D5.3

Needs for maintenance and refurbishment of bridges in urban environments

Low-disturbance sustainable urban construction

PANTURA

D5.3

Management of bridges for strengthening and repair

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Table of contents

Executive summary

This report presents deliverable D5.3 from the Work Package 5, defined in the contract documentation as “Needs for maintenance and refurbishment of bridges in urban environments”.

The goal of this report is to underline the need for strengthening and repair of bridges in Europe by presenting a general view of the condition of European bridges and what bridge authorities and owners have as their priorities when dealing with this part of road and railway networks.

The work in this deliverable was divided into three sub-deliverables as follows;

D5.3-A) Questionnaire and analysis of the returns,

D5.3-B) Experience from concluded or on-going projects by industrial partners in Pantura regarding the complexities and problems encountered during construction work and
D5.3-C) Literature study on strengthening and repair projects.

The participating partners in WP5 are; CTH (Sweden), NCC (Sweden), TNO (Netherlands), ACC (Spain) and MOS (Poland) and ROT (Netherlands) and the partners in preparation of this deliverable were CTH (Sweden), NCC (Sweden), ACC (Spain) and MOS (Poland).

The work in this report has been carried out during January to December 2011 and the responsible partner for sub-deliverables D5.3A and D5.3C was CTH while MOS was in charge of D5.3-B.

The approach to achieve the goal of this report was to collect data from road and railway authorities and bridge owners by sending a questionnaire regarding the project’s areas of interest. A questionnaire was prepared and sent to 15 European road and railway administration and project’s stakeholders’ panel members. The results from the returns on questionnaire were analyzed and formatted. The questionnaire mainly included the following areas;

(1) Demography of European bridges: demography of European bridges with regard to bridge type, span length, construction material and age,
(2) The most common problems in bridges: the most common problems that bridge authorities in Europe are dealing with are presented,
(3) Priorities and demands: different aspects of bridge management such as client demands for the construction of new bridges in densely populated areas, demands for the maintenance (strengthening) activities of existing bridges in densely populated areas and demands for new strengthening techniques/methods for existing bridges in densely populated areas and maintenance issues are presented in this section.

Besides the information obtained from the returns of the questionnaire, experience from the industrial partners in Pantura including MOS, NCC and ACC on on-going and

concluded projects has been included in the report. The goal was to bring up the practical problems involved in strengthening and repair operations and issues which should be taken care of during strengthening and repair projects in urban areas.

The last part of the report presents a list of case studies on completed strengthening and repair projects in Europe (mainly England). The information in this section was collected from literature where a short description of the problems, strengthening and repair solutions and the involved problems are presented.

In the past two decades, rapid deterioration of bridge structures has become a serious technical and economic problem in many countries. The issue of maintaining the bridges has, therefore, become one the most important challenges in bridge industry. The term maintenance is usually defined as the systematic works performed by maintenance departments to ensure the functionality of bridges and safety of the users. It usually includes inspection, repair and strengthening and replacement of the whole or a part of a bridge. In general, strengthening and repair of bridges is preferred to replacement of structures since it is cheaper, more effective and less disruptive.

Study of the returns on the questionnaire and the literature reveals that different reasons leading to the need for maintenance of bridges may be categorized as;

- Increase in traffic flow and weight of vehicles compared to original design situations,
- Harmful influence of environment such as environmental pollution,
- Use of de-icing salts especially in countries with cold climates,
- Poor quality of construction materials,
- Limited maintenance and inadequate standards,
- New safety measures.

Many bridges in Europe suffer from the above mentioned factors and are in need for strengthening and repair. For example in Sweden, 10% of roadway bridges and 23% of railways bridges owned by Swedish traffic administration are in need for strengthening and repair.

The most important demands for strengthening and repair operations mentioned by bridge owners and authorities were found to be;

- Less traffic disruption
- Cost

Generally, the cost for strengthening and repair of bridge structures can be divided into direct costs and indirect costs. The former include the material and labor and the latter cover the costs from interruption in the bridge function such as traffic disruption.

Depending on the scale, indirect costs might be several times higher than direct costs and therefore it has a high priority for bridge owners.

The strengthening and repair of bridges, especially in urban areas, should be seen as multi-disciplinary operation covering not only the bridge engineering aspects such as techniques and solutions but also urban planning such as traffic and construction management. The social issues in cities may completely affect the choice for strengthening and repair solutions, materials and approach. Therefore, it is important to provide a systematic interaction between the engineering solutions and urban planning for different strengthening and repair projects in order to minimize the costs and disturbance.

1 Introduction

1.1 The aim

The aim of this report is to underline the need for maintenance and refurbishment of bridges in Europe by providing information on the demography of bridges in Europe, the most common problems in existing bridges and priorities and demands from bridge authorities and owners regarding construction of new bridges and maintenance of existing ones in densely populated areas. Even though the focus of the report is on existing bridges, consideration of new bridges can give an insight about the future demands for these bridges.

1.2 Approach

The approach to achieve the aim of this deliverable was;

(1) To collect data from bridge owners and authorities in Europe: During the course of the project in the first year, a questionnaire was prepared and sent out to 15 European road and railway authorities as well as the stakeholder panel members. The goal of the questionnaire was to provide general information regarding the demography of European bridges, condition of bridges and bridge authorities' and owners' demands and priorities with regard to their bridges to be built in the future and existing bridges,

(2) To gather the experience from on-going or conducted strengthening and repair projects from industrial partners in the project (ACC, MOS and NCC),

(3) To collect the information from the literature regarding conducted strengthening and repair projects. This information included the problems, considered strengthening and repair solutions and also complexities involved in the projects.

1.3 Limitations

Even though the maintenance of bridges is a comprehensive term and covers practices from refurbishment of asphalt layer on a bridge to major strengthening and repair works, the focus of this deliverable, as defined in description of the work, is on the strengthening and repair of bridges.

Another limitation in WP5 is that the focus of the work is mainly on the superstructure of bridges because of two reasons; (1) the superstructure is subjected to greater wear and tear from traffic while the substructure is less affected. As a result, substructures are not subjected to strengthening and repair as often as superstructures. Hence, the life cycle costs and rehabilitation efforts are greater for the superstructure components and (2) replacement of superstructure components is more frequent than those of the substructure.

2 Definitions

2.1 Definitions

In general, when speaking about strengthening and repair of structures, the following definitions are applied;

Maintenance: to keep the performance of a structure at its original level

Repair: to upgrade the performance of a structure to its original level

Strengthening: to upgrade the performance of a structure above its original level

Upgrading: to increase the performance of a structure.

It should be mentioned that upgrading of a bridge could be performed by more refined calculations on performance of the structure. This means that, there is a possibility to carry out more refined calculations, e.g. by using FE analysis, using real material data and geometry to perform an accurate assessment of the structure showing an adequate performance level and thus no need for strengthening and repair. However, as mentioned in the limitations, since structural assessment is not in the scope of the project, this option is excluded and the upgrading term will be referring to strengthening and repair activities in this report. The term performance, in general, is related to durability, load carrying capacity, aesthetics and the serviceability of a structure.

2.2 Bridge components

According to definition, a bridge is a structure spanning and providing passage over a river, chasm, traffic intersection area, fjord, inlet or other physically obstacles with a span length equal or exceeding a certain value. This span is defined by national authorities and is usually in the range of 2-6 m. Structure of a bridge may also be divided into the superstructure and the substructure as shown in Figure 1.

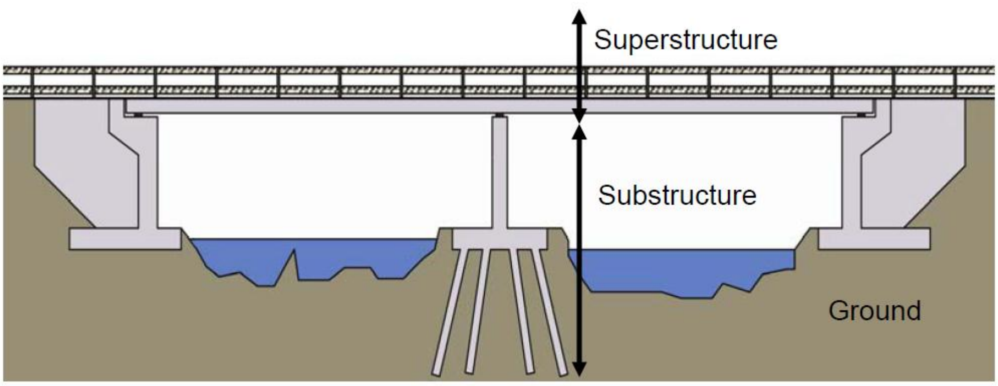

Figure 1 Definition of the superstructure and the substructure in a bridge.

The superstructure carries the traffic load together with its self-weight to the substructure through the bearings. Examples of structural elements which belong to superstructure are decks, girders and stringers.

The substructure carries the load from the superstructure together with its self-weight through the foundation to the ground. Examples of substructural elements are abutments, piers, columns and towers.

3 Strengthening and repair of bridges

3.1 Background

During 1950's and 1960's a large number of bridges were built due to the need for development in road and railway networks. For example, in Belgium, with a relatively small area (30500km^2), 210 bridges were built annually in the seventies [1].

During the period of 1945–1975, maintenance of existing bridges was mostly limited to urgent repairs. When the period of major bridge construction activities came to an end in the late seventies, problems concerning maintenance of the old bridge stock were shown to be very important. Nowadays, the bridge owners are dealing with a large number of structurally and functionally deficient bridges which are in need for upgrading.

Safety, continuity of use, and failure prevention are the primary reasons for strengthening and repair of bridge structures. The following factors might necessitate the strengthening and repair during the life time of a bridge.

1. Increase in the traffic load and intensity,
2. Damage and loss of cross section due to environmental attacks, e.g. corrosion,
3. Damage due to fatigue,
4. Change in the design codes,
5. Errors in design of the structure,
6. Errors in construction of the structure,
7. Additional safety requirements,
8. Improving traffic conditions, for example changing the geometry and increasing clearances,
9. Environmental concerns.

Statistics and reports provided by authorities show that a large number of bridges all over the Europe are in need for upgrading because they cannot meet the current requirements. For example, according to the collected data from 17 European railway administrations (Sustainable bridges, 2004) the general age profile of railway bridges in Europe is as depicted in Figure 2.

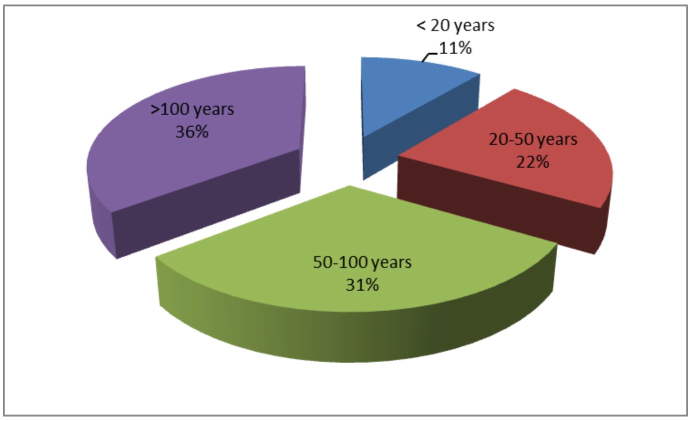

Figure 2 General age profile of European railway bridges based on the data collected from 17 European countries [2]

As can be seen in this figure, almost 67% of the railway bridges in Europe are older than 50 years. Many of these bridges were designed for design load levels well below the load levels that they are used today. Age profile of European railway bridges based on material is presented in Figure 3. As shown, the largest stock of old bridges, belong to metallic and masonry arch bridges.

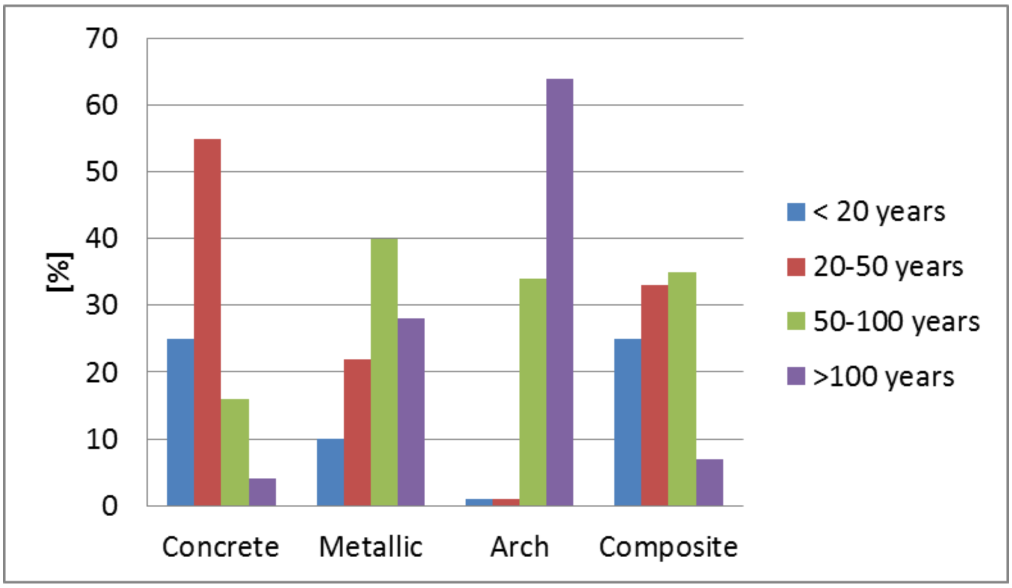

Figure 3 Age profile of European railway bridges with regard to bridge material [2] (Composite bridges refer to concrete-steel composite bridges)

Regarding the condition of bridges in Europe, for example in France, about 50% of more than 20000 bridges located along 30000 km of national roads are required to be repaired while in Hungary, about 45% of the main highway bridges and about 60%of the secondary ones need to be urgently repaired [1]. About 50% of more than 29000 highway bridges in

Poland are more than 50 years in service and nearly 20% of the bridges are structurally deficient and functionally obsolete [1].

When dealing with deficient bridges, two strategies might be considered; (1) upgrading of the bridge, including strengthening and repair of the structure and (2) replacement of the bridge. In the first option, the aim is to increase the performance of the structure such as load bearing capacity, durability, etc. to a desired level while in the second option the old structure is replaced by a new one.

The question, however, is how the decision is made for these two options. The answer to this question depends on national codes in each country as well as decision making processes and procedures and planning for investment. With thousands of bridges to be fixed, economics, inconvenience to the public during reconstruction, or sentimental/historical reasons can discourage replacement option. Replacement is expensive and causes interruption in service during the construction period. Environmental concerns and permit requirements will be greater for new bridges, especially those with four or more lanes. Therefore, in most cases, upgrading option is preferred.

3.2 Structural performance

All structures need a minimum level of performance to function as intended. However, all structures deteriorate over time. The deterioration process can in its simplest way be explained by the curve in Figure 4. When the structure is built, it has its original performance or safety. After some time, the structure reaches its actual performance at level A, the deterioration process continues and at B it reaches the lowest acceptable performance or safety level. If no measures are taken at this point the structure or component reaches its end of life and will need replacement.

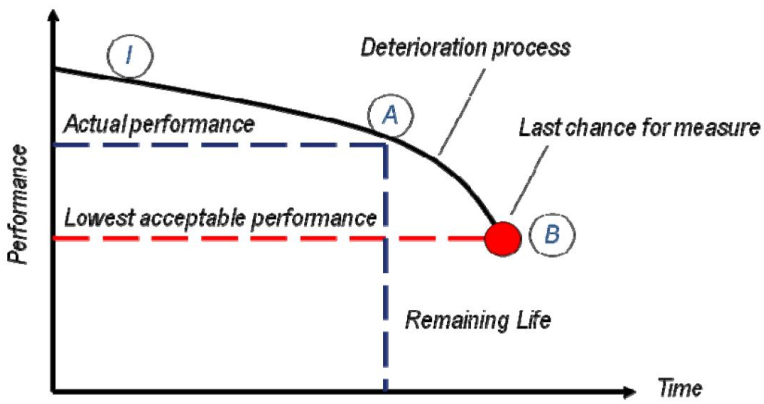

Figure 4 Deterioration of structures [2]

However, if the structure or component is upgraded at point B, it reaches a new performance or safety level C, as shown in Figure 5. The deterioration process will continue and new upgrading operations are often needed. Upgraded structure will eventually reach their end of life and need replacement, as illustrated by the point D in Figure 5.

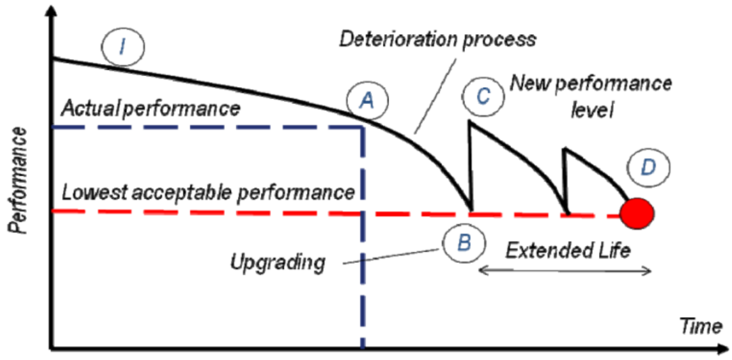

Figure 5 Upgrading of performance and safety [2]

3.3 Opportunities provided by strengthening and repair

Strengthening and repair strategies provide the following opportunities when dealing with deficient bridges:

1. Improving structural performance: example of improving structural performance could be increasing the flexural or shear load carrying capacity,
2. Improving serviceability: examples are possibilities for deck replacement and widening, increasing durability, improving maintainability and inspectability,
3. Economy: reduction of life cycle costs and use of efficient design and construction methods.

3.4 Steps to be taken for strengthening and repair

Initiation of repair and strengthening operations could be summarized in the following steps:

1. Field inspection and structural health monitoring,
2. Preparing an inspection report,
3. Computing the condition rating and sufficiency rating, for funding approval,
4. Analysis and load rating (both inventory and operating ratings),
5. Preparing a rehabilitation report,
6. Implementing diagnostic design procedures,
7. Selecting methods of repair and strengthening,
8. Preparing contract documents and selective reconstruction.

The scope of WP5 in PANTURA is limited to step 7.

