WORK PACKAGE 9: PRACTICAL BRIDGE MANAGEMENT

Task 9.1 Bridge End-user needs

D.9.1.1 “End-user practical bridge management requirements”

July 2003

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Work Package 9.1: End-Users Requirements and
Criterias for Interfacing.

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Preface

This report is a deliverable from the Growth Thematic Network “Structural Assessment, Monitoring and Control “ (SAMCO), which was initiated in October 2001.

The present report constitute the deliverable D.9.1.1*“End-Users Requirements”* under task 9.1 “Bridge end-users needs”. The report presents also the milestone M.9.1.1 “*Criteria to interface monitoring and control with bridge management*” under task 9.1.

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Table of Contents

1 INTRODUCTION

The SAMCO network covers all the relevant the fields of structural assessment, monitoring and control as a part of the bridge management. The network includes a total of 9 workpackages, where WP 9 deals with Practical Bridge Management. The task 9.1 deals with the End-users needs and the present report constitutes one of the deliverables and describes essentially the End-users requirements to monitoring and control of the structures.

The report describes first the EU infrastructure with costs and traffic growth, then gives a brief description of the bridges with age, factors affecting the performance and the resulting needs for management, monitoring and increased knowledge. This is followed by a brief State-of-the-Art in the bridge management and an overview of the different national approaches and traditions, which currently prevents a standardisation. The report rounds of with a presentation of the resulting end-users needs as well as the criterias for interfacing monitoring and control with the bridge management.

2 THE INFRASTRUCTURE AND THE TRAFFIC GROWTH IN THE EU

As a result of the economic growth, mobility is expected to increase in the next years and for this reason the transport system represents a fundamental factor for the economic and social development of Europe, as it allows the quick, safe and easy exchange of passengers and freight.

2.1 The new EU-member states

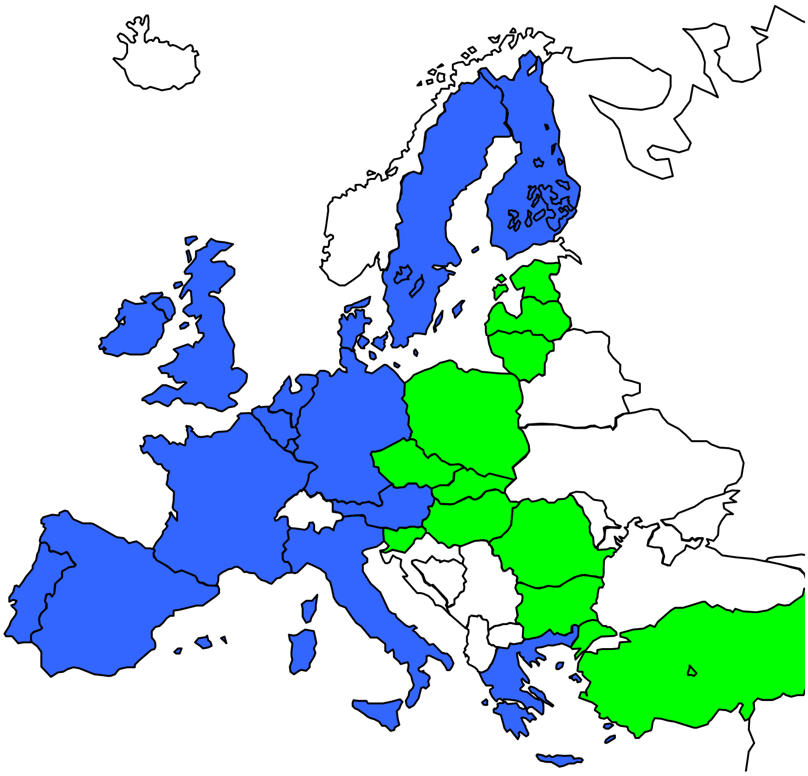

Fig. 1. The European countries with the 15 members (dark blue) and the countries applying for membership (light green).

The European Union has at present 15 members, but other countries are currently applying for membership in 2004 or later. This would most likely increase the amount of transport in central Europe and also change the directions.

2.2 Transport patterns

The distribution and development of passengers and goods among the different transport modes during the last 30 years can be found in the statistics prepared by the Eurostat /EUROSTAT, 2001/, just as some of the predictions for the future transport have been described in a “White paper” from the Commission /EU, 2001/. The distribution and growth shown on Figure 2 illustrates that by now, most of the transport is confided to the road system.

The transport on road dominates the person transport, where it accounts for 79% of the total person-km transport, while a 6% is by rail and 5% by air. Even the increasing share of the air transport have not been able to limit the growth of person-transport by road, since most of the growth in transport volume from 1970 to 1998, has been by road and have actually lead to app. 100 % growth of the road transport in this period.

It is still expected that road transport will continue to grow at a rate of 2-5 % each year, corresponding to a 100 % increase during the next 15-35 years.

As far as it concerns goods, the situation is a little different as only the 44 % of the whole market is allocated to roads and it is comparable only to the 41 % of short sea shipping, while only 8 % are allocated to the rail. In this case the most part of the transport growth of the last 30 years has been absorbed both by roads (expected 47 % by year 2010) and short sea shipping, while the rail share has dropped from the 21 % of 1970.

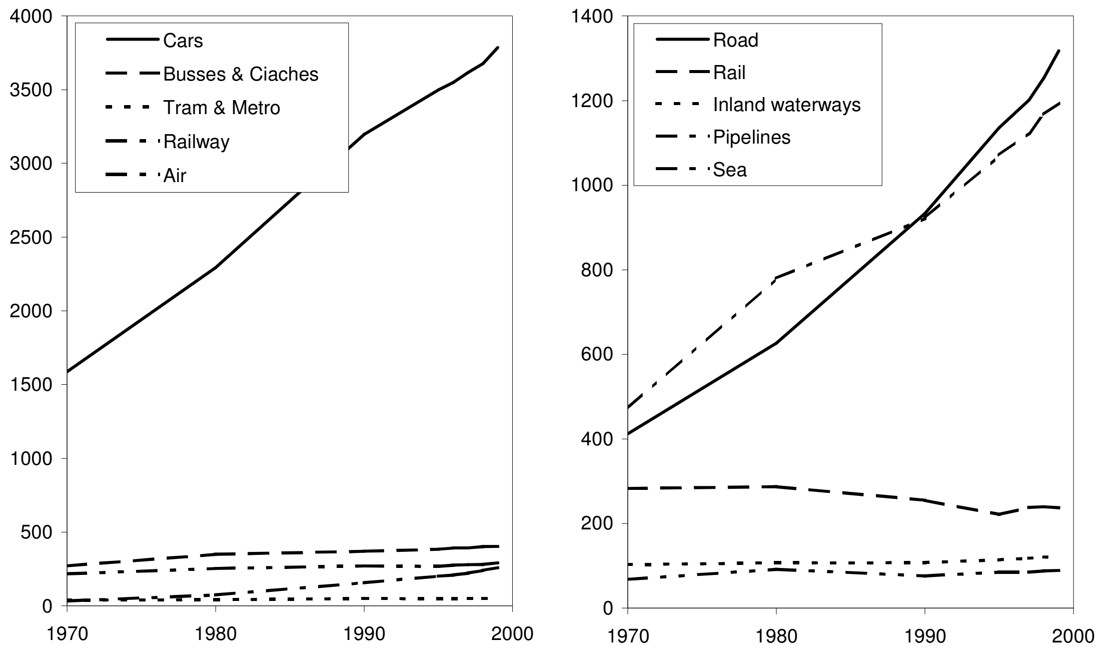

Fig. 2. Transport of passengers (left, mio pkm) and goods (right, mio tkm) /EUROSTAT, 2001/.

As a consequence of this uneven distribution of traffic, the problem of congestions is expected to spread out on the major trunk roads and trans-European corridors, with a 10% of traffic jams, as well as in the industrial and urban areas where saturation may be forecast /EU, 2001/. To complicate this scenario, it must be said that the car fleet is expanding by 3 million vehicles each year in the Union.

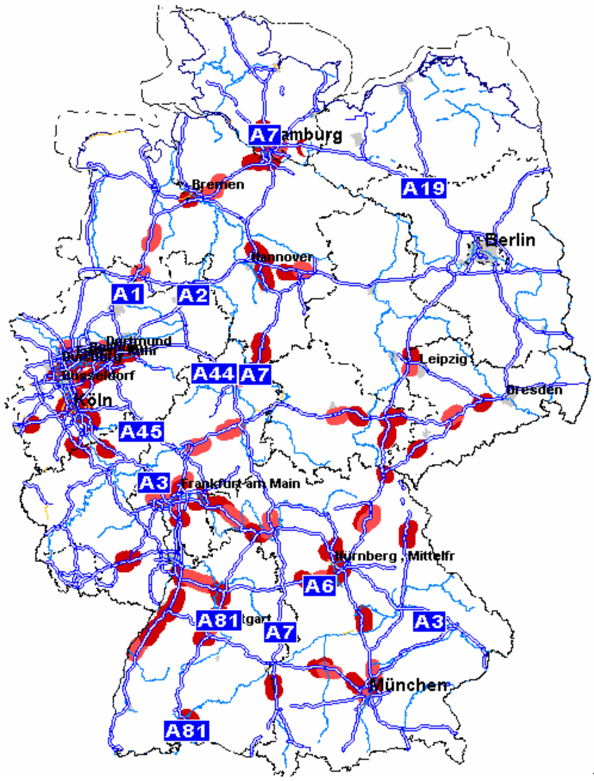

Fig. 3. Traffic map with main roads and risks of queues (delays) marked with red (from http://www.passo.de/servlet/vinfo Friday 2 August at 16.00).

Chronic congestion is experienced also on the rail system as well, with a 20% of the network classed as bottlenecks.

