Bridge owners benefits from probability-based management of old bridges

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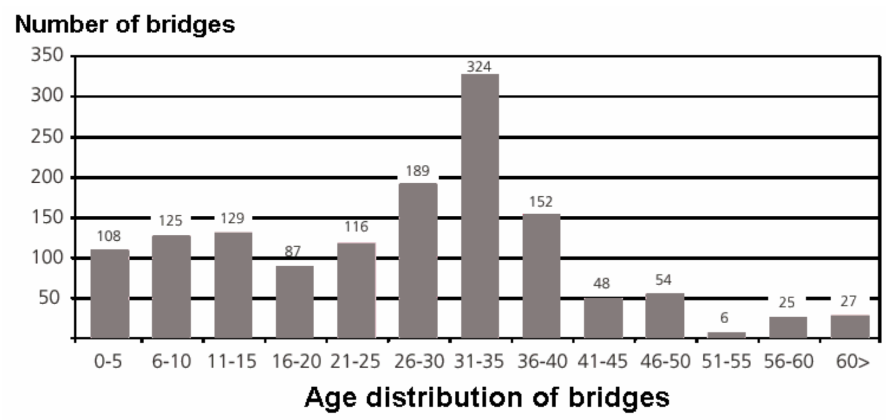
Introduction

- The Danish Road Directorate (DRD) is responsible for the 3500 km national road network and approximately 2100 smaller bridges and 50 special bridges and tunnels on this road network.

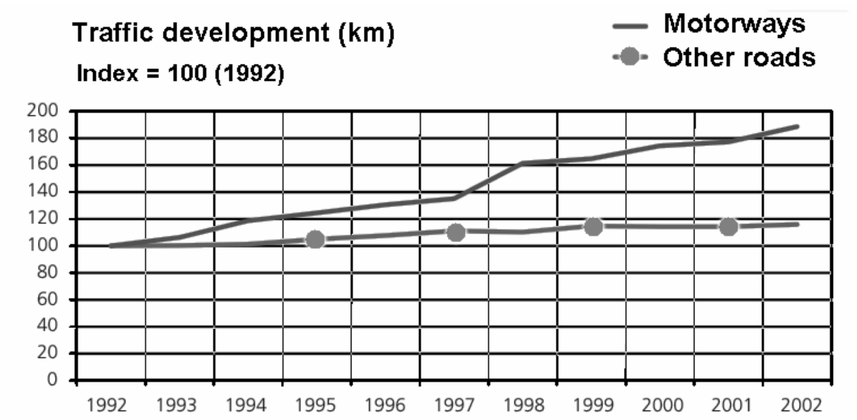
- The main focuses of attention for the DRD are on safety, preservation of invested capital and availability of an uninterrupted traffic flow.

Introduction

60% of the bridges administered by the DRD were built more than 30 years ago and 50% are between 25 and 40 years old.



Today the DRD faces the combination of an old deteriorating bridge stock and reducing maintenance budgets subjected to increasing volumes of freight transports.



In order to deal with this situation, the DRD employs probabilistic approaches, which can provide cost savings or give a better basis for decision or postponement of costly rehabilitation and strengthening projects.

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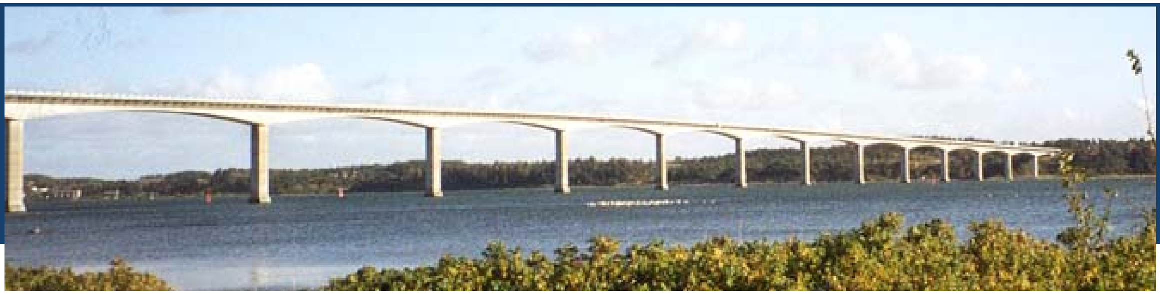
STATEMENTS

- Bridges are much safer than generally documented
- Modern methods, as probabilistic approaches can demonstrate higher safety
- Tremendous savings can be obtained by avoiding strengthening and replacement of bridges

Problem: Lack of load carrying capacity

- Weak bridges
- Deteriorated bridges

Low budgets for strengthening or rehabilitation

Idea: Determination of higher capacity

- Advanced analysis models

Motivation: Cost saving

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Advanced analysis models in assessment of bridges

- Advanced 3D FEM analysis
- Plastic limit state analysis
- Probability-based analysis and assessment
- Fatigue analysis
- Risk analysis
- Dynamic analysis
- Safety-based maintenance management

Assessment of bridges as a decision process

BASIS:Traditional standard assessment

Principle for refinement of assessment:

The benefit of further modeling or procurement of information must be shown in advance

- Identification of significant parameters
- Documentation of the importance of the particular modeling

Experience, sensitivity analysis and parameter studies

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Safety approaches for assessment of existing bridges