3.5 Defining the Objectives of strengthening and repair

With the aging of infrastructure, road and railway authorities, bridge owners and governments spend a lot of money on maintenance of their bridges. Strengthening and repair of bridges are project specific since no two bridges are alike and all are located in different traffic conditions. Design for strengthening and repair is diagnostic and the diversity and complexity of the issues make it different from conventional new bridge design [32]. It differs from new bridge design in a number of ways by requiring:

- Structure condition evaluation and load rating,
- Alternative analysis and computer applications,
- Use of new repair materials and state of the art rehabilitation techniques,
- Staged construction,
- Modern construction techniques,
- Decision making models such as decision matrix, life cycle costs, and risk analysis.

The objectives of upgrading (including strengthening and repair)are round-the- clock access for road users, rideability, inspectability, condition evaluation, and maintainability. It requires restoring structural members which are deficient. Different engineering solutions might be taken for this purpose. Basic objectives are to ensure safety by correcting deficiencies, providing comfort to users, maintaining the environment, and serviceability. It also means routine or incidental work necessary to maintain function of the bridge deck with improved traffic conditions, increased load capacity, and low cost.

4 Bridge inventory

4.1 Bridge demography

Bridge inventory forms the basis for developing relevant techniques and methods for structural assessment and upgrading of bridges in large scale. Different climate, environmental effects, national codes and construction practices in different countries might cause different problems which affect the way bridges should be managed in a certain country. Therefore, it is important to collect data for bridge stock in terms of type, span, age, etc.

4.2 Questionnaire in PANTURA

The questionnaire that was prepared and sent during the course of this project covered the following areas;

1. Bridge type,
2. Span length,
3. Superstructure material,
4. Age profile,
5. Client demands for the construction of new bridges in densely populated areas,
6. Existing strengthening activities,
7. Demands for new strengthening techniques/methods for existing bridges in densely populated areas,
8. Maintenance issues,
9. Maintenance activities,
10. Needs and priorities,
11. Life cycle issues of urban projects.

The conclusions are briefly presented in this report. The questionnaire was prepared and sent out in June 2011 and a deadline was set to 15th of November 2011. It was sent out to 15 European transportation authorities including road and railway administrations, stakeholders' panel members and engineering companies dealing with management of bridges. Four responses were obtained from three countries including;

- City of Rotterdam in Netherlands (ROT)
- ACL Diseño y Cálculo de Estructuras in Spain (ACL)
- Arnhem in Netherlands (AHM)
- Trafikverket in Sweden (TRV)

It should be noted that, these authorities and companies have reported the data regarding the bridges within the regions of their responsibilities and therefore this data cannot be extended to country level.

Due to the lack of returns on the questionnaire sent out in this project, in addition to the results obtained from the questionnaire, the results from two other European projects, Sustainable bridges (2003-2007) and BRIME (1998-1999), are included in this report.
The former project deals with railway bridges in Europe and the latter considers the roadway bridges. Even though the information from these two projects is useful and informative, it should be noticed that the focus of these projects was not on urban areas.
The detailed responses obtained from the questionnaire are presented in Appendix 1 of this report.

4.3 Sustainable bridges

A total number of 217000 railway bridges from 17 European countries were carried out in the survey of sustainable bridges project (2003-2007). The results from this project are presented in the following categories in this report:

- Bridge type
- Age profile
- Span profile

Detailed results can be found in Appendix 2 of this report

4.4 BRIME

A bridge inventory was carried out in the European project BRIME (Bridge management in Europe, 1998-1999). Information from six European countries was collected. A total number of 80723 roadway bridges were surveyed in this project. The breakdown of this number based on the countries is presented in Table 1. It should be noted, however, that in most cases this is only a small portion of the overall bridge stock, as bridges managed by local authorities are not included.

Table 1 Bridge stock of national highway networks [4]

Country	France	Germany	Norway	Slovenia	Spain	UK
Number	21549	34824	9163	1761	3911[1]	9515[2]
Area [1000m²]	7878	24349	2300	660	N/A	5708[2]

1) Number of bridges recorded until 1996
2) Bridge owned by the Highway Agency, i.e. in England only

Figure 6 presents the general age profile of bridges in the considered countries. Different bridge type as a proportion of total bridge stock is presented in Figure 8 and Figure 9 presents the span length of bridges with respect to total number of bridges.

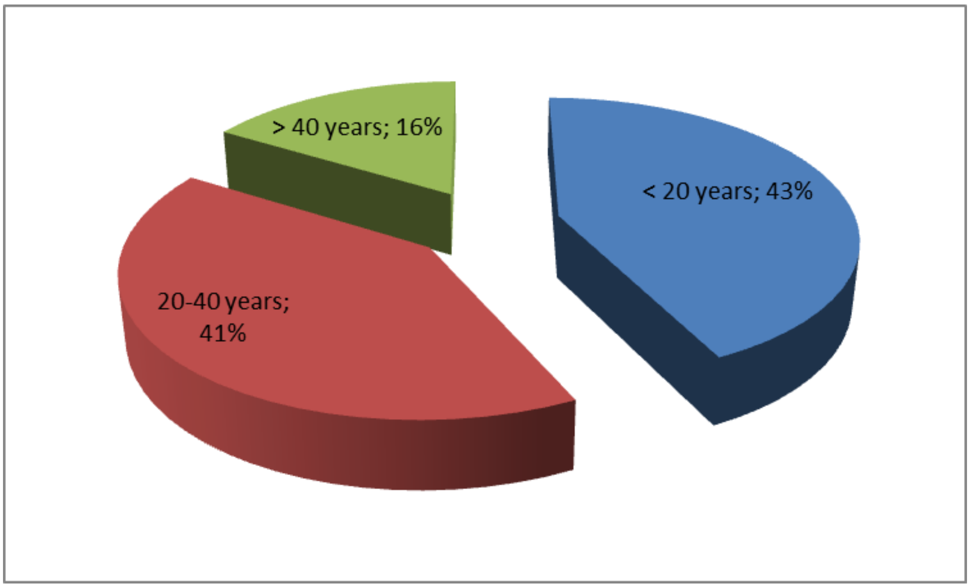

Figure 6 General age profile of roadway bridges in the considered countries [4]

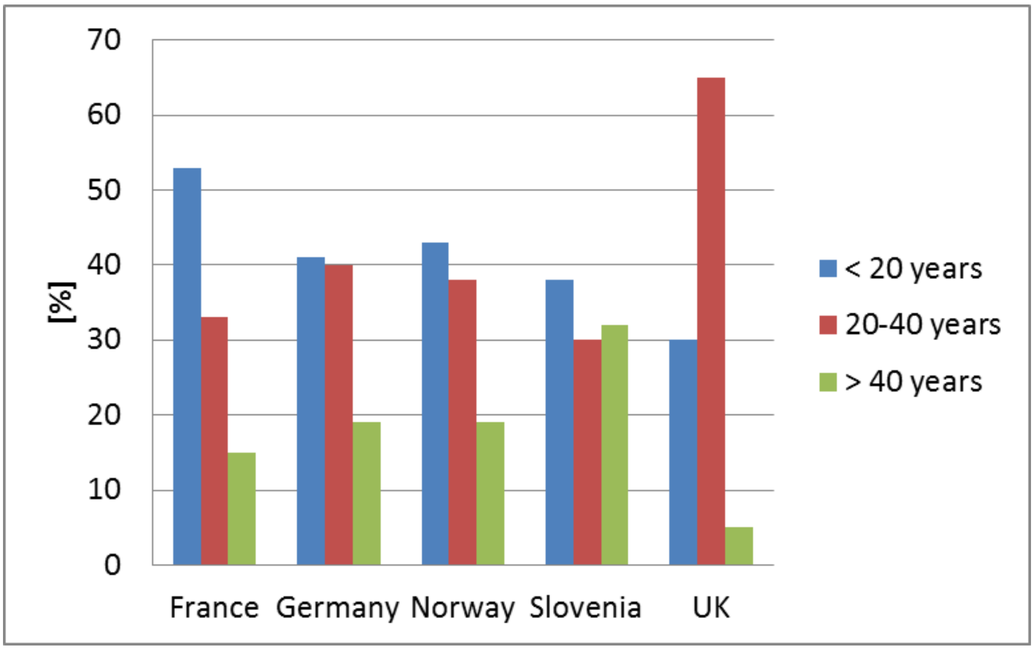

Figure 7 Age profile in accordance with respect to the number of bridges [4]

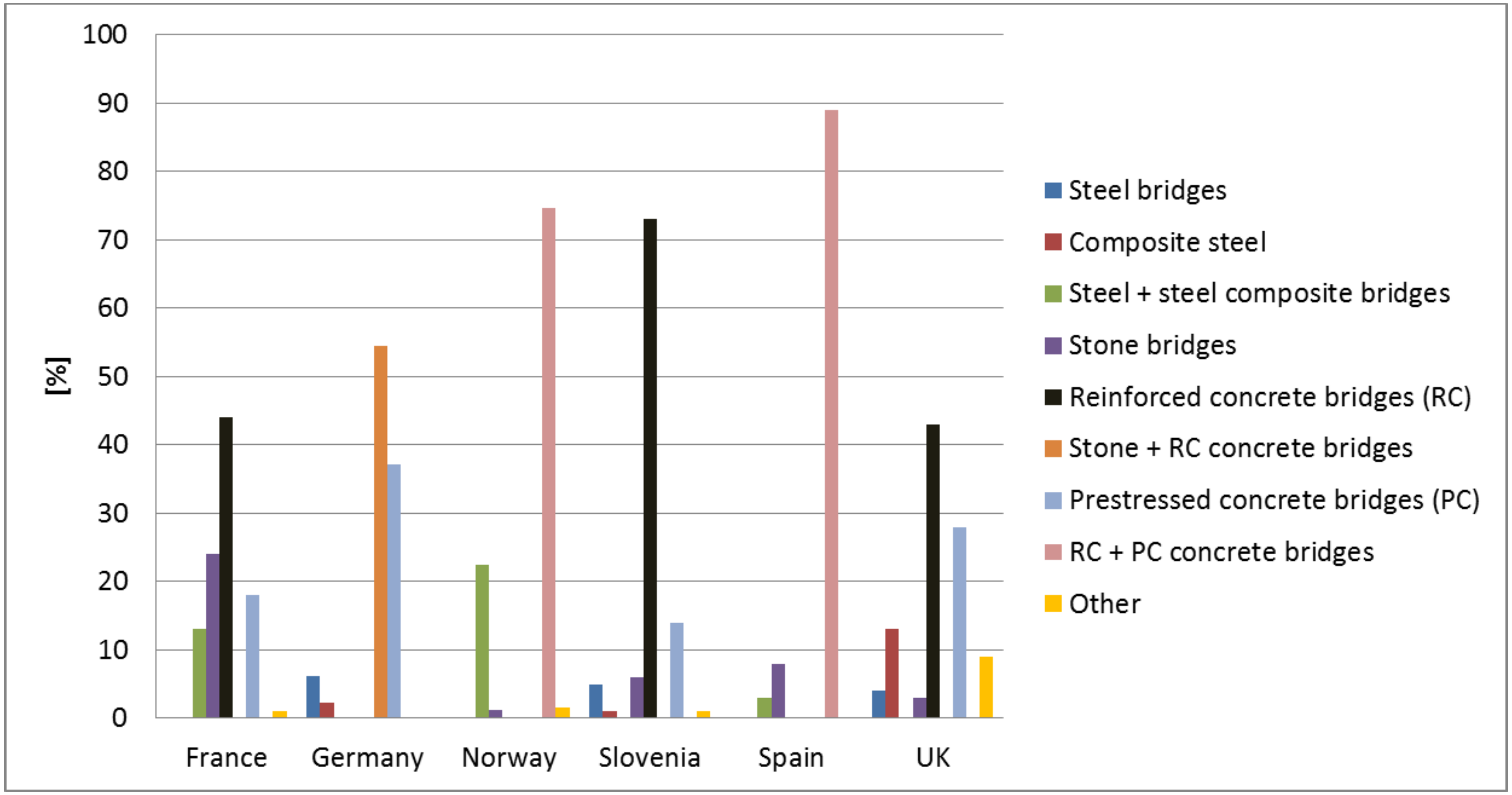

Figure 8 Different bridge type as a proportion of total bridge stock [4]

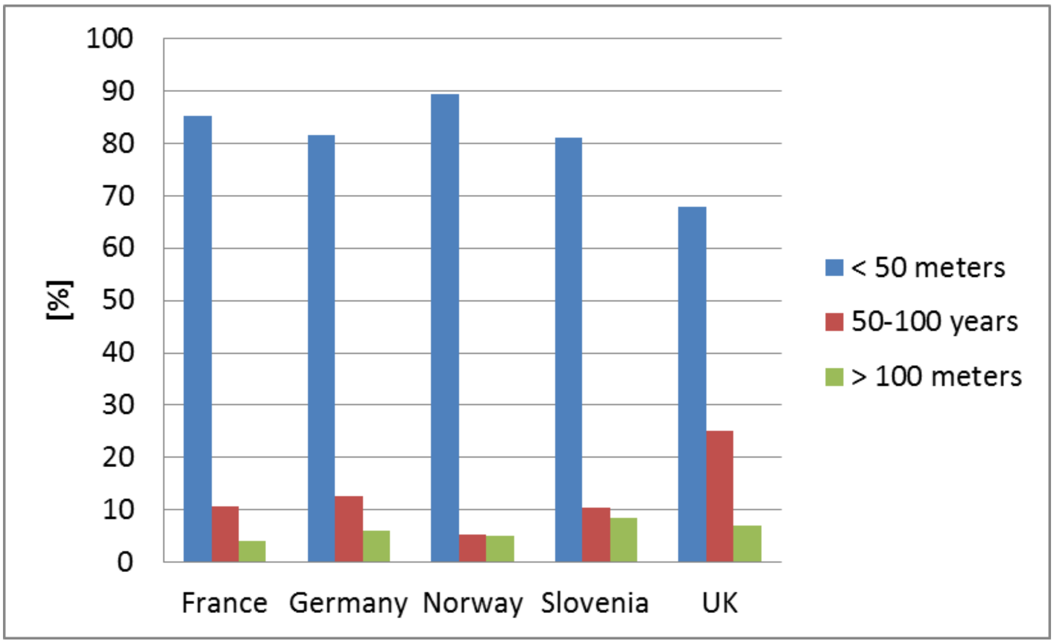

Figure 9 Proportion of bridge length with respect to number of bridges [4]

4.5 Bridge management system in Sweden

In order to support the data collected from the questionnaire and two other projects in this report, detailed information regarding the bridges and bridge management system in Sweden was also collected. This information is presented in Appendix 3 of this report where a short description of the database system used for bridge management in Sweden, BaTMan, is presented together with statistics regarding costs and condition of bridges in Sweden.

4.6 Common problems in bridges

Based on the collected information from the returns of the questionnaire, the most common problems with bridges in urban areas were identified and are reported in Table 2. The results are presented based on construction material for superstructure while for substructure the results are presented based on structural elements. The detailed results based on country and also importance of the problem can be found in Appendix 1 of this document.

Table 2 Common problems in bridges based on the data collected from questionnaire

Part	Bridge material /Element	Common problems
Superstructure	**Pre stressed/post tensioned concrete**	• *Inspection of tendons for corrosion* • *Measurements of tendons relaxation* • *Lack of grouting* • *Deck joints maintenance* • *Road surface maintenance* • *Drainage system cleaning* • *Reinforcements design* • *Concrete cracks injections* • *Anti-corrosion protection paintings* • *Tendons anchorage maintenance* • *Reparations due to vehicles impacts*
	Reinforced concrete	• *Corrosion of reinforcement* • *Deck joints maintenance* • *Road surface maintenance* • *Drainage system cleaning* • *Reinforcements design* • *Concrete cracks injections* • *Anti-corrosion protection paintings* • *Reparations due to vehicles impacts* • *ASR in synergy with frost*
	Steel/concrete composite	• *Deck joints maintenance* • *Road surface maintenance* • *Drainage system cleaning* • *Reinforcements design* • *Anti-corrosion protection paintings* • *Reparations due to vehicles impacts* • *Examination of shear studs* • *Temperature deformation control* • *Examination of welded seams* • *Rough Holes reparation* • *Cracking of the deck over supports*

	Steel and wrought iron	• *Fatigue* • *Deck joints maintenance* • *Road surface maintenance* • *Drainage system cleaning* • *Anti-corrosion protection paintings* • *Reparations due to vehicles impacts* • *Temperature deformation control* • *Examination of welded seams* • *Rough Holes reparation* • *Brittleness* • *Corrosion from lack of preventive maintenance* • *Fatigue of secondary members*
	Brick or stone arches	• *Road surface maintenance* • *Reinforcements design* • *Cracks injections* • *Reparations due to vehicles impacts* • *Calculation of load-bearing capacity* • *Repair methods that do not disrupt traffic*
Substructure	**Bearings**	• *Difficulty of inspection* • *Bearings maintenance* • *Bearings substitution* • *Anchoraged bearings substitution* • *Excessive friction coefficient* • *Bearings slide* • *Lack of movement* • *Anchorage of the footing plates on older bridges* • *Corrosion on older bridges*
	Abutments	• *embankment settlement* • *Anchorage design at walls* • *Embankment settlement* • *Insufficient compaction of embankment soil* • *Inefficient drainage system* • *Erosion, earth movement and vegetation*
	Piers/columns	• *Cracking, chloride, ASR* • *Scour at river bridges piers* • *Reinforcements design* • *Concrete cracks injections* • *Anti-corrosion protection paintings* • *Reparations due to vehicles impacts* • *Chloride-induced corrosion (De-icing salts)*

	Foundations	• *Settlement, pile bearing capacity, chloride* • *Scour at river bridges piers* • *Concrete cracks injections in deep foundations* • *Compression of natural soil due to embankment loads* • *Calculation of the load-bearing capacity of timber piles*
	Approach embankments/transition zones/bridge ends	• *Settlement* • *Compression of natural soil due to embankment loads*

5 General problems involved in strengthening and repair

To strengthen or repair existing structures is a complicated task, mainly due to the fact that the conditions are already set and it can be complicated to decide about the underlying reason for the strengthening and repair need. In addition to this, repair and strengthening are mostly carried out for improved load carrying capacity in the ultimate limit state but a structure is almost only loaded in the service limit state, which here also includes fatigue and durability limit states. This means that the repair and strengthening needs and design should be based on theoretical assumptions that might be difficult to verify. Figure 10 shows an illustration of general problems in strengthening or repair of a structure or a structural member.

