European Co-operation in the Field of Scientific and
Technical Research

COST 345

Procedures Required for Assessing Highway Structures

Working Group 1 Report on the current stock of highway structures in European countries, the cost of their replacement and the annual costs of maintaining, repairing and renewing them

European Commission
Directorate General Research

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TABLE OF CONTENTS

Tables

Figures

Annexes

Executive summary

The movement of people and goods has a pivotal role in any society. The current annual expenditure in the EU on the transport industry is around €1000 billion or more than 10% of the gross domestic product, and it employs more than 10 million people. The highway system is the most important part of the land infrastructure in the EU; in 1998 some 92.7% of passenger kilometres were travelled on roads as well as 73.7% of the tonne kilometres of goods traffic. The 1998 goods traffic and passenger travel by road were respectively 3 and 2.2 times their 1970 levels; clearly the highway structure will have a considerable role to play in the social and economic life of Europe for many years to come.

Primary routes representing about 5% by length of the highway system are linked by secondary roads to the local road network which is in general lightly trafficked and makes up about 75 to 85% of the road network. Bridges, tunnels and earth retaining walls make up a substantial proportion of the fixed assets of the highway network. Such structures are vital elements in this network particularly on primary roads where failure may have severe economic and/or political consequences.

It was against the backdrop of the foregoing that COST Action 345 was undertaken to define the procedures required for the assessment of highway structures. Working Group 1 was charged with the collection of information for as much of Europe as possible, on the following:

- the number of structures on the road system
- the cost of replacing these structures
- the annual cost of maintaining, repairing and renewing this stock of structures.

Data were collected by means of a Questionnaire and replies were received from 13 countries; these countries have some 4 million kilometres of road and a population of about 328 million.

Based on these data it is estimated that there are about 1 million bridges in the 27 European countries considered, at least 50 thousand kilometres of retaining wall and about 4000 2-lane kilometres of tunnels; the best estimates of the replacement costs of these structures are €400 billion, €79 billion and €110 billion respectively. The estimate of the number of bridges would appear to be relatively robust; on the other hand the estimate for retaining walls is rather tenuous but is considered to be a realistic lower bound to the likely stock of such structures. The position on tunnels is more soundly based but unfortunately information is lacking in some crucial areas.

The annual expenditures required to sustain the stock of bridges and retaining walls is about €6.6 billion while €1.6 billion is needed annually to operate road tunnels but it is not possible at this juncture to derive a figure for their maintenance, repair and renewal. These are considerable sums of money and there is clearly merit in carrying out research to improve the accuracy of these estimates and to devise and develop strategies to reduce them.

The report has shown that the replies received to the Questionnaire, limited in number though they were, have provided very valuable information on the numbers and replacement costs of the structures on the highway infrastructure in Europe. However, the replies also showed that there were considerable gaps and shortcomings in the information available for structures on Local and to a lesser extent on Regional roads. Without adequate information it is impossible to develop coherent and cost effective strategies and policies to ensure that the structures on the highway network can be sustained in an efficient manner. Of the sixteen recommendations in this report nine relate to the rectification of the above deficiencies and the setting-up of regimes for sustaining the stock of highway structures in an acceptable condition over the long term.

Unfortunately, the information obtained showed that, with few exceptions, current levels of expenditure on maintenance, repair and renewal, particularly on Local and to a lesser extent on Regional roads were inadequate. There seems little doubt that the financing of maintenance, repair and renewal needs to be put on a more consistent and sustainable basis if the full benefits of the management systems and techniques being developed for sustaining the stock of structures on the highway infrastructure are to be fully realised. Five of the recommendations deal with the provision of an adequate stream of financial resources year in year out to achieve this objective and the remaining two with research and development.

As stated above the road network is by far the most important element of the land transport infrastructure in the EU; highway structures are crucial components in this network and this report reveals the deficiencies and limitations of current policies for their maintenance, repair and renewal. The situation is most critical on Local roads but not all is well on Regional and to some extent on National roads. The highway network is an essential element of economic development and considerable sums are still being spent on new road construction. However, it is now more important than ever to ensure that the capacity of the existing highway infrastructure is exploited to the full. For road structures this can only be done by dedicating sufficient resources each and every year to their maintenance, repair and renewal.

We hope that this report will provide a starting point in the rectification of the current situation and hopefully in the fullness of time help to maximise the worth of such valuable infrastructure.

Chapter 1 Introduction

1.1 BACKGROUND

1.1.1 The importance of the land-based transportation system within the EU

The movement of people and goods has a pivotal role in any society. The importance of transportation was recognised in the Treaty of Rome by the provision for a common transport policy across the EU.

Within the EU, the current annual expenditure on the transport industry is around €1000 billion, or more than 10% of the Gross Domestic Product (GDP), and the industry employs more than 10 million people (EC, 2001).

The highway system is currently the most important part of the land transport infrastructure in the EU: its value is so large that it almost defies quantification. In 1998 some 92.7% of passenger kilometres travelled were by the roads as well as 73.7% of the tonne kilometres of goods traffic (EC, 2000). And while the proportion of passenger travel carried by road has remained relatively static over the years the proportion of goods traffic has increased dramatically since 1970 when it was 47.9%. In absolute terms, in 1998 goods traffic and passenger travel by road were, respectively, 3 and 2.2 times their 1970 levels: see Figure 1. Over this 28-year period, in the remainder of Europe the increase in goods traffic is similar to the above whilst car ownership has increased about 11 times. It is clear that the highway infrastructure will have a considerable role to play in the social and economic life of Europe for many years to come.

The highway infrastructure is hierarchical. The primary routes, an increasing number of which are multi-lane high speed roads, form the backbone of a national highway network, but they only represent about 5% by length of the entire network. Secondary roads link these routes to the tertiary or local road network which, apart from localised trouble spots, is in general lightly trafficked particularly outside peak-hours and makes up about 75-85% of the road network.

1.1.2 Highway structures

Bridges, buried structures (such as tunnels and culverts) and earth retaining walls make up a substantial proportion of the fixed assets of the land based transportation network of Europe. The stock of such structures has been accumulating over the years: some in-service structures predate the 20th century with some masonry arch bridges dating back to Roman times.

Such structures are vital elements in the road network. The closure of a bridge or tunnel severs the highway on which it is located; failure of a retaining structure is often less dramatic but traffic is impeded and the public is put at some risk. The consequences of such incidents are related to the location of the unserviceable structure. For primary roads the resulting detours may have severe economic and political consequences, for example, the fires in the Mont Blanc and St Gotthard Tunnels (Bettelini, 2002; Tunnels and Tunnelling International, 2001). On the other hand the closure of a lightly trafficked local road inconveniencing at most a few hundred travellers will have little impact either economically or politically, and provided such incidents are not too numerous they can be overlooked at a national and even a regional level.

More commonly, defective structures on the highway result in the imposition of weight and/or speed restrictions and/or lane closure. Again the repercussions are greatest on national roads and least on local roads where, being less dramatic, their impact on the general public is reduced as is their political importance. However their economic consequences can still be serious with the heavier goods vehicles often being forced to make considerable detours and in some cases being completely excluded from some areas.

There can be and often is a fundamental dichotomy between the short-termism of political institutions and the long-term requirements of a highway system where the pavement needs resurfacing or reconstruction every 10-40 years and the structures on it are designed for a 50-100 year life-span or more. This mismatch is most apparent during periods of budgetary restraint although the World Bank (1994) is clear that ill-advised cuts in maintenance expenditure at such times 'is a false economy'. Lack of funds for maintenance invariably results in unnecessary deterioration of and possibly some damage to the highway infrastructure that is usually more expensive to rectify at a later date.

The increasing realisation that material and financial resources are finite and limited is encouraging greater emphasis on the conservation of the existing stock of highway structures in a serviceable condition. That said, whilst considerable effort has been put into the development of specifications and standards for the design of new structures, comparatively little has been done on the development of documents covering the assessment of existing structures. In the absence of specific documents covering assessment there will be a tendency to assess the serviceability and stability of in-service structures using the rules given in design documents. But such an approach might be inapplicable; and even where it can be followed it is likely to underestimate the stability of an existing structure. In some cases it could lead to the unnecessary replacement or strengthening of existing structures with all the attendant costs of traffic delays. What is required is a system of assessment within which longevity and structural condition are qualitatively or quantitatively balanced against the required factor or margin of safety deemed to be required: it inevitably involves some form of risk assessment.

A reliable integrated system of inspection, assessment and maintenance is required to ensure the safety of the public at large, and also the efficient allocation of resources to the upkeep of the highway network.

1.2 COST 345

It was against the backdrop of the foregoing that COST Action 345 was undertaken to define the procedures required for the assessment of highway structures: the Action was supported by the European Commission and involved experts from 16 European States. Note that the term 'procedures' in the title covers (a) physical methods, such as visual examination and testing, (b) methods of analysis, both qualitative and quantitative, and (c) construction practices for maintenance and refurbishment. These cover more or less, respectively, inspection, assessment and remedial works. The Action covered all types of highway structure and so encompassed bridges, buried structures (such as culverts and tunnels), and earth retaining structures, but low-value structures, such as street furniture, and very long span bridges were excluded.

The main objective was to describe current European practice on the inspection, assessment, maintenance and repair of the stock of in-service highway structures. Secondary objectives were to:

- collect information on the stock of highway structures and current expenditure levels

- define the requirements for future work
- identify the types of structure that are not amenable to simple inspection, analysis or repair.

The development and application of reliable inspection, assessment and maintenance procedures for the European highway network could ensure the continued high performance of the network and, potentially, could save billions of Euros in construction, maintenance and traffic delay costs.

The end-users of the results of this Action include International, National and Local Government highway organisations and agencies, construction companies and the technical and scientific world. At International and National levels, the data collected as part of this study could influence matters of policy regarding safety and the administration and operation of highways. Such data will also be of interest to different parts of these institutions for decision-making in the areas of transport policy, legislation, research and development.

At a regional or local level, engineers charged with the upkeep of a section of highway infrastructure will benefit from the availability of information on methods of inspection, assessment and analysis, and from improved whole life cost models. Together these could improve the efficiency of operations, provide more reliable predictions of expenditure, and assist in the planning and execution of inspection and maintenance works. The information will also be of benefit to road operators and contractors concerned with such works.

1.2.1 Work programme

The programme of work was undertaken by seven Working Groups as follows:

Working Group 1	Inventory
Working Group 2	Inspection
Working Group 3	Condition Assessment
Working Group 4	Numerical techniques
Working Group 5	Safety and serviceability
Working Group 6	Remedial measures
Working Group 7	Final report

The position of the areas covered by the various Working Groups in an asset management system is shown in Figure 2.

1.2.2 Working Group 1

A prerequisite to the development of sustainable and economical maintenance regimes is detailed information on the number of the different types of structure, including their location on the highway network, as well as an assured source of consistent annual funding.

To obtain information on the magnitude of the task involved in developing such maintenance regimes for highway structures the first meeting of the Management Committee of COST 345, in June 1999, charged Working Group 1 with the collection of information, for as much of Europe as possible, on the following:

- the number of structures on the road system
- the cost of replacing these structures
- the annual cost of maintaining, repairing and renewing this stock of structures.

The terms of reference and membership of Working Group 1 are given in Annex I. Data were collected by means of a Questionnaire which was widely distributed and a copy of which is attached as Annex II. Following receipt of the replies to this document some further information and clarification was sought by direct contact with respondents and also from countries which had not responded to the Questionnaire.

This report summarises and analyses the replies received to the Questionnaire and pertinent information from other sources; the limitations of these data are considered as well as the shortcomings of current maintenance regimes for all categories of road. Extrapolation of the results is undertaken to provide an estimate of the resources required to maintain the existing stock of structures on the road system across Europe. Finally, the steps required to develop and finance a comprehensive regime for the maintenance, repair and renewal of the stock of highway structures on much of the European road system are considered.

Within this report the following shorthand is used to refer to groupings of countries.

EU15: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden and United Kingdom.

Europe 25: The countries in EU15 plus Bulgaria, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovak Republic and Slovenia.

Europe 27: The countries in Europe 25 plus Norway and Switzerland.

Working Group 1 also obtained under the direction of Mr J-L Durville and Mr R Astudillo information on a Europe-wide basis on the Codes of Practice, Standards, Technical Guidelines and the like for the Assessment, Maintenance and Inspection of Highway Structures. This has been reported separately.

Chapter 2 Collection of information

2.1 THE QUESTIONNAIRE

The Questionnaire has been briefly referred to in Chapter 1 and is reproduced in full with explanatory notes and background information in Annex II. It is a thirty seven page document divided into six Sections together with an Appendix. Each of its Sections was arranged to request increasingly detailed information on a particular type of structure. Compilers of the responses to the Questionnaire were encouraged to provide the best information available to them and to give their best estimates where exact information was not available.

Each Section of the Questionnaire will now be considered and commented upon in turn.

2.1.1 Section 1: General information

This Section contained background information, notes for guidance, a timescale and definitions. It asked for information on the total length of the road system in a country and the breakdown of that figure into three categories as follows:

(a) National Roads.

These are primary roads of the highest commercial and strategic importance usually maintained by the National Road Authority but inter-urban toll roads are also included.

(b) Regional Roads.

Although not of national importance these secondary roads are major traffic routes carrying heavy traffic within the local region; many heavily trafficked urban streets fall into this category.

(c) Local Roads.

All roads anywhere in the country that are not in (a) and (b) above. These tertiary or local roads comprise about 75-85% of the road network.

For the purposes of the Questionnaire **a structure** was taken to be an individual construction on the road system such as a bridge, culvert, retaining wall, tunnel or avalanche shelter. Individual structures with a **replacement cost** of less than €25000 were not to be included. The replacement cost of a structure was defined as the cost of rebuilding the whole structure without either changing or improving its function and purpose, or enhancing it in any way or increasing its capacity.

Because an important objective of the exercise was to determine the long-run annual expenditures required to keep the existing stock of highway structures intact and in serviceable condition, information was requested on the current expenditure on **maintenance, repair and renewal**[1] for the various types of highway structure. For example **maintenance** of a steel suspension bridge would include repainting, damage to parapets would be **repaired**, while the replacement of corroded hangers and cables would constitute **renewal**. In the extreme, the rebuilding of a completely defective structure is a wholly

[1] The expression ‘maintenance, repair and renewal’ used in this report embraces the activities ‘rehabilitation, periodic maintenance and routine maintenance’ used in OECD (1994). It is, therefore, a catch all term to encompass all the expenditures used to keep the existing stock of structures in a satisfactory condition.

replacement expenditure unless the opportunity has been taken during that event to enhance the capacity of the facility in which case apportionment of funding between the cost of renewal and new works would be appropriate.

All thirteen respondent countries were able to supply the basic information required in this section (see Table 1).

2.1.2 Section 2: Bridges

For the purposes of the Questionnaire a bridge was defined as a structure with a minimum length or span of 2m or more. All respondent countries were able to provide information on the number of bridges on the National Roads but information was not always available for local roads. Particularly disappointing was the lack of information on the sums expended on maintenance, repair and renewal, especially the last mentioned.

2.1.3 Section 3: Culverts

In the Questionnaire a culvert was defined as a drainage structure with a minimum span of 2m and a maximum span of 10m. Many of the respondents to the Questionnaire did not recognise this nomenclature and in their records included these types of structures under bridges.

2.1.4 Section 4: Retaining walls

A retaining wall for the purposes of the Questionnaire was defined as an earth retaining structure which supported at least 2m of ground, i.e. the level of the ground in front of the wall was 2m or more lower than the level of the ground behind the wall; such structures would fall into Geotechnical Category 2 or 3 of Eurocode 7 and must be designed by a suitably qualified person. Not all respondents supplied data on retaining walls, three of them stating that they had no data available.

2.1.5 Section 5: Tunnels

For the purposes of the Questionnaire an enclosed road 100m or more in length was defined as a tunnel. Road tunnels usually have two traffic lanes which may take traffic in one or both directions (often referred to as unidirectional and bidirectional tunnels respectively); cut-and-cover and immersed tube tunnels as well as bored and driven tunnels were all to be included.

Tunnels, length for length, are on average the most expensive structures to construct on the road system: they are also the least numerous. Operating costs are high with lighting being continually required; mechanical ventilation is needed in all but the shorter and more lightly trafficked facilities.

2.1.6 Section 6: Rockfall/Avalanche structures

No information was received on any such structures from any of the countries responding to the Questionnaire.

2.2 GENERAL COMMENTS

In hindsight the Questionnaire was overly elaborate particularly with regard to the level of information sought in respect of Local Roads. Although these roads represent the bulk, about 75-85%, of the road network they are administered by local authorities and councils. A central focus to co-ordinate their efforts and consolidate information on these roads is generally lacking. Without such a body the information on the number, location and condition of bridges, retaining walls and other structures for which they are responsible is fragmented and often poor. A very simple Questionnaire would have obtained all the available information for such highways. Where more detailed information is required it is only likely to be available for National Roads and perhaps Regional Roads. This situation is of course unsatisfactory and cannot be condoned.

Culverts proved to be an ambiguous category of structure and where such structures are separately listed it would be appropriate to consolidate them into the returns for bridges where international comparisons are being made. It is not clear whether Rockfall/Avalanche Structures was a meaningful category and whether any country holds centralised data on such structures.

2.3 RECOMMENDATIONS

2.3.1 Recommendation 1

Without full information on the number, location, size and replacement value of all the various structures on the highway network it is impossible to develop and resource a realistic programme for the maintenance, repair and renewal to sustain the stock of these structures. It is, therefore, our first recommendation that such information be systematically collected without delay in all countries so that policy and management decisions are soundly based.

Chapter 3 The Information

The thirteen countries listed in Table 1 replied to the Questionnaire. These countries have some 4.03 million kilometres of road and a population of about 328 million (European Commission, 2000); the corresponding approximate figures for the eight EU countries in the list are 3.3 million kilometres of road and 265 million people. The data contained in these replies are summarised in Tables 1-16 and are considered below.

3.1 THE ROAD NETWORK

It is immediately apparent that the classifications of roads used in the various countries are not consistent (see Table 1). National Roads, which are usually funded by central government, vary from 1.8%[2] of the road system in Austria to 29.9% in Norway; Regional Roads make up 6.5% and 40.7% of the network in Sweden and Norway respectively with France only marginally behind the latter country at 36.6%. The percentage of the road network in the lowest category, Local Roads, varies from as little as 29.4% in Norway to 88.8% in Austria; four other countries Denmark, Poland, Sweden and the United Kingdom (UK) have percentages in the range 83.8%-88.3% while the nearest to the Norwegian figure is 59.7% for France.

3.2 BRIDGES

The information supplied on bridges was the most comprehensive received for structures on the road network; it is summarised in Tables 2-8. Information was most complete for National and Regional Roads but could be limited or non-existent for Local Roads.

3.2.1 Frequency of bridges

Complete information for the number of bridges on the whole road network was received from eight countries (see Table 2): in all there are 437046 bridges on 2483771km of highway giving an average of 1 bridge every 5.68km. A similar frequency has been quoted for Ireland (Molloy, 1984). On the other hand the frequency of bridges in the USA is about 1 every 10.8km of road (Chase, 1998) and the population density there is 29 per km^2 while the estimated figure for Sweden, with a population density of 20 per km^2, is 1 bridge per 16.8km of road (European Commission, 2000). Perhaps an even more interesting relation is the number of bridges per head of population which for the 8 countries giving data for all roads in Table 2 is 1 bridge per 437 persons: the corresponding figures for Sweden and the USA are 1 per 356 and about 465 respectively.

In all countries, bridges are more frequent, on average, on National Roads by comparison with Regional Roads and where information is available the frequency on Regional Roads is greater than on Local Roads. This doubtless reflects the decreasing layout standards particularly of gradient, alignment and grade separation with reducing importance of the road.

[2] To avoid any delusions of accuracy, the percentages quoted in the text have been rounded to one decimal place.

3.2.2 Bridge superstructure

Information was received from 10 countries[3] on the type of superstructure and the material in the superstructure and this is summarised in Table 3. Again more complete information is available for National and Regional Roads than for Local Roads. Reinforced concrete in slab and beam-and-slab bridges are the most common material and types of construction; in France, Ireland, Spain and the UK 30% or more of bridges are arches and by inference most of these are constructed of masonry. Steel and composite structures combined comprise more than 20% of the bridge stock in three countries, with five countries having 10% or less. Suspension and cable-stayed bridges are rare.

3.2.3 The age of bridges

Ten countries provided information on the age of their bridge stock and this is summarised in Table 4. In only three countries was more than 8% of the bridge stock in existence pre-1900: this seems a very low proportion. On the other hand 48% or more of bridges are said to have been constructed from 1970 to date in Austria, Denmark and Sweden. It may well be that this is so on National and Regional Roads but it is difficult to conceive that this can be true for Local Roads; in simple terms it means that over half or more of the bridge stock on the whole road network has been constructed during the last 31 years.

3.2.4 Overall length and span of bridges

Data under this heading were provided by ten countries (see Table 5). With the exception of Spain, where a bridge was by definition 10m[4] or more long, a high proportion of bridges were less than 10m long; only a few per cent of bridges were longer than 100m. On average 62% of spans were shorter than 10m while 4.6% were greater than 50m.

3.2.5 Replacement cost of bridges

Information was received from ten countries on the replacement cost of bridges (see Table 6); six countries provided figures for all roads, the remainder related to either National or National and Regional Roads only.

Replacement cost was chosen as a straightforward measure of the present 'value' of the structures on the road network. This varies with time as the cost of construction works generally increase over time (occasionally it can decrease in an economic depression). Replacement cost is a measure of the resources that would need to be applied to rebuild the structure but does not include any amount for the value of the land on which the structure stands since this is already in the ownership of the road authority. A 'replacement value' approach was adopted in determining the asset value of the road infrastructure in OECD (1994).

The matter has been briefly considered in Chapter 2 above and it is worthwhile reiterating the definition given in the Questionnaire that replacement cost is the cost of rebuilding the whole structure without either changing or improving its function and purpose, or enhancing it in any way or increasing its capacity. In many ways it is akin to the amount an insurer would have to pay the owner of the structure in the event of it being completely destroyed and would exclude any betterment and improvement costs. It provides a useful and continuously

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[3] From here on, countries which did not provide information on any particular matter have not been included in the Tables.

[4] In Spain, bridges less than 10m long are classed as culverts.

updateable yardstick against which expenditures required to keep the existing stock of highway structures in a serviceable condition can be measured.

The total of the bridge replacement costs for all roads in the five countries providing this information and listed in Table 6 is €86 billion and their population is about 92 million. More striking perhaps is the wide difference in the average replacement cost per bridge in the various countries which range from €103k in the Czech Republic to €774k in Austria. These data have been plotted in Figure 3 and there appears to be some relation between the national GDP (PPP)/capita [Gross Domestic Product (Purchasing Power Parities)/capita] (see European Commission, 2000) and the average cost of bridge replacement. It may be noted too, before leaving Table 6, that the average replacement cost in these six countries also decreases with reducing road importance as would be expected reflecting the likelihood of larger and more impressive bridges on National and Regional Roads.

It is difficult to reconcile the data provided in Table 7 on the unit cost, €/m^2, of replacing bridges with average replacement costs in Table 6 and the relation shown in Figure 3. The range is somewhat reduced with the lowest costs in Spain being 16-27 per cent of UK figures, which were the highest, and somewhat greater than those for Denmark. Surprisingly unit replacement costs in the Czech Republic and Slovenia overlapped those in Sweden although the upper value in that country was approaching the lower end of the Danish figures. There is obviously something anomalous here and the reasons for this are unclear.

