A Basic Guide for Bridge Management

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Discussion Paper

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This guide has been prepared as a tool to the management of road bridges in developing countries. It is primarily intended for officials in road authorities who want to set up their own bridge management system (BMS) or to improve existing ones. Specifically, the first introductory chapter outlines the economic and strategic importance of road bridges and the need for adequate consideration and funding of bridge maintenance, and may be of interest to policy-makers and officials in charge of public transport expenditures.
CHAPTER 1

SUMMARY

1. This summary first describes the background and outlines the importance of bridge management, emphasizing that both developing and industrialized countries are currently faced with this issue; then it describes the objectives of a Bridge Management System (BMS) and the contents of the guide; finally, it provides the reader with recommendations on prerequisites for BMS.

1.1 BACKGROUND

2. Bridges represent a significant component of road networks because of their economic value and strategic importance:

(i) in many countries, the number of bridges is very high, and the funds needed for their maintenance, strengthening or reconstruction are correspondingly large. For example,

- in the United States, an estimated US$50 billion would be required to strengthen or replace 200,000 bridges (out of a total number of 574,000);

- on its national network alone, France has registered 6,700 bridges with a span larger than 5 m, and plans to allocate to bridges an estimated annual allocation of US$40 million for 20 years, of which 1/3 is to be spent for routine maintenance of the whole stock and 2/3 for rehabilitation and strengthening of about 25 percent of the stock;

- in Indonesia, about US$450 million was planned for bridge replacement and improvement programs for national and provincial roads during 1984-1989.

(ii) bridges are critical elements in the road system, since bridge deficiencies can disrupt an entire road system, causing considerable inconvenience and costs to users:

- a deficient bridge may not permit trucks to be fully loaded;

- traffic may be interrupted or diverted for quite a long time to allow for repair work or replacement;

- even larger losses, including loss of human lives, may occur when a bridge collapses.

3. In spite of their importance, bridge management and maintenance have been neglected both in developing and industrialized countries, partly because of the long service life of bridges and their supposed durability. Industrialized countries have become increasingly aware of
bridge management issues during the past two decades because a large number of bridges now in their third, fourth decade or even older require rehabilitation or replacement. Consequently, industrialized countries have developed and improved their bridge management systems, as attested by several reviews by the Organization for Economic Co-operation and Development (OECD) (see references [1], [2], [3] and [4]). In developing countries, much of the effort to improve road conditions has so far focused on pavements rather than bridges.

4. Bridge management is important for the planning and prioritization of maintenance and repair works and therefore needs to be emphasized. Developing countries will face growing difficulties in funding future bridge works, considering the often considerable extension of their road networks over the last three decades, the scarcity of alternate routes on which to divert traffic when a bridge becomes impassable, and the continuing increase in truck loadings. Additional resources will have to be directed towards existing bridges. Because of a lack of basic inventory and inspection data, it is not yet possible to give even an approximate estimate of the average time and funding needed by developing countries to make up for lost time in bridge management and maintenance. Based on current expenditure levels, the United States and France need about 20 years to reduce their backlog of deficient bridges. The World Bank's Road Deterioration Paper pointed out the tremendous amount of resources needed for maintaining or rehabilitating pavements, and since bridges are not likely to have been better maintained than roads, we can assume that the time needed will be considerable and that significant increase in bridge funding will be required. It is therefore timely and relevant to use some of the approaches to bridge management from industrialized countries in order to provide developing countries with pertinent guidelines.

1.2 OBJECTIVES OF THE GUIDE

5. This guide aims at providing officials and road managers in developing countries with technical advice on how to set up a bridge management system (BMS) that best meets the country's needs. Only road bridges will be discussed. This section gives a definition of BMS and comments on the basic principles for assessing a country's needs and the use of available resources.

1.2.1 Scope of Bridge Management Systems

6. According to OECD, bridge management deals with activities related to bridges "from their entry into service until their reconstruction" [2], excluding bridge planning, design and construction. Consequently, a BMS is a collection of organizational elements, regulations, standards and procedures set by a road agency to organize, implement and monitor the activities following bridge construction. Road authorities can use a BMS to better comply with stated objectives, the most important being optimum use of available funds, adaptation of existing bridges to traffic needs and public safety.
1.2.2 Assessment of a Country's Needs

7. Assessing a country's needs is of primary importance in order to demonstrate to policy-makers the importance of bridge management and justify the estimated funds required for such a program. Bridges compete for funding with many other structures or transport-related activities; careful assessment of the funds needed for bridges is all the more necessary given their past neglect and because often no budgetary provision was specified for their management and maintenance.

8. A country's needs are assessed by comparing the present level of service of a bridge with the level of service goals. The present level of service is usually understood to be a set of parameters describing the conditions for its safe use. This set basically consists of parameters concerning motorized users, namely load carrying capacity, clear deck width and vertical roadway underclearance and overclearance. However, additional parameters such as adequacy to other users (pedestrians, cyclists, users of non-motorized vehicles, waterway users) or utility companies (power, water, etc.) can also be taken into account. The level of service goals are target values or standards set for the same parameters. They should be established after careful analysis of traffic needs, which may vary considerably depending on traffic volume and weight, road classification and other factors.

1.2.3 Use of Available Resources

9. The objectives of a BMS are basically identical in industrialized and developing countries; thus the recommendations concerning the use of available resources included in the present guide are mainly based on techniques, methods and procedures developed in industrialized countries. But since the major difference between industrialized and developing countries lies in the availability of human, technical and financial resources, the guide focuses on specific approaches for implementing a BMS in developing countries. Such factors as rapid and recent growth of the road network, lack of awareness of bridge maintenance problems, scarcity of technical skills, and absent or inadequate planning and programming procedures may make the implementation of a BMS more difficult and time-consuming in developing countries than in industrialized countries. Also, external assistance, especially for training staff, may be needed to help establish a BMS. Therefore, a BMS should be implemented in progressive steps that are commensurate with the available technical skills and institutional capacity.

1.3 CONTENTS OF THE GUIDE

10. Chapter 2 discusses the Bridge Information System (BIS). A BIS is compiled by gathering and recording bridge data that will help decision-making in bridge management. In order to meet the previously mentioned concerns about efficiency and progressive implementation, the proposed BIS is divided into three subsets, namely (i) bridge inventory; (ii) bridge inspections; and (iii) bridge data files. The first two subsets are collections of organized data, the third deals with data organization, storage, retrieval and analysis.
11. This is a key chapter because the effective implementation of the subsequent tasks described in Chapters 3 and 4 relies heavily on the quality and sustainability of the BIS and the data it contains. Collecting bridge inventory data or carefully and regularly inspecting bridges are not goals in themselves, but tools to reach such major objectives as traffic safety or optimum use of funds for bridges. A reliable and complete BIS is then an indispensable first step. In particular, data from a sound inventory permit to (i) appraise the technical and financial needs for bridge management; (ii) inform and sensitize decision-makers in charge of allocating funds; and (iii) make basic decisions regarding bridge management organization, responsibilities, training courses and final work screening.

12. A major recommendation contained in this chapter is that as a first phase, a subset of bridges located on main routes, or considered vital, or situated within a given district be identified for implementation of bridge inventory and inspections. While the bridge inventory is a rather static element, describing more or less permanent conditions, inspections are dynamic activities covering changing features and thus should be carried out on a scheduled basis. To best establish inspection practices, inspections should be carried out regularly for a few years on a given subset of bridges before considering expanding them to all bridges of the network selected for BMS.

13. Chapter 3 covers Evaluation of Bridge Adequacy according to two main criteria, namely functional adequacy, i.e., adequacy of morphological features, such as width, clearances, approaches, alignment, ride condition; and structural adequacy, i.e., adequacy of structural components, such as foundations, decks, piers, abutments, to carry loads safely. The chapter contains technical considerations on how to compare the present level of service with the level of service goals, and outlines the importance of this evaluation to achieve both safety and economy. It recommends that geometric standards geared to the country be established as a reference against which bridge functional adequacy should be checked. It emphasizes the need for first taking into account bridge overall structural soundness. To evaluate deck structural adequacy, it recommends calculating an inventory load rating, i.e., rating the maximum load that can be safely carried by a bridge deck on a continuous basis, since most structurally deficient bridges were built using old design loads.

14. Chapter 4, Bridge Management Processes, describes the processes following bridge inspections and evaluation, particularly maintenance, repair or reconstruction works. It discusses various means of screening and prioritizing candidate projects for implementation, but only provides broad indications on economic analysis. The uncertainties pertaining to bridge work prioritization should not prevent developing countries from implementing the first components of a BMS, namely the BIS and Evaluation of Bridge Adequacy, which are valuable steps to identify dangerous structures and avoid major accidents. Finally, this chapter stresses that maintenance should be emphasized as the most cost-effective process in the long run.
Chapter 5, Institutional Elements, describes how institutional and human resources can be best used to implement the processes described in Chapter 4. It recommends that bridge management not be separated from road management, but entrusted to the same persons or at least that adequate coordination be ensured. It points out that technical, institutional and human resource issues are often complex and overlapping and should therefore be handled simultaneously when setting up the various procedures described in the previous chapters. It outlines the need for establishing adequate budgetary procedures and entrusting management of bridges of local interest to local authorities as much as possible.

1.4 HOW TO USE THE GUIDE: PREREQUISITE FOR BRIDGE MANAGEMENT SYSTEMS

16. Recommendations included in the guide are general, and should be considered as a check-list of elements to be consulted before making decisions in bridge management. Beyond using this basic guide, there is an obvious need for each country to develop its own adapted set of regulations, procedures and manuals, since the guide does not deal exhaustively with technical issues and refers to documents from industrialized countries; these documents can be used as examples to be tailored to particular needs or sometimes as models suitable for developing countries.

1.4.1 Analysis of External Factors

17. In order to adapt the proposed BMS to each country, the following factors should be analyzed first. This analysis would entail reviewing existing studies or schemes that may be available in various institutions, but not necessarily in the road agency itself:

- **strategic role of road bridges**: bridges can be considered strategic or vital from an economic viewpoint, e.g., if they carry a heavy traffic of basic commodities but also for administrative and political reasons, or simply because they are a unique connection between two areas.

- **geography**: the size of a country is an important element when discussing organizational issues; topography, climate, hydrology and geology have a significant influence on bridge types, sizes, foundations and costs; areas subject to possible floods or earthquakes should be determined.

- **institutions**: the governmental structure of the country, e.g., whether it has a federal or centralized government, affects such issues as the institutional organization of the transport sector, and more specifically, management organization and funding of maintenance work. In some countries, a BMS has already been at least partly initiated; the present guide does not intend to dispute past initiatives, but rather help to improve their efficiency.
- human resources: the availability of skilled engineers, technicians and foremen is of primary importance when determining the level of sophistication of a BMS; the availability of local manpower and domestic consultants and the need for outside assistance should also be checked.

- development level: the term relates to elements such as (i) types of bridge users (motorized and non-motorized vehicles, pedestrians or animals); (ii) traffic levels, both in number and weight of vehicles; (iii) capacity of the construction industry; and (iv) existing national regulations and standards for bridge design.

1.4.2 Definition of the Road Network Selected for BMS

18. After the above-mentioned elements have been analyzed, a definition of the road network selected for BMS should be given. Such definition often depends upon institutional considerations. There is no ambiguity if the road agency in charge is responsible for a given network and wants the BMS to be implemented on the whole network. In some countries, however, there may be a possible choice between a primary (national) or secondary (local) road network, and urban or interurban roads. Various criteria should be taken into account to make a consistent choice. First, traffic intensity appears to be the main criterion to define the network concerned. Some 70 to 80 percent of the whole interurban traffic in developing countries is carried by their main networks. The major risks for public safety as well as the major economic losses when a bridge fails or is temporarily impassable are directly related to traffic intensity. Also roads with vital and strategic bridges, as described above, should be considered. Finally, secondary roads which are likely to be used as diversion routes if major roads become impassable might be added to the network selected.

1.4.3 Definition of Bridges Considered in a BMS

19. Not all structures should be considered in a BMS. The definition of bridges to be included in it is often based on geometric features. The word bridge usually means that the structure has a significant length, as compared with culverts or pipes, and most countries have thus set a minimum length for bridges: e.g., 2 m in France, 5 m in Belgium, 20 ft. (about 6 m) in the United States. These limits aim at defining structures to which a set of guidelines or regulations applies.

20. There is no clear engineering reason to set up a minimum length of 2 m rather than 6 m, and such a threshold should rest preferably on economic considerations, mainly based on:

- the level of technical skills required to build a given type of structure;
- the cost of repair or replacement work of a damaged structure;
- the delay in carrying out such work; and
- the risk associated with failure.
In other words, a structure should not be considered a bridge if it can be replaced using readily available components such as steel or precast concrete pipes, and does not require complicated preliminary studies, specialized skills, or lengthy work. Conversely, structures such as large retaining walls or tunnels, though not bridges, might also be considered in the same management system given their importance and the amount of work, time and skills required to remedy possible deficiencies.
CHAPTER 2
BRIDGE INFORMATION SYSTEM

21. A Bridge Information System (BIS) is a set of data gathered and recorded to help decision-making in bridge management. In order to take account of budgetary, technical and human constraints, the proposed BIS is divided into three main components, which are:

- bridge inventory;
- bridge inspection; and
- bridge data file.

2.1 BRIDGE INVENTORY

2.1.1 Definition and Contents

22. A bridge inventory is a collection of the main administrative and technical data for each registered bridge; these data have a character of permanence, as opposed to those data collected during bridge inspections, which describe the current condition of a bridge at the time of inspection. In addition, some data related to the level of service (see para. 8) are recorded. All the data to be included in a bridge inventory are tentatively listed in Annex 1, which also provides the reader with examples of inventory forms. This guide makes a strong case for attaching photographs.

23. When devising an inventory form, an excessive amount of data should not be collected. An item should be included in a form only if the following two requirements are met:

- ease in data collection: inventory forms should not call for data that cannot be accurately checked by the staff in charge, such as the distinction between reinforced concrete or prestressed concrete girders, or between full or hollow concrete slabs. Rather than including unreliable data, an item should be excluded.

- usefulness: one should bear in mind how the listed data will be processed, for what purpose it has been collected, and how it will be used.

2.1.2 Objective

24. A bridge inventory aims at collecting basic data about the bridges of a defined network for managerial purposes, so as to (i) appraise the financial requirements needed for their management; (ii) inform and sensitize decision-makers in charge of allocating adequate funds, and (iii) make basic decisions regarding bridge management organization, responsibilities, training courses and summary work screening. It does not aim at making engineering decisions regarding an individual bridge; these can only result from bridge inspections and review of original design calculations when available.
25. Some data can provide estimates of funds needed for maintenance and reconstruction of an entire bridge stock. From the total number of bridges and their average deck surface, calculated from their length and total width, the "value-as-new" can be assessed and the "reconstruction cost" of the bridge stock estimated (accurate definitions of "value-as-new" and "reconstruction cost" are given in Chapter 4, para. 125). Assuming an average bridge lifetime, one can thus estimate the average annual amount necessary for reconstruction of the existing bridge stock, and compare the result with present budgetary allocations. Such rough estimates often demonstrate the importance of low cost maintenance works intended to extend the lifetime of bridges.

26. The bridge stock can be classified according to various criteria, such as construction date, total length, type of materials used, carriageway width, available clearance, etc. These classifications help to make decisions related to bridge management in the following fields:

- **maintenance organization**: when there is a significant number of long span, strategically important bridges, and the remainder of the stock is composed of much less costly structures, it may be appropriate in some countries that maintenance of the larger bridges be carried out by a specialized unit, while maintenance of smaller bridges could be performed by agencies usually responsible for maintaining roads;

- **definition of different service levels**: much the same way as service level requirements are different for paved roads and earth roads, so one may consider different management strategies for bridges depending on their construction materials used (e.g., timber or other materials) or the traffic level;

- **list of functionally inadequate bridges**: such a list can be drawn up from various technical data (width, clearances, etc.) and even prioritized according to traffic volume (ADT) and/or detour length, thus making up a first screening of bridges eligible for improvement works, namely widening;

- **list of potentially substandard bridges**: construction date gives information about the design load used at the time of construction, so that one can determine whether the structure is potentially substandard. Even if not substandard, old structures are more likely to entail distress or failure risks, especially if they have not been properly maintained and, therefore, should be given higher priority for inspection and evaluation of load carrying capacity; and

- **contents of training sessions**: at least at the outset, they must focus on the types of structures most commonly encountered and not those which happen to be favored by civil engineering teachers.
2.1.3 Implementation

Procedures

27. For practical reasons, it may be necessary to begin implementing the inventory on a subset of all the bridges selected for BMS, as defined in para. 18. This recommendation is particularly sound when the road network selected for BMS includes all the roads under the responsibility of the road agency and no prioritization has been made when defining this network. In that case, a prioritization should be made at the inventory stage, because it is preferable to have a complete inventory only on a subset of important bridges than partial data concerning the whole collection. This subset of bridges should also be identified on the basis of the criteria listed in paras 17 and 18, e.g.:

- bridges located on routes carrying traffic over a given volume;
- strategic and vital bridges; and
- bridges over a given length or span.

28. The basic contents of a bridge inventory are gathered in the field and are recorded on inventory forms after the structure has been adequately checked. This task can most often be facilitated by preparatory office work. First, the approximate location of the bridges to inventory can be established from existing maps, if they are sufficiently accurate and up-to-date to spot transportation infrastructure as well as hydrographic networks; this helps to minimize travel distance and expenditures. Second, existing bridge data files can be used to fill out some data required in the form. Finally, other data, e.g., traffic data, may be available only in the offices of the local or the central agency. In any case, field work remains necessary, not least because existing files and plans may be inaccurate, or out of date. A field cross-checking of data that have been recorded in the office is absolutely necessary.

29. Iterations are often needed to complete out the inventory forms, since large structures or river bridges do not always lend themselves to easy visual examination of their decks, bearings, piles and foundations. Therefore, the type and size of equipment required to complete data gathering should be noted on the form. Given the need for successive inspections, it may take some years to complete a bridge inventory.

30. After the forms have been partly or completely filled out, they are forwarded to and processed by staff at the central level; copies of the completed forms and any processed results should then be sent back to local staff. Processing the forms includes such tasks as checking the consistency of the data gathered, double-checking them against available files, completing missing data available only at the central level (e.g., possibly traffic data, construction date or reference number) and finally classifying bridges according to various criteria as mentioned above. Information feedback is highly desirable for effective bridge management; it contributes to enhance motivation of local staff.
by showing them that the inventory is not only to be used by specialists, but is a management tool for them also.

