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Autor: Wicke, Manfred

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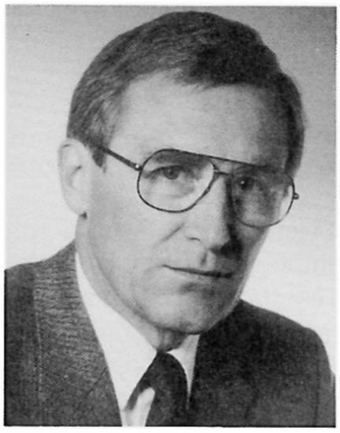
Inspection, Assessment and Maintenance

Surveillance, évaluation et maintenance

Überwachung, Zustandbewertung und Unterhaltung

Manfred WICKE
o.Univ.-Prof. Dipl.-Ing. Dr. techn.
Universität Innsbruck
Innsbruck, Austria



Manfred Wicke, born 1933, graduated in Civil Engineering and took his Dr.techn. degree at Vienna Technical University. For a 12 year period he firstly worked in and later on headed the design office of a firm. He was mainly involved in design work of buildings, bridges and power plants. Since 1971 he is full professor for concrete structures at Innsbruck University. Since 1977 he inspected more than hundred bridges.

SUMMARY
This introductory paper deals with the inspection of existing structures as well as the evaluation of established damages and defects and the overall assessment of its maintenance condition. These factors are the basis for the determination of appropriate methods for maintenance and repair. The diverse influential factors are described here as well as inferences which can be made with regard to applicable procedures. Using examples, particularly from the field of bridge construction, a picture of the present status of inspection procedures will be provided.

RÉSUMÉ
Cette introduction traite du contrôle des bâtiments déjà existants, de l'évaluation des dommages et des insuffisances constatés, ainsi que de l'analyse de l'état actuel. Ces données constituent la base pour le choix des mesures de réparation à prendre. L'auteur décrit les différents facteurs d'influence et en déduit les procédures à appliquer. Quelques exemples, notamment ceux du domaine de la construction des ponts donnent un apercu de l'état actuel des possibilités de contrôle.

ZUSAMMENFASSUNG
Diese Einführung behandelt die Überwachung von bestehenden Bauwerken sowie die Bewertung der festgestellten Schäden und Mängel und die Gesamtbeurteilung des Erhaltungszustandes. Diese stellen die Voraussetzung für die Auswahl geeigneter Instandsetzungsmaßnahmen dar. Es werden die verschiedenen Einflußgrößen beschrieben und daraus Folgerungen für die anzuwendenden Verfahren abgeleitet. Anhand von Beispielen, insbesondere aus dem Brückenbau, wird Einblick in den gegenwärtigen Stand der Überwachung vermittelt.

1. INTRODUCTION

Over the past few years, the question of the structural maintenance of buildings has gained substantially in importance. Even a decade ago, primarily historical buildings or railway bridges were mentioned in connection with the term "maintenance". Bridge construction provided the point of departure for other structural engineering work being confronted with the subject of maintenance, and the scope of that theme spread to cover buildings, even residential buildings. At this time, one would even be justified in stating that the question of structural maintenance will eventually play a lesser or greater role in all types of constructional works.

One of the reasons for the growing interesting in maintenance can certainly be traced to the tremendous building boom which has taken place throughout the world since World War II. Initially, it was the industrialized nations which began with the re-constructional activities; it did not take long for the pre-war stand to be attained and the amount of construction work being done far surpassed anything previously. Furthermore, active building began in all developing nations with the close of the colonial period. With the exception of short-term economic slumps, the last four decades have witnessed florishing building activities on a worldwide basis, which have brought about a tremendous increase of existing structures.

It is relatively easy to estimate the economic importance of structural maintenance. If one assumes, in a more or less random fashion, that maintenance costs amount to approximately 1 % those of rebuilding, then after a half a century of consistant construction activity, one-half of the annual building budget would be utilized for carrying out maintenance measures. When details with regard to the actual situation are known, it is possible to calculate differentiated predictions of the annual maintenance costs; such a calculation was, for example, carried out for the bridges of the West German Federal Highway system (Fig. 1).

Since that estimate was made, many owners, expecially highway administrators, have recognized the enormous amount of funds which will be necessary for maintenance in the future. This situation has naturally led to the circumstance that innumerable international experts and associations are increasingly directing their efforts toward answering the questions posed by structural maintenance. The catalog of questions on this subject is comprehensive as well as covering many levels.

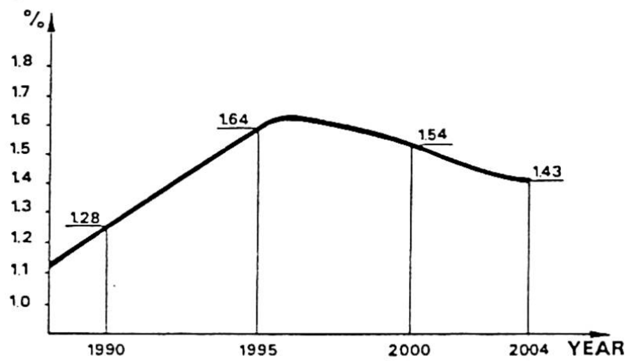


Fig. 1 Predicted annual maintenance cost in percent of rebuilding [acc. 1]

The following discussion is an attempt to present the methods and procedures which are available and being utilized at this time for structural maintenance.

