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Review of current practice for assessment of structural condition and classification of defects

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Review of Current Practice for Assessment of Structural Condition and Classification of Defects

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EXECUTIVE SUMMARY

SCOPE

Europe has a large capital investment in the road network including bridges, which are the most vulnerable element. As bridges age, deterioration caused by heavy traffic and an aggressive environment becomes increasingly significant resulting in a higher frequency of repairs and possibly a reduced load carrying capacity.

The purpose of this project is to develop a framework for the management of bridges on the European road network that enables bridges to be maintained at minimum overall cost i.e. taking all factors into account including condition of the structure, load carrying capacity, rate of deterioration, effect on traffic, life of the repair and the residual life of the structure.

SUMMARY

This report is giving an overview of procedures used in some European countries and in the United States for condition assessment of bridge structures. It is the first one of the two reports which are going to be delivered by the WP 1 -"Condition assessment". The main objective of this work package is to derive general guidelines and/or recommendations for condition assessment of reinforced and pre- or post-tensioned concrete bridges.

The first chapter of the report discusses the role of condition assessment of existing bridge structures in a Bridge Management System (BMS). Chapter 2 is dealing with the objectives for condition assessment and the main causes of deterioration of roads and bridges as the most vulnerable part of a road network. It is emphasised that usual lack of funds for proper and regular maintenance is consequently an important reason for delayed interventions affecting further deterioration and higher repair costs.

In Chapter 3 an overview of condition assessment procedures in some participating European countries (Austria, Denmark, France, Germany, Norway, Slovenia, United Kingdom) and in the United States is presented. It comprises types of inspections to be carried out at prescribed intervals, with short descriptions of the scope and method of inspection, and the main features of condition assessment procedures used in those countries. The overview for each country includes the main structural components and their constituent elements which need to be inspected and the main groups of characteristic defects or damage types which should be taken into account for the condition evaluation. Finally, the presently used and in some countries (Austria, Germany, Slovenia) also newly developed condition rating methods are shortly presented.

Chapter 4 contains a general survey and classification of the most common defects. The survey is based on existing national documents for bridge inspection and condition assessment, submitted by the partners. Namely, condition assessment is based on a number of classified defects related to distinct causes and appearing on specific elements or components of a structure.

In the last two chapters recommendations and conclusions for further work are made aiming at the improvement of the bridge inspection and condition assessment procedures in Europe.

IMPLEMENTATION

This review of condition assessment procedures is the basis for the discussion and further work within Workpackage 1 which should result in delivering of guidelines for quantitative evaluation of defects and for condition assessment of bridge structures. It should also stimulate further improvements of existing national assessment procedures and/or development of new ones.

Some results of this review can also be used in the Workpackage 6 "Prioritisation" and in the Workpackage 7 "Systems for bridge management". Namely, the optimisation of repair options and the prioritisation of candidate bridges highly depend on a reliable condition assessment.

REVIEW OF CURRENT PRACTICE FOR ASSESSMENT OF STRUCTURAL CONDITION AND CLASSIFICATION OF DEFECTS

ABSTRACT

Procedures for the assessment of the actual condition of existing bridges implemented in some European countries, partners in this project, and in the United States, are presented. The importance of bridge structures in the road network and their vulnerability to deterioration, which can not be avoided, is stressed. Some causes of deterioration and their influence on the progressing deterioration are also shown. Different methods for the evaluation of bridge condition and the possible further uses of these rating values are discussed. The defects to be checked and evaluated on individual bridge members for the condition assessment are also discussed.

An overview of condition assessment procedures in some participating European countries (Austria, Denmark, France, Germany, Norway, Slovenia, United Kingdom) and in the United States is made. Types of inspections to be carried out at prescribed intervals are explained and short descriptions of the scope and procedure of inspections are given. The need to consider the results of condition assessment in the design of new structures is also emphasised.

In the conclusion some recommendations are made for the development of harmonised inspection and condition assessment procedures in Europe.

1.0 INTRODUCTION

Infrastructure networks of roads and railways play a very important role in the everyday life of a country and its people. They provide mobility and enable people to reach their destinations as quickly and safely as possible, and they play a great role in transportation of goods. For these reasons it is important that the infrastructure network maintains its functionality with as little inconveniences as possible. To achieve this goal regular maintenance, repair and/or rehabilitation operations must be carefully planned and executed at the proper time. As the available budget funds are very often constrained for this kind of work, it is very difficult or sometimes even impossible to keep the bridge stock in good working condition.

Bridges, as the very important part of the transportation network, are especially vulnerable to constant and serious deterioration. Deterioration of bridges is the consequence of:

- poor planning maintenance operations,
- lack of funds for regular maintenance,
- poor design, detailing and execution of the structure,

- underestimation of the role of proper and in time maintenance in the past,
- environmental impact,
- ageing processes,
- increased length of the network and volume of the traffic,
- increased volume of bridge stock,
- increased axial loads on roads and railways.

Aware of the rising problems associated with the available funds for preservation of the functionality, safety, load carrying capacity and satisfactory condition of bridge structures, Road Authorities in many European countries have implemented various types of databases. The aim of these databases has been to help Road Authorities in making decisions regarding the activities to be taken to preserve or improve the condition of the bridge stock in the current budget year or in certain period of time. These databases usually provide data about bridge inventory and condition of bridges. In earlier times these data were stored on coded sheets and as such were very impractical for implementation. With development of computers, and especially the PCs, the databases became larger and are storing greater amount of data, which can be manipulated in different ways and for different purposes. The possibility of manipulation of bridge data for specific purposes is the basis for development a Bridge Management System (BMS). Each BMS is composed of several modules, which can be exploited, on the basis of demands and wishes of users and their technical capabilities, for updating already acquired data and for storing additional and new ones. One of the most important parts of a BMS is the condition assessment module. It can provide data about the condition or improvement of each element of the structure or the structure as a whole, and also about the progress of the revealed deterioration processes. These data can be used later also for the assessment of the load carrying capacity and durability of the structures as well as for the decision making about the procedures to preserve satisfactory safety and stability of the structure in certain period of time.

2.0 OBJECTIVES OF CONDITION ASSESSMENT OF BRIDGE STRUCTURES

The main objective of the condition assessment of bridge structures is to detect a deterioration process already in its initiation phase and to investigate and determine the causes of deterioration. The purpose of monitoring the progress of deterioration processes on each important part of a bridge structure, with respect to their intensity and extension of damages, is to take the right decisions in the right time. These decisions should then be followed by actions aiming at preservation of condition of the structure within acceptable limits by appropriate maintenance activities or repair work.

Another objective is to evaluate the efficiency of different repair techniques and the suitability of different material used in repair work, and to verify the right mode of application. The results of the assessment can be also used for verification of different site and laboratory test methods and measurement techniques, which have been developed for reliable assessment of the prevailing deterioration process and prediction of its further progress, or for checking the efficiency of the repair work.

Reliable assessment of the condition of a bridge structure or of its deteriorated parts can be made, and the progress of deterioration can be followed only by regular inspection of the structure at proper time intervals. For this reason several types of inspection are used which, when carefully performed, can bring very a useful results.

The initial or the reference inspection of newly built bridges is also very important. It must be made in the extent, which allows at later inspections detection and recording of progressed deterioration. In respect to the assessed condition also some relevant tests and measurements could be carried out in this scope.

Procedures for condition assessment of bridge structures, in order to follow up and monitor their condition, have been developed in many countries. They differ from each other in several aspects, and also in the way of expressing the final condition rating. In some countries such procedures are used already for a longer time, in some others the methods are in the phase of improvement on ground of users needs and past experience, and some countries are developing new or modified procedures. In the following chapter a review of procedures for condition assessment from several countries is given, together with their abilities, role in the BMS and envisaged improvements or changes.

3.0 REVIEW OF CONDITION ASSESSMENT PROCEDURES

The review of procedures for condition assessment and classification of defects is made for seven European countries and USA, on the basis of the available publications, proceedings and other official documents, and from personal contributions of some participants in this BRIME project. The aim of this review is to provide an insight into the existing procedures, their common features and significant differences.

3.1 Austria

3.1.1 Present procedure

In 1987 the Austrian Ministry for economical affairs issued "Procedures for assessment the extent of bridge rehabilitation", in which the procedures and instructions for the condition assessment of bridge structures are described (1). To obtain useful data about the condition of the bridge stock, a systematic inspection of bridge structures is implemented. In the bridge stock all bridge structures with spans over 2m are included. Three types of inspections are carried out:

- Superficial inspection, which is carried out by maintenance personnel during their regular control drives. The report is made only in case when damages or improper function of some parts of the bridge are observed, mainly in connection with the bridge surface, railings, drainage system, but rarely with the main structural components.

- General inspection, which is carried out by trained personnel under supervision of a bridge engineer. It is carried out every two years. General inspection is also carried out after exceptional events like earthquakes, floods, landslides, after long periods of high temperature, etc. At general inspection only the accessible parts of the bridge are inspected. Report on the assessed condition of the bridge shall be made after each inspection.

- Major inspection is carried out every six years. The aim of the major inspection is to obtain detailed information about the condition of the whole bridge and of all components, to assess the functionality and load carrying capacity of the bridge, and to recommend regular and urgent maintenance work, load restrictions and the delay until next major inspection. For these reasons all parts of the bridge must be accessible by simple or special devices. Report on the assessed condition of the bridge shall be made.

The condition of the whole reinforced and/or prestressed concrete bridge structure is described by 12 characteristic categories of damages, related to the main bridge elements. These categories are:

- **Damages of the concrete surface**, divided into two main categories:
  - damages caused by poor workmanship,
  - damages occurring during usage of the structure.

  These damages are divided into 7 categories, which are shown in table 1.1.

Table 1.1

category	Description
0	No damages
1	Deterioration of cement crust or of thin layers of concrete cover, without any voids
2	Deterioration of thin layers of concrete surface up to 1 mm deep, thin scars in concrete surface, partly loose fine sand grains
3	Heavier deterioration of concrete surface layer up to 4 mm deep, scars in concrete surface, loose larger sand grains
4	Damages of concrete surface up to 10 mm deep, loose large sand grains, scaled cement mortar between grains
5	Cracks in concrete cover along reinforcement, rust products along reinforcement
6	Delamination of concrete cover, revealed reinforcement

- **Cracks** because of surcharges, concentrated loads, settlement or displacement of supports, corrosion of reinforcement, etc. The intensity of cracks is classified by width into three categories:
  - $w \leq 0.2$ mm,
  - $0.2 < w \leq 0.4$ mm,
  - $w > 0.4$ mm.

The intensity of cracks in prestressed concrete structures in the direction of tendons shall be: w ≤ 0.1 mm and ≤ 0.2 mm.

- **Open joints** between the segments of free cantilever structures or launched segmental structures. The same classification of the intensity of cracks in joints as for other cracks is applicable.

- **Damages of the reinforcement** caused by thin concrete cover or progressing corrosion process. They are divided into six categories shortly described in table 1.2.

Table 1.2

category	description
0	No corrosion
1	Light corrosion on the surface (air corrosion), average depth of corrosion < 0.1 mm (depth of pitting excluded)
2	Light to medium corrosion, thicker layers of corrosion products, average depth of corrosion is between 0.1 mm to 0.3 mm (depth of pitting excluded)
3	Heavy corrosion, thick detached layers of corrosion products, average depth of corrosion is between 0.3 mm to 1 mm (depth of pitting excluded)
4	Very heavy corrosion, thick detached layers of corrosion products, average depth of corrosion is greater than 1 mm (depth of pitting excluded)
5	Very heavy corrosion with thick detached layers of corrosion products, average depth of corrosion is greater than 1 mm (depth of pitting excluded), the cross section of the reinforcement is significantly reduced

- **Post-tensioned tendons -** defects are caused by corrosion.

- **Wetting** of the concrete surface is caused by damaged waterproofing membrane, defective drainage system, defective sealing of the joints, etc.

- **Bearings** - damages depending on the type of bearings are caused by poor workmanship, improper installation, weathering, excessive deformations, etc.

- **Eexpansion joints -** damages are caused by deterioration of waterproofing membrane, mechanical damages due to heavy traffic loads, poor maintenance, etc.

