Risk Assessment with Statistical Data

Estimation de risques au moyen de données statistiques

Risikoabschätzung mittels statistischer Daten

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SUMMARY

This report deals with recent results of a risk analysis in the field of civil engineering, with special consideration of bridges. In addition to a weak point analysis, some statements are made about the risk from damages of large prestressed concrete bridges in two federal states of the Federal Republic of Germany.

RESUME

Ce rapport traite de résultats récents d'une analyse de risque dans le domaine des constructions civiles à l'exemple des constructions des ponts. A partir d'une analyse des points faibles, il est possible de prédire le risque dû à des dommages causés aux grands ponts en béton précontraint, de deux provinces de la Rép. féd. d'Allemagne.

ZUSAMMENFASSUNG

Dieser Bericht befasst sich mit neueren Ergebnissen einer vom Bundesminister für Forschung und Technologie geförderten Risikostudie für das Bauwesen am Beispiel von Brückenbauten. Neben einer Schwachstellenanalyse gelingt eine Aussage über das Risiko aus Beschädigung von grossen Spannbetonbrücken in zwei Bundesländern der Bundesrepublik Deutschland.

1. INTRODUCTION

The analysis of structural damages or accidents which has been made by various authors [1] [2] [3] in the past, will also been carried out in a study of my office which deals with the condition and the corresponding damages of struc- tures. The analysis is supported by the minister for r.a.t.. In contrast to the authors mentioned above the statistical empirical research is restricted to bridges which can approximately be combined to a parent population and for which data is available.

An arbitrary selection of great valley bridges in two German federal states has been taken as a sample for the analysis. In the first country prestressed con- crete bridges with a total length greater than 200 m and in the second country bridges of a single highway-line were selected.

As a result from the global registration of damages, it will be attempted to find a relation to the parent population, to make assessments of the risk of defects in the period of use, and to give advice for risk reduction.

2. STRUCTURE AND COLLECTING OF DATA

The investigation is based on files of construction time, on correspondence, drawings, static calculations, expertises and the report of the periodic bridge examinations of the responsible departments.

A method which is based on a fixed definition of terms and which must simulta- neously show high flexibility, is necessary because of the heterogenous struc- ture and the great number of data. Starting from a terminological chain with the causality:

fault - shortcoming - defect - damage - consequential damage

the terms, based on [1] and [2], are defined as follows:

fault	Deviation between the results of human actions and the issue of the action
shortcoming	Negative deviation between an aimed condition and the obtained condition, if the deviation exceeds certain tolerable values
defect	Alteration of an object or human being in the aimed or natural turn of occurence in regard of form, structure or function
damage	Enchroachment on protected interests as a consequence of a defect

If one now wants to register the condition of structures which are seemingly without any damage, i.e. structures which did not cause any cost for reparation, one has to concentrate the collection of data on the defects which can also be understood as damage-indicators [4].

By means of several terms, subjective as well as objective ones, it is possible to register very different kinds of defects numerically, so that they can be compared with each other. To describe a case sufficiently, one has to give in- formation about the following parameters:

- quantity
- state
- effect
- type of beginning
- type of defect
- place
- material
- extent

Fixed subterms can be provided for each term of the linguistic system "defect".
By means of the subterms, the most different cases are defined as combinations
of those terms. This method of splitting complex facts in previously defined
subtermgroups is very well suited for data storage by electronic data processing.
The necessary catalogues of the defined subterms are used for each case of de-
fect, to steadily fill in the questionaire which has been developed for this
reason. Apart from the specific data of defects, the basic data of the structu-
ral system, i.e. for example the cross-section of the superstructure, clear
spans etc., are registered according the same scheme. In that case, the que-
stionaire as well as the corresponding computer programmes only work on the
basis of the given numerical codes.