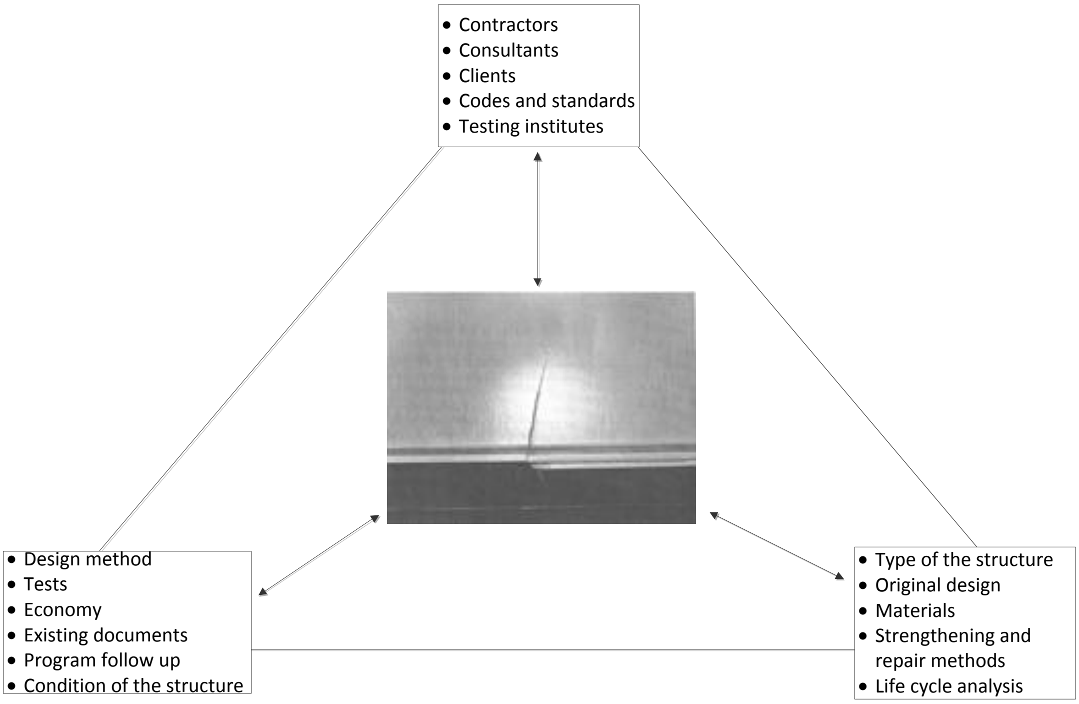

Figure 10 Complexities involved in strengthening and repair works

Considering the original design is always important, in particular for older structures which were designed based on other codes and guidelines. The original design forms the base in the repair and strengthening need and here also all existing documentation and history for the structure should be considered when applicable.

The next step is to consider the material in the structure and the material that are added after strengthening. Compatibility of the old and new materials is very important. Considering composite action to transfer the forces from one component to another is another issue to be noticed.

It is also important to consider environmental issues, issues such as using environmental friendly products is one of the criteria. Furthermore, the aesthetics and life cycle aspects must also be considered. For all methods the cost must be considered and it should take into account the desired function and the remaining expected life of the structure. In complicated cases tests may be needed and systems to follow up the strengthened and repaired structure over time introduced.

6 Experience on strengthening and repair of bridges

Experience from strengthening and repair projects regarding the complexities and problems encountered during operation is presented in two parts in this report. In Appendix 4, the experience of industrial partners participating in PANTURA (MOS, ACC and NCC) from on-going and concluded projects is presented. In Appendix 5, information gathered from literature from some other strengthening and repair projects is presented. It includes a short description of each bridge, the problems involved, strengthening and repair solution and some practical issues during the course of operation.

7 Conclusion

The conclusions from the collected data in this project and from two other projects considered in this report (Sustainable bridges and BRIME) are presented in this section.

7.1 Bridge demography

The data from Sustainable bridges project, which geographically covers most of Europe and its major climate zones, shows that the European railway bridge stock is generally quite old and contains a mix of bridge types. The predominant type of bridges is arch bridges, mostly having brick construction, with lesser, but almost equal, quantities of metallic and concrete bridges. The stock also contains a smaller number of composite bridges. The majority of European railway bridges are small span (below 10m), with spans over 40m only accounting for 5% of the bridges in the survey. Most long span bridges are of metallic construction.

The data from BRIME, on the other hand, indicates the European roadway bridge stock in the considered countries is younger than railway bridges. Showing 16% of the total bridges older than 40 years, UK has the least bridge stock with 5% older than 40 years and Slovenia has the largest of the old bridge stock with 32% among the countries investigated.

Results from this project also indicate that roadway bridges with spans shorter than 50 m dominate the whole stock. Data on types of bridges also reveals that concrete is the most common material in construction of roadway bridges in Europe.

Results from the returns of questionnaire reveal that the largest stock of bridges built in the past 10 years in urban areas belong to pedestrian bridges in Rotterdam, Netherlands and Spain while Sweden had the lowest number for this bridge type. Results regarding the span of bridges in urban areas vary between different countries and no conclusion can be drawn based on that. The age profile of bridges in urban areas indicate that with respect to the bridge material, steel/concrete composite, concrete and metallic bridges have almost a uniform distribution for age intervals of <20, 20-50 and 50-100 years. For arch bridges, the dominant intervals are 50-100 and >100 years indicating that the oldest bridges belong to this category.

7.2 Client demands for the construction of new bridges in densely populated areas

Based on the responses obtained, different authorities have introduced the following demands as their priorities when it comes to construction of new bridges. These demands based on priority are;

1. Initial cost
2. Maintenance costs
3. Short construction time

4. Minimizing traffic disruption
5. Life cycle costs
6. Minimizing the impact on the surrounding environment
7. Measures to minimize the noise coming from traffic flow on the bridge to the surroundings after the construction

7.3 Demands for maintenance (strengthening) activities of existing bridges in densely populated areas

Upgrading of existing bridges appears to be the first option for public authorities since they seem to seek the most cost-effective way of spending the public funding. Thus, replacing an existing bridge with a new bridged is often the last option when all other possibilities has been evaluated.

The results obtained in this area show that strengthening of decks in steel/concrete composite bridges, replacement of decks, FRP strengthening of concrete, widening of deck and FRP strengthening of steel bridges are the priorities for bridge authorities.

7.4 Demands for strengthening techniques/methods for existing bridges in densely populated areas

The priorities in this area are minimizing traffic disruption, application time, initial costs, long-term performance and maintenance costs. These priorities clearly indicate that methods which are more efficient in terms of shortening the application time and also better use of materials are appreciated. Examples of methods which could fulfill these criteria are strengthen and repair using bonded FRP composites which shortens the application time and using pre-stressed FRP laminates for strengthening and repair since it provides more efficient use of materials and reduces the initial cost.

7.5 Management of bridges in Sweden

Swedish traffic administration (TRV) owns about 20000 bridges and manages over 25000 bridges in Sweden. 75% railway bridges in Sweden owned by TRV are older than 50 years. This per cent for roadway bridges is 36%. Also 32% of bridges owned by communes, including roadway and railway bridges are older than 50 years.

According to definition of condition class in Sweden, condition class 3 is defined as critical and it is necessary to apply measures within a period of three months for these bridges, see Appendix 3. The number of roadway bridges in condition class 3, owned by TRV, is 964 which comprise 23% of total railway bridges and 1674 bridges for roadway bridges which comprise 10% of the total roadway bridges. These numbers indicate the large stock of bridges in need for strengthening and repair measures. The money that TRV has invested on maintenance of its bridges during the past 10 years also underlines the importance of this issue. During the years 1999 to 2009, TRV spent 2757000 Euros for maintenance of railway bridges which was about 5.6% of the total budget for railway bridges. This amount for roadway bridges was 473355000 Euros which was about 34% of the total budget for Roadway bridges.

Generally, it can be concluded from this report that upgrading of bridges in terms of strengthening and repair, is an important issue that bridge owners and authorities deal with nowadays. The measures needed for new strengthening and repair techniques emphasis on cost and operation time. It seems that using advanced composite materials is one of the solutions. Using fiber reinforced polymer, FRP, in form of prefabricated decks is also very promising for upgrading and construction of new bridges since it can result in saving time and minimizing the traffic closure time. There are some concerns regarding using FRP materials, among them are lack of design codes and long-term performance which demands more research and practice.

References

[1] Radomski W. (2002): *Bridge rehabilitation*, ICP, London.

[2] European Railway Bridge Demography, Sustainable Bridges: Assessment for Future Traffic Demands and Longer Lives, Sixth Framework Programme, 2003 – 2007

[3] Khan, M. A., Bridge and highway structure rehabilitation and repair, Mc Graw Hill, 2010, ISBN 978-0-07-154592-1.

[4] Review of current procedures for assessing load carrying capacity, Bridge management in Europe, BRIME,1999, PL 97-2220.

APPENDIX 1

Questionnaire

Low-disturbance sustainable urban construction

PANTURA

APPENDIX 1

Questionnaire

Type of report, Version, 28 December 2011

Colophon

This publication is produced by Pantura work group: WP5

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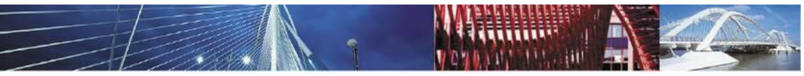


Table of contents

1. Types of bridges

The number or percentage of different types of new bridges that have been constructed during the last 10 years in densely populated areas in your working district, are presented in the following table.

ROT (Netherlands)

Type of bridge	Number	Percentage [%]
Pedestrian	290	93%
Highway	22	7%
Railway		
Total		100%

ACL (Spain)

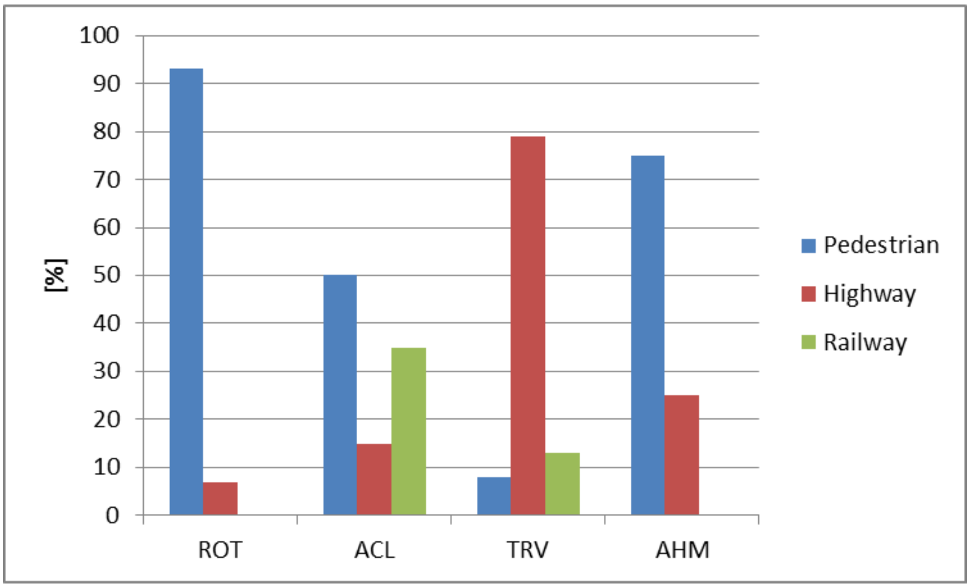
Type of bridge	Number	Percentage [%]
Pedestrian		50%
Highway		15%
Railway		35%
Total		100%

TRV (Sweden)

Type of bridge	Number	Percentage [%]
Pedestrian	14	8%
Highway	135	79%
Railway	22	13%
Total	202	100%

AHM (Netherlands)

Type of bridge	Number	Percentage [%]
Pedestrian/bike	136	75%
Highway	44	25%
Railway		
Total	180	100%


100
90
80
70
60
50
40
30
20
10
0
[%]
ROT
ACL
TRV
AHM
Pedestrian
Highway
Railway

2. Span length

The approximate span (superstructure) profile of each type of bridge by number or percentage is provided in the following table. For continuous beam bridge, the largest span is considered.

ROT (Netherlands)

Bridge type	Span range			
	<10 m	**10-25 m**	**25-40 m**	**>40 m**
Pedestrian	40%	55%	5%	
Highway	5%	80%	10%	5%
Railway				

ACL (Spain)

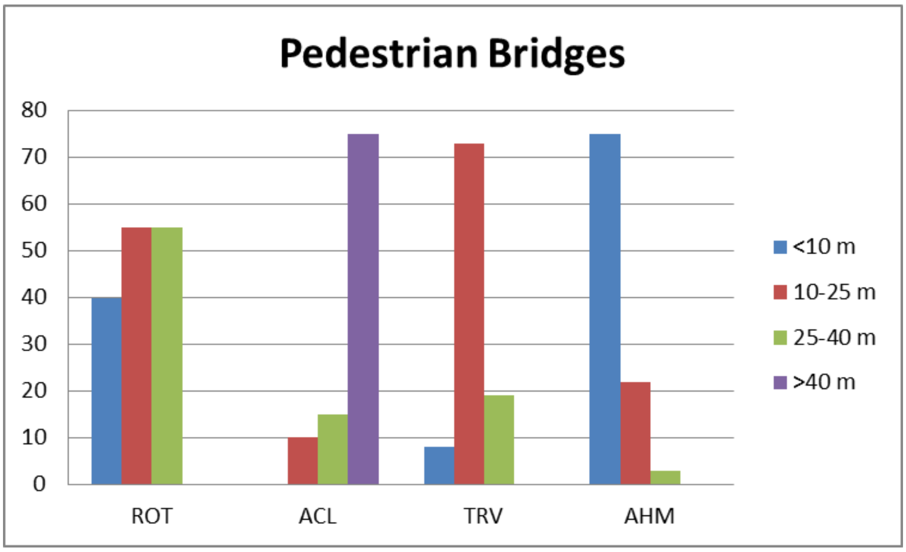
Bridge type	Span range			
	<10 m	**10-25 m**	**25-40 m**	**>40 m**
Pedestrian		10%	15%	75%
Highway	20%	30%	30%	20%
Railway	15%	15%	20%	50%

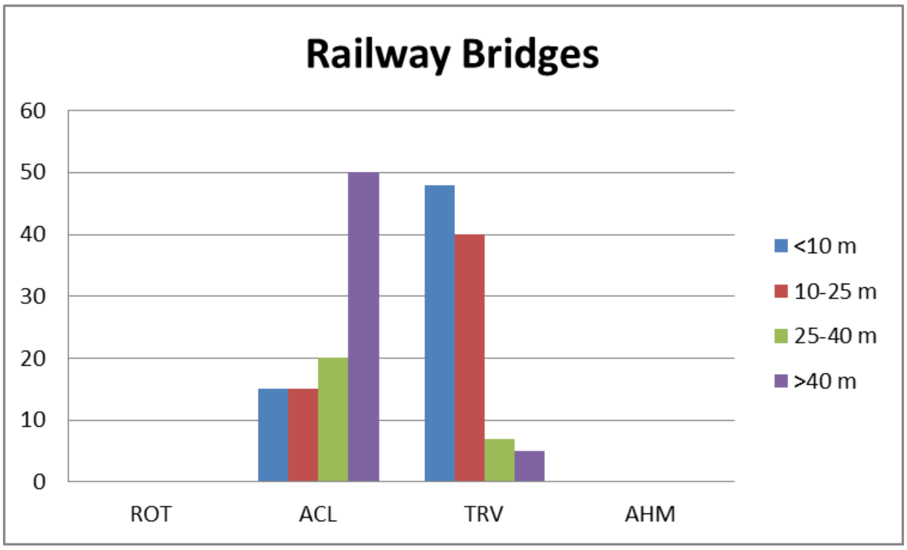
TRV (Sweden)

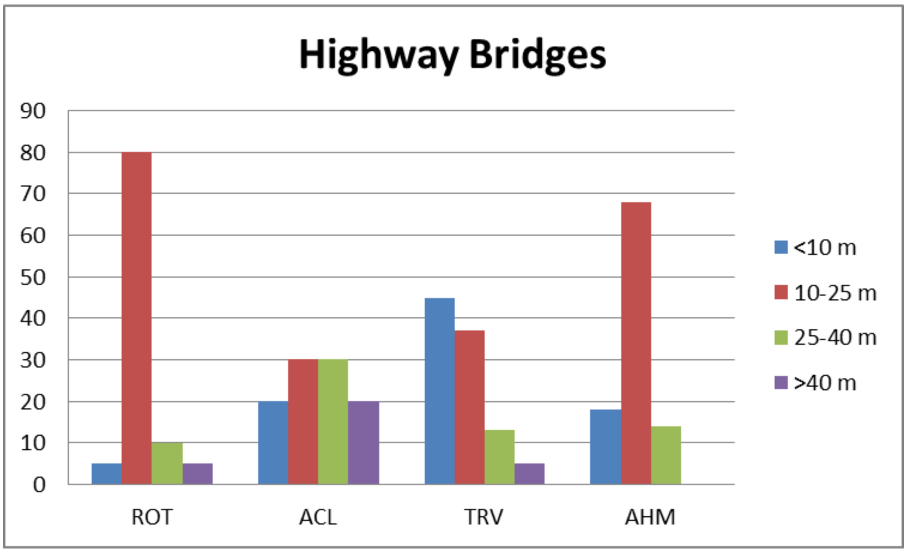
Bridge type	Span range			
	<10 m	**10-25 m**	**25-40 m**	**>40 m**
Pedestrian	2(8%)	19(73%)	5(19%)	
Highway	522(45%)	437(37%)	151(13%)	58(5%)
Railway	153(48%)	128(40%)	22(7%)	15(5%)

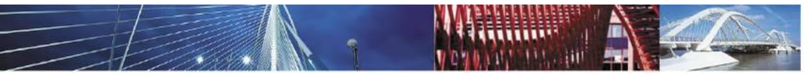
AHM (Netherlands)

Bridge type	Span range			
	<10 m	**10-25 m**	**25-40 m**	**>40 m**
Pedestrian	100(75%)	30(22%)	4(3%)	
Highway	8(18%)	30(68%)	6(14%)	
Railway				


Pedestrian Bridges
80
70
60
50
40
30
20
10
0
ROT
ACL
TRV
AHM
<10 m
10-25 m
25-40 m
>40 m


Railway Bridges
60
50
40
30
20
10
0
ROT
ACL
TRV
AHM
<10 m
10-25 m
25-40 m
>40 m


Highway Bridges
90
80
70
60
50
40
30
20
10
0
ROT
ACL
TRV
AHM
<10 m
10-25 m
25-40 m
>40 m



3. Client demands for the construction of new bridges in densely populated areas

With regard to the construction of new bridges in densely populated areas some specific client requirements have often to be considered. The following table indicates the important demands by ranking them from one to five (5 being the most important).