- **Carriage-way -** damages are classified into eight categories and described according to the cause of damage (swelling, loosening of the matrix compound, local damages of the joints, temperature effects, fatigue due to traffic loads, permanent deformations - wheel tracks, presence of water, crushing of the material).

- **Drainage system.**

- **Bridge equipment:** railings, safety barriers, traffic signs, lamp-posts, etc.

- **Landscape** around the bridge structure: slopes in the riverbanks, embankment slopes, etc.

The assessed condition of the bridge structure is expressed by the condition rating S, which in general form is given by the following function:

$$S = \sum_{1}^{32} G_i \times k_{1i} \times k_{2i} \times k_{3i} \times k_{4i}$$

where individual numerical attributes refer to:

G_i - Type of damage. There are 32 types of damages. The value of G_i is in the range of 1 to 5 and depends on the severity of the damage. For each type of damage a description of its extent, intensity and urgency of the intervention on particular structural member is given.

K_{1i} - Extent of damage. It is expressed by numerical values between 0 and 1. It can be described by words: few or some, frequent and very frequent or large. The description usually refers to one or more components of the bridge or to the whole bridge structure. The extent is never quantified by the measured sizes (length, area, etc.) of the damage.

K_{2i} - Intensity of damage. It is expressed by numerical values between 0 and 1. It can be also described by words: little or insignificant, medium, heavy and very heavy. The description of intensity is usually associated with the description of damage (e.g., width of the cracks, etc).

K_{3i} - Importance of the structural component or member. Values range between 0 and 1. The structural components are classified as primary, secondary and other parts.

K_{4i} - Urgency of intervention. Values range between 0 and 10 and depend on the type, seriousness and risk of the collapse of the structure or its part.

According to the obtained value of condition rating S bridge structures can be ranked into one of six classes, which are defined in table 1.3.

Table 1.3

Damage class	Definition	Condition rating value S
1	No or very little deterioration	0-3
2	Little deterioration	2-8
3	Medium to severe deterioration	6-13
4	Severe deterioration	10-25
5	Very severe deterioration	20-70 (k_4=10)
6	Very severe or total deterioration	>50 (k_4=10)

3.1.2 Proposed new evaluation function for damage assessment[2]

A new evaluation function is proposed in order to express the condition of the structure in a nonlinear form. The overall evaluation value S should be interpreted as "percentage of useful fitness" and not as the damage category. The proposed function is expressed by

$$S = \sum_{i=1}^{32} G_i \times \sqrt{k_{1i}2 + k_{2i}2 + k_{3i}2}$$

The attributes k_1, k_2 in k_3 have the same meaning and should all be in the same range between 0 and 10.

3.2 Denmark

The Danish Road Directorate uses for the management of the bridge stock on highways and motorways the DANBRO database system. The goal of this system is to assist the decision makers at maintaining the bridge stock in the desired condition at the lowest possible cost [3]. One of the main activities for proper decision making is to obtain data of the condition of bridge stock. On highways and motorways bridges with the span of 5 m[4] or greater undergo regular inspection procedures. The main activity to obtain valuable data for the condition assessment of the bridge structure or bridge stock is regular inspection of bridges ([3,5,6,7]). Three types of inspections are carried out:

- Superficial or routine inspection, where only major damages or abnormal conditions are considered. This inspection is carried out during the regular maintenance work within short intervals.

- Principal (major) inspection is carried out by well-trained engineers. It is a visual inspection of all accessible parts of a bridge structure. Normal inspection intervals are 3 years, however, depending on the condition of the bridge, this interval may be in the a range of 1 to 6 years. Important damages on all components of the bridge are registered and rated. In the report the time of the next principal inspection is recommended, and special inspection can be required in case of poor condition of the bridge.

- Special inspection is a detailed inspection of the whole bridge structure or only part of it. This inspection is carried out on the basis of the recommendation of the principal inspection or on the basis of the ranking list. A thorough investigation is performed combined with on-site and laboratory tests. The type and extent of deterioration or deficiencies are established together with their causes and the influence on further deterioration. This type of inspection must always be carried out before rehabilitation or replacement work, unless the extent of the damage is insignificant and the optimum repair strategy is obvious. The results of special inspection are used for deciding about the optimum repair strategy and to determine the priorities for repair or rehabilitation, in case of lack of funds.

Table 2.1

Component	Description
1	Bridge in general
2	Wing walls (wing walls and possible retaining walls)
3	Slopes (slopes with slope protection, adjacent to the abutments and wing walls)
4	Abutments (abutment structure with back wall, bridge seat, visible parts of the footings)
5	Piers
6	Bearings (bearings on abutments and piers)
7	Slab
8	Waterproofing
9	Girders/beams (main girders, cross beams, diaphragms, bracings,…)
10	Parapet/railing (parapets, guard rails and railings)
11	Bridge surface (normally the surface between the curbs)
12	Crossing passage
13	Expansion joints (all components of expansion joints including special overlays adjacent to the joint)
14	Drainage system
15	Other elements (bridge components, which are not included in the previous mentioned 12 components)

Damages which often require special inspection are:

- Slab:
  - Leakage of waterproofing after 25 to 30 years
  - Failure of expansion joint

- Superstructure:
  - Reduced load capacity due to deterioration of concrete members.

- Substructure
  - Chloride attack on columns, piers and abutments due to use of de-icing salt on motorways.

The condition is evaluated for 15 standard components of a bridge structure, one of the evaluation components refers to the general condition of the bridge. In table 2.1 all bridge components, which have to be considered in the evaluation process of the condition, are given.

For each component the type of damage must be assigned. The extent of the damage is estimated on site, if possible with the help of geometry data from the inventory. The condition rating is a numerical value, which describes the condition of the observed component of the bridge structure. In the table 2.2 description of condition ratings is given.

Table 2.2

category	Definition
0	No or insignificant damage
1	Small damage but no need of repair except routine maintenance
2	Some damage, repair needed when convenient. Component is still functioning as originally designed
3	Significant damage, repair needed very soon
4	Serious damage, repair needed at once
5	Ultimate damage, total failure or risk of total failure of the component

It is assumed that inspectors should be capable of assessing the degree of deterioration and to decide which parts of the bridge need close investigation. For each component are given: typical types of damages expected to occur, a description of each particular type of damage in case that the condition rating value equals 3, and a description of minor maintenance and standard repair works for some types of damage. When the condition rating is 3 or more, a repair work must normally be notified. For standard damages a list of standard repairs exists.

When the condition of all components is evaluated, the condition of the whole bridge is assessed on the basis of these values. The highest (most unfavourable) condition rating assigned to one of components is not necessarily the condition rating of the whole structure. The final assessment of the structure should identify the damaged components, type and extent of damages, expected development of the damage and its influence on the traffic flow and safety. The general rule is that the condition rating for the whole bridge can not be higher than the one assigned to the most deteriorated component and cannot be lower than the one assigned to either of main components, like abutments, piers, bearings, slabs and girders.

3.3 France

On the French road network all bridges with the spans greater than 2 m are subject to regular inspection and condition assessment [8]. Its purpose is to provide adequate and up-to-date information about the condition of the bridge stock. There are several types of inspection or survey performed on French bridges.

The main inspection levels are:

- Annual check (superficial inspection). It is a brief inspection carried out on all bridges in the bridge stock each year at the same time as the routine maintenance operations. The result of the survey is a report with identification of the bridge, date of checking and observed anomalies and signs of change.

- Assessment inspection. This is a rapid visual inspection of all accessible parts of the bridge. The result of inspection is the bridge classification according to the IQOA method (IQOA /Image Qualité des Ouvrages d'Art/ - Image of Bridge Quality) [9,10,11,12,13]. IQOA defines the methodology for classification the bridge condition. It is based on several descriptive catalogues of defaults for different types of structures. There are 25 catalogues in total. Inspection is carried out on all bridges of the bridge stock every three years (one third of the stock each year). The assessment is based on the inspection according to the IQOA method, and laid down in the report of standard format. If a detailed inspection has been conducted during the year, the assessment by the IQOA method is made on the basis of the report of detailed inspection.

- Detailed periodic inspection. It is carried out on medium and great bridges in principle every six years. Modifications of the inspection intervals are possible: 9 years for the structures in best condition, 3 years if necessary, 1 year for the most vulnerable. This type of inspection must be directed and carried out by a qualified engineer with special training in bridges and bridge pathology. For the detailed inspection all parts of the bridge must be accessible. A report of detailed inspection should give a detailed insight into the condition of the bridge.

Detailed inspections of specific level are carried out in specific cases like:

- Preliminary inspection - to define a reference state. It is conducted when a bridge is opened or after major repair works have been carried out.

- End of guarantee inspection to check the condition of the bridge before expiration of the guarantee (10 years), or at the end of the period of responsibility.

- Exceptional inspection - to check the condition of a bridge in case of specific circumstances (severe anomaly, start of the work in the vicinity, natural disasters like earthquakes, floods, fires, landslides, etc…) [14,15,16].

Other monitoring activities are:

- Continuous monitoring conducted by the qualified maintenance staff.

- Intermediate continuous monitoring, if justified by the condition of the bridge or if there is an uncertainty about the presence of deficiencies.

- High level monitoring, when observed deficiencies threaten the safety and strength of the structure, or its important part.

Standard forms for inspection reports have been developed for the inspection of the most usual types of structures. They are designed to enable the personnel without specific training for bridges to classify various defects. The report also contains graphic data about the morphology of the bridge and a list with systematic diagrams of all defects which may be present.

The condition assessment of a bridge is made either on the basis of the report of detailed inspection conducted in the year of periodic survey or on the basis of visual "IQOA" inspection. The IQOA method was designed to achieve separate assessment of different parts of the bridge. There are three main parts of the bridge, which are shown in table 3.1.

Table 3.1

Main part of the bridge	Description	Constituent parts
1	Equipment	Placed above and below the bridge like pavements, footpaths, barriers, cornices, drainage systems, pavement and footpath expansion joints, etc.
2	Piers and bearings	Columns, walls, foundations, bearings
3	Deck	Slab, longitudinal girders, transverse beams, cantilever slab; waterproofing layers, facings, etc.

During the inspection each part of bridge shall be inspected and the severity rating shall be assigned to each detected defect. These defects are described in the catalogue of defects for different type of bridge structures. In the catalogue the defects are numbered and graphically presented. Each defect should be described and classified with respect to its cause, origin and intensity. In table 3.2 the main defects or damages are shown.

For the condition rating only a small number of classes is used. The summary of the IQOA condition rating classification is given in table 3.3.

When the observed structural defects or deficiencies can endanger the safety of users and urgent treatment is required, the bridge is given an "S" rating in addition to one of the five condition classes defined in table 3.3.

Table 3.2

	Description
	Settlements, movements
	Erosion, scour
	Damages of the pavement (wheel tracks; cracks: width of cracks less or equal 2 mm and greater than 2 mm; longitudinal straightness: under or above 5 mm around the expansion joint and under or above 2 cm at the abutment on the approach on the bridge; defects of the surface: swelling, loosening of the matrix compound, presence of water, crushing of the material; etc.)
	Excessive deformations of the superstructure
	Cracks of different type, described by the presence of water or efflorescence, width of cracks less or equal 0.3 mm and greater than 0,3 mm; The cracks are also described with the possible cause, location and direction;
	Deterioration of concrete surface caused by corrosion of reinforcement (spalling, delamination) without or with significant loss of the reinforcement cross section
	Wetting of the concrete surface, water leakage
	Bearings (excessive deformation, damaged corrosion protection
	Damages of expansion joints (straightness, deformations of the contact surfaces, membrane, etc.)
	Drainage systems: mechanical damages, improper working of the drainage system, etc.
	Defects of the safety barriers (alignment, anchorage, protective coatings, etc.)