3. EVALUATION

A total of 76 prestressed concrete bridges were examined and about 15.000 de-
fects were registered. As a result, 12.500 different cases at diverse compo-
nents of the system "bridge" can be separated. A component can be for example
a cross-section of the main girder, a bearing or an expansion joint. Evaluating
the results, one has to consider that the chosen bridges are built in a period
of 20 years (1960 - 1980, see figure 1). The mean value of the observed service
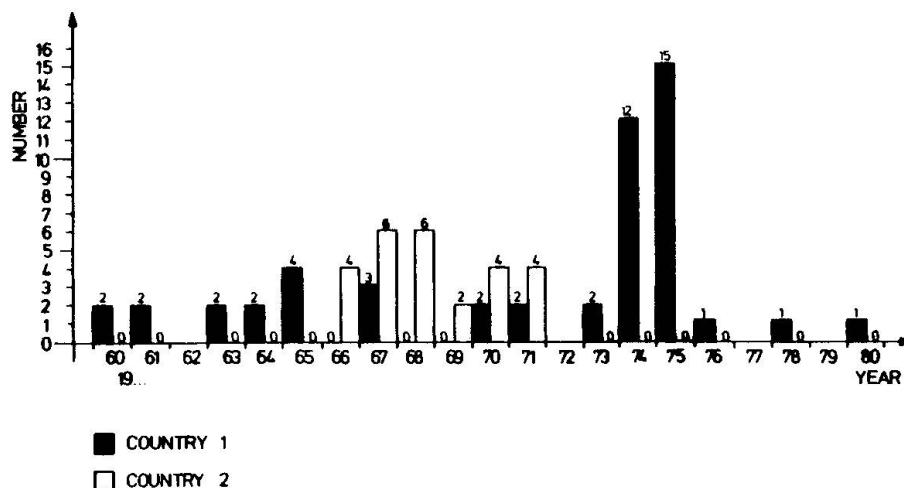life is about 10 years, i.e. a total of 713 years of use were examined.

■ COUNTRY 1
□ COUNTRY 2

figure 1: Examined bridges - year of end of construction

Looking at the distribution of the effects of the defects in regard to the futu-
re condition of a component (figure 2), it appears that in the majority of all
cases the durability of the building is endangered. Consequently, considerable
costs arise from the maintenance of the bridges. Drawing a conclusion of this
state of affairs, two main questions have to be asked:

- How many cases can be prevented directly and how much percent has to be added
  to the deviations of the resistances?
- How great is the real extent?

To answer the first question, weak-point-analyses are useful which are best
carried out by correlations between the defects and the place of defects. As an
example, the relationship between uncovered reinforcement and the surface of the
superstructure will be presented. The analysis shows that the appearance of such a
defect is no longer dependent on the type of the cross-section. Thus, the rela-
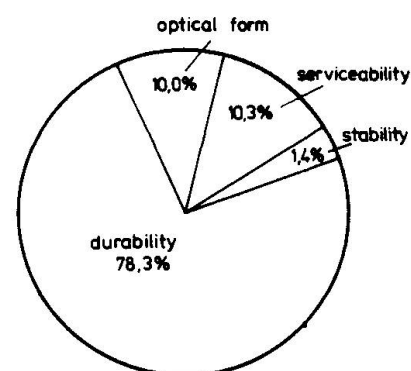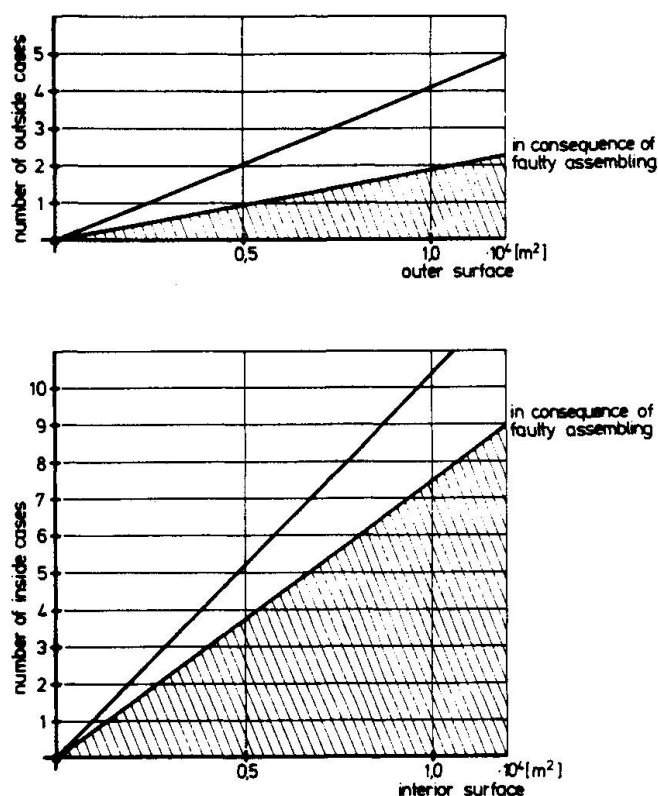tion outlined in figure 3 can be deduced.