Limited new constructions are planned, the most of it is currently taking place in the regions and countries furthest from the center, to help their economic development and favor the access to the central market. In particular in the cohesion regions (the new members states) the motorway density increased by 43% in the years from 1988 to 1998, even if it still remains below the Union average.

The situation of the road sector in the 15 Countries of the Union is well represented in following Figures 4 to 6. The situation varies among the different nations as evaluated/described by the indicators: motorization cars/citizen, km of road/citizen, vehicles/km.

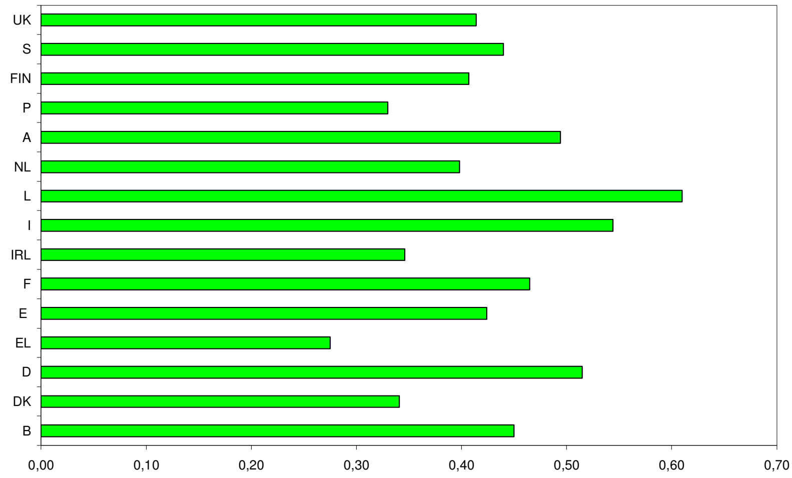

Fig. 4. Car per citizen in EU /EUROSTAT, 2001/.

For instance the situation is approximately the same all over the Union as far as it concerns the comparison of the number of cars for the population in Figure 4. The scenario changes if we consider the other indicators.

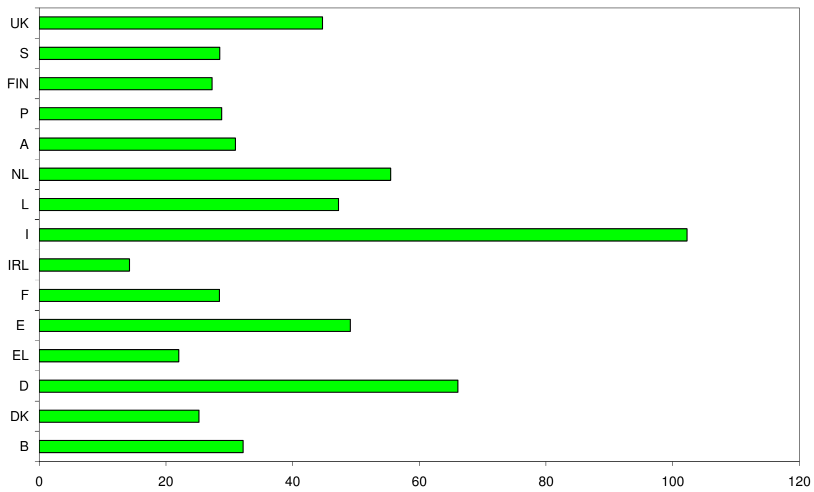

Fig. 5. Cars per km road in the EU /EUROSTAT, 2001/.

For instance, the number of vehicles per 100km is totally different (Figure 5) with the best ratio for Ireland while Italy, Germany and the Netherlands are in the lowest places. Also as far as the ratio km of roads/inhabitants the situation appears more critical in these countries.

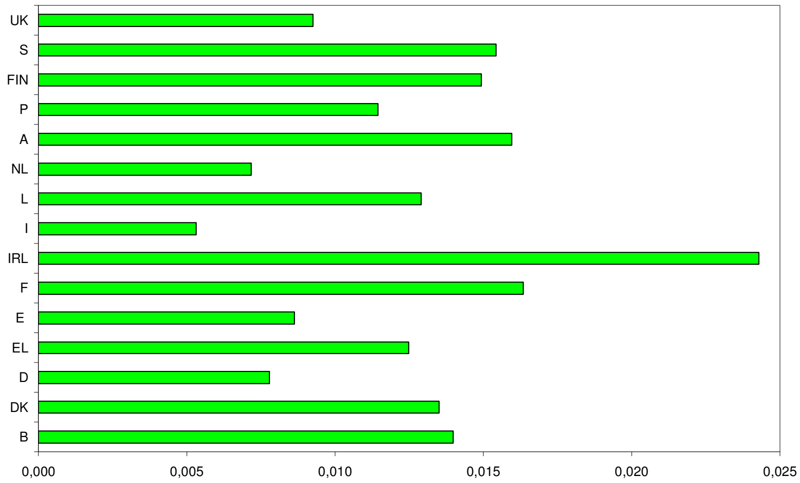

Fig. 6. Total km road per citizen in the EU /EUROSTAT, 2001/.

As a conclusion of this brief excursus, it may be said that the problem of offering adequate levels of service to the users in terms of safety and mobility on a network which is on one hand ageing and reaching the expected end of service life, defined as the minimum acceptable level of performance, and on the other hand insufficient to meet the transport demand rapidly increasing in volume and weight is commonly shared among all the countries of the Union.

To keep up, larger interventions of maintenance, repair and upgrading will be necessary with, of course, a negative impact on the circulation and a larger demand of funding.

2.3 Resources spent on (or in) infrastructure

The EUROSTAT /EUROSTAT, 2001/ presents a number of relevant data. The data shows that the transport sector employs a large number of personnel (1 million in rail transport and 2.6 million on road transport in the EU). The transport of goods and personnel accounts for 32 % of the energy consumption in the EU.

The daily transport time has remained constant around 1 hour during the period from 1970 to 2001, during which the average transport distance has increased from 17 to 35 km.

The time wasted in traffic delays (congestion) amounts to 40 000 million EURO annually, corresponding to 0.5 % of the G.D.P., but is expected to be twice as high by 2010. The direct costs of road accidents amount to 45 000 million EURO annually and involves 40 000 persons killed annually.

The new investments in the infrastructure correspond to app. 1 % of the G.D.P., just as the maintenance costs correspond to 1.5-2 % of the G.D.P.[/BRIME, 2001a/.] The current maintenance costs are app. 1 % of the replacement costs [/BRIME, 2001a/.]

3 THE EUROPEAN BRIDGES

The bridges are key elements in the infrastructure, since they represent 30 % of the infrastructure investments and are the critical parts of the infrastructure in terms of safety and functionality for the whole infrastructure.

The ageing and deterioration of the bridges and the increased traffic intensities and loads, makes the bridges the bottlenecks of the transport infrastructure. The inconveniences (congestions) created by the necessary activities for upgrading and repairing the bridges grow rapidly with increased traffic and age.

3.1 The age of the bridges

In the second half of the past century, the road network throughout the world was developed/expanded and the number of bridges increased correspondingly. This growth has reached its peak around the '70s in many countries, but there is still a limited request of new constructions although the maintenance costs for the more mature bridges (especially if built in the 50s and '60s) grow with an increasing speed.

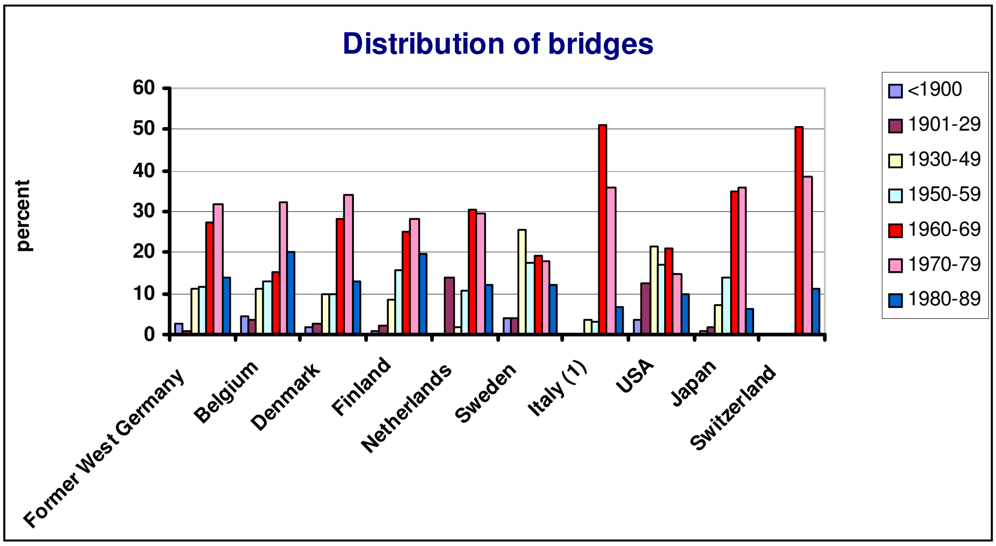

Fig. 8. Distribution of the age of road bridges /OECD, 1992/, /Di Mascio et al, 1998/.

Note (1) indicates that data are only for the bridges under Autostrade.

In general the limited availability of economic resources has made necessary a careful analysis of the conditions of the existing bridges with the aim of foreseeing and planning the interventions of repair not only for the existing population, but also for the bridges to be built by formulating new methodologies of design, able to optimize the type of structure and the choice of materials to minimize the totals cost of the structure (construction + maintenance)

The planning of maintenance interventions is possible only by knowing the performance of the structure in terms of durability and evolution of defects. This knowledge needs to be continuously updated with observations and information necessary to create the predictive models of the structural and functional degradation of the bridge.

A large part of the bridges in the new member states are not as well maintained as the bridges in the EU and will need substantial repairs and upgrades, before they fulfill the requirements for bridges in the EU.