31. There is no need for updating the inventory often, since most data it contains are permanent or semi-permanent; nevertheless, procedures should be established to include systematically newly constructed bridges, older bridges that have been strengthened or rehabilitated or when significant changes in traffic counts have occurred. To compile the history of a bridge, new data relating to traffic or work carried out on the structure, should be added without removing previous information.

Personnel

32. Involving local staff in a bridge inventory is important for its successful implementation. While the decision to carry out a bridge inventory is taken by officials at the central level, it is strongly recommended that the central staff rely upon their local staff to complete the inventory forms, rather than entrusting this task to external consultants. Since inventory is the very first task of a BMS and bridge management inspection and maintenance are on-going processes, it is important for local staff to become acquainted with their bridges from the outset. Such commitment is essential, and local staff should clearly be made responsible for implementing the inventory thus ensuring continuity.

33. Delegation of responsibility does not preclude external assistance. Such assistance is always required, even though the data called for may be relatively simple. First, local staff must learn the vocabulary of structural components, how to take bridge measurements such as span length, total length, carriageway width, etc., in order to ensure data reliability and consistency. Second, equipment available locally may not be adequate. However, hiring consultants or renting equipment should clearly involve local staff to ensure that they do not feel as subordinates to consultants or specialists.

34. Selecting staff to implement a bridge inventory is a starting point for the recruitment of personnel who will be involved in further processes, namely inspections and routine maintenance. Each local agency should select candidates among its existing staff and appoint, say, one road supervisor and a few foremen. Criteria for selection are intelligence, motivation and resourcefulness, and also physical ability to perform bridge inspections. Subsequently, this staff would liaise between bridge inspectors and local personnel in charge of preparation work and brush clearing and attend inspections as part of their training. Their knowledge of the conditions of the bridges at different times of the year can then be of great value to bridge inspectors.

35. For a given bridge, the inventory should be carried out by at least three persons; measuring bridge dimensions requires one person at each end of a tape while the third person, appointed party chief, notes down the results. The average time needed to perform the inventory of a bridge varies considerably depending on local conditions and the size
and skill of the party; the time needs therefore to be checked while testing the form or training staff. In particular, the time needed to complete inspection forms, sort documents and photographs, maintain the equipment, and prepare subsequent trips should be assessed.

Logistics

36. In some cases, preparatory work such as cleaning the approaches to the bridge itself or even brush clearing is needed to inspect a bridge or some of its components efficiently. Responsibilities for such preparation should be clearly defined, work carefully planned and adequate equipment supplied. Annex 1, Section B gives a list of basic and special equipment required during bridge inspections.

37. Equipment for recording and retrieving the data gathered is also needed. Computerized processing, for example, will help considerably to perform various classifications of the bridges, e.g., by route, age, length, etc. Considering on the one hand the design lifetime of bridges and on the other the fast pace of changes in computer hardware, the choice of dependable and well-established makes is recommended. This point will be further elaborated in Chapter 2, Section 2.3.

38. Safety is a major concern for the staff in charge of an inventory. Warning signs should be posted, and trucks and other equipment should be carefully parked to avoid danger to road users.

2.2 BRIDGE INSPECTION

2.2.1 Definition and Contents

39. Inspecting a bridge consists in gathering and recording data while checking the condition of its various components. Structures age and deteriorate from the day they are built, due to natural weathering of materials, environmental conditions, and traffic. Bridge inspection aims at following up this aging and deterioration process and recording which bridge components have changed since the last inspection and to what extent.

40. All the components of a bridge should be checked during an inspection: superstructure, substructure and foundations, as well as its surroundings, such as roadway approaches, river or waterway. Nothing should be neglected, because all these elements are important and their poor condition or malfunctioning may entail further damage to the whole structure. A summary review of the various bridge components to be checked during inspections is given in Annex 2.

2.2.2 Objective

41. The data collected during a bridge inspection will be used subsequently to check the adequacy of a given bridge to carry traffic. According to the definitions given in para. 8, this data, together with inventory data, will permit assessment of the current level of service
and comparison with level of service goals, in what is known as Evaluation of Bridge Adequacy. This evaluation is discussed separately in Chapter 3 because it is a further step in the inspection process and is often carried out by staff other than the inspectors. Though bridge inspection includes a quantitative analysis of defects and a subjective appraisal of the potential for further deterioration, it does not include the analysis of the causes of defects.

2.2.3 Implementation

Procedures

42. Several types of bridge inspections can be defined, depending upon the intensity and duration of inspection, the skills of the staff performing the inspection and available logistics. The following classification is drawn from OECD's report on Bridge Inspection [1], and is found suitable for developing countries, provided the contents of each type of inspection are specified:

- superficial inspection;
- principal inspection; and
- special inspection.

(a) Superficial Inspection

43. A superficial inspection is a cursory, informal, unplanned inspection. It may be carried out by any staff from a road agency, whether they have had training in bridge inspection or not, as the opportunity arises, e.g., during road maintenance work. It may also be carried out by road users, riverside residents or inhabitants of a village close to the bridge, who may have a special interest in the bridge. Since it does not involve planning, equipment or specialized staff, a superficial inspection may not necessarily include all bridge components and could be limited to reporting sudden changes and conspicuous deficiencies of a bridge or its approaches. The output of a superficial inspection can be only an oral warning of deficiencies observed, or better a written memo, but without formal presentation.

44. Though not subject to specific procedures, superficial inspection is most important. First, it is conducive to continuous bridge surveillance and timely reporting of serious deficiencies, thus permitting urgent action to be taken and possibly preventing accidents or casualties. Second, it involves a large number of non-specialized staff, thus contributing to overall sensitization; in particular, road supervisors, even if not assigned to bridge inspection, should not limit themselves to inspecting pavements, shoulders and traffic signs, but be encouraged to walk along the bridges and keep an eye on bridge super- and substructures.

(b) Principal Inspection

45. In contrast to a routine inspection, a principal inspection should be planned, formal, exhaustive, and carried out by trained inspectors:
planned: each year, bridges for principal inspection should be selected from a master list, according to their specified inspection frequency. Planning of principal inspections also includes the time of the year for the inspection, personnel and equipment required and preparatory work to be done either in the office (research of documents related to the bridge) or in the field (cleaning and clearing);

formal: principal inspection reports should be produced in writing, according to specified inspection forms. Since inspection reports will be used by engineers in charge to appraise and compare the condition of a number of bridges, and prioritize decisions about them, they should be standardized. An example of a simplified inspection form is provided in Annex 2;

exhaustive: during a principal inspection, all bridge components should be carefully checked, using the necessary equipment. There may be some exceptions, if inspecting some components requires skills (e.g., for underwater inspection) or equipment (e.g., boats or mobile platforms for inspection of bridge soffits or pier caps), that are not available. But as a general rule, bridge inspectors will endeavor to inspect all parts of a bridge and carefully prepare all equipment required. Defects should be described as to their type, location and extent. For damaged areas, sketches should be drawn or photographs taken and precisely identified; and

carried out by trained inspectors: given the requirements of principal inspections, inspectors should be given adequate training in checking bridge components and filling out standardized forms fully and correctly.

To summarize, before carrying out a principal inspection on a selected bridge, a bridge inspector should have previous inspection reports available, including reports from possible superficial inspections, and know a priori:

- what type of structure he is going to inspect;
- what equipment is needed;
- what to check in each bridge component; and
- how to quantify defects related to these types of components.

46. A further distinction can be made between two levels of principal inspections. According to OECD's report [1], "this type of inspection will probably fall into two categories referred to as general and major defined by frequency and intensity. The general inspection will be made at intervals of one to two years... It will be primarily a visual inspection supplemented by standard instrument aids... The major principal inspection will be more intensive and will require close examination of all elements, involving the setting up of special access facilities... The interval between major inspections will vary between
three and five years and may be as long as ten years for elements which have shown little or no deterioration since previous inspections." This distinction between two categories and the frequencies defined are also convenient for developing countries; for instance, a general inspection may be carried out every year by local staff, if previously trained, whereas a major principal inspection may involve bridge engineers from a central office and take place every 5 years.

47. Since principal inspection follows bridge inventory, it should be implemented during a first stage on the subset of bridges selected for inventory (see para. 27), and progressively extended to all bridges selected for EMS. Moreover, bridges in poor or critical condition which are not part of this subset may be identified during routine road inspections or superficial bridge inspections. For safety reasons, such bridges should also be included in the list of bridges selected for principal inspection.

48. The first principal inspection should be given particular attention. If few or no documents concerning the bridge are available prior to the inspection, the first principal inspection usually aims at filling this gap and producing a "zero-status reference" from which subsequent inspections will be organized. This "zero-status reference" should contain a few photographs of all components, indicate which components require specific equipment for inspection, and become a basis from which to draw up an inspection check-list for the future. Benchmarks and tell-tales should be placed whenever possible, for instance, on cracks in concrete structures. For major structures or if the condition of the bridge warrants it, a topographical survey should be made.

(c) Special Inspection

49. According to reference [1], a special inspection is usually made "in connection with unusual circumstances, such as exceptional loading, with occurrence of major weaknesses or with reassessment of the structure against revised specifications or regulations." Special inspections "may require a good deal of supplementary testing and structural analysis and will invariably require detailed involvement of a bridge engineer... The special type of inspection may require supporting investigations of a research if the background information is meagre and the criteria for assessing adequate performance not well understood."

50. This type of inspection is an important element in the process of evaluation of bridge condition. Typically, some defects revealed during a principal inspection may be rated as serious by the bridge inspector. Based on the results of this inspection and assessment of these deficiencies, a summary evaluation is made by the bridge engineer in charge, who may then wish to have a special inspection carried out in order to ascertain particular points, e.g., determine material properties by means of specific testings. After such special inspection has been carried out, its results can in turn be used to refine the evaluation of the bridge condition.
Personnel

51. Since there are many types of inspection and various staff may be involved in each, it is recommended that one person, such as a road supervisor, be appointed locally as a liaison. He should participate to varying degrees in the inventory process (see para. 34) and keep in touch with staff involved in superficial inspections. He might carry out general inspections himself and attend all further inspections involving technical staff such as bridge engineers, divers and specialists involved in special inspections. In short, he ensures that specialists benefit from the knowledge of local staff and nearby residents.

52. As stated above (paras 33 and 45), bridge inspectors should receive adequate training, at least in the following fields (see also Chapter 5, Section 5.2):

- vocabulary related to bridge components and bridge defects;
- measurement of defects and defect progression;
- adequate filling out of forms;
- drawing and sketching; and
- photography.

53. Even when adequate training is provided, external help is often required for principal or special inspections. Great care should be exercised in appointing specialists and in monitoring and coordinating their work. If consultants are engaged, they should have previous experience of bridge inspection, preferably for the same type of structure as the bridge in question. If a special inspection is carried out, supplementary testing is often needed which requires two types of additional skills:

- laboratory-type skills, in order to operate sophisticated testing devices;
- structural engineering-type skills, in order to interpret those test results and use them for structure appraisal and possibly work proposal.

In case these skills are supplied by two different agencies or firms, careful definition and coordination of their tasks is required by the officials in charge, who should not delegate their responsibilities. In all cases, the person appointed as liaison staff (see para. 51 above) should be given notice of any intervention on a bridge and be continuously associated with studies and decisions concerning a bridge under his responsibility.

54. An attitude of openness is recommended towards non-specialized people involved in superficial inspections, since their knowledge of the bridge and its surroundings is often very useful. In particular, people who live close to the bridge, if they are alerted to be observant, often help ascertain how a bridge performs at various times of the year or under various climatic circumstances. Since the bridge is usually of vital interest to them, they can carry out continuous surveillance and even perform minor maintenance tasks.
Logistics

55. The primary tool for bridge inspection is the human eye. Therefore, as for the inventory, there is a strong case for taking a sufficient number of photographs during inspections. Good photographs are of considerable help because they can give a fair idea of the condition of a bridge to engineers who may not be able to inspect all bridges personally. All significant defects should be photographed, and their accurate location reported on sketches or plans.

56. Only after visual inspections have been carried out and defects observed can one contemplate using more sophisticated devices for in-depth inspection. Some of these devices are expensive and require specialized operator skills; others are perhaps less accurate, but can still help considerably during inspections. Annex 2 describes both the more common and the more sophisticated equipment to be used during inspections. However, given the large variety of items to be inspected, one simple and automatic device can not perform a complete bridge inspection, so only partial information can be obtained from each. From this viewpoint, bridges are significantly different from pavements, for which comprehensive information can be gathered by means of automatic instruments, e.g., road roughness measuring equipment. At present, bridge inspection does not lend itself to such automation.

57. The recommendations made in para. 38 concerning the safety of road users and bridge personnel during the inventory must also be followed during inspections. Superficial inspections although cursory and unplanned must not be improvised or carried out casually. The scope of an inspection should always be commensurate with available equipment and compatible with traffic conditions. One should not attempt, for instance, to inspect bridge approaches without boots or at least good shoes; inspectors should make themselves visible and recognizable to road users or police officials, and place adequate posting if necessary. In most cases, it is highly advisable not to carry out an inspection alone, but with at least one colleague. Finally, instructions for use of specific testing devices should be followed carefully.

2.3 BRIDGE DATA FILE

2.3.1 Definition and Contents

58. A bridge data file is a collection of all the data pertaining to the history and condition of a bridge, recorded and classified according to standardized procedures. For a complete bridge data file, all the data related to the bridge since it was designed should be included. Setting up a bridge data file system appears now quite timely for most developing countries, since the process is time consuming, their bridge stock is gradually coming of age and thus needs increased surveillance, and limited resources demand rational planning and prioritization.

59. Booklet n° 01 "Bridge data files" from reference [12] gives a detailed list of the technical data contained in bridge data files which
may be referred to for drawing up a similar list in a given country. These contents are summarized below:

**Design, Construction, History**

**Design Data:** preliminary studies (geotechnical, hydraulic, civil engineering studies); topographical survey; bidding documents.

**Construction Data:** contract documents; complementary studies (geotechnical, hydraulic, civil engineering); as-built drawings, calculation listings; certificate of completion of works; material testing results; site meeting proceedings; construction photographs; reports about possible incidents.

**Maintenance, Repair or Improvement Work Data:** same documents as for construction.

**Zero-Status Reference:** previous documents allow to draw up the zero-status reference, either after construction or after improvement work has been carried out, i.e., the basic condition reference against which a bridge should be checked during bridge inspections. This document also contains practical data as to possible detours if the bridge is impaired, the right-of-way or agreements with utilities for encroachments.

**Bridge Life:** this part covers all events that have occurred since the last zero-status reference; it should contain surveillance, maintenance and inspection reports. Also updated traffic data and reports concerning exceptional events (such as earthquakes, floodings, landslides, etc.) should be included.

60. In addition to these technical data, financial data should be included. Reference [21] mentions only financial data related to bridge construction, and resulting from contracts or final certificates of payments. However, one should also include, as some U.S. agencies do, more detailed data about the cost of subsequent maintenance work, whether it has been carried out by contract or by force account.

2.3.2 Objective

61. The objective of a bridge data file system is to store all data, in order to have adequate information available when needed. All the technical data included in bridge data files are required to make relevant decisions on bridge repair, strengthening or load limitation. Data from bridge inspections give information about bridge condition and therefore are essential to trigger such processes. However they are generally not sufficient for complete bridge evaluation and work proposal, and additional information concerning design, materials used, construction processes or even load history is often required.
62. Careful and timely collection and storage of the technical data in bridge data files avoids costly subsequent research. Bridge data, when not initially stored, may later be no longer available or at least very expensive to acquire, particularly if testing is required. For instance, if no plans are available of the size and location of reinforcement bars in a concrete structure, some testing devices permit to obtain this information but at much higher cost and with much less accuracy than can be obtained from as-built drawings. This holds true for most bridge components and especially for bridge foundations. In any case, such testing is often quite lengthy and may be inadequate if an urgent decision has to be made.

63. Keeping track not only of construction costs, but also of costs of repair, improvement or maintenance work permits to compare the costs of various technical solutions, ascertain which ones have been adequate and then improve the cost-effectiveness of future work. By using a more or less detailed breakdown of maintenance tasks, one can keep track of the quantities and costs of work performed in order to develop a better understanding of the cost-effectiveness of such work. However, such analyses of bridge maintenance costs are seldom made even in industrialized countries.

2.3.3 Implementation

Procedures

64. Since producing bridge data files requires time and patience, bridge authorities who wish to make up such data files should establish priorities among bridges and adapt the contents of data files according to this priority order. From the outset, the data drawn from the inventory may prove useful to list bridges for which a complete file is required, based on such criteria as traffic, length, number of spans and type of structure. For bridges that are not eligible for a complete file, only elements collected during the inventory and bridge inspections, including forms, reports, sketches and photographs would possibly constitute the file; this simplified file should be updated on a regular basis after each inspection.

65. For new bridges meeting the requirements for a complete bridge data file, the file should be prepared as soon as the construction is over. The supply of as-built drawings and documents related to construction should be specified in future construction contracts from the moment a BMS is set up. Procedures should ensure that these documents are forwarded to the officials responsible for bridge management and maintenance and not kept by those in charge of construction.

66. Bridge data files should be preserved carefully. They should not be dismantled by lending or removing some documents for whatever purpose, instead, copies should be made and original documents immediately returned to the data file.
Personnel

67. In order to collect the main data of a bridge data file, and particularly as-built drawings, investigations should be carried out either in the road agency itself or in existing archives, or even among the consultants and contractors who reportedly took part in design and construction. After the list of bridges has been drawn up, collection of existing documents for listed bridges could be done by consultants.

Logistics

68. Maintaining bridge data files is not a rewarding job, since files may be of interest only years or even decades after they have been prepared. It is therefore absolutely necessary that the staff in charge of keeping such files be provided with adequate equipment to perform this task. This equipment includes:

- a properly lighted, furnished and clean office with sufficient space and protection from dust and pests;

- furniture, including shelves of appropriate length for files and racks for vertical storage or, even better, drawer units for flat storage of plans and maps. The latter should never be kept rolled up, as they may become brittle and quite impossible to unroll after some years. Good quality paper for reports and for tracing and film for reproduction of drawings are ways to maintain a bridge data file in good condition. Microfilms should be considered a costly support, sometimes distorting drawing dimensions and requiring careful handling and maintenance to obtain sufficient durability.

- a copier and a blueprint machine possibly shared with other users.