Table 3.3

Condition class	Definition
1	Bridge is in a good apparent condition requiring only routine maintenance as defined in the Instructions for Bridge Survey and Maintenance (ITSEOA)
2 2E	Bridge is in good apparent structural condition or with minor defects which require specialized maintenance. • Not urgent • Urgent, in order to prevent rapid development of structural deficiencies. The urgency which can lead to a bridge being placed in class 2E should be assessed with reference to defects whose development can lead within a short period of time to the structure entering class 3 because of the appearance of major defects in the structure.
3 3U	Structurally impaired bridge which requires repair works • Not urgent • Urgent, because the bearing capacity of the bridge is either already inadequate or will become so in the near future as a result of the rapid development of deficiencies
NE	Not assessed

The class assigned to a piece of equipment, a protection device or inspected part of the structure depends on the highest rating given for all the defects it possesses. The lowest class ascribed to one of the constituent parts of the bridge is governing also the overall condition class of the bridge.

3.4 Germany

In Germany the condition of the bridge structures is presently registered in accordance with the existing set of guidelines [17]. The monitoring of structures in accordance with DIN 1076 consists of several types of inspections or observations:

- Superficial inspection intends to detect major faults. It is usually performed on a quarterly basis and by the annual inspection. It is carried out to check the functionality of expansion joints, bearings, drainage systems and safety barriers. Annual visual inspection of all accessible parts of the bridge is performed to detect major defects that may occur.

- General inspection is carried out every three years. It consists of visual inspection and simple test without any specific test equipment of all parts of the bridge, which are accessible without any special devices.

- Major inspection is carried out every six years. At this type of inspection the access of all parts of the bridge must be provided. At very large structures access is provided with special devices. Beside a visual assessment also some field test for material examination should be executed by specific test equipment. The first major inspection is carried out before the bridge structure is handed over to the traffic. The second major inspection is carried out before the expiration of the guarantee period, which is 5 years. After this inspection the regular interval for major inspection is six years.

- Special inspection is carried out if necessitated by the results of structural monitoring. The intention of this inspection is to obtain a more in-depth view of some particular damage or of the deterioration process.

- Testing and monitoring of mechanical as well as electrical equipment is in accordance of special regulations.

The results of monitoring and testing are documented in a test report. This report forms part of the construction register, which must be prepared for each individual structure. Already during the design phase files are created for the purpose of documenting all structural details of importance for maintenance.

In Germany a new approach to the condition assessment of bridge structures was developed and it is integrated in a new version of RI-EBW-PRÜF (issued 1998). In the following two chapters the present and the new method for condition assessment are shortly described.

3.4.1 Method for evaluation of damage and bridge condition in accordance with RI-EBW-PRÜF, 1994 Edition [18,19]

The document RI-EBW-PRÜF, 1994 edition, which was the basis for condition assessment of bridge structures in Germany until 1998, contains rules for simple and standardized recording of bridge condition or its part. The main part of this documentation comprises catalogues for coding of components, damages, extent of damage and evaluation of individual occurrences of damage by degrees of severity.

The edition 1994 does not contain a detailed explanation of the degrees of severity. However in the 1988 edition the degrees of severity and maintenance requirements were described as follows:

1) Minor damage/faults, no risk posed to safety or durability. Maintenance not yet required.
2) Damage/faults which would impair the durability of the structure in the long term. Maintenance required.
3) Damage/faults which are likely to impair safety. Maintenance required urgently.
4) Damage/faults which pose an obvious threat to safety. Immediate action required.

Specification of the degree of severity of damage thus not only indicates the traffic safety, stability and durability of a structure, but also the urgency of the maintenance.

The bridge structure is divided in eight main parts, which are further subdivided into constituent components and sub-components. The main parts of a bridge are shown in table 4.1.

Table 4.1

Main part of the bridge	Description	Main constituent parts
1	Superstructure	Slabs, voided slabs, girders, box girders, transverse beams, etc…
2	Substructure	Foundations, abutments, piers, columns
3	Bearings	Roller bearings, fixed bearings, reinforced elastomeric bearings, pot bearings, etc…
4	Expansion joints	Modular joints, rubber joints, waterproofing membrane, etc…
5	Bridge surface	Carriage-way, sidewalk, curbs, sealing joints, etc…
6	Safety structures	Safety barriers, parapet walls, etc…
7	Equipment/railings	Railings, drainage systems, signs, etc…
8	Moving structures	Lifting bridge, rolling bridge, etc…

Damages are described according to the material the component of the structure is made of. The catalogue is too comprehensive to describe damages in the frame of this review. Just for example:

- cracks of concrete structures are divided in four classes regardless of their cause (width of crack w is < 0.1 mm; w < 0.2 mm; w = 0.2 mm - 0.5 mm; w > 0.5 mm);
- wheel tracks (wt) in the pavement are divided into three categories (wt = 0.5 - 1.0 cm; wt = 1.0 - 3.0 cm; wt > 3.0 cm).

The instructions for the condition assessment of the whole bridge structure, which take into account the effects of damage on traffic safety, stability and durability, are presented in table 4.2. To allow a more precise determination of trends over several inspection cycles, it is possible to specify every condition grade by a one decimal point number. In the table some examples of the condition rating are given.

Table 4.2

Condition rating	Description	Examples of the condition rating evaluation
1.0 - 1.9	The structure exhibits no or only slight occurrences of damage, which do not - individually or as a whole - impair the stability, traffic safety or durability of the structure. Regular maintenance is required.	- Soiled visible surfaces. - Evidence of slight unevenness/crushing/ track grooves on road surfaces. - Minor alluvial deposits and erosion. - Soiled/illegible traffic signs referring directly to the structure.
2.0 - 2.9	The structure exhibits occurrences of a damage which do not impair stability or acutely impair traffic safety. However, long-term durability is not ensured. Maintenance and repair works are required.	- Minor damage to railings and their corrosion protection - Minor damage to riverbanks and side-slope stabilisation, embankment steps, water drainage facilities, road joints, joint sealing and masonry. - Moderate unevenness/crushing/track grooves on road surfaces.

Table 4.2 – continued

Condition rating	Description	Examples of the condition rating evaluation
3.0 - 3.9	The structure exhibits occurrences of damage which - individually or as a whole - are likely to impair the stability and/or traffic safety of the structure in the near future. This damage considerably impairs the durability of the structure. It might become necessary to restrict usage of the structure in order to fully restore traffic safety. Extensive repair work is required.	- Major unevenness/crushing/track grooves on road surfaces. - Damage to seals, joint sealing, drainage facilities, etc., which might lead to considerable consequential damage. - Corrosion accompanied by attenuated cross sections of reinforcements. - Damage indicating partial failure to withstand loads (deformation, cracks on bending sections, coupling joints, etc.). - Railings, protective devices, coverings and other structural fittings exhibiting damage which could impair their functionality. - Exposed or ungrouted tendons, rusty prestressing steel components. - cracks at the level of prestressing elements.
4.0	The structure exhibits occurrences of damage which - individually or as a whole - impair the stability and/or severely affect the traffic safety of the structure. Durability of the structure is no longer ensured. Extensive repair work and restoration is required.	- Failure of prestressing elements. - Major damage to main stress-bearing elements, indicating partial failure to withstand loads. - Railings, protective devices and other structural fittings exhibit damages, which considerably impair their functionality. - Components exhibit damages which pose a high risk to traffic in the form of falling objects or protruding sections, which restrict clearance for upper and lower passageways.

Described condition rating in the table 4.2 serves as an easy means for evaluation of the engineering structures, with the view:

- To draw attention to the critical progress of deterioration of the structure.
- To support requirements concerning budget allocation.
- To compare the maintenance requirements of individual administrations.

The technique of structural inspection used so far in accordance with RI-EBW-PRÜF is characterised by detailed recording and assessment of individual occurrences of damage and faults. In practice, identical occurrences of damage are evaluated differently. Furthermore, there is no unique relationship between the evaluation of damage and assignment of condition ratings. On the contrary, condition evaluation applies only to overall structure. Although the evaluation is derived from individual inspection results, it is based in the final analysis on subjective opinion of the inspector. For these reasons a new technique of condition recording and evaluation was developed and is presented in the following chapter.

3.4.2 New technique for the evaluation of damages and bridge condition [18]

The new technique is based on a detailed evaluation of individual occurrences of damage. Every occurrence of damage detected during structural inspection performed in accordance with DIN 1076 must be evaluated separately in accordance with the criteria for "traffic safety", "stability" and "durability". In addition, the extent of every occurrence of damage must be registered in qualitative terms like "small", "medium" and "large".

For this purpose, a new technique for damage and condition evaluation has been newly developed with respect to the technique used so far in accordance with the 1994 edition of RI-EBW-PRÜF. Separate degrees of severity have been defined as follows for damage/faults on engineering structures as specified by DIN 1076 in accordance with the criteria of "stability", traffic safety" and "durability".

For each definition of damage in terms of stability, traffic safety and durability a description for each grade (0,1,2,3,4) of damage evaluation is given.

To ensure a standard approach for the evaluation of damages, inspection teams will be equipped with catalogues containing detailed examples of damage evaluation.

For this new method ranges for condition ratings have been newly defined, taking into account the effects of damage on stability, traffic safety and durability of structures. Precisely speaking, a conversion has been made from the 4-stage evaluation method (rating 1 to 4) to the 6-stage evaluation method (rating 1 to 6). This 6-stage rating of bridge condition is described in table 4.3. The new rating grades are advantageous, if compared to the former 4-stage rating system, because they allow for warnings and establish operational thresholds in accordance with the precepts of the German Pavement Management System. They can be considered as the cornerstone for preparing standardized techniques of damage evaluation.

Table 4.3

Condition rating	Description
1.0 - 1.4	Very good structural condition. The stability, traffic safety and durability of the structure are assured. Routine maintenance is required.
1.5 - 1.9	Good structural condition. The stability and traffic safety of the structure are assured. The durability of the structure might be impaired slightly in the long term. Routine maintenance is required.
2.0 - 2.4	Satisfactory structural condition. The stability and traffic safety of the structure are assured. The durability of the structure might be impaired considerably in the long-term. Proliferation of damage or the occurrence of consequential damage, leading in the long term to a considerable reduction in stability and/or traffic safety or increased wear, is possible. Routine maintenance is required. Repair work is required in the medium term. Measures for reconstruction or warning signs for upholding traffic safety might be necessary in the short-term.
2.5 - 2.9	Temporarily satisfactory structural condition. The stability of the structure is assured. The traffic safety can be impaired. The durability of the structure might be impaired considerably. Proliferation of damage or the occurrence consequential damage, leading in the medium term to a considerable reduction in stability and/or traffic safety or increased wear, is to be expected. Routine maintenance is required. Repair work is required in the short term. Measures for reconstruction or warning signs for upholding traffic safety might be necessary in the short-term.
3.0 - 3.4	Critical structural condition. The stability and/or traffic safety of the structure are impaired. The durability of the structure might no longer be assured. Proliferation of damage or occurrence of consequential damage might negate stability and/or traffic safety in the short term. Routine maintenance is required. Repair work is required immediately. Measures for reconstruction, warning signs for upholding traffic safety or restrictions of usage might be urgently necessary.

Table 4.3 – continued

Condition rating	Description
3.5 - 4.0	Inadequate structural condition. The stability and/or traffic safety of the structure are considerably impaired or negated. The durability of the structure might no longer be assured. Proliferation of damage or occurrence of consequential damage might negate stability and/or traffic safety in the short term, or lead to an irreversible decay of the structure. Routine maintenance is required. Repair work or replacement is required immediately. Measures for reconstruction, warning signs for upholding traffic safety or restrictions of usage might be immediately necessary.

The condition rating of the overall structure Z_{ges} is a function of the 3-stage damage evaluation set involving the parameters S^V (traffic safety), S^S (stability) and S^D (durability), taking into account a defined evaluation key as well as the total extent of damage U and the number of individual occurrence of damage n:

$$Z_{ges} = f(S^V, S^S, S^D, U, n).$$

For a new method of condition rating assessment a structure is divided in the following component group:

- Superstructure
- Substructure
- Prestressing elements
- Foundations
- Ground and rock anchors
- Bridge cords and cables
- Bearings
- Road
- Joints
- Carriage-way surface
- Caps (Bridge concrete surface)
- Protective facilities
- Miscellaneous items

Each component group can be broken down into smaller components or structural members. In table 4.4 a short summary of the new catalogue for the standardized evaluation of damages on concrete superstructure and some other elements is presented, including short description and subdivision of some characteristic damages.