The general approach

Based on codes for bridges

- New bridges
- Existing bridges

Generalisation

- Partial safety factor format
- Load specification
- Many types of bridges

Benefit

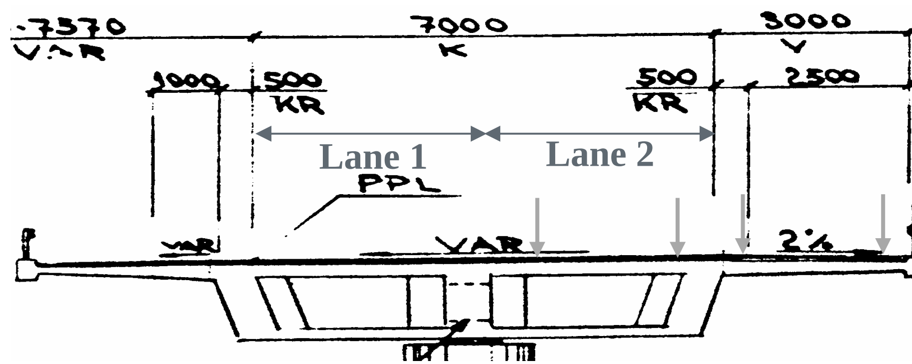
- Efficient and easy to use

Drawback

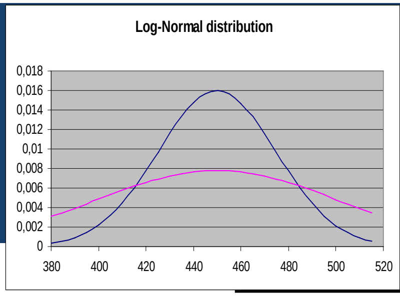
- Costly in case of lack of capacity

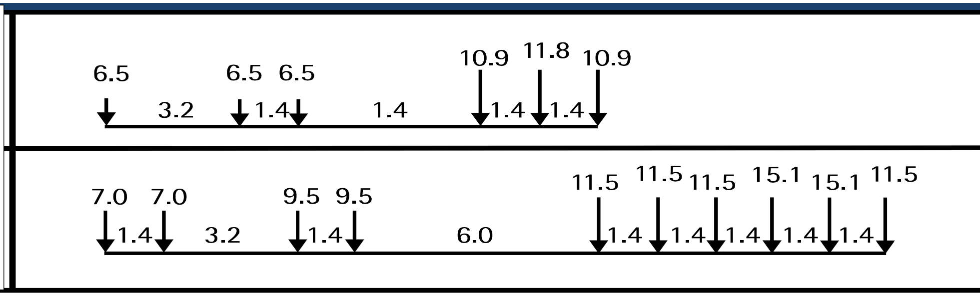
Conservative combination of extreme cases

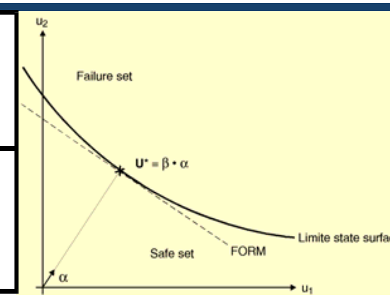
- Conservative capacity models
- Conservative response models
- Conservative load magnitudes
- Conservative location of loads
- Conservative impact factors
- Conservative occurrence models



Conservative load modelling







The individual approach

Concept:

- Don’t necessarily have to fulfill the specific requirement of the general code
- Overall requirement for the safety level must be satisfied

Purpose:

- Cut strengthening or rehabilitation costs
- without compromising the safety level

Method:

Probabilistic-based assessment

Uncertainties of the specific conditions:

- Traffic load
- Capacities
- Models

Bridge specific “code” is obtained




Nordic Background for Safety Requirements

Failure consequence (Safety class)	Failure type I, Ductile failure with remaining capacity	Failure type II, Ductile failure without remaining capacity	Failure type III, Brittle failure
Less Serious (Low safety class)	$p_f \leq 10^{-3}$ $\beta \geq 3.09$	$p_f \leq 10^{-4}$ $\beta \geq 3.71$	$p_f \leq 10^{-5}$ $\beta \geq 4.26$
Serious (Normal safety class)	$p_f \leq 10^{-4}$ $\beta \geq 3.71$	$p_f \leq 10^{-5}$ $\beta \geq 4.26$	$p_f \leq 10^{-6}$ $\beta \geq 4.75$
Very Serious (High safety class)	$p_f \leq 10^{-5}$ $\beta \geq 4.26$	$p_f \leq 10^{-6}$ $\beta \geq 4.75$	$p_f \leq 10^{-7}$ $\beta \geq 5.20$

Nordic Committee for Building Structures (NKB)
“Recommendation for Loading and Safety Regulations for Structural Design”
NKB report no. 35, 1978 & NKB report no. 55, 1987.

Reliability-based assessment guideline

Structure of the Guideline

- The guideline itself consists of 55 pages broken into 7 chapters.
    - Chapter 1 Introduction
    - Chapter 2 Bridge classification by reliability analysis
    - Chapter 3 Reliability requirements
    - Chapter 4 Model uncertainties and computation models
    - Chapter 5 Loading
    - Chapter 6 Materials
    - Chapter 7 Dealing with supplementary information