figure 2: Effect of the defects

figure 3: Uncovered reinforcement per surface (outside, inside respect.)

Corrosions of reinforcement were specially marked during the collecting of data, if the cause of damage could clearly be recognized, i.e. the shortcoming 'too low cover' in consequence of faulty assembling. Thus it is now possible to eva- luate the influences separately. Figure 3 shows first of all, that there are more interior cases than outside ones. This effect is not due to different kinds of examination methods because all bridges have been checked inside as well as outside. As shown in the following, the cause of this is rather a shortcoming depending on the site method. Secondly, the part of those cases is almost con- stant, whose cause wasn't clearly recognizable, i.e. about $2.5 \cdot 10^{-4}$ cases per m^2-surface, inside as well as outside. This value sould be connected with the dispersion of the resistance. Moreover, one can see that a high percentage, outside ~45%, inside even ~70%, can be prevented by controlling the position of reinforcement. More developed analyses which consider the special place in the cross-section, i.e. deck slab, web, bottom chord, reveal other weak points.

Thus, bridges with bottom chord for example show the following measured values:

- In the webs, the number of interior uncovered reinforcement is more than double the size of outside cases. It seems, that the site method may be a factor because the interior formwork is assembled finally or 'blindly' as one might say.
- In the bottom chord, the number of outside cases is even five times as bis as the number of the interior ones. The cause may be tipping of spacers or simple deformation of the bottom reinforcement by the workers.

In bridges without bottom chord (e.g. T-beams), the high portion (85%) of the uncovered reinforcement in the webs can probably be explained by inexact rein- forcement work in the narrow space of the web framework. In most cases the reinforcement is inserted from the top.

4. CLASSIFICATION

The second question about the real extent requires a graduation in accordance with the importance and size of the different cases. According to several publications [5] [6] [7] [8], it is possible to classify the cases into damage classes:

S1 - very small damage (no real financial loss)
S2 - small damage, with effect on serviceability
S3 - small damage, with effect on serviceabilty and durability
S4 - medium-sized damage (can be reconstructed at limited expense)

S5 - big damage (can be reconstructed at big expense)/ endangering of persons
S6 - very big damage (big financial loss)/ personal injury

A - measures for maintenance necessary in due time
B - counter-measures necessary immediately

A corresponding procedure of classification which rates the different parameters of the defect mentioned above, in accordance with their importance, results in frequencies of the damage classes which are shown in figure 4.
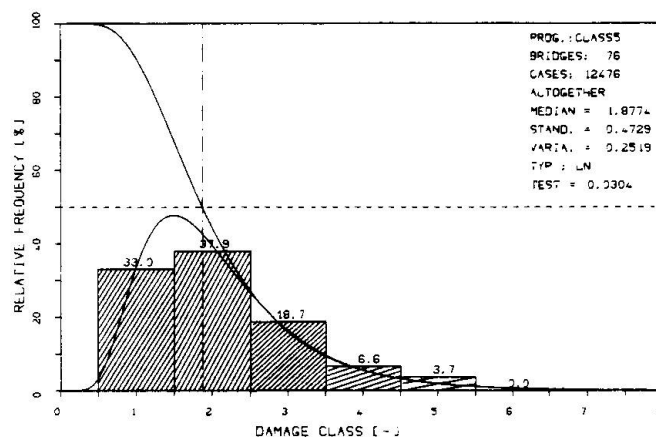