69. To facilitate conservation, it is advisable to concentrate all bridge data files in a limited number of places rather than having them scattered all over the country. Most agencies in both industrialized and developing countries experience frequent changes in offices, building, etc., and archives often suffer during such moves.
CHAPTER 3

EVALUATION OF BRIDGE ADEQUACY

3.1 DEFINITION AND EVALUATION CRITERIA

3.1.1 Definition

70. Evaluation of bridge adequacy consists of (i) assessing the present level of service; and (ii) comparing the present level with level of service goals and estimating the seriousness of the deviation between the two levels. The present level of service of a bridge is understood to be a set of parameters describing under which conditions the bridge can be used safely. The level of service goals are target values or standards set for the same parameters.

71. Evaluation of bridge adequacy is basically an engineering matter and the parameters selected for evaluation are technical ones. It is necessary to have such technical reference parameters available, even though objectives assigned to bridges are sometimes expressed in general and rather qualitative terms, mixing both technical and economic requirements, such as ability to carry traffic loads and vehicles of given dimensions effectively and safely, adequacy as components of a strategic route, economic efficiency, etc. Only after a technical assessment has been made can one contemplate proceeding with an economic evaluation concerning a given bridge.

3.1.2 Evaluation Criteria

72. This subheading describes the basic parameters that should always be included in the set used for evaluation. They fall into two categories or criteria: (i) parameters regarding structural adequacy, mainly load carrying capacity; and (ii) parameters regarding functional adequacy, mainly carriageway width and vertical roadway underclearance and overclearance. Concerning structural adequacy, this guide will also give special attention to overall structural soundness because of its importance, and briefly discuss issues pertaining to estimated remaining bridge life, even though it is less susceptible to engineering evaluation.

73. Each country may wish to tailor its own set of parameters to its specific needs, mainly by specifying which codes and/or standards should be used for evaluation of load carrying capacity, or even by considering additional parameters for functional adequacy. As shown in OECD's report Evaluation of Load Carrying Capacity, referred to in this chapter as OECD's report [3], design codes from industrialized countries vary significantly. Since design codes are often, though not systematically, used for evaluating existing bridges, these differences reflect different design approaches and risks accepted, apart from different axle loads also taken into account (see attached charts in Annex 3). Moreover, countries with specific traffic needs may wish to consider not only motorized traffic, but also pedestrians, cyclists or users of non-motorized vehicles when defining functional standards for bridges.
However, gearing evaluation parameters to a country's needs is closely related to possibly existing national design codes and standards, a consideration beyond the subject of this guide. This guide simply recommends that such codes and standards be established if they are not currently available.

Structural Adequacy

74. This criterion encompasses all parameters pertaining to bridge ability to carry loads. Among these parameters, the load carrying capacity is the most widely considered. It covers more than a simple weight limit: according to OECD's report [3], "two major problems regarding load carrying capacity can be identified. These are:

- the ability of existing bridges to carry road traffic complying with the prevailing motor vehicle regulations on a long-term basis,

- the ability of existing bridges, at least of those bridges located along major roads or trunk routes, to carry an acceptable volume of abnormally heavy vehicles at any given time."

75. The estimated remaining life of a bridge is not often considered as a structural parameter per se, basically because it is not known how to quantify it precisely. It is important, however, since it is related to load carrying capacity. Each load carried by the bridge would consume a small part of its ability to carry future traffic. The heavier and the more frequent the loads carried, the larger the loss of carrying ability, often referred to as fatigue. Consequently, there is a trade-off between bridge loading and its remaining life.

76. Finally, a special emphasis is put on overall structural soundness. Load carrying capacity is mainly related to bridge deck or superstructure. Overall structural soundness concerns the stability of the structure as a whole including substructure and foundations, and usually depends much less on the traffic carried by the bridge.

Functional Adequacy

77. This criterion encompasses all parameters related to the geometric characteristics and signposting of a bridge. They are listed below:

- bridge dimensions: namely carriageway width, lane widths, sidewalk width; clearances (vertical and horizontal clearance above and/or under the bridge, when relevant);

- approach geometry: vertical and/or horizontal alignment and their effects on sight distance; approach width;

- traffic safety signposting: other than related to load limitations, such as speed limitation, clearance, right-of-way in case of one-lane-bridge, stripping, barrier railings, etc.
3.2 IMPORTANCE OF EVALUATION OF BRIDGE ADEQUACY

78. Evaluating bridge adequacy is important for both safety and economy, i.e., for preventive and curative reasons:

- in order to prevent accidents, evaluation is the second most important step after bridge inspection. When bridge deficiencies have been noted, evaluation of bridge adequacy permits to assess if their importance may jeopardize users' life and, if so, to take adequate measures;

- when deficiencies are to be remedied, a sound evaluation permits deficiencies to be precisely evaluated and works carried out accordingly. Evaluation can help avoid costly improvements or reconstruction not strictly required and can, therefore, yield large economies.

79. Each parameter of the evaluation criteria is associated with a certain type of direct risk involved in bridge use. These risks are considerable and from a historical viewpoint, industrialized countries often set up or at least gave renewed impulse to their inspection and evaluation programs after accidents had occurred; this was the case in the United States, after the collapse of the Silver Bridge over the Ohio river in 1967, and in France, after the collapse of the Wilson Bridge at Tours in 1978. These risks are:

- for **structural adequacy**, the risk of collapse, failure and/or impairment and their direct and immediate consequences, such as loss of capital, vehicles and possibly life or limb. Not only are the superstructures involved in bridge structural adequacy, but also substructures and foundations. This guide, therefore, strongly emphasizes the importance of structural soundness. OECD's report [3] mentions that among a review of 143 bridge failures, flood and foundation movements were accountable for about 50 percent of those failures, earthquakes and wind for 10 percent and overloads or accidents only for another 10 percent. The following elements should also be borne in mind: (i) a bridge may be structurally impaired without a complete failure occurring, e.g., because of excessive deformations due to foundation tilt, or settlement, or displacements due to earthquakes; and (ii) brittle failures may occur in steel components. When main components are impaired, they may cause the immediate collapse of a bridge, and are to a large extent unpredictable;

- for **functional adequacy**, the risks related to (i) road traffic accidents, whether they involve vehicles, pedestrians or animals; or (ii) other types of accidents, e.g., insufficient span lengths or poor signing favor accidents involving navigation under a bridge. All these risks are quite significant: the 1978 n°1 issue of U.S. News and World Report mentioned that about 99 percent of highway deaths associated
with bridges are related to geometric deficiencies (poor bridge approaches and lack of adequate signs or signals). These risks also reflect the ability of the bridge to clear traffic with adequate efficiency and speed—large economic losses are incurred when traffic is slowed down or stopped due to inadequate geometric capacity.

3.3 IMPLEMENTATION OF EVALUATION OF BRIDGE ADEQUACY

80. Typically, a bridge engineer in charge of evaluation of bridge adequacy is faced with such questions as:

- What is the maximum safe load authorized on a bridge? What will happen if no load limitation is enforceable?

- Is its condition critical? When is it going to collapse? Can it and/or should it be widened to take account of a particular traffic volume or type?

In attempting to answer such questions, one should bear in mind that not all industrialized countries have a systematic, streamlined rating system of existing bridges and, even for those that do, the figures resulting from these procedures are viewed with skepticism. This is illustrated by two tables and one example of rating calculation (Annex 3) from OECD's report [3]. Rating methods from different countries lead to notably different results. Because of this uncertainty and the technical nature of the problems, sound evaluation of bridge adequacy requires considerable engineering judgment. Given these difficulties, the guide does not provide the reader with a specific evaluation method, but rather gives general recommendations for progressively setting up an effective evaluation policy.

3.3.1 Procedures

Use of Inspections

81. Bridge evaluation requires for bridges to have been carefully inspected in the past. The evaluation process is often linked to bridge inspections, as mentioned in Chapter 2, and the need for good inspections must again be emphasized. To illustrate, a bridge inspector should ascertain whether steel components are badly rusted and should measure the loss in thickness (principal inspection). The bridge engineer should then assess the practical consequences of these defects, e.g., how they affect load carrying capacity and possibly have a special inspection carried out to check the most vulnerable components.

82. Past experience should guide future inspections. For example, if a bridge has collapsed because of scour or flooding, bridge engineers should have other bridges on the same river inspected and evaluated for overall structural soundness. If deficiencies are found in a bridge, other similar bridges built at about the same time should also be inspected and evaluated. Also records of previous accidents on bridge decks should help determine adequate functional standards for given
types of traffic. This \textit{a posteriori} method of assessment relies, however, on adequate information and feedback being forwarded to the engineers in charge.

\textbf{Recommendations for a Two-Step Evaluation}

83. A two-step evaluation should be used in developing countries:

- \textit{first step}: on an emergency basis for the sake of safety, evaluation of bridges which appear to be in critical condition should be carried out following the results of first inspections and/or reports of past accidents. This step should possibly involve local bridge engineers and consultants, or foreign experts as needed. However critical the condition of those bridges may be, they should be used as hands-on case studies in order to sensitize and train staff who will be involved in the second step; and

- \textit{second step}: on a routine basis, in-house evaluation of other bridges should be carried out when the backlog of critical bridges decreases.

\textbf{Rating Systems}

(a) Structural Adequacy

84. \textit{Overall structural soundness} should be addressed first since evaluating load-carrying capacity of bridge decks is irrelevant if foundations and substructures have not been properly checked for soundness. Several rating systems have been developed in order to evaluate the risks pertaining to substructures and foundations. This evaluation is often more difficult and less accurate than the evaluation of load carrying capacity. Unlike decks on which traffic loads are exerted, foundations are invisible, and acting forces cannot be easily duplicated or measured (e.g., earthquakes, loads). However, inspection equipment as well as calculation, can help engineers in this task.

85. As regards risks due to scour and flooding, evaluation methods are described in references [15] and [22]. Their main characteristics are the following:

- they rely on the various inspection techniques available, from the simplest (visual underwater inspection) to the most sophisticated (ultrasonic testing);

- they illustrate the basic difference between inspection and evaluation, since the engineer in charge of evaluation is seldom able to perform the inspection himself. As mentioned in reference [15], foundation capacity analysis is largely an engineering judgment;

- for some types of deficiencies, there is almost no degree or nuance in condition appraisal; according to [15], "in Maryland, once scour of a spread footing is discovered, it takes
highest priority." The risk is deemed high and the damage so unpredictable that no one would take a chance to let the situation continue.

Reference [15] contains a guideline booklet (see excerpts in Annex 5), providing a rating scale for various types of deficiencies. Though these scales are questionable, the guide may be of some help to those developing countries that have reached this stage of development of their BMS or to those who may wish to know what deficiencies to look for when entrusting specialized units or contractors with underwater inspections.

86. As regards risks due to earthquakes, reference [16] provides a seismic rating system; it is comprehensive to the extent that it includes a specific inventory of bridges susceptible to seismic risks and a rating system including both technical and economic considerations, with cost-effective measures proposed to reduce those risks. Developing countries where such problems exist should at least use this reference to ascertain which areas are most exposed to seismic risks and thus warrant more detailed inspections and/or bridge file research.

87. **Load Carrying Capacity.** As mentioned in para. 74, the engineering issue is not simply to set up a weight limit, but to define: (i) maximum vehicle loads for unrestricted use of the bridge, i.e., at any time, frequency or speed; (ii) maximum loads under given conditions of axle loads, axle spacings, speed, wheelpath and/or frequency. Based upon these considerations, some countries consider two levels of evaluation, depending on the frequencies of load application. For instance, the United States uses (see references [10] and [13]):

- an **inventory rating**, which results in a load level that can be safely borne by an existing structure for an indefinite period of time;

- an **operating rating**, which results in the absolute maximum load level permissible for the vehicle type used in the rating.

Developing countries should first aim at adapting their deficient bridges to the bulk of the loads carried and should therefore focus on the inventory rating. If a bridge inventory rating is adequate for most of the loads carried, loads in excess of this rating should not be frequent and could be tolerated within existing safety margins, provided the bridge contains no weak element and, possibly, inspection frequency is increased. This recommendation should lead to acceptable safety levels for most types of structures. Conversely, bridges with inventory ratings insufficient for a significant part of the loads carried should be given higher priority in subsequent work programs. Again OECD's report [3] contains a review of rating systems available in a few industrialized countries, U.S.A., United Kingdom, Norway and Canada. More detailed technical information on how to establish the previous ratings is also available in reference [10].
In addition to the need for inspections outlined above, detailed traffic data may also be required to improve bridge evaluation. Specific traffic surveys are called for when heavy trucks represent a large part of the total traffic, e.g., for bridges located in forest areas and used by heavily loaded timber trucks.

Several different methods are available: (i) re-calculation; (ii) full-scale load testings; and (iii) vibration testings (see reference [6]). However, no one method can be applied to every type of structure, and it is obviously necessary to take into account the specifics of each bridge. Roughly, two steps can be identified in the evaluation process when recalculating a bridge:

- first, evaluating the effects of traffic and environment on the main structural members. In other words, one has to appraise the strength of bridge critical components required to withstand estimated forces and environmental parameters acting upon a bridge deck. This step leads, for example, to the assessment of bending moment at midspan of a main girder, or tension force in the lower chord of a steel truss;

- second, evaluating whether these components are actually able to resist these effects, given material properties and actual geometric parameters checked during component inspection.

For the first step, the following recommendations are given:

- design codes and standards of various industrialized countries have their own internal consistency. This makes a strong case for avoiding mixing different codes, e.g., taking into account live load and impact factor prescriptions from one design code and allowable stress from another. This recommendation applies particularly to those countries that do not have national codes available;

- effects of various load factors mentioned above need not be systematically compounded in all cases. Temperature effects should be taken into account only for those structures that, based on previous experience, are likely to be affected (for instance, for statically indeterminate structures). Priority should be given to the assessment of those effects resulting from the most probable actions. As mentioned in reference [23], "for the combination of actions, the probability of simultaneous occurrence of unfavorable values of several independent actions is reduced, in accordance with J.C.S.S. and ISO documents. For instance, it would be unreasonable to combine the heaviest loading with the strongest wind action."

- great care should be exercised in assessing the actual behavior of the structure, which may differ significantly from the initial design, due to oversimplified design assumptions, poor workmanship and/or behavior changes caused by
inadequate functioning of bridge components. Assessing such changes remains undoubtedly the most delicate part of the evaluation process, requiring experience and engineering judgment. On the whole, required strength cannot be determined with the same level of accuracy for all bridge types. Actions in simple structures, with statically determinate spans, are less serious and far better known than in more complex ones, such as skew bridges, statically indeterminate structures, box-girders, etc. The following examples should illustrate the point:

* bridge design is often carried out by considering various bridge components separately and neglecting their potential interactions; this is the case, for instance, for concrete slab on steel girders, either when unintended composite action occurs or when intended composite action fails;

* lateral distribution of loads may be different from the one assumed in design;

* improper functioning of bearing devices may induce friction forces often reaching significant intensities;

* foundation settlements can cause considerable changes in longitudinal distribution of loads and bending moments of statically indeterminate structures.

91. For the second step the following recommendations are given:

- one should use all available information to determine the actual material properties and characteristics of the bridge component under study. One should not be satisfied with using either design specifications or even "as is" results of tests made at the time of construction, because material properties may have changed since that time for better or for worse:

* for better: strength of sound concrete in the presence of moisture usually increases over time; this increase should be allowed for in the recalculation. Also, the knowledge of past behavior of a bridge can sometimes be used to update material properties (see reference [14]): if a bridge has proven able to carry a known traffic volume for years without apparent damage, this information can be used to upgrade material properties, on the basis of estimated conditional probabilities;

* for worse: thickness of steel components is often reduced by rust, and corresponding losses in cross-sectional area and moment of inertia have to be assessed. Past overloads may have caused fatigue and loss of strength, but this point is much more difficult to assess. As mentioned in
OECD's report [3]: "most countries do not rate the bridges for fatigue loadings. A few make allowances for repetitive loads by some stress reduction in certain main members subjected to stress reversals, ...the magnitude of this reduction... depending to a large extent on the judgment of the rating engineer."

92. **Estimated Remaining Life** issues related to material fatigue, i.e., to loss of strength over time due to repeated stresses, are increasingly being addressed by many industrialized countries, and notably the United States. But this approach is not appropriate to all types of structures, especially since metal bridges are affected, along with bridge structural components on which low dead load stresses, together with comparatively significant cyclic live load stresses, are exerted. Moreover, for an individual bridge, remaining life is not a fixed quantity, but strongly depends upon further surveillance and maintenance actions to be taken as well as future traffic. Ongoing work in the United States (see reference [13]) reviews practices and studies related to bridge lifetime assessment. The latter rely heavily on statistical studies of available historical records. However, they basically take into account surviving bridges, and therefore introduce a bias in lifetime evaluation. Finally, due to a comparative lack of historical records and to bridge populations often smaller and more heterogeneous in design standards than in the U.S.A., such studies cannot be easily duplicated where good inventories and bridge data files often are not available. Nonetheless, the issue is of major importance for the technical and economic evaluation of alternatives and priorities.

93. **Functional Adequacy**

It is recommended that developing countries should establish their own geometric design standards for road bridges as part of general standards for their road networks, as the best way to achieve consistent and homogenous requirements for a given class of road. In order to make evaluation of bridges more systematic, it is also recommended that a range of standards be defined, e.g., absolute minimum, acceptable and desirable standards by striking a fair balance between the country's present and long-term predictable needs. Risks related to bridge functional adequacy pertain to both the bridge itself and users' behavior. Concerning the bridge, it should provide at least the minimal geometric dimensions to allow users to cross; as to the users, their behavior is all the safer if they know the particulars of the bridge. This implies that characteristics along a given route should be homogeneous to avoid misuse, poor visibility and inconsistent behavior. Specific width standards should be established for bridges, particularly in those countries where road traffic is mixed and includes not only motor vehicles but also large quantities of animal-powered vehicles, cyclists or pedestrians. Also approach characteristics should be given attention. Reduction in carriageway width may be acceptable if sight distances due to good vertical and horizontal alignments, control of vegetation around the bridge, and posting are adequate and allow road users to adapt their speed to current conditions.
3.3.2 Personnel

94. Evaluation of bridge adequacy is basically a task entrusted to bridge engineers. As for special bridge inspection, various types of skills are often required to address the technical issues involved. Even if not sophisticated, tests have to be carried out by competent and trained agency or laboratory personnel in order to get useful and reliable information. Structural analysis should be entrusted to agencies or consultants who know the type of structure concerned well and are conversant not only with design of new bridges, but also with evaluation of existing ones. In fact, the latter requires much more engineering judgment and experience and involves less standardized procedures than bridge design. References should be carefully examined when hiring consultants for evaluation purposes, because some may feel comfortable with design techniques but reluctant to evaluate existing structures.
CHAPTER 4
BRIDGE MANAGEMENT PROCESSES

4.1 DESCRIPTION OF PROCESSES

95. Three types of management processes can be identified:

- regulatory processes, namely bridge posting and permits for exceptional vehicles;
- reinforced surveillance;
- works, which can in turn be subdivided into the following categories: (i) maintenance works; (ii) repair and rehabilitation works; (iii) improvements (either functional or structural); and (iv) reconstruction or replacement.