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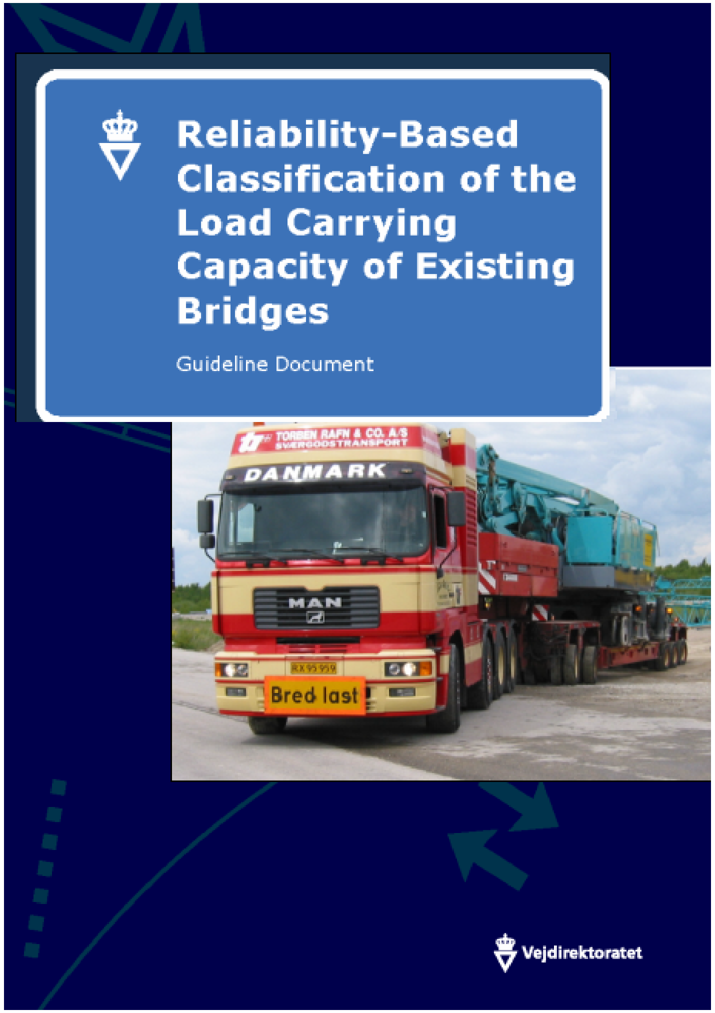
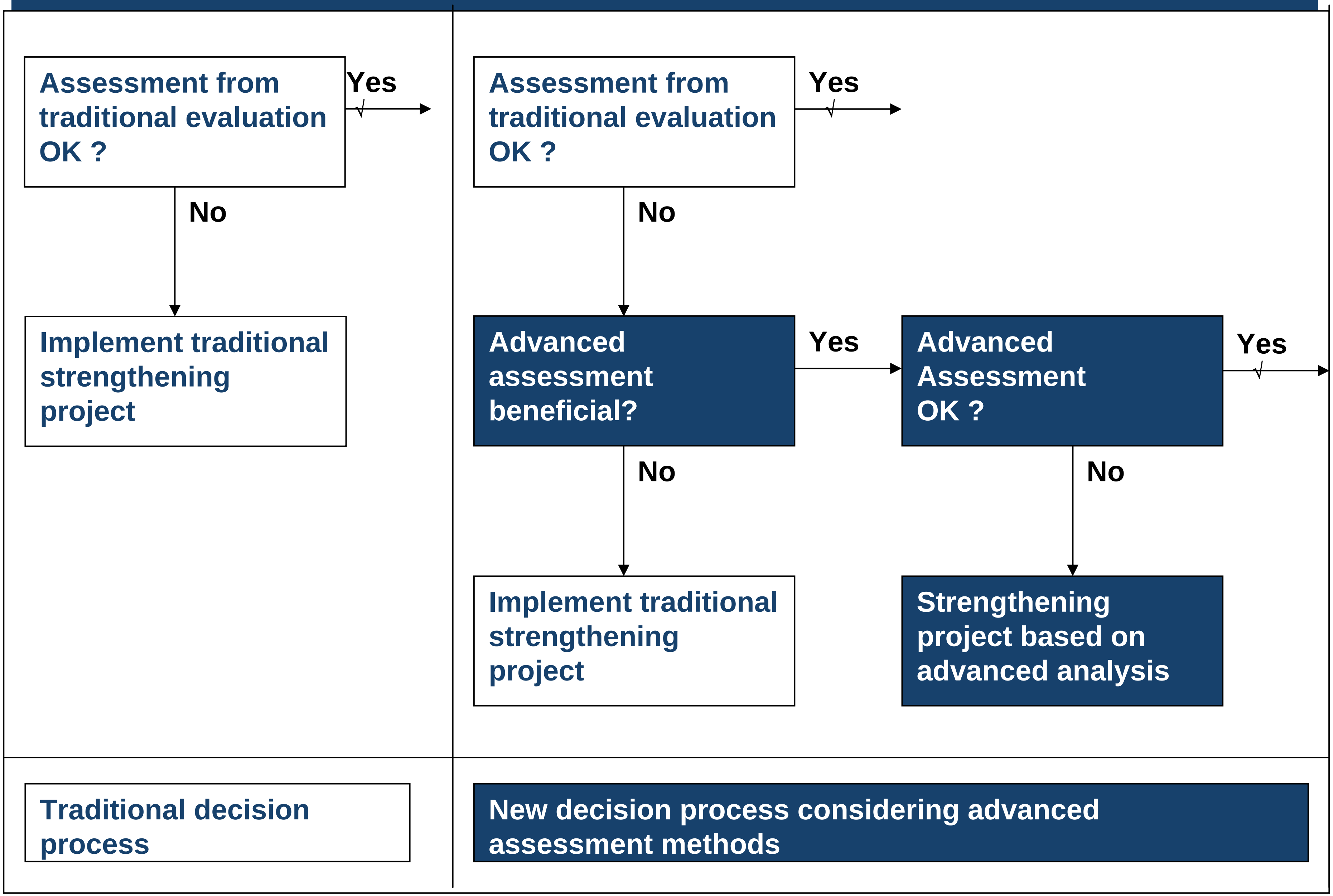


Revised Decision Process



Basis for Probabilistic Approaches

Procedure for Individual approach

1) Pre-evaluation
2) Modelling of critical limit states
3) Traffic load modelling
4) Modelling of stochastic variables
5) Calcultaion of Beta
6) Evaluation of safety level
7) Post evaluation

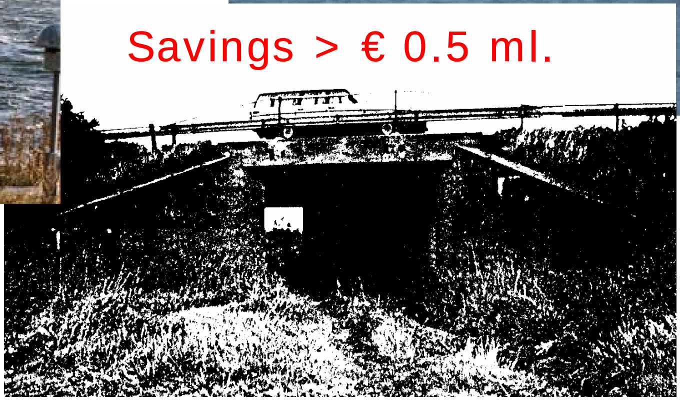
Modelling of Stochastic variables → Solver in standard reliability software ← Programming of limit states

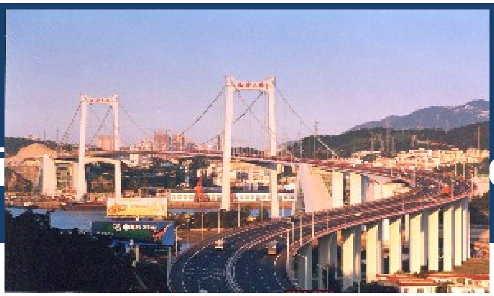
Solver in standard reliability software → β Sensitivities