Information from the USA which put the replacement cost of their 600000 bridges at $300 billion or $500k (currently (July 2002) €500k approximately)[5] each would suggest that the higher figures in Table 6 are of the correct order of magnitude. (Briaud and Gibbens, 1999)[6].

3.2.6 Annual running costs of bridge stock

This heading embraces the costs of maintenance, repair and renewal of the bridge stock as well as its management and the cost of regular inspection of bridges. Data was received on these topics from ten countries and these are summarised in Table 8.

Apart from Slovenia, Sweden, Switzerland and the higher UK figure the annual running costs of the bridge stock **do not include renewal** costs which are usually part of the capital or investment budgets. As such they are at the mercy of political exigency and structures where the more economic solution is replacement may have to be patched-up year in year out from funds devoted to maintenance and repair. Such a situation wastes resources. The evolution of the financial arrangements for bridge maintenance in Sweden is briefly described in Annex III. This explains why the percentage of replacement cost expended under the heading maintenance, repair and renewal is on the high side for Sweden in Table 8. It is of interest to see from the footnotes to the Table that the percentage of replacement cost expended annually by authorities responsible for bridges on National Roads can be much higher than that devoted to Regional and Local Roads.

3.3 CULVERTS

As already mentioned this nomenclature was not used by the majority of respondents to the Questionnaire with only three countries supplying information. The general comments

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5 Since its introduction the value of the Euro has varied between €1 and 1.2 to the US$.

6 Chase (1998) states that there are “more than 581000 highway bridges greater than six metres in length on the public road network in the USA”.

received on culverts are given in Table 9 while the data supplied by Ireland, Slovenia and Spain is summarised in Table 10. In the case of Ireland and Slovenia the data on culverts could well have been included in the Bridges Section since the minimum span is 2m for both classifications. This is not the case for Spain where bridges are defined as having a span of 10m or more. The disparity in the frequency of culverts on the highways of these countries is doubtless due to the matters mentioned above.

No clear pattern emerges from the information on materials given in Table 10, while average replacement costs per culvert are quite low compared to those given in Table 6 for bridges.

3.4 RETAINING WALLS

Only six countries supplied information on retaining walls and the position is detailed in Table 11. Denmark, France and Spain did not supply data for Regional and Local roads while in the case of Sweden very limited data were supplied for SNRA roads and the Stockholm area. As already mentioned in the Introduction, retaining walls are less critical to the functioning of the highway network than either bridges or tunnels and the lack of information on them no doubt reflects this. For example Austria is in the process of compiling an inventory of their retaining walls having already completed them for bridges and tunnels.

The more detailed information supplied by the Czech Republic, Denmark, France, Spain and the United Kingdom is summarised in Table 12; much of this relates to retaining structures on National roads but information for the whole road network was supplied by the Czech Republic and the United Kingdom. Apart from Denmark, which has a generally subdued topography, the length of retaining wall per km in the other four countries on National roads is reasonably consistent averaging between 23.40 and 28.64m/km. For the whole road system the length of wall averaged 8.25 and 11.1m/km in the Czech Republic and the United Kingdom respectively.

Only Spain and the United Kingdom supplied information on the type of construction: gravity retaining walls were the most common in both countries but the extremely high estimate of the percentage of such structures in the United Kingdom is doubtless a reflection of the large number of drystone and improved drystone retaining walls in that country. There are striking differences too in the use of reinforced concrete and more particularly reinforced and anchored soil retaining structures in the two countries.

According to the information supplied there are considerable numbers of drystone and improved drystone retaining walls in the Czech Republic and United Kingdom, but this form of construction appears to have been little used in Spain. It is also known that there are considerable lengths of drystone retaining walls and their derivatives in France (Walker et al, 2000).

The height of ground supported by most retaining structures on highways is between 2 and 4m. Few walls support more than 10m of ground and the somewhat higher percentage of high walls in France and Spain presumably reflects the more rugged terrain in parts of those countries.

Replacement costs per km of wall vary widely and the total cost of replacing the stock is much less than the replacement costs of the stock of bridges (see Table 6), being 4.1% and 13.8% of the bridge replacement costs in Spain and the United Kingdom respectively. Expenditure on the maintenance, repair and renewal of these structures was often extremely low and well below any figure which could be reasonably expected to maintain them in good condition over extended periods of time.

3.5 TUNNELS

Information on the number of tunnels on the road network were received from 12 countries and there are at least 2235 road tunnels in them: these data are summarised in Tables 13-16 and apart from bridges are the most comprehensive received for structures on the road network; also shown in Table 13 is information on the number of tunnels at least one kilometre long (UNECE, 2002). Unfortunately data were not supplied by Italy where there are known to be 180 tunnels exceeding 1km long, 76 of them having twin tubes. For the seven countries giving information for all roads some 50% of tunnels are on National Roads, although in France, for example, about 30% of tunnels are on both Regional and Local Roads with the remaining 40% or so on National Roads.

3.5.1 Operational characteristics

The information on the traffic flow and ventilation of road tunnels is summarised in Table 14. Apart from Norway about 68% by length of road tunnels operate with unidirectional traffic flow which is inherently safer for the road user. It avoids head-on conflict between opposing traffic streams and the ventilation strategies to be used in emergencies can be simpler. The major fires in the Mont Blanc and Tauern tunnels in 1999 and in the St Gotthard tunnel in October 2001 were in single-tube tunnels carrying bidirectional traffic. At that time there were no emergency escape tunnels or passages at the Mont Blanc and Tauern tunnels but there were at the St Gotthard tunnel. Although 11 lives were lost there, the indications are that this escape facility was very effective in reducing casualties. It would also have provided a safe route for emergency services to approach the fire, but whether it enabled fire fighters to control the conflagration and limit damage more quickly is as yet unknown. Emergency escape routes have been incorporated into the recently reopened Mont Blanc tunnel.

Mechanical ventilation was fitted in a little over 60% of tunnels. With an average tunnel length of less than 500m in many countries (see Table 13) this is not altogether unexpected as the drag effect of unidirectional traffic alone provides effective ventilation of road tunnels of up to a kilometre or more in normal driving conditions.

3.5.2 Method of construction

Most tunnels are bored and lined (see Table 14). This type of construction includes both tunnels in rock driven by drill and blast and in soft ground constructed using a shield; more recent examples of either of these types of tunnel may be driven by a tunnel boring machine (TBM) or the New Austrian Tunnelling Method (NATM). Unlined tunnels were only reported in France, Spain and Sweden and would have to be located in very hard and stable rock conditions. Cut and cover tunnels are quite common and are usually to be found in urban areas where the presence of buildings and other man-made obstructions hamper the development of the road network. Tunnels constructed by the immersed tube method are rare in the countries supplying information; again the European country where the greatest number of tunnels constructed by this technique are to be found, namely the Netherlands, did not respond to the Questionnaire[7].

[7] According to Leendertse and Oud (1989) there would have been 16 road tunnels in the Netherlands by the early 1990s, the majority of them constructed by the immersed tube method.

3.5.3 The age of road tunnels

Only three countries France, Spain and the United kingdom reported having any tunnels constructed in the Nineteenth Century and indeed few were constructed in the opening 45 years of the Twentieth Century (see Table 15). At least half of all road tunnels in all the responding countries were constructed in the period 1970-2000.

3.5.4 Replacement and operating costs

Information on the replacement costs of road tunnels was received from seven countries and on the costs of operating, maintaining, repairing and renewing them from six (see Table 16); for brevity the latter costs are referred to in this Section as **whole life operating costs**. Replacement costs per metre length of tunnel vary enormously from €156250 in Denmark to €8710 in Austria, which is somewhat surprising given that the average cost of bridges in the latter country was the highest returned; the very high figure from Denmark probably reflects the impact of the high costs and traffic capacity of immersed tube tunnels there.

The somewhat artificial nature of the concept of replacement costs is most apparent for tunnels. In the event of renewal being required the most likely way forward would be to refurbish the existing tunnel on the present alignment thus obviating the need to excavate a new tunnel and avoiding this major expense. This type of work has already been undertaken when, for example, redundant railway tunnels have been enlarged to carry road traffic[8]. In road tunnels such an exercise in refurbishment would be facilitated by the provision of generous clearances in all new tunnels; for example the provision of full-size hard shoulders on the Bell Common and Holmesdale tunnels on M25 in the UK will enable those sections of that motorway to be widened from 3 to 4 lanes in each direction without the need for any major structural works.

No clear pattern emerged from the information supplied on the whole life costs of operating etc road tunnels and it is doubtful whether expressing these as a percentage of replacement costs is appropriate. At the present time the annual costs of operating tunnels are likely to be much greater than the costs of the maintenance, repair and renewal of the facility given the fact that such a large proportion of the stock of the tunnels have been constructed within the last 50 years or so. However when renewals are required, such as the road deck at the Dartford Tunnel, the cost can be extremely high (Greeman, 2000; Healey, 1999).

As regards the absolute costs of operating road tunnels it seems anomalous that only €5.5 million is spent annually in Austria on whole life costs for 320 tunnels while €2.0 million and €6.0 million are spent in Denmark and Sweden to operate 6 and 25 tunnels respectively: Spain spends €13.1 million annually on 226 tunnels which also seems rather low.

3.6 GENERAL

There are a number of general points arising from the replies to the Questionnaire. Perhaps the most important of these is the lack of information on the local or tertiary road system. As already mentioned a severance of a road in this network being confined to a limited area does not normally inconvenience large numbers of people; it is not news[9] and unless such events

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[8] Redundant railway bridges have also been used to carry highways.

[9] Contrast the reaction to the deaths of 11 people recently in the St Gotthard tunnel, which grabbed headlines on TV and in the press for 4 days and the ensuing political and legislative activity, with the average toll of 100+ people killed day in day out on the roads of the EU15 countries.

become commonplace is usually of little consequence politically. This does not mean, however, that the investment tied-up in this sector of the road network is small; indeed the figures provided for bridges (Table 6) show that their total replacement costs on local Roads can exceed those for National Roads.

Secondly it is clear that there has been and still is likely to be under-recording. For example the figures in Table 1 and Table 17 (European Commission, 2000) for Sweden are only reconciled when it is realised that only 138200km of their roads are public roads. Also a footnote to Table 17 indicates that 503000km of secondary roads in Spain have not been included; it is only by including these latter roads that the figures for France, Spain and Sweden which have similar land areas become compatible.

In Table 2 the number of bridges in Germany is clearly an estimate and looks suspiciously low: comparison with the United Kingdom, which has a very similar population density (see Table 17), would suggest a figure of the order of 150000 bridges rather than the 100000 in their reply to the Questionnaire. Other anomalies and inconsistencies in the data have been mentioned above, all of which point to the under-recording or overlooking of information.

Finally attention must again be drawn to the question of financing expenditure on maintenance, repair and renewal. These categories are all part of the same process, i.e. that of conserving the stock of structures on the road network. It is counter-productive for the Engineers in the Maintaining Authority to have their decisions constrained by bureaucratic rules and regulations which distinguish between various elements of expenditure aimed at a single objective. The recognition of this in Sweden is certainly a step in the right direction and is to be commended. Unless Engineers are free to select the most appropriate course of action they cannot undertake these functions in the most effective and economical manner. It is hard, too, to see how the existing policy of putting renewal expenditures on the capital budget is consistent with a policy of sustainability.

In conclusion it is clear from the analysis of the results that even where information is available there are often serious gaps and deficiencies in the data. Surely in this day and age there should be the equivalent of a log book or the like attached to all significant highway structures on which are recorded all the important information needed to develop a realistic programme of maintenance, repair and renewal for the lifespan of that structure. This really should not be a problem for newly built and renewed structures where as-constructed details are available; for existing structures information may often be lacking but the accumulation of maintenance and work records is a much more sensible option than the ‘do nothing’ scenario.

3.7 RECOMMENDATIONS

3.7.1 Recommendation 2

It is clear from the replies to the Questionnaire that detailed information on the structures on the highway system is often lacking. This is particularly so for Local and Regional Roads and even for National Roads in some countries. It is, therefore, recommended that in order to develop and refine long-term programmes of maintenance, repair and renewal to the stock of highway structures on all the road network there is a need to expand the basic data outlined in Recommendation 1 (see Section 2.3 above) to include as much detail as possible, including historic information, on the condition, work undertaken and expenditure relating to every structure on the highway network.

3.7.2 Recommendation 3

Renewal is part and parcel of the process of sustaining the stock of structures on the highway system and it is recommended that steps be taken to alter the relevant financial rules to ensure that this is so.

Chapter 4 Development of questionnaire results

Although only 13 countries replied to the Questionnaire it is possible using the data supplied to provide reasonably reliable estimates of the numbers of bridges on the road network in Europe using two simple approaches:

(i) through the relation between road length and bridge numbers, and

(ii) based on the relation between population and the number of bridges.

The first of these approaches implies that there is some connection between the occurrence of watercourses draining the countryside and the length of roads traversing it and could be considered as a reflection of the need for bridging such obstructions to permit movement. The second infers a relation between the numbers of bridges and the physical and monetary resources available to construct them; this supposition appears reasonable given that there are significant relationships between the extent and quality of the paved road infrastructure and the national per capita income (Hudson et al, 1997; Queiroz et al, 1994). Bridges by comparison with the roadway itself are expensive and their number and scale decrease as the importance of the road reduces.

On the other hand the information available for retaining structures is fragmentary while that on tunnels is obviously incomplete.

4.1 BRIDGES

4.1.1 The relation between road length and bridge numbers

As already indicated in Section 3.2.1 there are 437046 bridges on 2483771km of road in the eight countries supplying complete information for their whole road networks. This gives an average of 1 bridge for every 5.68km of road in these 8 countries; the value in the individual countries varies from 1 per 3.77km in Austria to 16.80km in Sweden with all but two of the values being 6.00 or below (see Table 2). For these eight countries there was no obvious connection between the km of road per bridge and population density; the proportionality between km/bridge and population density in the USA and Sweden quoted in Section 3.2.1 may well be fortuitous.

For the fifteen EU countries and the ten Central European Counties listed in Tables 17 and 18 respectively, compiled from data in the Statistical Pocketbook (European Commission, 2000), the total length of road is 4336323km to which must be added the 503000km of secondary roads in Spain and the 281800km private roads in Sweden (see Table 1). This gives a grand total of 5121123km of road in these 25 countries. At a bridge every 5.68km of road it puts the estimate of their bridge stock at about 902000 such structures. When Norway and Switzerland are included the figure for Europe 27 countries is 930000 bridges.

4.1.2 Relation between population and bridge numbers

Again in Section 3.2.1 it was shown that the number of bridges per head of population did not vary greatly, being a bridge for every 437 persons on average for the eight countries giving data for all roads in Table 2 by comparison with a figure of about 465 persons in the USA. For the five EU countries in Table 2 which give information for all the road network the value is a bridge for every 362 persons. The total population of the 25 countries listed in Tables 17 and 18 is 479.7 million which at 1 bridge per 437 persons gives an estimate of 1098000 bridges; this estimate is 19.1% higher than the figure derived in 4.1.1 above. When

Norway and Switzerland, with populations of 4.4 and 7.1 million respectively, are included the figure increases to 1124000 bridges.

The two approaches have given estimates, which are in reasonable agreement, of the bridge stock for the greater part of Europe outside the former Soviet Empire; the omissions being Albania and the countries with the exception of Slovenia which made up the former Yugoslavia. Given the limitations on the Questionnaire data discussed in Section 3.6 these estimates are likely to err on the low side.

4.1.3 Overall replacement cost

The average replacement cost of a bridge on the road systems of the six countries listed in Table 6 is €400k per structure. This puts the overall estimate of the replacement costs of the stock of about a million or so bridges in the 27 countries discussed above at about €400 billion or a little less than 5% of the GDP of the countries concerned (European Commission, 2000). Given that bridging represents somewhat less than 20% of the average costs of roads (James, 1972) it would mean that the overall replacement cost of the road network in these countries is about 30% of GDP. This figure would appear to be well below the range quoted in OECD (1994).

4.1.4 The annual expenditure on maintenance, repair and renewal

In Table 8 the annual expenditure on maintaining, repairing and renewing the bridge stock is given as a percentage of its replacement cost. As already mentioned only the values of 2.6% to 0.9% from Slovenia, Sweden and Switzerland and the 1.1% figure from UK include the costs of renewal. As already indicated there is some artificiality with replacement costs and it is of interest to note in Table 7 that the unit costs used to determine replacement costs are lower in Sweden than in the UK; this means that the actual amounts of money being spent in both countries relative to the bridge stock is closer than these percentages suggest. Although this does indicate a shortcoming in the approach it is difficult to identify a normalising yardstick other than replacement cost which would improve the situation. It should be noted too that many of the figures including those from Sweden and Switzerland are essentially for National Roads only.

On the basis that the replacement cost of the bridges in the 27 countries considered in 4.1.3 above is €400 billion then an annual expenditure on maintenance, repairs and renewals of 1-1.5% of bridge replacement cost would require an annual expenditure of some €4-6 billion annually. Expenditure would almost certainly need to be somewhat greater in the initial years to make up for the current shortfalls and backlogs. Indeed it could well be that in the long-run average annual expenditure could be lower than the amounts given above. Improving the durability of new structures, which can be achieved at low additional cost, should ensure that the renewal element reduces over time. This is an area where there could be significant returns from research into the strategies used to conserve the bridge stock in the long term.

The information on expenditure on the maintenance, repair and renewal of bridges in Table 8 can also be used to provide some indication of the amounts currently being expended on those activities but some interpretation is required. Many of the figures do not include renewal costs and they are often for National or National and Regional Roads; also the high percentage, 2.6%, for Slovenia may well be because of the lower replacement cost of structures in that country. Making due allowance for these factors would suggest that the amounts currently being spent on maintenance, repair and some element of renewal of bridges in the Europe 27 countries could be €2-3 billion or so annually. Indeed given the lack of information for Local Roads it could well be less and is certainly unlikely to be more.

4.2 RETAINING WALLS

As already indicated above little information was received on earth retaining structures and what there is has been summarised in Table 12. Clearly there is little need for such structures in the subdued topography of a low-lying country such as Denmark where there are only 18 such retaining walls on the National Road system. Similar considerations would presumably apply to the Netherlands also bordering the North Sea much of which lies in the Rhine delta and also to coastal Belgium. On the other hand data was received only from France of the Alpine countries and that only for National roads, although limited data is available elsewhere (Walker et al 2000). Retaining structures are numerous and spectacular in this terrain, as tourists to Southern France and the neighbouring Northern Italian coasts are well aware.

A very conservative stab at the length of earth retaining walls in the 25 European countries listed in Tables 17 and 18, where data are available on the length of their road network, is obtained by assuming that 1% of that length, i.e. 10m/km, is supported by such structures. This would give a length of 51200km of retaining wall; Norway and Sweden added, the figure for the Europe 27 countries becomes 52837km. Assuming a value of €1.5 million per km would put the overall replacement cost of the stock of retaining walls on the road network of these countries at €79 billion or 20% of the value of the stock of bridges. This is not greatly different to the position in the UK where the replacement cost of the stock of earth retaining walls is 17% of the replacement cost of the bridge stock (see Tables 6 and 12).

4.3 TUNNELS

As has already been mentioned, tunnels are the most expensive of the elements of the road system to construct and operate. In the Questionnaire the operation, maintenance, repair and renewal of road tunnels were lumped together which was mistaken since the operation is a function of the road space created by the tunnel while the remaining three tasks are, to a considerable extent, related to the cost of constructing the tunnel structure.

Annual operating costs of road tunnels are about €400 per 2-lane m on average or €400k per kilometre. (This is less than the UK figure which is well researched, equal to the Danish figure and greater than the Swedish figure of €260 per 2-lane m per annum. The other values deriving from Table 16 would appear unrealistic.) The total length of the 2235 tunnels given in Table 13 is about 2400 2-lane km and the annual cost of operating them is, therefore, of the order of €1 billion. Although no information has been received from Italy it is known that there are 180 tunnels exceeding 1km long in that country with a length of about 500 2-lane km. Based on the relative proportions of tunnels in Austria and France it would be reasonable to infer that there are a further 600 – 800 road tunnels in Italy less than 1km long and perhaps 200 or so road tunnels on Regional and Local roads in Germany and Switzerland. This would put the total length of road tunnel in the Europe 27 countries mentioned in Section 4.1.2 close to 4000 2-lane km with annual operating costs of about €1.6 billion.

For tunnels on National Roads and those financed by the collection of tolls there is generally no difficulty in meeting these costs. On the other hand where tunnels are neither financed by central government nor self-financing through tolls there may well be problems. For example, with tunnels carrying Regional Traffic but financed by taxation on a more limited area there is an immediate conflict of interest - the motorists using the tunnels get the benefit of reduced journey length and travelling time at the expense of taxpayers who may never use the facility or indeed possess a car[10]. In such circumstances Engineers and staff running the tunnel are put in an impossible and potentially unsafe situation. Everything has to be pared down to the minimum and necessary activities may have to be skimped and curtailed. This perhaps is the ultimate example of the consequences of uncertain financing of necessary annual expenditure on the road infrastructure.

It is extremely difficult using the replacement costs given in Table 16 to make a reliable estimate of the overall replacement cost of the road tunnels in the 25-27 countries being considered in this report. Taking the low value of €10000 per 2-lane m would give a value of €40 billion and would appear unreasonably low being 11 times the replacement cost of 45 tunnels in the UK. The unit cost of tunnels can vary tremendously depending on ground conditions and quite a lot of the variation in the average values in Table 16 is doubtless due to differences in the predominant ground conditions in the various countries. Taking all of that into account it is estimated that an average replacement cost of €25-30000 per 2-lane m might be reasonable. On that basis the replacement cost of the stock of road tunnels in the 27 countries considered in 4.1.2 would then be €100-120 billion or 25-30% of the replacement cost of their bridge stock.

Maintenance, repair and renewal of the tunnel structure have not been considered in the above and the difficulty of using replacement costs as a yardstick in tunnel renewal has already been considered. This is perhaps not as pressing a problem as it might seem as the majority of tunnels are either on National Roads or financed by tolls; in addition over 60% of tunnels are less than 30 years old with only about 10% older than 50 years. However in the longer term average expenditures of perhaps €1-2 billion annually could be involved.

4.4 OVERALL PICTURE

Although some data was received on culverts given the ambiguity of their definition and their lack of usage it was not sensible to use them to obtain overall figures for their contribution to the structures element of the road infrastructure in the 27 countries considered.

Summarising therefore, the best estimates of the replacement cost of the stock of bridges, retaining walls and tunnels are as follows:

Bridges	€400 billion
Retaining Walls	€ 79 billion
Tunnels	€ 110 billion
Total	€ 589 billion

The estimate for the number of bridges in the stock of highway structures would appear to be relatively robust with the estimates obtained by two quite different approaches in reasonable agreement. However, there are some differences in the definition of bridges in various countries and it would be useful if standardised definitions could be agreed. Almost certainly such an exercise would result in an increase in the recorded bridge stock; e.g. Spain defines bridges as having a length of 10m or more.

The estimate for retaining walls is rather tenuous but is considered to be a realistic lower bound to the likely stock of such structures; it is unfortunate that many highway authorities

10 This situation is not unique to road tunnels and may also apply to bridges and other road structures: it also can apply to subsidised mass-transit systems which extend beyond the boundaries of the community providing the subsidies and which are used by people commuting from outside.

do not know how many such structures they are responsible for given that their replacement value is on average some €1.5 million per km.

The position on tunnels is more soundly based than that for retaining walls but unfortunately the information from Italy is sparse although it is thought to have the largest number of road tunnels in any European country: information is also lacking from the Netherlands, where there are a significant number of immersed tube tunnels. Again their replacement cost of €110 billion is considered to be a realistic lower bound value.