4.1.1 Regulatory Processes

96. Bridge posting gives road users notice of the present level of service of a bridge, and therefore applies to either structural or functional parameters, mainly authorized load, speed limit, bridge width, right-of-way on one-lane bridges and vertical clearance. The need for posting should be assessed from the evaluation of the adequacy of each bridge taking also into account the need for homogeneity along a given route. Load carrying capacity, assessed according to a procedure similar to the U.S. inventory rating, should be posted if such capacity is smaller than the maximum load authorized by national regulations. Speed limits should be displayed in an effort to diminish the impact factor of vehicle loads on a structure already deficient because of excessive loads or local deterioration. Exceptional vehicle permits should be granted to vehicles with exceptional loads or dimensions only after careful evaluation of an operating or similar rating.

97. Decisions to implement regulatory processes, particularly load limitations should be guided by a realistic assessment of compliance and enforcement. In industrialized countries, these processes cannot be considered absolutely effective. Although industrialized countries have been faced with a considerable increase in requests for exceptional load permits over the last 20 years, compliance with load limitations is far from satisfactory. According to OECD's reference [3], "... in some areas, up to 40% of freight vehicles do in fact exceed these limits and this, to an overwhelming extent, without legal permits." In developing countries, enforcing bridge regulations may pose even more problems because there are often no alternate roads for diverting traffic. Therefore, regulatory processes should be systematically developed only as and when bridge adequacy can be considered as satisfactory on the main routes and possibilities to divert traffic from inadequate bridges actually exist. In particular, setting up a permit system for exceptional vehicles will be at best ineffective and at worst an additional bureaucratic hurdle if the procedures are not credible, i.e., a road agency must be able to grant a permit within a rather short time and its decision must be based upon sound engineering analysis.
98. Special devices can be used to enforce traffic restrictions on bridges: bumps on the road surface for speed reduction or dolphin-like devices (made of concrete, steel or both) for access restriction based on vehicle width. Such devices are, however, rather aggressive and may entail costs to users or be vandalized; they should be set up only if highly justified by bridge condition. To be effective, all these devices or sign posts should be carefully maintained and cleaned.

4.1.2 Reinforced Surveillance

99. This process consists in carrying out frequent inspections of deficient bridges, on a continuous basis, in order to analyze whether the deficiencies are worsening, or developing in cycles, e.g., under temperature changes, or have stabilized. Reinforced surveillances are similar to those carried out for major principal or special inspections and are focused on precise points related to the deficiencies; however, surveillance frequency is much higher (say, every month, week or even continuous), depending on the seriousness of the deficiencies. For instance, checking of crack width in structural components, topographical surveys or more sophisticated measurements can be carried out during reinforced surveillance.

100. Reinforced surveillance allows close monitoring of the evolution of deficiencies over time, and taking actions such as bridge closure if specified thresholds are exceeded. It is a cost-effective, basic way of limiting risks on deficient bridges and ensuring public safety under budgetary constraints. This process can be used either separately from or together with other initiatives, such as speed or load limitation (see above) or temporary strengthening work (propping falsework, centering, etc.).

4.1.3 Bridge Works

101. Bridge maintenance and rehabilitation is a lively topic in industrialized countries. Many seminars and conferences are held yearly on this subject so that it is impossible to draw up a complete and up-to-date list of all available references. OECD's reports on Bridge Maintenance [2] and Bridge Rehabilitation and Strengthening [4] provide the reader with a review of the state-of-the-art techniques in industrialized countries; the Road Maintenance Handbook (5) also gives simple and practical advice mainly for maintenance works, with special attention to timber bridges. The French Technical Guidelines for Bridge Inspection and Maintenance [21] give more detailed technical information on routine or specialized maintenance activities for each particular type of structure. One can also refer to the proceedings of the International Conference on Inspection, Maintenance and Repair of Road and Railway Bridges [6].

102. Bridge works can be divided into four main categories:

- maintenance works;
- repair and rehabilitation works;
- functional or structural improvements;
- reconstruction or replacement.
These terms are briefly defined below and the relevance of the most usual definitions is discussed. The remainder of the chapter mainly focuses on maintenance works. Maintenance is the most cost-effective yet little practiced activity and because it can help reduce future costs is of particular value in developing countries. Replacement and reconstruction of bridges will not be elaborated upon, since corresponding techniques are more related to bridge design.

Definitions

103. Maintenance is defined by OECD’s report [2] as "the work needed to preserve the intended load-carrying capacity of the bridge and ensure the continued safety of road users. It excludes any work leading to betterment of the structure, whether by strengthening to carry heavier loads, by widening or by vertical realignment of the road surface." However, since maintenance is usually understood as a task that neither requires too many resources nor causes much inconvenience to road users for an extended period, this guide supplements this definition as follows: activities of limited scope and cost that aim at maintaining the initial level of service of a bridge. For instance, replacing the concrete slab of a bridge deck meets OECD’s definition, yet is not consistent with the common understanding of maintenance. Maintenance activities are sometimes subdivided into further categories, such as routine, periodic, preventive or corrective maintenance.

104. Repair and rehabilitation activities also meet OECD’s above definition for maintenance, but are larger in scope and cost than maintenance. Repair and rehabilitation are carried out when the current condition of a bridge differs, respectively, moderately or significantly from its initial level of service. These activities are more expensive than maintenance and often cause significant costs to users; because bridge closure may be needed for a few weeks or even months.

105. Improvement works aim at upgrading the level of service of a structure; the basic parameters taken into account in such improvements are:

- load carrying capacity;
- geometric parameters (carriageway or sidewalk width, vertical clearance, sometimes also vertical alignment).

106. Replacement or reconstruction works are carried out when the whole structure, or at least large components such as a whole superstructure, are removed and replaced.

107. In addition to magnitude and cost of work, other criteria such as work schedule or entity performing the work are sometimes taken into account to categorize bridge works, which further blur the distinction between categories. Each country should properly define works especially when contemplating using definitions to set up a particular type of organization, procedures, financing or procurement. For instance, the installation of expansion joints or bearings when they did not previously exist or their replacement by more modern or adequate components
might be considered an improvement; however, this guide recommends that work concerning joints or bearings be considered part of periodic maintenance, because these components generally have a shorter lifespan than the whole structure and will normally have to be replaced several times during the life of bridge.

**Implementation of Bridge Maintenance, Repair and Rehabilitation**

(a) Personnel

108. The work processes described above can be entrusted to various entities, typically either governmental agencies or private contractors. Institutional issues will be discussed in Chapter 5. Whatever the choice, the following requirements should be emphasized from a strictly technical angle: stability in staff responsibilities, expertise in work evaluation and safety in work implementation.

109. To the largest possible extent, the same staff should be entrusted with a number of tasks on a regular basis. These tasks possibly include routine maintenance of a bridge and its approaches and certain periodic maintenance activities, such as spot painting of steel components, repair of non-structural parts (e.g., parapets) or replacement of damaged timber planks on timber bridges. Chapter 2 has emphasized the importance of superficial inspections; having maintenance done and supervised by the same staff permits to customize maintenance activities, and ascertain possible changes of the structure and the effects of previous maintenance or repair activities. If possible, the same staff should also participate in major works implemented on the structures they personally know.

110. Complex activities often require hiring more specialized staff. Maintenance, repair or rehabilitation work should be carried out on the basis of accurate previous evaluation, and not by merely transferring techniques that were used in other apparently identical cases. For instance, if a crew from a road agency knows how to repair spalled parts of a concrete parapet with exposed reinforcement bars, the same technique may not be appropriate when similar defects appear on a structural beam. Also private contractors who have developed specific techniques may tend to propose using systematically the full range of their techniques; only a technical expert can determine case-by-case whether the whole or part of the package proposed, meets the technical requirements. When devising a repair or strengthening project, not only must the structural analysis be carried out in advance, but also the analysis of the structure after work has been completed and possibly during the intermediate stages. Evaluation of the materials constituting the initial structure, of additional products used, as well as their compatibility is required (particularly when adding metallic components, or paints, chemical products or resins for injections to an existing structure).

111. Great care should be exercised to avoid hazards to road users during the implementation of any kind of work. Since maintenance and repair work aim at reducing potential risks to the structure and to road
users, those risks should not be increased by poor signing, inadequate or dangerous equipment (temporary falsework, scaffolding, etc.) or insufficient structural analysis of transitory stages of the structure.

(b) Cost Estimates

112. When inviting tenders from specialized contractors for bridge repair or strengthening, alternative proposals should be permitted, because a contractor may have specific equipment available, and therefore propose slight adaptations, or want to use specific products to be able to guarantee work. This holds true even if the road authority has designed the project in order to better control the technical quality and costs and avoid expensive proposals such as bridge replacement.

113. It is recommended that arrangements be made to allow for possible extension of work or quantities if technically justified, both at a budgetary level and in contract documents. The number of tasks may have been precisely determined, particularly if the project is relatively simple, or has been analyzed in detail, with well-known cost elements. In that case, costs can be estimated accurately. However, as often happens in repair or rehabilitation projects, some work quantities are little known or subject to extensive changes, due to the technical nature of the work; for example, when components have to be removed or demolished, one does not always know precisely what will be found underneath, or the respective proportions of defective and sound materials; another example relates to quantities of resins for injection into cracks that cannot be appraised, even by an order of magnitude. In these cases, costs are much more difficult to estimate.

(c) Three Basic Technical Recommendations

114. Water should be systematically removed from every part of a structure. Most routine maintenance activities such as cleaning of decks, sidewalks, joints, gutters and roadside channels and removal of vegetation contribute to accomplish this objective. Routine cleaning is inexpensive and effective, and should be practiced in developing countries. More sophisticated maintenance or repair techniques also aim, in part, at preventing water from seeping into bridge components where its action alone or combined with other elements might accelerate the deterioration process. Among these techniques are replacement of expansion joints, restoring of masonry or brickwork, sealing or repair with cement or resin mortars, waterproofing using bituminous materials, painting to protect steel against corrosion, restoring concrete with protection of re-bars, etc.

115. Maintenance of foundations should be given particular attention. According to [2], foundations "are constantly subject to the effects of water currents, scouring, impacts of objects transported by the waters and, in some countries, ice." As outlined in Chapter 3, para. 79, these are the main cause of bridge collapse. Reference [2] describes several methods available to control erosion effects. Among those described, the use of gabions in order to protect banks and break currents is widely used; though they are difficult to lay at great
depths and require that suitable rocks be available locally, they offer a convenient solution in developing countries because they are labor-intensive, with small foreign exchange cost. Similar materials can be used to build riprap around the piers as a good preventive and sometimes corrective measure against water erosion. Reference [22] gives sound advice on these matters.

116. **There should be no improvisation in maintenance or repair work.** If work is carried out without previous analysis of defects, using inappropriate materials, or without taking into account structural stability during the work, it may do more harm than good; in fact, it could mask on-going deterioration and thus prevent its detection, or even endanger workers or road users. Final repair may ultimately be even more costly than the damage maintenance tried to prevent. This is particularly true of foundations in water: repair work has to be carefully designed in order to avoid possible ruin of the structure. It is imperative to consult experts before undertaking repair of damaged foundations. Some repair techniques of foundations are described in reference [4]; they often involve materials and equipment that may not be always available in developing countries.

**Improvement Works**

117. It is only through effective inspection and evaluation that the need for improvement work can be ascertained. According to OECD's report *Bridge Rehabilitation and Strengthening* [4]: "the increase in traffic, both in terms of volume and load, as well as greater requirements on the part of road users and socio-economic constraints, are all factors which may necessitate bridge improvement. The increase in traffic loads may require a corresponding increase in load-carrying capacity which must be ascertained (cf.[3]); this involves strengthening. The need to adapt to actual vehicle dimensions may call for improvements in bridge clearance. Growth of total traffic carried by the bridge may require widening; it may prove necessary to add new load-carrying elements or strengthen existing ones. An increase in heavy freight vehicle traffic is liable to cause fatigue and the bridge must be safeguarded against this risk. The need to improve traffic conditions may require alterations in bridge geometry (improving road alignment with possible repercussions for bridges)."

118. The OECD report [4] continues, "Widening of an existing bridge could be done in two different ways; if the existing piers have sufficient load bearing capacity, the new wider superstructure may be supported by them on widened abutments. Otherwise the new widened superstructure has to be supported on extended piers and on extended abutments; the problem of possible differential settlements between the old foundations and new ones has to be given due attention." Techniques applied in order to increase load carrying capacity more and more often use supplementary post-tensioning (in concrete or prestressed concrete structures), additional stiffeners, or diaphragms added to structural members in steel structures; therefore they also require careful expertise, design and workmanship.
119. Some developing countries have already implemented important programs of bridge improvement. For example, in Mexico, concrete bridges built on average around 1948 were widened between 1971 and 1973, most often by widening existing piers or abutments, and adding one or more concrete T-beams to allow for wider carriageway and new sidewalks. Two other techniques have also been developed in Mexico, both using steel: the first consists in splitting truss bridges longitudinally into two parts, replacing floor beams by longer ones and strengthening the other parts, thus providing wider deck; the second consists of using tridilosas (tridimensional tubular steel girders), which support the widened part of the deck irrespective of the initial type of structure. It is worth noting that using prefabricated components for widening allows a reduction of falsework, shortens work duration, and altogether reduces costs.

4.2 SELECTION AND PRIORITIZATION OF PROCESSES

4.2.1 Scope of the Problem

120. For a given bridge, a whole range of technical options may be considered, for instance:

- doing nothing;
- regularly maintaining the bridge;
- posting (e.g., load limit restrictions);
- keeping the bridge under reinforced surveillance;
- repairing (without structural improvement);
- strengthening; and
- rebuilding.

These options obviously differ considerably in cost and efficiency. Moreover, the total cost of all desirable processes generally exceeds by far the funds available to a road agency. The theoretical solution is therefore to select and prioritize the processes that should be financed with available resources for a given period, generally a fiscal year, after the various options have been listed for each bridge and their costs assessed. Selecting the processes means that both the candidate bridges and the processes for each of these bridges are selected. Prioritizing the processes means drawing up a list of the selected processes and selecting bridges from the top down until available funds are exhausted.

4.2.2 The Economic Approach

121. In order to carry out an economic evaluation, one should be able to determine:

- the lifetime of each option or the extension in bridge lifetime gained which enter into the economic evaluation of the alternatives;

- the costs and benefits attached to each option. The benefits of an improvement (or of maintenance at time t) consist first of the user cost savings for the transit over the bridge, or,
when the bridge is improved to take wider or heavier loads, by the user cost savings for the entire, i.e., the average, trip. Where the unimproved bridge constitutes a real impediment to transport by trucks above a given size or weight common in the region's traffic, part of the benefit will consist of the saving in the user cost of transporting a given volume of traffic by larger (heavier) rather than those carried by lighter trucks. A second component of the benefit consists of the agency's savings from carrying out the work at time t rather than undertaking heavier repairs later. In each case, the savings should be counted over bridge life, and discounted to the present. The costs are those incurred by the agency from the improvement, repair or maintenance measure under consideration.

- The economic decision is then arrived at by computing net present values, using the discount rate accepted for public projects. In the simple case of one particular improvement or maintenance measure compared with doing nothing, the intervention should be accepted in principle if NPV (discounted benefits over life minus discounted costs over life) is positive. (If the decision criterion is the internal rate of return, the intervention is accepted if that rate equals or exceeds the public authorities' target rate, or the rate at which they can borrow.) When several "incompatible" options are compared (including the option of doing nothing at time t) an appropriate method is to find the option that gives the minimum present value of costs to users and agency, over bridge life: user costs for the average trip (weighted by length and loads) plus agency cost of present and future works. The least cost solution is then tested for sensitivity to timing of the works by comparing it with a broadly similar operation in year (t+1). (This is a rough rule. In principle, all the options should be tested for the effect of timing.) If the present value of cost rises through delay, the minimum cost option (time t) is then compared with the zero option (doing nothing) to compute a NPV. If positive, the option is economically preferred. The obvious alternative is to compute NPV for each option, and accept the highest value if it is positive.

**Agency Costs**

122. Assessing agency costs is often more difficult for bridges than for roads, due to the large variety of materials, techniques and components used in bridge construction, and the high degree of expertise required. Moreover, the agency cost of replacing some bridge components is often considerably higher than their cost at the time of construction, so that replacements often require a careful analysis on a case-by-case basis. This is particularly true for expansion joints and bearings.
User Costs

123. For bridges, the user costs taken into account are accident costs, vehicle operating costs (VOCs), and travel-time costs. According to the World Bank, trip VOCs are deemed the largest component of road user costs. This probably holds true for bridges as well as for roads since in developing countries road networks are often limited and any bridge impairment may cause long detours and consequently large trip VOCs. However, VOCs on bridges differ from VOCs on roads. For roads, VOCs increase continuously over time as road deterioration proceeds gradually, so that the deterioration process can be satisfactorily described by a few parameters. For bridges, a distinction should be made depending on functional adequacy:

- if a bridge is not functionally adequate, part of the traffic is prevented from using it, which increases trip VOCs through detours;

- if a bridge is functionally adequate, or when one considers only the traffic that actually uses a functionally inadequate bridge, the increase in actual VOCs does not seem to be directly affected by the bridge deterioration itself, as long as the bridge remains passable. Except possibly for timber bridges, vehicle speed does not appear to be significantly reduced by deck or joint deterioration. But expected VOC increases as deterioration progresses because of the higher probability of detours and losses to life, limb and assets.

124. The probabilities of the various risks that enter into expected costs are difficult to estimate particularly because a large variety of unpredictable causes such as floods or earthquakes may entail a bridge collapse. A bridge may also be temporarily impassable due to administrative decisions or simply repair work, which in turn may be caused by poor design, workmanship or previous maintenance. Measuring the probability of all these factors calls for considerable engineering expertise and carefully recorded and analyzed experience.

Trade-offs between Agency and User Costs

125. In most cases, there will be possible trade-offs between agency costs and user costs. By setting up a temporary structure for all or part of the traffic, one can avoid inconvenience to users and detours. More expensive prefab techniques can shorten the time to completion of the work. The "value-as-new" of a bridge (see Chapter 2, para. 25) refers to the cost of replacing a given structure by an identical one, without the additional agency costs that tend to arise, but which have to be added to the "value-as-new" to make up total reconstruction costs. In some cases, these additional costs can be of the same order as the "value-as-new."