ROT (Netherlands)

Client demands for the construction of new bridges in densely populated areas	Ranking
Short construction time	5
Minimizing the impact on the surrounding environment	2
Minimizing traffic disruption on underlying the bridge in case of flyover highway or railway bridges	4
Measures to minimize the noise coming from traffic flow on the bridge to the surroundings after the construction	3
Initial costs	5
Maintenance costs	3
Life cycle costs	1
Other demands not mentioned above?	

ACL (Spain)

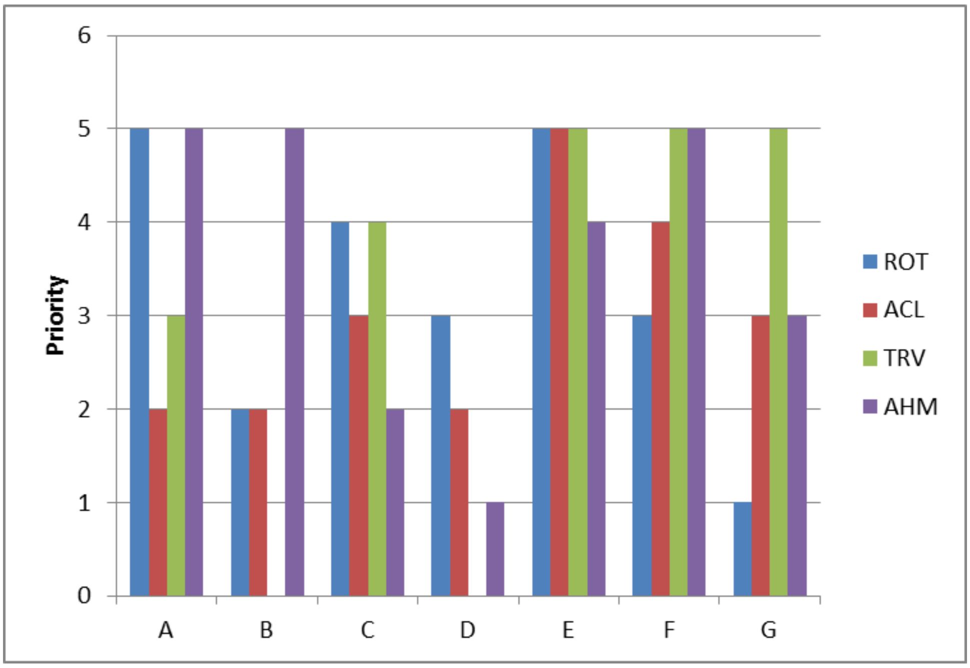
Client demands for the construction of new bridges in densely populated areas	Ranking
Short construction time	2
Minimizing the impact on the surrounding environment	2
Minimizing traffic disruption on underlying the bridge in case of flyover highway or railway bridges	3
Measures to minimize the noise coming from traffic flow on the bridge to the surroundings after the construction	2
Initial costs	5
Maintenance costs	4
Life cycle costs	3
Other demands not mentioned above? • Geometrical limitations • Suitable and available materials • Affected services • Traffic requirements	

TRV (Sweden)

Client demands for the construction of new bridges in densely populated areas	**Ranking**
Short construction time	3
Minimizing the impact on the surrounding environment	yes
Minimizing traffic disruption on underlying the bridge in case of flyover highway or railway bridges	4
Measures to minimize the noise coming from traffic flow on the bridge to the surroundings after the construction	yes
Initial costs	*
Maintenance costs	*
Life cycle costs (*Initial and maintenance costs included in LCC)	5
Other demands not mentioned above?	

AHM (Netherlands)

Client demands for the construction of new bridges in densely populated areas	**Ranking**
Short construction time	5
Minimizing the impact on the surrounding environment	5
Minimizing traffic disruption on underlying the bridge in case of flyover highway or railway bridges	2
Measures to minimize the noise coming from traffic flow on the bridge to the surroundings after the construction	1
Initial costs	4
Maintenance costs	5
Life cycle costs	3
Other demands not mentioned above?	



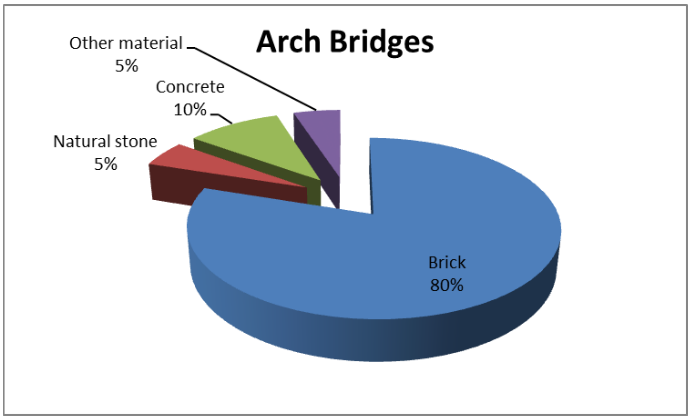
A	Short construction time
B	Minimizing the impact on the surrounding environment
C	Minimizing traffic disruption on underlying the bridge in case of flyover highway or railway bridges
D	Measures to minimize the noise coming from traffic flow on the bridge to the surroundings after the construction
E	Initial costs
F	Maintenance costs
G	Life cycle costs

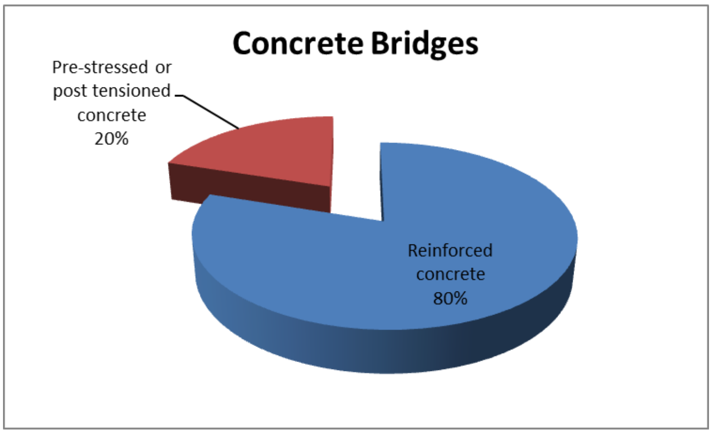
4. Superstructure materials

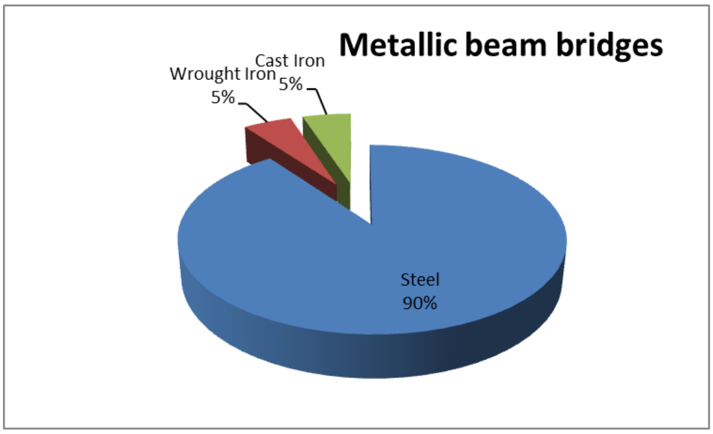
The total number of bridges owned and maintained, divided based on the material.

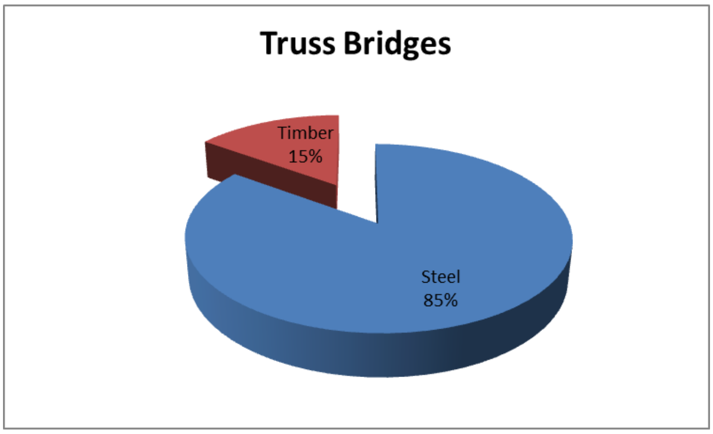
ROT (Netherlands)

Bridge type			Number
Arch		***Type total***	
Brick	No. or %	80%	
Natural stone	No. or %	5%	
Concrete	No. or %	10%	
Other material	No. or %	5%	
Concrete beam Type total			
Reinforced concrete	No. or %	80%	
Pre-stressed or post tensioned concrete	No. or %	20%	
Steel/concrete		***Type total***	
Without composite action	No. or %	95%	
Concrete acting compositely	No. or %	5%	
Metallic beam		***Type total***	
Steel	No. or %	90%	
Wrought Iron	No. or %	5%	
Cast Iron	No. or %	5%	
Truss bridges		***Type total***	
Steel	No. or %	85%	
Timber	No. or %	15%	
Timber bridges		***Type total***	
		Grand total	







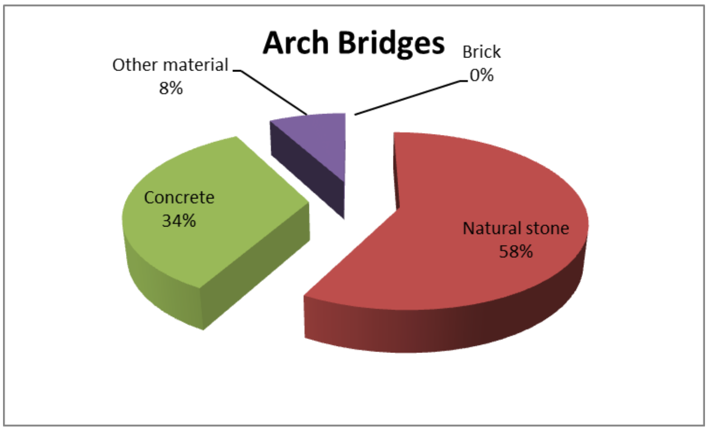


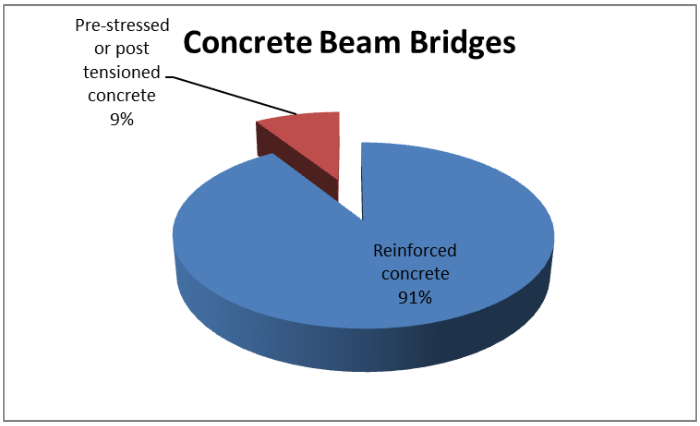
ACL (Spain)

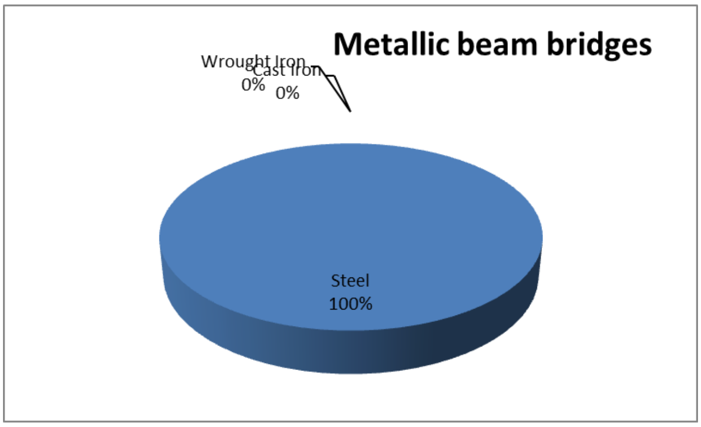
No information was provided by ACL

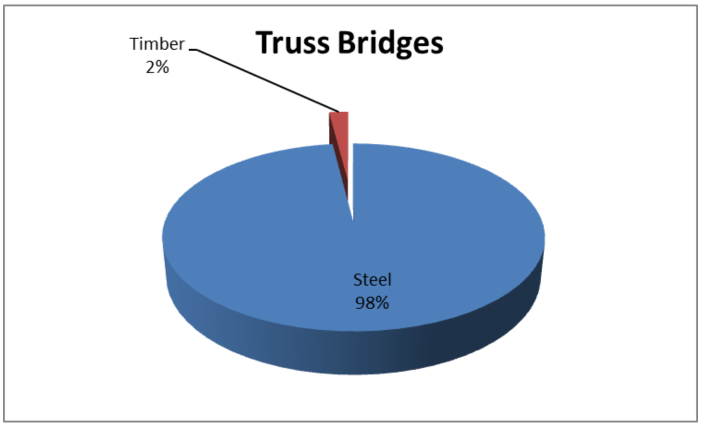
TRV (Sweden)

Bridge type			Number
Arch (bågbroar & valvbroar)		***Type total***	1321
Brick	No. or %	0(0%)	
Natural stone	No. or %	770(58%)	
Concrete	No. or %	445(34%)	
Other material	No. or %	106(8%)	
Concrete beam and slab		***Type total***	13545
Reinforced concrete	No. or %	12295(91 %)	
Pre-stressed or post tensioned concrete	No. or %	1250(9%)	
Steel/concrete		***Type total***	820
Without composite action	No. or %	298(36%)	
Concrete acting compositely	No. or %	522(64%)	
Metallic beam		***Type total***	642
Steel	No. or %	642(100%)	
Wrought Iron	No. or %	0(0%)	
Cast Iron	No. or %	0(0%)	
Truss bridges		***Type total***	122
Steel	No. or %	119(98%)	
Timber	No. or %	3(2%)	
Timber bridges		***Type total***	69
Note that there are other types that are not listed here.			
Grand total			



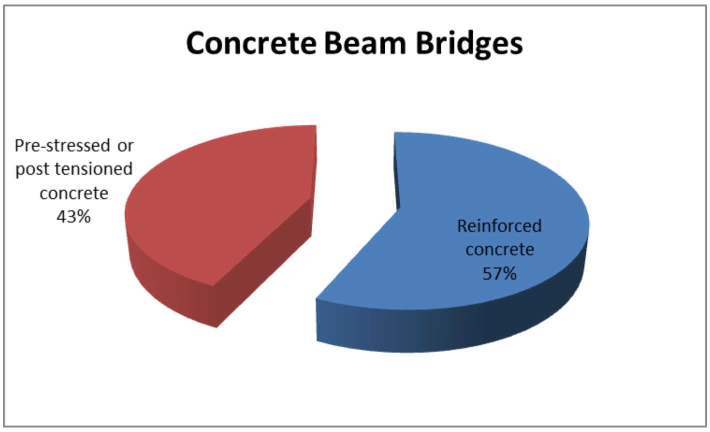

Concrete Beam Bridges
Pre-stressed or post tensioned concrete 9%
Reinforced concrete 91%

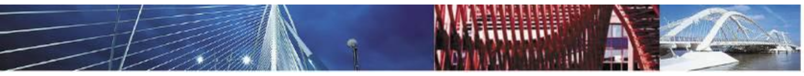

Metallic beam bridges
Wrought Iron 0%
Cast Iron 0%
Steel 100%

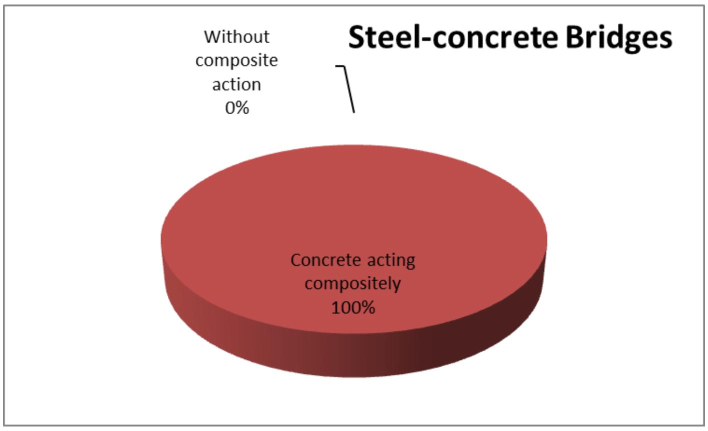

Truss Bridges
Timber 2%
Steel 98%

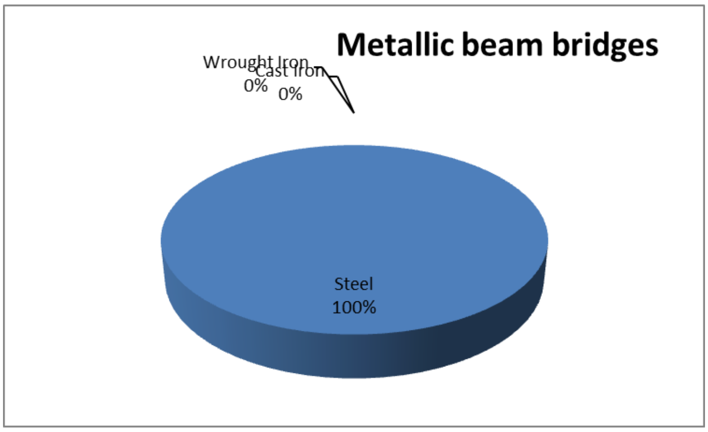
AHM (Netherlands)