4.5 RECOMMENDATIONS

4.5.1 Recommendation 4

It is obvious from Section 4 above that the current knowledge of the numbers of structures on the highway networks of Europe is imperfect and that the estimates of the cost of replacing them leaves much to be desired. However, it is virtually certain that the estimates given are of the correct order of magnitude and very probably err on the low side.

It is, therefore, recommended that steps be taken to refine the above figures and obtain more precise information on the numbers and replacement values of the stock of all highway structures on the European road system.

4.5.2 Recommendation 5

The task outlined above would be much facilitated by the development of a unified classification system for highway structures to be used in all European countries.

4.5.3 Recommendation 6

It was shown in Section 4.3 above that information on the costs of construction and replacement of road tunnels as well as on the expenditure on their operation, maintenance, repair and renewal was incomplete and flimsy. There is, therefore, a need to obtain these data so that the appropriate levels of funding can be identified and provided for these crucial structures on the road network.

Chapter 5 Sustainable conservation

With Working Groups 2-6 of COST 345 dealing in depth and detail with the various processes needed to assess, maintain and ensure the conservation of the stock of structures on the highway network it remains for this Working Group to consider the amount and sources of the financial resources needed to implement these processes on a consistent and continuing basis. Put simply Engineers are saying ‘We have the tools, give us the resources and we will undertake and finish the job’.

5.1 THE AMOUNT OF EXPENDITURE REQUIRED

A yardstick commonly used to normalise the expenditure on the maintenance, repair and renewal of structures is the replacement cost of those particular objects. It is also important to consider the amount of these expenditures relative to the GDP; there is not a bottomless purse and investment in the transport infrastructure for example averaged 1.1% of GDP in the EU15 in 1995 (European Commission, 2000).

5.1.1 The present position in Europe

Information on the current levels of expenditure on maintenance, repair and renewal provided by countries replying to the Questionnaire is summarised in Tables 8, 12 and 16.

In only four returns, Slovenia, Sweden, Switzerland and UK, do any of the figures include expenditure on renewal and this matter has been considered in Section 4.1.4 above for the case of bridge structures. The question, therefore, must be asked whether an expenditure of 1.0 to 1.5% annually of the replacement cost of bridges – and a somewhat lower percentage on retaining structures – is likely to be adequate to maintain the stock of highway structures over the long term, i.e. over the next 50 years or about half the design life of a new structure.

5.1.2 Other information

Like the returns to the Questionnaire, there is little information on the financial resources required to sustain the stock of structures on the highway network in acceptable condition.

In the late 1980s, the Department of Transport in the UK commissioned a survey of the performance of 200 concrete bridges out of their stock of 5900 such structures. On the basis of this representative sample Wallbank (1989) estimated that an annual expenditure of 1.73% of replacement value would be required over the following ten years on the Department’s stock of bridges. Subsequently the Highways Agency as successor to the Department of Transport, and currently the National Road Authority for England with the exception of London, developed a strategic plan in 1997 for their stock of structures (Das and Micic, 1999): Figure 4 taken from that paper shows the projected levels of expenditure from 1998 to 2040. In 1997 the Highways Agency was responsible for 16000 structures including 10000 bridges (Narasimhan and Wallbank, 1999); if one takes an average replacement cost per structure of €1 million - a not unreasonable figure for structures on National roads - then the average annual expenditure shown in Figure 4 is about 1.75% of replacement value.

Assuming the above strategy still reflects the outlook of the Highways Agency in general terms there are two points which emerge:

(a) there was a current backlog of maintenance which needed to be cleared, and

(b) it showed the mix of essential, preventative and routine maintenance required to keep these expenditures at a reasonably steady level for the next 40 years or so.

It is also worth noting that studies for the Agency have shown that a maintenance regime such as that in Figure 4 is more economical overall than one where the funding for routine and preventative maintenance were inadequate (Wallbank et al, 1998). The two situations are compared subjectively in Figure 5.

More recently, a comprehensive review of the funding required for bridge and retaining wall maintenance was undertaken by the Bridges Group of the CSS (CSS, 2000). In the context of their review, maintenance included “preventative maintenance, regular inspection and eventual replacement”, i.e. all the elements covered by the terms maintenance, repair and renewal in the Questionnaire. The results of the review are summarised in Annex IV to this report.

The various approaches considered by them gave expenditures of 0.41% to 1.39% of the replacement cost as the annual expenditure needed to sustain the bridge stock. Of particular interest was the indication that the maintenance costs of masonry arch bridges might well be as low as a half those of steel bridges supported on reinforced concrete supports. With regard to retaining walls the methods reviewed indicated a range of annual expenditures from 0.48% to 1.39%. Their conclusion was that the “the level of funding required for maintenance should be 1.0% of the Replacement Cost for Bridges and 0.9% of the Replacement Cost for Retaining Walls”. Unfortunately the report also stated that existing expenditures on bridges and retaining walls in England on roads maintained by Local Authorities were 0.32% and 0.03% of replacement cost respectively.

The information on the cost of maintaining, repairing and renewing drystone retaining walls and their derivatives on National roads in England and Wales is given in O'Reilly et al (1999); a consistent average annual expenditure of 0.75% of replacement cost was found to be sufficient to sustain the stock of these structures.

The position regarding bridge maintenance in the USA was set out by Chase (1998). There are 581000 bridges, with a span of 6m or greater, on the 6.3 million kilometres of road in that country, or 1 bridge every 10.8km. On the National Highway System, some 260000km long, there are 122000 bridges or a bridge on average every 2.13km: this latter figure would sit very comfortably with the data given in Table 2 for National Roads in Europe. Information on the replacement value of the above bridge stock is not given in the paper but Briaud and Gibbens (1999) have put it at $300 billion (currently €300 billion or so).

According to Chase, expenditure on the operation and maintenance of all the highways in the USA in 1995 was $51.6 billion together with a capital expenditure of $46.5 billion: these sums together would represent about 1.3% GDP. Chase estimates that about a tenth ($5 billion) of the operation and maintenance expenditure was expended on bridges; this would represent 1.6% of the replacement value given above.

5.2 ANNUAL EXPENDITURE REQUIREMENTS

In the above the annual expenditure as a percentage of replacement cost to sustain the bridge stock varied from 1 to 1.75%. This is quite a difference and needs to be examined and if possible explained.

The lowest figure, 1%, relates to the stock of bridges on Regional and Local Roads in England where over 40% of the bridges are masonry/brick structures most of which would have been constructed before 1900. On the other hand about 90% of bridges on the National Roads in England were constructed in reinforced or prestressed concrete or steel after 1955 (Highways Agency et al, 1999). On the road network of the USA less than 15000 bridges are of pre-1900 vintage and over 70% of bridges were constructed after 1970 (Chase, 1998);

again reinforced and prestressed concrete and steel are the predominant materials of construction.

There is a great deal of information on the deterioration of reinforced and prestressed concrete structures and this is considered in Annex V. The decks of bridges in the USA seem to be in a particularly poor condition but the condition of bridges on the National Road networks in England and France also gives cause for concern. Concrete bridges with metallic reinforcement, as well as steel bridges, are particularly susceptible to chloride attack from salt which is regularly applied to highways to control the formation of ice; in the present context it may also be relevant to note that the frequency of such saltings in England is least on local roads. There is also the question of levels of service where, as has already been discussed, the impact of delays on the local road network are less noticeable and politically significant.

A way forward, therefore, is to accept that in their current condition an annual expenditure of 1.6 to 1.7% of replacement cost is needed to sustain bridges on the National Road networks. A somewhat lower expenditure year in year out may be acceptable on Regional and Local Roads and the amount needed may vary from country to country depending on the composition of the stock of bridges: in the early years too there is likely to be a need to eliminate a backlog of repairs. As a starting point to be confirmed by subsequent experience it is suggested that an amount of about 1.25% of replacement value be expended on sustaining the existing stock of bridges on the Regional and Local Road network. Only time will tell if this is adequate.

Applying these figures to the bridge stock gives an expenditure of about €5.8 billion annually in the 27 European countries considered above and is strikingly similar to the expenditure for this purpose in the USA where there are fewer bridges but with higher replacement costs. It does, however, indicate that the outcomes of the analyses carried out are not unrealistic and of the correct order of magnitude.

The expenditure needed to sustain the stock of retaining walls of the 27 European countries considered is less certain. A figure of 0.75% per annum of replacement value has been found adequate to maintain gravity-type retaining structures of masonry construction, i.e. drystone walls and their derivatives: the needs of reinforced and prestressed concrete structures are likely to be greater. On the basis of a figure of 1.0% of replacement cost a sum of €790 million per annum would be required.

In Section 4.3 the annual expenditure on operating road tunnels in Europe 27 was estimated to be €1.6 billion while the question of the appropriate levels of expenditure on the maintenance, repair and renewal of these facilities was put to one side to be determined at a later date by further investigation and study.

The annual expenditure of €5.8 billion, €790 million and €1.6 billion just mentioned are all considerable sums of money by any standards and there is clearly merit in carrying out research to revise them and to devise and develop strategies to reduce the amounts needing to be spent. On the latter score one possibility that has just been mentioned is the use of structures such as gravity retaining walls where all the structure is in compression and which do not contain degradable materials such as steel that can corrode in the longer term. Arch bridges have similar characteristics and advantages; given the vicissitudes of reinforced and prestressed concrete structures in the latter half of the last century perhaps the time is now ripe for the reintroduction of the arch bridge. The scope is great; reducing the above figures by just 0.1% for bridges and retaining walls could save about €480 million annually.

5.2.1 Recommendation 7

On the basis of the limited information currently available it is necessary to earmark or dedicate the sum of €6.6 billion every year to be expended exclusively on the maintenance, repair and renewal of the bridges and retaining structures on the road networks of the Europe 27 countries. This compares with a current annual expenditure in these countries of perhaps €2-3 billion on the maintenance, repair and renewal of road bridges (see Section 4.1.4 above) and perhaps 10-20% of that amount on retaining walls.

5.2.2 Recommendation 8

The adequacy or otherwise of the above expenditure should be reviewed about 5 years or so after implementation of Recommendation 7 using the results of detailed monitoring and updating of inventories.

5.3 ASSURING FUNDS FOR MAINTENANCE

Although left until last this is undoubtedly the most important consideration in the development of long-term strategies for the maintenance, repair and renewal of the stock of structures on the road network. Without an adequate and consistent flow of funds for these purposes year on year the best laid schemes are put at nought.

The financing of the capital and maintenance expenditures - and indeed the maintenance of the road network as a whole - are in the end political decisions. The subject has already been broached in the Introduction above where the World Bank (1994) stricture on the false economy of cuts in maintenance expenditure during periods of budgetary restraint was cited. Examination of Figure 4 and 5 make this point clear: indeed it might well eventuate that continuous and adequate routine and preventative maintenance would reduce the requirement for essential maintenance in the longer term as indicated diagrammatically in Figure 6. This is, of course, something which could only emerge over a period of time when the maintenance regimes recommended above have been implemented and any current backlogs eliminated. That such a supposition is not fanciful relies on the common sense adage that 'a stitch in time saves nine' as well as the reasonable inference that the postponement of the time to replacement due to the enhancement of the life of structures - as a consequence of adequate routine and preventative maintenance - will eventually show through in reduced replacement expenditures; these can be a significant element of the cost of sustainable conservation. With such a prize in prospect it is worthwhile giving some consideration to the methods used to finance the road network.

5.3.1 The existing situation in the EU15

The types of vehicle tax structures across the EU are shown in Table 19 (Commission of the European Communities, 1998). All countries levy Vehicle Tax and Excise Duty and VAT on motor fuels but the tax levels differ considerably as is shown in Table 20 for 1994 (Bousquet and Queiroz, 1996). Apart from Luxembourg there would appear to be an excess of revenue over expenditure on roads in the remaining EU countries.

Ten countries collect tolls on roads and bridges and with the exception of Ireland it would appear that these are considered as taxes rather than charges (see Table 19). In France more than 70% of the 8250km of motorways and expressways are toll roads operated by either state owned or private company concessionaires (Bousquet and Queiroz, 1996); toll rates are set by Government with the concessionaires responsible for the construction, operation and maintenance of their motorways. The financial strength of the concessionaire companies enables them to construct new toll roads without Government support; for example a half of the investment in the French road network in 1991 came from these sources.

5.3.2 Dedicated, earmarked or hypothecated road user charges

In this method a road fund, that is an off-budget fund, is set-up in which the monies extracted from the road user are held. Proponents of the concept argue that it (i) gives more assurance of minimum levels of financing, (ii) provides more stability and continuity, (iii) establishes a strong link between the levy or charge and spending and (iv) can preserve critical expenditure on high priority requirements. The argument goes that it should be used for items of expenditure which are associated with high rates of return but which are politically less visible. Interestingly the World Bank (1994) has found that the rate of return on expenditure on road maintenance was twice that on new construction! The objections to dedication of road user payments are that it (i) hampers budgetary control (ii) can lead to misallocation of resources and (iii) tends to make the budget inflexible.

A recent study for PIARC has looked into the matter (Bloom, 1999). Table 21 summarises the information where some of the fees paid by road users are dedicated: according to OECD (1997) Japan has also earmarked national and local revenue sources. According to Bloom (1999) Argentina, Columbia, Hungary, Madagascar and Russia were said to have a dedicated road fund, although their operation was considered to have some shortcomings. In the USA some $20 billion are provided annually by the US Federal Highway Trust Fund which derives its income from motor-fuel and motor vehicle taxes (Chase, 1998; Bousquet and Queiroz, 1996): this represents about 20% of the total expenditure on highways in that country.

Accepting there is an argument against the dedication of road user charges for new road construction, because of its interference with budgetary control and political decision making, there is a very good case that the expenditures for maintenance, repair and renewal be retained within such a ring-fenced source. After all the decisions to create the highway infrastructure have already been taken, with those made during the past century or so being democratically approved by elected representatives. Once created, infrastructure needs to be maintained on a regular basis; one way of achieving this without the annual budgetary wrangle is by having a dedicated fund for this purpose. And for the future, if this system were adopted, elected representatives would be asked to realise that when deciding on a new piece of infrastructure they are voting on the provision of maintenance resources for the lifetime of that structure as well as on the capital to construct it in the first instance.

5.3.3 Recommendation 9

There is a need to ensure adequate financing of the maintenance, repair and renewal of highway structures on the whole road network but particularly on Regional and Local roads year in year out.

5.3.4 Recommendation 10

The setting up of dedicated funds derived from charges on the road user should be considered as a means of insulating such necessary annual expenditures from the vagaries of the economy as well as short-term political pressures.

Chapter 6 Implementation, development and research

6.1 INVENTORY OF HIGHWAY STRUCTURES

All the **thirteen** countries who replied to the Questionnaire provided information on the extent of their road networks and some data on the number of bridges on them (see Tables 1 and 2); information on road tunnels was provided by twelve countries (see Table 13). Only six countries provided information on retaining walls (see Table 11) with only five giving much detail (see Table 12). On the other hand in many cases information was not supplied for Regional and Local Roads particularly the latter. And where it was forthcoming it was often uncertain with estimates rather than actual figures being given.

The present situation, is that the inventory of structures on the European Road Network is incomplete; in many instances comprehensive data for the National Road Network is lacking and the situation is much worse for Local and Regional roads. As already intimated in the Recommendation at 2.3, the first step in implementing a programme for assessing and sustaining the stock of highway structures on the European road network is the completion of an inventory of highway structures as has already been advocated in Recommendations 1 and 2. Without clear identification of all the assets involved it is difficult to establish, finance and manage a sensible programme of work to achieve these objectives.

6.2 FUNDING

Regional and Local Roads which often represent some 90-95% of the road network are the major problem here. Revenue from road users - commercial vehicles and motorists - is in the main collected by Central Government and the trickle down effect is not consistent. The Regional and Local authorities responsible for roads have no direct access or inalienable rights to such funds. This is of course anomalous: these authorities provide and maintain roads but in general have no means whatsoever of obtaining revenue directly from those who use them. And it is not immediately clear that the recent EU White Papers (European Commission, 1998 and 2001) have recognised this problem although to be fair the main thrust of their argument has been on the improvement of commercial traffic on national and international routes.

But whatever mode of transport - rail, road or sea - is used for the long haul it is almost inevitable that the secondary and tertiary tiers of the highway network are used for final delivery of the goods and very often their initial pick-up as well. An efficient transportation system also depends on the well-being of these roads as well as of the more heavily utilised and high profile primary system.

There are two immediate problems here:

(i) Current expenditure on the maintenance of bridges on Regional and Local Roads is 0.3% or less of their replacement value in many countries and can be derisory for retaining structures.

(ii) Maintenance of bridges and other highway structures cannot be divorced from the overall funding of maintenance of the whole road system.

A useful starting point here could well be that EU countries should aim to spend similar amounts on the administration, operation and maintenance of their road networks as does the USA, i.e. something in excess of $60 billion annually (Chase 1999) given that the GDP of both regions is approximately equal. If the objective is to emulate and surpass the US economy then these are the levels of expenditure needed to sustain an effective highway network. (The annual capital expenditure in the USA on their road system although a little less is of a similar order of magnitude but is of course outside the scope of this report).

6.2.1 Recommendation 11

There is a pressing need for each and every country to set aside, year in year out, adequate sums of money to sustain all their road infrastructure, including Regional and Local roads, and all the structures on it in an acceptable way.

6.3 MONITORING THE PROGRAMME

The systematic collection of information on the work carried out on highway structures, its cost and subsequent performance is essential to success and this has been advocated in Recommendations 1, 2 and 4. The accumulation of such data should, over time, improve the allocation of resources and ensure that they are being applied in the most cost effective fashion.

A particular problem here is the trend to contract out maintenance and renewal to the private sector for periods of up to 10 years perhaps or even longer. In these circumstances much valuable information can - and has already been - lost since an organisation which, for whatever reason, knows that its contract is unlikely to be renewed has no incentive whatsoever to undertake this data collection chore and pass on the information to the new incumbent. Here the innate short-termism of the private sector is clearly at odds with the long-term objectives of the public sector client; even in the public sector itself the reorganisations of Central, Regional and Local Government can result in the loss of much data on the road network. Assets which have a life span of 50-200 years all need to have a 'log book' attached in some fashion for the period of their existence. Loss of as-constructed drawings and details of major maintenance works can be costly and result in the expenditure of limited resources on needless investigations and reinvestigations.

In Road Authorities themselves there is also a mismatch between the long-term needs of their stock of structures and the career span of their engineers. The latter can be pressured too by politicians with even shorter horizons who need the quick cheap fix to achieve their objectives and leave it to posterity to deal with any problems which may arise. One way of tackling this problem would be the formation of a centralised repository where all records of highway structures are archived. One possible location for this would be the vehicle registration and licensing organisation which might already have a computing capability suitable for keeping such data.

6.3.1 Recommendation 12

There is a need for each country to consider the setting up of a centralised repository for all data on the structures on their highway network.

6.4 RESEARCH

The continuous record keeping advocated above provides the basis on which new forms of construction, maintenance techniques and the like may be judged. For example, the experience of structures with steel reinforcement has not been good but it is only some 25-40 years after their construction that the financial implications have become obvious to all. As there would appear to be no viable alternative to salting of the road network to control ice formation, apart from odd localised situations, then the durability of reinforcement or its alternatives need to be improved. Stainless and epoxy coated steel have been used in special situations but are expensive; plastics may well be the final answer but that is some way off. However given the difficulties mentioned in Section 6.3 above it may be many years before structures reinforced with plain steel cease to be built.

But already there are many examples of sustainable structures around us. For example scores of arched buildings, particularly cathedrals and bridges, have survived since the Middle Ages some even from Roman times. Granted that the increased headroom needed for arched bridges may lead to difficulty and additional cost elsewhere, is there not a case for the re-evaluation of their applicability? Similar considerations would apply to earth retaining structures although here there are already indications of the efficacy of gravity structures and some inklings of the promise of plastics.

In the latter half of the 20th century the emphasis in research and development was on minimising first cost. But the outcomes have not been as expected: although modern and ever improving technology did produce adequately strong and enhanced structures these constructions have proved to be much less durable than their counterparts from earlier times. The trend towards whole-life-costing should eventually lead to amelioration of the problem but dramatic improvement must await the development of more durable new materials and structural forms. Sustainability recognises that there are limits to the world's resources and the highway network is a significant consumer. An effective system of assessing and sustaining the stock of road structures has a part to play in this scheme of things; so also has the supporting research and development.

It is also clear that the rate of road building and of the structures on them is set to slow down in the more affluent of the Europe 27 countries where their highway networks are already well developed and comprehensive. In these circumstances the priority will be on retaining the existing highway infrastructure in good condition and research needs to be directed to achieving these objectives effectively and economically. The development of rational processes and procedures which enable a trade-off to be made between the age of a structure and the margin of safety required of it needs to be addressed in order to maximise the utilisation of the existing stock of structures. There is need here for the development of a suite of standards for the assessment of existing structures to complement the plethora of standards for the design and construction of new structures; Supplement No 1-1990 to the Canadian Standard for Highway Bridges is an example of what is needed here (Canadian Standards Association, 1990).

Bridges due to their direct exposure to salt used for de-icing the highway are most at risk. Here increases in the cover to reinforcement and the elimination of movement joints - integral bridges - would go some way to reducing the rate of deterioration. The use of stainless steel would also help but the present perception is that the material is too expensive for general use. Carbon fibre reinforced polymer composites have been trialed in a number of bridges (ISIS Canada, undated; Christoffersen et al, 1999). Tilly et al (2002) has commented on the good performance of mass concrete bridges, while some steel-free deck slabs have been trialed on bridge rehabilitation projects (Newhook et al, 2001). Where structural deterioration is not universal there may well be a case for incorporating the structurally sound elements into the renewal scheme. This can result in significant economy; two such schemes are described in Annex VI. A peculiar blind spot is the lack of advice and guidelines in codes and other documentation on scour at bridge piers, a phenomenon which is responsible for about half of all dramatic bridge failures (Tilly et al, 2002).

Deterioration problems with tunnels have not yet revealed themselves to any large extent presumably due to their relatively young age and to the generally lower exposure to de-icing salt. However chlorides have been a problem in the road tunnels beneath sea or brackish water at Dartford, Dubai, Limfjord and Suez where significant repairs have been needed within 30 years or less of their opening to traffic. The comments above on the shortcomings of concrete reinforced with plain steel are equally relevant here.

The concrete linings of circular and arched tunnels usually contain reinforcement the function of which is principally to resist tensile stresses during the construction process. Although this does not appear to have resulted in durability problems in normal ground conditions there may well be a case for reviewing the situation since tunnel linings are essentially in compression for most of their life.

Reinforced gravity structures, often masonry faced, are commonly used for earth retaining walls supporting up to 3m of soil. Given the evidence of the deterioration of concrete reinforced with plain steel considered above it would be logical to use this form of construction to support even greater height of ground where this is feasible. The development of a range of suitable precast units to be erected by crane may overcome some of the problems in doing this although there will be situations where limitations on space renders such a solution impossible. Reinforced and anchored earth solutions would appear to have much to offer in such circumstances: there are also situations where the use of lightweight fills would be advantageous.

A particular problem in the assessment of highway structures is the discrepancy between the actual and predicted failure loads for bridges where the load applied at collapse can be up to five times that calculated (Tilly et al, 2002; Cullington and Beales, 1994). The development of realistic assessment methods would ensure that bridges are not unnecessarily replaced as a result of the use of inappropriate assessment procedures. Similar problems may well arise with retaining walls and tunnels but these have yet to be researched.