The purpose of all structural maintenance procedures is ensuring that the intended lifetime of a structure is maintained throughout the entirety of its functional life. It is therefore necessary to prevent the reliability of a structure from sinking below a predefined limit. Eventual reductions in reliability must be recognized at as early a stage as possible, to allow the timely commencement of maintenance and repair work. This can be accomplished with regularly scheduled inspections of the structure, or inspections subsequent to accidental or extraordinary circumstances. The maintenance status of the structure which was determined during the inspection can be utilized in conjunction with subsequent, more detailed inspections to present a basis for maintenance and repair decisions.

The questions of maintenance do, however, not only concern themselves with existing structures, but als have repercussions on new construction works. Structures which are easy to maintain continue to gain in importance, since apparently, one is beginning to realize that the economy of a structure is calculated by means to the overall costs throughout its functional life; the overall costs are comprised of the initial expenses as well as those which are incurred for maintenance.. The opinion that only the minimization of the initial building costs is important should finally be laid aside.

2. CATEGORIZATION

It has proven effective to subdivide the extensive field of structural maintenance according to diverse criteria. In so doing, one should utilize at least four categories, such as:

- Type of construction
- Type of structure
- Environmental conditions
- Maintenance procedures

2.1 Types of Construction

The type and extent of necessary maintenance measures are extremely dependent on the type of construction involved. During the categorization phase, it is recommended that the division be made according to convential methods, for instance:

- Stone construction
- Masonry / brick construction
- Reinforced concrete construction
- Prestressed concrete construction
- Composite construction
- Steel construction
- Timber construction
- Other

Within certain fields of construction, for example steel construction, structural maintenance already enjoys a long history. Other fields, such as concrete construction, have only begun to consider the problem of structural maintenance recently.

2.2 Type of Structure

Here it is also recommended that the conventional categorization methods are followed. One should determine between:

- Bridges
- Civil engineering works
- Buildings and
- Residential buildings

It was primarily bridge construction/engineering which provided the foundation for concern with the questions of structural maintenance. Naturally, a vast amount of experience and information is already available in the field of railway bridges, whereas road bridge construction has only recently begun to consider these questions.

2.3 Classification of Environmental Conditions

Environmental aggression continues to gain in importance. The intensity with which the environment attacks structures covers an extremely broad range, making it logical to classify the aggressivity of the environment. The following categories have developed in the field of concrete construction:

Class 1: Dry environment
Class 2: Humid environment
  a) without freezing
  b) with freezing
Class 3: Humid environment with freezing and use of road salt
Class 4: Marine environment
  a) without freezing
  b) with freezing
Class 5: Aggressive chemical actions
  a) mild attack
  b) intermediate attack
  c) severe attack

These classes can also be utilized for any other types or methods of construction.

2.4 Maintenance Procedures

For this section, one can apply the time at which necessary maintenance procedures must be carried out to enable making a subdivision. The procedures begin with the inspection and documentation of the structure's present condition; these are then followed by the evaluation and assessment of the situation encountered. These factors represent the prerequisites for the selection of the appropriate maintenance measures. Thus, a distinct separation is made between the initial inspections and the selection of the necessary maintenance activities. Maintenance is then divided into servicing and repairs; the former shall be defined as measures to maintain the expected condition, whereas the latter means the returning to that condition.

3. INSPECTION PROCEDURES

3.1 Inspection Schedule

The nature and extent of the necessary number of inspections shall be established in an inspection schedule. This schedule should be determined by those executing the project and turned over to the owner at the time of structure's acceptance. The persons responsible for carrying out the inspections and the scope of associated responsibilities should be established within the schedule as well; in most countries, legal regulations determine that the owner himself is responsible for the structure's maintenance. In addition, the time intervals between the regular inspection tours should also be established. It is advisable that diverse kinds of inspections which differ in terms of extent, qualifications of personnel, as well as in frequency be carried out.

Within the field of bridge construction, detailed working inspection schedules, which, in some countries, have attained the status of obligatory guidelines or standards, are already being utilized. Such inspection schedules generally recognize several different types of inspections, as well as continuous monitoring by road service crews (Fig. 2).

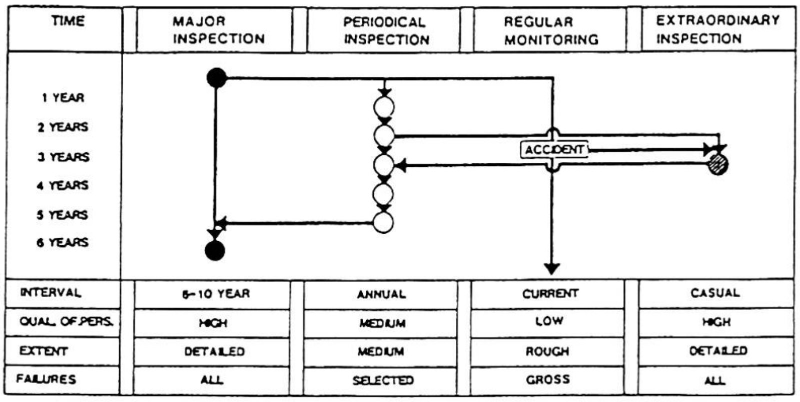


Fig. 2 Inspection schedule for bridges

Major inspections take place every six or ten years, whereas the intermediate inspections are carried out on an annual basis.

The personnel responsible for the major inspection should be more highly qualified - at least the head of the inspection team must have had an appropriate education to permit his determining what effects the detected defects and damages could have on the carrying capacity of the structure. The person or persons responsible for the annual inspection need not have such a high degree of schooling, but must be capable of detecting and describing damages as such; usually, special training is sufficient.

