Analysis of BMS Reference Bridges in Finland

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ABSTRACT

A set of about 120 bridges has been selected for regular, special observation to improve knowledge of bridge age behaviour and durability. This reference group consists of bridges of different material and type, age and condition located throughout the country.

The research programme consists mainly of studies of concrete as bridge construction and repair material. Concrete chloride content and carbonation are of particular interest. Samples have been analysed in the laboratory and various non-destructive testing methods have been used. The collected information is used to improve age behaviour modelling in the bridge management system. The main principles, like model simulation, of the BMS model development will be given.

BACKGROUND

The Finnish National Road Administration (Finnra) started the bridge management system (BMS) development in 1986 (*1, 2*). At that time there was no bridge inspection and damage data available in the Bridge Register database to create age behaviour models for the BMS. The road districts have been carrying out regular inspections since the 1970's, but the information was not stored electronically.

Today Finnra maintains 10,686 bridges and 2,763 culverts (span length ≥ 2.00 m) with a total length of 315 km, a total deck area of 3.16 million m^2 and an estimated replacement value of 18 billion Finnish marks (3 billion Euros).

The modelling of deterioration acceleration and age behaviour of those bridges is based on the information of damages gathered during the inspections (*3*). Because there was lack of information of this kind in the beginning, expert evaluations were made for getting the first age behaviour curves and models (*4*).

The inspection period of a bridge is about 4 to 8 years depending on the condition. Thus a set of 99 bridges and 23 culverts, which as a sample group represent the whole bridge stock, has been selected for regular, special observations to improve both knowledge of bridge age behaviour and durability and modelling in the management system.

The reference bridges are also used to compare bridge maintenance costs and life span costs for different bridge types. The economical and structural suitability of different bridge types and materials for various purposes will be analysed to improve future bridge design.

The first large analysis of the investigation results was reported in the end of 1998 (*5*). This analysis gives information on especially age behaviour of concrete as bridge construction material. Also recommendations for further research are given.

REFERENCE BRIDGE GROUP

General

The reference bridge group has been chosen as a random sample to represent the whole bridge stock in the country. The reference bridge group consists of bridges of different material and type, age and condition, geographically situated throughout the country. The overall description of the reference bridge group is given in Figures 1 to 4: Figure 1 describes the material distribution, Figure 2 age distribution, Figure 3 maintenance class distribution and Figure 4 overall condition of the reference bridges. In the figures the bridge area is the product of bridge total length and effective width.

Inspections and concrete core sample investigations have been made since 1992. All the 122 bridges were inspected at least once in 1997. The inspections were carried out according to a special inspection plan. The yearly reports give an estimate for the condition of the bridge structural parts for every inspected individual bridge. Also samples were taken for laboratory tests.

Surface deterioration, which is usually preceded by map cracking, is the greatest problem in the reference bridge group. These damages are mostly located in edge beams and substructures like retaining walls and wingwalls. Also erosion of front slopes and cones are often observed damages. More serious damages are cracking and water leakage among surface deterioration and reinforcement corrosion of concrete deck superstructures. The most usual damage in steel bridges is rusting: many of the steel culverts constructed in the 1960s are in a very bad condition.

Statistical Reliability

The statistical reliability analysis proved that the reference bridge group is quite a representative sample of the whole bridge stock. In Figure 5 there is the age distribution and in Figure 6 the material distribution of the whole bridge stock.

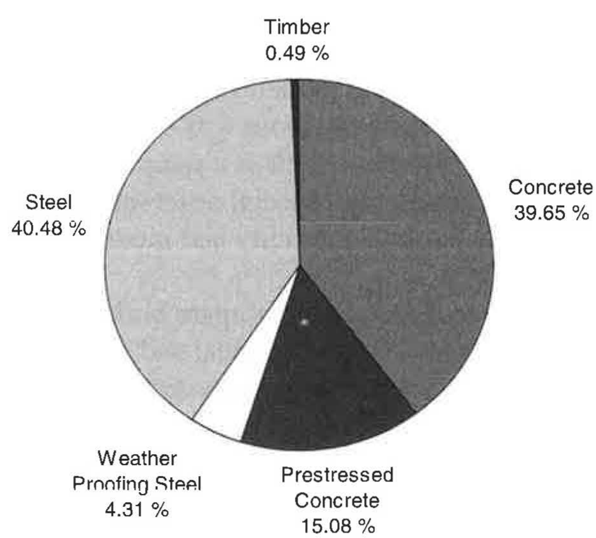

Figure 1: Material distribution of the reference bridge group by bridge area.