There are two modes for progressing research and development. The more common is through evolution by the slow and gradual improvement of existing technology and materials; the enhanced performance of pneumatic tyres during the past fifty years is a good example of this. The bulk of the improvements to the means of inspecting, assessing, maintaining, repairing and renewing highway structures are likely to stem from this kind of research. On the other hand there is the occasional revolutionary advance - often triggered by the exigencies of war or other emergency - where a breakthrough creates a new material or technology; the computer is a notable example of this.

Routine research can often be packaged but it is more difficult to cope in a bureaucratic structure with flashes of genius. There is much to said for the centre of excellence and this is most easily achieved in universities and the like. However where long-term research and development is needed over periods up to 50 years or more other types of organisation may be more appropriate; there may well also be a case for creating a Europe wide organisation to obviate parochialism.

Finally it must be recognised that research is carried out because the outcome is unknown or uncertain. It is only some way down the line that the potential of any particular avenue of enquiry can be judged; often it is the least expected of the contenders which comes up trumps in the long term. But negative results are not a waste since they prevent resources being applied ineffectively: they are particularly important today when miracle cures are aggressively being marketed by commercial organisations.

6.4.1 Recommendation 13

There is a need to develop a series of assessment standards for highway structures complementary to the existing standards for the design and construction of new structures.

6.4.2 Recommendation 14

There is a need to ensure that programmes of research and development are in place to ensure that the expenditures on maintenance, repair and renewal of highway structures are cost effective and achieve their purpose.

6.4.3 Recommendation 15

There is a need to review the arrangements for road research and development within Europe to assess its effectiveness and determine whether any changes are needed to ensure its organisation and funding are appropriate and adequate for the future.

6.5 VERIFICATION AND EVALUATION

Given the large annual expenditures proposed for the maintenance, repair and renewal of the structures on the highway networks of the European 27 countries it goes without saying that systems need to be in place to ensure that such sums are spent wisely. To ascertain this three matters need to be addressed as follows:-

(i) the appropriateness of the systems and methods being used,

(ii) the quality of the products and services supplied, and

(iii) the auditing of the finances.

Dealing with these in reverse order it is normal for the current expenditure of Highway Authorities to be controlled and audited. But this is only part of the story as the level of expenditure may be inadequate and result in a reduction in the value of assets. Replacement cost is not a measure of value since a dilapidated structure in need of major repair or even requiring immediate replacement has the same monetary amount attached to it as a newly commissioned structure with 50 - 100 years of useful life ahead of it. There is, therefore, a need to provide a measure of the overall asset value of highway structures so that the effects on such assets of shortfalls in expenditure can be monitored and accounted for. Financial accounting is currently under a cloud; and it would appear that cosy relationships often involving conflicts of interest have resulted in auditors failing to spot financial improprieties and in some instances fraud. It is foolish to suppose that such evils will ever be completely eliminated but financial systems and operating procedures should minimise the opportunities for their occurrence; the use of truly independent auditors is an obvious way forward here.

The problem is very similar when it comes to assessing the quality of products and services. Quality Assurance relying as it does in the main on self-certification has been shown to be open to abuse and even Quality Control can be circumvented by the determined miscreant. Again there is a need for independent supervisors and assessors and for the retention by clients of sufficient in-house staff capable of overseeing and checking that the standards of quality and safety they require have been achieved.

And lastly there is the question of the appropriateness of the systems and methods being used. Here clients need to have available either highly experienced professional staff within their own organisation or access to a truly independent second opinion on the merits of proposals at the formative and design stages. A wrong choice at these times can lock a client into an inappropriate course of action which can lead to unnecessary expenditure when another strategy would have been more appropriate. Arrangements where a firm checks another's work and it is possible for their roles to be reversed on another scheme in the future can also lead to less than rigorous review of proposals and designs. On the other hand organisations such as CEDEX and LCPC in Spain and France respectively would appear well suited to undertake many of the independent roles suggested above in their respective countries.

6.5.1 Recommendation 16

There is a need to provide sufficient checks and balances in the system to ensure financial probity, impartial advice on design and the appropriate standard and cost effectiveness of expenditure on maintenance, repair and renewal of highway structures.

Chapter 7 Concluding remarks

This report has shown that replies received to the Questionnaire circulated by COST 345 WG1, limited in number though they were, have provided very valuable information on the numbers and replacement cost of the structures on the highway infrastructure in European countries. These data have been extrapolated and conservative estimates have been made of the numbers of bridges and tunnels as well as the extent of retaining walling on much of the European road network. In particular the value of structures on the local road network have been identified and roughly quantified.

However the replies to the Questionnaire also showed that there were considerable gaps and grave shortcomings in the information available particularly for structures on Local and to a lesser extent on Regional roads. Without adequate information it is impossible to develop coherent and cost effective strategies and policies to ensure that the structures of the highway infrastructure in all their facets can be sustained in an efficient and consistent manner. Of the sixteen Recommendations in this report nine relate to the rectification of the above deficiencies and the setting-up of regimes capable of sustaining the stock of highway structures efficiently in an acceptable condition over the long-term. For ease of reference the Recommendations made throughout this report have been consolidated in Annex VII.

Unfortunately, the information obtained show that, with few exceptions, current levels of expenditure on maintenance, repair and renewal are inadequate; this is particularly so for Local and to a lesser degree for Regional Roads. The levels of financing needed to undertake these activities year on year were considered and recommendations made on the appropriate levels of such funding. Lastly the means of assuring the uninterrupted flow of these finances were considered.

There seems little doubt that the financing of the maintenance, repair and renewal needs to be put on a more consistent and sustainable basis if the full benefits of the management systems and techniques being developed for sustaining the stock of road structures on the highway infrastructure are to be fully realised. Five of the other Recommendations in this report deal with the provision of an adequate stream of financial resources year in year out to achieve this objective and the remaining two with research and development.

As stated at the beginning of this report the road network is by far the most important element of the land transport infrastructure in the EU and as such is essential to its wellbeing and economic development. Highway structures, particularly bridges and tunnels, are crucial components in this network and this report has brought into the open the deficiencies and limitations of current policies for their maintenance, repair and renewal. The situation is most critical on Local roads but not all is well on Regional roads and to some extent on National roads. An adequate and comprehensive infrastructure is an essential element of economic development and considerable sums have been, and are still being, spent on new road construction. However given the extent of the existing road network it is now more important than ever that the capacity of the existing highway infrastructure is exploited to the full. For road structures this can only be done by dedicating sufficient resources each and every year to their maintenance, repair and renewal and so sustain the stock of such structures.

We hope that this report, by identifying these shortcomings and the means of their resolution, will provide a starting point in the rectification of the current situation and hopefully in the fullness of time optimise the worth of such valuable infrastructure.

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Country	Total length of all roads (km)	National Roads		Regional Roads		Local Roads	
		Length (km)	%	Length (km)	%	Length (km)	%
Austria	106 011	1 934	1.82	9 959	9.39	94 118	88.78
Czech Republic	121 960	6 505	5.33	14 686	12.04	100 769	82.62
Denmark	71 600	1 600	2.23	10 000	13.97	60 000	83.80
France	980 000	36 500	3.72	358 500	36.58	585 000	59.69
Germany	626 174	52 994	8.46	177 780	28.39	395 400	63.15
Ireland	94 774	5 429	5.73	11 690	12.33	77 655	81.94
Norway	90 880	27 213	29.94	36 960	40.67	26 707	29.39
Poland	364 460	18 120	4.97	28 170	7.73	318 170	87.30
Slovenia	20 116	1 530	7.61	4 723	23.48	13 863	68.92
Spain	664 822	24 124	3.63	139 645	21.00	501 053	75.37
Sweden	420 000*	21 500	5.12	27 500	6.55	371 000	88.33
Switzerland	71 000	1 640	2.31	2 300	3.24	67 060	94.45
United Kingdom	399 624	18 334	4.59	39 123	9.79	342 167	85.62
Total	4 031 421	217 423	5.39	861 036	21.36	2 952 962	73.25

* Only 138,200km are public roads

Table 1 Distribution of roads

Country	All Roads		National Roads		Regional Roads		Local Roads	
	Number	km/bridge	Number	km/bridge	Number	km/bridge	Number	km/bridge
Austria	28 149	3.77	4 383	0.44	7 137	1.40	16 629	5.66
Czech Republic	16 106	3.44	3 579	1.82	4 468	3.29	8 059	12.50
Denmark	11 925	6.00	1 375	1.16	3 300	3.03	7 250	8.28
France	228 850	4.28	28 850	1.27	85 000	4.22	115 000	5.09
Germany	100 000(E)	6.26(E)	41 222	1.29	-		-	
Ireland	-		1 853	2.93	-		-	
Norway	-		10 177	2.67	5 904	6.26	-	
Poland	29 009	12.56	3 517	5.15	3 491	8.07	22 001	14.46
Slovenia	4 323	4.65	981	1.56	954	4.95	2 388	5.81
Spain *	-		12 305	1.96	21 513	6.49	-	
Sweden	25 000(E)	16.80(E)	3 750(E)	5.73(E)	3 750(E)	7.33(E)	17 500(E)	21.2(E)
Switzerland	-		3 345	0.49	-		-	
United Kingdom	93 684	4.27	15 992	1.15	← 77 692 / 4.91 →			

(E) Estimate

* All 10m or more long

Table 2 Number of bridges

Country	Type of superstructure (%)							Material in superstructure (%)						
	Arch	Slab	Beam & Slab	Box Girder	Suspen-sion	Cable Stayed	Other	Masonry	Reinf. Concrete	Pre-stressed Concrete	Steel	Comp-osite	Timber	Other
Austria	2.83	8.22	76.90	7.10	0.29	0.20	4.47	2.26	74.40	6.58	9.80	1.66	0.76	4.54
Czech Republic	0.84	43.11	23.30	0	0	0	32.75	13.07	48.86	18.32	5.88	0.42	0	13.44
Denmark (All roads)	5 (E)	50 (E)	40 (E)	1 (E)	0 (appx)	0 (appx)	4 (E)	1 (E)	80 (E)	10 (E)	5 (E)	3 (E)	1 (E)	0(appx)
(National roads only)	6.69	62.79	24.64	1.74	0.07	0.07	4.00	0.29	50.84	42.11	5.45	0.36	0.22	0.73
France *	29.97	31.20	7.63	1.54	0.04	0.03	29.59	25.86	47.13	22.31	0.85	3.84	0	0
Ireland *	33.80	39.79	17.66	0	0	0	8.75	33.65	43.54	0	4.75	18.06	0	0
Norway *	2.00	34.79	21.79	0.60	← 0.50 →		40.32	1.32	← 76.06 →		← 22.62 →		0	0
Slovenia **	6.54	38.34	25.00	0.84	0	0.05	29.24	5.62	72.79	15.14	5.25	0.73	0.47	0
Spain **	30.00	10.62	50.27	4.01	0	0.03	5.07	31.48	17.65	48.31	0.49	2.07	0	0
Sweden ***	0.82	56.00	17.35	0.85	0.01	0.02	24.94	4.00	66.40	4.00	24.00	1.20	0.40	0
United Kingdom	40 (E)	30 (E)	13.5(E)	0.5 (E)	0 (appx)	0 (appx)	16 (E)	40 (E)	35 (E)	9 (E)	6.5(E)	7.5 (E)	1.5(E)	0.5 (E)

(E) Estimate
* National roads only
** National and Regional roads only
*** SNRA and one local authority only

Table 3 Distribution of superstructure type and construction material for bridges

Country	Age (per cent)				
	Pre 1900	1900 – 45	1946 – 69	1970 – 2001	Not known
Austria	0.52	4.47	34.15	56.61	4.25
Czech Republic	8.06	23.40	22.08	33.53	12.93
Denmark	3 (E)	16 (E)	30 (E)	51 (E)	0
France *	0.43	4.25	35.82	59.50	0
Norway *	1.19	9.30	33.50	56.01	0
Slovenia **	3.62	18.66	22.22	55.50	0
Spain **	28.40	10.58	21.54	39.48	0
Sweden	1.20 (E)	12.00 (E)	38.80 (E)	48.00 (E)	0
Switzerland*	0	0	39.85	60.15	0
United Kingdom	40(E)	20(E)	20(E)	20(E)	0

(E) Estimate
* National roads only
** National and Regional roads only

Table 4 Age distribution of bridges

Country	Overall length (%)			Span lengths (%)		
	< 10 m	10 – 100 m	> 100	< 10 m	10 – 50 m	> 50
Austria	55	40	5	54	40	6
Czech Republic	70.09	27.83	2.08	70.09	23.01	6.90
Denmark	74 (E)	25 (E)	1 (E)	69 (E)	30.99 (E)	0.01 (E)
France	50	46	4	-	-	-
Ireland *	65	32	3	76	23.7	0.3
Norway *	58.9	34.9	6.2	48.5	31.2	20.3
Slovenia **	35	55	10	-	-	-
Spain ** +	0	90.6	9.3	31	67.7	1.2
Sweden	60	37	3	61	38	1
United Kingdom	80 (E)	18 (E)	2 (E)	85 (E)	14 (E)	1 (E)

(E) Estimate
* National roads only
** National and Regional roads only
\+ To be classified as a bridge length must be 10m or more

Table 5 Overall length and span of bridges

Country	All Roads		National Roads		Regional Roads		Local Roads	
	Total (billion €)	Average cost/bridge (thousand €)	Total (billion €)	Average cost/bridge (thousand €)	Total (billion €)	Average cost/bridge (thousand €)	Total (billion €)	Average cost/bridge (thousand €)
Austria	21.8	774	10.9	2487	5.45	764	5.45	328
Czech Republic	1.662	103	0.940	263	0.382	85	0.340	42
Denmark	6.85	574	2.69	1956	2.28	691	1.88	259
France	-		11.0	381	-		-	
Norway	-		← 6.25 / 389 →				-	
Slovenia	0.910	211	-		-		-	
Spain	-		3.504	285	3.157	147	-	
Sweden	5.2	208	2.1	560	0.8	213	2.3	131
Switzerland	-		8.00	2392	-		-	
United Kingdom	49.581	529	22.389	1400	← 27.192 / 350 →			

Table 6 Replacement costs of bridges

Country	Replacement Costs (€/m²)				
	Arch	Slab	Beam and Slab	Box Girder	Average
Czech Republic	1000 – 1550	500-700	570-740	570-740	796
Denmark	2000	1350	1600	2000	1738
Slovenia	← 800 approx →				800
Spain	-	450	490	1000	647
Sweden	← 700-1400 →				1050
United Kingdom	2000 – 3000	1600 - 2500	2000 - 2200	2100	2188

Table 7 Typical unit replacement cost of bridges

Country	Maintenance, repair and renewal		Management	Inspection
	Total (million €)	Percentage of replacement cost	(million €)	(million €)
Austria	80*	0.4*	0.53	
Czech Republic	-	0.04*	4.2	0.06
Denmark	40*	0.6* +	4	1
France	81	-	12**	9**
Norway ***	23*	0.46*	3	2
Slovenia	24	2.6	-	0.18***
Spain ***	20.88*	0.3*	0.81	1.34
Sweden ****	73	1.4	2	2
Switzerland **	78.8	0.98	-	-
United Kingdom	-	0.3 - 1.1*****	-	-

* Renewal not included
** National bridges only
*** National and Regional bridges only
**** SNRA figures only
***** Higher percentage contains renewal cost
+ 1% National, 0.3% Regional and Local roads

Table 8 Running costs of bridges

Country	Comment
Austria	Classification not used – included in bridges
Czech Republic	Classification not used – included in bridges
Denmark	Classification not used – included in bridges
Ireland	119 on National roads
Norway	Classification not used – included in bridges
Poland	Classification not used – included in bridges
Slovenia	1040 on National and Regional roads
Spain *	90891 on National and Regional roads
Sweden	Classification not used – included in bridges
United Kingdom	In general classification not used – included in bridges

* Bridge structures less than 10 m long are classed as culverts

Table 9 General comments on culverts

Details / Country	Ireland	Slovenia	Spain
Spacing (km/culvert)	45.62	6.01	1.80
Materials of construction (%)			
Concrete	2.42	91.35	36.97
Pipes (precast concrete)	38.71	0	2.23
Corrugated steel	58.87	0	2.33
Other	0	8.65	58.47*
Replacement cost			
Total (billion €)	-	0.038 (E)	2.649
Average per structure (thousand €)	-	36.54 (E)	29.15
Annual expenditure on maintenance, repair and renewal (% of replacement cost)	-	-	0.028

(E) Estimate
* Masonry

Table 10 Detailed information on culverts

Country	Comment
Austria	Database not yet complete
Czech Republic	5543 walls average length 82.5 m
Denmark	18 walls on National roads; average length 341.7 m No data for Regional and Local roads
France	13 729 walls on National roads; average length 67 m No data for Regional and Local roads
Spain	3641 walls on National roads; average length 70 m No data for Regional and Local roads
Sweden	600 walls (E) SNRA roads and Stockholm area
United Kingdom	4433 km of walls (E)

(E) Estimate

Table 11 General information on retaining walls

Details \ Country	Czech Republic	Denmark	France *	Spain	United Kingdom
Distribution (m wall / km)					
All roads	8.25	-	-	-	11.1
National roads only	28.64	3.84	33.0	10.6	23.4
Type of construction (%)					
Gravity retaining walls	-	-	-	41.23 (E)	85 (E)
Reinforced concrete retaining walls	-	-	-	36.40 (E)	10 (E)
Reinforced and anchored soil retaining walls	-	-	-	21.42 (E)	1 (E)
Other (including unknown)	-	-	-	0.96 (E)	4 (E)
Materials of construction (%)					
Drystone	57.41 (Drystone and Improved drystone combined)	0	15.80	0.15 (E)	40 (E)
Improved drystone		0	46.53	12.64 (E)	30 (E)
Plain unreinforced concrete	29.41	11.11	12.24	10.52 (E)	15 (E)
Reinforced concrete	7.02	61.11	12.00	75.92 (E)	10 (E)
Other (including unknown)	6.17	27.78	13.44	0.77 (E)	5 (E)
Height distribution (%)					
2.00 to 4.00 m	-	77.78	77.84 (2.00 to 6.00 m combined)	61.59 (E)	70 (E)
4.01 to 6.00 m	-	16.67		29.59 (E)	25 (E)
6.01 to 10.00 m	-	5.56	16.72	7.03 (E)	4.3 (E)
10.01 m and higher	-	0	5.44	1.79 (E)	0.7 (E)
Replacement cost					
Total (billion €)	-	0.027	-	0.142	6.86 (E)
Per m of wall (thousand €)	-	4.39	-	0.561	1.55
Maintenance, repair and renewal per annum (% of replacement cost)	-	0.1	-	0.0044	0.03 - 0.75

(E) Estimate

* National roads (excluding motorways)

Table 12 Detailed information on retaining walls

Country	All Roads		National Roads		Regional Roads		Local Roads		Number of tunnels at least 1km long*
	Number	Average length (m)	Number	Average length (m)	Number	Average length (m)	Number	Average length (m)	
Austria	320	897	181	1127	84	607	55	582	55
Czech Republic	17	-	6	-	9	-	2	-	-
Denmark	6	427	5	453	1	293	0	-	1
France	406	628	166	1 024	122	295	118	415	46
Germany	-		165	792	-		-		38
Ireland	1	1 320**	1	1 320**	0	-	0	-	-
Norway	-		665	1 060	125	683			203
Slovenia	-		32	406	14	79			-
Spain	-		226	535	-		-		25
Sweden	25	620	19	526	5	1 000	1	500	3
Switzerland	-		188	882	-		-		67
United Kingdom ***	45	1 230**	32	1 420**	12	753**	1	890**	7

* data from UNECE (2000)

** 2-lane m

*** over 150m long

Table 13 Number of tunnels

Country	Traffic flow		Ventilation		Type of construction (km)				
	Unidirectional (km)	Bidirectional (km)	Mechanical (km)	Without mechanical (km)	Cut and cover	Bored and lined	Bored and unlined	Immersed tube	Composite
Austria	206	81	202	85	145	175	0	0	0
Czech Republic	7	1	8	0.3	6	11	0	0	0
Denmark	2.6	0	2.3	0.3	4	0	0	2	0
France	160	94	166	88	163	222		1	6
Ireland	1.3*	0	1.3	0	0	0	0	1	0
Norway**	61	729	428	359	-	-	-	-	-
Spain ***	73	47	85	36	17	184	25	0	1
Sweden	8	7.5	11	4.5	6	2	16	1	0
United Kingdom	48*	8	47	6	22	18	0	2	0

* 2-lane km

** National and Regional roads

*** National roads only

Table 14 Operational and construction information for tunnels

Country	Age (per cent)				
	Pre 1900	1900 - 45	1946 – 69	1970 – 2000	Not known
Austria	0	2.81	8.13	85.0	4.06
Denmark	0	0	16.7	83.3	0
France	6.16	10.34	13.05	51.48	18.97
Ireland	0	0	0	100	0
Spain *	3.10	2.21	15.04	79.65	0
Sweden	0	0	40	60	0
United Kingdom	1.11	5.56	26.67	66.67	0

* National roads only

Table 15 Age distribution of tunnels

Country	Replacement cost		Cost of operating, maintaining, repairing and replacing tunnels	
	Total (billion €)	Per metre length (€)	(million €)	% of replacement cost
Austria	2.5	8710	5.5	0.2
Czech Republic	0.088	10633	0.64	0.73
Denmark	0.4	156250	2.0	0.2 – 1.0
Slovenia	0.166	11773	-	-
Spain *	1.065	8802	13.1	1.2
Sweden	1.5	96774	6.0	0.4
United Kingdom	3.6	65556	28.3	0.8

* National roads only

Table 16 Replacement and running costs of tunnels

	B	DK	D	EL	E*	F	IRL	I	L	NL	A	P	FIN	S	UK	EU 15
	Length of road network 1996 (×1000 km)															
Motorways	1.7	0.9	11.3	0.5	7.3	8.3	0.1	6.4	0.1	2.4	1.6	0.7	0.4	1.3	3.3	46.3
National roads	12.5	3.7	41.5	9.1	17.6	26.9	4.4	44.8	1.0	2.1	10.3	9.0	12.3	14.6	12.4	222.2
State roads	1.3	7.1	178.3	29.1	70.5	360.1	10.7	113.4	1.9	8.6	19.8	46.1	29.1	83.4	38.1	997.5
Municipal roads	129.4	60.0	418.6	75.6	67.1	569.0	76.3	142.0	2.3	114.0	98.0	62.5	35.9	38.9	339.1	2228.7
Toll roads	0.001			0.871	2.083	6.768		5.575			0.179	0.600				16.1
Total	144.9	71.7	649.7	115.2	164.6	971.1	91.5	312.2	5.3	127.1	129.9	118.9	77.7	138.2	392.9	3510.9
	Population 1998 (million)															
	10.2	5.3	82.0	10.5	39.4	58.8	3.7	57.6	0.4	15.7	8.1	10.0	5.2	8.9	59.1	374.9
	Area (×1000 km^2)															
	30.5	43.1	357.0	132.0	506.0	544.0	70.3	301.3	2.6	41.5	83.9	91.9	338.1	450.0	244.1	3236.2
	Density (persons/km^2)															
	335	123	230	80	78	108	53	191	164	378	96	108	15	20	242	116

* Spain : in addition 503000 km secondary roads

Table 17 Statistical information for EU member countries

(Compiled from Tables 2.4 and 1.6 of EU Transport in Figures Statistical Pocketbook 2000: European Commission, 2000)

	BG	CZ	SK	EST	H	LT	LV	PL	RO	SLO	Total
	Length of road network 1996 (km)										
Motorways	314	423	215	65	365	404	0	258	113	310	2 467
State roads	3 030	55 088	3 073	15 303	6 487	20 717	7 037	45 376	14 570	1 370	172 051
Provincial/local roads	33 943	66 449	3 921	58 800	23 197	39 161	44 618	329 315	58 477	13 189	671 070
Total	37 287	121 960	17 867	44 168	30 049	60 282	51 655	374 949	73 160	14 869	826 246
	Population 1998 (million)										
	8.3	10.3	5.4	1.5	10.1	3.7	2.5	38.7	22.5	2.0	104.8
	Area (×1000 km^2)										
	110.9	78.9	49.0	45.2	93.0	65.3	64.6	312.7	238.6	20.3	1 079
	Density (persons/km^2)										
	75	131	110	33	109	57	39	124	94	99	97

Table 18 Statistical information for Central European countries

(Compiled from Tables 8.12 and 8.15 of EU Transport in Figures Statistical Pocketbook 2000: European Commission, 2000)

Member state	Annual taxes	Taxes on motoring		
	Vehicle tax	Excise duty on motor fuels + VAT	Tolls on roads or bridges	User charges (Euro-vignette[2] etc)
Belgium	*	*		*
Germany	*	*		*
Denmark	*	*	*	*
Spain	*	*	*	
Greece	*	*	*	
France	*	*	*	
Italy	*	*	*	
Ireland	*	*	*[1]	
Luxembourg	*	*		*
Netherlands	*	*		*
Austria	*	*	*	
Portugal	*	*	*	
Finland	*	*		
Sweden	*	*	*	*
United Kingdom	*	*	*	

1 Tolls applied so far are private charges rather than taxes

2 This is a regional 'Euro-tax-disc' on heavy goods vehicles and is valid for periods of 1 day, 1 week, 1 month or 1 year; annual cost varies from €750 - 1550 (European Commission, 2001, p19&74).

