Assessment and Rehabilitation of Central European Highway Structures

ARCHES

FEHRL

Bridge safety assessment and maintenance with the use of monitoring techniques

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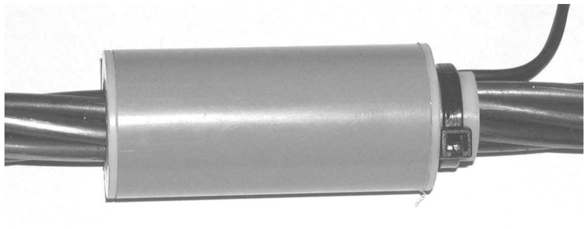
Application of monitoring techniques

- *Safety assessment*
  - *Determination of stress*
  - *Fatigue damage accumulation*
  - *Model updating*

- *Extension of bridge service life*
  - *Deterioration monitoring*
  - *Early warning systems*

Determination of stress

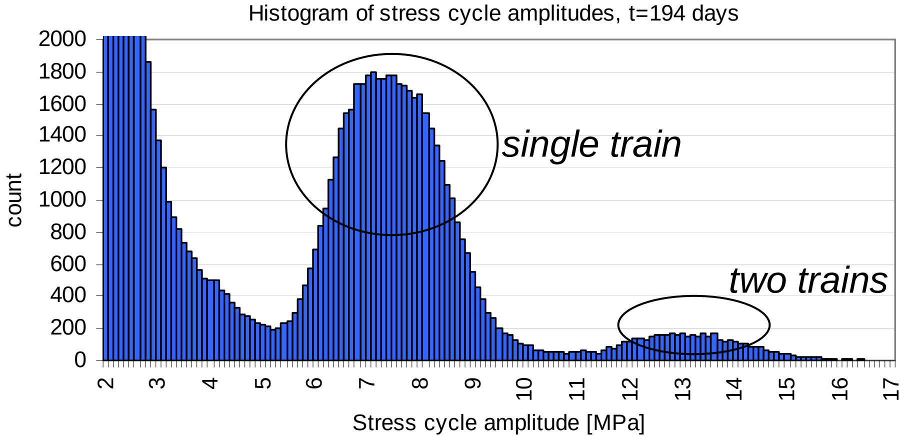
- *Intended use: to correct design assumptions*
- *Technique*
  - *for dead load stresses: Elastomagnetic method*
    - *Limited to external tendons or cables*
    - *Alternative to vibrational method*
    - *Insensitive to boundary conditions*
    - *Already being used in NMS*



  - *for traffic load stresses (using load models): Soft load testing*
- *Possible benefit: real stress may be lower than calculated*

Fatigue damage accumulation

- *Intended use: to measure stress cycles on bridge with relevant fatigue failure (e.g. steel railway bridges)*
- *Technique*
  - *Strain measurements → converted to stresses*
    - *cheap foil-type gauges are sufficient*
  - *Stress cycle counting by rainflow method*



Fatigue damage accumulation

- *Technique (continued)*
  - *Calculation of damage accumulation in monitored period (Palmgreen-Miner rule)*

$$d_t = \sum_{i=1}^{m} \frac{n_{\Delta\sigma,i}}{N_{\Delta\sigma,i}}$$

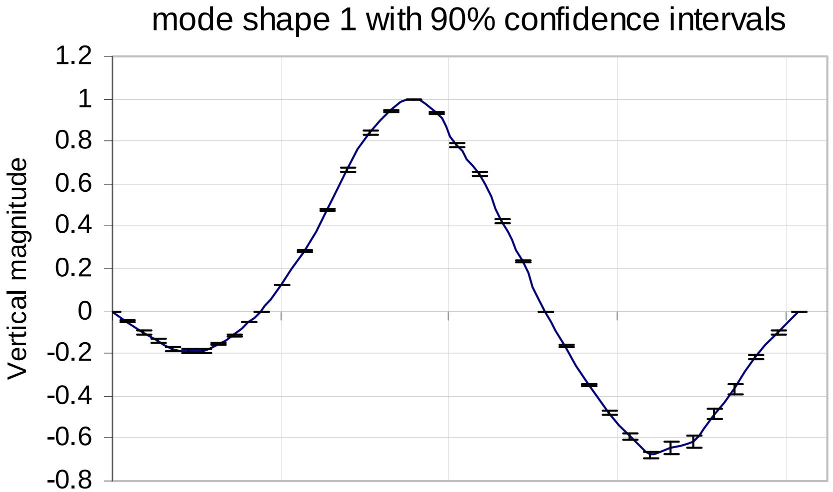
  - *Extrapolation in time → remaining lifetime of measured structural detail*