For these reasons, special attention is focusing on the evaluation of the long-term performance and residual life in the project SAMCO on the monitoring and assessment of bridges considered to be main activities in the general sector of the management of bridges.

3.2 Factors affecting the long-term performance of bridges

Bridges are designed to carry traffic across an obstacle, their minimum length varying among the different countries form a minimum of 2m. (France) to 10 m. (Italy). They are supposed to resist loads from a number of different sources such as the weight, traffic, impact, horizontal forces and the environment. Of course, bridges should be designed for a given economic service life and of course they are supposed to resist in a harsh environment. However, during their service life, bridges are likely to deteriorate as a result of a loss of strength due to structural damage and for material degradation, but to remain serviceable.

Their performance is influenced by the interaction of two main factors: the environment and the traffic.

Even if these two mechanisms are generally known, it is quite difficult to assess their effects, to predict their evolution and to determine the consequences on the response of bridges.

First of all it is difficult to describe them in detail to choose adequate preventative measures at the design stage. For instance, when a structure or a component starts deteriorating, the process of damage of the whole bridge tends to increase as the presence of deteriorated parts might reduce the load carrying capacity and make the structure more “vulnerable” under heavy loads, as it might be the case of fatigue of materials.

Not all the factors that interfere in the service life of a bridge may be considered since the design stage. National and international standards and recommendations give only the criteria for modelling traffic and other actions generated by environmental factors, such as earthquakes, wind and thermal effects. Other types of actions, such as those linked to the type of environment or to the presence of aggressive factors may be considered only indirectly, by recurring to specific adequate design solutions, to specific construction techniques and maintenance policies. For instance, the increase in cover in reinforced or pre-stressed concrete structures to be built in coastal areas, or the adoption of special concrete mix with entrained air in cold countries are solutions that may slow down the process of deterioration of structures. Even the choice of a particular structural scheme, which allows the reduction or the elimination of the expansion joints, may lead to an increase of the durability of the structure over time.

Apart from a correct design and an attentive construction, the activities of monitoring and assessment are decisive for the long duration of bridges when carried out during the operation of the structure. For example, sometimes simple problems and defects, if not reported, and let free to deteriorate in an uncontrolled way, may lead to severe damage as e.g. in the case of:

- Chloride-induced corrosion, which may lead to very concentrated and local corrosion near a joint and no spalling, but where e.g. 50 % of the reinforcements cross-section may disappear and lead to unexpected structural collapse.

- Prestressed cables in ducts, which may also corrode without visible signs and lead to unexpected failures.

- Alkali-silica reactions and the carbonation-induced corrosion, which may lead to crack formations or spalling, which may not damage the structures safety, but where the debris may fall from the structure on to the road or railway and cause accidents.

Moreover, it may be said that the factors that influence the long-term performance of a bridge are difficult to be described theoretically. Their influence on the durability of structures may be assessed only on the basis of the information derived from experience.

For this objective, surveillance and monitoring of structures over time allow to derive structural and functional information on the process of deterioration. This information is useful at every stage into the life of a bridge.

First of all they are used to control and to assess the conditions of the structures during their service life. In this way it is possible for the road responsible to guarantee an adequate, at least sufficient, level of safety to traffic.

Second, as a consequence of the evaluation of safety, of the assessment of the extension of damage and of its evolution, on the basis of the results of surveillance and monitoring, it is possible to prioritise the interventions of repair and to choose the most effective maintenance actions. This will result in a reduction of the economic needs

Finally, all the information may be used as a feedback at the design and construction stage: to give indications on the type of materials and static scheme more suitable for the environment, where the structure will be built and for the foreseeable traffic.

3.3 Bridge management

Bridge management addresses all the activities that concern the life of a bridge from design and construction, through maintenance, surveillance and monitoring, to eventually replacement, and it is aimed at ensuring its safety and functionality also in terms of minimum traffic disruptions, efficiency and quality of the service offered to customers.

Deterioration of bridges may lead to a number of undesirable consequences such as:

- Loss of serviceability;
- Loss of load carrying capacity;
- Reduction in safety (of structures and/or of traffic);
- Increase in traffic restrictions;
- Loss of aesthetic value.

Management of bridges for owners of large infrastructures as well as for local authorities is becoming a critical problem, as while the bridges are ageing and transport is expected to increase in the future, on the contrary, the available funding allocated to management and maintenance is limited so that it will be necessary to extend the service life of structures while minimising the overall costs.

The problem is further complicated as bridges and their component parts may deteriorate at different rates and following different mechanisms as they are exposed to different macro and micro climates. Moreover bridges of similar construction may vary in age, structural scheme, materials, composition of traffic, presence of latent defects, all factors that can significantly affect the rate of deterioration.

It is therefore of the utmost importance to know the actual conditions of bridges and to predict their future state. Monitoring and assessment are therefore two important inputs in the general framework of the bridge management.

3.4 Need for assessment

Assessment may be loosely defined as the estimation of the bridge conditions. It may be the result of visual observations with all the limits of this practice; in this case, no complex computations are required. Or else, it may be the result of periodic (on site local testing) or continuous monitoring. In this case, testing results are linked to the definition of alarm thresholds or limit values for the monitored parameters, which might require a deeper knowledge of the structural behaviour (displacements below an acceptable value) or of the characteristics of the bridge (acceptable chloride content).

Finally bridge assessment may consist in determining the load carrying capacity in relation to specific loadings. It may be necessary or advisable:

- When loads are modified from the original design loads;
- When the geometry is changed (number of lanes or the deck is widened);
- When a structure has been damaged;
- When repairs or alterations have been carried out which modify the structural performance;
- In presence of exceptional loadings.

3.5 Need for monitoring

Within the general framework of bridge management, monitoring may be seen as the periodic or continuous observation and recording of information on the conditions or performance of bridges. Its main purpose is to detect and follow the initiation and progress of deterioration, should it occur.

Periodic observations are carried out at discrete intervals. Within this category fall both measurements and visual inspections.

Visual inspections, in particular, are widely used as a monitoring system, mainly due to their easiness of execution and low cost, even if their results are quite conservative. They give a qualitative estimation of the conditions of bridges, by identifying the level and extent of deterioration. Their frequency varies in function of the level of damage ascertained (from a few months to a few years).

Measurements (both periodic or continuous), as part of an on-site investigation, provide a necessary input for the subsequent assessment of the structural elements and the bridges conditions.

Their results are also used to calibrate and validate the predictive models of deterioration. In particular they are used to:

- Determine the extent of damage;
- Determine the strength of concrete, steel, etc (for instance from laboratory testing);
- Determine the condition of concrete, depth of carbonation, chloride penetration;
- Determine corrosion of steel;
- Determine loss/rupture of pre-stressing;
- Determine the load-carrying capacity (on-site load testing);

A specialised field of monitoring is represented by the long-term monitoring of the structural (deformations, temperature, cracks, pre-stressing forces) and dynamic behaviour (wind, traffic).

Measuring techniques are only one aspect of a monitoring programme, which must be tailored to the different monitoring objectives, to the bridge type and to the bridge life cycle situation. For instance in the service life of concrete bridges, a monitoring objective may be detection of corrosion.

A number of different techniques are available, from portable equipment to sensors permanently installed on the structure. For this last category of continuous monitoring, in particular with remote systems, their convenience depends on the type of construction, level of damage observed, installation costs and foreseeable consequences in terms of costs of maintenance and costs for data acquisition and interpretation.

Applications of remote systems may be envisaged for:

- Prototype structures or structures of strategic importance;
- Large structures;
- Structures in particularly aggressive environment;
- Parts of the structures difficult to access;
- Individual structures representative of a population of similar bridges;
- Structures where damage has been detected and monitoring is used to gather further information before repairs are carried out;
- Testing the efficacy of repairs when this type of repair is typical for a large number of structures (i.e. surface treatment).

4 BRIDGE MANAGEMENT IN EUROPE

4.1 State-of-the-Art

Bridge management involves in all countries and for all owners or operators a number of actions, as e.g. described in the BRIME-project [/BRIME, 1999/,/Brime, 2001/]. Bridge management will, however, always consist of the following main steps:

1. Assessment of the bridge;
2. Prediction of damage growth;
3. Net Present Value estimation of the different alternatives;
4. Deciding the maintenance of the individual bridges.

The assessment of the structures condition is based on one or several inspections, carried out over a long or short period. These inspections can be visual or involve use of NDT-equipment, sampling and testing. The terms used for the inspections as well as the frequencies varies from one country and/or bridge owner to another as described in the later clauses.

The result of the assessment is normally expressed as a value for the condition of the bridge as a whole or as a value for each of the structural components. This value is often a sum of a rating of the structural parts condition (e.g. 0=perfect, 3=totally damaged), the growth rate (e.g. 0=no growth, 1= extreme growth) and the damages influence of other components. The system for rating the structural part and the bridge varies also from one country and/or bridge owner to another as described in the later clauses.

The ratings from the assessment are always stored in a BMS (Bridge Management System), which in some cases also allow the user to store other information as e.g. inspection reports, drawings, illustrations, expected repair costs etc. The BMS used varies often from one country or owner to another, just as an owner or country may be using several different BMS.

The prediction of the damage growth is usually carried out in one of the following two manners:

1. The growth towards initiation of damage (usually corrosion) and the growth of the later damage are estimated, based on semi-empirical formulas, which essentially extrapolates the observations from NDT-mapping or sampling of the chloride content. This prediction is carried out on each bridge and structural part individually and will usually focus on the expected changes over a period of 5, 10 or 20-25 years.

2. The growth is represented by a move from a damage rating to another. This growth is modeled by Markov-chains, which essentially uses a prediction of the probability for moving to a certain other damage rating over the next period. This next period is usually 5, 10 or 20-25 years.

The repair options are considered by the bridge manager, by estimating the repair costs, the service life of the repair and evaluating which repairs, that are possible at a given damage rating.