Table 19 HGV taxes in Member States (EU 15) as of 1 January 1998 (Commission of the European Communities, 1998)

Country	Revenue from road users (€ million)	Road expenditure (€ million)	Ratio Revenue / Expenditure
Germany	45656	21823	2.09
Netherlands	10390	1347	7.71
Spain	17121	6026	2.84
United Kingdom	35407	9464	3.74

Table 20 Road revenue and road expenditure in 1994 (Bousquet and Queiroz, 1998)

Country	Dedicated fees? [1]	% of budget [2]	Frequency of adjustment of user fees [3]	Purpose [4]
Australia	Part (Remainder of fees considered taxes)	N/A[5]	N/A	National Highways and Roads of National Importance Distribution to State and Local Governments for other roads
New Zealand	Yes	4	Several times per decade	All highways and roads Safety enforcement Subsidies for public transport
Switzerland	Yes	8	Approximately once per decade, requires popular vote	National Highways and Rail projects Shared with Cantons for National Highways and other roads
United States	Yes	1.5	4 times in last 13 years	Highways and Mass Transit
1	Dedicated fees? indicates whether or not fees or taxes collected from highway users are dedicated for transportation purposes			
2	% of budget indicates what per cent of the total government budget is supported by highway user taxes and fees, if known			
3	Frequency of Adjustment of User Fees indicates how frequently the dedicated fees are reconsidered, raised or adjusted			
4	Purpose indicates any limitations on the use of the dedicated fees. Are the fees used for highways and bridges only; for highways bridges and mass transportation; or for other transportation purposes?			
5	N/A indicates not applicable or not available			

Table 21 Dedicated user fees (Bloom, 1999)

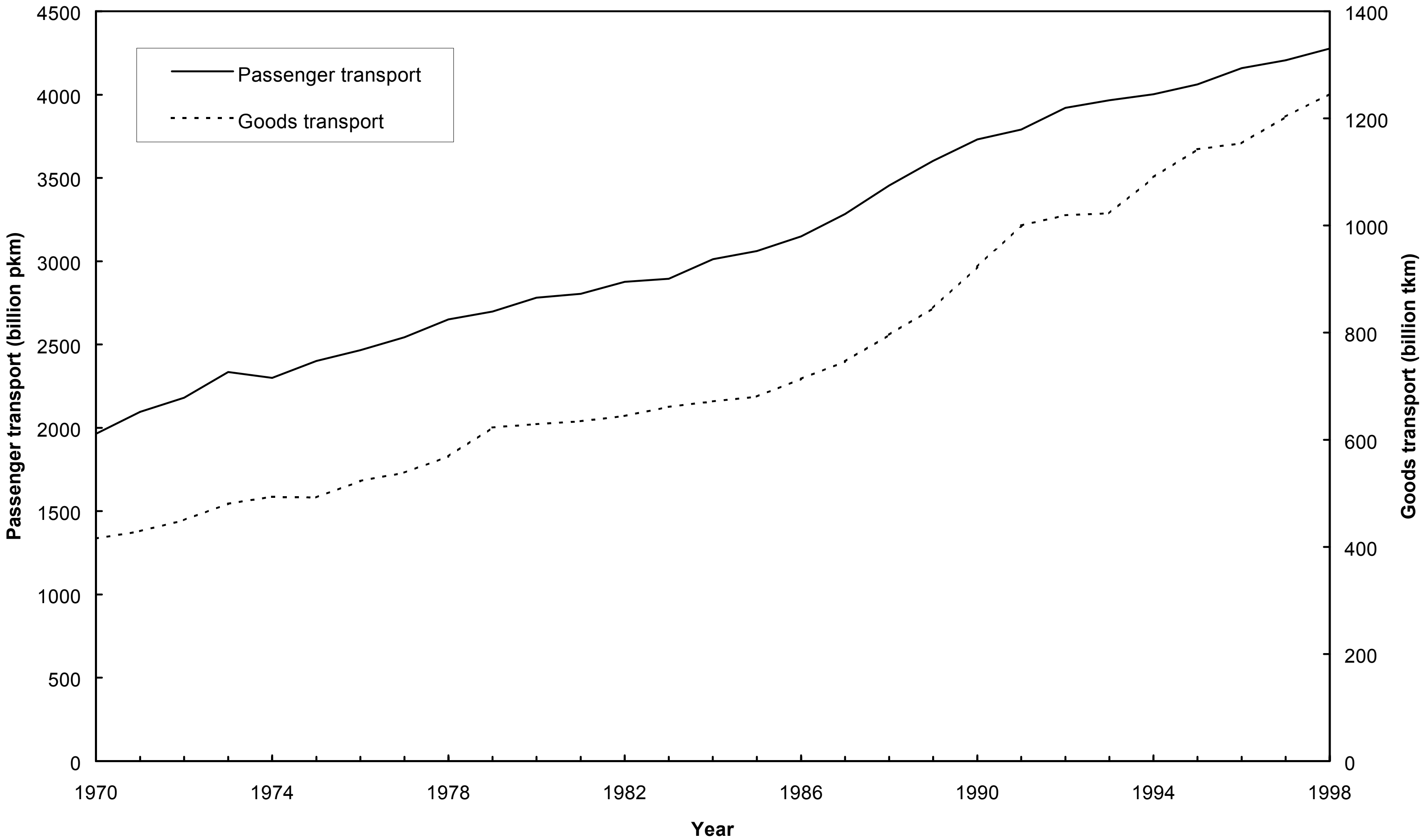


Figure 1 Evolution of passenger and goods transport on roads 1970-1998 (European Commission, 2000)

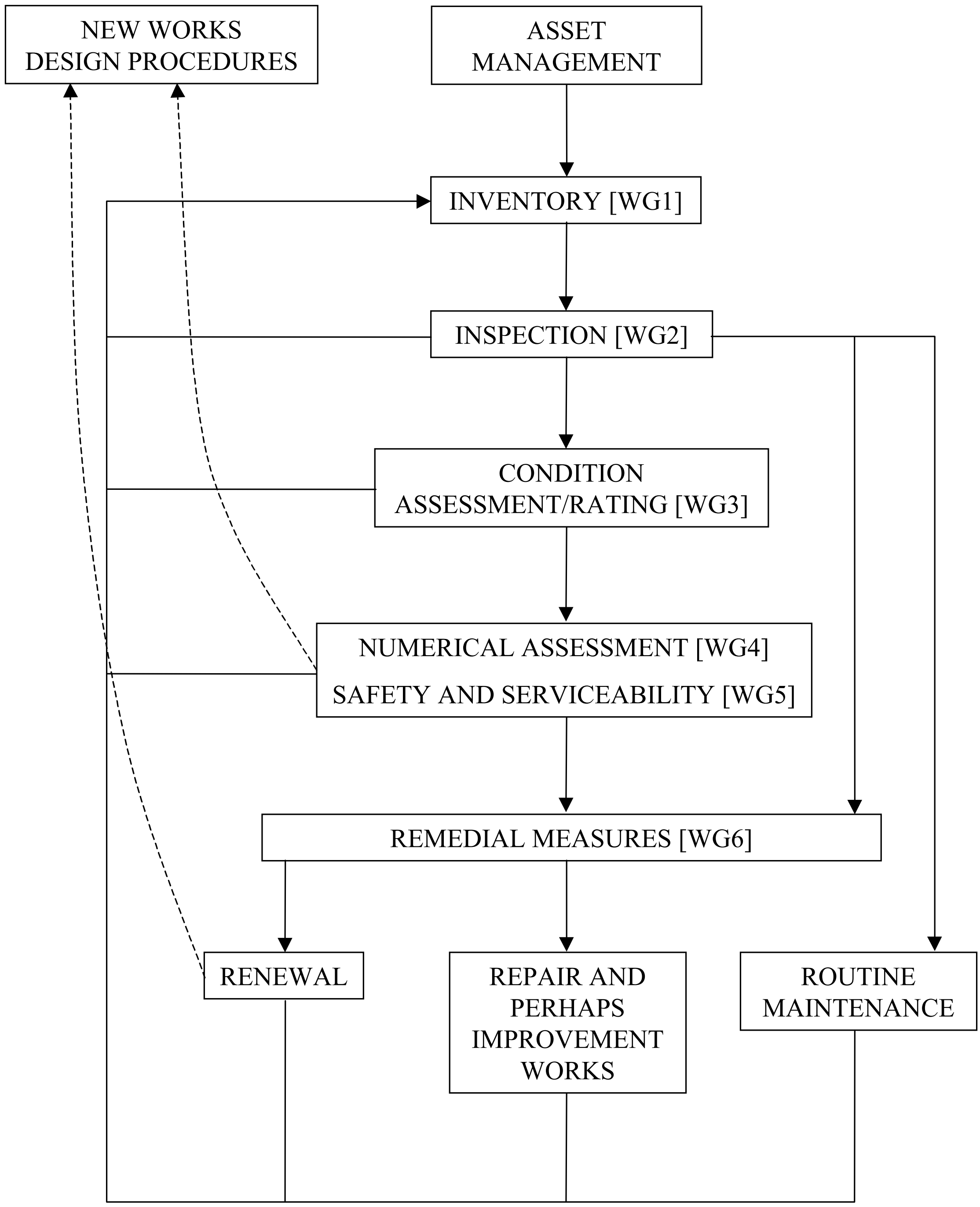


Figure 2 Asset management cycle

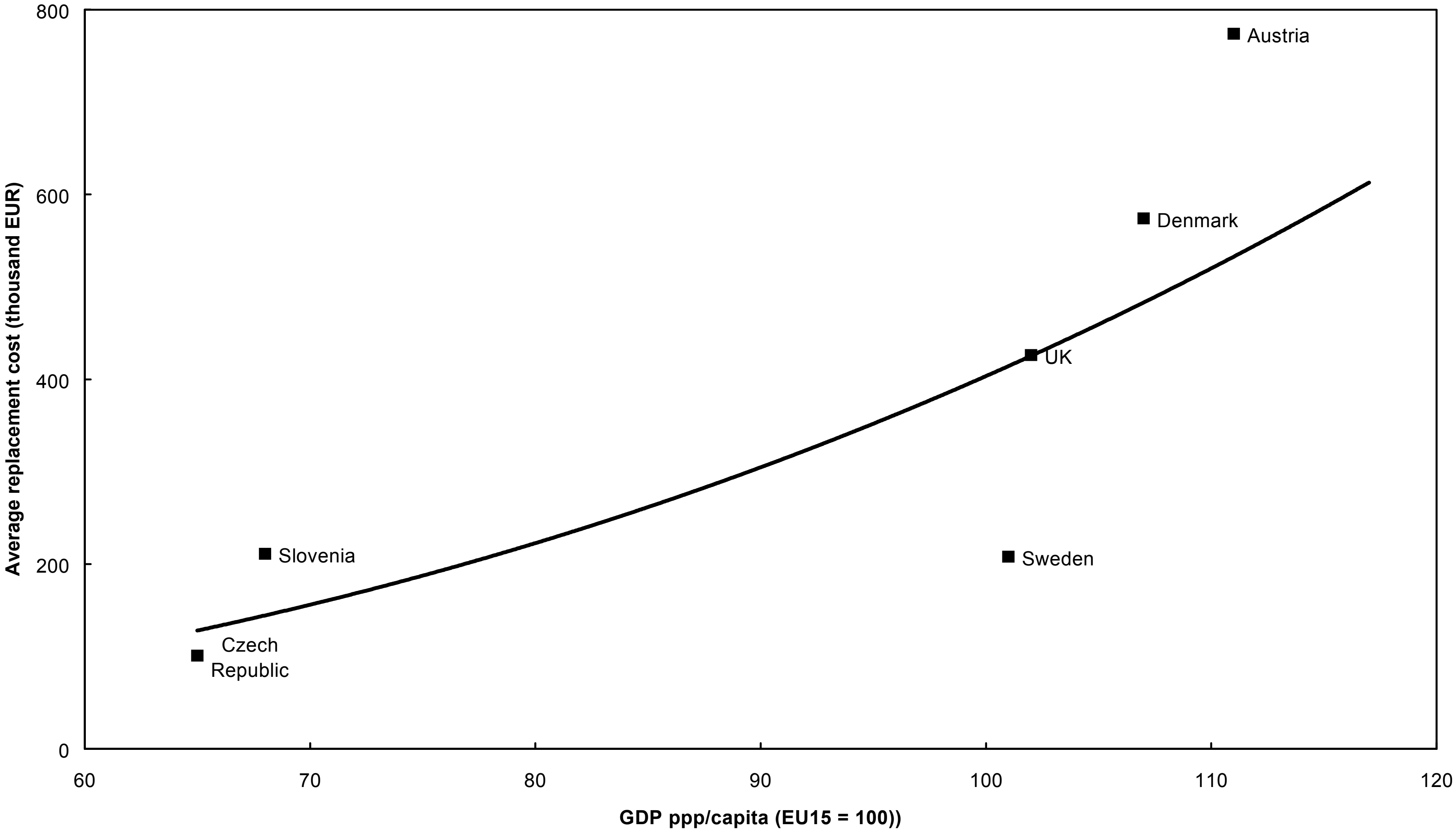


Figure 3 Relation between ppp/capita and average bridge replacement cost

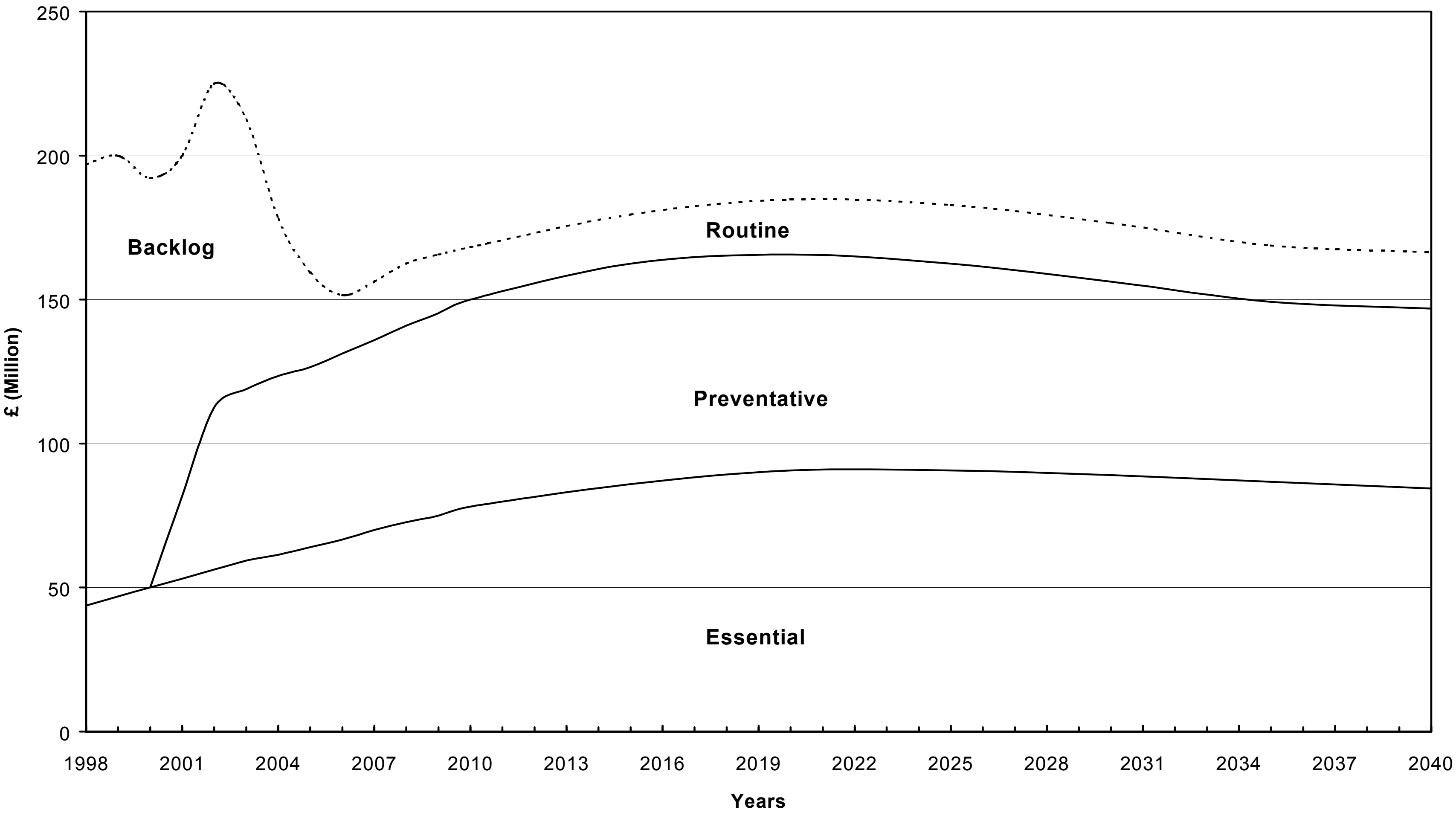
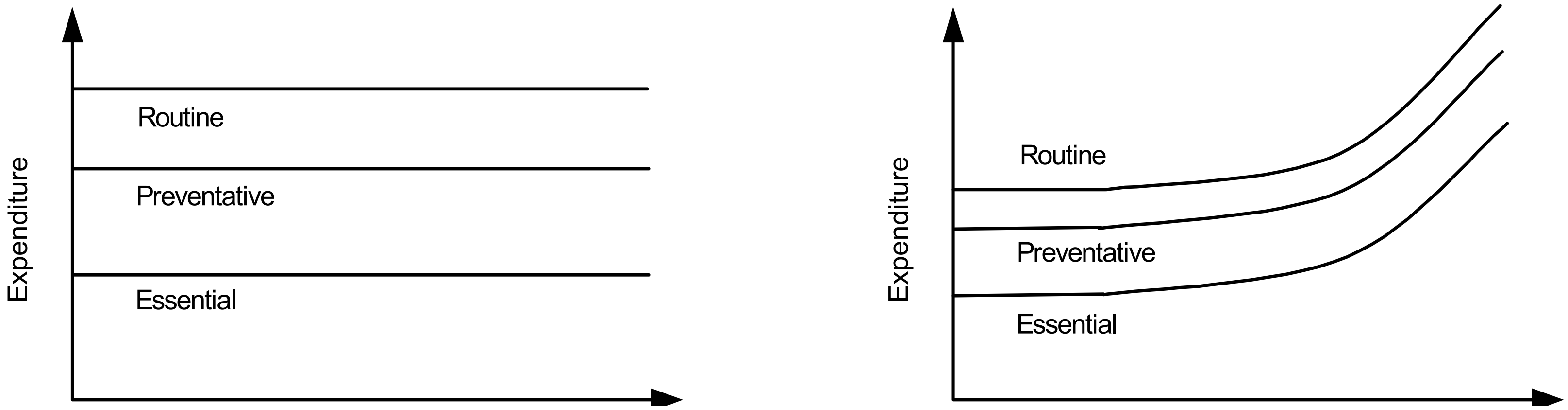


Figure 4 Strategic plan for future structures' maintenance expenditure (Das and Micic, 1999)



(a) Ideal bridge maintenance programme (b) Effect of long-term underfunding

Figure 5 The effects of different maintenance strategies on costs

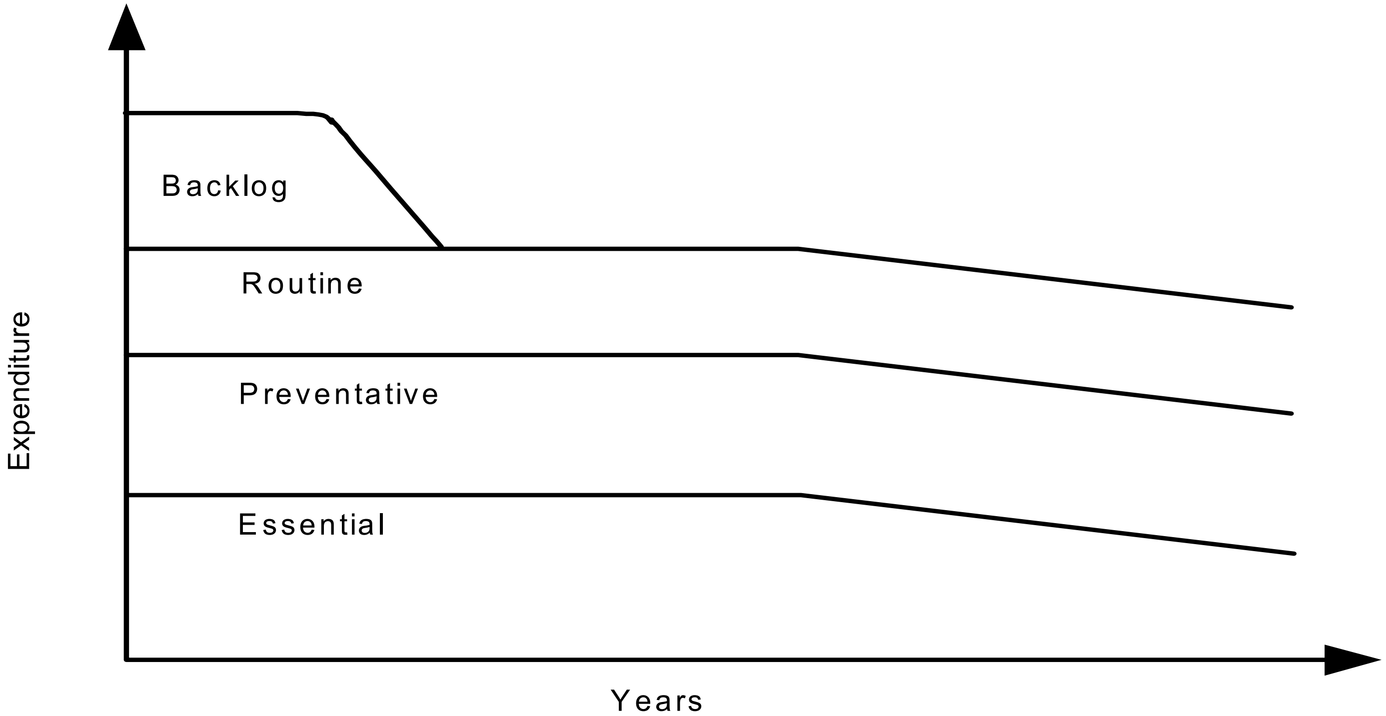


Figure 6 Idealisation of likely long term trends in maintenance expenditures

Annex I. COST 345 Working Group 1

I.1 TERMS OF REFERENCE

To collect analyse and report on information from COST countries on the extent, magnitude and value of the structures on their highway infrastructure in order to provide reliable estimates of:

(i) the current stock of highway structures

(ii) the cost of their replacement, and

(iii) the annual costs of maintaining, repairing and renewing them.