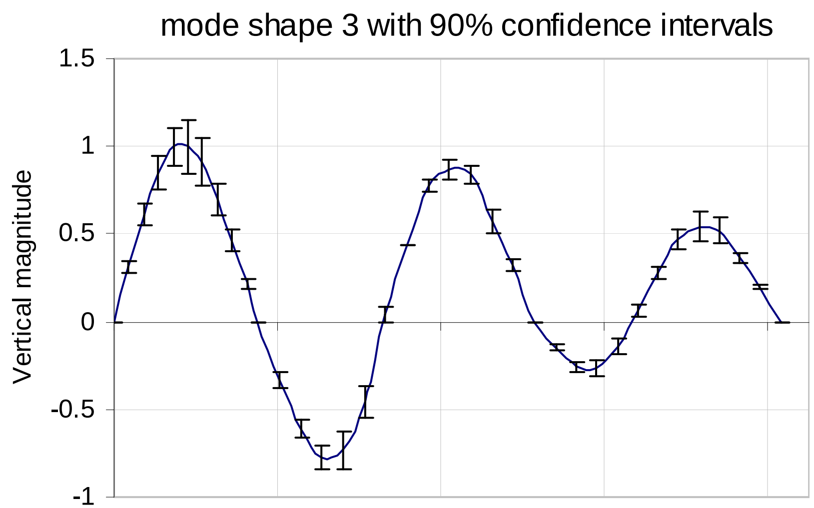
$$t_{rem} = \frac{t}{d_t} - t_{past}$$

- *Possible benefit: real damage accumulation may be lower than expected*

Model updating

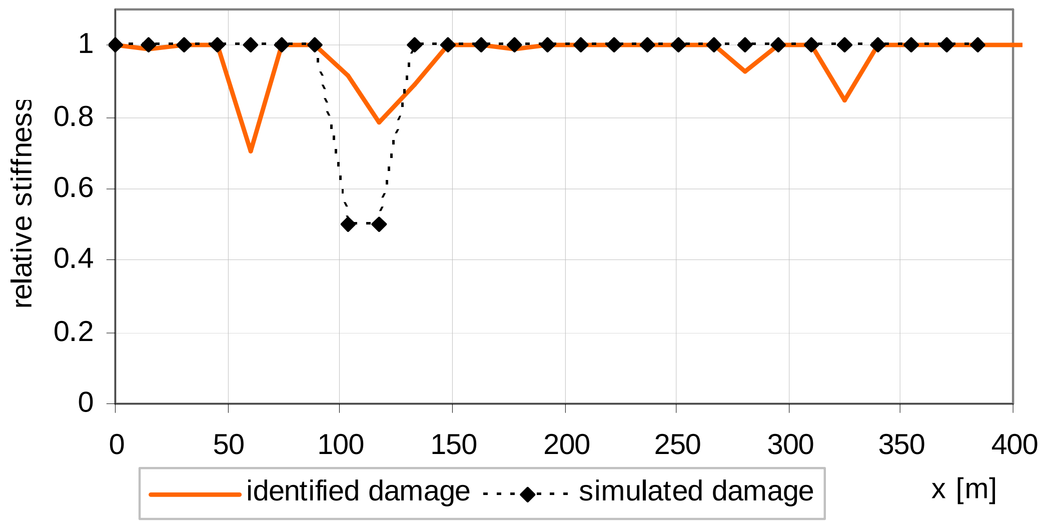
- *Use: to detect structural changes by adapting a model to measurements (damage localization and quantification)*
- *Technique*
  - *measurement of structural properties (eigenfrequencies, mode shapes, change of strain and inclination)*
  - *accuracy evaluation*





Model updating

- *Technique (continued)*
  - *Model optimization by updating selected model parameters*
  - *Result may deviate from real damage due to measurement accuracy*