The major inspection involves close inspection of all accessible surfaces of the superstructure as well as the substructure. Generally, simple tests, such as measuring the concrete cover, estimating the strength of the concrete with a rebound hammer, determining the depth of carbonatization or measuring crack widths, are carried out as well. Should the inspector suspect that something is amiss, special tests would include drill core tests, determination of chloride penetration depth, measuring length and deflection, ultrasound tests, endoscopic and radiographic tests, measurement of the electric potential, as well as taking dynamic tests. Special tests, like the dye penetration procedure and the magnetic powder method, are used for steel and/or composite structures to detect cracks; the thickness of the coatings being utilized is also measured. Annual inspections are limited to determining new damage and/or the progress of existing damage. In addition, selected damage sites, for instance cracks, can be measured on a predetermined basis.

It would be advantageous if similarly detailed inspection schedules could be established for civil engineering works as well. For standard buildings, on the other hand, it would suffice to provide simpler procedures. Here it would be vital that the project contractor indicate all points of the structure which deserve particular attention, as well as establishing the type of inspection to be carried out, its extent and time intervals.

Regardless of construction type, any structure which has undergone unusual circumstances such as fire, vehicle collision, avalanche activity, etc., must undergo a detailed inspection analagous to the major inspection described above.

3.2 Equipment and Tools

The kinds of equipment and tools used during the inspection procedure depend on the type of structure. The equipment is used to reach otherwise inaccessible surfaces on sections of the structure to enable visual inspection. In the field of bridge construction, specially designed bridge inspection devices which allow direct inspection of the underside of bridges as well as the upper zones of the supporting piers and abutments from the roadway have been developed (see Fig. 3 and 4).

Fig. 3 Placing of inspection device

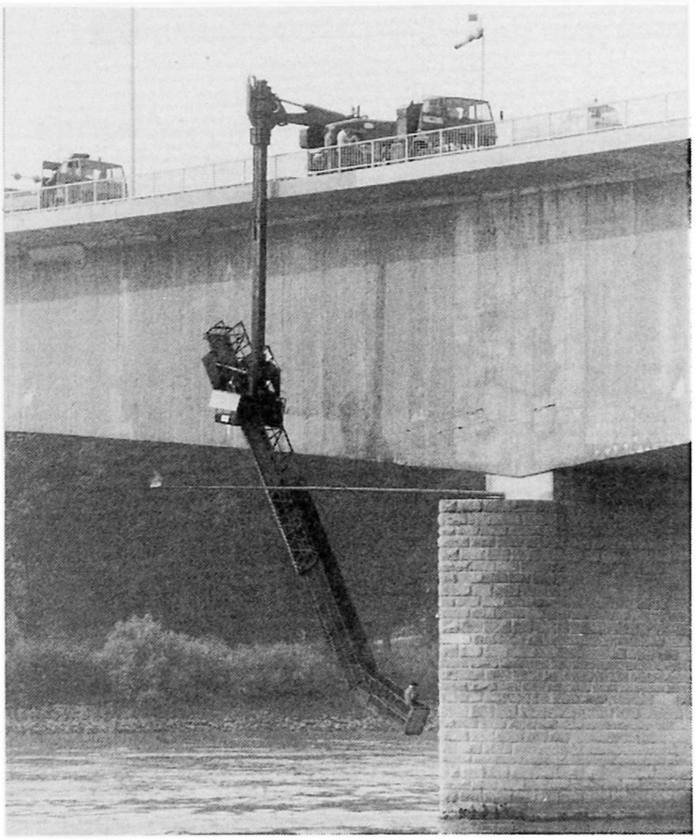


Fig. 4 Inspection device in working position

By using an auxiliary device, a suspended basket, it is possible to inspect entire piers from top to bottom (see Fig. 5). Lifting devices are also used to reach the undersides of bridges from the ground surface below, though the use of such equipment requires adequate access roads. A more modern version of such lifts enable inspection of the bridge understructure from the roadway (Fig. 6).