Table 4.4

Damage description	S	V	D
Concrete superstructures: - Different kind of dirt on the visible concrete surface (graffiti, soot, soil); - Appearance of the concrete surface (coarse grained segments); - Concrete cover on bottom surfaces of superstructures is too low(3.0 – 3.9 cm; up to 3.0 cm, high-quality of the concrete; up to 3.0 cm, low-quality of the concrete); - Carbonation front reaches support reinforcement; - Occasional or large-scale exposure of the reinforcement; traces of rust stains; minor, advanced attenuation of the reinforced cross-section; - Corrosion of the reinforcement due to the carbonized concrete cover (not applicable to prestressing steel sections);			
Substructures: - different kind of dirt on the visible concrete surface (graffiti, soil); - formation of moss and resulting absorption of moisture; - open or cracked masonry joints; - breakage and splintering of stones on faced brickwork; - pervasion by moisture on individual sections, on a large-scale or complete pervasion of masonry or concrete and reinforced concrete sections;			
Prestressing: - occasional exposure of tendons; - ungrouted tendons (prestressing steel is not corroded or exhibits only traces of superficial rust; steel exhibits traces of initial corrosion; corroded prestressing steel – formation of scars); - failure of prestressing elements);			
Foundation: - partial or large-scale of scouring of foundations;			
Bearings: - soiled roller bearings (movement still possible); - impermissible slant of deformed bearings; - first traces of corrosion on bearings;			
Road joints: - soiled (movement still possible) and heavily soiled (restricted movement);			
Caps (concrete surface): - cracks (width w is <0.2 mm; individual fissure's width w is > 0.2 mm; major formation of fissures with w > 0.2 mm); - exposed reinforcement and splintering on the bottom surfaces of cantilevers (with or without general accessible terrain below); - accumulation of dirt on the surface: can attract the moisture in conjunction with chemical defrosting agents; - low-grade concrete: no resistance to defrosting salts, extensive abrasion;			

Table 4.4 – continued

Damage description	S	V	D
- **Protective facilities:** - inadequate thickness of anti-corrosion coatings on railings; - damage caused by corrosion (tiny spots of initial rust; attenuation of cross-section); - railings and/or crash barrier are missing; - railing cord is missing (with or without imposed speed limit of 50km/h); - deviation of the railing heights (up to 5 cm and from 5 to 10 cm from regulations); - deviation of web-member spacing from regulations (up to 2 cm; more than 2cm); - deviation of crash barrier from regulations (up to 5 cm and more than 5 cm); - deviation of curb's height from regulations (up to 3 cm and more than 3 cm);	-	-	-
Fittings: - splintered or missing steps on embankment stairways;			
Carriage-way surface: - subsidence in the backfill area (up to 2 cm - slight – and more than 2 cm - considerable); - wheel tracks (depth < 1 cm; depth 1 to 2 cm; depth > 2 cm);			
Terrain, vegetation, measurement points, markings: - restriction of clearance; - damage caused by erosion on embankments (not in the region of foundation); - damage of the riverbanks in the vicinity of pillars, signs of the scouring; - alluvial deposits (alteration of the flow cross-section; considerable attenuation of flow cross-section); - inadequate signposting of carrying capacity or other traffic-related limitations;			

Evaluation key for this procedure is given in the Appendix 1 of this report.

In the process of evaluation of the condition rating for component groups Z_{BG}, for each individual occurrence of damage a condition number Z_1 is ascertained. The value Z_1 is supplemented by a positive or negative value ΔZ_1, which takes into account the total extent of the damage U. Extent of damage U is described as follows:

- U = "small" $\rightarrow$ $\Delta Z_1 = -0.1$;
- U = "medium" $\rightarrow$ $\Delta Z_1 = \pm 0.0$;
- U = "large" $\rightarrow$ $\Delta Z_1 = +0.1$;

The condition rating of the component group Z_{BG} is based on the maximum corresponding number Z_1, taking into account a positive or negative value ΔZ_2 for the number of occurrence of damage n within the component group. Value ΔZ_2 for the substructure component group is:

- $n < 5$ → $\Delta Z_2 = -0.1$;
- $5 =< n =< 15$ → $\Delta Z_2 = \pm 0.0$;
- $n > 15$ → $\Delta Z_2 = +0.1$;

and for all other component groups:

- $n < 3$ → $\Delta Z_2 = -0.1$;
- $3 =< n =< 5$ → $\Delta Z_2 = \pm 0.0$;
- $n > 5$ → $\Delta Z_2 = +0.1$.

The condition rating of an overall structure Z_{ges} is based finally on the highest condition rating of the component groups ${}_{max}Z_{BG}$ taking into account a positive or negative value ΔZ_3 for the extent of damage to different component groups:

- 1 to 3 damaged component groups → $\Delta Z_3 = -0.1$,
- 3 to 7 damaged component groups → $\Delta Z_3 = \pm 0.0$,
- more than 7 damaged component groups → $\Delta Z_3 = +0.1$.

Intermediate values are interpolated along a straight line by the program system.

3.5 Norway [20,21]

Structures in the Norwegian road network owned by the Public Roads Administration are considered to be bridges when the accumulated spans or total length equals or exceed 2.5 m. Those are regularly inspected. The inspection types reflect the thoroughness and frequency of inspections. The bridge inspection cycle starts when construction is complete at which point the following inspection types shall be performed:

- Acceptance inspection
- Guarantee inspection.

An acceptance inspection with associated measurements and materials investigations shall be the first inspection to be performed on the bridge. Acceptance and guarantee inspection are also performed on existing bridges after a major repair or renewal.

After bridges have been handed over, routine inspections shall be carried out for the rest of the bridge's service life. This involves the following inspection types:

- General inspection
- Major inspection
- Major inspection of cables
- Major inspection under water

To compliment these inspections, or in the event of extraordinary occurrences there may be a need to perform:

- Special inspection.

<u>Acceptance inspection</u>

The purpose of the Acceptance inspection is to uncover any deficiencies, damage or defects to the structure which have arisen during the construction phase, as well as identifying inappropriate design solutions and any sources of deterioration that may be of significance in conjunction with future maintenance. Act as a basis for accepting a hand over or not. Check the quality of the maintenance work and act as a basis for accepting these or not.

An acceptance inspection is to be undertaken before or simultaneously with the handing over of new bridges, or after the maintenance/renewal of existing ones have been completed.

Acceptance inspections should include a visual check of the entire bridge together with any supplementary measurements and materials investigations as indicated below. For new bridges major inspections under water or of cables may also be required.

Guarantee inspection

The purpose of the guarantee inspection is to check that any work done during the construction phase or repairs following the completion inspection are acceptable, and that no new damage, faults or deficiencies have appeared on the bridge. Any new source of deterioration of relevance for later maintenance should also be identified. Guarantee inspections shall be undertaken well before the claims deadline.

Guarantee inspections should include a visual check of the entire bridge, if necessary supplemented by measurements and materials investigations as stated below. For new bridges major inspections under water or of cables is to be undertaken where relevant.

General inspection

The purpose is checking for damage that can affect the load carrying capability of structures, traffic safety, future maintenance or adversely affect the environment/aesthetics. Minimum requirements are that damage assessed as requiring repair by the next inspection shall be recorded, that is damage degree 3 or 4. The normal requirement is that general inspections are performed each year, and that the first inspection happens during the year after the hand over. General inspections may be dropped in the year of a major inspection.

For bridges with uncertain future development of damages it should be considered to inspect more frequently than general recommended. The interval must be considered and fitted for each bridge. Important factors to have in mind are: traffic volume, proportion of heavy traffic, bridge type and size, significance of the road network, low load carrying capability, condition and damage development that might lead to too low capacity, bridges exposed to flooding or erosion.

In special occasions it is possible to increase the intervals depending on total bridge length and bridge type. It is granted that the person responsible for the bridge management, consider this when a major inspection is carried out. Maximum interval between each general inspection is then:

- 2 years for bridges with span less than 10 m without streaming water underneath,
- 1 year for bridges with span less than 10 m with streaming water underneath,
- 1 year for bridges with span equal or greater than 10 m,
- 1 year for movable bridges.

General inspections have to include a simple visual check. No measurements, materials investigations or use of inspection equipment are required. Exposed details or locations should be specially checked.

Major inspection

The purpose of the major inspection is ensuring that the condition of the entire bridge is functional; determining any need for maintenance activities, and making cost estimates of these activities. A major inspection is generally required every fifth year for bridges. The first major inspection shall be performed at the required interval after the end of the claims deadline.

If a bridge has suffered damage whose potential for development remains unknown, then far more frequent than normal inspections should be considered. These intervals must be determined for each case and adapted for the bridge in question. Some significant conditions to consider include: traffic volume, proportion of heavy traffic, bridge type and size, significance of the road network, low load carrying capability, condition and damage development that might lead to too low capacity, bridges exposed to flooding or erosion. Bridges older than 50 years should have major inspection at least every fifth year. Checking machinery etc. on movable bridges should normally be made simultaneously with routine servicing. Intervals for these are determined individually in each case.

In special occasions it is possible to increase the intervals depending on total bridge length and bridge type. It is granted that the person responsible for the bridge management, consider this when a major inspection is carried out. Maximum interval between each general inspection is then:

- 10 years for bridges with span less than 10 m without streaming water underneath,
- 5 years for bridges with span less than 10 m with streaming water underneath,
- 5 years for bridges with span equal or greater than 10 m,
- 3 years for movable bridges.

Major inspection will include a close visual check of the entire bridge structure. Major inspections can be supplemented with measurements and material investigations as necessary to assess the bridge's condition.

Major inspection of cables

The purpose is to undertake a check of the condition of cables, hangers with connections and anchoring to verify their functionality. Determine any maintenance needs and make cost estimates for these activities. Major cable inspections shall be performed every fifth year.

Cables with uncertain damage development should be considered inspected more often than the general five year interval. Intervals must be determined in each case adapted to the bridge in question and taking into consideration traffic volume, proportion of heavy traffic, bridge type and size, significance of the road network, low load carrying capability, state and development of damage leading to reduced capacity.

Major inspections of cables shall include a close visual check of cables, hangers with connections and anchoring. The inspection shall be supplemented by measurements and material investigations where necessary to assess the condition of these elements.

Major under water inspection

The purpose of this inspection is to check the condition of any foundations under water and that of the bottom to ensure that they are functional. Determine the need for maintenance activities and make cost estimates for these.

The general requirement is that major inspections under water shall be carried out every fifth year. Foundations exposed to erosion or undermining should be considered for inspection more often than is generally required. The timing must be determined in each case, adapted to the structure in question. In special cases extended intervals for major under water inspections may be accepted. This applies to foundations bedded in rock, or where there is no risk of erosion and scour. The precondition for this is that the Bridge Division considers it to be safe. An under water inspection of such foundations will be undertaken during the completion inspection, guarantee inspection and the initial major inspection. This does not apply to foundations where damage has been observed.

Major under water inspections shall include a close visual check of foundations and the bottom. The inspection shall be supplemented by measurements and material investigations to the extent required to assess the condition of the foundations.

Special inspection

The purpose is to investigate closer any damage, movement and/or deterioration observed during previous inspections or from notes made. Describe any costly and/or complicated activities, which might be anticipated.

Special inspections may be considered in the following situations: previous major inspections have proven the need, accidents such as collision, overloading, flood or flooding, when experience with similar types of bridges and environment indicates so.

A special inspection is normally undertaken of particularly exposed or damaged elements, but may also encompass the entire bridge. It may include a visual check, measurements or materials investigations or a combination of these.

During the inspection, a description of observed damages/deficiencies in various elements shall be prepared. An assessment shall be made on how the damage/deficiency could affect each element and a bridge as a whole and impact of the damage. For a uniform description standard types of damages are described in "Inspections Handbook for Bridges". The location of each damage/deficiency on the bridge and/or element should also be recorded.