Bridge Lifetime

126. Different bridge components have different lifetimes, but average bridge lifetime is longer than road lifetime. Economic evaluation
is therefore more difficult. The prediction of time to failure has also to take account of the effects of posting, maintenance, repair and/or strengthening of different components of a bridge and of its approaches. Maintenance—or the lack of maintenance—of non-structural components such as expansion joints, bearings and drains can have dramatic effects on structural components and therefore on the lifetime of the whole structure.

4.2.3 The Experience with BMS in Industrialized Countries

127. OECD's reports [1], [2], [3] and [4] have reviewed the various bridge management practices of industrialized countries. These practices have been developed considerably in some of these countries since the first report dated 1976. Three examples are described in Annex 4, concerning Denmark, France and the United States. For each country, the institutional context is briefly explained, and the process selection and prioritization methods in use are explained.

128. In spite of a progressive shift towards a network level approach, decision-making concerning selection and prioritization of bridge management processes remains widely based on a case-by-case approach of individual bridges, i.e., relying heavily on inventory, inspection and bridge adequacy evaluation. When the 25-year period of major bridge construction in the industrialized countries came to an end around 1975, maintenance of the existing stock took precedence and was often triggered by spectacular bridge accidents. The first approach to bridge management remained basically focused on individual bridges. However, the scale of bridge management issues changed progressively, the financial aspect became of primary importance since funds available for maintenance or rehabilitation, even if constant over time, could hardly solve the problem within the next 20 years. Moreover, the industrialized countries were often faced with significant budgetary cuts and had to seek streamlined methods for cost-effective spending of available funds. Consequently, a second approach is progressively being developed, reflecting a growing interest in an assessment of bridges at the network level.

129. Due to the difficulties of the economic evaluation, selection and prioritization processes involve most often a high degree of subjectivity and/or engineering judgment. France relies heavily on engineering judgment of bridge experts, whereas the United States uses a formula which aggregates all sorts of data acquired through inventory, inspection and evaluation processes.

4.2.4 Recommendations for Developing Countries

130. Developing countries should not shift too hastily from the case-by-case approach towards the network level approach. Even in a sophisticated BMS, there is simply no way of escaping basic tasks such as bridge inventory, inspection and adequacy evaluation. The United States can develop BMS only because it can rely on satisfactory practices at the individual bridge level. The basic tasks that have been listed are valuable steps to identify dangerous structures and avoid
major accidents. The statistical data required for a network level approach emerge only after these tasks have been implemented for a number of years.

131. During the first stages of BMS implementation, many developing countries will have to rely on a case-by-case approach to selecting bridges for priority financing. Although some industrialized countries rely only on engineering judgment to select and prioritize bridge works, developing countries may wish to set up more systematic processes for this purpose, namely in an attempt at maximizing the utility of public expenditures. Until selection and prioritization processes have been improved and adapted to the specificities of bridges, two methods can tentatively be suggested:

- using ranking formulas basically similar, but possibly simplified to those used in the United States, i.e., aggregating level of service criteria (see reference [12]);

- using an economic evaluation of the benefits yielded by various alternatives and maximizing these benefits under budgetary constraints, i.e., for the funds available to a given agency. A detailed example is given in reference [13].

Both methods call for accurate data collection, which implies that the BMS must have reached a certain degree of development. Neither method can currently be considered satisfactory. The first will require political adjustments to define adequate coefficients and the economic benefits of the priority order may be questionable; the second will require rules of thumb or engineering judgement and its forecast of remaining bridge life and extension of service life by work alternatives may also be very questionable.

132. The chief conclusion is that the prioritization as suggested in Chapter 2 for inventory and inspection processes is mainly based on the selection of main routes, according to their traffic volumes. Any type of work carried out on a comparatively highly trafficked bridge is likely to yield significant savings in VOCs. Consequently, deficient bridges on these routes should be registered and selected for future work.
CHAPTER 5
INSTITUTIONAL ELEMENTS

5.1 PROCEDURES AND RESPONSIBILITIES

5.1.1 On-going Procedures of a BMS

133. Procedures should focus on the schedule of tasks. The following description of a working BMS shows that proper and timely monitoring of funding, inspection and execution of works require great care. It is therefore necessary to set up realistic deadlines for all of these tasks and provide versatile mechanisms for possible substitution of works, if for any reason those to be implemented under established priorities cannot be carried out.

134. The following bridge management activities should be undertaken each year:

- **bridge inventory**: update of existing inventory. Since the data have a permanent character, the forms will need updating only after a number of years. However, procedures should be set up for systematically (i) adding inventory forms for newly constructed bridges; (ii) discarding inventory forms of old bridges when they are taken out of service; (iii) modifying inventory forms if work has been done the previous year; and (iv) adding missing data as and when they become available through inspections;

- **bridge inspection**: general, major principal and/or special inspection of bridges programmed for inspection, using either in-house personnel or external consultants and laboratories. In the latter case, actual start of inspection may depend on fund availability if a contract has to be awarded before inspection. In both cases, inspections should be carried out within a specified period, taking into account such conditions as water level for foundation inspection, road passability, equipment availability, seasonal traffic volume, etc. Procedures should ensure that adequate time is allowed for the inspections;

- **routine maintenance**: cleaning and brush clearing, possibly linked with similar road activities, and other routine bridge maintenance activities as described in Chapter 4;

- **repair work carried out by road agencies, contractors or hired lengthmen**: these are ad hoc tasks, depending on funds for trips, fuel, materials, etc. made available in due time;

- **major repair, rehabilitation, strengthening or replacement work**: entrusted to private companies as appropriate funds are available and when adequate procurement procedures have been followed;
preparation of next year's inspection program: towards the end of the year, after reports from all types of inspections have been collected, the program for next year's inspections is drawn up according to prioritization procedures. Bidding for studies or tests before next year's inspections are prepared. The program should take into account not only priorities concerning bridges per se, but also external events, such as programmed road works. If a road section is scheduled for an overlay for the following year, bridges on this section should be inspected and their ability to support an additional thickness of overlay assessed; if this evaluation cannot be done, such bridges should at least be listed to avoid adding dead load;

preparation of next year's work program: towards the end of the year, as inspection reports have become available, assessment of funds needed for next year's program is made and bidding procedures for the works concerned are followed.

5.1.2 Effects of Existing Institutions on Bridge Management

135. Institutional arrangements result from political considerations. However, strictly from the point of view of bridge management, not all arrangements are equally effective. Two institutional issues which have a strong influence on bridge management are discussed below, namely (i) centralization versus decentralization; and (ii) budgetary procedures. Considerations pertaining to bridge management alone are not likely to tip the scales towards one particular institutional system; however, they have to be kept in mind when setting up a BMS, so that proposed procedures can be as effective as possible.

Centralization versus Decentralization

36. Centralization means that the decision-making process, including allocation of funds, takes place at a central level; while decentralization means that both management and funding responsibilities rest with a local authority. It is recommended for effective bridge management that (i) national networks not be extended excessively each year by adding newly constructed roads of doubtful national interest; and (ii) bridges of local interest be placed under the jurisdiction of local authorities for both managerial decisions and funding. Bridges located on roads in remote areas or serving rural development areas are far better maintained by those who have a direct interest in them, i.e., local user groups or rural development agencies. Bridge management, unlike that of pavements, relies on in-depth knowledge and inspection of individual bridges, which is better acquired at the local level than from a remote governmental agency. Also, the costs and benefits of bridge transit may be better assessed at the local level, since transit users may have alternative roads available when a bridge is not passable, while local users may be faced with long detours to cover relatively short distances. Finally, because patterns of climate and agricultural production are area-specific, local management can best determine the schedule for bridge management operations.
Industrialized countries give contrasting examples as regards this issue:

- France has a highly centralized national road network (about 27,500 km and about 8,000 km of toll-roads), and a highly decentralized départemental road network (about 200,000 km), especially since 1981 when a decentralization law granted greater autonomy to départemental authorities. The départements can freely determine their own policies, fundings and to some extent, technical standards. Since about 1973, management of 50,000 km of national roads was transferred from the central government to the départements; these transferred roads have been as a whole far better maintained than previously and the challenge of funding has been successfully met. An indirect drawback of this autonomy is that statistics are far better known for the national and toll-road networks than for départemental roads.

- In the United States, the various states have great autonomy in decision-making and setting standards as long as they do not rely on federal funds. However, they do rely heavily on federal funds for bridge rehabilitation and replacement which may influence their policies in maintenance or strengthening versus rehabilitation or replacement and cause some inconsistencies in bridge standards.

Budgetary Procedures

A bridge authority, either governmental or local, being responsible for decision-making should also be directly responsible for funding all bridge management processes, possibly including new construction, but certainly for all processes from maintenance to reconstruction. Indeed many more savings are realized from sound funding practices than from refined estimations of bridge repair life expectancy. Often central government grants significant subsidies to local authorities for major work such as rehabilitation or replacement, because local resources are not sufficient to perform these activities, while maintenance expenditures continue to be borne by the local authority. Such practice is not recommended as it often discourages maintenance. Instead of adjusting scarce resources to needs, which should favor maintenance as the most cost-effective alternative, the local authority tends to adjust its work projects to available fundings and thus replace structures that could have been repaired or strengthened at much smaller cost. Results of economic evaluations comparing various alternative bridge works are of little value if those works are not funded by the same authority.

It is recommended that budgetary procedures be versatile enough to avoid bureaucratic rigidities that often lead to non-optimal solutions. The budgets of a bridge authority are usually divided into two parts: operating budget and investment budget. Operating budget funds usually arise from national resources, while investment budget funds may partly come from external loans. Borrowing funds for bridge management
activities such as strengthening, rehabilitation and replacement is financially justified, given the usually long lifetime of such work in relation to loan amortization period. However, due to rather arbitrary work classifications (see para. 107), budgetary regulations often require that work classified as maintenance be financed from an operating budget, while other work defined as major work or rehabilitation, be authorized from investment budgets. Since most of the works for bridges have current lifetimes of 5 to 10 years or longer (e.g., steel painting, replacement of bearings, expansion joints or railings), a high degree of flexibility is recommended in allocating funds from either budget to any type of repair or improvement work. Except for routine maintenance, which is definitely an operating budget expense, most repair work, including rehabilitation, improvement or reconstruction, should be financed from the investment budget, especially if similar repair work for several bridges can be grouped in one contract. Such versatility is also advisable for donors who may wish to distinguish between work to be financed from the country's own resources and work eligible for their loans. In all cases, budgetary regulations should possibly allow to itemize and categorize the expenditures pertaining to a given bridge by type of work, in order to improve knowledge of related costs.

5.1.3 Recommendations for Bridge Management Organization

140. Three major causes of poor organization and management of road maintenance can be identified, namely:

- the nature and constitution of the typical road agency, marked by an absence of incentives and suffering from conflicting objectives and functions;

- the absence of pressure for better performance from a strong public constituency; and

- the inadequacy and unreliability of funding.

These three elements are discussed below as they relate to bridge management, and recommendations are provided.

The Road Agency

141. The World Bank paper entitled Road Deterioration in Developing Countries has recommended that the execution of works should be clearly separated from their planning and control. Following this recommendation should be less difficult for bridges than for roads: road agencies have used force account much less frequently for bridge than for road works because of the specialized skills and the smaller amounts of machinery, staff or materials required. Overall, pragmatism should be exercised in structuring the bridge management organization and decisions should be based on the following broad principles:

- bridge management should not be separated from road management; adequate coordination should be ensured with services and agents responsible for roads;
- in all cases, responsibility for the following tasks should rest with the agency: bridge inventory; planning and monitoring of all types of bridge inspections; implementation of superficial and general inspections; planning and monitoring of evaluation of bridge adequacy; planning and supervision of works;

- depending upon its skills, the agency should also implement major principal and/or special inspections, as well as routine and periodic maintenance and minor repair work;

- the agency should not implement major work, rehabilitation, improvement or reconstruction.

It is worth noting that an agency can, at times, perform some routine maintenance tasks, such as deck cleaning, while still delegating the bulk of them to private contractors. The agency would perform these tasks on an opportunity basis, e.g., during similar work for roads, whereas private contractors would perform them regularly. Whatever entity is in charge of bridge maintenance it should meet the requirement for stability in staff appointment outlined in Chapter 4, para. 109.

142. At the local level, the staff appointed should not be given responsibility over an excessively large area, but rather, staff have to be given adequate time to acquire in-depth knowledge of their bridges. They should be responsible for bridge surveillance and general inspection and planning of routine maintenance, and entrusted with the supervision of all tasks carried out by consultants or contractors. They should warn authorities about sudden deficiencies and make timely proposals for funding of next year’s program of special inspections and works. This type of organization is suitable for most bridges but could be modified for exceptional structures warranting special organization and/or private management and maintenance.

143. At the central level, the authority responsible for road maintenance should clearly define who is in charge of bridge inventory, and establish effective links between services in charge of road maintenance and bridge design. This is particularly important for bridge evaluation, since skills and equipment for this task are often located in a service responsible for bridge construction independent of the road maintenance service. Setting up procedures for bridge maintenance and at the same time avoiding conflicts between these services often requires a strong commitment at the highest level of the road authority.

144. Great care should be exercised when implementing a BMS so that activities entrusted to the road agency do not exceed previous recommendations. For example, after agency crews are given a few training courses about bridge deficiencies and the basic equipment (namely a pick-up truck) for inspections and routine maintenance, they may be pressured to perform more sophisticated maintenance or repair, to purchase special equipment and hire more staff. As observed for pavement maintenance, these extended responsibilities lead to inefficiency. The inefficiency would probably be even greater since bridge repair techniques require
more specialized skills than those for pavements; such skills are best available in private companies, or in very specialized entities and corresponding work might not be properly implemented by public agencies.

Public Pressure

145. Public pressure to bring about needed improvements is even less evident for bridges than for roads, since on average bridges are sturdier and last longer than roads, and increased vehicle operating costs are often not direct but expected. Blame for accidents related to bridge collapses can often be attributed to fate or natural causes. Public concern about bridges can then only be raised by protracted efforts to educate users relying mainly on visual information such as photographs taken during bridge inspections and by emphasizing the dangers of bridge-related accidents. Even in industrialized countries, bridge practices have improved as much from spectacular accidents as from administrative action.

Inadequacy and Unreliability of Funding

146. When funding is scarce, road maintenance activities are often neglected and priority is given to employment, leaving no resources for fuel, spare parts or materials. Among road maintenance activities, those related to bridges have fared even worse. Even though fundings for bridge maintenance are extremely scarce, road authorities in developing countries should focus on the tasks considered the most effective, i.e., bridge inventory, general inspections and routine maintenance, even if the scale of these activities may, at first, be modest.

147. Inspections require limited funding, essentially for light equipment, fuel and trip allocations and should be limited to a small number of main roads if funding is scarce. This funding, however, should continue for a couple of years to start a dynamic process of regular inspections. More in-depth inspection processes should begin only when there are reasonable expectations for continuous funding for these tasks during the next few years for example through external lending. The limited funds available preclude hiring specific staff to carry out inventory and inspection. These tasks should be entrusted to crews currently in charge of road maintenance, whether they are from the road agency, or separately hired lengthmen, or one-man contractors. They should, however, be given adequate training initially. Such arrangements bring both savings in utilization of resources and consistency in road maintenance activities.

148. Finally, a more comprehensive system may be considered only if reasonable prospects of funding for repair and rehabilitation work exist for the next 10 years. Such favorable expectations may warrant setting up specific procedures and responsibilities for bridges.

5.2 TRAINING

149. All industrial countries that have developed successful BMS stress that bridge management requires extensive teamwork involving all levels of responsibility. A large effort of sensitization has to be
made from the top level of a Ministry of Transport to the lengthmen in charge of cleaning bridges in the field. This guide proposes that training sessions be organized in order to develop this sensitization; they should rely heavily on visual supports and photographs.

5.2.1 Need for Extensive Teamwork

150. Sensitization to bridge management and maintenance issues should be developed at all levels of responsibility, in order to foster cooperation. Staff in charge of training sessions for bridge maintenance or inspection have often reported a strong interest by attending road supervisors or bridge inspectors, but also complaints about lack of results; reports about bridge deficiencies were made in time, but no action followed. At a higher level, engineers in charge of bridge design often have little experience of bridge maintenance and may not easily accept comments or criticism concerning poor design practices from personnel in charge of maintenance. These examples show that bridge management should not only involve specialists, but the whole team dealing with bridges. Local consultants and contractors could also be profitably involved in technical training sessions to develop a common language and better understanding of mutual needs and practices.

Training Sessions at the Central Staff Level

151. Staff at the central level should learn how to best get their message across to local staff. Adequate dissemination of BMS procedures should be made by visual supports and bridge photographs, not by lengthy memos, which is probably the least effective way to gain the interest and cooperation of local staff. Explaining procedures, deadlines and inventory, and inspection form contents personally to staff is also much more effective than by an impersonal memo. From experience, bridge management and particularly maintenance is a subject that can arouse great interest and participation if adequate sensitization has been promoted.

152. Once such initial sessions have been organized, it is also important to monitor the evolution of processes, take stock of previous actions and discuss improvements and further step which can be the subject of future training sessions. Such sessions involve feedback of information from the central staff to the local staff aimed at receiving more reliable data by providing evidence that previous information has been processed and analyzed.

Training Sessions at the Local Staff Level

153. These sessions aim at providing the basic technical background needed to perform inspections and the simplest tasks of routine maintenance. Therefore, teachers should not try to cover the largest variety of techniques. The technical information should preferably concern the most frequently found structures, not those considered most technically interesting by civil engineers or professors. Local staff seldom need detailed courses about prestressed concrete or exceptional cable-stayed and suspension structures, but rather sound and basic knowledge of
simple timber, concrete and steel bridges. Training may be of more value if some of the sessions are planned and performed by the country's central and local staff with little or no help from external consultants; each participant then shares with his colleagues his own experience, based on inspection reports, photographs, work reports, etc. This practice may provide participants with more relevant information than courses completely devised and implemented by external consultants; it encourages local staff by giving value to their work, especially if engineers participate in these sessions with an open attitude.

154. The initial sessions should aim at teaching basic routine maintenance tasks, the basic language used for bridge components and their deficiencies, and the proper way to fill out inventory forms (see references [17], [18], [19] and [20]). Beyond these first steps, further sessions, should focus on the way inspections should be carried out, by teaching how to spot warning signs and how to use a camera to make appropriate photographs of observed defects. Elements of structural engineering should be limited to what can be understood from everyday experience and is strictly needed to improve the quality of inspections.