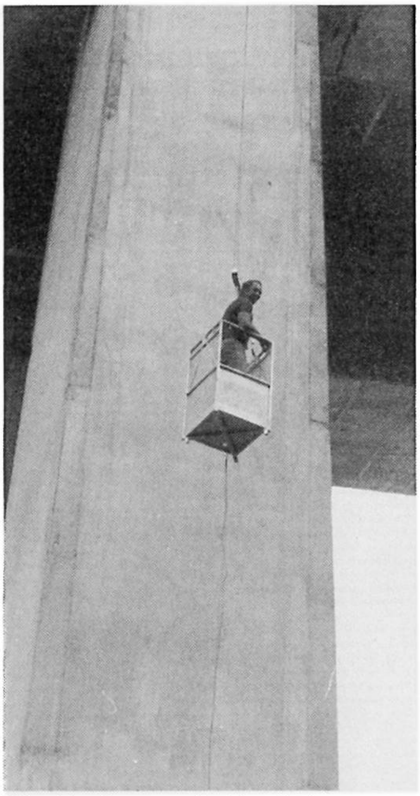


Fig. 5 Suspended basket

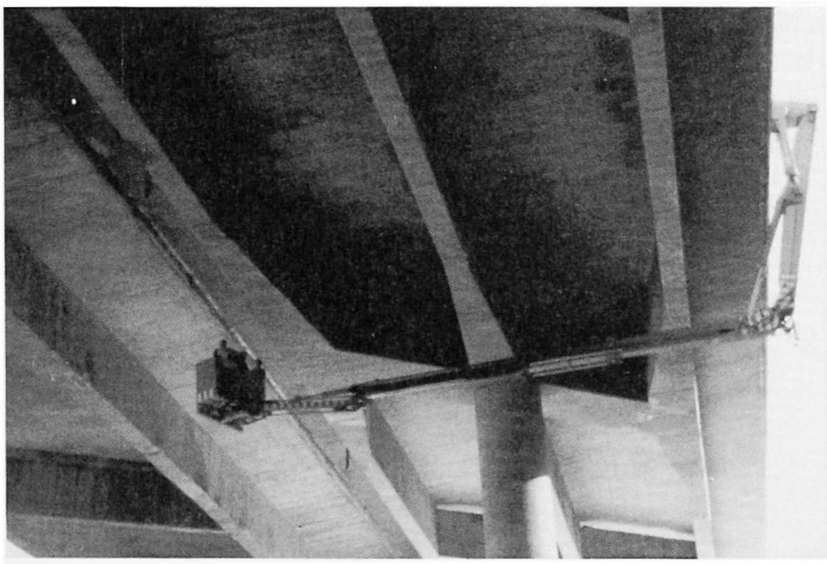


Fig. 6 Lifting device

Inside buildings, access to the surface of the construction is usually hindered by facings or other interior works. It is therefore necessary to plan that facing be removable at critical sites. Generally, a ladder is sufficient for the inspection of the structure at such locations. Outer surfaces could be reached by means of lifting devices or inspection platforms installed directly on the building.

Simpler tools for inspection purposes such as measuring devices, those for on-site surface inspections or for taking samples shall be carried by the inspection crew. The inspection of steel structures requires additional tools to ascertain the condition of joining materials. Furthermore, smaller testing apparatus such as crack microscopes, endoscopes, magnetic detection devices, extensometers and coating thickness gauges are required. Rapid information with regard to the depth of carbonatization and/or chloride content is also gained by the use of indicator solutions. To carry out the special inspection procedures discussed above in Section 3.1, specific sampling devices must also be taken along by the inspection crew.

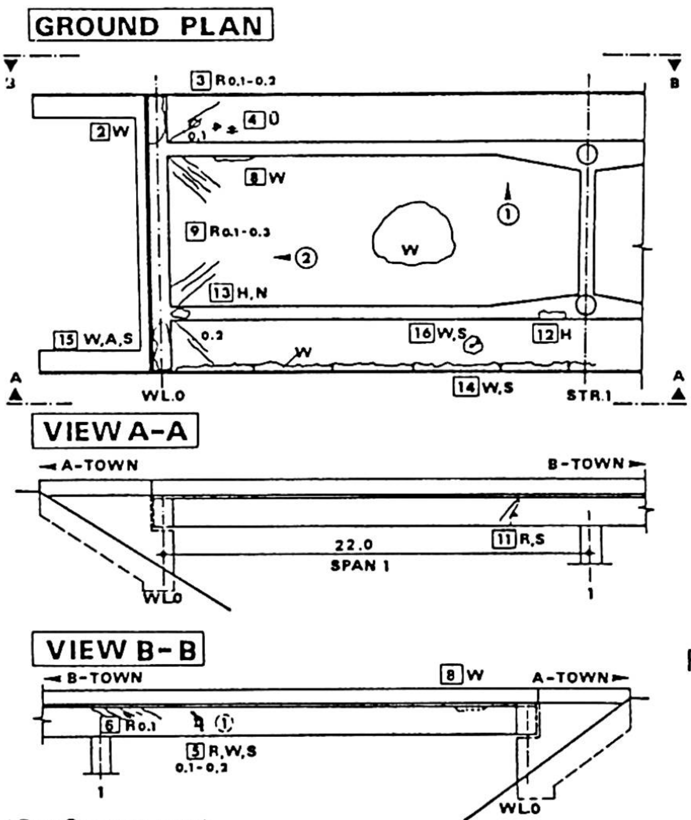
4. DOCUMENTATION

4.1 Purpose of Documentation

Documentation should provide sufficient information with regard to the maintenance condition determined during inspection activities. These records serve as the foundation for the evaluation of the structure. They should also enable consequent and precise determination of eventual changes in the damage situation by recording information taken at periodic inspections. To accomplish these goals, the maintenance situation shall be recorded in a number of ways.

4.2 Graphic Representation

Graphic representation is particularly suited in providing a rapid summary of the situation and should therefore be included in any sort of documentation. Overstated drafting precision is not required, since schematic drawings are sufficient; for example, bridges which are curved according to sideview and/or overview can be drawn as straight lines. It is far more important to select a method of presentation from which the greatest amount of information can be obtained. The damage diagram of a T-beam bridge has been chosen to illustrate this point (Fig. 7).



On this diagram, the cracks on both vertical surfaces were drawn into only one view of the web, though different markations were used for either side, whereby cracks resulting from shear were clearly clearly distinguishable from those caused by torsion. Had one, on the other hand, mapped the cracks on a developed view of the surfaces, the patterns would probably not have been so distinct. Moreover, it is also advantageous to present the structure it as it is viewed from the inspection device.

Fig. 7 Schematic drawings

It is not usually necessary to take exact measurements of the damage site. The drawing should, however, facilitate finding the location of the damage site on the structure as well as serve as the basis for evaluations. In the field of bridge construction, for example, it is often sufficient to provide meter markations on the girders and piers, and then approximating the position of the damage site between two such marks. More precision is not necessary for drawings used for this purpose. In contrast to this rule, the location of damaged tendons must be drawn in exactly as measured to enable their identification.

To increase the amount of information which can be contained on such a drawing, texts should be avoided and symbols indicating the individual types of damage should be used. It is immaterial what symbols are chosen to represent damages, though they should not require extensive explanations to make them understandable. A standardization of such symbols should, however, be desirable, to facilitate informational exchange (Fig. 8).