The degree of damage is measured by a numerical scale used to give a technical assessment of the magnitude of the damage/deficiency; that is, whether maintenance activities must be executed or not, and if so, how soon. In the table 5.1 the codes for the degree of damage are presented.

Table 5.1

Code	Description
1	Slight damage/deficiency, no action required
2	Medium damage/deficiency, action needed during next 4 - 10 years
3	Serious damage/deficiency, action during the next 1-3 years
4	Critical damage/deficiency, immediate action required or within ½ year at the latest
9	Not inspected

The impact of the damage is represented by a letter code used to indicate the consequences any damage/deficiency might have on the bridge, bridge users and/or environment. The codes are presented in the table 5.2.

Table 5.2

Code	Description
B	Damage/deficiency threatening load carrying capability
T	Damage/deficiency threatening traffic safety
V	Damage/deficiency that may increase maintenance costs
M	Damage/deficiency that may affect the environment/aesthetics

The results of measurements and materials investigations shall, along with inspections, form the basis for establishing the degree of damage and the consequences of the damage. The codes for the degree and the consequence of the damage shall be used together when damage is to be assessed (e.g., 3B - serious damage/deficiency that can reduce bridge carrying capability if it remains untouched for more than 1-3 years. Action required within 1-3 years).

For each damage type the activating condition is described in "Inspections Handbook for Bridges". The term activating conditions means that a structure or an element has suffered damage or developed faults or deficiencies that require maintenance soon. The activating condition must be determined when inspecting bridges, that is, what can be accepted and what will require action. This shall be indicated using the degree of damage in the following manner:

- **Degree of damage 1:** condition may be accepted without action.
- **Degree of damage 2-4:** condition will require short or long-term action (up to 10 years).

If possible, the cause of the damage should be reported (not claim for General inspection).

The condition assessment of the bridge is based on the assessment of individual bridge elements. For this reason the bridge is divided in elements like expansion joints, bearings, drainage systems, rails, pavement and watertight membrane, superstructure, columns, abutments, etc.

In the table 5.3, 5.4 and 5.5 evaluation of some typical damages of concrete structures (cracks, spalling, corrosion) is described.

Table 5.3 - Cracks (only concrete members are described)

Causes:

- Design mistakes leading to too low load carrying capacity
- Poor materials leading to shrinkage of concrete, AAR, etc.
- Construction mistakes as poorly vibration and curing
- Lack of maintenance as for instance blocked joints with restricted movements
- Corrosion of the reinforcement
- Settlement
- Traffic loads
- impact loads

Measurements, material investigations:

- Crack width (w) and/or pattern
- Removal of concrete cover in some local areas in order to observe the condition of the reinforcement
- Structural microscopy on concrete cores in order to detect AAR

Degree of damage/consequence of damage:

Degree of damage must be considered depending upon the crack width w, number and pattern of cracks, the cause(s) and expected future development of the cracks. The location of bridge, its age and the prevailing environment which influences further deterioration must also be considered.

Usually cracks in concrete will affect the future maintenance costs. The degree of damage could be determined in this way:

Minor aggressive environment:	w<0.5 mm	1V
	0.5 mm =< w =<1.0 mm	2V
	w>1.0 mm	3V
Major aggressive environment:	w<0.2 mm	1V
	0.2 mm =< w =<0.5 mm	2V
	w>0.5 mm	3V

Cracks with leaking water should always be considered according to major aggressive environment.

Activating condition:

Crack could be caused by other damages as settlement, corrosion, etc. Those damages must be repaired before the cracks are repaired.

Cracks should be repaired before other damage types develop as for instance corrosion of the reinforcement that could lead to reduced load carrying capacity and higher repair costs.

Table 5.4 - Spalling (only concrete members are described)

Causes: - Design mistakes. Bearings too close to the edge of vertical wall on abutments for instance, faulty reinforcement - Construction mistakes as lack of concrete cover leading to corrosion and spalling - Prevailing environment causing carbonation or chloride penetration, corrosion and spalling - Loads - Impact loads **Degree of damage/consequence of damage:** Degree of damage/consequence must be considered depending on size of the spalling, the location and the expected future development. Spalling may influence the load carrying capacity in elements carrying compression. It will disturb the bond and anchoring of the reinforcement. This will have influence on the load carrying capacity. Spalling because of corrosion may increase maintenance costs if the damages are not repaired. Spalling will threat the traffic safety if spalled concrete could fall down on people underneath the bridge. Spalling may affect the environment/aesthetics making poor impression of the bridge and the users feeling unsafe. The degree of damage should reflect the way the bridge affects the surroundings and the impression given bypassing people. **Activating condition:** Spalling that has caused reduced load carrying capacity should be repaired as soon as possible. Spalling that will reduce the load carrying capacity if it goes further should be repaired before the load carrying capacity is too low. Spalling that may fall down and cause damages on people should be repaired immediately. Spalling that affects the environment/aesthetics should be repaired if this gives a poor impression of the bridge and the damage(s) is clearly visible to the public.

Table 5.5 - Corrosion (only concrete members are described)

Causes:

- Design mistakes. Lack of cover, improper concrete mixture, improper construction details.
- Material fault - improper mixture.
- Construction mistakes as lack of concrete cover or concrete cover of bad quality leading to corrosion.
- Prevailing environment, carbonation or chloride penetration causing corrosion.
- Impact load could cause spalling and corrosion.

Degree of damage/consequence of damage:
Degree of damage/consequence must be considered depending on amount of the corrosion, the effect on the load carrying capacity and the expected future deterioration.

Pre- or post-tensioned reinforcement is very vulnerable for corrosion and essential for the carrying capacity. Degree of damage should be considered to be 3 or 4.

Elements that are very vulnerable due to corrosion as the superstructure or slender columns should be given a high degree of damage. In environments with a high humidity, corrosion will progress rapidly and affect the load carrying capacity after a short period of time. The degree of damage must reflect this. Corrosion leading to spalling could also affect the load carrying capacity because the distribution of stress is disturbed.

Corrosion in massive columns, abutments, etc. normally have a minor effect on the load carrying capacity. The degree of damage should be low.

Degree of damage must reflect the anticipated future deterioration and related maintenance costs.

Corrosion will cause spalling that may affect the environment/aesthetics making a poor impression of the bridge and the users feeling unsafe. Degree of damage should reflect the way the bridge affects the surroundings and the reactions of passing by people.

Activating condition:
Corrosion that has caused reduced load carrying capacity should be repaired as soon as possible.

Corrosion that will reduce the load carrying capacity if it goes further should be repaired before the load carrying capacity is too low.

Corrosion that will affect future repair costs should be repaired before costs increase considerably.

Corrosion that affects the environment/aesthetics should be repaired if this gives a poor impression of the bridge and the damage(s) is clearly visible for the public.

3.6 Slovenia

3.6.1 Present procedure

At the moment Slovenia has no official regulation or guideline for carrying out the inspections and procedures for assessment of the condition of bridges. In the existing regulation[22] there are only two articles dealing with the maintenance of structures. The first article emphasises that concrete and reinforced concrete structures must be maintained as specified in the design documents and that safety and functionality shall be preserved. The second article requires that bridges must be visually inspected every two years, and special attention shall be paid to cracks, deformations and damages that are essential for the safety of the structure. If the inspection reveals that the safety level of the structure is lower than designed, deflection must be checked by the load test.

In the early eighties the Road Administration has made the first complete inventory of all bridges, under its jurisdiction. One of the main results of this inventory was the comprehension that a more systematic approach is needed to acquire useful data for bridge management and maintenance. For this reason a research work was undertaken in 1986 through 1988 by the Slovenian National Building and Civil Engineering Institute. The main goal of this work was the survey of current practices for the inspection and assessment of bridges in several European countries, and to prepare some basic guidelines for the assessment of the condition of bridges, managed by the state Road Administration.

The result of this work is a three-volume report[23] which was later the basis for the implementation of regular inspection and assessment of the condition of bridges. In the 1st volume the compilation of current practice for the assessment and inspection of bridges from several countries was presented. The 2nd and 3rd volume contained tables with sketches and photos of characteristic damages on different parts of a bridge structure, and short description of their possible causes. In 1990 a methodology[24] was developed for determination and selection of the capacity reduction factor ϕ, figuring in the expression of the rating factor RF.

In Slovenia, the whole inventory of bridges, viaducts, over and underpasses with spans of 5 m or longer has been regularly inspected since 1990. The tunnels are also included in the inventory and in the system of inspection. The following types of inspection are carried out at indicated intervals:

- Superficial inspection is carried out by maintenance personnel at least once a year. It consists of the visual check of condition of some visible components of the bridge, like pavement, railings, expansion-joints, etc. This inspection is part of regular maintenance activities which are carried out by the maintenance personnel.
- General inspection is carried out every two years by trained personnel guided by the structural engineer. The inspection consists of visual examination of all accessible parts of the bridge without using special equipment. Inaccessible parts of the bridge may be inspected by binoculars. The report of general inspection comprises coded descriptions of bridge components and elements, type, extent and intensity of detected damages. The location of distinctive damage is described with reference to the inspected element or

component. The recommendations for maintenance, repair work, major inspection at an earlier time than regular interval, or for special inspection with field measurements or laboratory tests are also stated. The condition rating of four main bridge components and of the entire bridge is then computed on the basis of the estimated intensity and extent of each damage type and the impact of each affected bridge element on bridge safety.

- Major inspection is carried out every six years. The inspection consists of visual check of all bridge elements. For this reason the access by ordinary or special equipment must be provided to every part of the bridge. All damages must be assessed from close distance which assures satisfactory estimation of the extent, intensity and type of the damage. The report is set up in the same scope and format as for the general inspection. A part of major inspection is also underwater inspection of foundations and riverbed around foundations. For bridges on highways major inspections are obligatory also before their handover to the traffic, before the expiration of the guarantee period and after every substantial repair work.
- Special inspection is carried out when recommended after a major or general inspection. The purpose of this in-depth inspection, which is basically carried out on the distressed parts of a bridge, is the thorough examination and assessment of the extent, intensity, type and cause of previously detected damages. Within its scope all detected damages must be first carefully mapped. The damaged spots must be examined by field measurements (thickness of the concrete cover, concrete strength with rebound hammer, electrochemical potentials, concrete permeability, remaining cross section of the reinforcement and concrete sections, depth of carbonation, etc..) and laboratory tests (chloride profiles, concrete alkalinity, concrete strength on concrete cylinders, metallographic and fractographic test of the prestressed wires or strands, mechanical properties of the prestressed reinforcement with different grades of corrosion damages, electrochemical properties of the concrete, etc.). The results of these examinations are used for categorisation of detected damages and for giving general recommendations about the most suitable repair method to be applied on typical damaged areas in reliance to the type and category of the damage.

General or major inspections of bridges are also carried out after major natural disasters like major earthquakes, floods, fires, landslides, etc. The scope of these inspections depends on the importance of the bridge, its size and its accessibility.

The condition of the bridge is expressed by the condition rating for every main bridge component and for the entire bridge, the latter being simply the sum of all component condition ratings. In table 6.1 the main components of the bridge to be considered in bridge rating and their main constituent parts are given.

Table 6.1

Component	Constituent parts
Substructure	Landscape around bridge structure, riverbed, foundations, supporting members
Superstructure	Superstructure, tunnel
Bridge surface	Bridge surface
Bridge equipment	Bearings, expansion-joints, safety equipment, drainage system

For recording and evaluation of damages the bridge structure is divided into eleven main elements, which are further divided into sub-elements. They are listed in table 6.2 according to their numerical codes.