The strategies possible for the individual bridge are compared and the NPV (Net Present Value) estimated for each strategy. The NPV would usually include the indirect traffic delay costs for the users of the bridge (drivers, passengers etc.).

It must here be pointed out that major traffic delays leads to quite direct costs for the private operators, since they will immediately lose costumers and income, just as their approved rates may not be increased as otherwise expected. The public funded operators will usually be able to argue for an increased funding in case of major traffic delays, due to the political pressure.

The optimal strategy would usually be considered to be the cheapest (lowest NPV) and would often lead to the conclusion that the repairs should be postponed for another 5-10 years.

The priorities for choosing the bridges to repair are that the bridges with safety problems will receive the highest priority and the rest will be based on the NPV-estimations and the availability of funding. Safety problems can be for the structure or for the users, e.g. due to cover falling off and falling down on the highway.

The private operators of highways (toll-roads) have the option of actually postponing the repairs until the optimal point (from a financial point), since they can invest the money in e.g. bonds, new facilities or take a loan for financing the repairs.

The government-funded operators (national road directorates) are not allowed to take up loans and can not place the money anywhere, but are obliged to either spend the money in the fiscal year or accept a reduced funding. These operators will therefore be forced to carry out a more constant amount of repair activities in order to avoid a major backlog of repairs in e.g. 10 years time.

The biggest uncertainties for the bridge management are in the assessment of the structures condition and in the damage growth and the consequences on this growth. These uncertainties can be reduced to a large extent by monitoring and NDT-inspections combined.

The lack of standardization in the following items:

- Types of inspections/assessment of a bridge;
- Rating of the structures and the structural components damage degree;
- The bridge management system (BMS) used and the data stored in the system;

provides, however, still a substantial barrier for real exchange of knowledge and experience.

The three points above will be presented briefly country by country in the next sections.

The presentations are based on contributions from the partners and members in SAMCO and have been edited to some extend by the WP9.1-leader. The partners, members and leader have made an effort to present the information in the manner for each country. The differences in the contents of the types of inspections, the ratings and in the data stored in the BMS-systems makes is, however, difficult to present the information from different countries in the identical same way for all countries.

4.2 Denmark (RAMBOLL)

The Danish practice (in the Danish Road Directorate) includes the types of inspections listed in Table 1 and uses the ratings described in Table 2.

Inspection type	Frequency	Result
Routine	1-6 years	Visual inspection, leading to the condition rating of the 13 basic components, which the bridge may consist of. Needs for maintenance, cleaning, repairs or additional inspections are identified.
Principal	< 6 years	Extensive visual inspection, leading to recommendations for special inspections incl. which methods, areas and sample types to be considered.
Special	When needed	Visual inspection combined with NDT-testing and sampling with the purpose of determining the causes and extend of damage and to propose the optimal actions to be taken.

Table 1. Inspection types in Denmark.

Rating	Description
0	Only insignificant deteriorations. No or little damage and the structures condition is as a new.
1	Only minor signs of deterioration. Damage may occur and develop over many years. No repair required as the condition is almost as new.
2	The observed damage is only slightly developed or only few, developed cases of damage are observed. Repair is only carried out if convenient, as the element will function for many years still.
3	The damage has reached such a condition and size, so the functionality is at risk in a few years. Repair will be required in a few years time.
4	The element is severely damaged and the functionality is no longer present or will disappear in a few years time. Repair is required in near future.
5	The element is completely deteriorated and must be repaired immediately.

Table 2. Condition rating used in Denmark /VD, 1994/ is a sum of the damage rating (0-3), the functionality rating (0-1) and the consequence rating (0-1).

The bridge management systems used in Denmark are DANBRO, DANBRO+ and DANBROweb.

4.3 United Kingdom (TRL)

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

Superficial inspection: These are carried out regularly by staff from the Maintaining Agent. It is a cursory check of obvious defects that might lead to accidents or high maintenance costs. It can be made from ground and deck level or from any walkway or platform, built into a structure. If any superficial inspection reveals a possible defect, which is a hazard to road, rail or other users, the Maintaining Agent immediately takes the actions required to safeguard the public. The overseeing organisation and the owner of the structure are informed immediately.

General inspection: This is a visual examination of all parts of the structure, adjacent earthworks or waterways which can be visually inspected from ground and deck level or from any walkway or platform, built into a structure, without the need for special access or traffic management arrangements. Inspections are required not more than two years after the last General or Principal inspection.

Principal inspection: This is a close examination within touching distance of all inspectable parts of the structure and adjacent earthworks and waterways, utilising suitable access or traffic management where necessary. The inspection is carried out at intervals set initially by agreement, which normally would be six years and exceptionally may be up to ten years for less important structures. For the new structures it is carried out about one month before the end of the construction contract Maintenance Period, or opening of the structure to traffic. In recent years limited testing has been included.

Special inspection: This is a close examination of particular areas or defects causing concern. It is carried out to investigate a specific problem, either found during inspection or already discovered on other similar structures. It is also carried out in other specific circumstances, for example on cast iron structures at intervals not exceeding six months, on structures strengthened using bonded plates and on structures which have weight or other forms of restrictions. Other examples include structures that have to carry an abnormal heavy load before, during and after the passage of the load, where a structural assessment has indicated that it is necessary.

Reporting inspections

Defects revealed during a superficial inspection are reported to the Maintaining Agent and appropriate action taken as described in the previous section.

The findings from General, Principal and Special Inspections are recorded on special forms. These include basic information such as structure number, structure name, date and type of inspection and an overall assessment of the structure as either good, fair or poor.

The forms include a list of 33 structural items (e.g. foundations, piers or columns, abutments, wing walls, retaining walls, approach embankments, fenders, bearings, main beams/tunnel transverse beams, diaphragms, concrete slabs, waterproofing, surfacing, expansion joints). Any defects observed on any of these structural items are assessed in terms of the estimated costs, extent, severity, work and priority. Table 3 defines the four categories for the extent of any damage that is present and Table 4 defines the four categories of severity of the damage. Table 5 lists the seven types of recommended work. Table 6 lists the eight investigation types, which can only be used when actual work is not recommended and Table 7 lists the three levels of priority.

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

Table 3. Extent of damage.

Severity	Description
1	No significant defects
2	Minor defects or of a non-urgent nature
3	Defects which shall be included for attention within the next annual maintenance programme
4	Severe defects where urgent action is needed

Table 4. Severity of damage.

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

Table 5. Action types.

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

Table 6. Investigation types to be used for different cases.

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

Table 7. Priority levels.

In addition to completing the forms, the findings from Principal and Special Inspections are described in detailed reports. These include details of the structure including a drawing showing the form of construction and a description of the deck, supports, articulation, deck ancillaries such as expansion joints, waterproofing, parapets, and any other relevant information. The reports also include the maintenance history of the structure, previous inspections and a detailed description of the condition of each element inspected.

4.4 France (LCPC)

The practice prescribed by the French Directorate of Roads and Highways includes the types of inspections listed in Table 8 and the condition ratings described in Table 9.

Inspection type	Frequency	Result
Annual check	1 year	Identification of bridge, date of check observed anomalies and signs of change. Work must be carried out by a Subdivision employee (brief inspection at the same time as routine maintenance).
Assessment inspection (IQOA inspection)	3 years	If a detailed inspection has been conducted during the year, an assessment of the bridge is made (according to the IQOA classification) on the basis of the detailed inspection report if not assessment is performed after inspection as laid down by the IQOA method with production of reports in standard form. Work must be carried out by a Subdivision employee, with District Bridge Unit support.
Detailed periodic inspections	Only medium or large bridges: in principle 6 years, but modifications are possible: • 9 year for the strongest • 3 year if necessary • 1 year for the most vulnerable	Detailed report amounting to a report on the health of the bridge. Directed and exploited by a qualified engineer with special training in bridges and bridge pathology (from District Bridge Unit, technical network or approved external sources).

Table 8. Inspection types in France

The IQOA method (Image Qualité des Ouvrages d'Art - Image of Bridge Quality) is based on a classification of bridges, which is intended to provide an indicator of the mean condition of a set of bridges from an assessment of each bridge.

Rating	Description
1	Bridge in good apparent condition requiring only routine maintenance as defined in the Instructions for Bridge Survey and Maintenance (ITSEOA)
	Bridge in good apparent structural condition or with minor defects which requires specialized maintenance
2	Defects, of whatever severity, affect equipments or structural protection devices and minor (i.e. superficial and localized) defects affect the structure of the bridge, but not urgent
2E	As above, but action is urgent, in order to prevent rapid development of structural deficiencies (*)
	Structurally impaired bridge requiring repair works
3	There are major structural defects, but action is not urgent
3U	As above, but action is urgent because the bearing capacity of the bridge is either inadequate already or will become so in the near future as a result of the rapid development of deficiencies
NE	Not assessed

Table 9. Condition ratings used in France. Note (*): The urgency which can lead to a bridge being placed in class 2E should be assessed with reference to defects whose development can lead in a short period of time to the structure entering class 3 because of the appearance of major defects in the structure.

4.5 Italy (SPEA)

The problem of the maintenance of structures is currently becoming more and more important and the resources allocated to it have non-negligible weight on the budget of the structures' operators.

It is now in fact a consolidated opinion that structures are subject to ageing partly because of the specific use they are intended for, and partly due to the environmental agents affecting them. These two factors together are of particular importance as it regards the maintenance of road structures, where the need has now become pressing to check that nothing occurs to jeopardise the conditions of structures, their duration and the safety for the users.

A correct maintenance policy calls, first of all, for the surveillance of structures, since its precise implementation is the first step to be taken in order to assess the durability of structures as well as to define the most suitable maintenance actions under the technical and temporal point of view.