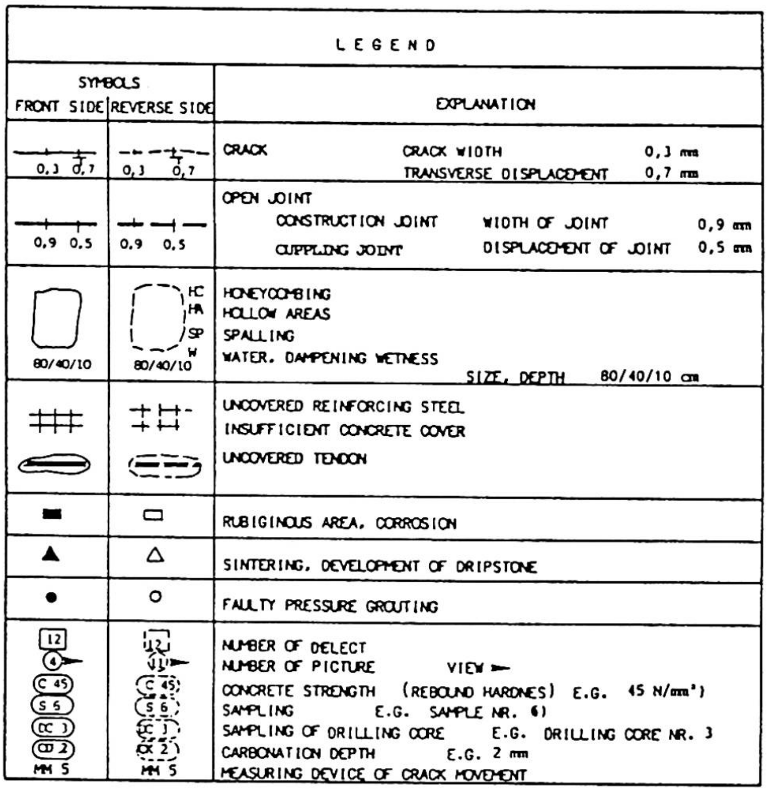


Fig. 8 Symbols of defects

4.3 Listing and description of damage sites

A verbal explanation should supplement the graphic representation, whereby all details which could not be reflected in the symbols should be provided. Insofar as conclusions can be drawn from the visual inspections, they should als be mentioned. Furthermore, comments as to whether and/ or which typ of additional inspections procedures would be useful in clarifying the cause of the damage should also be included.

When numerous damage sites have been detected, their consecutive numeration is expedient. A list can then be prepared according to those numbers. While the compilation of similar defects is necessary for the repair work tender, it is not required for documentation purposes. Should the list be prepared with a computer, an additional list according to the type of damage can be presented without significant additional expenses.

4.4 Photographs

Coloured photographs increase the informational value of any type of documentation. Black and white photos should no longer be used. One must remember that not every type of damage is equally suited for photographic presentation. For example, colour photographs of cracks serve no practical purpose, whereas those of rust and wet spots could prove extremely informative. Colour photography should therefore applied with care, though should it promise informative results, film should not be spared. It is also necessary that the photographs be clearly assigned to the damage sites; the simplest way of accomplishing this is by writing the number of the photograph on the drawings as well as by noting the photo number on the damage list.

In addition to photographs taken of surficial damages, those taken during endoscopic activities can prove extremely valuable for documentation purposes. The latter process is imperative during the inspection of the condition of grouting around tendons as well as of inaccessible voids (Fig. 9).

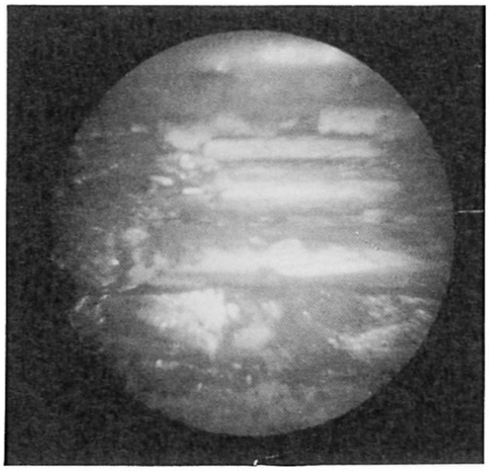


Fig. 9 Endoscopic photograph

4.5 Test Results

The results of the various tests which were carried out during the inspection procedures are to be included in the documentation. Such results would include, for example, measurements of the depth of carbonatisation on concrete structures or the thickness of protective coatings on steel structures. Insofar as samples were taken and the associated laboratory tests carried out, test results should also be included in the documentation. The applied sampling and/or testing methods must be mentioned in the test records or in the documents.

4.6 Computer-aided Documentation

Since the personal computer has become almost ubiquitous, it seems logical that this tool be applied for damage documentation as well. However, this does not mean merely using a word processing unit instead of a typewriter for writing the documentation. The full advantages of using data processing for documentation procedures are first realized when one includes additiona data processing functions. These auxiliary systems should at least provide the capability of using the damage documentation for the preparation of repair work tenders. Integrated evaluation procedures would be desirable to assist in preparing the assessment of maintenance conditions. A more detailed discussion will be presented below in Chapter 6.

5. ASSESSMENT OF DAMAGES

In assessing damages, it is important to include not only the type of structural damage, but the method of construction, the type of construction, and the aggressivity of the environment as well. An additional assessment tool can be gained from the degree of damage, whereby it must be realized that the damage situation can change as damage progresses. One must also make the distinction as to whether the damage negatively influences the structure's bearing capacity, its serviceability, its durability or a combination thereof. The evaluation of individual types of damage as well as their extent must be included in the assessment of the overall condition of the structure.