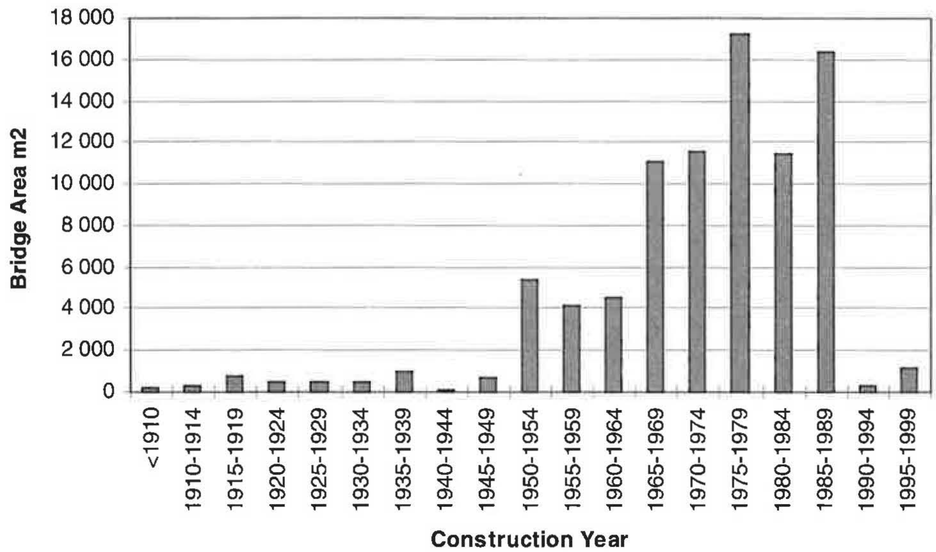

Figure 2: Age distribution of the reference bridge group.

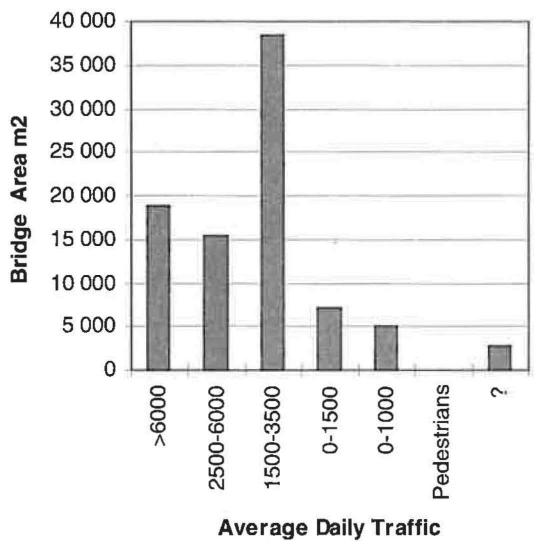

Figure 3: Distribution of the reference bridge group by road maintenance class.

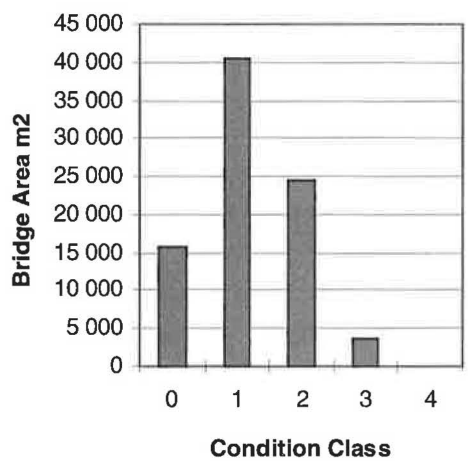

Figure 4: Calculated overall condition (0 very good, 4 very bad) of the reference bridge group.