In Italy surveillance is carried out through a series of operations aiming at drawing up, maintaining and keeping up to date the monitoring records and the documentation regarding the structures. On the basis of the data collected from the records, specific "inventory charts" are drawn up. These enable the immediate identification and location of every structure, as a whole, together with its main administrative and technical data.

The types of inspections carried out in Italy are described below and summarised in Table 10.

General inspections. This is a visual examination of all parts of the structure, which can be visually inspected from the ground and deck level. They are carried out quarterly, in obedience to the Italian law by trained personnel. A general inspection by an engineer is carried out once a year. Defects revealed on the bridges are rated according to the classification given in Table 11. The results emerging from this kind of inspections are reported on special forms, together with short comments regarding irregular behaviours occurred and the possible need to carry out more careful inspections. Therefore general inspections are allowed to have general information about the condition state of the structures. On the basis of the indications highlighted by the general inspections, both principal and special inspections are planned.

Principal inspections. This is a close examination within touching distance of all inspectable parts of the structure. It may require the use of a moveable platform thus interfering with the circulation. They are scheduled in function of the level of deterioration shown. Defects are recorded on a geometric representation of the structure and its component parts.

<u>Special inspections.</u> Special inspections are carried out when needed, in general, to assess the structural relevance of visual damage. They aim at detecting, by means of instrumental control, faults and irregular behaviours, which by simple visual checks, cannot be identified. They are mostly used as input for design of repairs.

Over the years a shift from handicraft surveillance systems, grounded on each surveyor's sensitivity and expert eye, to advanced systems characterized by uniform criteria for assessment of faults has been witness. This result has been achieved through longstanding experience and careful and through scientific research. Today, thanks to an electronic data bank storing both coded historical data and data collected during inspections, an immediate knowledge concerning the condition state of each structure is possible.

Inspection Type	Frequency	Personnel	Description	Result
General (Systematic)	3 months	Trained personnel	Visual inspection of each part of the structure	"Faults Report"
	1 year	Engineer		
Principal	1 - 2 - 4 years	Engineer	Close visual inspection of each part of the structure	"Faults Chart"
Special	When needed	Engineer	Visual inspection combined with NDT-testing and sampling.	Report

Table 10. Inspection types in Italy.

Rating	Description
0	No significant defects. Feedback to routine maintenance.
1	Only minor signs of deterioration. Damage does not develop . No specific action is needed.
2	Only minor defects, at a preliminary stage, that might develop further. No specific action is needed.
3	Defects are developing, but no specific action is needed.
4	Defects are developing, but they are of a non-urgent nature. Measures to stop damage are not foreseeable up to 5 years.
5	Damage has reached such a condition that repair is required within 5 years. However damaged does not affect the structural safety.
6	Damage does not compromise safety, but actions must be taken within 2 years.
7	Damage reduces the safety coefficient, actions must be taken within 2 years.

Table 11. Condition ratings used in Italy.

4.6 Germany (BaSt)

The federal road network of Germany contains a large number of bridges and other highway structures. The maintenance programs to be prepared for this purpose requires a high budget, and influences the traffic infrastructure and, thus, the economy and society as a whole. Due to growing volumes of traffic and higher weights of trucks, bridges in roads are subjected to increasing loads, which implies that maintenance costs will be rising in the future. Considering the fact that financial resources become continuously tighter, the maintenance costs have to be spent in a way to obtain the greatest possible benefits. This task will in the future be supported by the application of a Management System (Bridge Management System, BMS).

The competencies and tasks related to road construction are specified in the constitution of the Federal Republic of Germany. In accordance with the German basic law, the Federal Government is the owner of the federal road network. The states administer these roads under their own responsibility as authorities commissioned by the Federal Government.

An important task of administrators is the observation and inspection of the structural inventory. To ensure a constant supply of actual data concerning existing structures, the structural data are registered, stored and evaluated by the administrative authorities of the states with the help of electronic data processing equipment. In Germany these data are acquired and stored in accordance with the instructions ASB (Road Database Instructions), 1998 edition[1]. The SIB-Structures program system (Road Information Database - Structures) was conceived and realised simultaneously to the ASB; this system is intended for the registration, storage and evaluation of the structural data and is introduced by the state agencies. In addition SIB-Structures is also used for registration of data concerning inspection results and damage, maintenance measures as well as maintenance costs. Beside this, SIB-Bauwerke contains a tool to analyse data on network level and to produce statistics.

To improve the information situation at the federal level, the Federal Ministry of Transport, Building and Housing is presently developing a database titled BISStra (Federal Road Information System) and an analysing tool titled ISBW (Information System – Structures) to include and to analyse state-level data in accordance with the ASB. BISStra also includes a linkage to traffic- and accident related data and it contains a global information system (GIS).

DIN 1076 ”Engineering Structures in Connection with Roads; Observation and Inspection” [2] regulates the technical observation, inspection and testing of the stability and traffic-safety of bridges and other engineering structures in connection with roads. Inspections are performed by an experienced civil engineer who records damages and faults directly at the structure supported by the SIB-Bauwerke program system. The German practice includes the types of inspections listed in Table 12.

Inspection	Frequency	Result

Major	6 years	Extensive inspection of every component from touching distance, damage and deterioration assessment acc. to RI-EBW-PRÜF, leading to the condition rating of the entire structure. Needs for maintenance, cleaning, repairs or additional inspections are identified, recommendations for special inspections are given.
Minor	6 years, 3 years after main insp.	Visual inspection of every component without viewing equipment. The damage and defects identified in the major inspection are investigated.
Ad-hoc	When needed	Follows major events affecting the condition of the structure. The extent is determined on a case-by-case basis.
Regulatory requirements	When needed	Machinery and electrical equipment are inspected in accordance with other regulations and standards

Table 12. Inspection types in Germany.

The RI-EBW-PRÜF ”Guideline for Standardised Registration, Processing and Analysis of the Results of Inspection in Accordance with DIN 1076”, 1998 edition [3] contains rules for a simple and standardised logging of the results of inspection. The standardised procedure allows structural conditions to be rated in accordance with the various criteria and the inspection results to be linked with the construction-related data in accordance with ASB. The technique of condition assessment is characterised by a detailed damage and condition assessment in accordance with standard criteria. As part of inspection, every single damage is evaluated separately in terms of its effect on the stability, traffic safety and durability of the structure and recorded by SIB-Bauwerke. This damage evaluation is used as a basis for automatically calculating the condition grade for the entire structure. The extent of damage and the number of individual occurrences of damage is also considered in this process. RI-EBW-PRÜF contains detailed definitions of assessment criteria and sample catalogues for a standard evaluation of damage.

Inspection results form the basis for all maintenance planning activities. At state level in most cases construction agencies are in charge of performing inspections. The findings obtained from the bridge inspections and additional object-related analyses are used to prepare the maintenance concepts at the construction agencies. The preparation of performance specifications, announcements/allocations as well as the processing and documentation of projects are also performed here. Annual construction programs are prepared by the agencies and co-ordinated with the responsible, higher-level authorities. Prioritisation is performed on the basis of the existing severity of damage, operational and traffic-related circumstances and available financial resources. Cost estimates prepared by the agencies generally result in the requirement reports for the Federal Ministry.

For controlling purposes, the states annually supply the Federal Ministry with average structural condition grades classified in accordance with structural type. The states have to report a medium-term requirement program for maintenance and an annual program plan for the following year. These reports provide the federal authorities with important information concerning major upcoming repair measures and the corresponding resource requirements.

At present, in Germany, the Federal Ministry of Transport is developing a comprehensive management system for structural maintenance. The planned management system is to provide the Federal Ministry with an overview of the current condition of structures at the network level, estimate future funding requirements and develop strategies for achieving long-term objectives and carrying out routine maintenance. In addition, it will provide the state bridge authorities with the programmes of work required to obtain improvements at the project level that maintain structures in an acceptable condition and meet network level strategies, long-term objectives and budgetary restrictions. Some of the above mentioned topics have already been realised. Computer programs for cost/benefit-analysis on project level and for network-wide maintenance optimisation are currently being prepared.

4.7 Spain (Geocisa)

The Bridge-management in Spain is carried out by two different approaches: The first is used on the Madrid Regional Road Network and the second is used on the State Road Network.

Madrid Regional Road Network

The practice in Madrid Regional Road Network includes the types of inspections listed in Table 13 and the condition ratings described in Table 14.

The BMS used by this regional administration is GEOCISA BMS.

Data stored in the system includes:

- Inventory data.
- Inspection data.
- Proposed repair: technical data and budget needs.
- Actually executed repair: technical data and amounts really invested.
- Others (Inspection reports, project documents, etc.)

Inspection type	Frequency	Description
Routine	1-6 months	Visual Inspection. Non technically specialised staff required (performed by road maintenance personnel). General maintenance (cleaning, simple repair…). Higher level inspection should be performed if unusual cases of damage are detected.
Principal (General)	15-21-27 months	Visual Inspection. Instructed Technical staff required. Data collection of all detected damages leading to condition rating. No special means of access used. Frequency varies depending on the significance of the road (3 levels exist). Higher level inspection should be performed if unusual cases of damage are detected.
Principal (Detailed)	5-7-9 years	Extensive visual Inspection. Instructed Technical staff required. Data collection of all detected damages leading to condition rating. Special access used if required (crane, automobile platforms etc.). Frequency varies depending on the significance of the road (3 levels exist). Higher level inspection should be performed if unusual cases of damage are detected.
Special	When needed	Extensive visual Inspection. NDT, sampling, numerical analysis, performed as required. Experienced Technical staff required. Detailed assessment of the bridge performed.

Table 13. Types of inspections in Madrid Regional Road Network.

Rating	Description

0-20	No or few non-significant cases of damage
20-40	Damage may develop in the future or is in its initial step.
40-60	Damage is already developing. Repair is needed in short/middle-term.
60-80	Severe damage which could affect the structural behaviour. Short-term repair is needed.
80-100	Quite severe damage. The bridge, or part of it, is close to its structural limit. Use restrictions and urgent repair is needed.