155. As stated in Bridge Inspector's Training Manual [11], the following is required from bridge inspectors in the U.S.: "Aside from physical fitness, the inspector trainee must be literate, have an understanding of drafting, be capable of reading bridge construction plans, and be able to use simple inspection equipment." These requirements hold true also for developing countries. More than formal education, "a realization of the importance of this work and the dedication and determination to do a good job are essential prerequisites."
A. Contents

(i) Bridge Identification

The objectives of an accurate identification are the following:

(1) eliminate every possible ambiguity concerning the name of a bridge, its location (particularly in relation to other bridges nearby), the identity of the local agency or division in charge, or whether it actually belongs to the road network selected; and

(2) facilitate data processing, especially if computerized processing is contemplated. For both purposes, it is recommended to give each bridge an identification number.

The following bridge identification items should be included in an inventory form:

- bridge name (or names);
- localization in relation to the country: state or region, county, district or province;
- local agency or division in charge, as far as management activities are concerned;
- localization in the road system: type of network, road number, road section, location above or under the road;
- ways crossed (river or waterway, railroad, other road); and
- mile point or kilometric point, or distance from a milepost, or equivalent.

An identification number is usually given based on the above data and consists of several numbers related to the state, the county, the road, plus a reference number particular to the bridge. For the latter, common systems are to number bridges in each kilometer or mile (e.g., 36/1, 36/2, etc. for bridges between milepost 36 and 37, or 75+140 for a bridge located about 140 m from kilometric point 75). The less dense the road network, the simpler the numbering system. Whatever system is chosen, it has to fit in with the following constraints:

- consistency and compatibility with existing or projected road data bank and the data it contains, such as road number and conventional direction, which may be used to define the right and the left of a bridge; and

- versatility to accommodate possible changes in political or administrative jurisdictions, road numbers or status, and milepost changes that may occur during the lifetime of a bridge due to road works.
Industrialized countries have developed sophisticated systems for numbering bridges, according to:

(1) the complexity of existing networks and various transportation systems, especially in urban areas, and the possible need for taking account equally of the two or more road links to which the bridge is related (e.g., in a road interchange) if these links are equally important; and

(2) the complexity of the structure itself, e.g., parallel structures built at different times or bridges composed of different types of structures, which may cause different performance characteristics and which may be under the aegis of different agencies.

However, such sophisticated systems will probably not be relevant for most bridges in rural areas in developing countries, especially if only few intricate interchanges or complex structures exist. If the network selected is basically made up of interurban routes that carry the most significant part of the traffic both in terms of weight and number of vehicles, it is advisable to focus on this network and thus number bridges by route. In urban areas with high traffic volumes and road interchanges, a more specific system may be developed on a smaller scale.

(ii) Construction Date

Not only the construction date, but also the data of past repair or rehabilitation work should be listed. If these dates are not known accurately, at least approximate dates should be indicated.

(iii) Technical Data

The following technical data should be included in a bridge inventory form:

- type of structure: (i) superstructure (e.g., reinforced concrete deck, steel truss), including data about the cross-section of the deck, such as number and approximate dimensions of girders or T-beams; (ii) substructure, including piers, bents, abutments (materials used, existing channel or embankment protections) and (iii) foundations, if visible or known;
- number and length of spans, total length;
- total width, carriageway width, number of lanes;
- vertical and horizontal clearances (both above and under the bridge, if relevant);
- width of sidewalks, type of handrails, and/or other safety devices such as barrier railings;
- type of bearing devices and expansion joints, if existing and known;
- surfacing type;
- main features regarding the approaches, such as alignment or roadway width at both ends of the bridge;
- other utilities carried by the bridge;
- daily traffic (ADT) and, if known, percentage of trucks over a given weight;
- traffic limitations regarding vehicle weight and dimensions; and
- detour length in case the bridge were out of service.

In addition, the following data can be included, but only if one is sure that the information will be properly and reliably listed on the form:

- skew;
- surfacing thickness and type of waterproofing, if known;
- existence of approach slab;
- existence of antiseismic devices (restrainers); and
- existence of special hydraulic devices (dolphins, fenders).

(iv) Sketches and Photographs

Numerous photographs are very useful, especially if experienced engineers are in short supply and cannot inspect all structures. Photographs taken during the inventory may be an effective link between the inventory and the inspection stage by showing indicative signs of distress or deterioration and facilitating subsequent inspections. However, great care should be exercised in clearly identifying the photographs in the field as and when they are taken; this can be done either by using films that allow space for noting down date and bridge name, or by simultaneously photographing a placard with this data written on it.

(v) Other Items

Other items should be included in a bridge inventory, such as:

- data related to updating, such as author and date of the last updating of the form;
- existence and location of bridge data files.

B. Equipment

The following basic equipment is needed for all bridges:

- pick-up type vehicle;
- tools for vegetation control on roadside areas (sickles, machetes and scythes);
- shovels, brooms and brushes;
- ladders and scaffolding as appropriate;
- boots or good shoes, first-aid kit;
- clipboards with waterproof covering, pen, pencils, markers;
- inventory forms
- slate and chalk or similar markers for bridge identification on photographs;
- pocket tape, folding rule, tapes (from 10 m to 50 m long);
- pick, hammer, ripping bar;
- ropes and safety belts; and
- Polaroid-type or reflex-type camera.

Camping equipment may be desirable, depending on how inventory trips are organized. Also, river bridges and large structures require additional equipment due to problems of accessibility, such as a rubber boat, an expandable levelling rod, and binoculars. Finally, more sophisticated equipment such as mobile platforms or gear for underwater inspection are used to reach remote components. Since they are often costly and require specialists for their operation, they will normally be used for principal or special inspections or in conjunction with other inventory operations being undertaken in the same area.

C. Various Systems

(i) Industrialized Countries

Most industrialized countries have devised inventory forms that meet their own needs; two examples are attached to this Annex:

- the U.S. federal Structure Inventory and Appraisal Sheet, (SIAS); and
- the French bridge form included in the road data bank for the national road network.

Some others, from Switzerland, Sweden and Germany, are described in [1]. In most industrialized countries, the forms used contain significantly more items than recommended above. They call not only for more technical data, but also for data related to bridge condition and history. This results partly from the fact that these countries usually have data readily available from archives in fair condition, and partly from the ability of skilled bridge inspectors to collect data related to bridge condition and even carry out summary bridge appraisal. Because these two factors are often missing in developing countries, great care should be exercised in using forms in which inventory data are not clearly separated from inspection or history data.

(ii) Recommendations for Developing Countries

A simplified form has been drawn up and is also attached to this Annex. It contains the basic items listed above in section A. It is recommended to include a photograph in the form, showing an overall view (full elevation), which by itself gives a good idea of the location, type and size of the structure. Other photographs taken in the field can simply be attached to the form or saved in the bridge data file.
# STRUCTURE INVENTORY & APPRAISAL SHEET

## IDENTIFICATION
- **State:** 
- **District:** 
- **County:** 
- **City/Nea:** 
- **Curtain Number:** 
- **Building Name:** 
- **Building Type:**

## CLASSIFICATION
- **Transfer or Data:** 
- **Maintenance Data:** 
- **Condition Analysis:** 
- **Approval:** 
- **Cost Estimate:**

## STRUCTURE DATA
- **Structure No:** 
- **Type Service:** 
- **Year Built:** 
- **Structure Type:**

## DEFENSE DECK DESCRIPTION
- **Defence Deck Description:** 
- **Approach:** 
- **Approach:** 
- **Approach:** 
- **Approach:**

## DEFENSE LENGTH
- **Length:** 
- **Structure Length:** 
- **Structure Length:** 
- **Structure Length:**

## TREE SHAPE
- **Height:** 
- **Tree Shape:** 
- **Tree Shape:** 
- **Tree Shape:**

## TREE SHAPE
- **Tree Shape:** 
- **Tree Shape:** 
- **Tree Shape:** 
- **Tree Shape:**

## CONDITION
- **Tree Shape:** 
- **Tree Shape:** 
- **Tree Shape:** 
- **Tree Shape:**

## APPRAISAL
- **Tree Shape:** 
- **Tree Shape:** 
- **Tree Shape:** 
- **Tree Shape:**

## PROPOSED-IMPROVEMENTS
- **Tree Shape:** 
- **Tree Shape:** 
- **Tree Shape:** 
- **Tree Shape:**

## COST OF IMPROVEMENTS
- **Cost of Improvements:** 
- **Cost of Improvements:** 
- **Cost of Improvements:** 
- **Cost of Improvements:**
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<table>
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<th>IDENTIFIANT B.O.R.</th>
<th>FICHE D’OUVRAGE N°</th>
<th>DATE D’ÉTABLISSEMENT :</th>
<th>DERNIÈRE MISE À JOUR :</th>
<th>RÉFÉRENCES DES DOSSIERS ARCHIVÉS</th>
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<tbody>
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<td>Vex pour</td>
<td>PR. engagé</td>
<td></td>
<td></td>
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<tr>
<td>Nom</td>
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</table>

PHOTOGRAPHIE OU ÉLÉVATION

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<th>MAÎTRIÈRE D’OUVRAGE :</th>
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<tr>
<td>MAÎTRIÈRE D’ŒUVRE :</td>
<td></td>
</tr>
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<td>ENTREPRISE :</td>
<td></td>
</tr>
<tr>
<td>SERVICE(S) GESTIONNAIRE(S) :</td>
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</tbody>
</table>

LIMITATION DE CHARGE : 1) par essieu [ ] 2) poids total en charge [ ]

date de la décision

AMÉNAGEMENTS POSTÉRIEURS À LA MISE EN SERVICE ET DATE :

DÉVIATION : impossible — possible par :

ÉTAT DE L’OUVRAGE : | DATE DE LA DERNIÈRE VISITE : |
### Caractéristiques fonctionnelles

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<th>LONGUEUR TOTALE DE L'Ouvrage</th>
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<tr>
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<tr>
<td>OU PROFIL</td>
<td>Largeur roulable</td>
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<tr>
<td>EN</td>
<td>Largeur droite</td>
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<tr>
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<td></td>
<td>- des trottoirs</td>
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<td></td>
<td>- de la B.A.U</td>
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<tr>
<td></td>
<td>- de la piste cyclable</td>
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<tr>
<td></td>
<td>- du passage de service</td>
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<tr>
<td>Nombre de voies</td>
<td>Largeur utile</td>
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<td>(ouvrage sous remise)</td>
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### DISPOSITIFS DE RETENUE

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<td>ÉTANCHETÉE</td>
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<tr>
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<td>Type</td>
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<tr>
<td>OBSERVATIONS</td>
<td>APPAREILS D'APPU</td>
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<tr>
<td>RÉSEAUX DIVERS</td>
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### Caractéristiques techniques générales

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<td>OBSERVATIONS</td>
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<tr>
<td>TABLIER</td>
<td>DISTRIBUTION DES PORTÉES</td>
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<tr>
<td>BIAIS</td>
<td>RAYON DE COUPLAGE</td>
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<tr>
<td>HYPOPÉSIES DE CALCULS</td>
<td>RÈGLEMENT DE CHARGES</td>
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<tr>
<td>RÈGLEMENTS APPLIQUÉS</td>
<td>RÈGLEMENT DE STRUCTURES</td>
</tr>
<tr>
<td>CHARGES</td>
<td>MILITAIRES</td>
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<tr>
<td>SPÉCIALES PRISES EN COMPTE</td>
<td>EXCEPTIONNELLES</td>
</tr>
<tr>
<td>LARGEUR CHARGEABLE</td>
<td>DIVERS</td>
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</table>
**Simplified bridge inventory form**

<table>
<thead>
<tr>
<th>Identification number:</th>
<th>Traffic volume (at km point)</th>
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<tbody>
<tr>
<td></td>
<td>Year: Volume:</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Name:**

**State:**

**District:**

**Road number:**

**Section:**

**Kilometric point:**

### GENERAL DATA

**Authority responsible for management:**

- Ways crossed:
  - Road n°
  - River, waterway
  - Railway

- Construction date:

- Design load:

**Name of Builder Contractor:**

**Date of latest improvement/rehabilitation:**

**Traffic limitations:**

- Possible detour

### TECHNICAL DATA

**Total length:**

**Number of spans:**

**Distribution of spans:**

**Total width:**

**Rolling width:**

**Vertical clearance:**

**Superstructure**

- Material: Steel, Concrete, Composite, Timber

- Expansion joints

**Substructure**

- Abutments: Type, Material

- Piers: Type, Material

**Foundations**

**Observations:**

**Equipment required for inspections:**

**Utilities carried:**
ANNEX 2

BRIDGE INSPECTIONS:
CONTENTS, INSPECTION REPORTS AND EQUIPMENT

This annex gives (i) a summary review of the various components of a bridge that should be inspected and indications about quantification of defects; (ii) the basic documents for inspection reports; and (iii) a list of the equipment required for such inspections.

A. Contents

(i) What to Look for During Inspections

The following classification reviews the various components of a bridge that should be inspected, emphasizing the points that bridge inspectors with minimum training should focus on. Thus, this review emphasizes the contents of superficial and general inspections, but refers to publications from industrialized countries for major principal and special inspections. For more detailed information, the reader should particularly refer to the publications referenced as [1], [5], [8], [9], [11] and [18] to [21] in the bibliography.

Wearing Surfaces

Wearing surface defects often lead to further deterioration of the superstructure itself and, therefore, must be carefully observed. For instance, deteriorations of asphalt or concrete wearing surfaces on concrete decks may facilitate water penetration through cracks in the concrete and lead to corrosion of the reinforcement. Experience of road defects can help bridge inspectors assess defects of bridge wearing surfaces. For asphalt or concrete wearing surfaces, defects on bridge decks are quite similar to those observed for pavements, that is, for concrete: scaling, spalling and cracking or exposed reinforcement bars and, for asphalt courses: cracking, rutting, ravelling or potholes. For the types of wearing surfaces that are specific to bridge decks and not encountered at the top of pavements, assessment of defects relies mainly on common sense. This is the case, for instance, for timber decks, where defects such as weathering or decay of timber planks or exposed nails may entail hazards to vehicles, or for steel-grid decks that may rattle as vehicles cross the bridge.

For all types of wearing surfaces, the overall cleanliness of the deck is also important. Accumulation of debris can block drains and expansion joints, in some cases favor vegetation growth and in all cases retain water which always presents a potential for further damage. Special emphasis should be given to deck observation during certain periods, e.g., some hours after a shower, in order to check that water runs off adequately and that puddles, mud or wet areas do not remain on the deck because of poor camber of uneven surfacing.
Structural Components Above the Deck

Depending on the type of bridge superstructure, some structural components may be located above the bridge deck, and therefore be visible from it. For instance, this is the case for:

- steel or timber trusses;
- concrete structures such as arches; and
- suspension or cable-stayed bridges.

Bridge inspectors should take advantage of this accessibility to check these structural components and report possible defects. Plain defects should be noted, such as:

- for steel structures: rust, especially at the bottom parts of structural members, where water and debris can accumulate easily;
- for timber structures: weathering of timber;
- for concrete structures: spalling, scaling or cracking of concrete, rust stains, exposed re-bars;
- for suspension or cable-stayed bridges: corroded or broken wires, damaged suspender sockets.

Equally related to the behavior of the structure, even if structural components are not located above the deck, are the movements and vibrations caused by vehicles crossing the bridge; in that field, bridge inspectors should not hesitate to report what they feel is abnormal.

In addition to these deterioration causes, structural components above the deck are subject to being hit by vehicles. This occurs particularly on trusses and arches where vertical or diagonal members may be hit when two vehicles cross a narrow bridge, or where horizontal bracings can be hit by overclearance vehicles.

Deck Appurtenances

These include items that are not structural members but (i) improve traffic safety for pedestrians (curbs, sidewalks, handrails, parapets) as well as for vehicles (barrier railings); or (ii) accommodate various climatic circumstances, such as rainfalls (drains, scuppers) and temperature changes (expansion joints); or (iii) simply use the bridge as a support for crossing (encroachments such as cables and pipes from various utilities). Inspecting these components consists in checking their proper functioning, ascertaining possible recent damages, e.g., to a parapet after a traffic accident, and reporting the deficiencies. In addition to damage of parapets or railings due to traffic, one should particularly focus on the following defects:

- blocked scuppers preventing proper run-off;
- noisy functioning or displacement of expansion joints, or impact on the deck due to traffic;
- joints blocked by debris;
- poor alignment or deflection of handrail or parapets, which may attest to foundation defects.

Road agency staff are generally not responsible for encroachments, but should check their condition and proper functioning and report any malfunctions to utility companies in charge; for instance, leaking water pipes are likely to entail damages in many structures and should be checked carefully.

**Approaches**

Approaches should be inspected as to their possible effects on a bridge, mainly in the following areas:

1. poor drainage of the adjoining road may concentrate run-off towards the bridge deck, entailing accumulation of water and dirt, especially if the bridge is located at a low point of the road profile;
2. poor design of drainage may cause soil erosion in the areas of abutments, and therefore a risk of instability;
3. vegetation around the abutments may progressively grow and reduce sight distance, prevent convenient inspection of the abutment area and cause structural deterioration, for instance if deep roots grow through masonry substructures;
4. settlement of the road adjoining the bridge often occurs when there is no approach slab; it entails vehicle impact on the deck and, in some cases, attests to a settlement of the whole embankment; which may be hazardous for the abutments, especially if horizontal thrusts occur simultaneously;
5. finally, as for pavements, inspections should be an opportunity to check if traffic signs are properly posted and visible.

**Superstructure and Bearings**

For most bridges, structural components such as girders, beams and diaphragms are located under the deck, and are therefore not easily accessible. In extreme cases (e.g., large river bridges), specific equipment is required for close inspection of remote components. However, bridge inspectors should endeavor to check these components by using all means available, such as binoculars, provided adequate safety is ensured. Inspecting structural components is very important, since they are most subject to deterioration due to high traffic volumes and/or inferior design loads. A list of the main defects that should be looked for during inspections follows:

- concrete bridges: look for scaling, cracks and exposed reinforcing steel in critical parts of beams (vertical cracking at midspan, diagonal cracks or spalls near the ends, horizontal cracks in top parts adjoining the deck, etc.);
- steel bridges: look for rusted parts, cracks especially near weldings, deformations such as buckles, missing or loose rivets or bolts;
- timber bridges: look for weathered or broken parts, fungus decay, holes or sawdust attesting to possible attack of borers;
- bearings: look for displacements of steel bearings such as rockers, deformations of elastomeric pads; check proper functioning of bearings and their ability to move as intended.