Practical Experience

Bridge	Result of Deterministic Analysis	Probability-based assessment	Cost Saving €
Vilsund	Max W = 40 t	Max W = 100 t	4,000,000
Skovdiget	Lifetime ~ 0 years	Lifetime > 15 years	12,500,000
Storstroem	Lifetime ~ 0 years	Lifetime > 10 years	2,500,000
Klovtofte	Max W = 50 t	Max W = 100 t	2,000,000
407-0028	Max W = 60 t	Max W = 150 t	1,500,000
30-0124	Max W = 45 t	Max W = 100 t	500,000
Norreso	Max W = 50 t	Max W = 100 t	500,000
Rødbyhavn	Max W = 70 t	Max W = 100 t	500,000
Åkalve Bro	Max W = 80 t	Max W = 100 t	1,500,000
Nystedvej Bro	Max W = 80 t	Max W = 100 t	2,000,000
Avdebo Bro	Max W = 80 t	Max W = 100 t	3,000,000
		TOTAL	30,000,000

Practical Experience



Practical Experience with Probability-Based Assessment of Bridges

Bridge	Deterministic analysis	Probability-based assessment
C 295	*B* = 115 kN (Max *W* = 39 t)	*B* = 240 kN (Max *W* = 81 t)
T 531	*B* = 118 kN (Max *W* = 40 t)	*B* = 226 kN (Max *W* = 76 t)
E 129	*B* = 170 kN (Max *W* = 54 t)	*B* = 215 kN (Max *W* = 71 t)

Three Swedish Road Bridge cases
with classification of load carrying capacity

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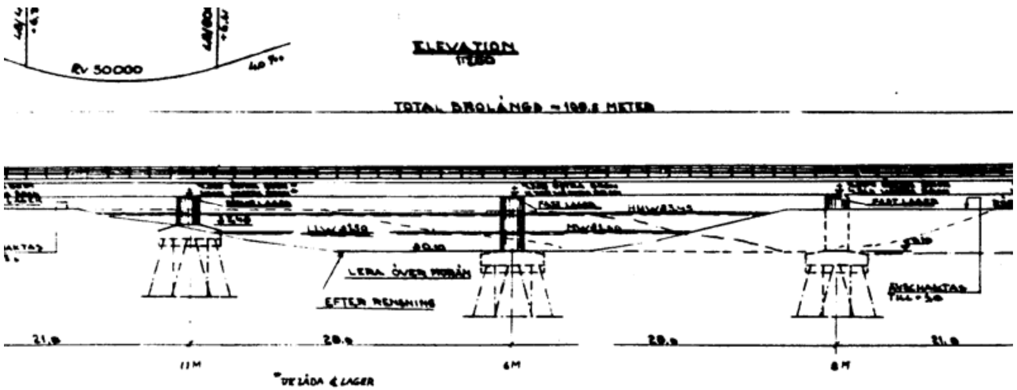
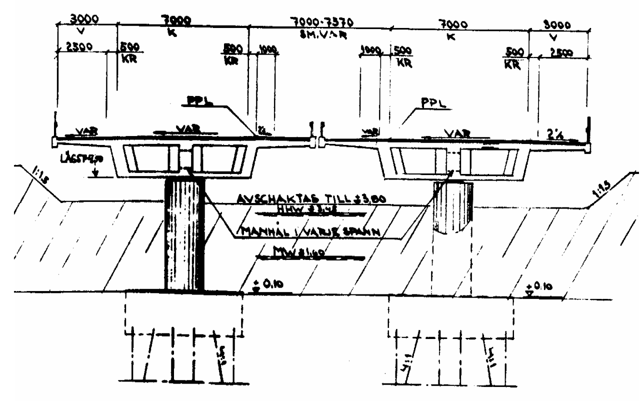
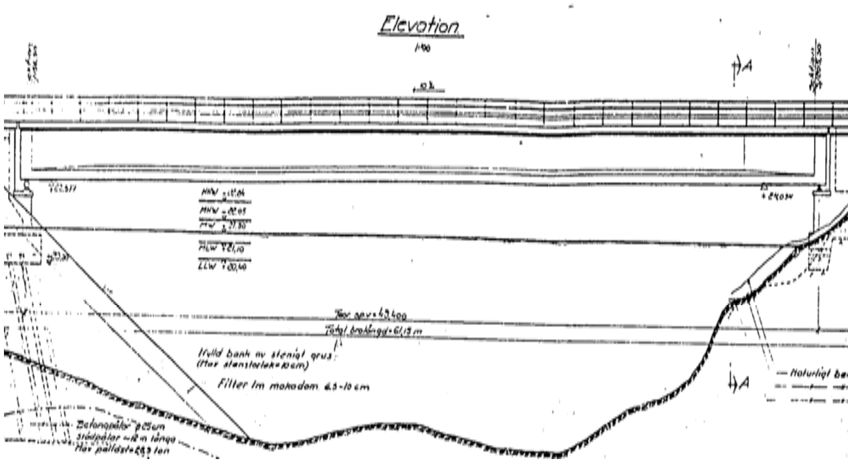
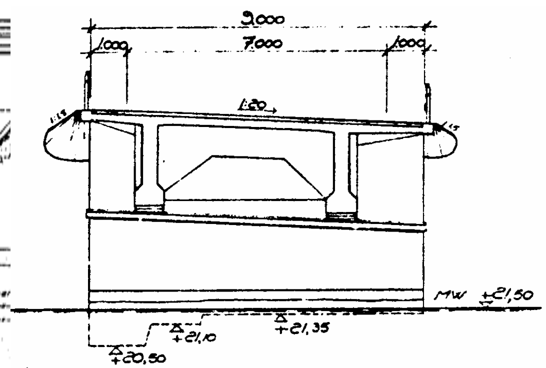
Practical Experience with Probability-Based Assessment of Bridges