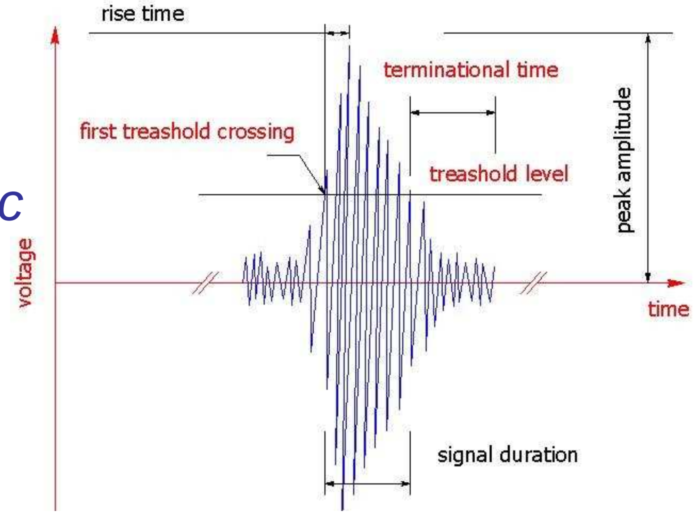
- *Possible benefit*
  - *Provides hints of damage locations, to be verified by inspection*
  - *Without verification: use of results not recommended for capacity assessment*

Deterioration monitoring

- *Intended use: to observe deterioration development*
- *Technique*
  - *Crack width, strain increase, stress, relative displacements measurements on problematic locations*
  - *Limit values defined by structural analysis*
  - *Detection of active cracking by acoustic emission (AE)*
- *Possible benefit: extension of service life of bridges with known deterioration problems*
  - *Measurements also applicable during load tests*

Acoustic Emission (AE)

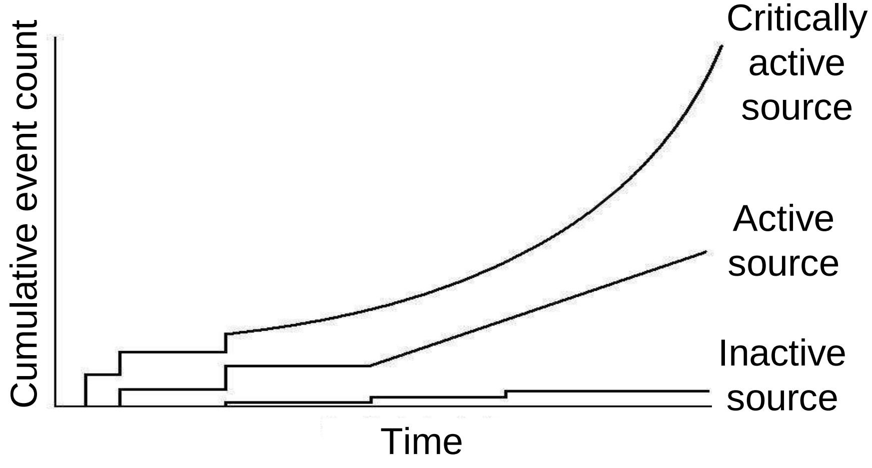
- *Principle: detection of transient elastic waves produced by*
  - *Micro and macro crack formation in concrete*
  - *Concrete crushing*
  - *Crack surface rubbing*
  - *De-bonding of steel rebars or their plastic deformation*



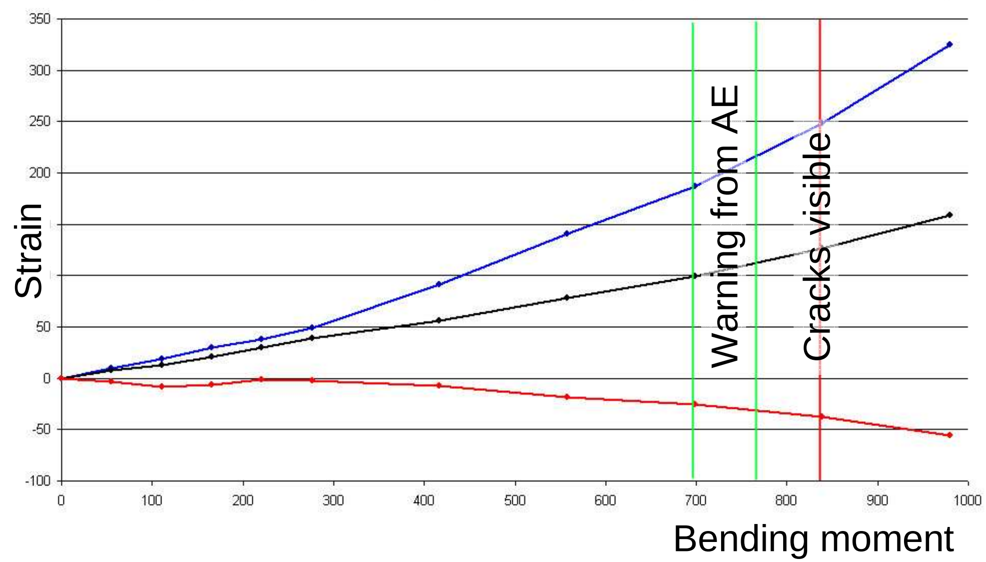
- *Evaluation parameters*
  - *Acoustic event rate*
  - *Local concentration of cracking*
  - *Stress at start of AE activity, AE activity during unloading*
  - *NDIS criterion*
  - *Felicity ratio, Kaiser effect*

