The proposal associated to the determination of the structural reliability is based on the reliability index β, which depends on the bridge structural collapse probability P_f, which is a function of time:

$$\beta(t) = -\phi^{-1}(P_f(t)) \tag{8-1}$$

For each bridge, the most conditioned cross sections are defined along with their respective ultimate limit states with the greatest occurrence probability. The most plausible global collapse mechanisms are identified. The index β evolves in time according to the degradation mechanisms that it is necessary to implement. The parameters (type 5 from Chapter 11) that govern them must be identified and must be capable of being measured (directly or indirectly) during the periodic inspection. The index can therefore be updated based on the inspections report and, using a computer program, a prediction of its evolution with time can be made (Thoft-Christensen).

According to the decision criteria, if, according to the estimate obtained based on the last periodic inspection, the value of β goes below a certain limit β_{min} during the time until the next periodic inspection, a structural assessment must be proposed. The urgency of this assessment would also be based on the β index value: if $\beta < \beta_1$ ($\beta_1 < \beta_{min}$) during the referred period, the structural assessment must be performed immediately; if the opposite happens, the assessment must be performed only before the next periodic inspection. If, during the period mentioned, β never goes below β_{min}, no structural assessment needs to be implemented before the next periodic inspection, when the β index is updated again.

Regardless of the proposal of decision criteria, the last word belongs to the head of bridge authority and should take into account the limitations in terms of personnel and equipment as well as the bridge's location.

The input, output, and detailed flowchart of this decision submodule are presented in detail in Chapter 13 (Figures 13-1 and 13-5).

8.2.7.3. Repair

Scope

This submodule concerns all repair/rehabilitation techniques defined as structural repair in Table 10-3. The repair work is of a structural or semistructural nature and may or may not have consequences with regard to the functionality of the bridge. In a larger sense, this submodule also conditions situations in which the possibility of capacity upgrading (deck widening or structural strengthening), functional limitations (by posting), or bridge replacement is under consideration.

Time of Use

This submodule must always be used when a structural assessment is performed and its use is suppressed if, within the inspection strategy submodule, it is concluded that no structural assessment is needed until the next periodic inspection. Even when it is decided that the best solution from an economic point of view is to do nothing about the structural defects found, this decision must be made by resorting to this submodule and must be based on an economic analysis. Budget limitations are paramount in the decision-making process, since it is almost impossible to predict the number of bridges that will need to be repaired each year and the extent of work needed. A bridge may not need to be repaired for 10 or more years and, in the following year, it may be subjected to a rehabilitation program with associated costs similar to the initial costs of the bridge.

Decision Criteria

As described in Chapter 13, the decisions made in this submodule are basically the result of an economic analysis. This analysis can be made at three different levels:

- Level 1—elimination of the defect(s);
- Level 2—bridge repair;
- Level 3—bridge network management.

All the decisions are made according to the cost efficiency index (CEI) (Aylon 1990). The CEI index gives an indication of the planned action option as compared with the no action option. The bigger the index of a certain action, the bigger the dividends obtained from the investment made. In the calculation of CEI, the repair costs (C_R), the failure costs (C_F), and the benefits (B), defined in detail in Chapter 10, are considered.

$$CEI = \frac{(C_R + C_F - B)_{\text{repair}}}{(C_R + C_F - B)_{\text{no-action}}} \tag{8-2}$$

The initial costs (C_0), the inspection costs (C_I), and the maintenance costs (C_M), discussed in the same chapter, are excluded from the analysis. This is possible because these costs are not relevant to the analysis (being identical to all the options under analysis) or because they have already occurred when this decision is made.

At decision level 1, the objective is to select the best repair technique to eliminate a specific type of structural defect from the options presented in the "Repair Work Needed" database file of the last inspection. Associated with this technique are its cost estimate and service life. This period can be determined using deterioration models that take into account local aggressiveness. If the mathematical models are not reliable enough or if the necessary data to implement them are not available, tables that provide a statistical average of service life for different materials, elements, and repair techniques can be used.

After this type of analysis is applied to every defect detected in a certain bridge, decision level 2 begins. A list of the structural defect types detected with their respective optimal repair techniques and values CEI_{max} is available. Due to budget limitations, not every defect can be repaired. The type of defect with the highest CEI_{max} value (CEI_1) is the first to be

Table 8-5. Scope of the decision modules

Module		Scope
Maintenance		Selection of the repair techniques classified as maintenance work
Inspection	A	Decision about the performance of a structural assessment before the next periodic inspection
Strategy	B	
Repair (work selection)		Selection of the repair techniques classified as (structural) repair work

Table 8-6. Time of use of the decision modules

Module		Time of use
Maintenance		Always after a current or detailed inspection is performed
Inspection	A	Always after a current or detailed inspection is performed
Strategy	B	
Repair (work selection)		Only after a structural assessment is performed

repaired and so on. Costs C_1, C_2, and so on are deducted from the available budget for the bridge under analysis until all of it is spent. If there are no individual budgets for each bridge, the decision as to whether to repair each type of defect must be made at level 3.