Table 14. Rating of the structures and structural components damage degree. Condition rating is the combination of 4 indexes: damage extension (1-4), gravity (0-2), predictable evolution (0-2), and influence on other elements (0-2).

State General Interest Road Network

The practice in the State General Interest Road Network includes the types of inspections listed in Table 15 and the condition ratings described in Table 16.

The BMS used by this administration is SGP 2000.

Data stored in the system includes:

- Inventory data.
- Inspection data.
- Maintenance data.

Inspection type	Frequency	Description
Principal	5 years	Visual Inspection. Instructed Technical staff required. Data collection of all detected damages leading to condition rating. No special means of access used. Higher level inspection should be performed if unusual damages are detected.
Special	When needed	Extensive visual Inspection. NDT, sampling, numerical analysis, performed as required… Experienced Technical staff required. Detailed assessment of the bridge performed.

Table 15. Types of inspections in State General Interest Road Network.

Rating	Description
0 – 11	No or few non-significant damages
11 – 16	Damages may develop in the future or are in its initial step.
16 - 32	Damages are already developing. Repair is needed in short/middle-term.
32 - 64	Quite severe damages. The bridge, or part of it, is close to its structural limit. Use restrictions and urgent repair is needed.

Table 16. Rating of the structures and structural components damage degree. Condition rating of the bridge is the combination of indexes: worst condition grade of the individual elements, importance of this element in the bridge and importance of the bridge in the State General Interest Road Network

4.8 Poland (Ibdim)

In the beginning of nineties the system of bridge inspection system was established on Polish road network. The system deals with structures existing on national network only, which is administrated by General Directorate for Public Roads. The national network covers only 15% of bridges in rural roads in stock but 33% in length, which means that the national network shelters the biggest and most important bridges in Poland. Apart from that independent administrators, have incorporated this system as well. Therefore it is in power claiming that the system is represented for Polish road network.

Instruction prepared for supervising highway engineering structures was addressed for bridge, culverts and tunnels only. There are no special guidelines for inspecting other highway structures as retaining walls or specialized constructions, unless a special program of investigation or monitoring was elaborated for any particular object. No standard test (test loading for example) is being conducted except bridges. Other highways structures are being examined during routine inspection of road carried out every three months.

There are four grades of inspections predicted by the instruction for bridge structures as described in Table 17.

The inspections are part of the Bridge Management System (SGM) and they enable the road maintenance services to plan and carry out the necessary repair. The Inspection System is in line with the OECD recommendations on bridge management.

Inspection type	Frequency	Result
Routine	3 month	The aim of this investigation is the following findings: structure technical usefulness and conditions of safe service, list of potential detriments, which should be made in a near future or in urgent procedure, the necessity of general investigation of structure or principal inspection of particular elements. The routine inspection should be conducted by road maintenance service.
General	1 year	The general aim of this investigation is the assessment structure condition and listing of any structure changes occurred during its service. There are the following findings obtained after the investigation: the structure technical usefulness and conditions of safe service, list of potential detriments, which should be made in a near future or in urgent procedure, the necessity of principal investigation of structure or special inspection of particular elements. The general inspection should be conducted by graduated in Civil Engineering person, who has been trained at special bridge courses.
Principal	< 5 years	The general aims of the investigation are the following findings: the structure technical usefulness and safe service conditions, list of potential deteriorations, which should be made in a near future or in urgent procedure, the necessity of special inspection. The principal inspection should be conducted by the team of specialist leaded by graduated in Civil Engineering person, who has been trained at special bridge courses.
Special	When needed	This inspection is set up when the previous ones show its necessity or a minor accident has happened (severe impact, flood, fire etc.). The main aim of the special inspection is to asses whether the structure or its part assure the safe service and to point out potential repairing or strengthening method. The inspection is carried out by qualified specialist (usually universities or research institutions) using sophisticated tools (calculations, investigations, experiments, test loading etc.)

Table 17. Inspection types in Poland
(One inspection may recommend a new inspection of a higher level).

The condition assessment of the whole structure is composed from the partial assessment of every part of the structure, organized in 12 main groups. Each of them receives an evaluation rated in a six grading scale shown in Table 18 and the current bridge technical condition is calculated as the average of each element assessment.

Rating	Description
5	Adequate
4	Satisfactory
3	Alarming

2	Inadequate
1	Pre-emergency
0	Emergency

Table 18. Condition rating in Poland

There is no catalogue of the defects approved for official use, so the evaluation of severity as well the influence on whole bridge safety must be done by experienced inspector. Every fatigue is documented with photocopy so consultants if necessary can reassess the defect. This documentation together with the whole structure report is being stored in the administrator archive to be used during next inspection.

This procedure is used in a matter of bridge constructions (bridges, viaducts, trestle bridges or footpath bridges) only. The other road structures are evaluated on behalf of inspector experience and knowledge in everyday practice. In special incidents, which usually means that the structure shows the first signs of poor behaviour (or even worse – calamity), research centres (technical universities or science institutes), which are not in the Polish Road Administration organisation, are asked to prepare the construction condition evaluation. This estimation is based on calculation and investigation but it is extraordinary practice.

The bridge management systems in Poland are CEDOM (road bridges) and SMOK (railway bridges). Both are elaborated by relevant administrations together with some leadings research centres in Poland. SMOK and CEDOM were created in the beginning of nineties, last century. Systems collect and process information regarding stock of structures, their location and ownership status as well as the condition of bridges.

Additional information about the Polish road and bridge network is found below in Table 19 and Table 20.

It.	Road category	Estimated road length [km]
1	National roads	18 067
2	Voivodship (province) roads	28 381
3	District roads	128 170
4	Communal roads	197 351
Total		371 969

Table 19. Road categories and lengths in Poland.

<table>
<tr><td colspan="2">Road category</td><td>Administration unit</td><td>No of bridges</td><td>Length [m]</td><td>Surface [m²]</td></tr>
<tr><td rowspan="4">Rural roads</td><td>National roads</td><td>GDPR</td><td>3 517</td><td>144 685</td><td>1 767 702</td></tr>
<tr><td>Voivodship roads</td><td>voivodship administration</td><td>3 491</td><td>65 236</td><td>630 107</td></tr>
<tr><td>District roads</td><td>district administration</td><td>9 167</td><td>130 611</td><td>1 026 659</td></tr>
<tr><td>Commune roads</td><td>municipality</td><td>7 744</td><td>95 726</td><td>N a</td></tr>
<tr><td colspan="3">Total</td><td>23 919</td><td>436 257</td><td>-</td></tr>
<tr><td colspan="2">Urban roads (national, voivodship, district and commune roads)</td><td>GDPR, local governments (voivodship, district, municipality)</td><td>5 090</td><td>127 883</td><td>1 398 669</td></tr>
<tr><td colspan="3">Total</td><td>29 009</td><td>564 140</td><td>-</td></tr>
</table>

Table 20. Bridges in Poland.

4.9 Norway (NPRA)

Structures in the Norwegian road network owned by the Public Roads Administration are considered to be bridges when the accumulated spans or total length equals or exceed 2.5 m. Those are regularly inspected. The inspection types reflect the thoroughness and frequency of inspections. The bridge inspection cycle starts when construction is complete at which point the acceptance and guarantee inspections are carried out. After the bridges have been handed over to the owner, routine inspections shall be carried out for the rest of the bridge's service life. This involves the following inspection types:

- General inspection
- Major inspection
- Special inspection.

which are described in the following.

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

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

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

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

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

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

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

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

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

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

Additional actions are taken for the inspection of cables and under water inspections, which are described in the following.

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

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

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

Major under water inspection: The purpose of this inspection is to check the condition of any foundations under water and that of the bottom to ensure that they are functional. In addition, the inspection should determine the need for maintenance activities and make cost estimates for these.

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

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

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

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

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

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

The degree of damage is measured by a numerical scale used to give a technical assessment of the magnitude of the damage/deficiency; that is, whether maintenance activities must be executed or not, and if so, how soon. In the Table 21 the codes for the degree of damage are presented.

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

Table 21. Damage condition rating in Norway.

The impact of the damage is represented by a letter code used to indicate the consequences any damage/deficiency might have on the bridge, bridge users and/or environment. The codes are presented in the Table 22.

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

Table 22. Damage impact rating in Norway.

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

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

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

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

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

5 INTERFACING MONITORING AND CONTROL WITH BRIDGE MANAGEMENT

The interfacing of monitoring and control to the practical bridge management can only be established by focusing on the end-users needs, problems, budgets and experiences.

A number of these has been discussed in the previous part of the report and during discussions with the partners and members in the SAMCO network. A questionnaire dealing with these aspects has been sent out to additional, selected end-users. The results from the questionnaire are presented in the following section 5.1.

The criteria for the interfacing are finally presented in section 5.2 and incorporated the information obtained and presented in sections 2, 3 and 5.1.

5.1 Questionnaire on end-users requirements for monitoring

A questionnaire (in Annex A) dealing with end-user requirements to monitoring, which were to be used in practical bridge management was sent out in October 2002. The questionnaire dealt mainly with the monitoring and its intended use in management:

1. Requirements for the sensors (accuracy, calibration, installation).
2. Experiences with using monitoring.
3. What would your requirements be for a monitoring system ?.
4. What do you spend most of you maintenance costs on and what kind of monitoring would be required to reduce these costs ?.

A number of replies to the questionnaire were received during the period of November 2002 to January 2003. These answers came from institutions, directorates, companies and consultants, who manage over 45.000 European road and railway bridges in total, distributed as shown in Table 23.