In addition the WG is to obtain information on the methods currently being used to assess the adequacy of highway structures and the systems used to manage this valuable infrastructure; sources of data are to be identified and information of use to other Working Groups of COST 345 is to be collected.

In the context of these terms of reference the highway infrastructure embraces national, regional and local roads while highway structures include all types of bridges, earth retaining structures, drainage conduits and large pipes, tunnels, avalanche shelters and the like with current replacement cost in excess of €25000.

I.2 MEMBERSHIP

M P O'Reilly (UK) (Leader). Independent Consultant.

R Astudillo (ES). Director of Laboratorio Central de Estructuras y Materiales, CEDEX, Ministerio de Fomento, Madrid.

J-L Durville (FR). Chargé de mission géotechnique – risques, CETE de Lyon.

J Holst (DK). Senior Engineer, Road Directorate, Ministry of Transport, Copenhagen.

M J Greene (UK). Engineer, TRL Limited, Crowthorne.

Annex II. Copy of Questionnaire

COST 345

QUESTIONNAIRE ON HIGHWAY STRUCTURES

SECTION 1: GENERAL INFORMATION

1.1 Background information

European Cooperation in the Field of Scientific and Technical research (COST) is promoted by the European Commission. Some 32 countries are currently members of COST as well as international organisations and research establishments from non-COST countries.

In the transportation sector COST Actions are promoted and sponsored by the Directorate-General VII Transport of the European Commission. COST 345 – Procedures Required for Assessing Highway Structures – is one such Action: it was initiated in mid-1999 and as of the end of May 2000 there were 14 participating countries.

A knowledge of the value and relative importance of the various structural components of the complete road system is a prerequisite to the efficient progressing of this Action. Therefore, one of the first steps taken by the Management Committee of COST 345, at its initial meeting in Brussels on 29 June 1999, was to set up Working Group 1 charged with gathering information on the number, type and replacement value of the structures on the road system for as much of Europe as possible. This Questionnaire is the first step in that process.

1.2 Notes for guidance

It is realised that the level of information within any single country may vary. For example in England information on the structures on the motorway and trunk road system (i.e. National Roads – see definition below) will often be of a higher standard than for the Regional Roads and usually much better than that available for Local Roads: indeed it may also vary between Maintaining Authorities for the same class of road. A somewhat similar situation pertains in Sweden where the road network is also divided into three categories (i) state roads, (ii) local authority streets and roads, and (iii) private roads. The quality of information for (i) is very high, for (ii) less so and poor for (iii).

What we would like you to do is to supply the best information available to you in the current records. Where exact information is not available would you please give us your best estimate in whatever terms you consider appropriate. For example if you are unable to provide the exact number of bridges (2.3.2 below) on the various categories of road then your best estimate (or guestimate) in percentage terms would be appreciated.

Further information on the aims, objectives and work programme of COST 345 are contained in the Appendix.

1.3 Timescale and reporting

We would like you to return the completed Questionnaire by 30 November 2000.

It is proposed to let all responding countries have a copy of the preliminary report on the information obtained from the Questionnaire by July 2001.

1.4 Definitions

1.4.1 *Road categories.* A road system has a hierarchical arrangement varying from motorways connecting cities to the most menial track serving a house or two. For the purposes of this Questionnaire a three tier classification is appropriate and the road system is categorised as follows:

a) National Roads. These are roads of the highest commercial and strategic importance usually maintained by the National Road Authority, but interurban toll roads are also to be included.

b) Regional Roads. Although not of national importance these roads are major traffic routes carrying heavy traffic within the local region. Many heavily trafficked urban streets will fall into this classification.

c) Local Roads. All roads not in a) and b) above.

1.4.2 *A structure.* An individual element on the road system such as a bridge, culvert, retaining wall, tunnel or avalanche shelter. Individual structures with a replacement value less than 25,000 Euros are not to be included. (It is accepted that this value is a rather low amount with regard to bridges and tunnels, but is of more significance for pipe culverts and retaining walls).

1.4.3 *Replacement cost.* The cost of rebuilding the whole structure without either changing or improving its function and purpose, or enhancing it in any way or increasing its capacity.

1.4.4 *Expenditure on maintenance, repair and renewal.* This is a catchall or omnibus term used to include all expenditures used to keep the existing stock of a category of structure intact. For example on a steel suspension bridge maintenance would include repainting, damaged parapets would be repaired while the replacement of corroded hangers and cables would constitute renewal. All these, however labelled and financed, are needed at various times to maintain a structure in a serviceable condition fit for its intended purpose.

1.4.5 *Year of construction.* The year when construction of the structure was completed.

1.5 Information on administrative data

1.5.1 Total length of the road system

What is the total length of road in your country ?

The total length of road in my country is : _______________km

Comments: ....
....
....

1.5.2 Distribution of road length according to administration

What lengths of road in 1.5.1 above fall into the following categories ?

National roads : _______________ km

Regional roads : _______________ km

Local roads : _______________ km

Comments: ....
....
....

COST 345

QUESTIONNAIRE ON HIGHWAY STRUCTURES

SECTION 2: BRIDGES

2.1 Note for guidance

The attention of the compiler of the response to this section of the Questionnaire is drawn to the general information in Section 1 above and in particular to 1.2 and 1.4 of that Section. It cannot be stressed too strongly that where exact information is not available please give your best estimate of that particular quantity or cost since this can still be of considerable value.

2.2 Definitions

2.2.1 *Bridge.* A bridge is defined as a structure with a total length ≥ 2 m and minimum spanlength ≥ 2m and carrying road traffic. Both over- and underpasses are to be included.

2.2.2 *Length of bridge (L).* Length of the bridge deck is taken as the distance between the extreme edges of the deck, parallel to the longitudinal axis of the bridge.

2.2.3 *Width of bridge(W).* Width of bridge deck is taken as the distance between the extreme edges of the deck, i.e. between edge beams and/or parapets.

2.2.4 *Area of bridge.* The deck area is defined as L×W.

2.2.5 *Length of span.* The distance between the two theoretical support lines, parallel to the longitudinal axis of the bridge.

2.2.6 *Renewal value/replacement cost.* The cost to rebuild the existing bridge without changing the external configuration.

2.3 Information on administrative data

<u>2.3.1 Total number of bridges on the road system</u>

What is the total number of bridges on the whole road network in your country ?

The total number of bridges in my country is _______________ no.

Comments: ....……………………….....…...............................

....…………………………………........................
....…………………………………..............................

2.3.2 Distribution of bridges according to road administration

How many bridges included in the total number given in 2.3.1 above are on the following categories of road ?

National roads : _______________ no.

Regional roads : _______________ no.

Local roads : _______________ no.

If you do not have the exact information on numbers, please give your best estimate in % of how the numbers are distributed for the three different road categories.

Comments: ....………………………...…..
....…………………………………..................................
....…………………………………...................................

2.3.3 Total length of bridges according to road administration

What is the total length of bridge deck on the following categories of road?

National roads : _______________ km

Regional roads : _______________ km

Local roads : _______________ km

Comments: ....…………………………...............................….....................................
....…………………………………..................................
....…………………………………..................................

2.3.4 Total area of bridge stock divided on road administration

What is the total area of bridge decks on the following categories of road ?

National roads : _______________ $m^2 \times 1000$

Regional roads : _______________ $m^2 \times 1000$

Local roads : _______________ $m^2 \times 1000$

Comments: ....………………………………….......................................

....
....

2.4 Information on technical data

2.4.1 Type of superstructure.

Taking into consideration the whole bridge stock in your country, could you please provide information on the numbers and/or areas of the following types of superstructure:

Arch bridges:	____________	no.	and	____________	$m^2 \times 1000$
Slabs:	____________	no.	and	____________	$m^2 \times 1000$
Beam & slab:	____________	no.	and	____________	$m^2 \times 1000$
Box girders:	____________	no.	and	____________	$m^2 \times 1000$
Suspension:	____________	no.	and	____________	$m^2 \times 1000$
Cable stayed:	____________	no.	and	____________	$m^2 \times 1000$
Others:	____________	no.	and	____________	$m^2 \times 1000$

Comments: ....
....
....

2.4.2 Material in superstructure

Please provide information on the numbers and/or area of bridges with superstructures of the following types of materials:

Masonry:	__________	no.	and	___________	$m^2 \times 1000$
Reinforced concrete:	__________	no.	and	___________	$m^2 \times 1000$
Prestressed concrete:	__________	no.	and	___________	$m^2 \times 1000$
Steel:	__________	no.	and	___________	$m^2 \times 1000$
Composite:	__________	no.	and	___________	$m^2 \times 1000$
Timber:	__________	no.	and	___________	$m^2 \times 1000$

Comments: ....…...........………………………...
....……………………………..............................
....……………………………..............................

2.4.3 Age distribution of bridges

Please provide information on the numbers and/or the deck area of bridges constructed in the following periods:

Before 1900: ____________ no. and ____________ $m^2 \times 1000$

1900 to 1945: ____________ no. and ____________ $m^2 \times 1000$

1946 to 1969: ____________ no. and ____________ $m^2 \times 1000$

1970 to 2000: ____________ no. and ____________ $m^2 \times 1000$

Comments: ....……………………….......................................……..
....……………………………...
....……………………………...

2.4.4 Overall length of bridges

Please provide the information on the number of bridges with an overall length of the superstructure within the following ranges:

a) What percentage of the whole bridge stock by number is less than 10 m long ?

__________ per cent

b) What percentage of the whole bridge stock by number is between 10 and 100m long ?

__________ per cent

c) What percentage of the whole bridge stock by number is in excess of 100 m ?

__________ per cent

Comments: ....………………………....…..................................…
....……………………………...
....……………………………...

2.4.5 Spanlength of bridges

Please provide information on the number of bridges with a maximum spanlength of the superstructure within the following ranges:

a) What percentage of the whole bridge stock by number has a maximum spanlength less than 10 m ?

__________ per cent

b) What percentage of the whole bridge stock by number has a maximum spanlength between 10 and 50 m ?

__________ per cent

c) What percentage of the whole bridge stock by number has a maximum spanlength in excess of 50 m ?

__________ per cent

Comments: ....
....
....

2.5 Information on costs

2.5.1 Estimated replacement cost of total bridge stock

a) What is the estimated replacement cost of the existing stock of bridges on the whole road network in your country ?

_____________________ Euro

b) Are you able to break down the above figure in to the estimated replacement cost of the existing stock of bridges on the following categories of road ?

National roads : _______________ Euro

Regional roads : _______________ Euro

Local roads : _______________ Euro

c) What is the current average replacement cost per m^2 for the following types of bridges ?

Arch bridges: _______________ Euro/m^2

Slabs: _______________ Euro/m^2

Beam & slab: _______________ Euro/m^2

Box girders: _______________ Euro/m^2

Comments: ....
....
....

2.5.2 Annual expenditure on maintenance, repair and renewal

a) What is the annual expenditure on maintenance, repair and renewal of the stock of bridges on the whole road network in your country ?

_________________ Euro

b) What is the cost per m^2 of bridge deck area for maintenance, repair and renewal ?

_________________ Euro/m^2/year

c) What is your best estimate as a percentage of how much money is used annually to maintain, repair and renew the existing bridge stock in relation to its estimated replacement cost ?

_________________ per cent

Comments: ....
....
....

2.5.3 Annual costs of managing the bridge stock.

Do you know the amount of money spent each year on managing the bridge stock in your country ?

Total annual costs of management: _______________ Euro

Do you know the amount of money spent annually on inspections ?

Annual cost of inspections: _______________ Euro

Comments: ....
....
....

2.5.4 Bridge Management System (BMS)

Do you use a Bridge Management System (BMS) as a tool for managing and administrating your bridges ?

❒ YES ❒ NO

Comments: ....
....
....

COST 345

QUESTIONNAIRE ON HIGHWAY STRUCTURES

SECTION 3: CULVERTS

3.1 Notes for guidance

Culverts and small bridges often serve the same purpose. Whether a structure is termed a bridge or a culvert will depend on the classifying authority's definitions. The important point here is that no structure which has already been included in the return for Section 2 of this Questionnaire should also be included in Section 3 as that would constitute double-counting.

Nowadays many culverts are constructed of precast concrete in the form of pipes and box sections and from corrugated steel pipes and plates: in the past in situ concrete and masonry were commonplace. An almost invariable feature of all culverts is that the invert is protected either by the structure itself or by paving. Many culverts also have a significant cover of backfill over them.

The attention of the compiler of the response to this section of the Questionnaire is drawn to the general information in Section 1 above and in particular to 1.2 and 1.4 of that Section. It cannot be stressed too strongly that where exact information is not available please give your best estimate of that particular quantity or cost since this can still be of considerable value.

3.2 Definitions

3.2.1 *Culvert.* A drainage structure with a minimum span of 2 m and a maximum span of 10 m.

3.2.2 *Span of culvert (S).* The clear distance between the side walls or the internal pipe diameter as appropriate.

3.2.3 *Length of culvert (L).* The distance measured along the centreline from entrance to exit.

3.2.4 *Sidewall thickness of culvert (t).* The thickness of the walls on either side of the culvert; for pipes it is the pipe wall thickness.

3.2.5 *Plan area of culvert (A_p).* The length of the culvert (L) multiplied by the span (S) plus twice the thickness (t) of the side walls, i.e. $L \times (S + 2t)$.

3.3 Information on administrative data

3.3.1 Total number of culverts on the road system

What is the total number of culverts on the whole road network in your country ?

The total number of culverts in my country is ______________no.

Comments: ....
....
....

3.3.2 Distribution of culverts according to road administration

How many culverts in the total number given in 3.3.1 above are on the following categories of road ?

National roads : ______________ no.

Regional roads : ______________ no.

Local roads : ______________ no.

Comments: ....
....
....

3.3.3 Total length of culverts according to road administration

What is the total length of culverts on the following categories of road ?

National roads : ______________ km

Regional roads : ______________ km

Local roads : ______________ km

Comments: ....
....
....

3.3.4 Total plan area of stock of culverts according to road administration

What is the total plan area of culverts on the following categories of road ?

National roads : ______________ $m^2 \times 1000$

Regional roads : ______________ $m^2 \times 1000$

Local roads : ______________ $m^2 \times 1000$

Comments: ……………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………

3.4 Information on technical characteristics

3.4.1 Materials of construction

Taking into consideration the total stock of culverts on roads in your country could you please provide information on the numbers and/or areas of the following types of culvert:

Concrete : _________ no. and ___________ $m^2 \times 1000$

Pipes (precast concrete) : _________ no. and ___________ $m^2 \times 1000$

Corrugated steel : _________ no. and ___________ $m^2 \times 1000$

Other : _________ no. and ___________ $m^2 \times 1000$

Comments: ……………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………

3.4.1.1

Can you indicate the percentage of culverts that are constructed of:

a) Cast in situ concrete ? __________ per cent

b) Precast concrete ? __________ per cent

Comments: ……………………………………………………………………………………………

………
………

3.4.2 Age distribution of culverts

Please provide information on the numbers and/or plan areas of your culverts constructed in the following periods:

Before 1900 :	______	no.	and	______	$m^2 \times 1000$
1900 to 1945 :	______	no.	and	______	$m^2 \times 1000$
1946 to 1969 :	______	no.	and	______	$m^2 \times 1000$
1970 to 2000 :	______	no.	and	______	$m^2 \times 1000$

Comments: ……………………………………………………………………………………………
………
………

3.5. Information on costs

3.5.1 Estimated replacement cost of the total stock of culverts

a) What is the estimated replacement cost of the existing stock of culverts on the whole road network in your country ?

______________ Euro

b) Are you able to break down the above figure into the estimated replacement cost of the existing stock of culverts on the following categories of road ?

National roads :	______	Euro
Regional roads :	______	Euro
Local roads :	______	Euro

c) What is the current average replacement cost per m^2 of plan area for the following types of culvert ?

Concrete :	______	Euro/m^2
Pipes (precast concrete) :	______	Euro/m^2

Corrugated steel : _______________ Euro/m^2

Other : _______________ Euro/m^2

Comments: ....……………………...
....……………………….............
....……………………….........................

3.5.2 Annual expenditure on maintenance, repair and renewal

a) What is the annual expenditure on maintenance, repair and renewal of the stock of culverts on the whole road network in your country ?

_________________ Euro

b) What is the cost per m^2 of plan area of culverts for maintenance, repair and renewal ?

_________________ Euro/m^2/year

c) What is your best estimate as a percentage of how much money is used annually to maintain, repair and renew the existing stock of culverts in relation to its estimated replacement cost ?

_________________ per cent

Comments: ....……………………….........................
....……………………………
....……………………………

3.5.3 Annual costs of managing the stock of culverts

a) Do you know the amount of money spent each year on managing the stock of culverts in your country ?

Total annual costs of management :_______________ Euro

b) Do you know the amount of money spent annually on inspections ?

Annual cost of inspections : _______________ Euro

Comments: ....………………………...
....…………………………........
....……………………………

COST 345

QUESTIONNAIRE ON HIGHWAY STRUCTURES

SECTION 4: RETAINING WALLS

4.1 Note for guidance

The attention of the compiler of the response to this section of the Questionnaire is drawn to the general information in Section 1 above and in particular to 1.2 and 1.4 of that Section. It cannot be stressed too strongly that where exact information is not available please give your best estimate of that particular quantity or cost since this can still be of considerable value.

4.2 Definitions

4.2.1 *Earth retaining wall.* An earth retaining wall is defined as a structure which supports at least 2 m of ground, i.e. where the level of ground in front of the wall is 2 m lower than the level of ground behind it. This dimension does not include the height of any protective parapet barrier or the like which is provided for safety purposes. (Nowadays such structures fall at least into Geotechnical Category 2 of Eurocode 7 and must be designed by a suitably qualified person).

4.2.2 *Length of retaining wall (L).* The length of a retaining wall is taken to be that portion of the structure which retains 2 m or more of ground as described in 4.2.1 above.

4.2.3 *Height of retaining wall (H).* The difference in level between the ground in front of and behind the wall. As defined in 4.2.1 above this dimension must be 2 m or more for a structure to be termed an earth retaining wall.

4.2.4 *Face area of retaining wall.* The face area is defined as $L \times H_{average}$.

4.2.5 *Drystone.* A form of construction where blocks or pieces of stone are arranged to form a retaining wall without any cementitious material being used in the joints.

4.2.6 *Improved drystone.* Many retaining walls which started life as drystone walls have subsequently been repaired by pointing, back grouting, soil anchoring, soil nailing, etc. to extend their usefulness as retaining structures.

4.2.7 *Renewal value/replacement cost.* The cost of rebuilding the existing retaining wall without any alteration in the height of ground to be supported.

4.3 Information on administrative data

4.3.1 Total number of retaining walls on the road system

What is the total number of retaining walls on the whole road network in your country ?

The total number of retaining walls in my country is ______________no.

Comments: ………………………...
....……………………………...
....……………………………....

4.3.2 Distribution of retaining walls according to road administration

How many retaining walls in the total number given in 4.3.1 above are on the following categories of road ?

National roads : ______________ no.

Regional roads : ______________ no.

Local roads : ______________ no.

Comments: ....………………………...
....……………………………....
....……………………………

4.3.3 Total length of retaining walls according to road administration

What is the total length of retaining walls on the following categories of road ?

National roads : ______________ km

Regional roads : ______________ km

Local roads : ______________ km

Comments: ....………………………...
....…………………………….................
....……………………………..................

4.3.4 Total face area of retaining walls according to road administration

What is the total face area of retaining walls on the following categories of road ?

National roads : ______________ $m^2 \times 1000$

Regional roads : ______________ $m^2 \times 1000$

Local roads : ______________ $m^2 \times 1000$

Comments: ....
....
....

4.4 Information on technical characteristics

4.4.1 Type of construction

Taking into consideration the total stock of retaining walls on roads in your country could you please provide information on the numbers and/or areas of the following types of retaining wall:

Gravity retaining walls : _________ no. and ___________ $m^2 \times 1000$

Reinforced concrete retaining walls : _________ no. and ___________ $m^2 \times 1000$

Reinforced and anchored soil retaining walls : _________ no. and ___________ $m^2 \times 1000$

Other: _________ no. and ___________ $m^2 \times 1000$

Comments: ....
....
....

4.4.2 Materials of construction

Please provide information on the numbers and/or areas of retaining walls currently composed of the following materials:

Drystone : _________ no. and ___________ $m^2 \times 1000$

Improved drystone : _________ no. and ___________ $m^2 \times 1000$

Plain unreinforced

concrete : __________ no. and ____________ $m^2 \times 1000$

Reinforced concrete : __________ no. and ____________ $m^2 \times 1000$

Other : __________ no. and ____________ $m^2 \times 1000$

Comments: ....
....
....

4.4.2.1

Can you indicate what percentage of plain and reinforced concrete retaining walls:

a) Are faced with masonry ? ___________ per cent

b) Have a plain or textured surface ? ___________ per cent

Comments: ....
....
....

<u>4.4.3 Age distribution of retaining walls</u>

Please provide information on the numbers and/or face areas of your retaining walls constructed in the following periods:

Before 1900 : ___________ no. and ____________ $m^2 \times 1000$

1900 to 1945 : ___________ no. and ____________ $m^2 \times 1000$

1946 to 2000 : ___________ no. and ____________ $m^2 \times 1000$

Comments: ....
....
....

<u>4.4.4 Height distribution of retaining walls</u>

Please provide information on the numbers and/or face areas of your retaining walls constructed in the following retained height ranges:

2.00 to 4.00 m : ___________ no. and ____________ $m^2 \times 1000$

4.01 to 6.00 m : ___________ no. and ____________ $m^2 \times 1000$

6.01 to 10.00 m : ___________ no. and ____________ $m^2 \times 1000$

10.01 m and above : ___________ no. and ____________ $m^2 \times 1000$

Comments: ....
....
....

4.5. Information on costs

<u>4.5.1 Estimated replacement cost of the total retaining wall stock</u>

a) What is the estimated replacement cost of the existing stock of retaining walls on the whole road network in your country ?

____________________ Euro

b) Are you able to break down the above figure into the estimated replacement cost of the existing stock of retaining walls on the following categories of road?

National roads : ________________ Euro

Regional roads : ________________ Euro

Local roads : ________________ Euro

c) What is the current average replacement cost per m^2 for the following height categories of retaining wall ?

2.00 to 4.00 m : ________________ Euro/m^2

4.01 to 6.00m : ________________ Euro/m^2

6.01 to 10.00 m : ________________ Euro/m^2

10.01 m and above : ________________ Euro/m^2

Comments: ....
....
....

<u>4.5.2 Annual expenditure on maintenance, repair and renewal</u>

a) What is the annual expenditure on maintenance, repair and renewal of the stock of retaining walls on the whole road network in your country ?

__________________ Euro

b) What is the cost per m^2 of face of retaining wall for maintenance, repair and renewal ?