Table 6.2

Element code	Element description	Sub-elements
100	Landscape around bridge structure	Approaching carriage-ways, approaching embankment or excavation, lining of embankment or excavation slopes, drainage systems of the embankment or excavation slopes,…
200	Riverbed	Riverbed within and outside the area of the bridge, riverbanks, lining of riverbank slopes,…
300	Foundations	Single or strip footings, piles, pile caps, caissons
400	Supporting structures	Abutments, wing-walls, retaining walls on approaching ramps, piers, single or multicolumn supports, caps over columns,…
500	Bearings	concrete bearings, steel bearings, elastomeric bearings, pot bearings, sliding bearings,…
600	Superstructure	Girders – main and secondary, hollow girders, bridge deck slabs – voided or solid, box girders with upper and lower plate and side webs, transverse beams, …
700	Bridge surface	Carriage-way, sidewalks, curbs, edge beams, waterproofing membrane, installation shafts,…
800	Tunnel	inner lining, portal structure
900	Expansion joints	steel parts, rubber membrane, fixing elements, …
1000	Safety equipment	Metallic safety barriers, guard rails, concrete blocks, concrete barriers, approaching guard rails, railings, columns for public lightening,…
1100	Drainage systems	pipelines, lids, pipe hangers,…

In table 6.3 main coded damage items, related to the construction material, behaviour of the structure and bridge equipment, and, the corresponding damage types are given.

Table 6.3

Damage code	Damage item	Corresponding damage types
0000	Deformations	Vertical and horizontal displacements, rotations, settlement, unevenness, …
0100	Surrounding landscape	Erosion of the riverbed slopes, scour, excessive vegetation on the riverbank slopes or embankment slopes, missing parts or damaged linings of the slopes, …
0200	Concrete	Cracks ($w \leq 0.2$ mm; $02 < w \leq 0.5$ mm; $0.5 < w \leq 1.0$ mm; $w > 1.0$ mm); spalling, delamination; surface defects; wetting; to low thickness of the concrete cover; mechanical damages; etc…
0300	Reinforcing and prestressing steel	Corrosion of stirrups and main steel, corrosion of prestressing reinforcement, exposed tendons, exposed reinforcement and stirrups, breakage of tendons or prestressing steel; etc…
0400	Structural steel	Damage of coatings, corrosion, cracks, etc…
0500	Structural timber	Moisture, fungus, moss, breakage of timber elements,…
0600	Stone, brick, plaster	Cracking, spalling of mortar, protrusion of moisture, separated bricks and stones, etc…
0700	Bridge surface	Wheel tracks in the pavement, damages of the joints, deterioration of joint seals, abrasion, deterioration of waterproofing membrane, unclean surface, etc…
0800	Bearings	Mechanical damages of steel parts, excessive deformations, blockage of movements, corrosion of steel parts, etc…
0900	Expansion joints	Mechanical damages of steel parts, deterioration of sealing elements, corrosion of steel elements, etc…
1000	Equipment	Corrosion of steel elements, mechanical damages, missing elements or parts of elements, etc…
1100	Drainage systems	Corrosion, missing elements, unclean drainage system, etc…

The condition rating R for assessing the condition of a bridge structure and its components in a quantitative form, is expressed by the following function:

$$R = \sum V_D = \sum B_i \times K_{1i} \times K_{2i} \times K_{3i} \times K_{4i}$$

The individual factors mean:

V_D - damage type value.

B_i – basic value associated with the damage type i. The value of B_i is within the range of 1 to 4 and expresses the potential effect of the damage type on the safety and/or durability of the observed structural element.

K_{1i} – Factor which describes the extent of the damage and is expressed by numerical values between 0 and 1. In the field record it is described by letters A, B and C (A – up to 30% (or number of the same elements), B from 30 to 60% and C for more than 60% of the observed surface of the structure). The description usually refers to one or more components of the bridge or to the whole bridge structure. The extent is not described by the measured sizes (length, area, etc.) of the damage on the affected component or structure.

K_{2i} – Factor which describes the intensity of the damage and is expressed by values between 0 and 1. In the field only the intensity grades I to IV (I – light, II – medium, III – severe, IV – very severe) are recorded. The description of intensity is usually related to the type of damage (e.g. width of the cracks, thickness of the delamination, etc).

K_{3i} – Factor which describes the importance of the structural component or member for the safety of the entire structure. The values range between 0 and 1.

K_{4i} – Factor which describes the urgency of intervention. The values range between 0 and 10. The chosen value depends of the type of structure, and seriousness and risk of collapse of the affected structure or its part.

According to the obtained value of condition rating R, the bridge structure is classified into one of five condition classes, described in table 6.4. On this ground the main bridge inspector will finally take decision about the global condition class of the whole bridge structure.

Table 6.4

Condition class	Definition	Condition rating R
1	Critical	>20
2	Bad	14-22
3	Satisfactory	8-17
4	Good	3-12
5	Very good	0-5

The condition rating is used for the first ranking of the bridges in a management system, and for screening those bridges, which should be commissioned for in-depth inspection, or undergo a more thorough maintenance, or repair, or rehabilitation intervention. However, the method has a minor drawback, because for different types of structures (e.g., slab superstructure or superstructure made of girders, transverse beams and deck slab) different condition rating values can be obtained, even the damage types, intensities and extent are estimated as being the same. This was the main reason, that this method has been recently modified and improved.

3.6.2 Proposed modified method for condition rating [25]

3.6.2.1 General

The above basic approach has been further developed by introducing the following modifications:

(1) The condition rating is not expressed by the simple sum of damage values, but by the ratio between:

- ⇒ the effective sum of damage values obtained by taking into account, from a closed list of potential damage types, the damage types detected at the inspection, and,
- ⇒ the reference sum of damage values obtained by taking into account from the same closed list every damage type that could realistically occur on the same structure, multiplied always by unit intensity and extent factors $K_2 = K_3 = K_4 = 1$.

Thus, the condition rating of a structure or of its observed portion/component is defined as the fraction or percentage of a reference rating value associated with an assumed average condition of this particular structure. By being related to a conventional reference deterioration level, the rating value is much less affected by the number of damage types, and by the number of members composing the observed structure, or by number of spans.

The reference condition level is not a fixed value, but shall always be in relation to the arrangement of the inspected structure and to potential damages on this structure. Therefore, the reference sum should take into account damages, which are with great probability expected to appear on the existing members of the observed structure, and shall ignore those damages, which can never occur on it. E.g. to calculate the condition rating of a reinforced structure the reference sum shall not consider damage values related to prestressed concrete.

(2) In the case of multi-span bridges, where the inspection is usually performed span after span, the condition rating of the whole structure or of its main components is expressed by the average sum of damage values calculated for each individual span. Namely, the intensity and the extent of the detected damages can be more adequately defined and be better balanced when the evaluation is carried out for individual spans.

(3) The factors to evaluate the intensity of a damage type on a structural member are characterised by general descriptive criteria, and for some damage types also by numerical criteria. Factors to evaluate the extent of damage on a structural component are defined by general descriptive criteria only. To achieve better sensibility of rating values in relation to the assessed condition, the two factors are applied in wider ranges, namely 0,5 - 1,0 - 1,5 - 2,0, establishing 4 intensity and 4 extent classes.

3.6.2.2 New rating function

According to 3.6.2.1, the condition rating of the observed structure is defined as:

$$R_C = \frac{\sum V_D}{\sum V_{D,ref}} \times 100$$

where:

V_D effective sum of damage values calculated for the observed structure or its part (e.g. bridge component), related to the detected damage types from a list, (values of K_2, K_3 and K4 should be allotted according to the newly defined ranges – see 3.6.2.1),

$V_{D,ref}$ reference sum of damage values obtained by taking into account every damage type from the same list that could potentially occur on the same observed structure or its part, multiplied by unit values of factors of intensity and extent. ($K_{2i} = K_{3i} = 2$, $K_{4i} =$ const. = 1).

In the practical evaluation procedure the above formula is applied in the following form:

$$R_C = \frac{\sum_1^k K_{1m} \times M_m}{\sum_1^k K_{1m} \times M_{ref}} \times 100$$

where:

$$M_m = \sum_1^n B_i \times K_{2i} \times K_{3i} \times K_{4i} \qquad \text{(i = 1 to “n”)}$$

is by the relevant factor K_{1m} reduced sum of damage values ΣV_D, computed for the structural member m, ($M_m = \Sigma V_D / K_{1m}$), and

$$M_{m,ref} = \sum_1^t B_i \times K_{2i} \times K_{3i} \times K_{4i} \qquad \text{(i = 1 to “t”)}$$

is by the respective factor K_{1m} reduced reference sum of damage values $\Sigma V_{D,\,ref}$ for the same observed member m ($M_{m,ref} = \Sigma V_{D,,ref} / K_{1m}$)

k number of members “m” within the observed structure

n number of detected and evaluated damage types “i” on a member “m”

t total number of potential damage types on the member “m” (from Table-1)

On the basis of the calculated condition rating the inspected structure is classified into one of the deterioration classes, described in table 6.5.

Table 6.5

Deterioration class	Description of the condition, necessary intervention, Deterioration examples ()	Rating range
I	No defects, only constructional deficiencies. No repair, only regular maintenance needed. (geometrical irregularities, aesthetic imperfections, discolouring,…)	0 - 5
II	Low degree of deterioration, which only after longer period of time might be the cause for reduced serviceability or durability of the affected structural component, if not repaired in proper time. Deteriorated locations can be repaired with low costs as part of regular maintenance works. (local cracks, smaller deficiencies resulting from bad concreting work, locally too thin concrete cover,…)	3 - 10
III	Medium degree of deterioration, which can be the cause for reduced serviceability and durability of the affected structural component or element, but still not requiring any limitation of use of the structure. Repair in reasonably short time is required. (cracking, greater deficiencies resulting from bad concreting work, very thin concrete cove on mostly wet areas, defects of waterproofing on bridges,…)	7 - 15
IV	High degree of deterioration, reducing the serviceability and durability of the structure, but still not requiring serious limitation of use. Immediate repair to preserve the designed serviceability and durability is required. (reinforcement corrosion on main carrying members, open joints, grouting deficiencies of prestressing ducts,…)	12 - 25
V	Very heavy deterioration, requiring limitation of use (e.g. restricted vehicle weight on the bridges), propping of most critical members, or other protective measures. Immediate repair and strengthening of the structure is required or the carrying capacity shall be adequately reduced. (heavy corrosion of reinforcement or prestressing tendons in the main carrying members, wide cracks because of overloading, presence of water in prestressing ducts,…)	22 - 35

Table 6.5 – continued

Deterioration class	Description of the condition, necessary intervention, Deterioration examples ()	Rating range
VI	Critical deterioration, requiring immediate propping of the structure and strong limitation of the use (e.g., closing of the bridge). Immediate and extensive rehabilitation works are needed, however the design serviceability and use of the structure, as well as acceptable remaining service life can no more be achieved with economic costs. (as class V and lower level of safety,…)	≥ 30

3.7 United Kingdom [26,27,28,29,30]

In the United Kingdom there are four main types of inspection for all bridges with the span greater than 3.0 m, culverts 1.8 to 3 meters span or multi-cell culverts with the cumulative span greater than or equal 5 m, if their cover to road surface is less than 1.0 m. In Scotland the minimum culvert size is 2 meters. The four main types of inspections are:

- Superficial inspection is carried out regularly by the staff of Maintaining Agent. It is a cursory check of obvious deficiencies which might lead to accidents or high maintenance costs. It can be made from ground and deck level or from any walkway or platform, built into a structure. If any superficial inspection reveal a possible defect, which should hazard to road, rail or other users, the Maintaining Agent shall immediately take actions required to safeguard the public. The overseeing organisation and the owner of the structure shall be informed without any delay.

- General inspection is a visual examination of accessible representative parts of the structure, adjacent earthworks or waterways. It can be made from ground and deck level or from any walkway or platform, built into a structure. Inspections are required not more than two years after the last General or Principal inspection.

- Principal inspection is a close examination of all inspectable parts of the structure and adjacent earthworks and waterways. A suitable access may need to be provided to enable a close examination. The inspection shall be carried out at intervals, which normally would not exceed six years, exceptionally may be up to ten years. For the new structures it is carried out about one month before the issue of the certificate of Completion or opening of the structure to traffic. In recent years limited testing has been included [31].