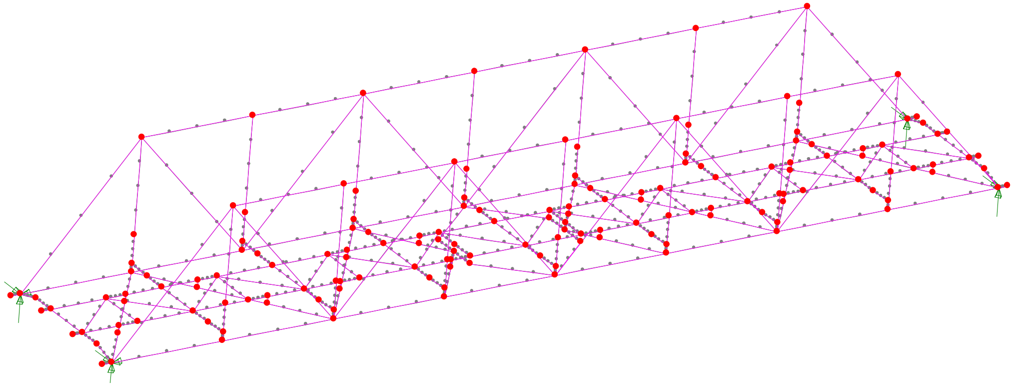




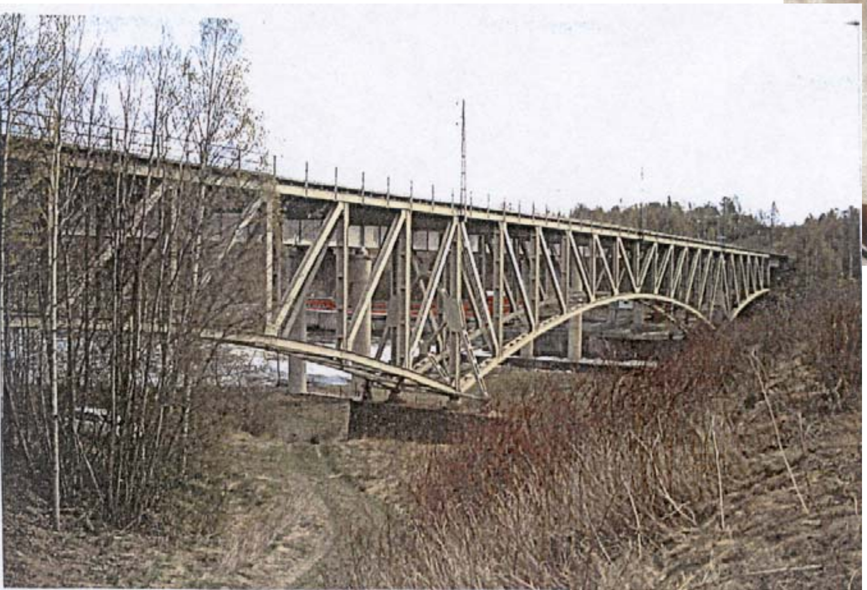




Probability-based assessment of the steel railway bridge over Södra Rautasjokk for the Swedish Railway authorities