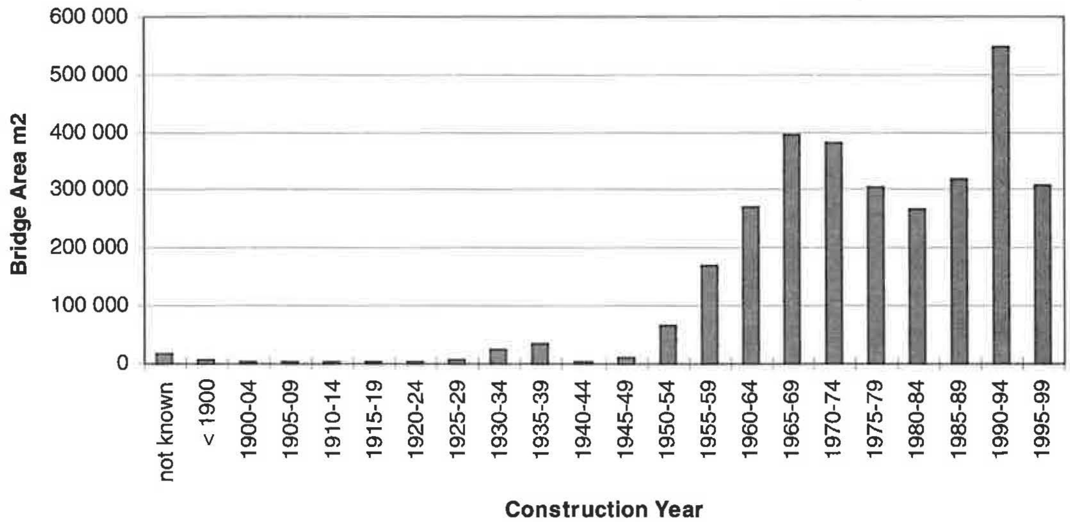

Figure 5: Age distribution of Finnra's bridges, 1 January 1999.

The proportion of steel bridges is greater in the reference bridge group than compared with the whole bridge stock. There are plans to add some short spanned concrete bridges in the reference group.

INSPECTIONS

Investigations on the Bridge Site

The reference bridges have been inspected twice since 1992 for BMS purposes. The inspections are very similar to general inspections but they are carried out by a leading consultant specialised in bridge inspection and repair together with a bridge management

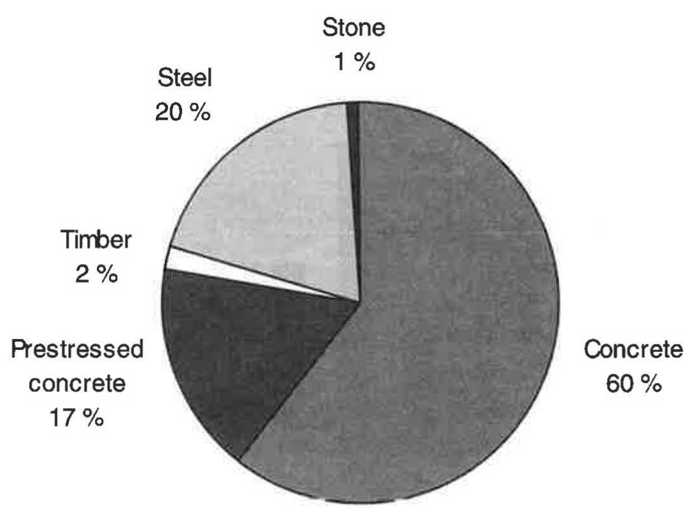

Figure 6: Material distribution of Finnra's bridges by bridge area, 1 January 1999.

expert from Finnra. The inspection interval varies with the research needs. Not all of the 122 bridges are inspected in a year, but every year bridges are inspected in different districts. The inspection interval for one bridge will be about two to five years.

The inspection data, bridge condition data and damage data are updated in the Bridge Register on the bridge site using a portable computer and a mobile phone connection. Non-destructive testing methods are used together with concrete core samples among others.

The following tests are used in the field investigations:

- Carbonation depth of the concrete is determined from core samples which are taken with a 50 mm corecase drill. The cores are cleft and phenolphthalein indicator is sprayed on the cleavage surface.
- Acid soluble chloride content of the concrete is determined using Rapid Chloride Test equipment. The concrete powder samples are taken from the depth of 0 to 20 mm using a hammer drill.
- Concrete deck covers are measured using an electromagnetic covermeter (Proteq Profometer 4).
- Thickness of coatings in railings and steel structures is measured using Elcometer 245F.
- Concrete compressive strength is measured using the rebound Shmidt hammer (Proceed N).
- Relative humidity of the concrete is measured using Vaisala HMI sensoring elements and data logger.

All the tests are taken according to a plan made by the Technical Research Centre of Finland, VTT.

Also radar measurements for bridge decks can be used for bridges which are planned to be rehabilitated in the near future. The suitability of radar measurements was proved by a research programme in the years 1990 to 1993. The bridge deck surfacing, the protective course and waterproofing were opened till the slab upper surface after the measurements. Comparisons with the radar results and empirical studies could be made and so valuable information gathered.