AE evaluation parameters & tests

- *Event rate*
  - *large increase near failure state*

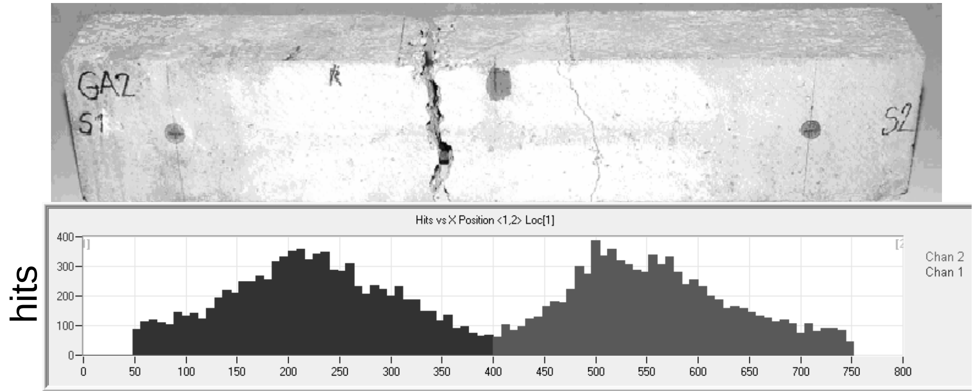


- *Barcza bridge load test*
  - *AE detected increased cracking before cracks were visible*
  - *Strain-load diagram remained linear even after cracks were visible*



AE evaluation parameters & tests

- *Local concentration of cracking activities*
  - *Indicator of growing damage*
  - *Tests at concrete specimens*

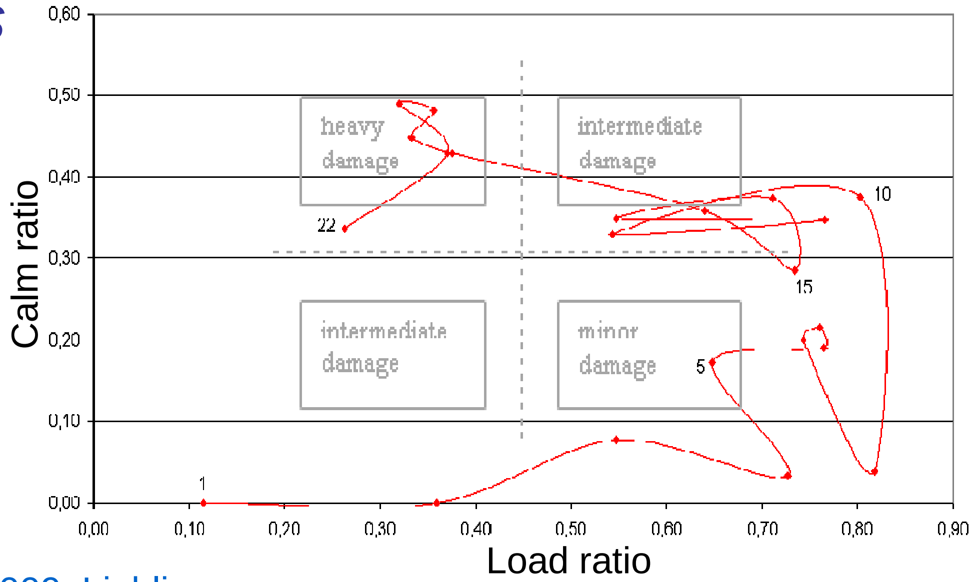


- *Stress at start of AE activity*
  - *Low stress → poor structure*

- *AE activity during unloading*
  - *High activity → high damage levels*

AE evaluation parameters & tests

- *NDIS criterion*
  - *Calm vs. Load ratio*
  - *Calm ratio: ratio of AE event count in unloading phase*
  - *Load ratio: load level relative to maximum load*
  - *Complete unloading necessary*
- *Tests on old bridge girders*