Level 3 manages the global bridge network budget available. It is at this level that the options of capacity upgrading and replacement of each bridge are analyzed. Level 2 analysis of all bridges within the network provides new lists in which, for each bridge, the defects are grouped and their respective accumulated costs C and indexes CEI are determined.

$$ACEI_i = \frac{\sum_{j=1}^{i} C_j CEI_j}{\sum_{j=1}^{i} C_j} \tag{8-3}$$

$$AC_i = \sum_{j=1}^{i} C_j \tag{8-4}$$

The value of $ACEI_i$ represents the cost efficiency index of performing all the repair work necessary to eliminate defect types 1 to i, and the value AC_i represents the respective cost. As the number of defect types considered increases, the $ACEI$ value decreases since the individual CEI values also decrease progressively. The aggregate of repair work with the highest $ACEI$ index value is the first to be performed and indicates the first bridge to be repaired. The accumulated cost of this repair work is deducted from the global budget available and the process continues with the second highest ACEI. Whenever a repair work aggregate for a certain bridge that contains n techniques is included in the list, the repair work aggregate

Table 8-7. Decision criteria of the decision modules

Module		Decision criteria
Maintenance		Human factor; economic analysis
Inspection	A	Human factor; structural reliability
Strategy	B	Structural reliability; human factor
Repair (work selection)		Economic analysis; human factor; structural reliability

in the same bridge containing n–1 techniques is eliminated from expenditures and the available budget value is corrected.

The description of the decision levels has been made for the situations in which the options are limited to repair (again achieving the initial after construction situation) or no action. The less common cases of capacity upgrading and replacement are particular situations that are described in Chapter 13. In the same chapter, the input, output and detailed flowchart of this decision submodule are also presented.

8.2.7.4. Summary

A summary of the several decision modules within DMM is presented in Tables 8-5 to 8-7 (de Brito 1992). For the strategy inspection submodule, two proposals are put forward in Chapter 13: one based on the defects rating (designated by A) and the other based on the determination of the structural reliability evolution with time (designated by B).

As a final note, the system proposed is of the fourth and most complex type of bridge management system according to the classification proposed by Vassie (1996): those with an inventory database, basic inspection scheduling, and recording and maintenance scheduling taking into account the rate of deterioration, minimizing life costs and prioritizing where the budget is restrained.

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PART 4

ORGANIZATION OF A BRIDGE MANAGEMENT SYSTEM

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CHAPTER 9

THE DATABASE

9.1. Introduction

The efficiency of a bridge management system is dependent to a great extent on its data storage and post-treatment data. In fact, the system uses a huge volume of information simultaneously with the acquisition of data about the inspection, normal use, maintenance, and repair of each bridge. Before computers, the support basis for all this material was paper in the shape of dossiers, reports, forms, manuals, drawings, photos, schemes, and so forth. This made accessing the information difficult and made it difficult to store all this bulky material in accessible places. The computer revolution and the advent of database software allowed for the storage of great quantities of information on relatively small objects (magnetic disks).

This evolution did not eliminate the necessity for continuing to use traditional information storage environments. To start with, access to digitalized data demands equipment that is not always available (at the bridge site, the best one can hope for is to resort to a personal computer of limited capacity, i.e., a PC). Some specific information (e.g., drawings) is easier to access when it is on paper, mostly because of the limited dimensions of the computer screen. The storage capacity of existing magnetic disks and CD's has greatly increased, but there is still some difficulty in storing graphic information due to the huge size of the corresponding files. There are also some hazards associated with the use of data in a computer (software and hardware bugs, mechanical damage, and sensitivity to temperature and magnetic fields) that make it more vulnerable than the data registered on paper. Finally, it is not economically feasible to systematically resort to computers to store the endless amount of information collected during the day-to-day management of each bridge (particularly at the construction stage), especially because all of this data must be manually inserted into the right files in a very time-consuming process.

Therefore, we discuss the simultaneous use of a digital database and a traditional means for the collection and storage of information, which will be assembled in the so-called "bridge dossier," which is described in greater detail in Chapter 8. The bridge dossier will put together all the information concerning the bridge, with a low degree of selectivity, merely organizing it to facilitate access. The database contains only selected information, synthesized to an indispensable minimum and organized as files that are easy to read on the computer screen and can also be printed on paper.

The main characteristics desired from such a reference database are found in de Brito and Branco (1991) and de Brito (1992):

- user-friendly in terms of both reading existing data and storing new data (most of the time, the person actually feeding the data into the computer does not have any knowledge of bridge designing or building);
- easy access (operations involving the introduction, modification, or reading of information from the database must be quick and simple);
- thoroughness without complexity (all information likely to be used in the future must be stored but over-specialized data should be avoided because of inspector time limitations);
- capacity to create specific reports adapted to the user's needs through comprehensive menus;
- possibility of easily transferring part of the information to portable microcomputers capable of being used at the bridge site;
- availability of simplified executable versions capable of being installed in the same type of equipment;
- clear but economical internal organization (the data must be separated into blocks that constitute by themselves complete and independent pieces of information);
- capacity to perform its own maintenance (backups generation, passwords protection, protection against misuse or users mistakes, etc.);
- adaptability to the system requirements both at the bridge site and at headquarters.