Bridges (not culverts)	Numbers	Percentage
Reinforced concrete bridges	33987	78%
Pre-stressed (1)	17281	40%
Post-tension (1)	225	1%
Un-reinforced concrete bridges	940	2%
Composite bridges	1271	3%
Steel bridges	3887	9%
Timber bridges	792	2%
Stone bridges	1376	3%
Other bridge types	1154	3%

Table 23. Types of bridges. (1): Included in the reinforced concrete bridges above.

Bridges (not culverts)	Numbers	Percentage
Large (more than 5 span or total length over 500 m)	1635	4%
Medium	7844	17%
Small (1-2 span and total length less than 40 m)	36532	79%

Table 24. Size of bridges.

The Table 23 shows that app. 80 % of the bridges were built with reinforced concrete and Table 24 shows that app. 80 % of the bridges are small bridges and that only 4 % of the bridges are classified as large bridges.

The end-users were also asked to give an overview of the distribution of their maintenance costs (as this would pinpoint the monitoring and inspection needs, seen from a market-based point-of-view). The precise cost allocation differed from one end-user to another, both due to the differences in bridge types and also due to the details in their answers in the questionnaires, but an overview is indicated in Table 25.

Causes of required maintenance	Approximate cost share
Defect moisture protection (not steel bridges)	up to 50 %
Defect surface protection (steel bridges)	up to 20 %
Chloride induced corrosion (concrete bridges)	up to 95 %
Carbonation (concrete bridges)	up to 15 %
Fatigue (steel bridges)	up to 60 %
Defective joints in concrete bridges	up to 30 %
Impact from high vehicles	up to 40 %

Table 25. Cost allocation in annual budgets.

The end-users spend annually considerable costs on the inspections, assessments and maintenance activities as shown in Table 26 for the selected end-users, who answered the questionnaire.

Activity	Annual budget (total and distribution)	
Budget for inspection and assessment	22 million EURO	5 %
Budget for maintenance	450 million EURO	95 %

Table 26. Annual budgets for the end-users, who answered the questionnaire.

The Table 25 identifies the main causes for the required maintenance and points towards the areas where efficient inspections, assessments and predictions are needed most. These causes and other lead to large costs for the end-users, who answered the questionnaire, due to these and other causes, as indicated in Table 26, however, the total costs in the EU are much larger.

The end-users (and their consultants, contractors, specialists etc.) have therefore used a number of Non-Destructive Test-methods (NDT) for the more detailed inspections, with more or less success as seen in Table 27.

Types of NDT used	Degree of success, from 0 (did not work) to 5 (perfect)
Visual inspection	2-5
Cover-meter	2-4
Potential mapping	1-5
Corrosion rate	2-4
Impact-echo	1-4
Thermography	1-3
Ambient vibration testing	4
Dynamic testing	4
Acoustic monitoring	2
X-ray	1-4
Schmidt-hammer	2-4
Falling weight deflectometer	2
Ground penetrating radar	2-4
Test loading (dynamic and static)	3-5
Ultrasonic testing	4

Table 27. Experiences with the use of NDT-methods in practise (reported success ranges).

The NDT-methods can yield very valuable information about the conditions at the time of inspection, however, the future growth in the damage, the chloride ingress etc. requires a more continuous monitoring. The end-users were therefore asked to describe their motivation for using monitoring and how they would rate the need for such monitoring.

The priorities differed again from one end-user to another, depending on their needs, but an overview of the results in the questionnaires is shown in Table 28.

Reason for using monitoring in the assessment of a structure ??	Need for this (*=minor, ***=major)
Feedback to design codes	* - ***
Check design assumption	* - ***
Loss of pre-stressing	* - ***
Cable tension	* - ***
Corrosion	** - ***
Carbonation and chlorides ingress	** - ***
Self healing of cracks and corrosion	* - **
Fatigue crack initiation and progress	* - ***
Shear crack (concrete)	* - ***
Water ingress	* - **
Vibration and damping	* - ***
Seismic risk	*
Scour Impact of floating debris, boats and ships	*
Weight in motion	* - ***
Load measurement at support	* - **
Periodic monitoring (deflections, strains, cracks, loads, etc.)	* - ***
Continuous monitoring (deflections, strains, cracks, loads, etc.)	** - ***
Evaluation of new techniques	***
Loss of stability	* - ***
Explosive collapse	*

Table 28. Motivation for using monitoring and the end-users need for such a type of monitoring (range in answers is indicated).

Types of sensors used in monitoring.	Name of sensor and / or supplier	Degree of success on a scale from 0 (did not work) to 5 (perfect)
Corrosion measurement sensors	GECOR	4
	FORCE: CW	4
	S+R Sensortec: ERS	4
	Half-cell (supplier not specified)	3
Humidity or moisture sensors	HOBO	4
	TESTO	4
	PROTOMETER	4
	FORCE: HUM	4
	S+R Sensortec: MRE	4
	Taywood Engineering: Resistivity Wenner 4-pin	4
Chloride sensors	FORCE-CHL	3
Temperature sensors	Numerous	4-5
Static deformation sensors	Straingauges (concrete)	3
	Straingauges (steel)	5
	OSMOS: Optical fibre strands	5
	Strago, stone	3
	Vibrating wire strain gauge	5
	Mechanical or electrical gauge	5
	OSMOS: Extensometers	5
	LVDT: Displacement sensors	5
Vibration sensors	Servoaccelerometers LVDT	5
	Piezo sensors	5
	Strago, stone	3
	OSMOS: Optical fibre strands	4
Laser spectrographic system	Deflections, movements	5
	Tunnel Scanner	5
Load cell	Unknown supplier	4
Pressure cell	Unknown supplier	3
Velocity sensor	Unknown supplier	4

Table 29. Experience with use of sensors.

The end-users (and their consultants, contractors etc.) have already used a number of different sensor and monitoring types as reported in Table 29.

The experiences are, however, still not sufficiently good. Two generals questions were therefore asked to the end-users in the questionnaires.

General question 1: How do you believe monitoring should be used in bridge management now and in the future ?.

A number of replies and comments were received to this question. In general the repliy:

1. Monitoring should only be used in special cases, on special structures or for special types of deteriorations and should not be used in general. This is partly due to the amount of data collected and partly due to the price of the monitoring.
2. Monitoring should be incorporated in the general inspection and assessment of the structure and be combined with visual inspections and NDT-measurements. Monitoring should not replace the traditional inspection, but should be a supplement.
3. Monitoring systems should be checked at regular intervals, in order to verify the performance of sensors, cables and datalogging facilities.
4. Monitoring should contribute to the management of the structure, e.g. should provide information for the traffic regulations, required in case of strong winds, low visibility, snow or risk of ice on the road or structure.
5. Monitoring should provide an early-warning of deterioration, enabling the proper actions to be planned and carried out at an optimal point in time.
6. Monitoring should always contribute to the general knowledge of the materials and a structure's performances in practice.
7. Monitoring could be used for verifying design assumptions or design performances in new structures, which extend beyond normal practice or experience.
8. Monitoring could be used as a part of the quality control of repairs, joints, sealers etc.
9. Monitoring could be used for extending the service life of structures, by providing an immediate warning in case of structural safety problems.

General question 2: What monitoring type would be the most relevant for you and what would the main requirements be for such monitoring ?.

A number of replies and comments were received to this question. In general the replies specify:

1. Condition monitoring would be very relevant. This would provide an continuously updated status of the structures condition and also establish a track record of the progress towards initiation of the damage and of the damage growth.
2. Monitoring which is cheap, cost-efficient, reliable and simple would provide a major improvement and enlarge the potential monitoring volume significantly.
3. Monitoring should include as few parameters as possible, as this reduces the costs and facilitates the data interpretation. The parameters and monitoring positions should be selected so they provide a representative assessment of the structure.
4. The short term methods (NDT) should be correlated with the long term monitoring. This would combine the best of the two approaches.
5. Monitoring should be designed, so it can be combined and compared with the visual and periodic inspections.

A number of more specific needs were also pointed out

6. A strong tool for the analysis of dynamic data would be required, if the data are to be used as an efficient input to the damage predictions.
7. Monitoring for loss of stress in cables in suspension bridges is needed.
8. Sensors for monitoring carbonation depth are needed.

5.2 Criteria to interface monitoring and control with bridge management.

The information in this report and the discussions with the members and partners in SAMCO has shown that:

> ***The criteria to interface the monitoring or control with practical bridge management is to describe how the monitoring data and the structural control is to be used as a part of the bridge management. This should be done in detail prior to the design and installation of any monitoring system or any structural control system and differs from one case to another.***

The criteria to interface the structural control with the practical bridge management is achieved by describing how it is used and when it is used to improve the performance of the structure. This can be by reducing the vibration amplitudes (earthquake actions, wind vibrations etc.), by heating the structures surface (prevention of ice on the bridge, removal of ice from cables etc.) or similar actions.

The criteria to ensure interfacing of the monitoring with the practical bridge management is to describe how the monitoring data are going to be used, e.g. by describing their translation into suitable parameters (e.g. chloride content, corrosion risk, corrosion rate) and to describe how these parameters are going to influence the management.

The monitoring can essential be divided into two groups: Ordinary cases, where monitoring is a part of the normal inspection routine and special cases, where the normal inspection routines are insufficient:

> Ordinary cases: This is the most common situation in bridge management, as many structures suffer from deterioration, but can be inspected with the normal inspection methods and where there is no urgent risk of collapse.

> Special cases: This is the more unusual situation, where the structures are essentially impossible or very difficult to inspect, where the design or performance needs to be verified or where the structure has a substantial risk of collapse, which requires a fast response in case the performance changes.

The criteria for interfacing the monitoring with the bridge management will be described in the next section.

The "ordinary" cases – the common situation for bridge management.

It is essential that it is specified from the beginning, what the problem is and how it is handled by the current inspections with or without NDT-methods and sampling and that the costs for this are listed. This will usually result in a number of alternative strategies being evaluated based on the latest inspections report and may involve monitoring as a new, alternative strategy.