AE evaluation parameters & tests

- *Felicity ratio*

$$\text{Felicity Ratio} = \frac{\text{Load at which significant emission restarts}}{\text{Previously applied maximum load}}$$

  - *Decreasing felicity ratio → growing damage*
  - *Effect observed in tests with old bridge girders*

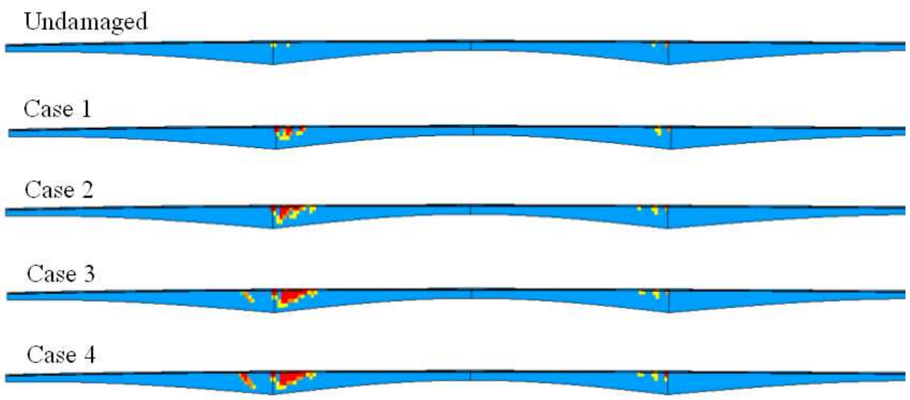
- *Kaiser effect*
  - *Felicity ratio ≥ 1*
  - *Used to determine maximal previous loading*
  - *Effect is temporary in concrete*
  - *Effect observed in concrete specimen tests*

AE benefits

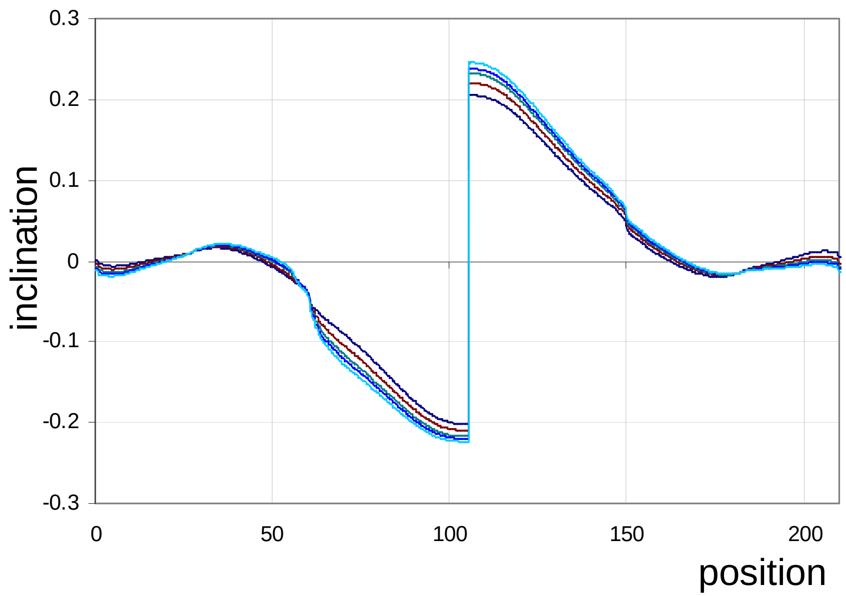
- *Detects cracking earlier than other monitoring methods*
- *Detects near-failure state → especially suitable for proof load tests*
- *Detects growing of damage*