5.1 Types of damages

Depending on the type of structure involved, damages can be ordered according to the structural group, whereby subdivision according to appearance is more useful than one based on causes or causative agents. In such a manner, it is possible to maintain the same method of classification form the beginning of the inspection process through the documentation procedures; this also avoids having to determine causes for damage during the inspection phase. The following major damage categories can be established according to the main methods of construction:

Concrete construction:

Concrete damage, cracks and open construction joints, damages to normal reinforcement (Fig. 10), defects in prestressing tendons (Fig. 11) and wet spots (Fig. 12)

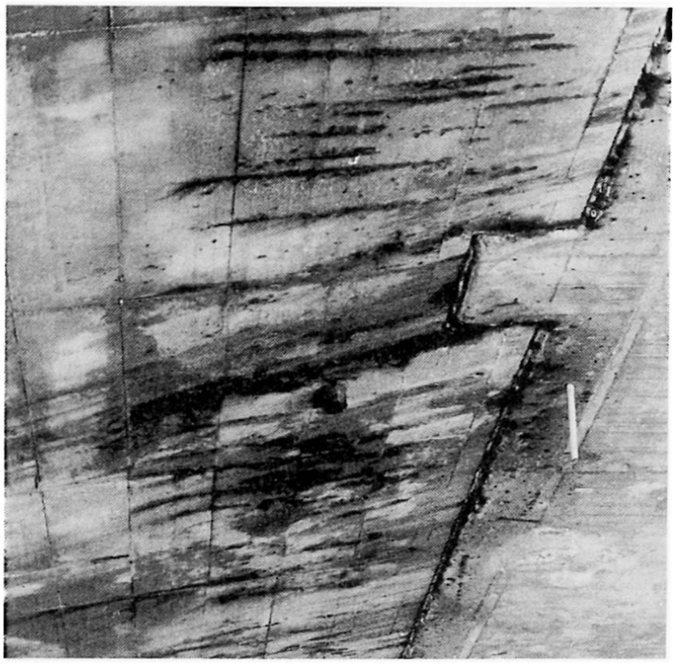


Fig. 10 Corrosion of reinforcing steel

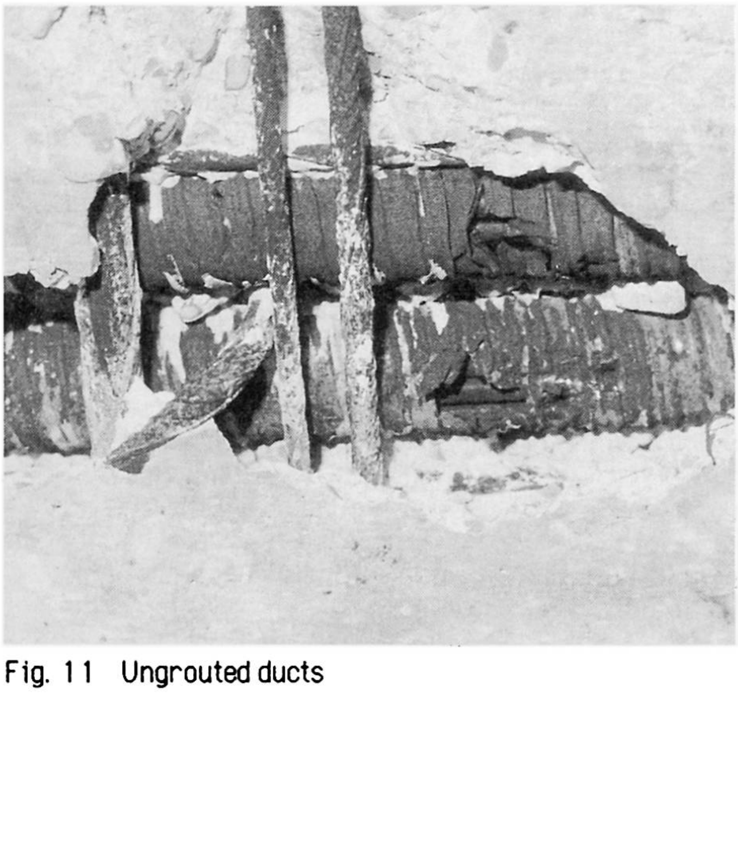


Fig. 11 Ungrouted ducts

Fig. 12 Wet spot

Particular effects with regard to the reliability of the structure can be assigned to each of the above-mentioned subdivisions. For example, a crack parallel to a bar is an indication that the bar is corroding and thus presents a problem with regard to durability. Should making the appropriate repairs be neglected, this could result in the splitting of the concrete cover, which in turn would mean more rapid rusting, again influencing the strength of the structure in a negative manner. On the other hand, a crack parallel to a tendon leads to the assumption of missing or insufficient grouting in the duct. Because of the voids within the duct, rusting does not cause the development of bursting pressure and spalling as a warning signal does not occur. It is thus not possible to exclude the reduction of the tendon cross-section and thus the reduction in load capacity and/or fatigue strength, which mean that rapid action must be taken.

The subdivision also provides a good foundation for drawing conclusions about the type of repair work which is needed. A constraint crack, which for instance might have been caused by the cooling of the concrete after placement (setting shrinkage subsequent to hydration heat), would not undergo significant width changes in the future and therefore could be injected with rigid synthetic resin. This repair method could, however, not be applied to a crack whose width continued to change because of loading, since new cracks would develop.

5.2 Environmental Aggression Classes

The same type of damage could be categorized differently according to diverse environmental aggression classes. For instance, wetness is generally harmless on reinforced steel structures. However, in combination with freezing and road salts (Aggression Class 3), it could mean a significant source of danger. Environmental aggression primarily affects the durability of a structure. If repairs are not carried out at an early enough time, the structure's serviceability as well as bearing capacity could also be affected.