The accuracies of the different strategies and their associated damage predictions should be determined as well, since this will show how safe or reliable a decision would be.

The service life, maintenance and warranty of the proposed monitoring systems should also be taken into consideration.

The monitoring of an existing structure should only be decided, after the following points have been met:

1. An initial inspection has been carried out with NDT-mapping and sampling. This will determine the relevant inspection areas.
2. The monitoring positions have been determined (precise positions and number of parameters to be measured).
3. The requirements to the sensors have been described as accuracy of the sensor, temperature range, service life and signal range, but also as the accuracy of the "translated" signal (e.g. degree of damage, change in corrosion risk, effect on service life).
4. A plan for sampling and on-site, temporary monitoring or NDT-mapping during the installation of the monitoring system has been set up (e.g. sampling of concrete dust from the drilled hole for installing sensors in order to determine chloride content, control measurements of optical fibre deformation sensors).
5. Rules have been described for the periodic checking of the monitoring system (e.g. failure of cables, deterioration or malfunction of corrosion risk sensor checked by NDT-equipment). This should at least be carried out at each inspection, where access to the structure is available.
6. The incorporation of the monitoring data in the reporting from the visual inspection and the NDT-measurements during the special inspections has been described.
7. A report or manual which describes exactly what the monitoring system includes, with drawings and photographs of the different sensors positions, list of sensor types, translation of the raw data into real parameters etc.). This shall be available at the end of the monitoring installation and should be such that independent controllers (or other suppliers) can check the system and even take over the responsibility of the systems performance.

The monitoring of a new structure should only be decided, after the following points have been met:

1. A simulation or an assessment has been carried out, identifying the presumed critical or optimal positions to monitor. This should preferably include a model, to which the monitoring results can be compared.
2. The points 3 to 7 in the list above have been met.

The "special" cases – where monitoring is commonly used

Monitoring is often used in the more special cases, where:

1. Normal inspection is difficult or impossible due to poor accessibility.
2. New or existing large structures, where deterioration may proceed unnoticed until a severe situation has been reached and excessive costs are required for the maintenance or repair.
3. Severe deterioration, where the degree of damage and the uncertainties in the damage growth forces the end-user to take action in order to ensure the safety.
   One action is to carry out monitoring, to get an improved logging of the damage growth and postpone the repair or replacement of the structure, until it is actually required.
   Another action is to incorporate surveillance monitoring of the structure performance, where the system can send alarm messages to the end-user when certain critical levels have been reached (e.g. deflections, crack widths, vibrations exceeding the allowed level).

The interfacing criteria is the same in these cases as in "normal" cases, but the economic and the safety aspects will usually lead the end-user to accept a monitoring strategy.

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Annex A.

Questionnaire on End-users requirements to monitoring for use in practical bridge management

QUESTIONNAIRE: End-users requirements to monitoring for use in practical bridge management

The SAMCO Network

SAMCO is a thematic network on "Structural Assessment, Monitoring and Control", funded by the European Commission (2001-2005) for the dissemination of the knowledge and know-how in the fields of structural assessment, monitoring and control of the different structures, with particular regard to the procedures based on a dynamic approach. More information is available on http://www.samco.org/.

A special workpackage WP9 deals with **"Practical Bridge Management"**, in which the end-users requirements for monitoring will be presented, focusing on the use in practical bridge management.

Why we really need the SAMCO network

Many results have been reached in the past years due to the progress in monitoring techniques, in the prediction of damage growth, in the assessment models so solutions are now available to monitor, evaluate and control the conditions of constructions.

What is now needed in an efficient exchange of information and experience within the engineering community to focus the design and use of the results in practical bridge management and to promote the application of proper solutions in the current management.

The Network aims at becoming a focal point of reference for industries, consultants and other organizations needing to transfer of knowledge and technology in the field of assessment, monitoring and control of structures of relevant civil and industrial interest particular the transport infrastructure.

Some of the objectives of the network are listed below

- To create a centre of knowledge and reference at JRC in Ispra, Italy.
- To carry out benchmark tests and distribute the raw data freely from a database established at JRC.
- To work out a recommendation as a basis for a code for monitoring, assessment and control of structures.
- To define necessary steps for a better handling of earthquake loads and the related structural response.
- To provide information about the experimental testing capabilities and allow a big audience to see the tests, use the capacities and learn from it.

- To disseminate the idea of a whole system – whole life approach in structural engineering.
- To offer newest monitoring and assessment technologies to end-users
- To organise summer academies for improvement of the education situation.
- To compare the European knowledge, standards, technologies and testing techniques with non-European countries.
- **To specify and clarify the end-users requirements to the use of monitoring and assessment in practical bridge management.**

The network is currently composed by a co-ordinator, 20 partners, 30 members and 150 observers.

WP9: PRACTICAL BRIDGE MANAGEMENT

A special work package is dedicated to the management of bridges in practice as the bridges represent a large part of the capital invested in the infrastructure. The infrastructure is in return essential for the economic development of Europe by favouring the exchange of goods and persons.

The work package aim at organising the knowledge and specific tools in SAMCO from the end-users point of view, so they will result in practical guidelines and criteria for which the end-users needs for the management of bridges.

It is therefore important to clarify and specify the end-users requirements and need for monitoring and assessment used in the bridge management and this is where the SAMCO network needs the input from the end-users. This input is important, as the end-user is the final decision maker for both the financial aspects and the operation of the structures.

To facilitate your commenting and input, we have set up the brief questionnaire, which we hope you will fill out and return it **before 28th November 2002** to:

Livia Pardi, Autostrade S.p.A. at lpardi@autostrade.it

or:

Per Goltermann, RAMBOLL at peg@ramboll.dk

Please feel free to forward the questionnaire to anybody, who may have an interest in the field of monitoring, assessment and control of bridges.

The questionnaire will also give you the opportunity to sign up as an observer in SAMCO, (observers receive information as newsletters, invitations etc. but have no obligations or responsibilities – contributions are, however, welcome).

Your input will be appreciated - and incorporated in "End-users requirement", which you in return will receive in early 2003.

Company name:	
	Non-profit organization
	Private company
	Public company
	Research Institution
	University
Contact person:	
Address:	
Telephone: **Fax:**	
e-mail:	

	I wish to receive the SAMCO Newsletter You will periodically receive the SAMCO Newsletter via e-mail.
	I want to become an observer of SAMCO You will be put in the mailing list of SAMCO and will be invited to the workshops.
	I want to receive the copy of the "End users requirements" You will receive the final report if you complete and return the question-naire.
	I wish to receive the questionairy on assessment You will later receive a questionnaire on your requirements and experi-ence with the current assessments.
	Other comments or contributions ? Please write a short statement.

Please check the table above and modify

My thoughts/ideas for this network are: (please insert below) Describe the problems you would like to be solved or addressed in the network

QUESTIONNAIRE ON THE PROBLEMS AND OBJECTIVES OF THE MANAGEMENT OF BRIDGES

1. Volume of bridges and maintenance

Which types of bridges do you own or operate ?	***Please mark***
Road bridges	
Railway bridges	

Bridges (not culverts)	***numbers***	***Age (if possible)***					
		Before 1950	*50-60*	*60-70*	*70-80*	*80-90*	*After 1990*
Reinforced concrete bridges							
Pre-stressed (1)							
Post-tension (1)							
Unreinforced concrete bridges							
Composite bridges							
Steel bridges							
Timber bridges							
Stone bridges							
Other bridges ??							

Note (1): These are also included in the reinforced concrete bridges in the row above.

Bridges (not culverts)	***numbers***
Large (more than 5 span or total length over 500 m)	
Medium	

Small (1-2 span and total length less than 40 m)	

Your annual budgets for inspection, assessment and maintenance (kEuro / year)	
Budget for inspection and assessment	
Budget for maintenance	

Causes of required maintenance	***Approximate percentage of costs***
Defect moisture protection (not steel bridges)	
Defect surface protection (steel bridges)	
Chloride induced corrosion	
Carbonation	
Fatigue	
Other problems (please list)	
……..	
……..	

2. *Your monitoring needs, requirements and wishes for the future*

What would be your reasons for using monitoring for the assessment of a structure ??	***Your priority number***
Feedback to design codes	
Check design assumption	
Loss of pre-stressing	
Cable tension	
Movement and damping	
Corrosion	
Carbonation and chlorides ingress	
Self healing of cracks and corrosion	
Fatigue crack initiation and progress	
Fatigue crack (steel)	
Shear crack (concrete)	
Water ingress	
Vibration and damping	
Seismic risk	
Scour Impact of floating debris, boats and ships	
Weight in motion	
Load measurement at support	
Vehicle/train collision	
Periodic monitoring (deflection, overall movement)	
Frequent instrumented monitoring (strain, cracks)	
Continuous monitoring (strain, cracks, loading, other)	
New techniques evaluation	

Loss of stability	
Explosive collapse	

Which types of NDT have you used in the past ?	***Degree of success on a scale from 0 (did not work) to 5 (perfect)***
Visual inspection	
Cover-meter	
Potential mapping	
Impact-echo	
Thermography	
Other types (please list)	
……..	
…….	
……..	

Which types of sensors have you used in monitoring ??	***Name of sensor or supplier***	***Degree of success on a scale from 0 (did not work) to 5 (perfect)***
Corrosion measurement sensors		
Humidity or moisture sensors		
Static deformation sensors		
Vibration sensors		
Fiber optical system (indicate type)		
Laser spectrographic system		
other, please list		
other, please list		
other, please list		

How do you believe monitoring should be used in bridge management now and in the future ?. **My thoughts/ideas are:** (please describe below)

What monitoring type would be the most relevant for you and what would the main requirements be for such monitoring ?. **My thoughts/ideas are:** (please describe below)

Please email your answer to Per Goltermann at peg@ramboll.dk or to Livia Pardi at lpardi@autostrade.it before 28th November 2002.