Bridge type			Number
Arch		***Type total***	
Brick	No. or %		
Natural stone	No. or %		
Concrete	No. or %		
Other material	No. or %		
Concrete beam		***Type total***	14
Reinforced concrete	No. or %	8(57%)	
Pre-stressed or post tensioned concrete	No. or %	6(43%)	
Steel/concrete		***Type total***	59
Without composite action	No. or %		
Concrete acting compositely	No. or %	59(100%)	
Metallic beam		***Type total***	11
Steel	No. or %	11(100%)	
Wrought Iron	No. or %		
Cast Iron	No. or %		
Truss bridges		***Type total***	
Steel	No. or %		
Timber	No. or %		
Timber bridges		***Type total***	73
Other			3
Grand total			
		Grand total	156






Steel-concrete Bridges
Without
composite
action
0%
Concrete acting
compositely
100%

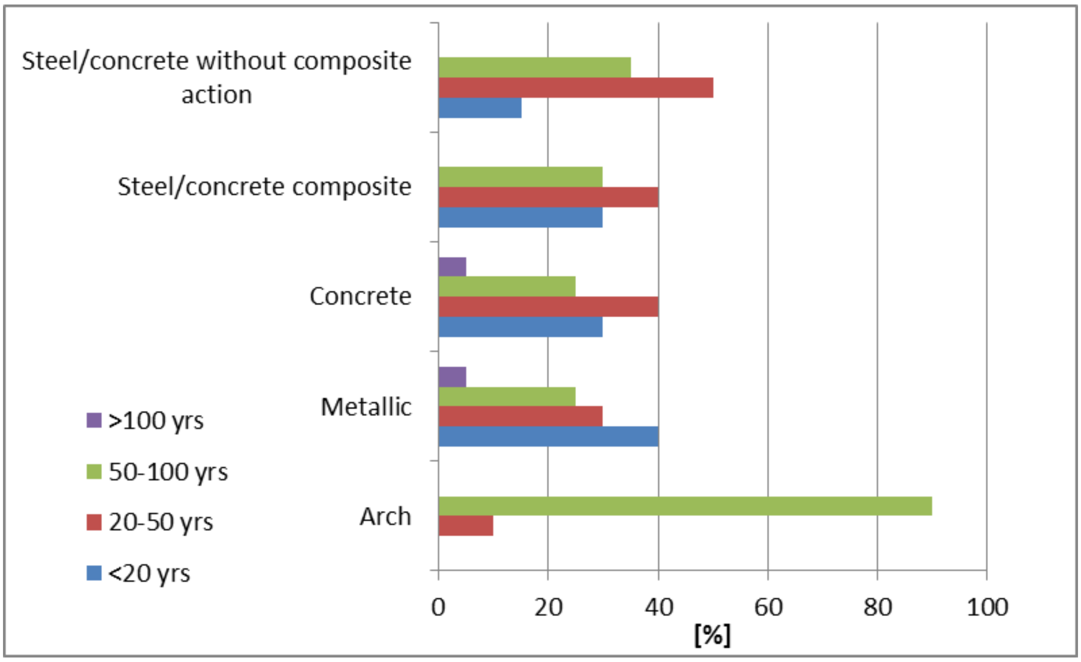

Metallic beam bridges
Wrought Iron
0%
Cast Iron
0%
Steel
100%

5. Age

Table below shows the approximate age profile of each category of bridges by percentage.

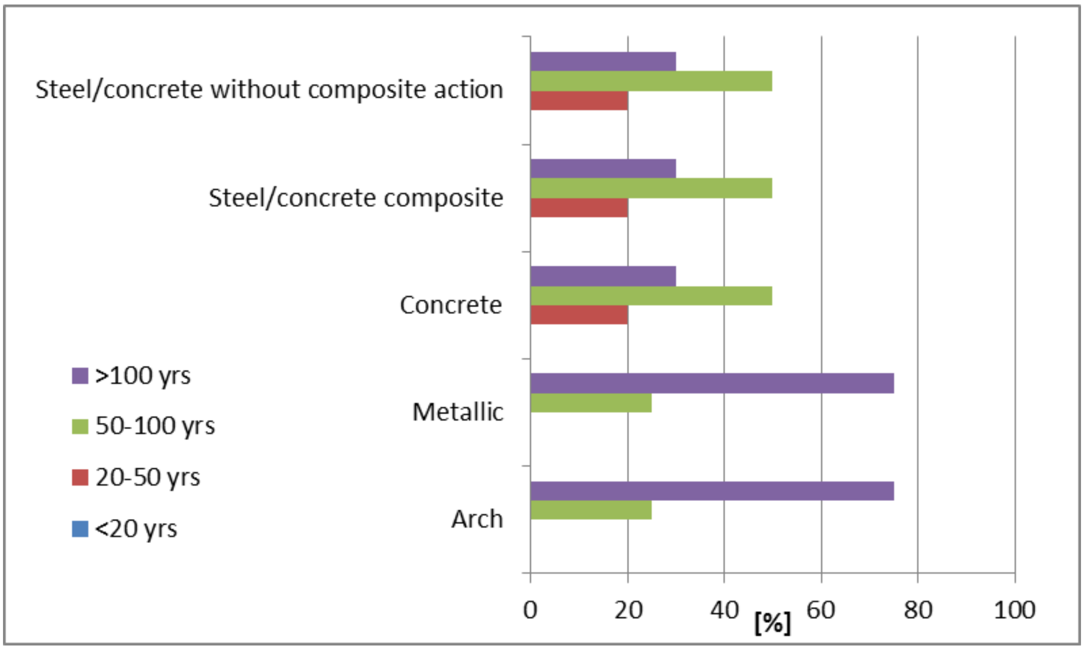
ROT (Netherlands)

Category	Approximate age			
	<20 yrs	20-50 yrs	50-100 yrs	>100 yrs
Arch		10%	90%	
Metallic	40%	30%	25%	5%
Concrete	30%	40%	25%	5%
Steel/concrete composite	30%	40%	30%	
Steel/concrete without composite action	15%	50%	35%	



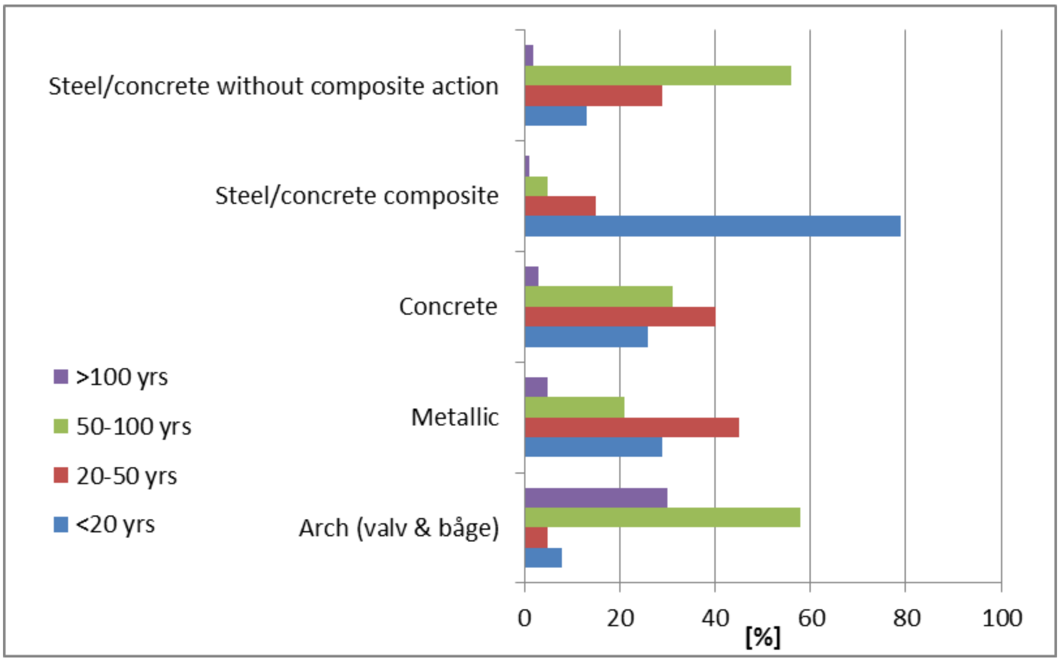
ACL (Spain)

Category	Approximate age			
	<20 yrs	20-50 yrs	50-100 yrs	>100 yrs
Arch			25%	75%
Metallic			25%	75%
Concrete		20%	50%	30%
Steel/concrete composite		20%	50%	30%
Steel/concrete without composite action		20%	50%	30%



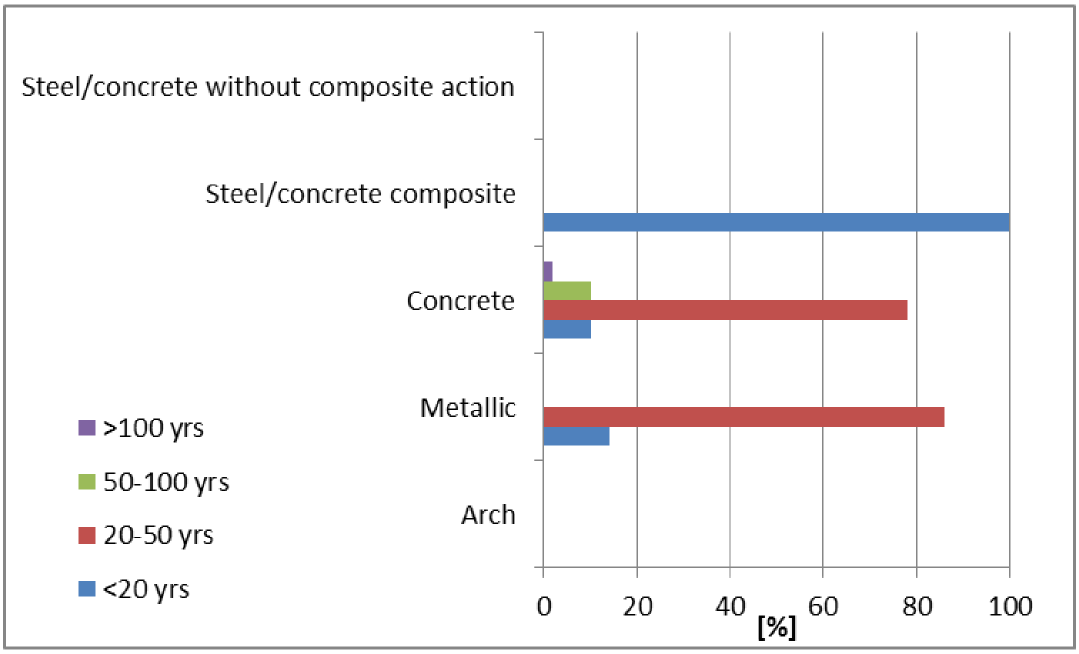
TRV (Sweden)

Category	Approximate age			
	<20 yrs	**20-50 yrs**	**50-100 yrs**	**>100 yrs**
Arch (valv & båge)	107(8%)	64(5%)	777(58%)	400(30%)
Metallic	1072(29%)	1657(45%)	777(21%)	174(5%)
Concrete	3828(26%)	5881(40%)	4626(31%)	416(3%)
Steel/concrete composite	414(79%)	76(15%)	30(65)	3(1%)
Steel/concrete without composite action	40(13%)	86(29%)	167(56%)	5(2%)



AHM (Netherlands)

Category	**Approximate age**			
	<20 yrs	**20-50 yrs**	**50-100 yrs**	**>100 yrs**
Arch				
Metallic	14%	86%		
Concrete	10%	78%	10%	2%
Steel/concrete composite	100%			
Steel/concrete without composite action				

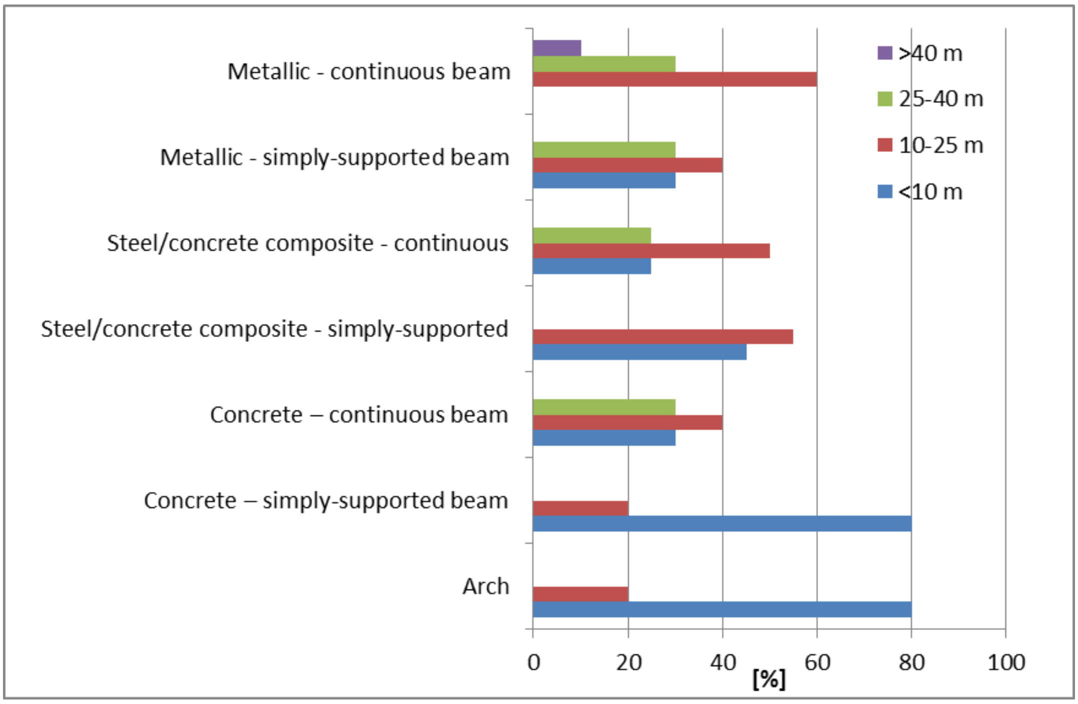


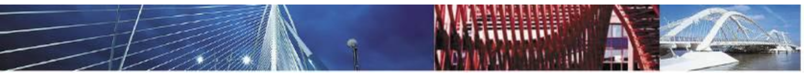
6. Span length

The approximate span (superstructure) profile of each type of bridge by percentage is indicated in the following table. For continuous beam bridge, the largest span is given.

ROT (Netherlands)

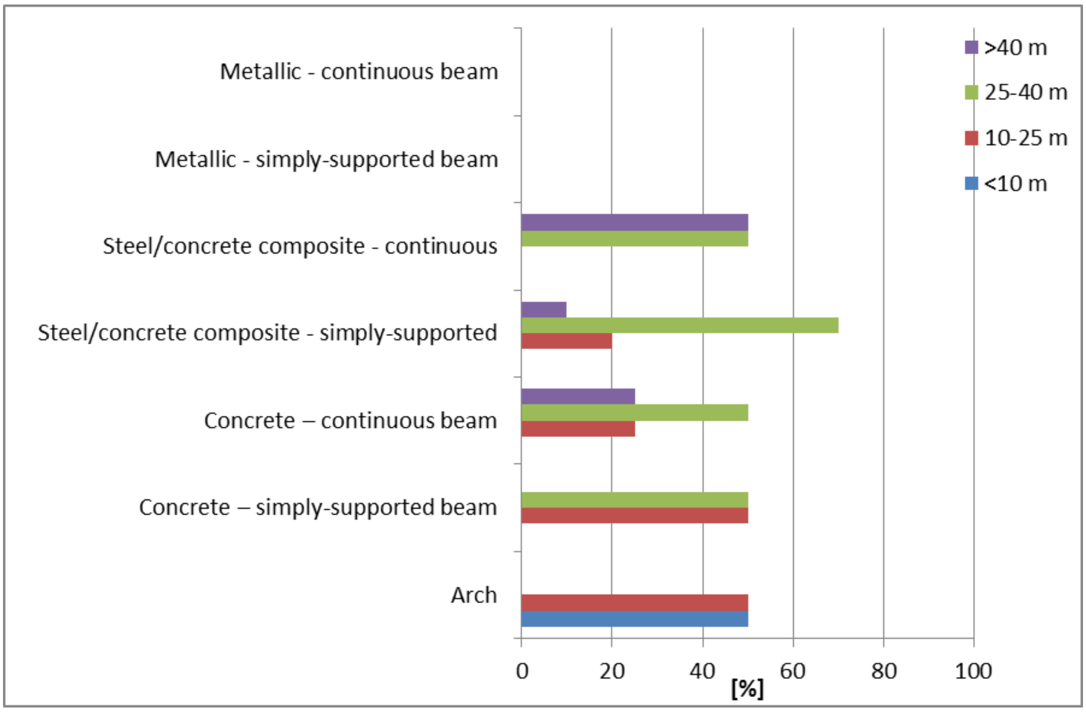
Bridge type	Span range			
	<10 m	10-25 m	25-40 m	>40 m
Arch	80%	20%		
Concrete – simply-supported beam	80%	20%		
Concrete – continuous beam	30%	40%	30%	
Steel/concrete composite - simply-supported	45%	55%		
Steel/concrete composite - continuous	25%	50%	25%	
Metallic - simply-supported beam	30%	40%	30%	
Metallic - continuous beam		60%	30%	10%





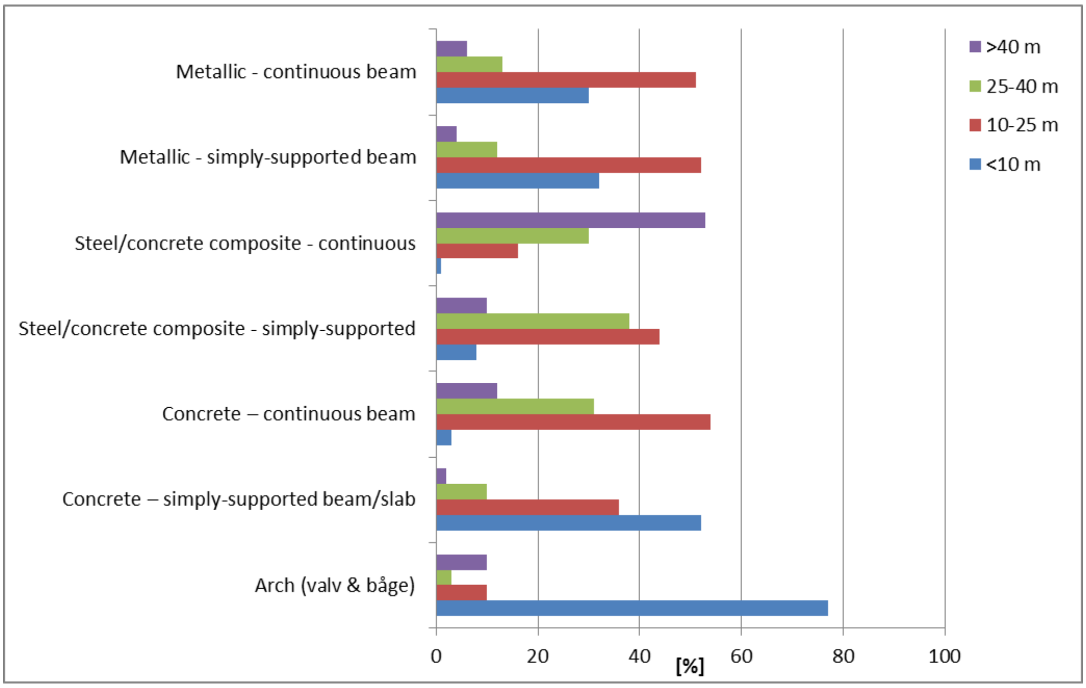
ACL (Spain)