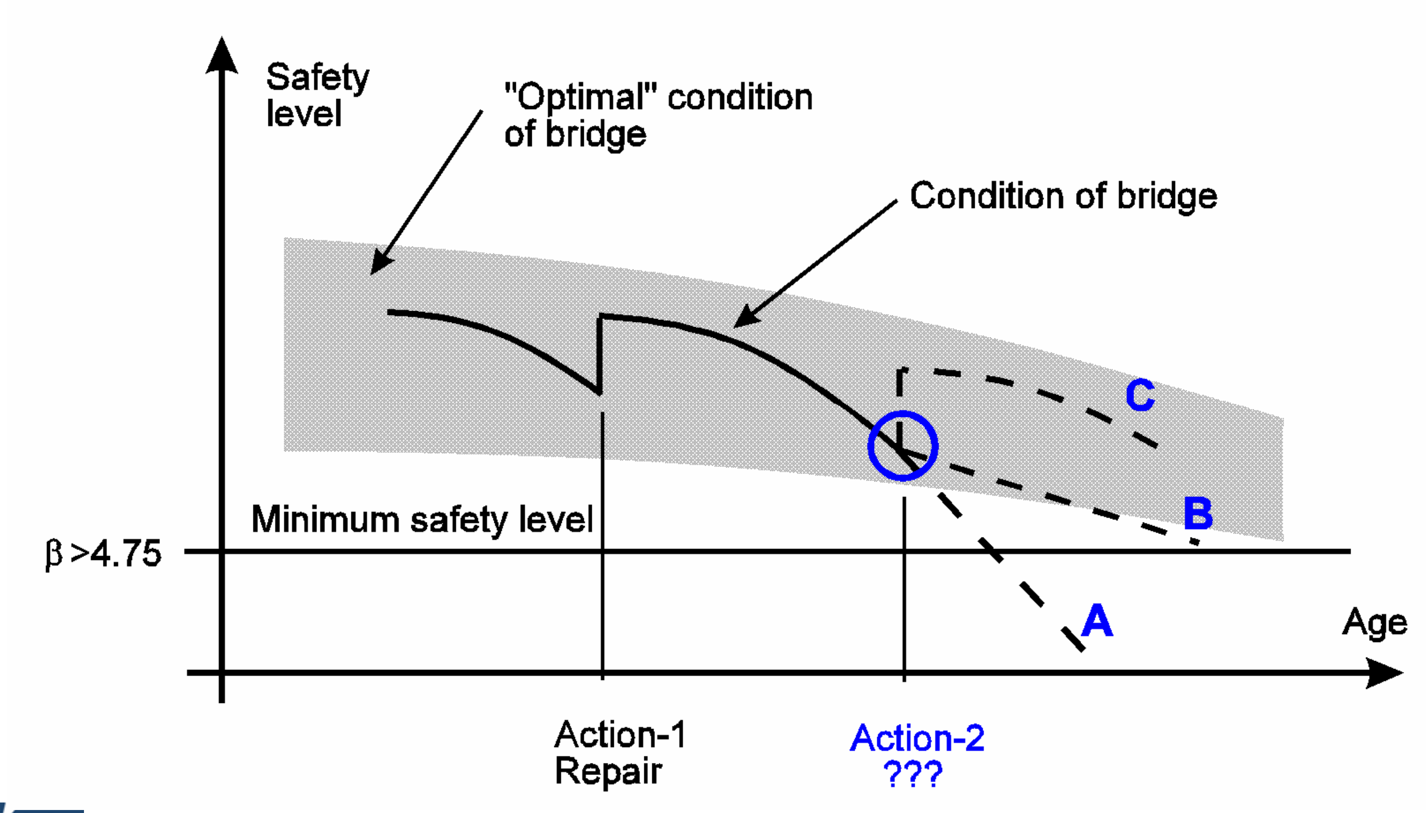


Probability-based assessment of Bergeforsen, Sundsvall-Harnösand



Probability based maintenance management

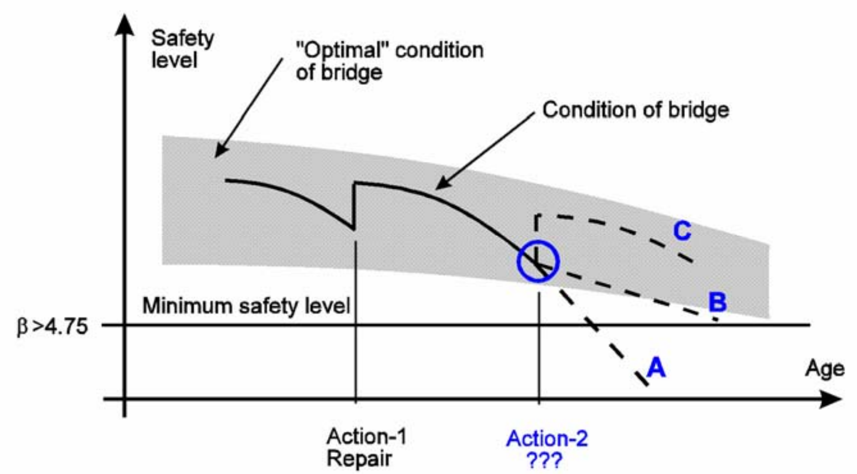
Maintenance of Bridge Safety



Probability-based maintenance management

- Requirements for the structural safety are always fulfilled
- Determination of safety effects of present and future deterioration
- Life-time until the safety requirement is no longer fulfilled
- Preventive actions are judged on their effect on the present and future safety
- Each preventive action is associated with a corresponding cost
- The safety-based management plan is established based on decision analysis
- The safety-based management plan must be updated and maintained as a part of the bridge management

Purpose: Cost saving by extension of life time without compromising the structural safety



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Probability based maintenance management

Practical 10-Phase Procedure

0. **Fact-finding**
1. **Formulation of problem**
2. **Safety requirements**
3. **Deterministic models for failure**
4. **Probability-based safety-model for critical failure modes.**
5. **Stochastic variables**
6. **Safety of the non-deteriorated bridge**
7. **Safety of deteriorated bridge**
8. **Analysis of repair and rehabilitation options**
9. **Requirements for the visual appearance of the bridge**
10. **Cost-optimal management plan using decision analysis to determine optimal rehabilitation options**

SAFETY (items 1–7)

MANAGEMENT (items 8–10)

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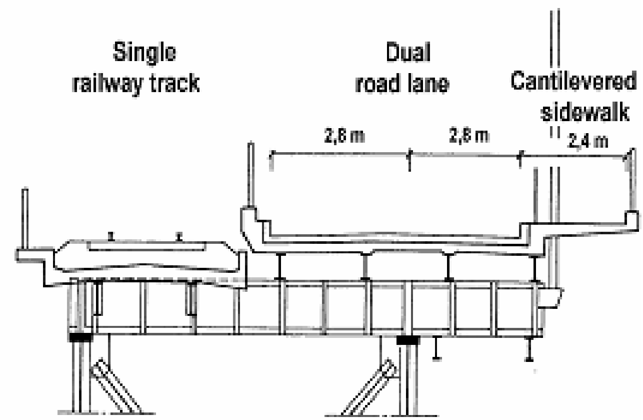
Practical experience – Deteriorated bridges

Storstrom Bridge

- The 3.2 km long Storstroem Bridge connects the Danish Island of Zealand with the southern Danish islands of Falster and Lolland.

- The contract for the building of the bridge was given to the British company Dormann, Long & Co., who also fabricated the main steel structure (The contract was awarded to a British company as a political move to offset the significant trade deficit which had developed between the UK and Denmark at his time due to Danish pork exports).



- The bridge opened in September 1937.

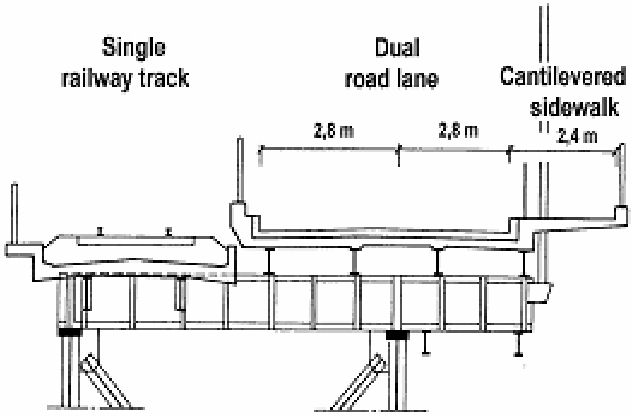
The Storstrom case

Storstrom Bridge

- The bridge carries dual road lanes and a single railway track and a cantilevered sidewalk for pedestrians.

- Until 1985 when the Faroe Bridge opened, Storstroem Bridge was the only fixed connection between Zealand and the southern Danish Islands. The Faroe Bridge carries only cars.

- Today the Storstroem Bridge carries only local traffic with an average annual daily traffic (AADT) of about 8000 vehicles.



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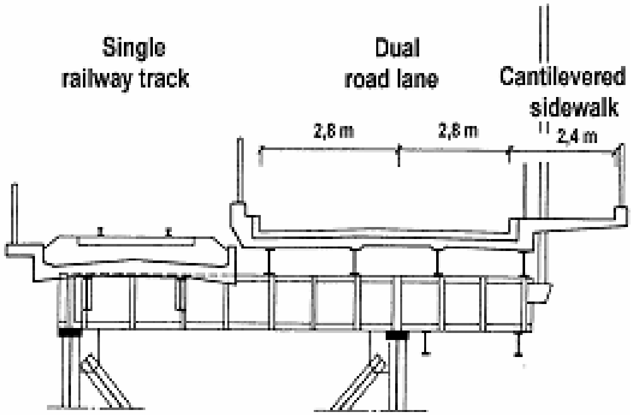
The Storstrom case

Storstrom Bridge

- The main deck slab of the 3.2 km long Storstroem Bridge has suffered serious deterioration to both the concrete and reinforcement.
- Replacement of the bridge would be extremely costly especially when considered in connection with the possibility of the construction of the Femern Bridge at some point in the future.
- Thus, the DRD would like to postpone any decision on a strategy for the Storstroem Bridge until a decision about the Femern crossing is made. However, at the same time the DRD must ensure that the structure has sufficient structural safety for both vehicles and pedestrians at all times.