Tests in the Laboratory

During the inspections, concrete core samples were taken for laboratory tests in VTT according to the sample plan. Altogether 112 cores were tested between 1992 and 1998. Carbonation depth, porosity and concrete compressive strength were measured from the core samples with a diameter of 75 mm. The samples needed in the tests were worked out of the cores as shown in Figure 7.

Also microstructure investigations were applied to a part of the cores. Concrete porosity, microcracking, carbonation depth and possible ettringite occurrences were studied.

The following main quantities were measured:

- Total, protecting and capillary porosity of concrete
- Protecting porosity ratio

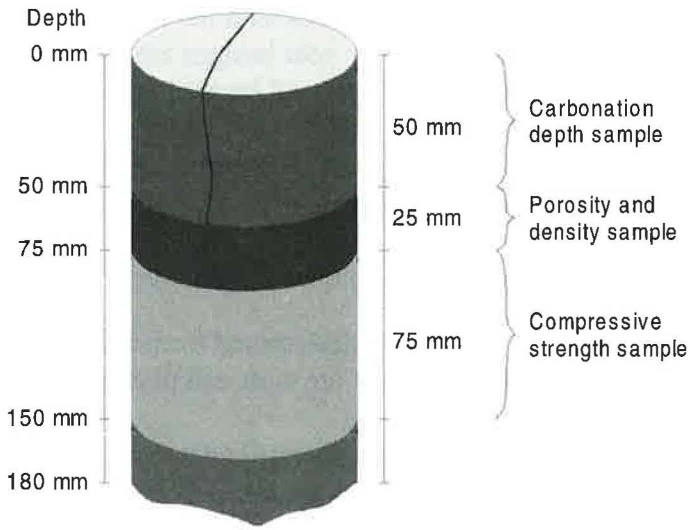

Figure 7: Partition of the concrete core samples for laboratory tests.

- Water penetration resistance factor
- Capillary factor
- Concrete compressive strength
- Concrete density and dry density
- Carbonation depth, minimum and maximum.

SAMPLE ANALYSIS

The samples were divided into groups by bridge structural parts, where they located. The same bridge structural parts were used as in the Network Level BMS (*4*). Samples were divided into two environmental categories: structures exposed to sea water or de-icing salt and other structures.

Statistical analysis of the test results was made by calculating the mean values, deviations and numbers of tests of those quantities listed above. From this information a statistical reliability index related to the (0,1)-normal distribution was solved to give a probability of mean value deviation for the structural part in question, compared with all tested structural part samples (*5*).

The statistical analysis gives a quite exact description of the concrete used as a construction material in the Finnish bridges. Information on compression strength, porosity, density, carbonation speed and concrete cover of the reinforcement can be used when estimating bridge deterioration and remaining life.

BRIDGE AGE BEHAVIOUR MODELLING

Models Developed for the Network Level BMS

When creating the first bridge deterioration and age behaviour models there was not enough information on damages gathered during the inspections. Instead, opinion surveys

(Delphi studies) and expert evaluations were carried out in order to set up the first age behaviour curves and models. One result from these expert evaluations is given as an example in Figure 8 (*4*). These polynomial curves can be presented mathematically as in equation 1:

$$S(t) = a_1 [t / (1 - k)] + a_2 [t / (1 - k)]^2 + a_3 [t / (1 - k)]^3 \quad (1)$$

where: S is the damage degree,
t is the time in years,
k is the relative shortening on account of the parallel damage type,
a_1, a_2 and a_3 are constants.

Model Simulation

A research project on service life modelling of durability against freeze-thaw weathering and reinforcement corrosion of concrete structures (*6*) was carried out in the years 1996 and 1997 in the Technical Research Centre of Finland VTT. The goal was to develop a calculation method based on computer simulation for predicting the deterioration speed and service life of concrete structures in real circumstances and for getting knowledge of the effects of different material parameters and structural and environmental elements on the service life of the structures.