Bridge type	**Span range**			
	<10 m	**10-25 m**	**25-40 m**	**>40 m**
Arch	50%	50%		
Concrete – simply-supported beam		50%	50%	
Concrete – continuous beam		25%	50%	25%
Steel/concrete composite - simply-supported		20%	70%	10%
Steel/concrete composite - continuous			50%	50%
Metallic - simply-supported beam				
Metallic - continuous beam				



TRV (Sweden)

Bridge type	Span range			
	<10 m	10-25 m	25-40 m	>40 m
Arch (valv & båge)	1037(77%)	134(10%)	39(3%)	137(10%)
Concrete – simply-supported beam/slab	1671(52%)	1138(36%)	310(10%)	65(2%)
Concrete – continuous beam	89(3%)	1438(54%)	816(31%)	332(12%)
Steel/concrete composite - simply-supported	34(8%)	181(44%)	156(38%)	39(10%)
Steel/concrete composite - continuous	3(1%)	62(16%)	115(30%)	203(53%)
Metallic - simply-supported beam	153(32%)	248(52%)	57(12%)	17(4%)
Metallic - continuous beam	25(30%)	43(51%)	11(13%)	5(6%)



AHM (Netherlands)

NO information was provided

7. Maintenance issues

The replies obtained for the maintenance issues show the following issues:

The major maintenance problems encountered on bridges (rating from 1 to 5 indicating the frequency and importance of these problems, where 5 is the very frequent problem)

7.1 Superstructure

7.1.1 Pre stressed/post tensioned concrete

ROT (Netherlands)

- Inspection of tendons for corrosion
- measurements of tendons relaxation

ACL (Spain)

- Inspection of tendons for corrosion (3)
- Lack of grouting (2)
- Deck joints maintenance (4)
- Road surface maintenance (3)
- Drainage system cleaning (1)
- Reinforcements design (2)
- Concrete cracks injections (3)
- Anti-corrosion protection paintings (2)
- Tendons anchorage maintenance (3)
- Reparations due to vehicles impacts (3)

TRV (Sweden)

- Inspection of tendons

7.1.2 Reinforced concrete

ROT (Netherlands)

- corrosion of reinforcement

ACL (Spain)

- Deck joints maintenance (4)
- Road surface maintenance (3)
- Drainage system cleaning (1)
- Reinforcements design (2)
- Concrete cracks injections (3)
- Anti-corrosion protection paintings (2)
- Reparations due to vehicles impacts (3)

TRV (Sweden)

- ASR in synergi with frost

7.1.3 Steel/concrete composite

ACL (Spain)

- Deck joints maintenance (4)
- Road surface maintenance (3)
- Drainage system cleaning (1)
- Reinforcements design (2)
- Anti-corrosion protection paintings (4)
- Reparations due to vehicles impacts (1)
- Examination of shear studs (4)
- Temperature deformation control (3)
- Examination of welded seams (3)
- Rough Holes reparation (3)

TRV (Sweden)

- Cracking of the deck over supports

7.1.4 Steel and wrought iron

ROT (Netherlands)

- Fatigue

ACL (Spain)

- Deck joints maintenance (4)
- Road surface maintenance (3)
- Drainage system cleaning (1)
- Anti-corrosion protection paintings (4)
- Reparations due to vehicles impacts (1)
- Temperature deformation control (3)
- Examination of welded seams (3)
- Rough Holes reparation (3)

TRV (Sweden)

- Brittleness
- Corrosion from lack of preventive maintenance
- Fatigue of secondary members

7.1.5 Brick or stone arches

ACL (Spain)

- Road surface maintenance (3)
- Reinforcements design (2)
- Cracks injections (3)
- Reparations due to vehicles impacts (3)

TRV (Sweden)

- Calculation of load-bearing capacity
- Repair methods that do not disrupt traffic

7.2 Substructures

7.2.1 Bearings

ROT (Netherlands)

- difficulty of inspection

ACL (Spain)

- Bearings maintenance (4)
- Bearings substitution (4)
- Anchoraged bearings substitution (5)
- Excessive friction coefficient (4)
- Bearings slide (3)
- Lack of movement (3)

TRV (Sweden)

- Anchorage of the footing plates on older bridges
- Corrosion on older bridges

7.2.2 Abutments

ROT (Netherlands)

- embankment settlement

ACL (Spain)

- Anchorage design at walls (3)
- Embankment settlement (4)
- Insufficient compaction of embankment soil (3)
- Inefficient drainage system (3)

TRV (Sweden)

- Erosion, earth movement and vegetation

7.2.3 Piers/columns

ROT (Netherlands)

- Cracking, chloride, ASR

ACL (Spain)

- Scour at river bridges piers (3)
- Reinforcements design (2)
- Concrete cracks injections (3)
- Anti-corrosion protection paintings (2)
- Reparations due to vehicles impacts (3)

TRV (Sweden)

- Chloride-induced corrosion (De-iceing salts)

7.2.4 Foundations

ROT (Netherlands)

- Settlement, pile bearing capacity, chloride

ACL (Spain)

- Scour at river bridges piers (3)
- Concrete cracks injections in deep foundations (4)
- Compression of natural soil due to embankment loads (4)

TRV (Sweden)

- Calculation of the load-bearing capacity of timber piles

7.2.5 Approach embankments/transition zones/bridge ends

ROT (Netherlands)

- Settlement

ACL (Spain)

- Compression of natural soil due to embankment loads (4)

8. Maintenance activities

The following table indicates approximate proportion of bridge maintenance activities undertaken in the following areas, with regard to the bridge type.

ROT (Netherlands)

Bridge Type	Maintenance activity		
	Rehabilitation	**Strengthening**	**Replacement**
Stone or brick arch	60%	20%	20%
Other arch types			
Concrete	60%	10%	30%
Steel/concrete non-composite	40%	20%	40%
Steel/concrete composite	60%	30%	10%
Metallic	40%	10%	50%

ACL (Spain)

Bridge Type	Maintenance activity		
	Rehabilitation	**Strengthening**	**Replacement**
Stone or brick arch	20%	40%	40%
Other arch types	20%	40%	40%
Concrete	20%	60%	20%
Steel/concrete non-composite	50%	25%	25%
Steel/concrete composite	50%	25%	25%
Metallic	50%	25%	25%

TRV (Sweden)

Bridge Type	Maintenance activity		
	Rehabilitation	**Strengthening**	**Replacement**
Stone or ~~brick~~ arch	30%	0%	70%
Other arch types	30%	20%	50%
Concrete	18%	2%	80%
Steel/concrete non-composite	0%	0%	0%
Steel/concrete composite	0%	0%	0%
Metallic	40%	5%	55%

In this table:

"Rehabilitation" means returning the bridge as nearly as possible to its original condition and carrying capacity.

"Strengthening" means improving the carrying capacity beyond that for which the bridge was originally designed.

"Replacement" means either the replacement of the superstructure or the total replacement of the bridge, either in its original position or in a new position.

8.1 Rehabilitation activities

For rehabilitation activities, the approximate percentage break down of the activities undertaken (by volume or cost), and also the priority order (most important scored 5) of the various activities are indicated in the following table:

ROT (Netherlands)

Rehabilitation Activity	%	Priority
Embankment remediation at bridge ends		1
Underpinning of foundations		2
Patch repair of damaged brick or masonry		2
Stitching of masonry (*Fondedile type*)		2
Patch repair of corroded metalwork		2
Patch repair of metalwork due to fatigue		5
Painting of metalwork		1
Repair of concrete deck in steel/concrete bridges		4
Repair of steel decks		5
Waterproofing		4
Bearing replacement		2

ACL (Spain)

Rehabilitation Activity	%	Priority
Embankment remediation at bridge ends	2	3
Underpinning of foundations	2	3
Patch repair of damaged brick or masonry	2	1
Stitching of masonry (*Fondedile type*)	2	1
Patch repair of corroded metalwork	8	3
Patch repair of metalwork due to fatigue	8	2
Painting of metalwork	8	2
Repair of concrete deck in steel/concrete bridges	35	4
Repair of steel decks	15	3
Waterproofing	8	4
Bearing replacement	10	3

TRV (Sweden)

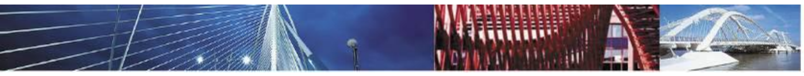
Rehabilitation Activity	%	Priority
Embankment remediation at bridge ends	20	
Underpinning of foundations	1	
Patch repair of damaged brick or masonry	5	
Stitching of masonry (*Fondedile type*)	0	
Patch repair of corroded metalwork	2	
Patch repair of metalwork due to fatigue	2	
Painting of metalwork	20	
Repair of concrete deck in steel/concrete bridges	0	
Repair of steel decks	0	
Waterproofing	10	
Bearing replacement	1	
Concrete repair	15	
Replacement of deck	20	

AHM (Netherlands)

Rehabilitation Activity	%	Priority
Embankment remediation at bridge ends	10	
Underpinning of foundations	0	
Patch repair of damaged brick or masonry	60	
Stitching of masonry (*Fondedile type*)		
Patch repair of corroded metalwork	20	
Patch repair of metalwork due to fatigue	20	3
Painting of metalwork	25	4
Repair of concrete deck in steel/concrete bridges	10	
Repair of steel decks		
Waterproofing		
Bearing replacement		

8.2 Strengthening activities

For strengthening activities, the approximate percentage break down of the activities undertaken (by volume or cost), and also the priority order (most important scored 5) of the various activities are indicated in the following table:



ROT (Netherlands)

Strengthening Activity	%	Ranking
Strengthening of the foundation		3
Reinforcement of arches		2
External pre-stressing – concrete bridges		4
External pre-stressing – metallic bridges		
Increasing section – concrete bridges		
Increasing section – steel bridges		
Strength. deck in steel/conc. composite bridges		5
FRP strengthening-steel		
FRP strengthening-concrete		
Replacement of metallic structural members		
Additional reinforcement		5
Additional metallic structural members		4
Replacement of the deck		5
Widening of the deck		1
Fatigue prevention		3

ACL (Spain)

Strengthening Activity	%	Ranking
Strengthening of the foundation	10	4
Reinforcement of arches	2	2
External pre-stressing – concrete bridges	2	2
External pre-stressing – metallic bridges	2	2
Increasing section – concrete bridges	2	2
Increasing section – steel bridges	2	2
Strength. deck in steel/conc. composite bridges	5	4
FRP strengthening-steel	10	3
FRP strengthening-concrete	30	3
Replacement of metallic structural members	2	2
Additional reinforcement	10	3
Additional metallic structural members	10	3
Replacement of the deck	2	4
Widening of the deck	10	3
Fatigue prevention	1	2

TRV (Sweden)

Strengthening Activity	%	Ranking
Strengthening of the foundation	1	
Reinforcement of arches	10	
External pre-stressing – concrete bridges	0	
External pre-stressing – metallic bridges	1	
Increasing section – concrete bridges	1	
Increasing section – steel bridges	2	
Strength. deck in steel/conc. composite bridges	0	
FRP strengthening-steel	0	
FRP strengthening-concrete	3	
Replacement of metallic structural members	5	
Additional reinforcement	1	
Additional metallic structural members	3	
Replacement of the deck	70	
Widening of the deck	0	
Fatigue prevention	3	

AHM (Netherlands)

No information was provided

9. Needs and priorities

With regard to the maintenance (strengthening) activities for existing bridges in densely populated areas some specific requirements have often to be considered. The importance of the demands by ranking from one to five (5 being the most important) is indicated in the following table.

9.1 Demands for the maintenance (strengthening) activities of existing bridges in densely populated areas

ROT (Netherlands)

Demands for the maintenance (strengthening) activities of existing bridges in densely populated areas	Ranking
Operation time	5
Minimizing the environmental impact on the surrounding environment	1
Minimizing traffic disruption during maintenance	5
Long-term performance	2
Ease of application	4
Initial costs	4
Future maintenance costs	3
Life cycle costs (the same question here)	3
Other demands not mentioned above?	

ACL (Spain)

Demands for the maintenance (strengthening) activities of existing bridges in densely populated areas	Ranking
Operation time	3
Minimizing the environmental impact on the surrounding environment	3
Minimizing traffic disruption during maintenance	4
Long-term performance	3
Ease of application	4
Initial costs	5
Future maintenance costs	5
Life cycle costs (the same question here)	3
Other demands not mentioned above? Geometrical limitations Suitable and available materials Affected services Traffic requirements	

TRV (Sweden)

Demands for the maintenance (strengthening) activities of existing bridges in densely populated areas	Ranking
Operation time ?	
Minimizing the environmental impact on the surrounding environment	
Minimizing traffic disruption during maintenance	Part of the LCC
Long-term performance	Part of the LCC
Ease of application ?	
Initial costs	Part of the LCC
Future maintenance costs	Part of the LCC
Life cycle costs (the same question here)	5
Other demands not mentioned above?	

AHM (Netherlands)

Demands for the maintenance (strengthening) activities of existing bridges in densely populated areas	Ranking
Operation time	3
Minimizing the environmental impact on the surrounding environment	5
Minimizing traffic disruption during maintenance	2
Long-term performance	5
Ease of application	5
Initial costs	1
Future maintenance costs	4
Life cycle costs (the same question here)	5
Other demands not mentioned above?	

9.2 Demands for new strengthening techniques/methods for existing bridges in densely populated areas

ROT (Netherlands)

Demands for new strengthening techniques/methods for existing bridges in densely populated areas	Ranking
Application time (in connection with lane closure)	5
Minimizing the environmental impact on the surrounding environment	3
Minimizing traffic disruption	5
Minimizing the impact on the surrounding (noise, dust) from construction site activities	4
Long-term performance	3
Ease of application	1
Initial costs	2
Future maintenance costs	3

ACL (Spain)

Demands for new strengthening techniques/methods for existing bridges in densely populated areas	Ranking
Application time (in connection with lane closure)	4
Minimizing the environmental impact on the surrounding environment	2
Minimizing traffic disruption	2
Minimizing the impact on the surrounding (noise, dust) from construction site activities	2
Long-term performance	2
Ease of application	4
Initial costs	5
Future maintenance costs	4

TRV (Sweden)

Demands for new strengthening techniques/methods for existing bridges in densely populated areas	Ranking
Application time (in connection with lane closure)	
Minimizing the environmental impact on the surrounding environment	
Minimizing traffic disruption	5
Minimizing the impact on the surrounding (noise, dust) from construction site activities	2
Long-term performance	5
Ease of application	
Initial costs	4
Future maintenance costs	3

AHM (Netherlands)

Demands for new strengthening techniques/methods for existing bridges in densely populated areas	Ranking
Application time (in connection with lane closure)	5
Minimizing the environmental impact on the surrounding environment	5
Minimizing traffic disruption	2
Minimizing the impact on the surrounding (noise, dust) from construction site activities	5
Long-term performance	4
Ease of application	5
Initial costs	3
Future maintenance costs	1

10. Lifecycle issues of urban projects

Use, including reuse and recycling, of resources (materials, energy, waste production) is of importance for sustainability of the built environment. The following table shows if these issues are taken into account in planning and design of bridges?

ROT (Netherlands)

Topics taken into account in planning/design/decision making	Ranking
Total use of material	4
Global heating potential/emission of CO2	4
Use of virgin material versus use of recycled materials	3
Energy use in construction process, type of energy	2
Emissions to water (which not require a permit)	1
Use of hazardous materials	5
Waste production – possibilities to reuse and recycle materials	2

ACL (Spain)

Topics taken into account in planning/design/decision making	Ranking
Total use of material	3
Global heating potential/emission of CO2	1
Use of virgin material versus use of recycled materials	2
Energy use in construction process, type of energy	3
Emissions to water (which not require a permit)	2
Use of hazardous materials	3
Waste production – possibilities to reuse and recycle materials	4

1.1.1 TRV (Sweden)

NO information was provided

1.1.2 AHM (Netherlands)

Topics taken into account in planning/design/decision making	Ranking
Total use of material	5
Global heating potential/emission of CO2	2
Use of virgin material versus use of recycled materials	1
Energy use in construction process, type of energy	3
Emissions to water (which not require a permit)	4
Use of hazardous materials	7
Waste production – possibilities to reuse and recycle materials	6

The construction process is of importance for people's health and well-being, and includes processes with energy and material use, and emissions to air, water and soil. The effect of disturbances and potential environmental impacts are taken into account based on the following.

ROT (Netherlands)

Topics taken into account in planning/design/decision making	Yes/No	Ranking
Transport to and from the construction site	YES	5
Potential noise/vibration from construction site	YES	4
Dust from construction activities and transportations	NO	2
Accessibilities to surrounding, barriers, for the nearby people	YES	3

ACL (Spain)

Topics taken into account in planning/design/decision making	Yes/No	Ranking
Transport to and from the construction site	YES	4
Potential noise/vibration from construction site	YES	2
Dust from construction activities and transportations	YES	2
Accessibilities to surrounding, barriers, for the nearby people	YES	3

TRV (Sweden)

NO information was provided

AHM (Netherlands)

Topics taken into account in planning/design/decision making	Yes/No	Ranking
Transport to and from the construction site	YES	
Potential noise/vibration from construction site	YES	
Dust from construction activities and transportations		1
Accessibilities to surrounding, barriers, for the nearby people		2

APPENDIX 2

Demography of railway bridges in Europe

Low-disturbance sustainable urban construction

PANTURA

APPENDIX 2

Demography of railway bridges in Europe

Type of report, Version, 28 December 2011

Colophon

This publication is produced by Pantura work group:
The main author is: Reza Haghani (CTH)
Co-authors are: Pawel Poneta (MOS), Juliana Patino (ACC)

Recommended publication reference:

The Pantura project is co-financed by the European Commission with contract No.: 265172.

