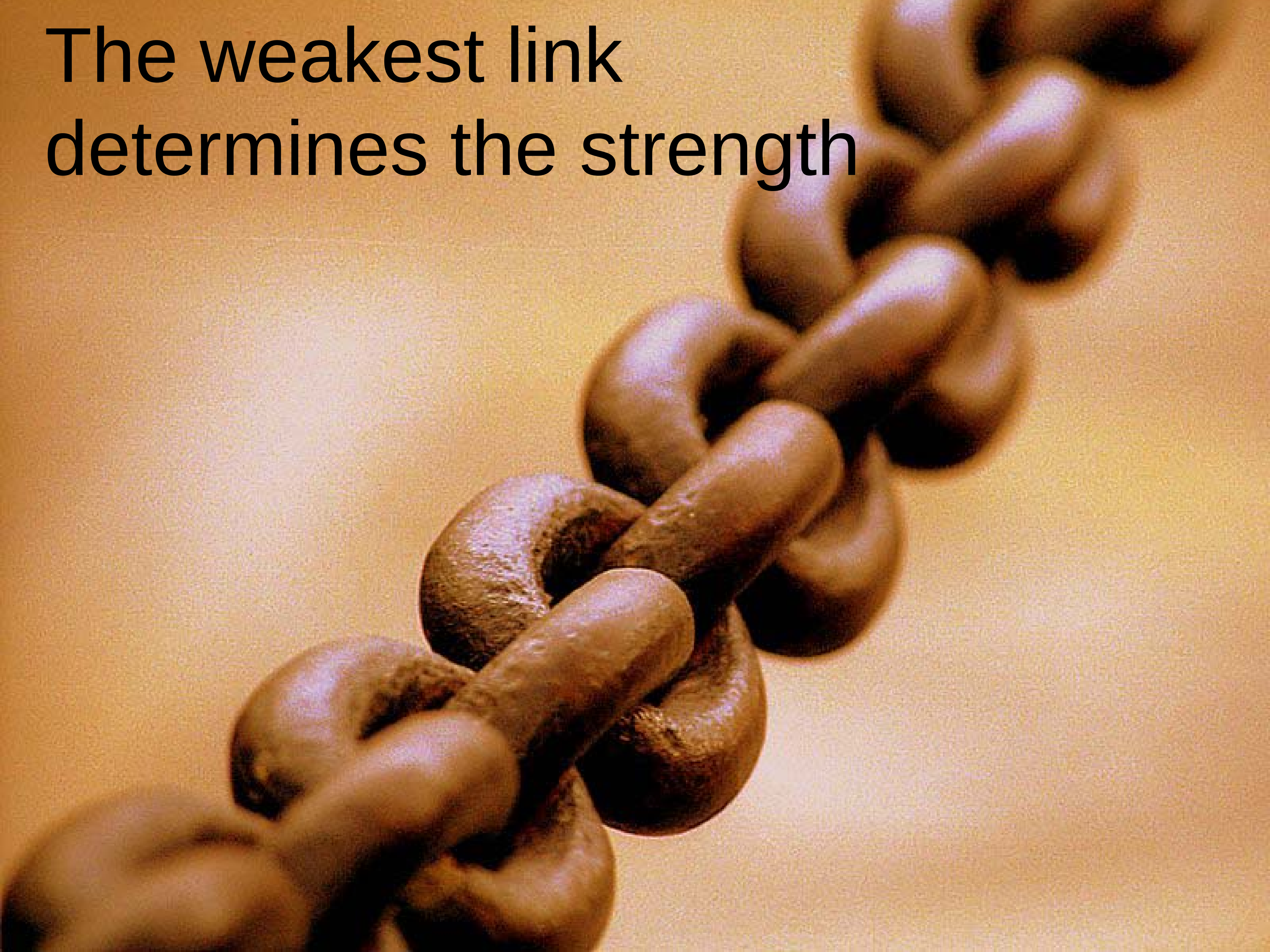
Target Reliability Index – major considerations

- Redundancy and Ductility
- Element and system reliability
- New design and existing structure
- Important and ordinary structures

Structural Systems

- Series systems – weakest link systems, to be avoided
- Parallel systems – components share the load, preferred systems
- Avoid brittle materials and elements, use ductile materials and elements

The weakest link determines the strength



Target Reliability Indices in AASHTO Bridge Design Code

- 3.5 for steel and prestressed concrete components
- 2 for wood components
- 5-6 for structural systems
- 0-1 for serviceability limit states (deflection, decompression)

Target Reliability by ISO-2394

Relative costs of safety measures	**Consequences of Failure**			
	small	some	moderate	great
High	0	1.5	2.3	3.1
Moderate	1.3	2.3	3.1	3.8
Low	2.3	3.1	3.8	4.3

Proposed Target Reliability for ACI 318

Relative costs of safety measures	**Consequences of Failure**			
	small	some	moderate	great
High	**0**	**1.5**	2.5	3
Moderate	**1**	2.5	3	4
Low	2	3	4	4.5

Implementation of the target reliability

- Design – by load and resistance factors, fool-proof design, protective design
- Construction – quality control of materials and workmanship, fool-proof construction
- Proper use and operation, maintenance, preventive repairs
- Preventive measures, monitoring, diagnostic testing


Golden Gate Bridge, San Francisco
built in 1933-1935, span of 1280 m

Golden Gate Bridge
San Francisco

Sunshine Skyway Bridge, Tampa, Florida

Thank you