__________________ Euro/m^2/year

c) What is your best estimate as a percentage of how much money is used annually to maintain, repair and renew the existing retaining wall stock in relation to its estimated replacement cost ?

__________________ per cent

Comments: ....
....
....

<u>4.5.3 Annual costs of managing the stock of retaining walls</u>

a) Do you know the amount of money spent each year on managing the stock of retaining walls in your country ?

Total annual costs of management: ________________ Euro

b) Do you know the amount of money spent annually on inspections ?

Annual cost of inspections: ________________ Euro

Comments: ....
....
....

COST 345

QUESTIONNAIRE ON HIGHWAY STRUCTURES

SECTION 5: TUNNELS

5.1 Notes for guidance

Many road tunnels are owned and operated by companies or organisations which charge tolls on the traffic using them. Responding authorities are requested to include details of such tunnels in their response.

The attention of the compiler of the response to this section of the Questionnaire is drawn to the general information in Section 1 above and in particular to 1.2 and 1.4 of that Section. It cannot be stressed too strongly that where exact information is not available please give your best estimate of that particular quantity or cost since this can still be of considerable value.

5.2 Definitions

5.2.1 *Tunnel.* An enclosed road at least 100 m in length. A road tunnel usually has two traffic lanes which may take traffic in a single or both directions. It includes cut and cover tunnels and immersed tube tunnels as well as bored or driven tunnels.

5.2.2 *Length of tunnel.* The distance between the facing of the portals measured along the centreline of the roadway.

5.2.3 *Width of tunnel.* The width of a road tunnel is normally given in terms of the number of lanes of traffic it can accommodate.

5.2.4 *Headroom.* The maximum height of vehicle which can use the tunnel without hazarding the tunnel structure and the equipment such as lighting and jet fans contained within it.

5.2.5 *Replacement cost of tunnel.* The cost of rebuilding the existing tunnel to the same internal dimensions, clearances and traffic capacity on the assumption that such work can be carried out on the existing alignment.

5.3 Information on administrative data

5.3.1 Total number of tunnels on the road system

What is the total number of tunnels on the whole road network in your country ?

The total number of tunnels in my country is ______________no.

Comments: ....
....
....

5.3.2 Distribution of tunnels according to road administration

How many tunnels in the total number given in 5.3.1 above are on the following categories of road ?

National roads : ______________ no.

Regional roads : ______________ no.

Local roads : ______________ no.

Comments: ....
....
....

5.3.3 Total length of tunnel according to road administration

What is the total length of tunnel on the following categories of road ?

National roads : ______________ km

Regional roads : ______________ km

Local roads : ______________ km

Comments: ....
....
....

5.3.4 Total length of tunnels according to traffic flow arrangement

a) What is the length of tunnel which normally carries traffic in both directions ?

_______________ km

b) What is the length of tunnel where traffic flow is normally unidirectional?

_______________ km

Comments: ....
....
....

5.4 Information on technical characteristics

5.4.1 Type of construction

Taking into consideration the total number of tunnels on roads in your country could you please provide information on the numbers and lengths of the following types of tunnel ?

Cut-and-cover : ______________ no. and ______________ km

Bored and lined : ______________ no. and ______________ km

Bored and unlined : ______________ no. and ______________ km

Immersed tube : ______________ no. and ______________ km

Composite : ______________ no. and ______________ km

Comments: ....
....
....

5.4.2 Ventilation characteristics

a) What is the length of tunnel which is fitted with mechanical ventilation systems ?

_______________ km

b) What is the length of tunnel which is not fitted with a mechanical system of ventilation ?

_____________ km

Comments: ....
....
....

5.4.3 Age distribution of tunnels

Please provide information on the numbers and/or lengths of your tunnels constructed in the following periods:

Before 1900 : ___________ no. and ____________ km

1900 to 1945 : ___________ no. and ____________ km

1946 to 1969 : ___________ no. and ____________ km

1970 to 2000 : ___________ no. and ____________ km

Comments: ....
....
....

5.5. Information on costs

5.5.1 Estimated replacement cost of the total road tunnel stock

a) What is the estimated replacement cost of the existing stock of tunnels on the whole road network in your country ?

___________________ Euro

b) Are you able to break down the above figure into the estimated replacement cost of the existing stock of tunnels on the following categories of road ?

National roads : _______________ Euro

Regional roads : _______________ Euro

Local roads : _______________ Euro

c) What is the current average replacement cost per m length for the following categories of road tunnel ?

Cut-and-cover : _______________ Euro/m

Bored and lined : _______________ Euro/m

Bored and unlined : _______________ Euro/m

Immersed tube : _______________ Euro/m

Composite : _______________ Euro/m

Comments: ....
....
....

5.5.2 Annual expenditure on operation, maintenance, repair and renewal

a) What is the annual expenditure on operation, maintenance, repair and renewal of the stock of tunnels on the whole road network in your country ?

_________________ Euro

b) What is your best estimate as a percentage of how much of the expenditure in (a) above is used annually to maintain, repair and renew the existing stock of road tunnels ?

_________________ per cent

Comments: ....
....
....

COST 345

QUESTIONNAIRE ON HIGHWAY STRUCTURES

SECTION 6: ROCKFALL/AVALANCHE STRUCTURES

6.1 Note for guidance

The attention of the compiler of the response to this section of the Questionnaire is drawn to the general information in Section 1 above and in particular to 1.2 and 1.4 of that Section. It cannot be stressed too strongly that where exact information is not available please give your best estimate of that particular quantity or cost since this can still be of considerable value.

6.2 Definitions

6.2.1 *Rockfall/avalanche shelter.* A protective structure against rockfalls, avalanches or debris falls, at least 50 m in length.

6.2.2 *Length of rockfall/avalanche shelter.* The length of roofed structure measured along the centreline of the highway from entrance to exit.

6.2.3 *Width of rockfall/avalanche shelter.* The width of the structure is taken as the distance between the extreme edges of the reinforced concrete roof.

6.2.4 *Protective barriers.* A structural fence, bund or soil structure positioned above the highway to prevent boulders and other debris rolling down the hillside from reaching the carriageway.

6.2.5 *Deformable protective barriers.* These may be composed of heavy netting such as anti-submarine netting strung between supports.

6.2.6 *Length of protective barrier.* The total length of such a structure parallel to the centreline of the highway. Where there are parallel structures the length of each should be included.

6.2.7 *Replacement cost of rockfall/avalanche shelters and protective barriers.* The cost of rebuilding the existing shelter or barrier to the same dimensions, clearances and protection level on the assumption that such work can be carried out on the existing alignment.

6.3 Information on administrative data

6.3.1 Total number of rockfall/avalanche structures on the road system

What is the total number of rockfall/avalanche structures on the whole road network in your country ?

The total number of rockfall/avalanche structures in my country is _________no.

Comments: ....…………………………...
....……………………………….........
....……………………………

6.3.2 Distribution of rockfall/avalanche structures according to road administration

How many structures in the total number given in 6.3.1 above are on the following categories of road ?

National roads : _______________ no.

Regional roads : _______________ no.

Local roads : _______________ no.

Comments: ....…………………………...
....……………………………….........
....……………………………

6.3.3 Total length of rockfall/avalanche structures according to road administration

What is the total length of rockfall/avalanche structures on the following categories of road ?

National roads : _______________ km

Regional roads : _______________ km

Local roads : _______________ km

Comments: ..…………………………...
....………………………………...
....……………………………...

6.4 Information on technical characteristics

6.4.1 Type of construction

Taking into consideration the total length of rockfall/avalanche structures in your country could you please provide information on the numbers and lengths of the following types of structures ?

Rockfall/avalanche shelters : ____________ no. and ____________ km

Protective barriers :

a) Concrete or other rigid structures : ____________ no. and ____________ km

b) Deformable structures : ____________ no. and ____________ km

c) Earth structures : ____________ no. and ____________ km

Comments: ....
....
....

6.4.2 Age distribution of rockfall/avalanche structures

Please provide information on the numbers and/or lengths of your rockfall/avalanche structures constructed in the following periods:

Before 1900 : ____________ no. and ____________ km

1900 to 1945 : ____________ no. and ____________ km

1946 to 2000 : ____________ no. and ____________ km

Comments: ....
....
....

6.5. Information on costs

6.5.1 Estimated replacement cost of the total stock of rockfall/avalanche structures

a) What is the estimated replacement cost of the existing stock of rockfall/avalanche structures on the whole road network in your country?

____________________ Euro

b) Are you able to break down the above figure into the estimated replacement cost of the existing stock of rockfall/avalanche structures on the following categories of road ?

National roads : ________________ Euro

Regional roads : ________________ Euro

Local roads : ________________ Euro

c) What is the current average replacement cost per m length for the following categories of rockfall/avalanche structures ?

Rockfall/avalanche shelters : ________________ Euro/m

Protective barriers

a) Concrete or other rigid structures : ________________ Euro/m

b) Deformable structures : ________________ Euro/m

c) Earth structures : ________________ Euro/m

Comments: ....
....
....

6.5.2 Annual expenditure on maintenance, repair and renewal

a) What is the annual expenditure on maintenance, repair and renewal of the stock of rockfall/avalanche structures on the whole road network in your country ?

__________________ Euro

b) What is your best estimate as a percentage of how much money is used annually to maintain, repair and renew the existing stock of rockfall/avalanche structures in relation to its estimated replacement cost ?

_________________ per cent

Comments: ....…………………………..
....…………………………………..................
....……………………………

6.5.3 Annual costs of managing the stock of rockfall/avalanche structures

a) Do you know the amount of money spent each year on managing the stock of rockfall/avalanche structures in your country ?

Total annual costs of management: _______________ Euro

b) Do you know the amount of money spent annually on inspections ?

Annual cost of inspections: _______________ Euro

Comments: ....…………………………......................................
....……………………………
....……………………………

APPENDIX

FURTHER DETAILS OF THE COST 345 ACTION

The present position

Bridges, earth retaining walls, tunnels, culverts and the like make up a substantial proportion of the fixed assets of the land based transportation infrastructure. The stock of such structures has been accumulating in developed countries over the years; some structures predate the 20th century and a number of masonry arch bridges on the European highway system date back to Roman times. Some of these old structures are of historic importance and have architectural merit.

Considerable effort has been put into the development of new standards and codes, such as CEN Eurocodes, covering the design of new structures and earthworks but few of the structures on the existing road system will have been designed to the requirements of such documents. It may be difficult to identify which version, if any, of the standard or code was used to design a particular highway structure, and in many cases the design process would have invoked a quite different approach to that promulgated in current design documents. Furthermore, for some structures, there may not be accurate as-built records. Problems of documentation could be expected to increase with the age of a structure.

What is important is that, despite many years of maintenance-free operation, the inherent level of safety of many in-service structures can be shown to be inadequate relative to current design documents. Owners and maintenance authorities are therefore in a difficult position in a world where public safety is paramount and the financial and other consequences of failure are great. The inherent uncertainty in methods of analysis has led, fairly recently, to the use of load tests for bridges, but advice on the operation and interpretation of such tests is lacking. Tests undertaken on redundant masonry arch bridges have shown that, in general, the ultimate carrying capacity of such bridges was well in excess of that estimated by numerical analysis. It is likely therefore that weight restrictions imposed on some bridges as a result of numerical analysis are unnecessary, and that the associated traffic diversions and delays in these areas could be avoided. Furthermore, little progress has been made on the structural assessment of earth retaining walls and buried structures such as tunnels, culverts and pipes.

It is not feasible to close or demolish structures that do not comply with current design criteria and standards, even if the financial resources required for their replacement were available. (As shown in the following section, the costs of replacement would be astronomic.) However, in the absence of adequate documentation covering the inspection and assessment of highway structures, there will be a tendency to assess stability using current design documents, and such assessments are likely to underestimate the inherent stability of a wide range of structures. In some cases, this will lead to the unnecessary replacement or strengthening of existing structures with all the attendant costs, particularly those associated with traffic delays. On the other hand, a reliable system of inspection, assessment and maintenance is required to ensure the safety of the public at large.

The processes involved in the design of a new structure and the assessment of an existing structure can be quite different, but little work has been undertaken on the development of codes or standards, which would, for example, compliment the structural Eurocodes for assessing the condition of in-service structures. The age (longevity), condition and the likelihood of failure of a structure are intuitively related and what is needed, therefore, is a system of assessment within which longevity and condition are qualitatively or quantitatively balanced against the factors of safety specified in current design standards. Information will often be limited, and at times even lacking, but the inspection regime and assessment process must provide a sensible procedure which enables the existing structures which have performed adequately over the years to continue to do so in the future.

Assessments are most needed at times of change to determine whether the stock of structures is adequate for the new situation. The introduction of 40 tonne lorries throughout the European Union is a good example of this. Structures which have sustained the current traffic loads since the previous increase in 1983 must be re-evaluated, and either passed as fit to carry the higher loads, or be strengthened appropriately. This can be a particularly difficult process with certain types of structure, such as drystone retaining walls, where current theory suggests that the majority of these structures are unstable but experience has shown that they are perfectly adequate.

Assessments are also needed on a more routine basis as part of a sensible maintenance programme. Importantly, such a programme should ensure that a satisfactory level of maintenance applies to the whole infrastructure.

Use of the COST framework

COST was seen as the most appropriate mechanism for dealing with this subject because it is essential to have agreement between the technical representatives of national governments. It is also highly desirable that there is input from, and to, those COST States which are not yet a part of the European Union.

Primary Objectives

The main objective of this Action is to specify the procedures and documentation required to inspect and assess the condition of in-service highway structures (e.g. bridges, earth retaining walls, tunnels and culverts). The project will also define the requirements for future research work into the inspection and assessment of highway structures.

Secondary Objectives

This project will also provide information on the age and condition of the stock of the more common types of highway structure in Europe. An inventory of highway structures and information on current maintenance expenditure are necessary input to the development of budgetary plans for maintenance works and for operating cost models for highways. Such information can be used to establish or refine whole life cost models for these types of structure, and could lead to recommendations regarding the building of particular types of structure.

The project will also identify those types of structure, such as masonry arch bridges, that are not amenable to analysis by simple numerical methods.

Benefits

The potential economic benefits of the project are substantial. For example, preliminary studies of the stock of masonry faced earth retaining walls along the highway network in the UK have shown that an annual expenditure of less than 1 per cent of their replacement cost is needed to keep the stock of such walls in satisfactory condition. The economic benefits for such a small sum are considerable; not only are the structures preserved in good condition but the costs of replacement works and the very much greater traffic delay costs associated with such works are avoided. The majority of these walls were constructed in the 19th and early part of the 20th centuries predominantly in drystone walling. However, despite the fact that the majority of such walls are still true to line and level, often a hundred years or more after their construction, numerical assessments of their stability undertaken to the strictures of current design documents generally lead to the erroneous conclusion that they are unsafe and, by implication, need to be replaced. The replacement costs of drystone walls, and their derivatives, along the highway network in the UK, for example, would be at least 10 billion Euros and could possibly be much higher.

In European terms, the development and application of successful inspection, assessment and maintenance procedures to a highway network would ensure the continued high performance of the network and save billions of Euros in construction, maintenance and traffic delay costs. The development and acceptance, throughout Europe, of such procedures and standards would also give rise to tangible and intangible benefits to highway users, maintaining authorities and owners.

A European-wide project would allow an exchange of information and, in particular, it would advertise the experience and expertise of those States which have a developed, mature highway network and, in that way, promote sound engineering practices. It would provide continuity and allow regional variations such as climate and environment to be considered and, by drawing from the expertise of the various States, maximise the value of the project to Europe as a whole.

In order to maximise the benefits from the work carried out in the Action, national delegates would be asked to supply lists of the most appropriate recipients of the results at national level and subsequently discuss implementation with them. The majority of recipients will be at national and regional levels, but there will also be significant users outside these two categories.

Depending on the country, responsibilities for highway structure inventories, inspection, assessment, maintenance and budgetary planning at national, regional and local levels will vary between public and private sector organisations. These variations are to be taken into account when producing the deliverables and final report, and when targeting the most appropriate recipients of the results of the Action. The needs of those responsible for whole life costing of infrastructure and highway operating cost models will also be addressed.

At European level, the work of the CEN Committee dealing with Eurocode 1 (Basis of Design and Actions on Structures) will be taken into account in the work and input will be given to future standardisation work in this area. Consideration will also be given to interaction with initiatives at global level such as those of the Permanent International Association of Road Congresses (PIARC).

In addition to the requirements of users in the field of highway maintenance, those of researchers will also be considered, and the specification of future research to be undertaken, mainly at national and European level, will be an important outcome of the Action. Again, the identification of those academic, public and private sector organisations which are in a position to maximise the benefits arising from the results of the work will form a critical part of the dissemination process.

For all the dissemination and implementation initiatives, the involvement of the embryonic Forum of European National Highway Research Laboratories (FEHRL) network will provide significant impetus in ensuring maximisation of the benefits in terms of cost, safety and environmental considerations.

Scientific Programme

Specification of Requirements

The owners of highway structures, whether at local, national or international level, and those charged with maintenance, are legally responsible for their safety and owe a duty of care to the public. By following a formalised and documented procedure of inspection, assessment and maintenance, maintaining authorities will be able to show that they have taken due care and owners will be assured that their fixed assets, i.e. the highway infrastructure, are being protected. This project is the necessary precursor to the development of procedures and documents covering inspection regimes and methods of assessment.

In the initial phase, the following information will be sought for representative lengths of the public highway network in various COST States:

- The number, type, age and condition of structures and, where possible, estimates of the cost of replacement. This will provide an estimate of the value of the existing highway infrastructure. Different classes of route, for example principal, primary and secondary, will be considered separately.

- The current expenditure on new highway works and on the maintenance of existing structures. The ratio of these expenditures gives an indication of the maturity of the highway infrastructure, and also provides an estimate of the in-service life currently required of highway structures. Where necessary, the ratio can be projected by taking into account the likely expenditure on construction and maintenance in future years.

- Current statutory requirements for the inspection, assessment and maintenance of in-service highway structures. This will identify procedures that have proven to be effective and also, by omission, define those types of structure for which no suitable procedures have so far been devised or documented.

- A review of the methods used to determine the stability of structures, this will include both proof testing and numerical analysis.

The above information will help to define those types of structure which are difficult to inspect and assess, and those that consume the highest expenditure on maintenance. In doing so, key areas for further research work will be identified.

The project will incorporate any relevant information obtained from the current Framework IV Transport RTD project BRIME, which is concerned with the evaluation of bridge management procedures. Also, it should be noted that the results will be made available for rail research purposes.

Work Programme

Implementation of the work, in order to meet the primary and secondary objectives, will require the completion of the following tasks and the generation of the associated deliverables.

a) Generation of a European highway structures database incorporating:

- the number, age and condition of various types of structure on representative lengths of the highway system in Europe
- information on the current replacement costs and maintenance expenditure on various types of highway structure
- the procedures used to inspect and assess the condition and performance of various types of highway structure including a comparison of the statutory requirements for different types of structure
- information on the methods used to define the serviceability and stability of a structure both at design and in-service stages.

The database generation phase will be implemented by undertaking reviews of literature, procedures and documentation and terminology, together with a comprehensive questionnaire exercise.

b) Assessment of the information contained in the European highways structures database.

c) Determination of the requirements (in terms of cost and safety) for procedures and documentation for the inspection and assessment of structures, taking into account environmental considerations and objectives.

d) Specification of the procedures and documentation for the inspection and assessment of structures.

e) Specifications of future research work necessary to improve methods for inspection and assessment of highway structures.

f) Guidelines to the development of budgetary plans for maintenance works and for operating cost models for highways.

g) Guidelines for input to the building of specific types of structure.

h) Generation of the Final Report.

Organisation

The Management Committee of the COST 345 Action is responsible to the COST Technical Committee on Transport and their programme of work is being co-ordinated by the Chairman Dr K C Brady, United Kingdom and Vice-Chairman Dr A Znidaric, Slovenia.

Six Working Groups have been set up to deal with the Action, their members providing the appropriate mixture of technical expertise and experience to address the tasks in hand. The six Working Groups are as follows:

WG 1 - Inventory
WG 2 - Inspection
WG 3 - Condition assessment
WG 4 - Numerical techniques
WG 5 - Safety and serviceability
WG 6 - Remedial measures

In due course a seventh Working Group will be initiated to integrate the outputs of the other Working Groups and prepare the final report.

Participation

As well as the European Commission, sixteen countries – Austria, Belgium, Czech Republic, Denmark, France, Germany, Ireland, Italy, Netherlands, Poland, Romania, Slovenia, Spain, Sweden, Switzerland and the United Kingdom – are participating in the deliberations of the Management Committee of the COST 345 Action.

This provides a strong basis of technical expertise and geographical spread which should ensure very high quality results. A number of other countries have expressed interest in joining this project. Each of the Working Groups will produce at least one technical report and these will form a major part of the final report of the Action.

Conclusion

It is of note that little, if any, research has been carried out at European level on the assessment of highway structures and the successful completion of this project should remedy this situation and lead the way in developing future thinking in this area.

Sustainability becomes an ever more pressing consideration with the realisation that our material and financial resources are finite and limited. Although some further development of the highway system is undoubtedly required the more pressing consideration in many countries is fast becoming the conservation of the existing highway infrastructure in good condition. This unfortunately is a mundane and routine task which may well be overlooked in the short term by authorities with apparently more important problems on their hands. However curtailment of maintenance expenditure on the highway infrastructure wastes money since it almost invariably results in some structural damage which is more expensive to rectify in the long term. The outputs from this Action will help to ensure that such oversights are less likely in the future and provide a sounder basis for highway authorities to develop a systematic long term policy for the maintenance of the existing stock of structures on the road system.

Annex III. Note on maintenance funding in Sweden

For many years the replacement of deteriorated bridges was financed from the investment budget, i.e. from money earmarked by politicians for investment. In these circumstances it was very difficult to convince the decision makers to put money into replacing old bridges instead of into new investments in the road infrastructure. The maintenance budget at that time contained money for 'normal' maintenance only and not replacements.

A few years ago a new definition of maintenance was accepted. Under this the replacement of a bridge, or a major part of it such as the superstructure, was considered to be maintenance and was to be financed from the maintenance budget where there was no requirement to improve the existing function, e.g. increasing load carrying capacity, carriage width etc. In this case a replacement is just one alternative and is sometimes more profitable from a socio-economic point of view than a major rehabilitation or repair.

The Swedish National Road Administration has defined a number of what are called 'Products and Services' and there are three main groups of these in the road management task.

- New investments
- Improvements (re-investments)
- Maintenance and operation

Considering the last mentioned the following is the organisational arrangement of the Bridge Maintenance service. Its planning and follow-up operations are based on the following activities.

- Inspections
- Preventive maintenance (procured for a bridge stock, e.g. all bridges in a maintenance area; general specifications)
- Corrective maintenance - elements necessary for the load carrying capacity (procured for a single bridge or a group of bridges; individual specifications)
- Corrective maintenance - elements not necessary for the load carrying capacity (procured for a single bridge or a group of bridges; individual specifications)
- Replacement due to durability problems

Today SNRA spends about €70 million per annum on bridge maintenance. Of this, 10-15% relates to replacement measures.

Annex IV. Funding required for bridge maintenance

This Annex consists of Section 6 from 'Funding for bridge maintenance', a report prepared by the CSS Bridges Group of the County Surveyors Society, UK.

Funding required for bridge maintenance

The following methods have been considered in order to determine the level of funding which is required to keep all highway structures in a safe condition for highway users and maintained on a whole life approach aimed at a 'steady state', avoiding disproportionate costs due to traffic delay. Funding levels also being such as to allow for retaining the visual appearance of easily visible structures, particularly those of significant or historical background.