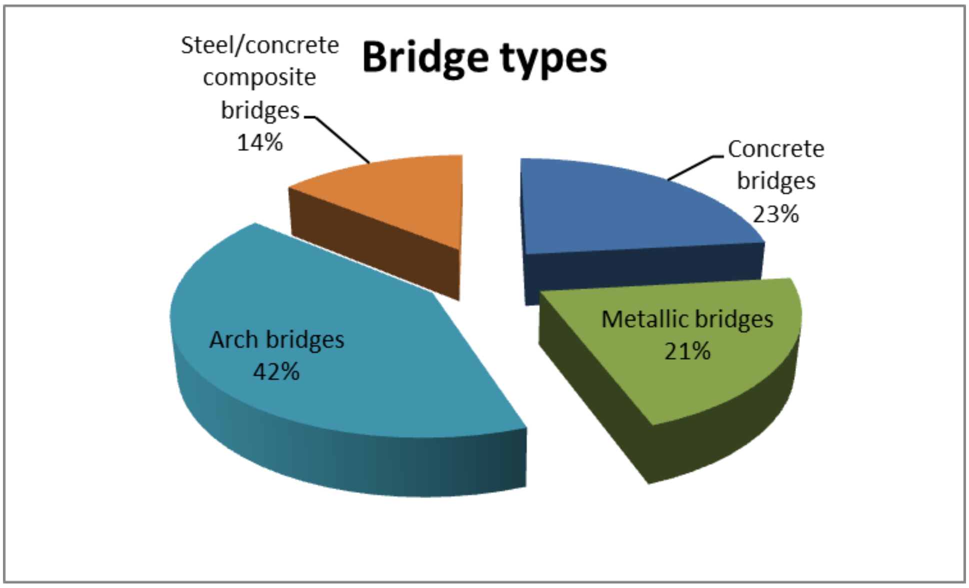
Table of contents

1. Results of survey on European railway bridges from "Sustainable bridges" project (2003-2006) [1]

1.1. Bridge types

Overall, nearly 23% of the bridges surveyed are of concrete construction, 21% are metallic, 41% are arches and 14% have steel/concrete composite or encased beams construction. These figures are broken down in more detail below. From the returns, it was not possible to determine material type for some 2,400 bridges, which is about 1% of the total number of bridges included in the survey. This very low rate of error means that the data presented below can be considered to truly reflect the European railway bridge stock.

Bridge type	Number	Precentage [%]
concrete	50000	23%
metallic	47,000	21%
arches	90,000	41%
steel/concrete composite	30,000	14%



(a) Concrete

The survey contains data relating to almost 50,000 concrete bridges. It shows that 78% of concrete bridges are classified as reinforced and 21% are either pre stressed or post tensioned. For a small number of bridges it was not possible to determine from the returns the sub type within the overall concrete category.

Bridge type	Number	Precentage [%]
Reinforced concrete		78%
Pre-stressed or post tensioned		21%
Other		1%

(b) Metal

The survey contains data relating to just over 47,000 metallic bridges. It shows that 3% of metallic bridges are cast iron, nearly 25% are wrought iron and almost 53% are steel. For 21% it was not possible to determine from the returns the sub type within the overall metallic category, but it can be assumed that the split would be similar to the percentages quoted above for each sub type.

Bridge type	Number	Precentage [%]
Cast iron		3%
Wrought iron		21%
Steel		53%
Other		21%*

- The summation of pre cents would be 102%.

(c) Arches

The survey contains data relating to nearly 90,000 arch bridges. It shows that 52% have brick arch barrels and 33% have stone barrels. The remaining 15% either have concrete barrels, or the construction material was not specified by the respondent. It is probably reasonable to assume that concrete barrels will equate to no more than 5% of the total, with the remaining 10% split 52:33 between brick and stone.

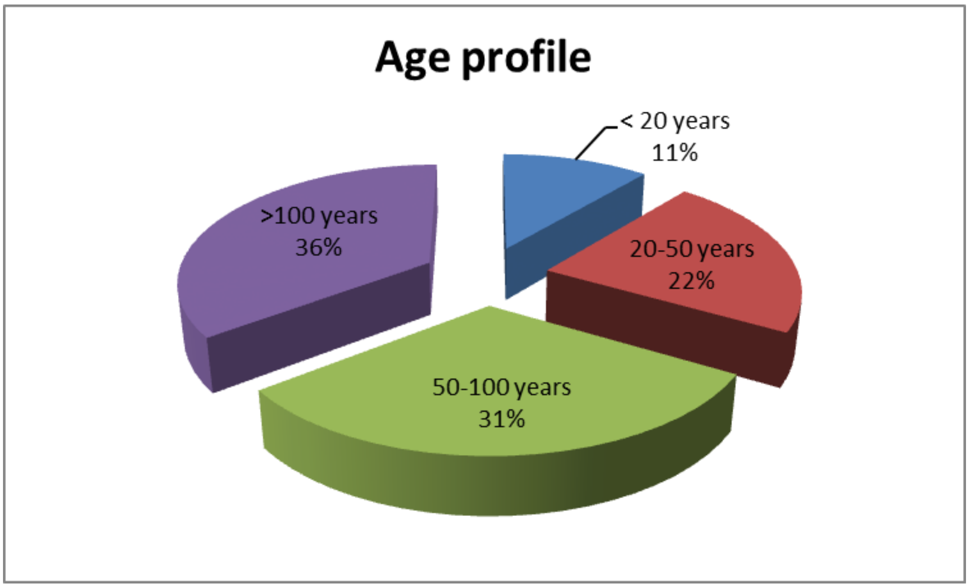
Bridge type	Number	Precentage [%]
brick arch barrel		52%
stone barrel		33%
Other		15%

(d) Steel/concrete and encased beam

The survey contains data relating to over 30,000 steel/concrete or encased beam bridges. This data has not been split down between these two sub types.

1.2. Bridge age profile

Overall, nearly 11% of the bridges surveyed are less than 20 years old, 22% are be-tween 20 and 50 years old, 31% are between 50 and 100 years old and 35% are over 100 years old. These figures are broken down in more detail below.



(a) Concrete bridges

The survey shows that 25% of concrete bridges are less than 20 years old, 55% are between 20 and 50 years old, 16% are between 50 and 100 years old and 4% are over 100 years old.

(b) Metallic bridges

The survey shows that 10% of metallic bridges are less than 20 years old, 22% are between 20 and 50 years old, 40% are between 50 and 100 years old and 28% are over 100 years old.

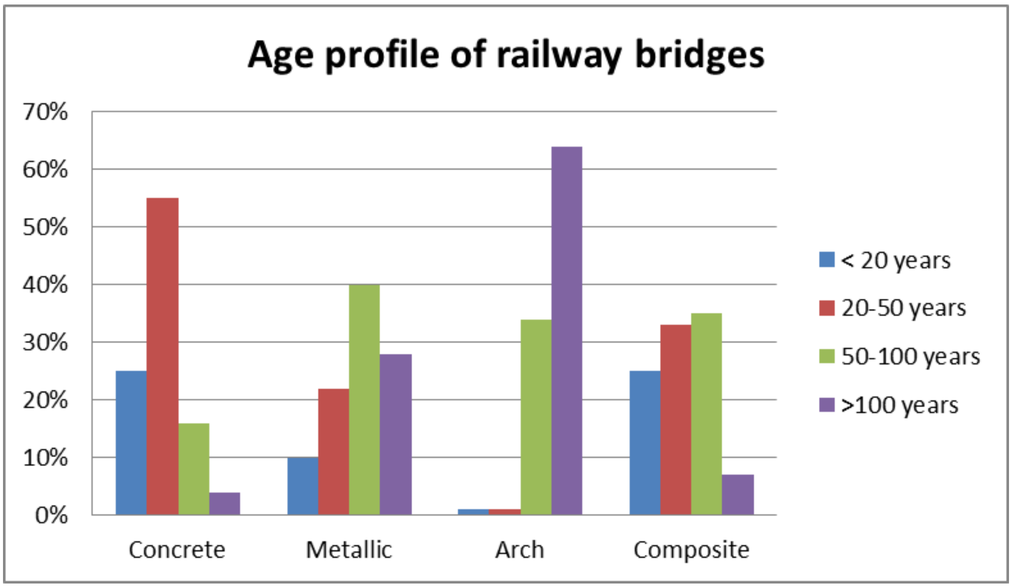
(c) Arch bridges

The survey shows that 1% are less than 20 years old, 1% are between 20 and 50 years old, 34% are between 50 and 100 years old and 64% are over 100 years old.

(d) Steel/concrete and encased beam bridges

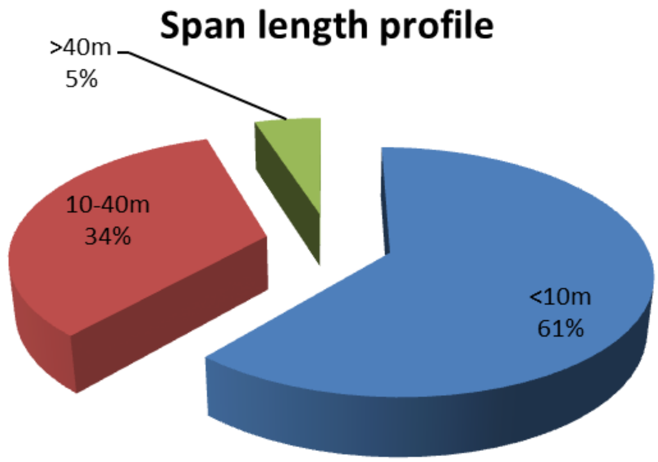
The survey shows that 25% are less than 20 years old, 33% are between 20 and 50 years old, 35% are between 50 and 100 years old and 7% are over 100 years old.

Bridge type	<20	20-50	50-100	>50
Concrete	25%	55%	16%	4%
Metallic	10%	22%	40%	28%
Arch	1%	1%	34%	64%
Steel/concrete composite	25%	33%	35%	7%



1.3. Bridge span profile

In dealing with spans, the data requested specified the size of individual spans in multi span bridges, rather than the full length of such bridges. Overall, nearly 62% of the bridges surveyed span less than 10m, 34% span between 10m and 40m and 5% have spans greater than 40m. These figures are broken down in more detail below.



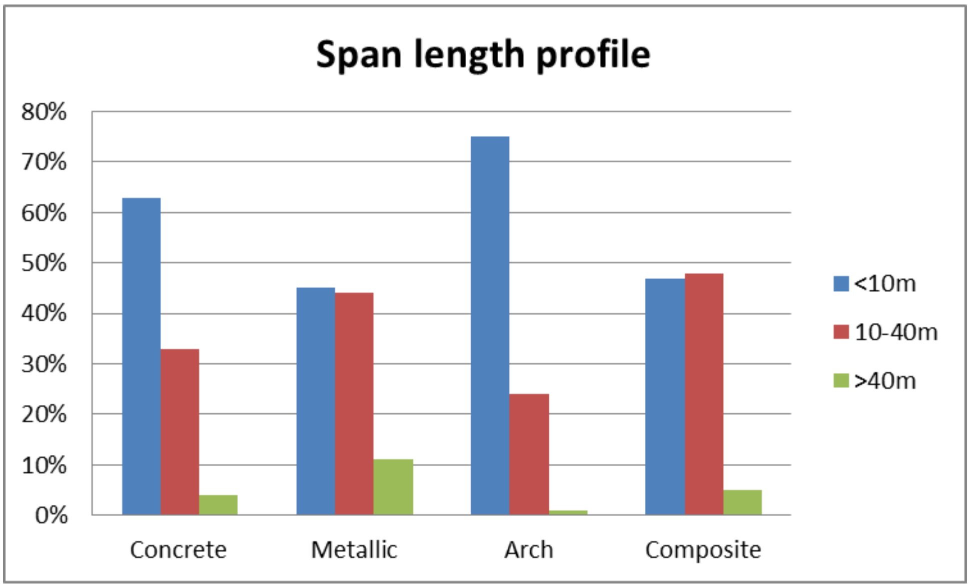
(a) Concrete bridges The survey shows that 63% of concrete bridges span less than 10m, 33% span be-tween 10m and 40m and 4% have spans greater than 40m.

(b) Metallic bridges The survey shows that 45% of metallic bridges span less than 10m, 44% span be-tween 10m and 40m and 11% have spans greater than 40m.

(c) Arch bridges The survey shows that 75% span less than 10m, 24% span between 10m and 40m and 1% have spans greater than 40m.

(d) Steel/concrete and encased beam bridges The survey shows that 47% span less than 10m, 48% span between 10m and 40m and 5% have spans greater than 40m.

Bridge type	**<10 m**	**10 m-40 m**	**>40 m**
Concrete	63%	33%	4%
Metallic	45%	44%	11%
Arch	75%	24%	1%
Steel/concrete composite	47%	48%	5%



References

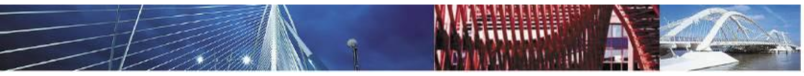
[1] D1.2 European Railway Bridge Demography, Sustainable Bridges – Assessment for Future Traffic Demands and Longer Lives, WP1-02-T-040601-F-Deliverable D 1.2, 2003-2007.

APPENDIX 3

Management of bridges in Sweden

Low-disturbance sustainable urban construction

PANTURA



PANTURA

APPENDIX 3

Management of bridges in Sweden

Type of report, Version, 28 December 2011

Colophon

This publication is produced by Pantura work group: WP5

The main author is: Reza Haghani (CTH)

Co-authors are: Pawel Poneta (MOS), Juliana Patino (ACC)

Recommended publication reference:

SEVENTH FRAMEWORK PROGRAMME

The Pantura project is co-financed by the European Commission with contract No.: 265172.

Table of contents

1. Background

Transport and communication network in Sweden consists of 13642 km railway and 98400 km roadway [1]. When terrain is not suitable for roadway and railway, bridges have been built to enable to communication and transport.

In Sweden a bridge must have a span of at least 3 meters to be called a bridge. This definition applied until 1998. Many pipe bridges, built of steel, were not categorized as a bridge according to this definition since most of them have a span of less that this limit. Therefore, they were not maintained and inspected according to bridge standards. In 1998 the definition of the bridge was changed and the new bridge definition specified a span of 2 meter. In USA a bridge shall have a span of 6 meter to be called a bridge [2].

The change of the definition caused an increase in number of bridges. Figure 1 shows the number of roadway bridges managed by former Vägverket (called Trafikverket today) between 1995 and 2003. In 1998 the number bridges increased by 2500 because of the new definition [2].

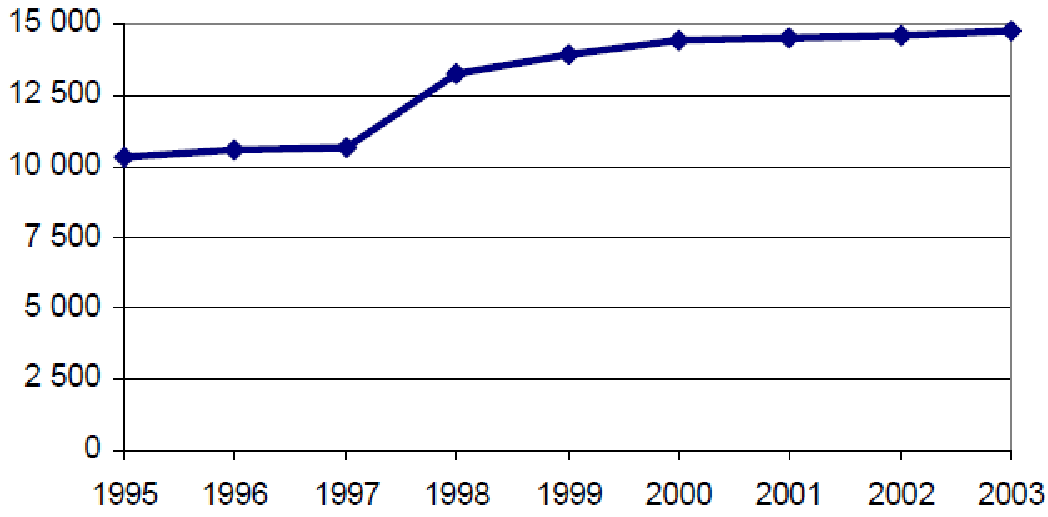


Figure 1Number of roadway bridges managed by former Vägverket (Swedish traffic Administration, TRV) [2].

2. BaTMan

In order to manage the bridges in Sweden, TRV developed software program called BaTMan (Bridge and Tunnel management, 2004). BaTMan has about 600 users and about 27000 bridges plus 3000 other constructions. These bridges are owned by TRV, 71 communes and private organizations and persons [16], however, Swedish traffic administration is the main owner of bridges in Sweden. Different information such as drawings, inspection reports and planning documents for each bridge could be found in BaTMan [16]. TRV has divided its working district in 5 regions for railway bridges and 6 regions for roadway bridges to manage them effectively. These regions are; (Table 1)

Table 1 Different districts, TRV [3].

TRV-working districts	
TRV-Railway bridges	**TRV-Roadway bridges**
TRV-Middle	TRV -Middle
TRV -East/Stockholm	TRV -East
TRV -North	TRV -Stockholm
TRV -South	TRV -North
TRV -West	TRV -South
	TRV -West

Figure 2 shows distribution of the bridges with regard to owner. In this Figure distribution of bridges owned by private persons or organization is not included. Table 2 shows the number of bridges owned by Swedish traffic administration and communes.