Substructures and Foundations

Foundations and substructures are essential components for bridge stability. Like superstructures and bearings, they sometimes cannot be closely inspected during superficial or principal inspections, since adequate equipment may not be at hand. Particularly when a bridge crosses a river, piles, bents or abutments may simply be out of reach or sight. When they are accessible, however, they should be checked for possible deterioration (cracks or spalls in concrete abutments and wing walls, rust of steel components and decay of timber piles, especially in the area of the waterline for river bridges), but also for settlements, tilt or scour - that is, for overall stability.

Bridge Crossing a Waterway

Because adverse waterway condition is the most frequent cause of bridge collapse, it is very important to inspect and be alert to waterway condition during inspections, even if it can only be done from the deck or by bending over a parapet. Even if some damage due to flooding may be considered beyond control, proper inspection and timely maintenance of the waterbed can often avoid major risks.

Since waterway condition cannot be easily ascertained by carrying out principal inspections at best once a year, it should be done during superficial inspections carried out on an opportunity basis. Correctly planned principal inspections should take place at times of low water, thus permitting to inspect foundations more efficiently and determine possible effects of scour on abutments, piers, riverbed and banks. At that time, however, one cannot ascertain changes that occur at times of high water or flooding, what the water level will be, how the stream is divided, and which piers or abutments are consequently most exposed. Moreover, the major effects of scour are often no longer visible at times of low water since depressions in the waterbed may have progressively been refilled by sand or gravel deposit. Therefore, the following elements should be checked during superficial as well as principal waterway inspections:

- effects of scour on riverbed and banks, and if possible on foundations and abutments, especially after floodings;
- condition of existing protection devices: riprap, linings on banks or abutments, cones, fenders, etc.;
- existing floating debris against piers or bents;
- activities that may in the long run lead to significant changes in waterway condition, such as gravel extractions from the riverbed or work carried out in the bridge area.

(ii) **How to Quantify Defects**

Quantification of defects is desirable in superficial inspections, but mandatory in principal inspections. For instance:

- damaged areas on a concrete deck should not only be identified (spalling, scaling, exposed re-bars, etc.) and located (on a sketch or photograph), but also quantified, e.g., by measuring the area of damaged surface;
- cracks should be indicated on a sketch or photograph, and their length and width noted. If acceptable from an aesthetic viewpoint, their length and extent should be underlined on the structure itself, to facilitate subsequent inspections;
- the tilt of a pile should be quantified, e.g., using a plumb line and measuring the deviation from the pile at a given height;
- the degree of corrosion of steel members should be accurately assessed with indication of their condition according to a standard scale such as the European Scale of the Degree of Rusting for Antirust Paint.

When photographs of such defects are taken during inspections, one should always photograph simultaneously any object, e.g., a coin, matchbox or folding rule showing the comparative size of the defect.

B. **Basic Documents for Inspection Reports, Examples and Recommendations**

The requirements for an effective inspection are the following:

- a check-list of the various bridge components to be inspected. This ensures that nothing will be overlooked and serves to recall the basic vocabulary. Depending on the types of bridges encountered in the country, the type of inspection and the degree of training of bridge inspectors; this list may be either general and suitable for all bridges or adapted to a given type of structure;
- a standard inspection form. Though some countries have devised different forms adapted to the various types of bridges encountered, it seems preferable to have only one type for better understanding and handling;
- the possibility of attaching documents such as notes, sketches or photographs to the inspection form. Together with the form, they make up the inspection report. These documents aim basically at quantifying the defects observed, as mentioned above.
In addition to the quantification of defects, bridge inspection should also include a rating for all components reviewed. Such ratings are based, partly on defect quantification, partly on a subjective appraisal of bridge component by the bridge inspector. They are best included in the inventory form since they are basically synthetic.

Checklists

Checklists can be drawn up from various publications which review bridge components and the main defects observed. In particular:

- U.K.'s *Bridge Inspection Guide* [8] is a very concise 50-page document. The second chapter deals with "faults and deterioration" of foundations, substructures, superstructures and components; all types of structures, including timber and masonry structures, are briefly discussed. It contains a detailed checklist of defects (attached to this annex). Since this list is only one page long, it is particularly convenient for bridge inspections and thus is recommended also for developing countries. It may be tailored to a given country, e.g., by excluding moveable bridges;

- the United States has published a series of manuals related to bridge inspection:
  * [AASHTO Manual for Bridge Maintenance] [9] contains a comprehensive review of the various components of a bridge, with indications on the problems they pose, their correction and prevention. Its scope is then broader than inspection;
  * [AASHTO Manual for Maintenance Inspection of Bridges] [10] summarily describes inspection procedures, classified by bridge components to be checked;

All these manuals can be used for training purposes and also possibly to draw up more detailed checklists as they are needed.

- France has published three manuals concerning *Apparent Defects of Structures* respectively for concrete [18], steel [19] and masonry [20] structures. They contain illustrated descriptions of such defects, with indications of their seriousness and potential for further deterioration. These are basic manuals for learning the standard vocabulary of bridge defects. They can also be used for devising checklists, but may be too large and detailed to be used as checklists in the field. Since 1979, France has also published extensive Technical Guidelines for Bridge Inspection and Maintenance [21], the second part of which consists of a set of booklets; each one describes either bridge components (foundations, bearings, accessories) or a given type of superstructure, according to the peculiarities involved in
their inspection and maintenance. Since they are very detailed, the booklets are most useful for major principal or special inspections.

Inspection Forms

Attached to this annex is a simplified bridge inspection form. It has been slightly adapted from the bridge report form included in the Road Maintenance Handbook [5], i.e., indications about repairs done have been excluded whereas simplified condition ratings have been added. This form is advisable as a first step for bridge inspection. As and when there is need for a more complete form, this form may be supplemented by: (i) breaking down bridge components into more detailed items, (ii) adapting the form to the type of bridge structure; and (iii) using a wider scale for bridge condition appraisal.

Regarding this last point, an extended, though quite simple scale is given in reference [8] where extent and severity of defects are appraised respectively on a four-level scale:

**Extent:**
- A - no significant defect;
- B - slight, not more than 5% affected (of area, length etc.);
- C - moderate, 5% to 20% affected;
- D - extensive, over 20% affected.

**Severity:**
1. no significant defects;
2. minor defects of non-urgent nature;
3. defects of unacceptable nature which should be included for attention within the next two annual maintenance programs;
4. severe defects where action is needed (these should be reported immediately to the engineer) within the next financial year.


C. Equipment

In addition to the equipment used for bridge inventory (see Annex 1, Section B), the following equipment is advisable for principal inspections:

- helmet;
- reflex-type camera with flash;
- straightedge, spirit level, plumb line, protractor;
- thermometer;
- sounding line;
- inspection mirror, magnifying glass;
- gauges such as crack-width gauges, tell-tales;
- tool box with knife, screwdrivers, pliers, hammers;
- for steel structures: corrosion meter or scale; emery paper, wire brush or scraper; fillet weld gauge; paint thickness gauge;
- for concrete structures: depth-of-cover meter for re-bars; Schmidt-hammer.

The equipment listed above should be made available to bridge inspectors as they become adequately trained. OECD's *Bridge Inspection Report* [1] contains a breakdown of inspection equipment according to the complexity level of inspections. Although other methods have been developed since its publication in 1976, the report is still valuable because it outlines the degree of engineering knowledge and training and the availability of laboratory facilities required for operating the various equipment items.
ANNEX TO CHAPTER 2
BRIDGE INSPECTION MANUAL

Check List

FOUNDATIONS (2.1)
Cracking of concrete
Corrosion of reinforcement
Spalling of concrete
Signs of movement
Scour
Erosion
Debris
Decay of timber piles
Settlement
Tilting
Differential movement

SUBSTRUCTURES (2.2)
Excessive or abnormal movement
Cracking
Fading
Safety fences
Debris
Drains and weep holes
Leakage: seepage and leaking
Spalling concrete
Exposed or corroded reinforcement
Cracks in masonry
Mortar joints
Vegetable growth

REINFORCED CONCRETE (2.3.1)
Cracking
Scaling
Spalling
Corrosion of reinforcement
Slurring
Leaching
Deterioration of deck concrete
Porosity in concrete (seepage)
Concrete box girders - cracks in faces of flanges and webs, cracks at junctions of interior diaphragms and webs, debris or water ingress
Loose rendering and honey of facing slabs
Accident damage
Excessive deformation or vibration
Chemical (Salt) attack

PRESTRESSED CONCRETE (2.3.2)
All as for reinforced concrete
Location and direction of cracks
Protective coating to exposed cables
Fracture of wires (excessive tension)

STEEL BEAMS, GIRDER AND TRUSSES (2.3.3)
Condition of protective system
Corrosion - magnitude location estimate
Loss of section
Identify cause, replacing and building surfaces
Reinforcement and residual thickness of weathering steel and water leakage

Crack in steel and welds
Deformation and distortion including
Buckling and warping
Bolts and nuts
Excessive wear in nuts etc
Clothes members - as above and effectiveness of seal, water leakage, condensation, mould and fungus growth

ACID damage
Cracks and vegetable growth

TIMBER (2.3.4)
Condition of protective treatment
Signs of wear, cracking or splitting
 Decay or vermin attack
Fire damage
Excessive vibration or deflection
Bolts and connectors
Accident damage

CAST IRON AND WROUGHT IRON (2.3.5)
All as for steel beams etc
Blow holes and cracking
Water accumulation in hollow members

MASONRY AND BRICK ARCHES (2.3.6)
Spalling or erosion of masonry
Cracking or splitting of masonry
Opening of joints
Movements of supports

Bulging and outward movement of spanndrel walls
Loss of arch shape
Longitudinal cracks in surfacing
Inadequate drainage
Loss of initial materials between spanndrel walls
Condition of mortar joints
Leakage of water
Debris and vegetable growth
Adequacy of surfacing
Condition of invert

CABLE SUPPORTED STRUCTURES (2.3.7)
All as for steel beams etc in relation to cables
Strand shoes and sockets, anchorages
Saddles, cable bands, hanger rods, suspenders ties and wrapping wires
Displacement of slippage or strand wires
Sockets, saddles and cable bands
Broken wires
Water seepage in cable bands and
Spatai castings
Tension of hangers and cables
Eye bars and links

MOVABLE BRIDGES (2.3.8)
Defects as listed for fixed bridges
Mechanical electrical and hydraulic equipment
Cables pipes etc
Wear to bearings, pinions, wedges, locking mechanisms, racks and pinions, ropes, pulleys and sheaves
Operating procedures for opening and closing
Fatigue
Counter weights and attachments
Guiding mechanisms and chambers

COMPONENTS (2.4)

BEARINGS AND SEATINGS (2.4.1)
Bearing material eg corrosion, bulging, splitting
Position and alignment
Freedom of movement
Excessive movement
Fixings
Drainage
Cracked concrete seating
Gaps between bearing faces and/ or seatings

Movement between bearings and seating
Adequacy of bedding
Splitting in neck of concrete hinge
Vegetable growth

EXPANSION JOINTS (2.4.2)
Lossening or movement of joint fixing
Movement clearance and alignment
Vertical profile
Water leakage
Surface cracking over buried joints
Accumulation of debris

SURFACING AND WATERPROOFING (2.4.3)
Cracking
Condition of seals
Deformation and tracking
Sliding of surfacing
Skid resistance
Defects in waterproofing
Clearance under bridges

DRAINAGE (2.4.4)
Water stains
Drain outlets
Damaged pipes
Accumulation of debris
Condition of drops or grooves
Surface falls
Open drains and gulley's
Drain in box girder bridges
Service ducts
Water tightness of fastenings

PARAPETS, SAFETY FENCES AND LIGHTING COLUMNS (2.4.6)
Traffic impact damage
Corrosion
Tightness of bolts
Soundness of welds
Alignment of rails and fences
Fatigue cracks
Frost damage to hollow members
# Simplified bridge inspection form

Bridge N°: __________ Type: __________ River: __________

Location: __________

Report:  
- Annual  
- Highwater  
- Accident

Inspector's name: __________ Date: __________

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<td>Piers</td>
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<td>Abutments</td>
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<td>Girders</td>
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<td>Crossbeams</td>
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<td>Bearings</td>
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<td>Expansion joints</td>
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<td>Decking</td>
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<td>Sidewalk</td>
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<td>Railing</td>
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<tr>
<td>Truss</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Signs; reflectors</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Other</td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

This copy for:  
- District Engineer
- Bridge Engineer


Simplified bridge inspection form
(reverse side)

Other sketches, comments:

Signed: ________________________ (Foreman)
ANNEX 3

Comparison of Design Calculations in OECD Countries

Graphs showing the comparison of design calculations in several OECD countries. The graphs display curves indicating different national standards or methodologies. Each country is represented by a distinct line or pattern on the graph.
Figure III.3
COMPARISON OF NATIONAL DESIGN CALCULATIONS:
6. equivalent - 4 lanes

Figure III.4
COMPARISON OF NATIONAL DESIGN CALCULATIONS:
Pm - 2 lanes
ANNEX 4

LOAD CARRYING CAPACITY RATING SYSTEMS:
EXAMPLES OF CALCULATIONS

(Excerpt from OECD's report Evaluation of Load Carrying Capacity of Bridges)

Calculation Method

Most countries use working stress methods for the rating calculations but many of them, especially for modern bridges, are using limit state methods.

In an effort to determine how the various rating systems affect the rating factor and consequently, the load permitted on the structure, four member countries - Canada, the United Kingdom, Norway and the United States - were asked to rate a 70-foot (21.3m) non-composite steel beam span for which details were provided (see attached figure). Examples of the calculations made by Norway and the United States are also attached.

The rating vehicle was the 3S2 (see "US Manual for Maintenance Inspection of Bridges," reference [10], page 59) shown below, and the axle loads are (1): 36 kN and (2) - (5): 71 kN, totalling 320 kN.

To rate the example structure or any structure, one must determine the capacity of the structure and deduct from this capacity the effect of all loads other than live load. The difference is the live load carrying capacity of the structure. Using the 3S2 vehicle, the structure was analyzed to obtain a required live load resisting capacity. The ratio then of the live load carrying capacity to the required live load resisting capacity for the 3S2 vehicle is the "Rating Factor."
In order to arrive at the permissible vehicle weight that can use the structure, one must multiply the GVW, 320 kN (used as the rating load), by the "Rating Factor:"

\[
\text{Rating Factor} = \frac{\text{Capacity of Structure} - \text{Effect of Dead Loads}}{\text{Effect of 3S2 Vehicle}}
\]

\[
\text{Permissible Vehicle Weight} = \text{Rating Factor} \times 3S2 \text{ Vehicle Gross Weight}
\]

Some of the ratings received were for trucks other than the 3S2 unit: therefore, in order to make the comparison more meaningful, it was necessary to adjust portions of the computations. Table 1 represents the results of this enquiry.

As seen in Table 1, considerable differences resulted in the allowable loads permitted on the same structure and the same vehicle configuration by the four rating agencies. For instance, the Canadian Standards Association S6 provisions (CSA S6) would design the bridge to carry a vehicle 1.046 times as heavy as the rating vehicle, and they would allow unsupervised overloaded vehicles (with proper overload permits), freely mixing in with other traffic, to be 1.533 times as heavy as the rating vehicle. For the very infrequent passage of a carefully controlled single vehicle slowly crossing the structure, they would allow a load of 3.255 times the rating vehicle.

The variations in allowable loads come about because of differences in lateral load distribution calculations, different impact factors, and differences in what the agencies think is safe or proper for the continuing undamaged operation of the bridge. The variations are more fully pictured in Table 2. The table shows that load distributed to a single beam can vary from .560 to .712, and that the impact varies from 15 to 45 per cent. It also shows that, using load factor methods, some agencies would allow very close to yielding of the beams for occasional very heavy loads. Others were more conservative.
Figure VI.1
CROSS SECTION OF RATED STEEL BEAM (U.S. DESIGN)

Beam properties
1. Elastic Section Modulus (E) = 18,100 cm³
2. Plastic Section Modulus (Z) = 20,848 cm³
3. Uniform weight (w) = 0.6064 ton/m
Table 1

RATING FACTORS

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<th>United Kingdom</th>
<th>Norway</th>
<th>United States</th>
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<tr>
<td>CSA S6 Supervised and Only Vehicle</td>
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<td>Working Stress Load Factor</td>
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<td>3.036</td>
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CSA = Canadian Standards Association

Table 2

VARIATIONS IN CALCULATION PARAMETERS

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<tr>
<th></th>
<th>Fraction of Lane per Stringer</th>
<th>Impact</th>
<th>Capacity of Structure</th>
<th>Load Multiples</th>
<th>Capacity of Structure</th>
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<td>0.92 fy Z</td>
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</tbody>
</table>

fy : yield strength of steel
S : elastic section modulus of stringer
Z : plastic section modulus of stringer
APPENDIX C
EXAMPLES OF RATING CALCULATIONS
IN THE UNITED STATES AND IN NORWAY
(See Section VI.6 of the full report)

UNITED STATES

\[
R_L = \frac{4.5P(10.67 - 1.235)}{21.34}
\]

\[
M_P = \left(\frac{4.5P(10.67 - 1.235)}{21.34}\right)^2 - 3.505 \times P
\]

Fraction of Wheel Load (FWL) to a stringer or beam

\[
= \frac{S}{5.676}, \text{ where } S \text{ is stringer spacing}
\]

\[
= 2.3876 \times \frac{S}{5.676}, \text{ when } S \text{ is in feet}
\]

FWL = 1.424

Impact = \(\frac{15.24}{L + 38}\) where \(L\) is span length in metres

= \(\frac{15.24}{27.34 + 38}\)

= 0.256

\[
P = \frac{3.632 \text{ ton (Wheel)}}{2} = \frac{16}{2} \text{kips} = 8,000 \text{ lbs}
\]

Live Load Mom of 3S2 Vehicle = \(M_P\)

= load \times \text{distribution} \times \text{impact} \times \text{distance to load centroid}

\[
M_P = 3.632 \times (1.424) \times (1 + 0.256) \left(\frac{4.5(10.67 - 1.235)^2}{21.34}\right) - 3.505
\]

\[
M_P = 99.20 \text{ ton - } a
\]
Dead Load Interior Beam

Slab = 1.0923 ton/metre
Haunch = 0.0744
Distributed(*) = 0.3601
Beam = 0.4464
Details = 0.0327

\[ \frac{2}{3} \times 2.0059 = 2.0059 \text{ ton/metre} \]

Mom = Mg = \[ \frac{2}{3} \times 2.0059(21.34)^2 \]
= 255.8 ton-m

Permissible stress = \( f_{\text{perm}} \) (Inventory)

\[ f_{\text{perm}} = 0.55 f_y = 20,000 \text{ psi} = 1406 \text{ kg/cm}^2 \]