The simulation research was found to be useful in development of the new age behaviour models. Information on material and both damage and deterioration data from the measures gathered from the inspections and from research on the reference bridges were very suitable for the calibration of simulation models for the bridge management system needs. For this reason the simulation program was developed further in 1998 (*7*). In the first phase, statistical mean values from the laboratory tests

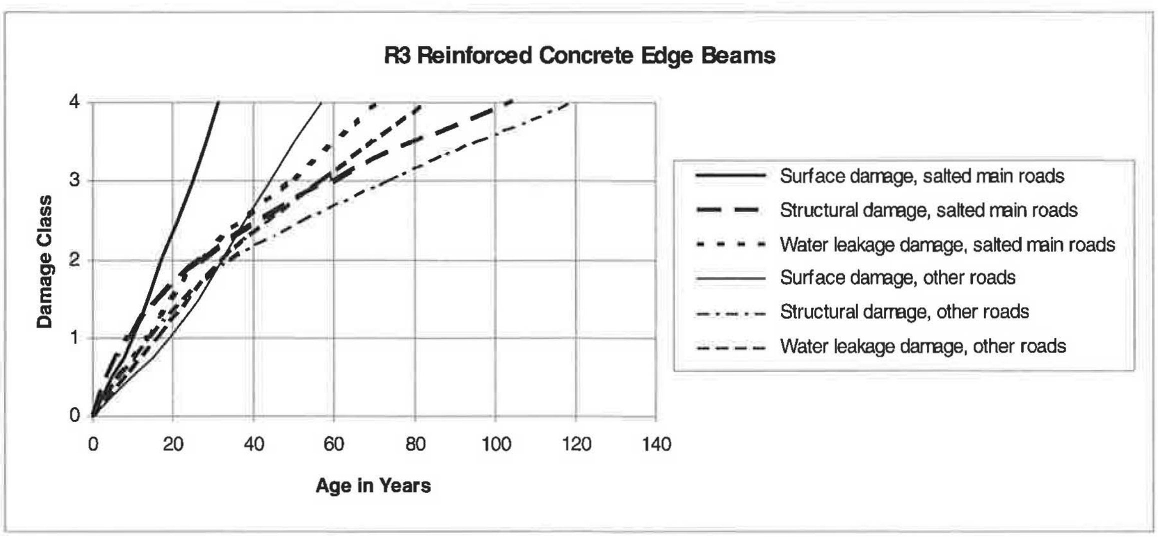

Figure 8: Age behaviour curves for reinforced concrete edge beams.

were used to calibrate the calculation models. The main models in the simulation program are among others:

- model for freeze-thaw weathering of concrete
- model for reinforcement corrosion

Project Level BMS Model Development

To produce age behaviour models for bridge structural parts using the simulation program means that the empirical and experimental information from the reference bridges will be combined with the calculation formulas of the simulation program. The models can be easily calculated after this calibration.

The final age behaviour models for the Project Level BMS will be interactive (*7*). They can be adjusted by bridge material properties and structural and environmental information on a specific structure given by the BMS user. The user determines the bridge structure, location, chloride stress, concrete cover, concrete compression, porosity and width of the crack. If all the information is not available, the default models based on the research mean values of the reference bridge group will be used. In addition to this data the user can also specify the following deterioration information:

- The age of the bridge at the time of inspection
- Carbonation depth
- Critical depth of the chloride content
- Deterioration depth of the concrete
- Depth of the reinforcement corrosion in the crack.

The reliability and quality of service life predictions depend on the available bridge-specific information.

BENEFITS OF THE REFERENCE BRIDGE GROUP

The reference bridges are not only inspected by the experts but also separately by the bridge engineers in the road districts. So the reference bridge group serves very well as a data quality control method for the inspection data carried out by the bridge engineers.

The main target is to get improved age behaviour models for both the whole bridge stock and the main bridge structural parts on the network level and specified age behaviour models suitable for individual bridges on the project level (*8*). The first results from the analysis are very promising.

FURTHER RESEARCH

The research of the reference bridges continues. About 10 to 15 new bridges will be added on grounds of the statistical analysis recommendations. There are needs for special samples taken out of bridges which are mainly exposed to de-icing salts or sea water and thus have a high chloride content. The models need new information to be improved continuously.

Investigations of the reference bridges have until now concentrated mainly on solving the basic properties of concrete and on studying the first stages of concrete damaging, that is, carbonation and chloride penetration. In the future, more attention should be drawn to the second stage damages like freeze-thaw weathering and corrosion, which determine the end of the bridge life cycle. Also cracking surveys should be included in the future research programmes.

The steel bridges in the reference group mostly have a concrete deck. The steel superstructures, girders and especially culverts, will be investigated as a separate group in a research programme in the near future. Timber bridges will have their own research programme, too.

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