Early warning systems

- *Use: to detect starting damage of unknown location*
- *Application on: bridges of special importance*
- *Technique:*
  - *Design of continuous monitoring system based on*
    - *Risk analysis*
    - *Sensitivity analysis*

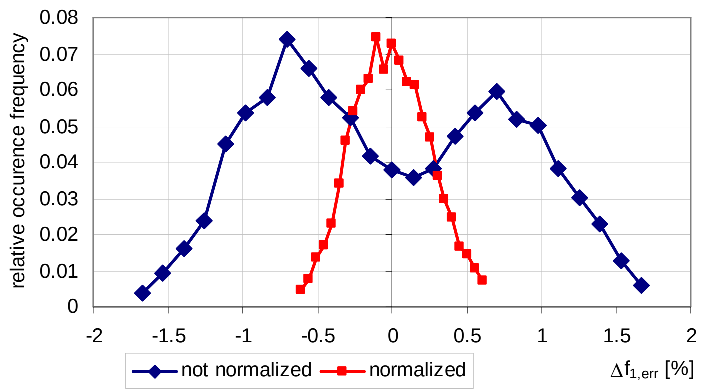


Crack patterns.



Early warning systems

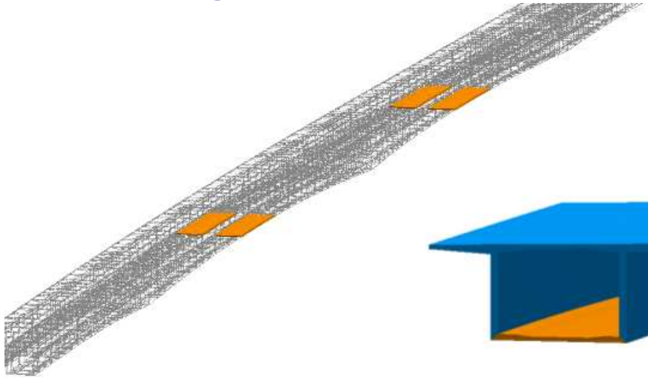
- *Technique (continued):*
  - *Normalization of measured data*
    - *Improves accuracy*
  - *Damage detection using data mining techniques*



- *Rail bridge in France*
  - *Clustering techniques applied on eigenfrequency measurements*
  - *Hierarchy-divisive technique showed best results*

Early warning systems

- *Testing damage detection ability by simulation*
  - *Statistical analysis considering accuracy of measurements*
  - *Testing damage detection ability of probable damage scenarios*
  - *Bridge Reichsbrücke, Vienna*