5.3 Type of Structure

The type of structure plays a role with regard to the environmental influences which are associated with its function, and thus the statements made in the previous section can be applied here. A dry environment is expected inside residential and/or office buildings, whereas road bridges in climatic zones with winter weather are exposed to frost and road salt action. Naturally, a structure's function is not necessarily coupled with a particular class of environmental aggression, as indicated by the example of a jetty wall at a river or marine harbour.

Furthermore, the type of structure provides information as to whether dynamic action is to be expected or whether primarily static loads are shown. When dynamic loading is apparent, damages are also to be evaluated with regard to their influence on the fatigue safety of the structure.

5.4 Supplementary Inspections

In some cases, the results of the inspections and documentation are insufficient in evaluating damages. Here, additional inspections should be initiated to help clarify the cause of the damage and thus make assessment possible. Such additional tests would include static or dynamic calculations which utilize realistic values for structural materials and material laws, as well as measurements of shape changes under known circumstances. An example is provided in Fig. 14, which shows the width measurements of a crack on a prestressed concrete bridge, whereby it would have to be determined whether the crack was caused by constraint or by overloading. For this reason, measurements were taken during loading of the structure with a vehicle as well as under the conditions produced by daily temperature changes. The results clearly show that constraint forces dominate. Measurements taken after repair work had been completed showed that it had accomplished its purpose.

Structural steel:

Local deformation, insufficient joining material, damages to protective coating (Fig 13) and hairline cracks

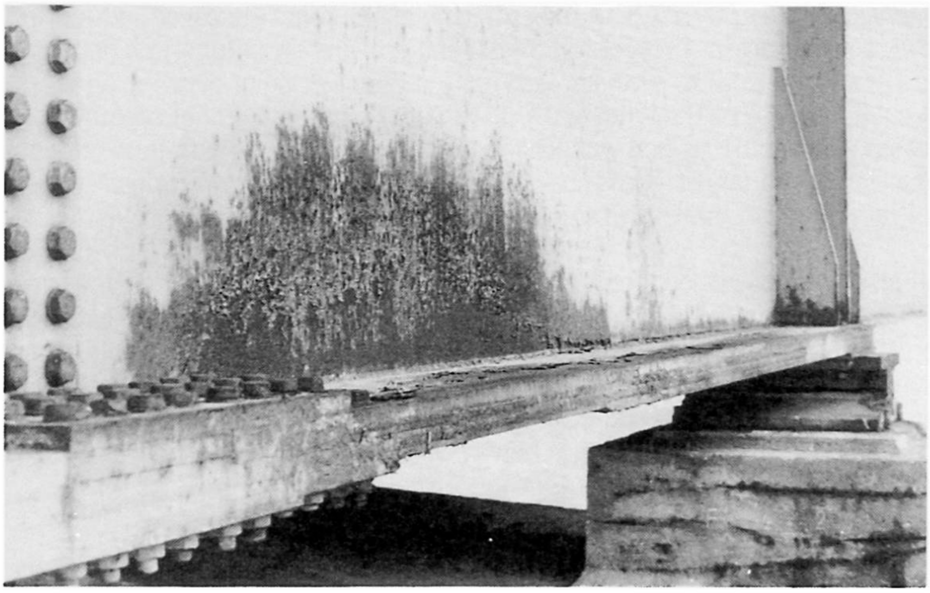


Fig. 13 Corrosion of steel structure

Composite construction:

All damages describes above under mass concrete construction and steel, as well as insufficient composite joining material

Bridge construction:

Damages to bearings, road expansion joints, insulation, drainage, etc.

Timber construction:

Changes in material, insufficient connections, cracks and wetness

Masonry/Brick work construction:

Cracks, wet spots, changes in material and plaster damages

Of course, other main groups can be selected for the categorization process. In any case, more detailed segregation into subdivisions is necessary. The manner in which damages belonging to several groups must also be established, for instance in the case water-carrying cracks. Subdivision does not necessarily have to be carried out on the basis of phenomenological criteria; here, classification according to cause could be useful in determining which measures should be applied for maintenance purposes. The subdivision of cracks in prestressed concrete have been provided below is representative for all types of damages.