- Special inspection is a close examination of particular areas or defects causing concern. It shall be carried out:

- To investigate a specific problem, either found during inspection or already discovered on other similar structures.
- For cast iron structures at intervals not exceeding six months.
- For structures strengthened by the use of bonded plates. It is carried out at intervals of 6 months for the first two years. After 2 years period at intervals prescribed in the maintenance manual.
- For structures which have weight restrictions or other forms of restrictions to reduce traffic loading at intervals not exceeding 6 months.
- When a structure has to carry an abnormal heavy load before, during and after the passage of the load, if assessment has indicating that the safety is below that which would be provided for a design to current standards, or similar loads are not known to have been carried.
- In areas of mineral extractions, when subsidence occurs.
- If settlement is observed greater than that allowed in the design. The cause shall be identified and programme prepared for monitoring the rate of settlement.
- Underwater inspections of bridge foundations after flooding. Where examination indicates the possibility of scour, further underwater inspection shall be carried out.
- After a major accident, chemical spillage or fire adjacent to a bridge structure.

In the report comments on the significance of various defects recorded and a statement of the overall condition of the structure should be made. Recommendations for a more detailed inspection are given or if special attention should be given to certain elements of components at the next general or principal inspection.

In the inspection report defect assessment for 33 structural items (e.g. foundations, piers or columns, abutments, wing walls, retaining walls or revetments, approach embankments, fenders, bearings, main beams/tunnel portals/mast, transverse beams, diaphragms, concrete slabs, waterproofing, surfacing, expansion joints, etc…) is made in terms of estimated costs, extent, severity, work and priority. In table 7.1 four categories of the extent of the damage are presented, in the table 7.2 four categories of severity of the damage, in table 7.3 seven types of recommended work and in table 7.4 eight investigation types, which can only be used when actual work is not recommended and in the table 7.5 three levels of priority.

Table 7.1

Extent	Description
A	No significant defect
B	Slight, not more than 5% of length or area affected
C	Moderate, 5 to 20% affected
D	Extensive, more than 20% affected

Table 7.2

Severity	Description
1	No significant defects

2	Minor defects or of a non-urgent nature
3	Defects which shall be included for attention within the next annual maintenance programme
4	Severe defects where urgent action is needed

Table 7.3

Work	Description
A	Add (new items to be provided, e.g. waterproofing)
B	Item present but not inspected
C	Change (e.g. replacement of a defective bearing or parapet)
P	Paint
N	No action at present, monitor only
R	Repair/maintain (repair to concrete, clean grease, rod etc….)
S	Silane impregnation

Table 7.4

Investigation type code	Description
1	Alkali-silica reaction
2	Chloride contamination
3	Carbonation
4	Corrosion of reinforcement/prestressing cables
5	Structural steel paintwork
6	Accidental damage
7	Spalling of masonry, brick or concrete
8	Chloride ion levels in reinforced concrete decks before waterproofing or on re-waterproofing

Table 7.5

Priority	Description
H	High; work should be done during the next financial year to ensure the safety of the public or safeguard structural integrity or avoid a high cost penalty.
M	Medium; work should be done during the next financial year. Postponement carries some cost penalty.
L	Low; work should be done within the next two financial year.

In table 7.6 the acceptable combinations of estimation of costs, extent, severity, recommended work and priority are given.

Table 7.6

Estimated costs	Extent	Severity	Recommended work	Priority
Blank or 0	Blank	Blank	Blank or S or B	Blank
Blank or 0	A	1	Blank	Blank
> 0	Blank	Blank	A	L or M or H
Blank or 0	B or C or D	2	N	Blank
> 0	B or C or D	2	R or C or P or 1-8	L
> 0	B or C or D	3	R or C or P or 1-8	H or M
> 0	B or C or D	4	R or C or P or 1-8	H

The overall condition assessment of the bridge is made in terms of G for good, F for fair and P for poor.

Existing post-tensioned bridges are to be examined by special inspection over a five year period. The method for determining inspection priorities and to ensure a degree of uniformity of bridge ranking throughout the road network was developed. The so called Total assessment rating TA is evaluated with the help of six different ratings, which are: Age of bridge rating R_a, Bridge form rating R_f, Vulnerable detail rating R_d, Traffic volume assessment rating R_v (24 hour annual average daily traffic) and R_u(annual average daily flow below or adjacent to bridge) and Route importance rating R_i. The values for each rating are given in tables. A value between 1 and 5 shall be assigned to Age of bridge rating R_a, which depends on the year of bridge construction. A bridge form rating has values 1, 3, 4 or 5 and it depends on the type of construction. Vulnerable detail rating R_d shall be assigned value between 1 and 5 and it depends on number of vulnerable details (few -1, many - 5). Traffic volume assessment rating R_v and R_u shall be assigned values between 1 (up to 20000 vpd) and 5 (over 80000 vpd), depends on the daily traffic flow in number of vehicles per day. The value for Route importance factor R_I lies between 0 and 5 (strategic importance of the route). Total assessment rating TA is calculated by the following expression:

$$TA = 4 \times R_a + 2 \times R_f + R_d + R_v + R_u + R_i$$

The value of TA will have a value between 8 and 50. The priority rating PR is determined on basis of the rating TA and is shown in table 7.7.

Table 7.7

Total assessment rating TA	Priority rating RA
43 - 50	1
36 - 42	2
29 - 35	3
22 - 28	4
8 - 21	5

Bridges, which got the priority rating 1 should be inspected first and those with 5 last. In special cases a bridge is automatically assigned a priority rating of 1 (e.g., immediate concern for public safety,…).

3.8 United States [32]

Bridges on all public roads with spans greater than 6.10 m are inspected at regular intervals of 2 years. The scope of the inspection depends on several factors like age, traffic characteristics, state of known deficiencies and maintenance. The evaluation of these factors is the responsibility of the person in charge of the inspection program. The maximum inspection interval may be greater than proposed 2 years interval, if it is justified on the basis of past inspection reports and analysis. During the inspection the overall condition rating is assigned for three major bridge components deck, superstructure and substructure. In the table 8.1 the main bridge components and corresponding elements are given.

Table 8.1

Component	Elements
Deck	Wearing surface, deck - topside, deck - underside, stay-in-place forms, curbs, medians, sidewalks, parapets, railings, expansion joints, drainage system, lighting, utilities
Superstructure	Stringers, floorbeams, floor system bracing, multibeams, girders, trusses (general, upper chords, web members, lower chords, lateral bracings, portals), arches, cables, paint, bearing devices, connections, welds
Substructure	Abutments, (piles, footing, stem, bearing seat, backwall, wingwalls), piers and bents, (piles, footing, column(s)/stem, cap
Channel	Channel (streambed, embankments, streamflow, drift and debris), channel protection (riprap, guidebanks or spur dikes, gabions, slope protection, footing aprons)

A descriptive condition rating in terms of good/fair/poor/not applicable is given by the inspector for each element of the component, based on the deficiencies found on the individual element. For each element of the component the type, extent, quantity and severity of deterioration and deficiencies must be described. Description of condition ratings is given in table 8.2.

Table 8.2

Condition rating	Description
Good	Element is limited to only minor problems
Fair	Structural capacity of element is not affected by minor deterioration , section loss, spalling, cracking or other deficiency
Poor	Structural capacity of element is affected or jeopardized by advanced deterioration, section loss, spalling, cracking or other deficiency

The numerical condition rating of the component should characterize the general condition of the entire component. In the table 8.3 the condition ratings for the component are given.

Table 8.3

Condition rating	Description
N	Not applicable
9	Excellent condition
8	Very good condition - no problems noted
7	Good condition - some minor problems
6	Satisfactory condition - structural elements show some minor deterioration
5	Fair condition - all primary structural elements are sound but may have minor section loss, cracking, spalling, or scour
4	Poor condition - advanced section loss, deterioration, spalling, or scour
3	Serious condition - loss of section, deterioration, spalling or scour have seriously affected primary structural elements. Local failures are possible. Fatigue cracks in steel or shear cracks in concrete may be present.
2	Critical condition - advanced deterioration of primary structural elements. Fatigue cracks in steel or shear cracks in concrete may be present or scour may have removed substructure support. Unless closely monitored it may be necessary to close the bridge until corrective action is taken.
1	Imminent failure condition - major deterioration or section loss present in critical structural components, or obvious vertical or horizontal movement affecting structure stability. Bridge is closed to traffic but corrective action may put bridge back in light service.
0	Failed condition - out of service; beyond corrective action.

4.0 CLASSIFICATION OF DEFECTS

A review of the most frequent and relevant defects on the elements of a bridge structure is given in this chapter. These defects have a more or less great impact on the bridge condition, and on the assessment of the condition. It is made after having examined the available documents on this subject from different countries. To some types of damages also a classification of intensity or severity is suggested without any numerical values. This gradation would mostly depend on the experience of inspection and condition assessment personnel as well as on national regulations.

- Riverbanks, riverbed, embankments

Erosion of riverbank

Erosion of riverbed

Erosion of embankments

Abrasion, deterioration of slope protection structures in riverbank

Abrasion, deterioration of riverbed protection structures

Abrasion, deterioration of slope protection structures on embankments

Scoured area beneath pier/abutment

Vegetation in riverbed and on riverbed and embankment slopes under and in the near vicinity of the bridge structure

- Substructure

Lateral movements

Tilt, rotations

Differential settlements

- Superstructure

Excessive vertical displacements

- Concrete

Poor workmanship (surface porosity, honeycomb, stratification,…)

Mechanical damages (abrasion, delamination and spalling due to impact load; delamination and spalling due to excessive load from temperature effects, differential movements of closely spaced elements, post-tensioning; small distance of the bearings from the free edge;)

Cracks and open joints between the segments (structural and nonstructural; with or without presence of water, exudation, efflorescence); width of the cracks should be graded into three or four grades)

Deterioration (peeling, spalling and delamination of concrete cover due to freezing and thawing, corrosion of the reinforcement, ASR, leakage through concrete, constant presence of dirt, moss and other vegetation…;); to be graded with respect to the thickness of the spalled concrete into three or four grades;

Wetting (wet exposed concrete surface in the tidal zone and in the splashing zone of waves and driving cars, or, exposure to the marine environment, leakage of water through concrete element due to the damaged or missing waterproofing membrane, damaged joint sealings on the sidewalk or edge beams,…); to be graded into three or four grades;

Concrete cover depth defects; to be graded into three or four grades with the respect to the required minimum concrete cover depth for certain environmental conditions.

Carbonation front in the concrete cover: to be graded into three or four grades with reference to the concrete cover depth and the level of the stirrups, main reinforcement and prestressed reinforcement.

Chloride penetration depth: to be graded into three or four grades regarding total chloride content threshold level and with reference to the concrete cover depth and the position of the stirrups, main reinforcement and prestressed reinforcement. It is based on some measurements performed on site or in the laboratory.

Reinforcement

Corrosion of the stirrups and main reinforcement: to be graded into three or four grades with reference to the reduced cross section of the reinforcement with regard to typical dimension of the element cross section. The assessment is made on the basis of special investigation.

Corrosion of the prestressed and post-tensioned tendons: to be graded into three or four grades with reference to the amount and depth of the pits of the prestressing steel and as the ultimate stage, the broken wires or strands. The assessment is made on the basis of special investigation.

Corrosion of the ducts for post-the tensioned tendons: to be graded into three or four grades with the respect to the amount of corrosion and amount of the total chloride content in the grout. The assessment is made on the basis of special investigation and measurements.

Corrosion of the anchorage elements and deviators for external prestressing and for stay cables (including the deterioration of the protective paint).

Damage of the protective cover of external tendons and stay-cables.