The Storstrom case

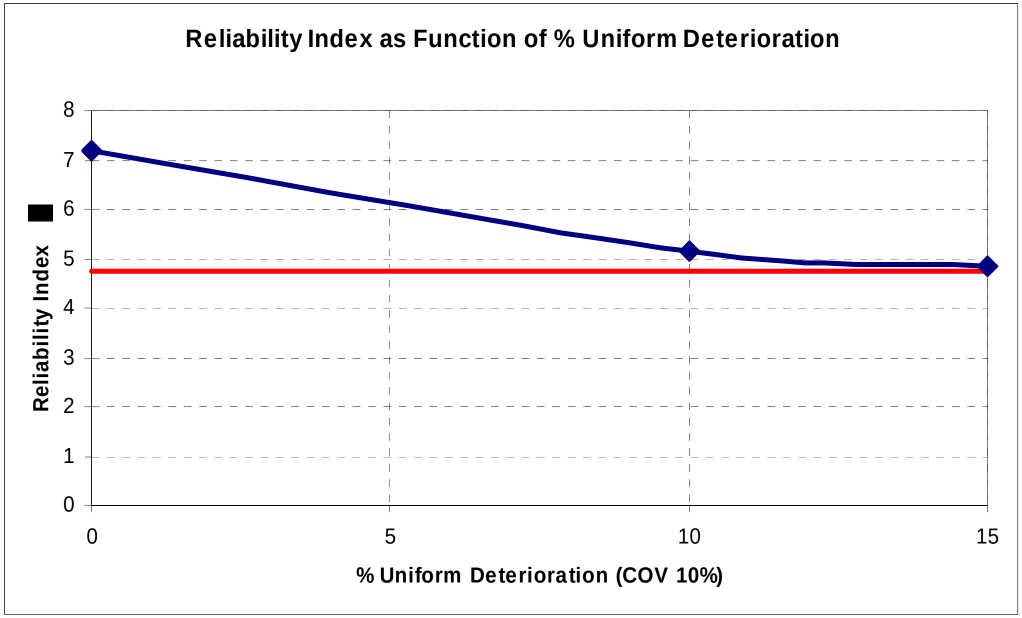
Deterministic vs. Probablistic Assessment

Deterministic assessment of the deck slab for combined dead and live load produced a maximum load factor of 0.61. This implies that the slab is incapable of sustaining the applied load. The recommendation would therefore involve costly rehabilitation of the structure.

Probabilistic Assessment coupled with Plastic Response Modelling yielded for:

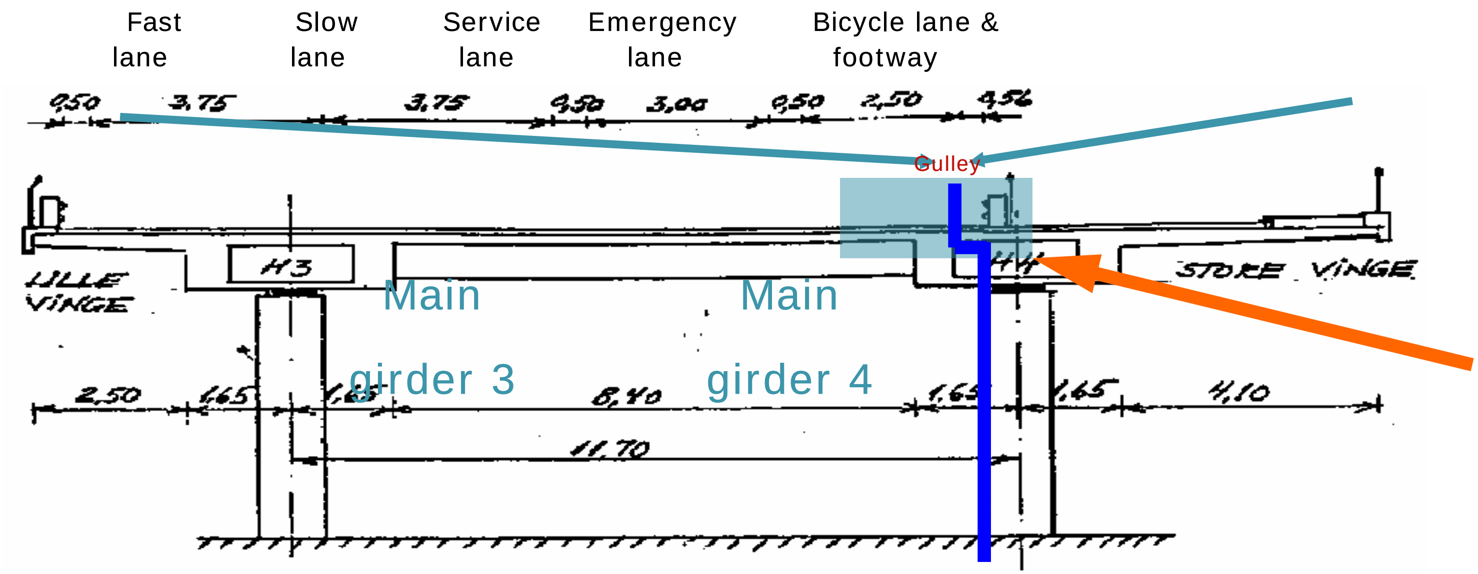
No Deterioration

β = 7.20



The Skovdiget case

Design & Deterioration



Poor workmanship during construction:

- un-injected or poorly injected post-tensioned cable ducts
- insufficient and poor drainage
- area around gulley poorly made
- bad waterproofing