(a) OECD Report

This report [2] concludes that 'An annual expenditure at least equal to 0.5% of the replacement cost of the bridges seems to be necessary to implement a rational policy of preventative maintenance'. However it also states that 'In the United Kingdom maintenance expenditure of about 0.5% per annum is sufficient to cope with essential work but may not be adequate to prevent long-term deterioration'.

It should be noted that the above figures exclude the cost of regular inspections and the cost of eventual replacement. Based on a survey of inspection costs it would appear that the annual cost of inspections is approximately 0.1% of the Replacement Cost. Also assuming that bridges have a useable life of 200 years (possibly optimistic – BS5400: Part 1[4] only gives a nominal design life of 120 years for modern structures) then the annual cost of replacing structures would be 0.5% of the Replacement Cost.

Therefore this method would recommend that the annual funding required for bridge maintenance should be:-

0.5 + 0.1 + 0.5 = 1.1% of the Replacement Cost.

The report does not cover the maintenance of retaining walls.

(b) British Rail Commuted Sum Method

This method[5] has been used for many years and is based on calculating the annual cost of inspecting, maintaining and eventually replacing the highway structure when it reaches the end of its useable life. It gives the cost of this as a percentage of the replacement cost for different forms of construction for both substructures and superstructures. These percentages vary from 0.375% to 1.5% for individual components and from 0.41 to 1.39% for complete bridges. The former represents a short span masonry arch bridge whilst the latter represents a multi span steel bridge on reinforced concrete supports. However, as these will only represent a small proportion of the total bridge stock it is likely that the range for individual highway authorities will be from say 0.7 to 1.1% with a national average of say 0.9% of the Replacement Cost based on the typical mix of bridge types in Local Authority ownership.

For retaining walls this method would give a range from 0.48% to 0.61% with a national average of say 0.55% of the Replacement Cost.

(c) Lincolnshire Method

This method is given in the document on the 'Strengthening of Railtrack owned Highway Bridges'(6). It gives a table of costs for all maintenance operations based on the experience of one highway authority. Using this document and including the eventual replacement of the bridge when it reaches the end of its useable life gives the following percentages of the replacement cost for an average size bridge (see paragraph 4):-

Steel composite deck	-	1.19%
Reinforced concrete deck	-	0.90%
Masonry arch	-	0.76%

This would give a national average of 0.87% of the Replacement Cost based on the typical mix of bridge types in Local authority ownership.

For retaining walls this method would give a range from 1.26 to 1.39% with a national average of say 1.3% of the Replacement Cost.

The three methods give figures which are remarkably close so it is suggested that the required annual level of funding required for maintenance should be 1.0% of the Replacement Cost for Bridges and 0.9% of the Replacement Cost for Retaining Walls.

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2. Bridge Maintenance, A report prepared by the OECD Road Research Group, OECD, Paris, 1981.
4. BS5400: Part 1 (1988). Steel, concrete and composite bridges: General statement. British Standards Institution.
5. Lancashire County Council, Bridge Client Instruction BCI 4.2A, Calculation of Commuted Sums, 1996. (Note – this is based on the Appendix included in the former British Rail's Works Agreements.)
6. Strengthening of Railtrack Owned Highway Bridges – Guidance for Implementation, CSS, Railtrack, SCOTS and LOBEG, 1999.

Annex V. Concrete durability and the condition of highway structures

A wide ranging review of the durability of concrete has been carried out by Mehta (1991): he blamed the current problems on the "over emphasis on strength alone in concrete mix proportioning to the exclusion of long-term soundness (i.e. freedom from cracking during service life)" which had resulted in a majority of concrete structures made today suffering from cracking due to excessive heat of hydration, drying shrinkage, creep and other causes.

According to one of the sources he references (Skalny, 1987) some 253000 bridges in the USA were deficient in the mid-1980s, mainly as a result of bridge deck deterioration, and some 35000 more were believed to become deficient each year. Skalny speculated whether the yearly expenditure on bridge deck rehabilitation was adequate to deal with the new damage. Of perhaps greater interest were his comments on the maintenance of US Navy facilities where he implies that an expenditure of 1% of their replacement value was inadequate.

Other sources cited by Mehta include Gerwick (1989) who mentions problems of concrete durability on undersea tunnels in Dubai, Hong Kong, Japan and Suez within as little as 4 to 10 years after construction; Leendertse and Oud (1989) refer to deterioration being noticed on the Zeeland Bridge 15 years after completion and extensive repairs to the Dubai tunnel after 11 years; Litvan and Bickley (1987) describe a study of deck deterioration in 215 multi-storey car parks in Canada; and Mehta (1986 and 1988) describes situations where concrete durability problems arose within as little as 4 years after construction.

Leendertse and Oud (1989) consider rates of deterioration in the Netherlands and United Arab Emirates and Figure AV.1 shows data from their paper. Fookes et al (1981) has shown that many concrete structures can reach their terminal condition in the Middle East in less than 10 years, see Figure AV.2.

Wallbank (1989) in his survey of 200 highway bridges on motorways in England found that 25 were classed on their visual condition as good, 114 as fair and 61 as poor: about 44% of bridges built in the 1960s, and less than 30 years old, were already in poor condition at the time of survey in 1987-89. Most recently Tilly et al (2002) have commented that early concrete bridges had performed surprisingly well with comparatively few having to be demolished due to deterioration in contrast to bridges of the motorway era in the UK, some of which have developed serious corrosion in as little as 20-30 years.

On the National Road network in France some 18% of the total surface area of bridges required repair work and 5% of it urgently: a further 30% of bridge surface area needed urgent attention to prevent the rapid development of defects in the structure (Highways Agency et al, 1999). Serious deterioration was found in the early 1980s in some of the 156 reinforced concrete piers of the Öland Bridge, Sweden which was opened in 1972 (Bolin et al, 1997); 112 of the low-level bridge piers have already been rehabilitated or reconstructed at a cost of €48 million.

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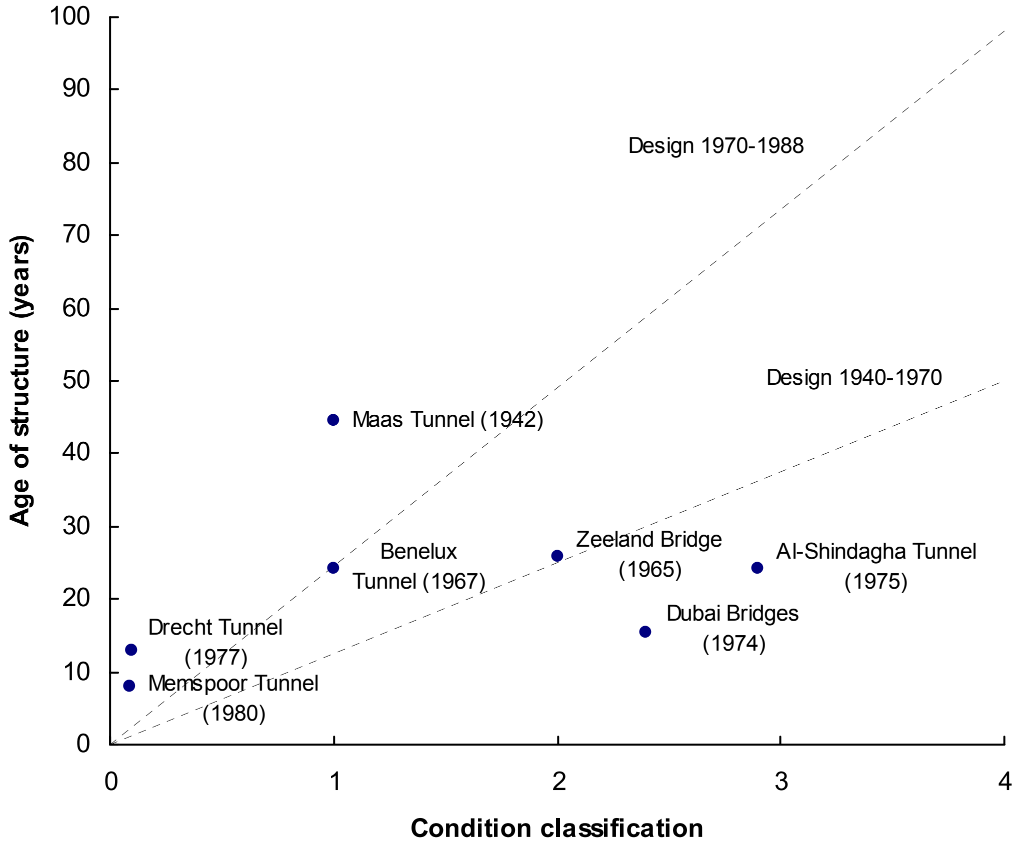

Class	0	1	2	3	4
Reinforced	No defects	Rust staining and minor cracking	Onset of corrosion cracking	Moderately severe cracking Some spalling	Severe cracking and spalling Terminal condition
Mass	No defects	Minor surface weathering or pop-outs or cracks	Moderate surface weathering Isolated crack	Moderate to severe weathering or interconnected cracks	Severe loss of concrete surface Disruptive cracking Terminal condition

Figure AV.1 Effect of climate condition on deterioration of concrete structures
(after Leendertse and Oud, 1989)

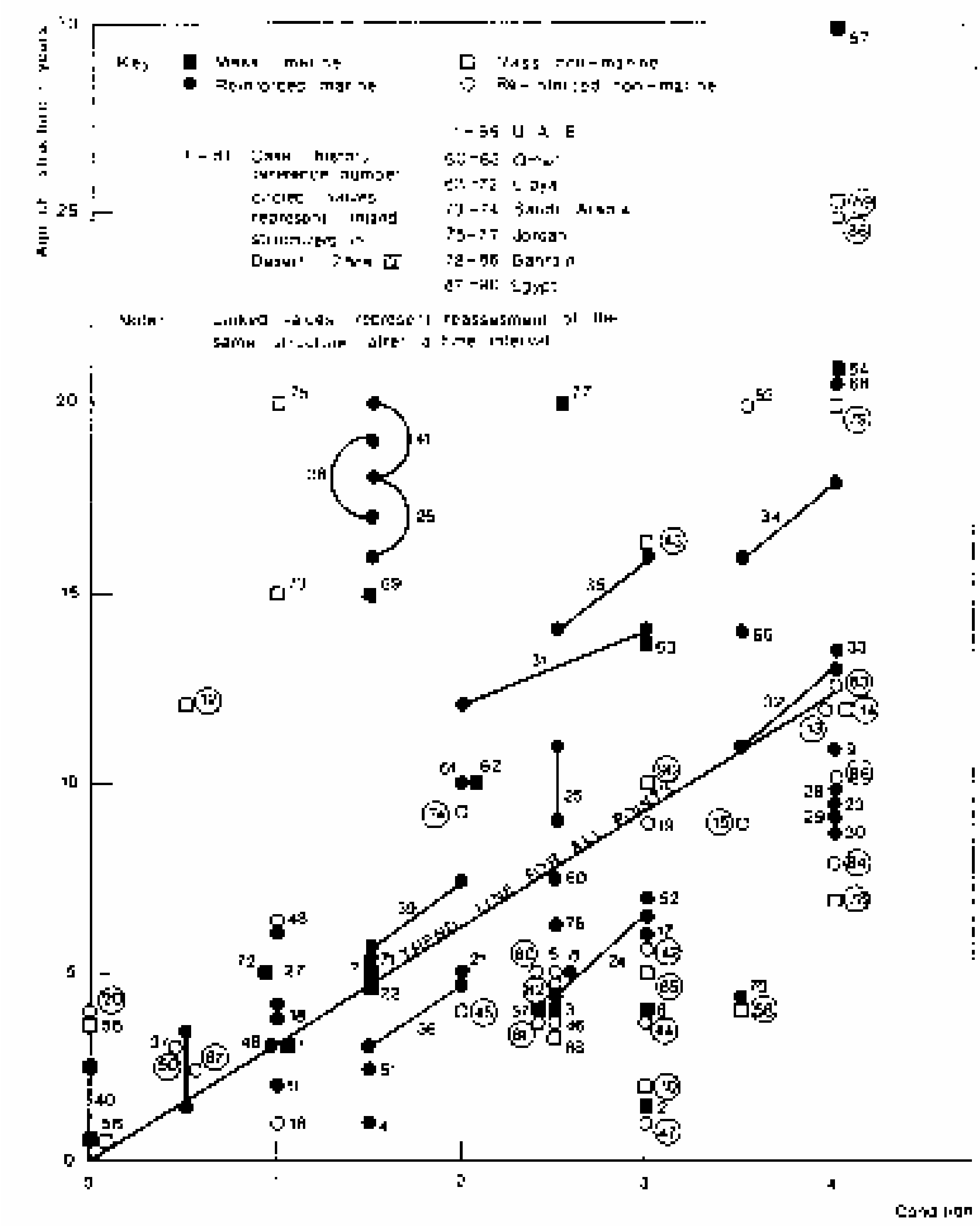

Figure AV.2 Deterioration of structures in the Middle East
(from Fookes et al, 1981)

Annex VI. Note on the renewal of bridges

The Tamar Bridge in the UK and the Traneberg Bridge in Sweden are two examples where the sound structural elements and members of an existing bridge have been incorporated into the renewed structure. Brief descriptions of both schemes are given below.

Tamar Bridge

This was the UK's first large, 335m mainspan, modern suspension bridge when opened to traffic in 1961 (Figure AVI.1). The traffic then was 4000 vehicles per day but this had increased tenfold by the mid-1990s. At this time, an engineering assessment showed that while the primary structural elements were in good condition the reinforced concrete deck was deteriorating and a 17 tonne vehicle weight restriction would have to be introduced.

Because the Tamar Bridge carries the A38, the main trunk road between Devon and Cornwall, such a restriction was not acceptable. Either a major repair or an entirely new replacement bridge would be required, with the concomitant proviso that no traffic interruption was acceptable. However despite the bridge's importance responsibility for funding its repair or renewal rested entirely with the Tamar Bridge and Torpoint Ferry Joint Committee, a local organisation which owned the existing bridge and collected tolls from traffic using it. With preliminary cost estimates of between £150 and £300 million for a new bridge ruling out that solution, attention turned to renewing the existing structure.

It was proposed initially that traffic during the replacement of the old road deck be carried on sections of temporary deck cantilevered from the sides of the steel truss stiffening girder of the existing bridge: once the old road deck had been replaced and opened to traffic these temporary constructions could be removed. Further development of that scheme, however, led to the idea that it would be much better to incorporate the temporary decking into the structure with the money thus saved being used to reconfigure the structure to carry increased live load permanently. The Act of Parliament required to implement such a change to the existing structure was obtained in 1998.

The renewal took 34 months to complete. It was carried out by a closely knit team of client, designer and contractor. For £34.6 million (approx €52 million) cantilever decks carrying a single lane of traffic were added to each side of the main girder and traffic switched to them. The 3500 tonne central 3-lane concrete deck was then sliced in 9m × 3m slabs and removed while keeping one of the three lanes open during each rush hour. A new lightweight orthotropic steel deck was then placed while stay cables, saddles and anchorages were added to carry the additional live loads applied to the stiffening girder. A cross-section of the completed renewal is shown in Figure AVI.2.

Traneberg Bridge

The first Traneberg Bridge, a pontoon bridge, on the Drottningholmsvagen (Road No. 275) on the western outskirts of Stockholm was completed in 1787. The present arched bridge, some 446m long overall, 27m wide and 26m high, was opened in 1934 and now carries some 75000 vehicles per day (Figure AVI.3); the span of the arch is 181m. In the 1990s deterioration of the reinforced concrete deck was so severe that weight restrictions were imposed and heavy goods traffic was forced to make a detour which increased their journey by 50km.

The current improvement scheme consists of the renewal of the existing road and subway bridges and the construction of a completely new road bridge. Deterioration of the existing bridges was confined to their decks and supporting columns; the arches supporting these columns were in good condition and were retained. Traffic on both road and subway had to be maintained throughout the work.

Construction of an identical new arch to the south of the two existing bridges began in 1999 and is scheduled for completion in 2002. When the new bridge is completed the old road bridge will be renovated by constructing new columns and deck on the existing arch: it is expected to reopen in 2004. Once this work is completed the subway will be diverted over it while the subway bridge is renovated: it is expected that renewal of this bridge will be completed in 2005.

Conclusion

These case studies demonstrate that considerable economy can be achieved by re-using existing structural elements and members when renewing structures. It is also clear that such schemes are intellectually and technically more challenging than the design and construction of completely new replacement structures.

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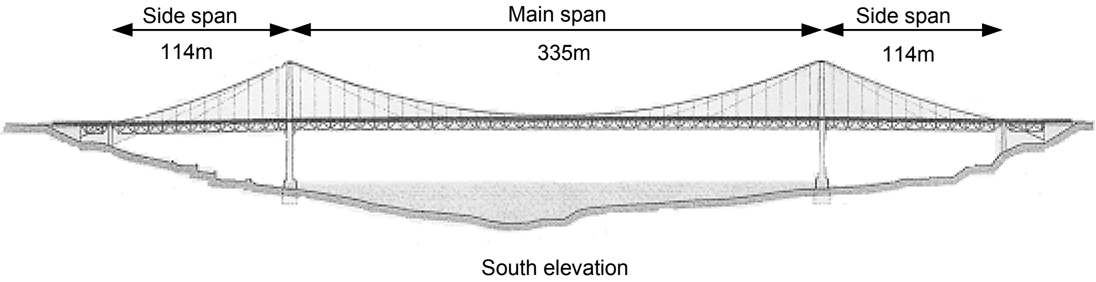

Figure AVI.1 Longitudinal elevation of the Tamar Bridge

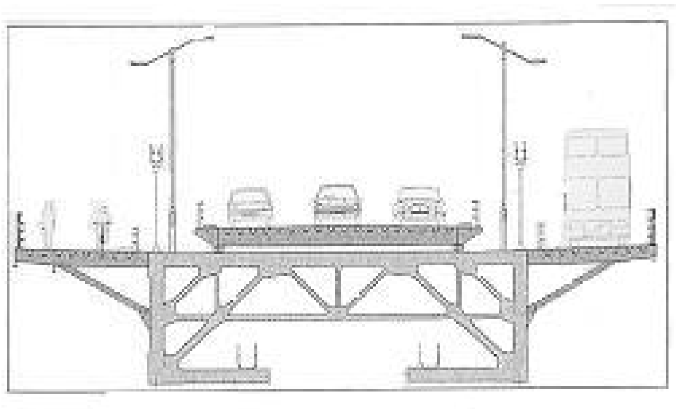

Figure AVI.2 Cross section of Tamar Bridge following completion of renewal works

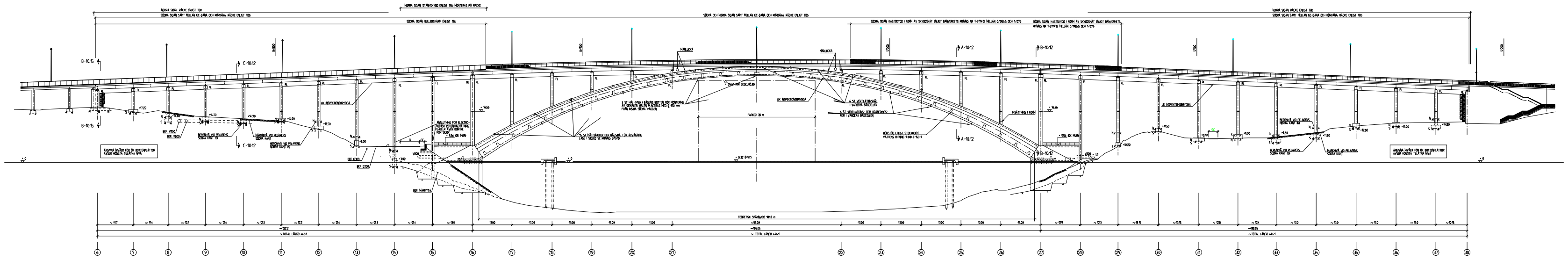

Figure AVI.3 Longitudinal elevation of Traneberg Bridge

Annex VII. Consolidated listing of recommendations

Recommendation 1

Without full information on the number, location, size and replacement value of all the various structures on the highway network it is impossible to develop and resource a realistic programme for the maintenance, repair and renewal to sustain the stock of these structures. It is, therefore, our first recommendation that such information be systematically collected without delay in all countries so that policy and management decisions are soundly based.

Recommendation 2

It is clear from the replies to the Questionnaire that detailed information on the structures on the highway system is often lacking. This is particularly so for Local and Regional Roads and even for National Roads in some countries. It is, therefore, recommended that in order to develop and refine long-term programmes of maintenance, repair and renewal to the stock of highway structures on all the road network there is a need to expand the basic data outlined in Recommendation 1 (see Section 2.3 above) to include as much detail as possible, including historic information, on the condition, work undertaken and expenditure relating to every structure on the highway network.

Recommendation 3

Renewal is part and parcel of the process of sustaining the stock of structures on the highway system and it is recommended that steps be taken to alter the relevant financial rules to ensure that this is so.

Recommendation 4

It is obvious from Section 4 above that the current knowledge of the numbers of structures on the highway networks of Europe is imperfect and that the estimates of the cost of replacing them leaves much to be desired. However, it is virtually certain that the estimates given are of the correct order of magnitude and very probably err on the low side.

It is, therefore, recommended that steps be taken to refine the above figures and obtain more precise information on the numbers and replacement values of the stock of all highway structures on the European road system.

Recommendation 5

The task outlined above would be much facilitated by the development of a unified classification system for highway structures to be used in all European countries.

Recommendation 6

It was shown in Section 4.3 above that information on the costs of construction and replacement of road tunnels as well as on the expenditure on their operation, maintenance, repair and renewal was incomplete and flimsy. There is, therefore, a need to obtain these data so that the appropriate levels of funding can be identified and provided for these crucial structures on the road network.

Recommendation 7

On the basis of the limited information currently available it is necessary to earmark or dedicate the sum of €6.6 billion every year to be expended exclusively on the maintenance, repair and renewal of the bridges and retaining structures on the road networks of the Europe 27 countries. This compares with a current annual expenditure in these countries of perhaps €2-3 billion on the maintenance, repair and renewal of road bridges (see Section 4.1.4 above) and perhaps 10-20% of that amount on retaining walls.

Recommendation 8

The adequacy or otherwise of the above expenditure should be reviewed about 5 years or so after implementation of Recommendation 7 using the results of detailed monitoring and updating of inventories.

Recommendation 9

There is a need to ensure adequate financing of the maintenance, repair and renewal of highway structures on the whole road network but particularly on Regional and Local roads year in year out.

Recommendation 10

The setting up of dedicated funds derived from charges on the road user should be considered as a means of insulating such necessary annual expenditures from the vagaries of the economy as well as short-term political pressures.

Recommendation 11

There is a pressing need for each and every country to set aside, year in year out, adequate sums of money to sustain all their road infrastructure, including Regional and Local roads, and all the structures on it in an acceptable way.

Recommendation 12

There is a need for each country to consider the setting up of a centralised repository for all data on the structures on their highway network.

Recommendation 13

There is a need to develop a series of assessment standards for highway structures complementary to the existing standards for the design and construction of new structures.

Recommendation 14

There is a need to ensure that programmes of research and development are in place to ensure that the expenditures on maintenance, repair and renewal of highway structures are cost effective and achieve their purpose.

Recommendation 15

There is a need to review the arrangements for road research and development within Europe to assess its effectiveness and determine whether any changes are needed to ensure its organisation and funding are appropriate and adequate for the future.

Recommendation 16

There is a need to provide sufficient checks and balances in the system to ensure financial probity, impartial advice on design and the appropriate standard and cost effectiveness of expenditure on maintenance, repair and renewal of highway structures.