Ungrouted ducts

Bearings (steel, reinforced concrete, reinforced elastomeric, pot bearings, …)

Excessive deformations (displacements, rotations)

Deterioration (reinforced concrete, rubber)

Corrosion and/or deterioration of the protective coatings (steel bearings, steel elements of the pot bearings, reinforced elastomeric bearings, fixing bolts,…)

Mechanical damage (broken bolts, broken or deformed steel elements, cracked welds due to impact load, damaged sliding surface, malfunction of the bearings due to specific causes - dirt, uncleanliness, lack of grease on sliding bearings,…)

Construction defects (missing bolts, thin welds, welding imperfections,…)

Expansion joints

Corrosion and/or deterioration of the protective coatings of steel elements

Mechanical damage (broken fixing bolts, broken or deformed steel elements, cracked welds due to impact load, damaged rubber surface, malfunction of the expansion joints due to specific causes - dirt, cleanliness,…)

Construction defects (missing fixing bolts, thin welds, welding imperfections, missing waterproofing membrane, missing or malfunction of expansion joint drainage system,…)

Deterioration (rubber membrane - leakage; sealant along the expansion joint; surface rubber; expansion joint sealant;…)

Pavement with waterproofing membrane (asphalt and concrete pavement of carriage ways and sidewalks)

Cracks (single, several, congested)

Crushed surface (with or without visible reinforcement - sidewalk)

Wheel tracks: to be graded into three or four grades with the reference to the width and/or depth of the track)

Damaged or missing waterproofing membrane (leakage through concrete element)

Uneven approach on the bridge and/or over expansion joint

Curbs (made of concrete or stone)

Crushed surface (with or without visible reinforcement - concrete curbs)

Deformations (transverse or vertical displacements)

Missing elements of the curbs (stone, concrete, steel edge profiles)

Safety barriers (steel and concrete, on the bridge and on the approach ramps)

Deterioration of concrete elements (due to freezing and thawing, presence of de-icing salts,…)

Deformations (transverse or vertical displacements)

Corrosion of steel elements

Mechanical damages due to impact loads (concrete and steel elements)

Joint sealing (between : curb - sidewalk; sidewalk - edge beam; on sidewalk; between edge beam and safety barrier sections)

Deterioration (light cracks, severe cracks, spalled sealing, totally damaged; presence of vegetation in the cracks,…)

Missing sealant

Protective devices (steel railings, noise barriers with steel or concrete support elements and metal, plastic or wooden filling panels)

Corrosion

Deterioration of the protective paint (steel, plastic, wood)

Deterioration of concrete elements

Mechanical damages due to impact load

Missing elements

Drainage systems (mechanical damage, corrosion of the pipelines or fasteners, etc….)

5.0 RECOMMENDATIONS

Adequate condition assessment of bridge structures and monitoring of the progress of deterioration highly depends on the results of periodical inspection. Properly executed and timely scheduled maintenance operations, based on requirements of regular inspections, should secure the durability and reasonably extend the service life of bridge structures. It should also minimise the volume of repair works and significantly contribute to the reduction of repair costs, as well as of environmental claims connected with noise, atmosphere and water pollution, deposition of debris, etc… With other words, it is important to do the right thing in the right time.

Therefore, structures should be inspected in reasonable time intervals dependent on the scope of particular type of inspection. Three basic types of inspection should be carried out to assure adequate monitoring of the condition of bridge structures:

- **Superficial inspection** is carried out by skilled maintenance personnel, trained for checking primarily the hazards to traffic safety on the bridge, but without special knowledge of bridge pathology. During the regular maintenance surveys of the road section any major anomalies (defects) on and under the bridge should be checked. All observations (date and detected anomalies) must be recorded. The period of this inspection is at least once a year.

- **General inspection** is a visual examination of all accessible parts of the bridge without using special access equipment. Normally, it is carried out by technicians, trained in bridge pathology. In case of very complex bridge structures an inspection team of highly qualified experts would be required. All defects, which can be visually detected from the ground must be recorded and the condition of the structure must be evaluated in an appropriate manner. The frequency of general inspections should not be less than two to three years, provided the superficial inspection is carried out regularly. The report shall include description of all detected defects, and, if necessary, shall call for the in-depth inspection. If general inspection follows a major inspection, and if no repair or maintenance work was done, only the newly observed defects should be assessed and recorded, but the evaluation of the condition assessed by the preceding major inspection need not be changed.

- **Major inspection** is a visual inspection of all parts of the bridge structure. It is carried out by a specialist engineer for bridge pathology. A visual check of all parts of the bridge should be made from the touching distance of each bridge element, therefore the access with special equipment or facilities must be provided to enable reliable assessment of existing damages. Examination of some bridge parts can be made with a camera having a powerful zoom. The frequency of the major inspection should be five to ten years, or, depending on the structural condition, load carrying capacity, etc, it should be performed also more often. On some specific and characteristic spots selected site- and/or laboratory tests and measurements should be performed, e.g. chloride profiles, electrochemical potentials, permeability, depth of concrete cover, crack width, depth of carbonation, as well as position of bearings, deflections, settlements and joint openings. The scope of these measurements depends on the complexity and condition of the structure. A full report containing description of detected defects, condition assessment and recommendations for the special i.e. detailed inspection and necessary urgent repair work must be set up. The damages and their extent should be described in detail and evaluated, to provide reliable data for the first estimation of costs for the proposed repair work. Unsuitable construction details causing damages on structural elements and impairing the durability of the bridge should also be identified.

Acceptance inspection is carried out before opening the bridge to the traffic. As later assessments and monitoring of the condition of a bridge structure highly depend on the reference condition of the new bridge this first inspection should be made for every new bridge. It should be performed in the same scope as the major inspection including some measurements. The scope of measurements depends on the location of the bridge (its environment) and its dimensions. During the inspections the measurements of the concrete cover depth, chloride profiles and electrochemical potentials on superstructure, if the bridge is located in coastal regions, and columns in the tidal zone, deflections of superstructure and settlements of supports, position of bearings, openings of expansion joints, permeability or porosity and strength of concrete should be performed. Some data may be obtained also from the construction documents, e.g. concrete strength, concrete cover, etc….

Acceptance inspection should be performed also after any substantial repair work.

Guarantee inspection must be carried out before the expiration of the guarantee period. It should be performed in the same scope as the major inspection.

It should be performed also after expiration of the contractual guarantee period for the repair work.

Acceptance and guarantee inspection should be attended by the representatives of the contractor and of the supervising personnel. Owner's staff should attend major inspections of more complex structures and be sometimes also involved in the inspection.

Detailed or special inspection is usually carried out on complex bridge structures, foreseen for repair or rehabilitation. It can be performed on the whole structure or be restricted to some components or its elements. Extensive site and laboratory tests and measurements are usually performed to provide data for the reliable design of the repair work and for an in-depth view to the damage pathology.

The estimation of costs for repair or maintenance work should generally not be the subject of the inspection report, but of further optimisation procedures including also the cost / benefit analysis.

Condition assessment should be systematically reviewed and be considered in the design of new bridges. Thus, past mistakes can be avoided by improving the structural details, what will contribute to the economy and reduction of the maintenance costs in a longer period of time. Design of structural details, providing easier access to the parts of the structures, which must be regularly inspected from close vicinity, can also be improved. The performance of the executed repair work should be permanently re-evaluated by the systematic review of the results of major and detailed inspections in relation to the data of acceptance and guarantee inspections. This will enable taking the right decisions in the future and contribute to better designs of future repair works.

Special attention shall be paid to the safety of inspectors, which should be safeguarded also by regulations. Safety measurements should be covered in the inspection handbook.

For a reliable condition assessment an inspection handbook should be prepared, describing and illustrating by sketches or photos all potential defects expected to appear on individual parts of a bridge. The handbook should propose also some standard wording for the description and evaluation of individual damage types. It is advisable to provide such a handbook also in the electronic form, where a defect can be presented with several pictures, which can be continuously updated or added, and the descriptions can easily be modified or amended. Such electronic form can be also a useful training tool for the inspectors.

Condition rating is a suitable quantitative indicator of the bridge condition, especially in case of a series of structures of similar type, like bridges in a road network. It serves for ranking of bridges in the road network as the first step in the planning process of further actions. It should be calculated on a regular basis for every inspected bridge structure, by using mostly data of the visual inspection and results of some basic tests.

Condition rating can be based on

a) simple scoring, i.e. by assigning a more or less subjectively chosen number of deficiency points to the inspected structural member, in compliance with the adopted rules for the classification and evaluation of damages, or on

b) numerical evaluation of a set of selected essential damage types, revealed during regular inspection.

If the second procedure is applied, every damage value should take into account:

- type of damage and its effect on the safety and/or durability of the affected structural member;
- impact of the affected structural component on the overall safety and durability of the whole structure;
- degree or intensity of the damage type;
- extent and expected propagation of the damage type.

Condition rating e.g. of a bridge structure can be

- the worst score or deficiency point, allotted to one of the main bridge component or e.g.
- simply the sum of scores or deficiency points allotted to each inspected component of the structure, or e.g.
- a ratio between the evaluated and a predefined reference condition.

Condition rating serves for

- *primary ranking,* to screen the most deteriorated bridges in a road network or within a road agency, usually bridges with high rating values are commissioned for further in-depth examination;
- determination of the capacity reduction factor Φ,
- establishing the *adequacy rating* of a bridge;
- assessing the tendencies of deterioration processes and providing rough estimation of the expected service life by plotting a regression curve of condition rating values calculated at successive inspections.

6.0 CONCLUSIONS

A review of condition assessment procedures used in some European countries and in the USA is presented in this report. The procedures are demonstrating the practices and experiences with condition assessment in these countries, which should lead to reliable description of the condition of bridge structures. Most of them are presently undergoing a process to improve the techniques of acquiring more and better data about bridge distress and deterioration. Consequently, more exact quantitative condition assessment procedures and decision-making tools can be developed in the frame of Bridge Management Systems.

By computerised BMS the results of condition assessment can be manipulated in several ways. This would include the condition rating of bridges in a network, the optimisation of the available repair techniques and the prioritisation of the candidate bridges with respect to the available funds. Condition assessment data can be further used as input parameters for the evaluation of the load carrying capacity and the safety of the structure.

Although the procedures for assessing the bridge condition differ among themselves regarding the method of calculation, the steps to reach the final result are very similar. They include continuous supervision of the structure by means of several types of inspection, the condition assessment usually based on rating of the essential bridge elements, or on the cumulative evaluation of detected damage types. Such quantitative assessment should consider the intensity and extent of each damage type in relation to the material and the affected element, as well as the nature and cause of the damage.

Some recommendations are made for further development and improvement of existing condition assessment and monitoring procedures which could be used also for the evaluation of the executed repair work. Some recommendations are made also for training of the inspection personnel and for the design of structural details to assure longer working life of bridges.

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APPENDIX 1: Evaluation key for new German proposal

From the matrices the condition rating is evaluated for each classified damage with the respect of Stability (**S**), Traffic safety (**V**) and Durability (**D**).

D=0						
	4	4,0	4,0	4,0	4,0	4,0
	3	3,0	3,2	3,4	3,6	4,0
S	**2**	2,1	2,2	2,3	2,7	4,0
	1	1,2	1,3	2,1	2,6	4,0
	0	1,0	1,1	2,0	2,5	4,0
		0	**1**	**2**	**3**	**4**
				V		

D=1						
	4	4,0	4,0	4,0	4,0	4,0
	3	3,1	3,3	3,5	3,6	4,0
S	**2**	2,2	2,3	2,4	2,8	4,0
	1	1,5	1,7	2,2	2,7	4,0
	0	1,1	1,3	2,1	2,6	4,0
		0	**1**	**2**	**3**	**4**
				V		

D=2	**4**	4,0	4,0	4,0	4,0	4,0
	3	3,2	3,4	3,6	3,8	4,0
S	**2**	2,3	2,5	2,6	2,9	4,0
	1	2,2	2,3	2,4	2,8	4,0
	0	2,0	2,1	2,2	2,7	4,0
		0	**1**	**2**	**3**	**4**
				V		

D=3	**4**	4,0	4,0	4,0	4,0	4,0
	3	3,3	3,5	3,7	3,9	4,0
S	**2**	2,8	3,0	3,1	3,2	4,0
	1	2,7	2,8	2,9	3,0	4,0
	0	2,5	2,6	2,7	2,8	4,0
		0	**1**	**2**	**3**	**4**
				V		

D=2	**4**	4,0	4,0	4,0	4,0	4,0
	3	3,6	3,7	3,8	4,0	4,0
S	**2**	3,3	3,5	3,6	3,7	4,0
	1	3,2	3,3	3,4	3,5	4,0
	0	3,0	3,1	3,2	3,3	4,0
		0	**1**	**2**	**3**	**4**
				V		

Jumps between categories through the use of negative delta values, which account for the influencing variables "proliferation of damage" and "extent of damage" are not permitted. Jumps between categories through the use of positive delta values are only permitted to the start value of the following categories.