Section Modulus furnished = \( S_x \) (from steel tables for 36 WF 300)

\[ S_x = 1110 \text{ in}^3 = 18,190 \text{ cm}^3 \]

Permissible Mom = \( M_{\text{perm}} \)

\[ M_{\text{perm}} = S_x (f_{\text{perm}}) \]
= 18,190 (1406)
= 25,575,140 kg-cm
= 255.8 ton-m

**Working Stress:**

Rating Factor = \( \frac{M_{\text{perm}} - M^*}{M_p} \)

\[ = \frac{255.8 - 114.2}{99.2} \]

R.F. = 1.427 (Inventory)

**Permissible Stress = \( f_{\text{perm}} \) (Operating)**

\[ f_{\text{perm}} = 0.75 f_y \text{ where } f_y = 36,000 \text{ pounds per square inch (psi)} \]
= 0.75(36,000)(0.0703065)
= 1898 kg/cm²

\[ M_{\text{perm}} = 1898(18,190) = 34,524,620 \text{ kg-cm} \]
= 345.2 ton-m

R.F. = \[ \frac{345.2 - 114.2}{99.2} \]

R.F. = 2.329 (Operating)

*) Future Wearing Surface + Parapet Wall + Railing
Load Factor:

\[ f_x = 1260(2.54)^3 = 20,648 \text{ cm}^3 \]
\[ S_x = 1110(2.54)^3 = 18,190 \text{ cm}^3 \]
\[ f_y = 2531(0.0703069) = 178,190 \text{ kg/cm}^3 \]
\[ f_y^2 = 2531(20,648) \times 10^{-5} = 522.6 \text{ ton-m} \]
\[ f_y^3 = 2531(18,190) \times 10^{-5} = 460.4 \text{ ton-m} \]

Inventory

Strength

\[ R.F. = \frac{f_y^2 - 1.3f_y}{1.3(573)(LL + I)} = \frac{252.6 - 1.3(114.2)}{1.3(573)(99.20)} = 2.901 \]

Serviceability

\[ R.F. = \frac{0.8f_y^2 - f_y}{573(L + I)} = \frac{0.8(460.4) - 114.2}{573(99.20)} = 1.537 \]

Operating

Strength

\[ R.F. = f_y^3 - 1.3f_y \]
\[ R.F. = \frac{252.6 - 1.3(114.2)}{1.3(99.20)} = 2.901 \]

Serviceability

\[ R.F. = \frac{0.8f_y^3 - f_y}{L + I} = \frac{0.8(460.4) - 114.2}{99.20} = 2.562 \]

NORWAY

Working Stress

\[ f \text{ permissible} = \frac{1.75}{2.75} f_y \]

Elastic Section Modulus = 18,190 cm³ (furnished)

\[ M_{\text{perm}} = S_x f_{\text{perm}} \]
\[ M_{\text{perm}} = 18,190 \times 1.75 \times (2530)(10^{-5}) \]

\[ M_{\text{perm}} = 292.9 \text{ ton-m} \]

Load Factor

\[ f_{\text{permissible}} = T.25f_y \]

Plastic Section Modulus = 20,648 cm³ (furnished)

\[ M_{\text{perm}} = S_x f_{\text{perm}} \]
\[ M_{\text{perm}} = 20,648(1.25)(2531)(10^{-5}) \]

\[ M_{\text{perm}} = 417.9 \text{ ton-m} \]
Dead Load Movement

\[ M_g = \frac{wL^2}{2} = \frac{wL(1)}{2} = \frac{43.6(21.3)}{2} \]

\[ M_g = 116.1 \text{ ton-m} \]

- 352 Vehicle

\[ \frac{352 \text{ Vehicle}}{0.5 \text{ P}} \frac{P}{1.4 \text{ P}} \frac{P}{P} \]

\[ \begin{array}{c|c|c|c|c|c}
3.35 & 1.219 & 6.706 & & 1.219 \\
\hline
6.154 & 1.135 & 10.668 & & 10.668 \\
\end{array} \]

- See Manual for Maintenance Inspection of Bridges page 59 (Ref. 45).

\[ M_p = 4.9P(10.668 - 1.135) \]

\[ M_p = \frac{4.9P(10.668 - 1.135)}{21.356} \]

\[ M_p = \frac{6.9(10.668 - 1.135)^2}{21.356} - 3.505P \]

\[ M_p = 17.37P \]

Axle load distribution factor to a stringer = 0.56

\[ P = 16 \text{ kips} = 7.257 \text{ tons (axle)} \]

Therefore

\[ M_p = 17.37(7.257)(0.56) = 70.59 \text{ ton-m per stringer} \]

Rating Factor

**Working Stress**

\[ \text{R.F.} = \frac{M_{\text{perm}}}{M_p} \]

\[ \text{R.F.} = \frac{222.9}{70.59} = 2.505 \]

**Load Factor**

\[ \text{R.F.} = \frac{M_{\text{perm}}}{1.2M_p} \]

\[ \text{R.F.} = \frac{417.9}{1.2(70.59)} = 3.036 \]
ANNEX 5

ABRIDGED EXCERPTS FROM FHWA PROPOSED GUIDELINES FOR ASSESSING SUBSTRUCTURE ELEMENTS

The purpose of the guidelines is to provide a guided, objective method to measure the threat to the integrity of a structure from a maintenance viewpoint. The guidelines and modifications as presented aid inspection personnel in arriving at an initial assessment of a deficiency expressed as a numerical value. This assessment, in turn, indicates the urgency of corrective action, and prescribes the type of action to be taken during the inspection process as well as by maintenance forces in scheduling work to be performed.

Instructions

When using these guidelines, the following steps should be taken:

1) Inspection personnel are to select the description which most closely depicts the severest example of deterioration found. The number appearing adjacent to the chosen description is the initial assessment of the deterioration. 2) The deficiency should then be photographed or sketched for the purpose of documentation in the inspection report. 3) The initial assessment may then be modified based on the threat to the integrity of the structure caused by the effect of supplemental or external factors. In this way, deficiencies may first be evaluated by the guidelines shown and then modified by conditions which are unique to a particular area or climate. The right hand chart provided on the back of each form is to be used to perform this function for all deficiencies. 4) The assessment modification should then be algebraically added to the initial assessment to produce the maintenance urgency index. Assessment and modification numbers may be circled to highlight the guidelines used. The statement next to the numbers chosen should be underlined to document the reason for the selection. 5) Once an urgency index has been selected, the type of action to be taken during inspection and by maintenance forces can then be selected. This is done by consulting the chart on the next page. The administrative level at which the assessment modification should be approved is not addressed here.

With the aid of this method, the assessment of underwater deficiencies of bridge substructures can be performed in an objective manner. Inspection personnel can uniformly arrive at a numerical value to indicate the urgency of corrective action from a maintenance viewpoints.

The instructions apply to the following elements:

Scour around Piles
Undermining of a Footing
Section Loss of a Concrete Pile
Section Loss of a Steel Pile
Section Loss of a Timber Pile
General Deterioration of Concrete
General Deterioration of Timber
Settlement

For each of these, Inspection Forms are standardized - by way of example the form for Scour around Piles is attached hereto.
### Maintenance Urgency Index

<table>
<thead>
<tr>
<th>Maintenance Urgency Index</th>
<th>Maintenance Immediacy of Action</th>
<th>Inspection Course of Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>No repairs needed.</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>No repairs needed. List specific items for special inspection during next regular inspection.</td>
<td>Note in inspection report only.</td>
</tr>
<tr>
<td>7</td>
<td>No immediate plans for repair. Examine possibility of increased level of inspection.</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>By end of next season - add to scheduled work.</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Place in current schedule - current season - first reasonable opportunity.</td>
<td>Special notification to superior is warranted.</td>
</tr>
<tr>
<td>4</td>
<td>Priority - current season - review work plan for relative priority - adjust schedule if possible.</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>High priority - current season as soon as can be scheduled.</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Highest priority - discontinue other work if required - emergency basis or emergency subsidiary actions if needed (post, one lane traffic, no trucks, reduced speed, etc.)</td>
<td>Notify superiors verbally as soon as possible and confirm in writing.</td>
</tr>
<tr>
<td>1</td>
<td>Emergency actions required - reroute traffic and close.</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>Facility is closed for repairs</td>
<td></td>
</tr>
</tbody>
</table>
Assessment Modification Chart Based on Threat to Integrity of Structure

<table>
<thead>
<tr>
<th>Modification</th>
<th>Description</th>
</tr>
</thead>
</table>
| +2           | No threat for minimum of 5 years and one or more of the following:  
               1. Deficiency condition is slowing;  
               2. External causes of deterioration substantially reduced or eliminated;  
               3. Deficiency has history in similar circumstances of being self correcting; and  
               4. Deficiency is entirely "cosmetic" in nature and has little or no structural effect.*  
               (Note: May be used for original rating of 2 to 6 inclusive.) |
| +1           | No threat for minimum of 3 years and one or more of the following:  
               1. Deficiency condition is stable;  
               2. External causes of deterioration have lessened somewhat;  
               3. Deficiency has history in similar circumstances of growing no worse; and  
               4. Deficiency is mostly "cosmetic" in nature and has little structural effect.*  
               (Note: May be used for original rating of 2 to 7 inclusive.) |
| 0            | No threat for minimum of one year and one or more of the following:  
               1. Deficiency condition worsening at expected or "normal" rate;  
               2. External causes of deterioration have remained constant;  
               3. Deficiency has history in similar circumstances of growing worse at consistent rate; and  
               4. Deficiency has structural effect but has not seriously reduced structural capacity.  
               (Note: May be used for any original rating.) |
| -1           | Threat anticipated within one year and one or more of the following:  
               1. Deficiency condition worsening at increasing rate;  
               2. External causes of deterioration are gradually increasing;  
               3. Deficiency has history in similar circumstances of growing worse at gradually increasing rate; and  
               4. Deficiency has structural effect.  
               (Note: May be used for original rating of 3 to 8 inclusive.) |
| -2           | Threat is imminent and one or more of the following:  
               1. Deficiency condition is worsening rapidly;  
               2. External causes of deterioration are rapidly increasing;  
               3. Deficiency has history in similar circumstances of growing more severe at rapidly increasing rate; and  
               4. Deficiency has severe structural effect.  
               (Note: May be used for original rating of 4 to 8 inclusive.) |

* Structural effect includes redundancy of load path and other factors.
DESCRIPTION:

SKETCHES:
<table>
<thead>
<tr>
<th>GUIDELINES</th>
<th>Initial Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>No scour</td>
<td>9</td>
</tr>
<tr>
<td>No scour</td>
<td>8</td>
</tr>
<tr>
<td>Light scour around piles</td>
<td>7</td>
</tr>
<tr>
<td>Moderate scour around piles</td>
<td>6</td>
</tr>
<tr>
<td>Moderately heavy scour pockets around piles</td>
<td>5</td>
</tr>
<tr>
<td>Heavy scour pockets around piles</td>
<td>4</td>
</tr>
<tr>
<td>Scour pockets have increased unsupported length dramatically</td>
<td>3</td>
</tr>
<tr>
<td>Pile is completely exposed</td>
<td>2</td>
</tr>
<tr>
<td>Structure is threatened</td>
<td>1</td>
</tr>
<tr>
<td>Structure is closed</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>Modification</th>
</tr>
</thead>
<tbody>
<tr>
<td>No threat for minimum of 5 years and one or more of the following:</td>
<td></td>
</tr>
<tr>
<td>1. Deficiency condition is stable;</td>
<td>+2</td>
</tr>
<tr>
<td>2. External causes of deterioration substantially reduced or eliminated;</td>
<td></td>
</tr>
<tr>
<td>3. Deficiency has history in similar circumstances of being self correcting;</td>
<td></td>
</tr>
<tr>
<td>4. Deficiency is entirely &quot;cosmetic&quot; in nature and has little or no structural effect. (Note: May be used for original rating of 2 to 6 inclusive.)</td>
<td></td>
</tr>
<tr>
<td>No threat for minimum of 3 years and one or more of the following:</td>
<td></td>
</tr>
<tr>
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<td>+1</td>
</tr>
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<td>Threat anticipated within one year and one or more of the following:</td>
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</tr>
<tr>
<td>1. Deficiency condition worsening at increasing rate;</td>
<td>-1</td>
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<tr>
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<td></td>
</tr>
</tbody>
</table>
ANNEX 6

THREE EXAMPLES OF BMS IN INDUSTRIALIZED COUNTRIES

Denmark is a relatively small country: 43,000 km². All administration of national roads has been centralized in the Road Directorate under the Ministry of Transport since the middle of this century, when the dramatic development of a modern road network required more attention. The following chart illustrates the consequences of the national road network extension as to the number of bridges in Denmark.

Based upon elaborate procedures of bridge inspection and evaluation, bridge deficiencies are registered and repair work alternatives proposed by bridge inspectors. For each individual bridge under study, benefit/cost ratios of the various alternatives are calculated and the alternative with the highest benefit/cost ratio is selected. Costs include both agency costs and user costs. Once a year the recommended repairs are rated at the network level in order to use the allocated funds in an optimum way; this rating stage of the selection process, however, does not rest on a benefit/cost analysis, rather on engineering judgment. Finally, the works are implemented after tenders have been invited.

France has 550,000 km² of surface. Each authority is responsible for funding maintenance, repair and rehabilitation works on its own network, that is, the government for the state network, road concession firms for toll roads and the départements and communes for their respective networks. However, except for most large cities, the local technical services have been common to state, département and commune authorities for a long time. As far as the state network is concerned, detailed inspection procedures have been set up during the last 10 years [21]. Funds for routine maintenance of bridges are not separated from
those roads; for major repair work, specific funds are allocated after projects submitted by local engineers have been reviewed and prioritized at the central level by a team of four specialized General Bridge Engineers acting on behalf of the Road Directorate. Selection is therefore carried out at the local level by field bridge engineers; then the relevance of this selection is checked and prioritization is carried out at the central level. Though technical and economical elements are taken into account at both local and central levels, no specific economic analysis is carried out. The prioritization process is rather a multi-criteria analysis, based on simultaneous consideration of technical, economical and financial elements; these elements are aggregated subjectively by senior engineers. For major rehabilitation or reconstruction, the procedure is identical to that for new construction and comprises an economic analysis and the calculation of an internal rate of return. Départements and communes have often developed similar systems for inspection, since the local technical authorities used to be the state agencies; however, unlike the Ministry of Transport, the départements and communes have seldom allocated specific funds for repair and rehabilitation on a continuous basis, and have generally made decisions on a case-by-case basis.

The United States has also developed streamlined procedures for bridge inspection and evaluation, [10] and [11]. A National Bridge Inventory was first established by Congress following the collapse of the Silver Bridge in 1967. In addition, the various States are required to provide the Federal Highway Administration annually with data about bridge condition; the SI & A sheet (Structure Inventory and Appraisal sheet; attached to Annex 1) is the basis for this data, even if some States have later developed more comprehensive data systems. Procedures are centralized at the federal level because Congress makes grants to the States for rehabilitation and replacement programs. These grants are made for bridges on both the Federal Aid System and the Non-Federal Aid System and make up the bulk of funding for bridge repair and rehabilitation. So as to allow for streamlined fund distribution among the various States, the data are used to determine: (i) the total allocation of federal funds for each State, based on an apportionment formula that takes into account the relative share of the total cost of deficient bridges; and (ii) the eligibility of each bridge for finance, based on a calculated federal sufficiency rating (FSR; [12]).

Once funds have been apportioned to the States by the Federal Government, the States in turn use various procedures to select and prioritize their bridges for repair or replacement according to their own policies. An ongoing study on Bridge Management Systems as well as reference [13] have reviewed the various methods used by the States. These methods can be broadly broken down into two categories: the first category can be characterized as based on aggregated level of service parameters; the second rests on economic calculations based on lifecycle cost analyses.
First category methods rely on accurate data pertaining to the bridge, most of them being included in the SI & A sheet and referring to levels of service; these data are then aggregated by various formulas. One simple example consists of using the FSR; most often, however, this rating is not taken into account alone, but combined with other items which the States consider is important and not sufficiently allowed for in the FSR, such as ADT, alternative work cost, clear width, estimated remaining life, etc. There are more or less sophisticated methods, which may comprise a first screening and a review of alternative works. But basically they consist of aggregating not directly comparable criteria by means of formulas which reflect the State’s management policy, and therefore contain a substantial amount of subjectivity. Reference [13] has compared various priority ranking formulas and shown that they are significantly different; for instance, some are very sensitive to assessed deficiencies in load carrying capacity, while others tend to minimize the effects of such deficiencies.

Second category methods have tried to streamline the prioritization process by assessing the economic effects due to each of the above mentioned level of service criteria; this approach is similar in its principle to that of the HDM Model, which has assessed the economic effects of road condition, geometric characteristics and maintenance strategies. These methods are much less developed than the first category methods. They involve statistical studies of bridge deterioration rates over time, estimated service life and remaining life, and estimated service life extension resulting from maintenance or repair activities. An important research effort is still warranted to obtain significant improvements in predicting the effects of various maintenance strategies, and the present and future costs.
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(Dates indicated are of the latest available editions)


2. OECD Bridge Maintenance (OECD, Paris 1981). Published in French under the title Entretien des Ouvrages d'Art.

3. OECD Evaluation of Load Carrying Capacity of Bridges (OECD, Paris 1979). Published in French under the title Evaluation de la Capacité Portante des Ouvrages d'Art.


6. International Conference on "Gestion des Ouvrages d'Art:" Inspection, Maintenance and Repair of Road and Railway Bridges; proceedings. (Brussels-Paris; April 13 - 17, 1981). Three volumes.


The first part consists of a book dealing with overall instructions applying to all structures. The second part is composed of a series of booklets, each one dealing with a specific subject; following are the available booklets:

- 01. Bridge data files;
- 02. Generalities about bridge surveillance;
- 10. Foundations below the waterline;
- 12. Piers and abutments;
- 21. Bridge appurtenances;
- 30. Masonry bridges and viaducts;
- 32.1 Prestressed concrete bridges; common structures;
- 32.2 Prestressed concrete bridges; box-girder bridges; ribbed slab bridges and similar structures;
- 34. Suspension bridges and cable-stayed bridges;
- 35. Temporary bridges;
- 40 Tunnels;
- 50. Corrugated steel pipe structures;
- 51. Retaining walls; - 51.1 classic structures - 51.2 anchoring rods - 51.3 Retaining walls; reinforced earth structures;
- 52. Cuts and fills.