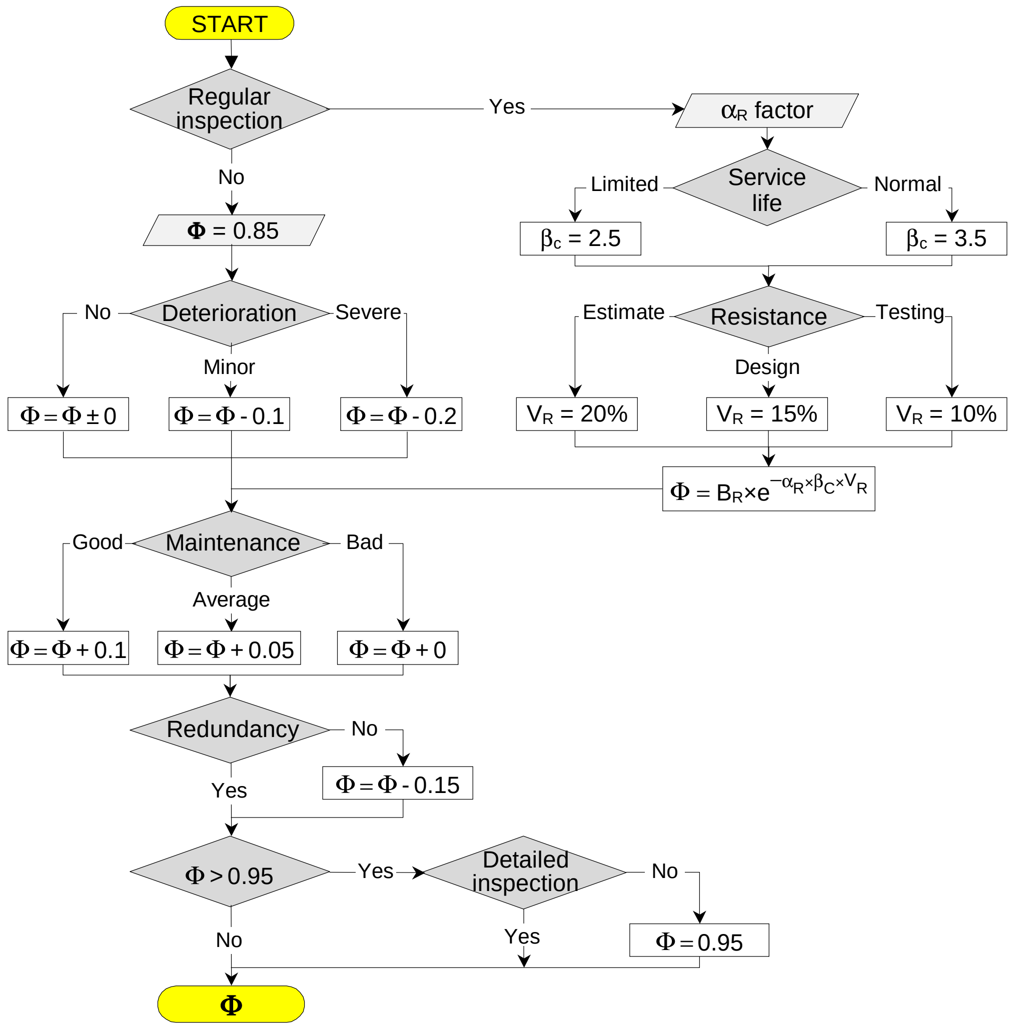


E_c reduction	Identifiable?
10 %	No
25 %	Relatively well
50 %	Yes

- *Benefit: early damage detection allows quick maintenance response*
  - *Expected detection abilities: cracks in concrete, loosening of connections*

Capacity reduction factor by visual inspection

- *Method used in Slovenia compared to method by Moses&Verma (1987)*

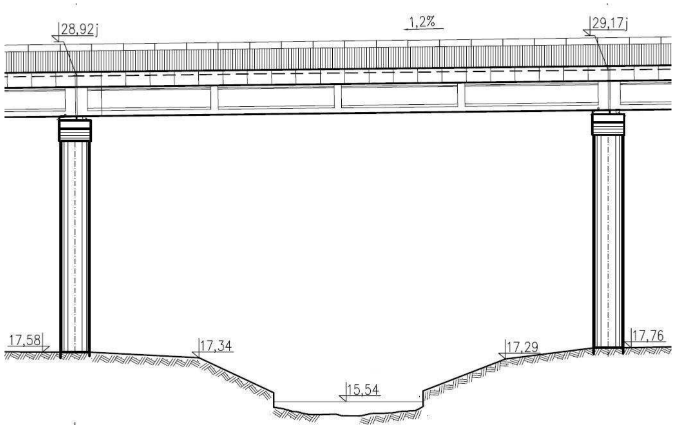


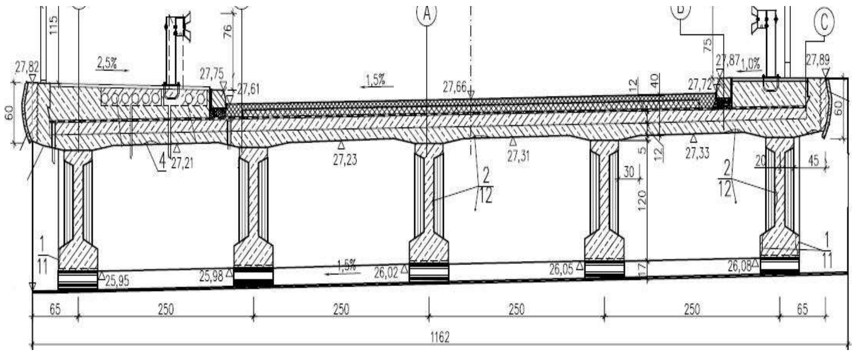
- *Rating factor:*

$$RF = \frac{\Phi \times R_d - \gamma_G \times G_n}{\gamma_Q \times Q_n}$$

Capacity reduction factor by visual inspection

- *Both methods applied on Koszalin Bridge*





- *Identical result from both methods: $\Phi = 0.8$*

- *Method used in Slovenia can be recommended for other NMS as well*