Cracks caused by external loading

Cracks caused by the introduction of concentrated forces

Cracks caused by constraint and self-equilibrating stresses

Surface cracks

Cracks along reinforcement bars

Cracks along tendons

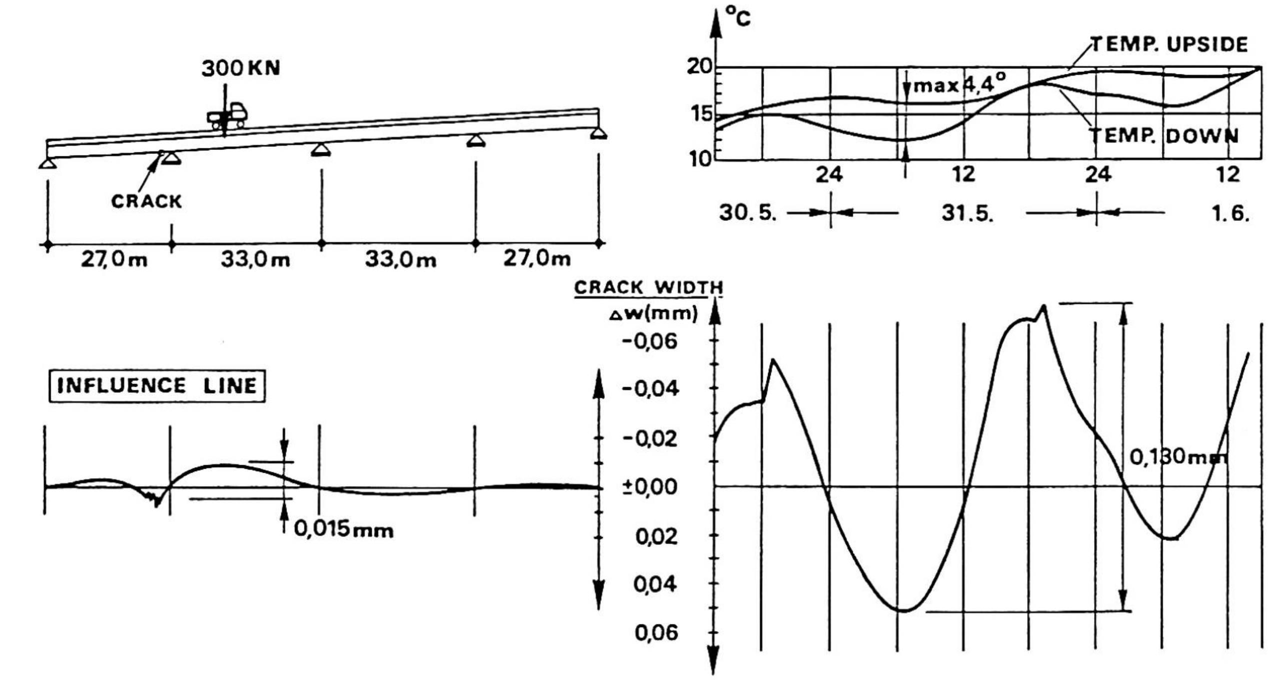


Fig. 14 Results of insite measurement of crack opening

6. ASSESSMENT OF MAINTENANCE CONDITION

A compreheensive assessment of all damages and defects established on a structure should reflect its maintenance condition and provide indications of the urgency of repair. The evaluations with regard to individual damages and their extent, as described above in Chapter 5, shall provide the foundation of this overall assessment.
Owners who have a large number of structures to maintain are also confronted with having to establish priorities for the maintenance work required, while taking available funding into consideration. To facilitate this activity, special assessment procedures have been developed, which can, however, due to the great quantity of data, only be carried out with electronic data processing.

An example of such an assessment procedure is one which was developed during a research project which dealt with road bridges constructed of concrete [2]. This procedure simplifies assessment process in a schematic manner to enable evaluation being carried out with the help of a blank form. A basic damage value "G" is assigned to each type of damage; "G" is then multiplied by four factors (k_1 to k_4), so that an evaluation of the damage can be calculated as follows:

$$G \cdot k_1 \cdot k_2 \cdot k_3 \cdot k_4$$

where

$0{,}5 < k_1 < 1$ is the factor of extent

$0{,}5 < k_2 < 1$ is the factor of intensity

$0{,}3 < k_3 < 1$ is the structural factor

and $1 < k_4 < 10$ is the factor of urgency

The factor of extent reflects the areal extent of a type of damage and/or the frequency with which it appears. The factor of intensity expresses the degree of damage. The structural factor takes the affect of a defect on the carrying capacity of a section or entire structure into consideration. The factor of urgency is applied to express the rapidity with which repairs of the particular type of damage should be carried out. To obtain a value expressing the overall condition, one adds the values attained for each type of damage.

Of course, though this schematic procedure cannot make decisions in place of the person responsible in individual situations, it does present a valuable tool for making such decisions. The procedure described has been tested on about 100 bridges and presented a clear picture of the bridges which should be given priority with regard to repair work (Fig. 15).

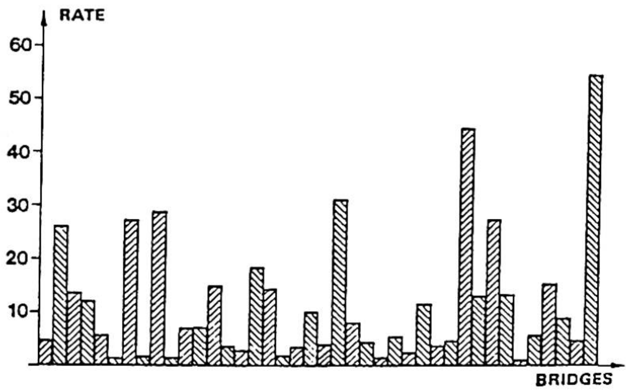


Fig. 15 Rating of maintenance situation

7. DEVELOPMENTAL TENDENCIES

Further developments would be desirable in two fields - in the field of inspection methods and in the field of assessment systems. Both fields promise good opportunities for further research as well as in the practical application of such results.

With respect to inspection methods, procedures which up until now have been primarly manual in nature, should be expanded and have engineering character. Indications of such a direction are provided by dynamic procedures as well as by the sound emission method. Here, the problem of adopting the equipment to the requirements of structural inspection as well as the improvement of result interpretation should be taken into consideration. A further point worth mentioning would be the application of video cameras for damage recording; these could also be used in conjunction with thermography.

Documentation procedures will continue to develop toward data processing and storage, whereby stored data can be used for assessment and tendering procedures. Another logical development would be replacing photographs with video clips. In conjunction with scanners (image recognition systems), electronic evaluation of the optical information would also be conceivable.

REFERENCES:

[1] Der Bundesminister für Verkehr: Erhaltung der Brücken und anderer Ingenieurbauwerke der Bundesfernstraßen, Prognose des Finanzierungsbedarfes 1986

[2] Wicke, M.; STEHNO, G.; STRANINGER, W.; BERGMEISTER, K.: Verfahren zur Vorhersage des Umfanges von Brückensanierungen; Schriftenreihe Straßenforschung des Bundesministeriums für wirtschaftliche Angelegenheiten, Heft 338, Wien 1987

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