9.2. General Organization

9.2.1. International Experience

In the bridge management systems presently being used or implemented, the database is, save for a few exceptions, one of the most important modules of the system. This is the situation in Austria (Straninger and Wicke 1993); Canada (Reel et al. 1988); Colombia, Croatia, Denmark, Honduras, Malaysia, Mexico, and Saudi Arabia (Lauridsen and Lassen 1999); Finland (Söderqvist 1999); Germany (Krieger and Haardt 2000); Hong Kong and Sri Lanka (Blakelock 1993); India (Cox and Matthews 2000); Italy (Camomilla and Romagnolo 1999); Japan (Yokoyama et al. 1996); the Netherlands (El Marasy 1990); Poland (Legosz and Wysokowski 1993); Portugal (Santiago 2000); South Africa and Taiwan (Nordengen et al. 2000); Sweden (Lindbladh 1990); Switzerland (Grob 1989); Thailand (Sørensen and Clausen 1989); the United Kingdom (Hayter and Allison 1999); and the United States (Thompson 1993). There are, of course, a number of differences between the several databases according to the specific needs of each system.

The United States National Bridge Inventory (NBI) registers the data recorded during the inspection of public bridges in accordance with the Federal Aid Highway Act of 1968, and is used to determine a sufficiency rating that allows or disallows federal funding for bridge rehabilitation and replacement (according to the Federal Coding Guide, Report no. FHWA-PD-96-001 "Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges"), and deserves some special attention. Since the early 1980s, the biennial inspection program has been fully implemented, and all U.S. transportation agencies are required to supply detailed inspection information to the Federal Highway Administration (FHWA).

According to McClure (2002), 614,083 bridges are covered by the inventory whose results have been analyzed and reveal that 87,801 of the bridges are structurally deficient and 79,860 are functionally deficient (an additional 20,517 are scour critical according to federal guidelines). Based on analysis, it can be inferred that even in the most developed country of the world, with an efficient database and working BMS systems in all its states, funding below the critical level can lead to a huge backlog (the total improvement cost is more than $210 billion).

The structure of some of the databases/systems mentioned above is presented here in terms of simplified diagrams:

- the Austrian Road and Traffic Research Association database (Figure 9-1) (Straninger and Wicke 1993);

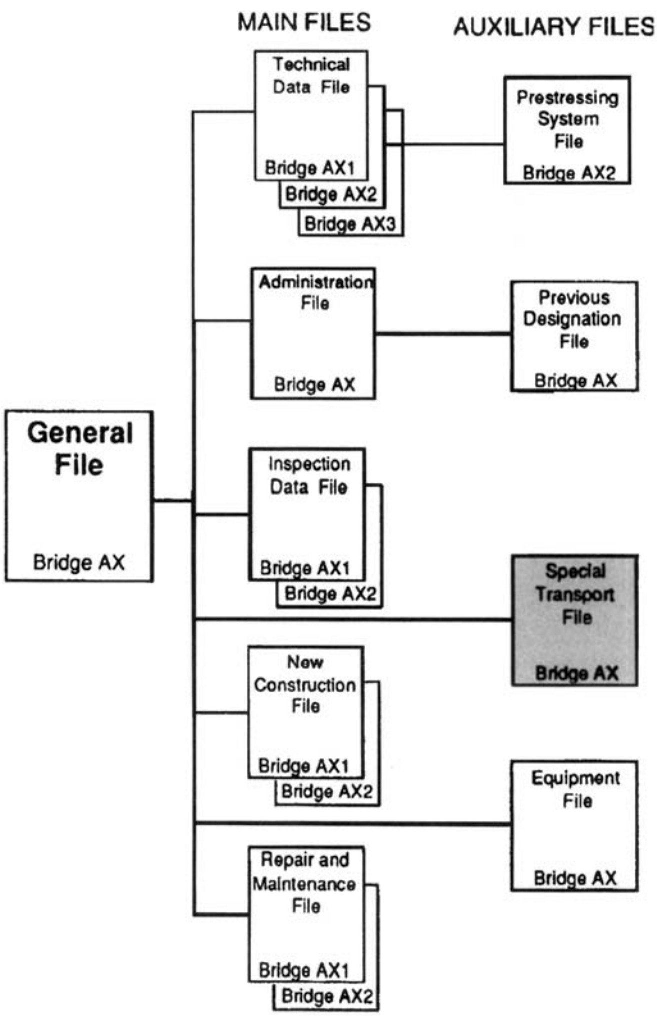

Figure 9-1. Subfile structure of the Austrian bridge database