figure 4: Damage classes

On the supposition that the cases of defects are a sufficient random sample of a probabilistic model, one can derive a model of failure for the system "bridge" in form of a distribution of the damage classes. The density function refers to a constant damage rate λ $[1/a \cdot m^2]$ which can be obtained satisfactorily by figure 5. This rate depends on different factors, such as type of cross-section, site method, method of bearing etc. By means of the model, the values of class S6, which were not measured in the observed service life, can theoretically be extrapolated to $7 \cdot 10^{-3}$.

To compare the damage classes with each other, a cost model is necessary. Such a model can be outlined on the following conditions:
- an annual rate of costs for maintenance of 2.5% (corresponding to the construction expenses for the superstructure) (see [8])
- an average damage rate λ $[1/a \cdot m^2]$
- an average factor of interest of 5% (German index from 1960 to 1980 [7], uniformly distributed beginning of defects in the time of use)
- frequencies from figure 4

$$c_i = p^{s_i}$$

s_i = damage class
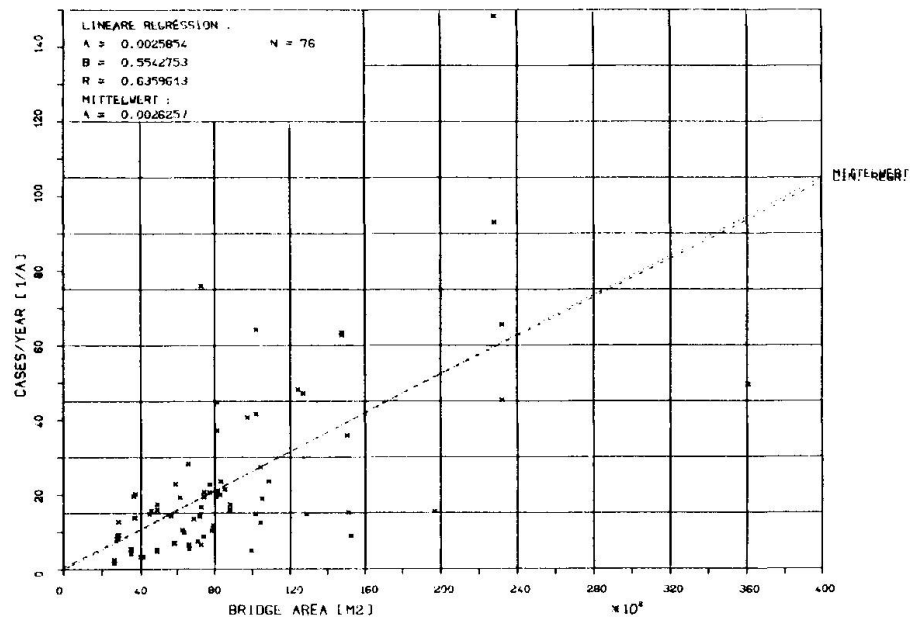c_i = costs per class [DM]

figure 5: Damage rate

Taking the average over all examined bridges, one computes the basis to

$p = 9.8 \approx 10$ (exactly valid for 1980)

$c_i = 10^S i$ [DM]

Assuming this model and comparing group S1 to S4 with S5 + S6, it is obvious that the contribution of the many small damages to the estimation of the critical risk of total failure can be neglected.

5. CONCLUSION

The statistical empirical method which has been introduced makes it possible to give statements about weak points in a structural system and to draw conclusions about the risks of defects. This method is practicable for every other structural system with suitable classification and calibration.

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