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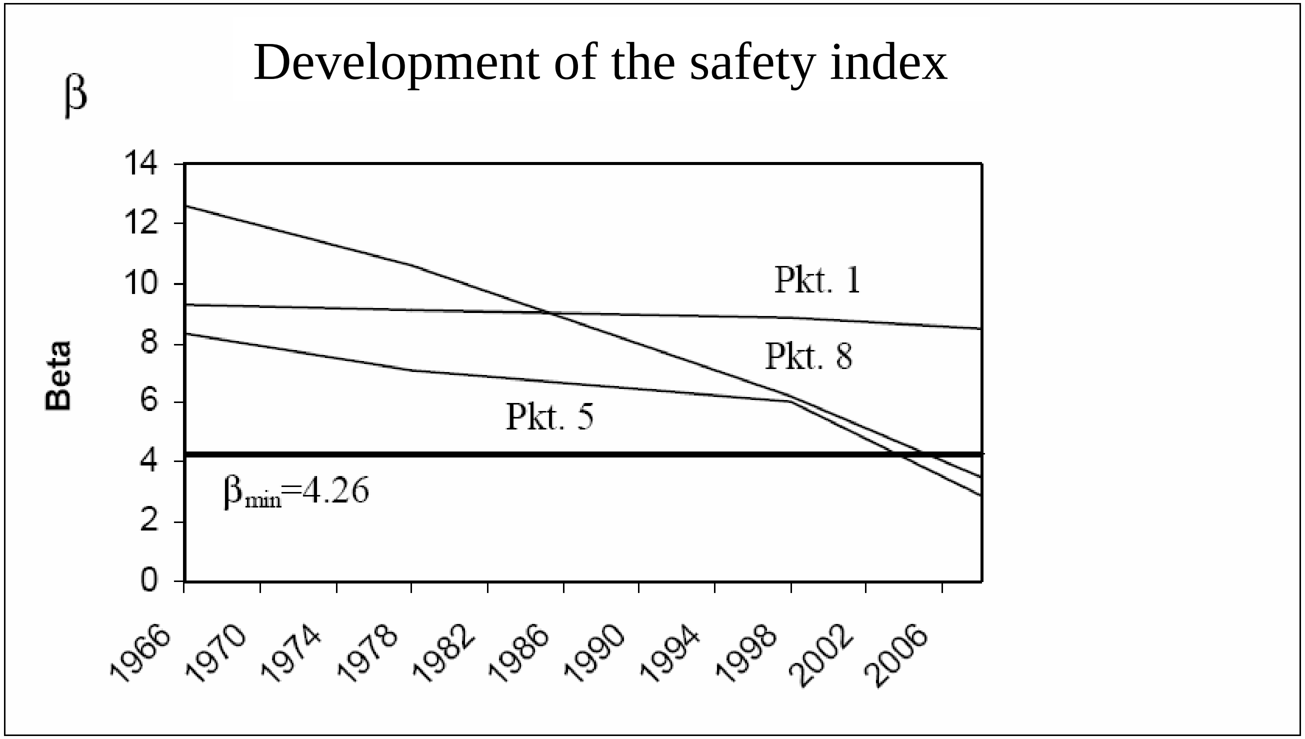
The Skovdiget case

Estimated lifetime 1998: 6 years



The Skovdiget case

Cost Optimal Management Plan

Safety-updating inspections
- verify model
- update deterioration models (increase safety)

New wearing course in 1999

Continue with extended routine and special inspections

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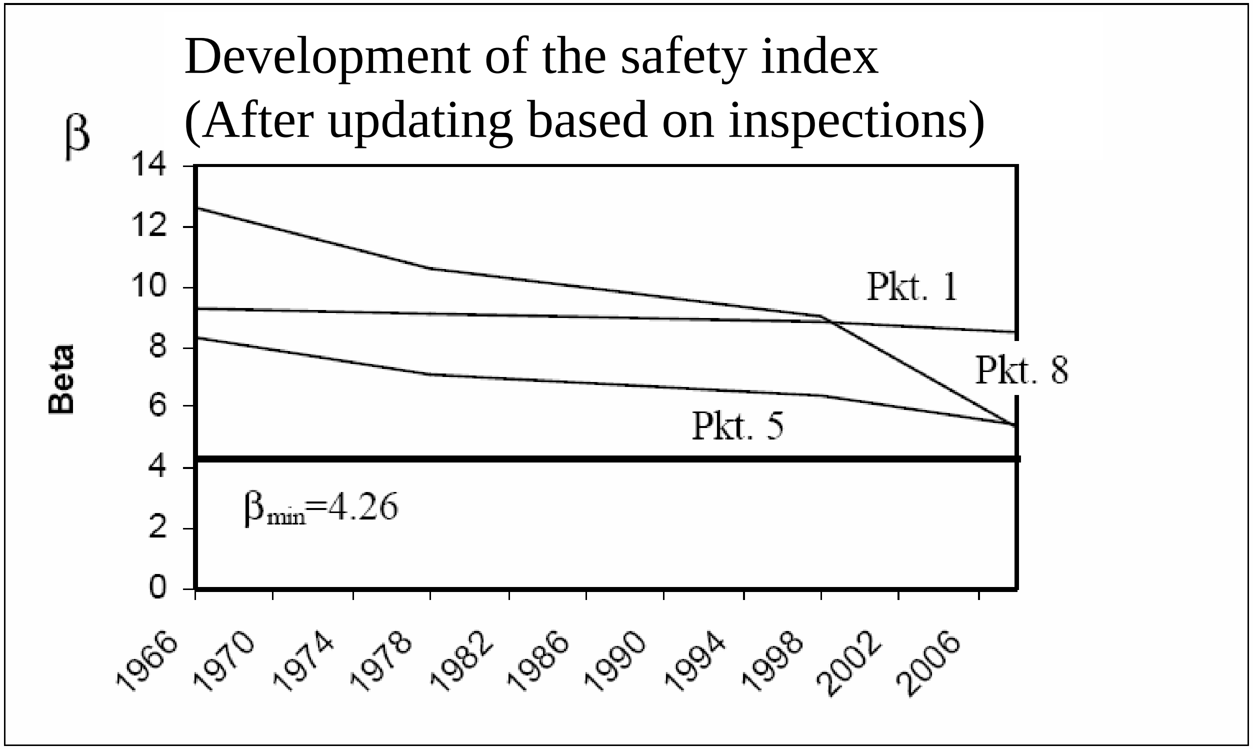
The Skovdiget case

Estimated lifetime 2002: 10 years



Planned replacement: 2010

Result 12 additional years

Conclusions

- Reliability based assessment of bridges and Probability Based Maintenance Management cuts strengthening or rehabilitation costs
- The safety level is not compromised
- A well established methodology is implemented for practical application by the Danish Road Directorate
- The cost saving can be millions of € per year

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