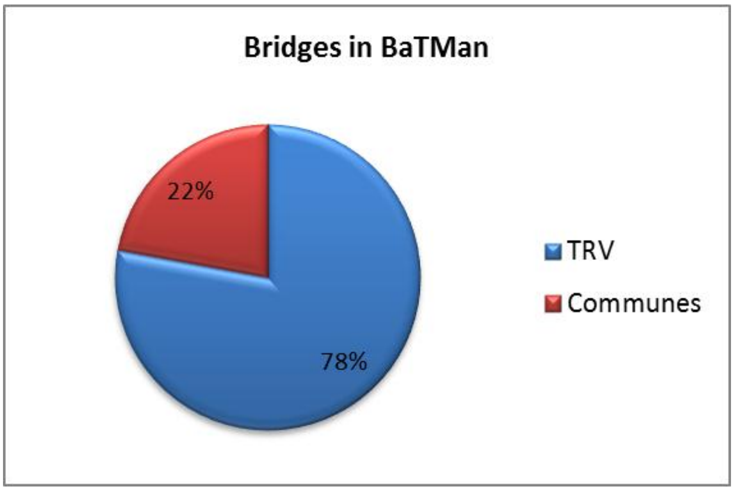


Figure 2 Distribution of the bridges in BaTMan with regard to owner [3].

Figure 3 shows distribution of roadway and railway bridges owned by TRV. It can be seen that most of the bridges in this category are roadway bridges.

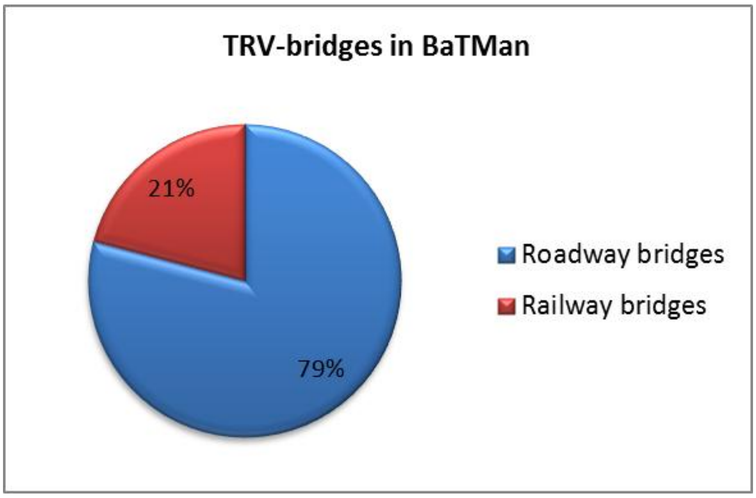


Figure 3 Distribution of the road- and railway bridges owned by TRV and registered in BaTMan [3].

Table 2 Number of bridges with regard to owners

Owner	Number of bridges
Trafikverket Roadway bridges	15951
Trafikverket Railway bridges	4217
Communes	5727

3. Age profile of bridges in Sweden

In Sweden, 53% of TRV´s railway bridges and 36% of roadway bridges are older than 50 years. Figure 4 and 5 show age distributions of bridges owned by TRV for railway bridges and roadway bridges, respectively.

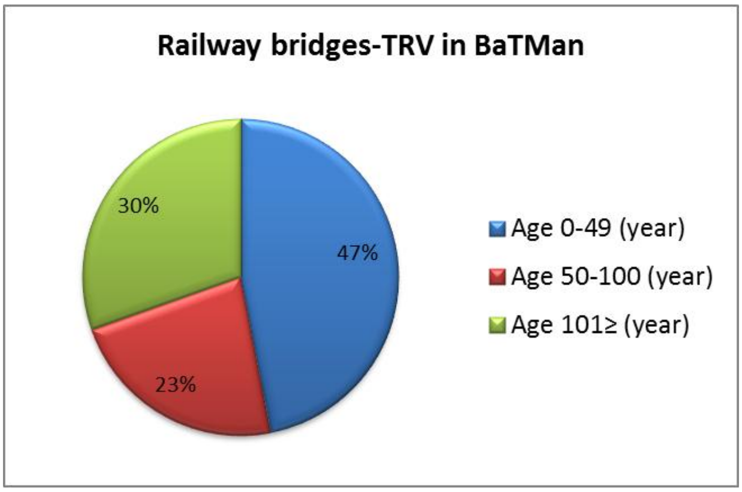


Figure 4 Age distribution of railway bridges owned by TRV [3].

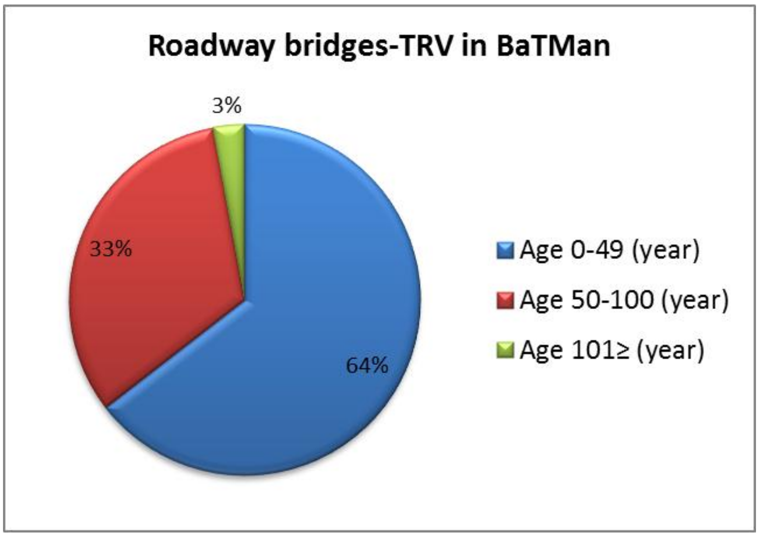


Figure 5 Age distribution of roadway bridges owned by TRV [3].

Age profile for railway- and roadway bridges owned by communes (registered in BaTMan) is presented in Figure 6. It can be seen that 32% of the bridges are older than 50 years.

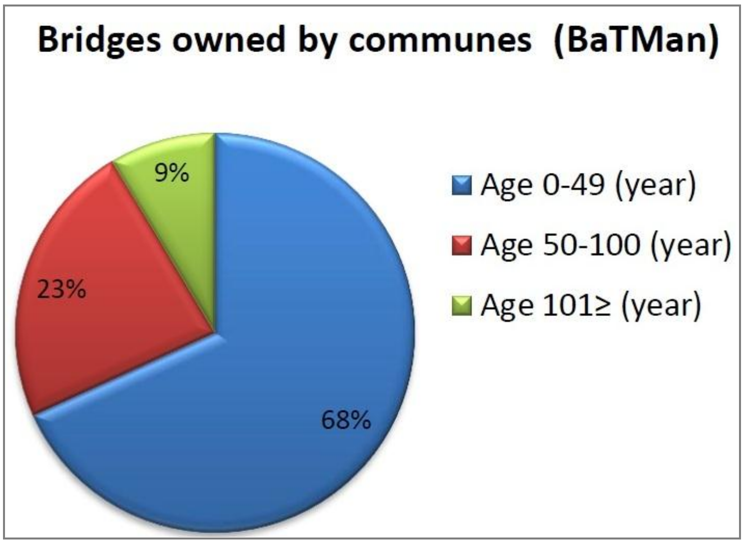


Figure 6 Age distribution of bridges owned by communes [3].

4. Condition of existing bridges in Sweden

As can be seen, many bridges in Sweden are older than 50 years and according to information obtained from BaTMan, have some type of damage and require continuous maintenance and repair or strengthening.

In Sweden, condition classes are used to describe the condition of an existing bridge. Table 3 shows the description of condition classes.

Table A2.3 Classification of the condition of bridges in Sweden [2,4].

Condition class	Definition
0	Failure beyond 10 years
1	Failure within 10 years
2	Failure within 3 years
3	Failure at inspections time

The condition classes are used as indicators for bridge management process. For example, if damage in a structural member is categorized as class 3, this damage and its effect on the structure should be investigated in maximum 3 months and suitable action should be taken [2]. Table 4 and 5 show the number of railway and roadway bridges in different regions with condition class 3, respectively.

Table 4 Number of railway bridges with condition class 3 [3].

Roadway Bridges	Classification of function (condition class 3)				
Owner /manager	Durability	Bearing	Traffic safety	Other	Total
TRV-Middle	59	54	58	16	187
TRV-North	44	40	45	8	137
TRV-Stockholm	155	94	70	35	354
TRV-South	114	19	24	20	177
TRV-West	343	55	96	66	560
TRV-East	108	68	57	26	259
Total	823	330	350	171	1674

It can be concluded that Region West has most problem or damaged members to be repaired or strengthened.

Table A2.5 Number of roadway bridges with condition class 3 [3].

Railway Bridges	Classification of function (condition class 3)				
Owner/manager	Durability	Bearing	Traffic safety	Other	Total
TRV-Middle	42	41	31	15	129
TRV-East/Stockholm	17	72	14	6	109
TRV-North	1	4	3	5	13
TRV-South	59	55	39	58	211
TRV-West	106	129	124	143	502
Total	225	301	211	227	964

5. Investments and costs

Figure 7 shows distribution of investment made by TRV between years 1999-2009 for new and existing constructions. TRV spent 8 billion SEK to build new roadway bridges and 66 billion SEK for improvement, maintenance and etc. to keep roadway bridges service.

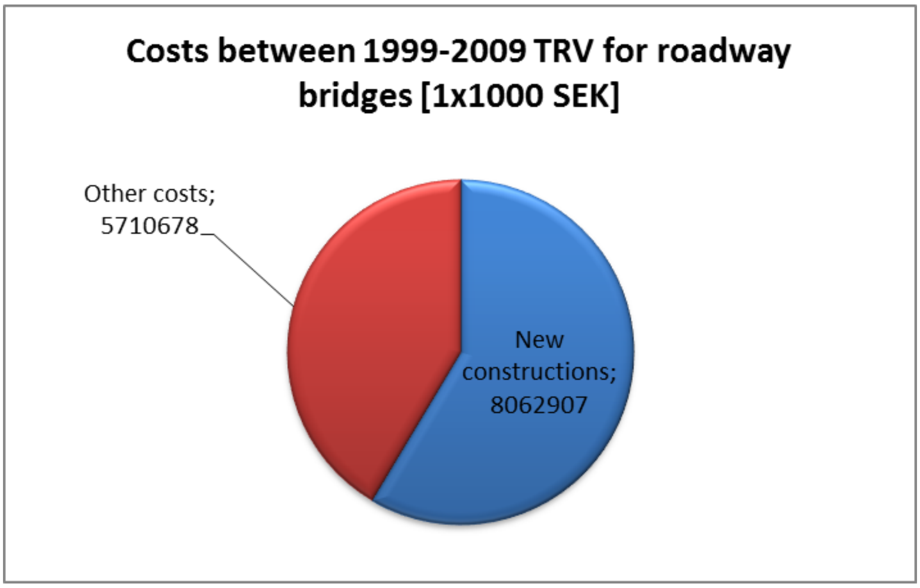
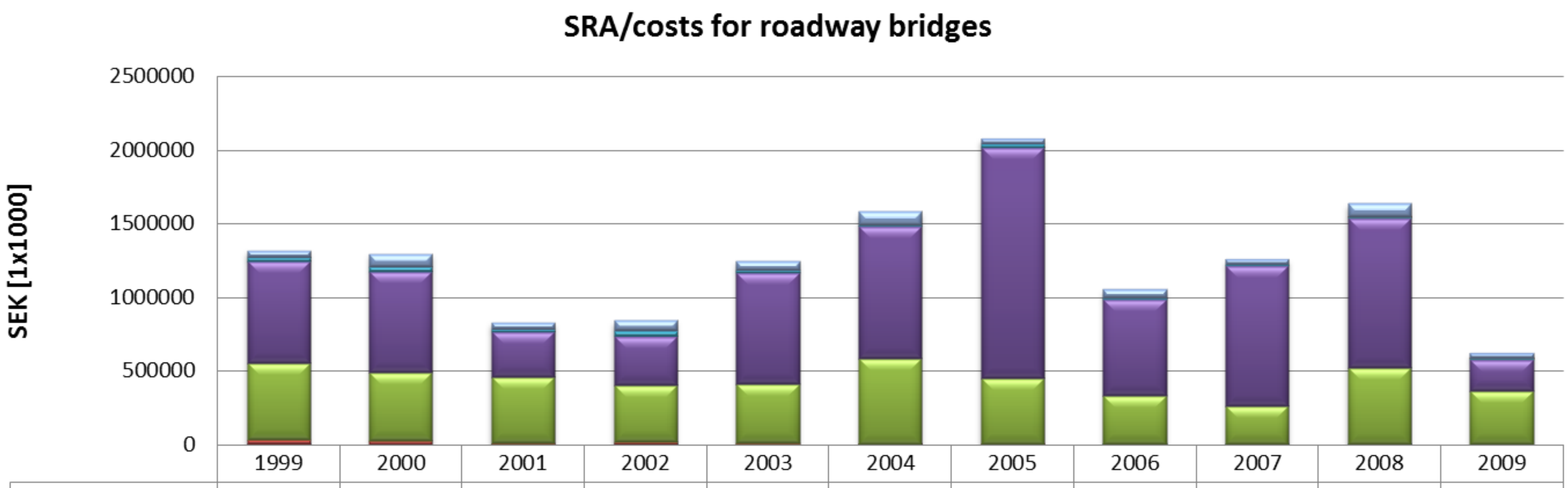


Figure 7 Investment distribution made by TRV for roadway bridges [3].

The cost breakdown for roadway bridges is shown in Figure 8.



	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Improvement	47389	88068	47238	71975	63424	95251	36383	57890	36432	90849	34426
Other costs	0	0	0	0	0	0	0	0	0	14	151
Road measure	29697	35015	17132	33085	18396	9230	23072	10645	8597	7653	7945
New construction	687720	684165	312228	333617	749781	890271	1569435	652883	950174	1018231	214402
Maintenance	523458	459560	448844	381397	402445	587107	448942	332133	264125	520084	365458
Removing	27868	28246	6746	20205	13307	927	50	0	0	0	0
Service	4350	0	121	1759	0	249	0	2006	681	653	0

Figure 8 Cost breakdown of the investment done by TRV during 1999 to 2009 on roadway bridges [3].

The investment distribution for the railway bridges is shown in Figure 9

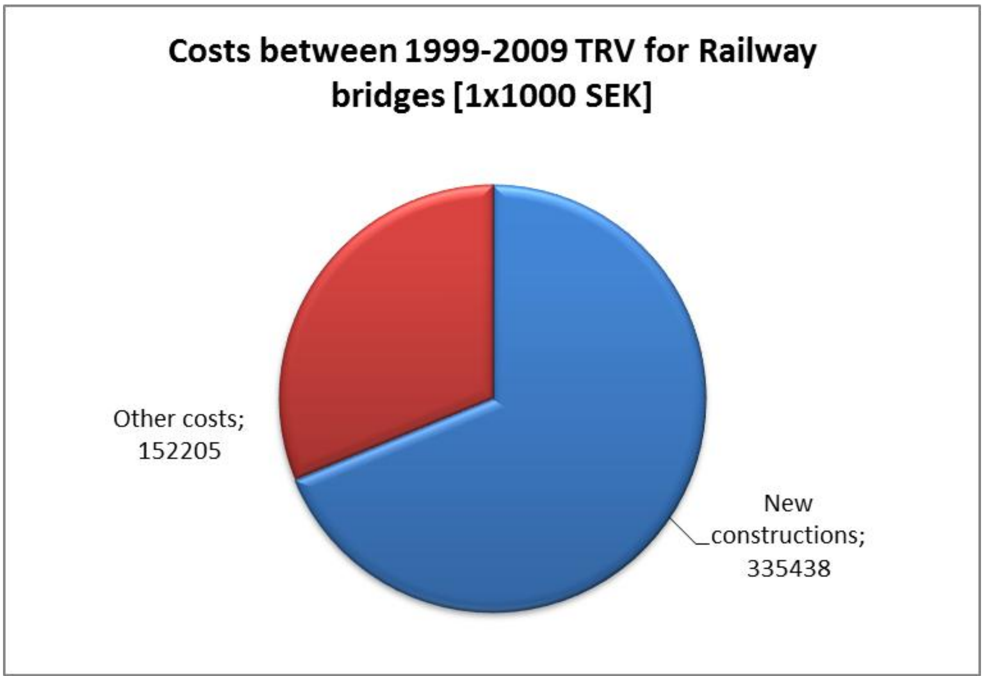
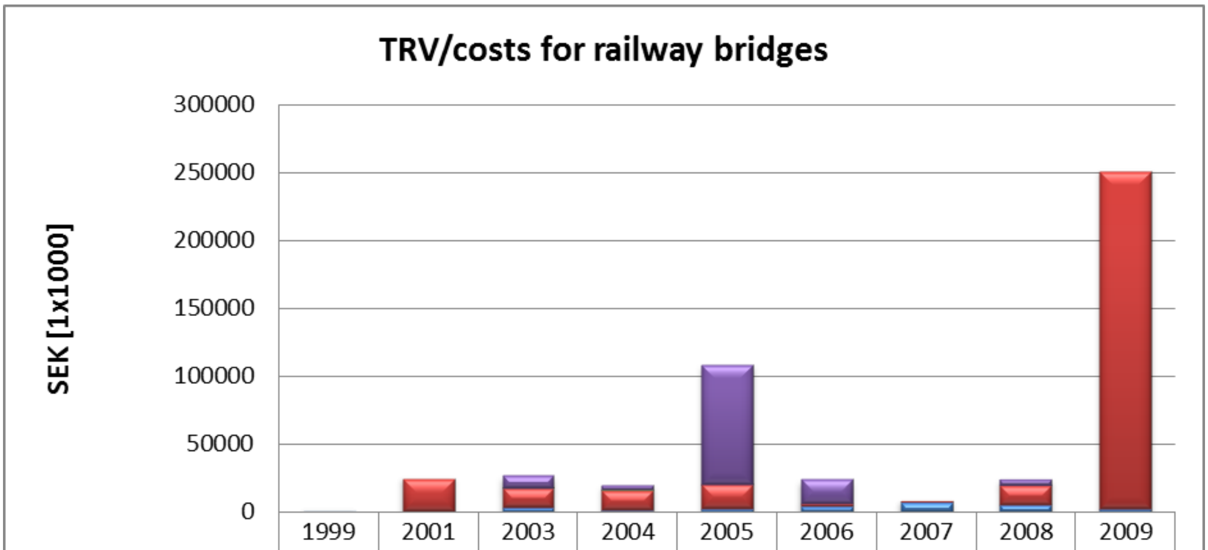


Figure 9 Investment distribution made by TRV for railway bridges [3].

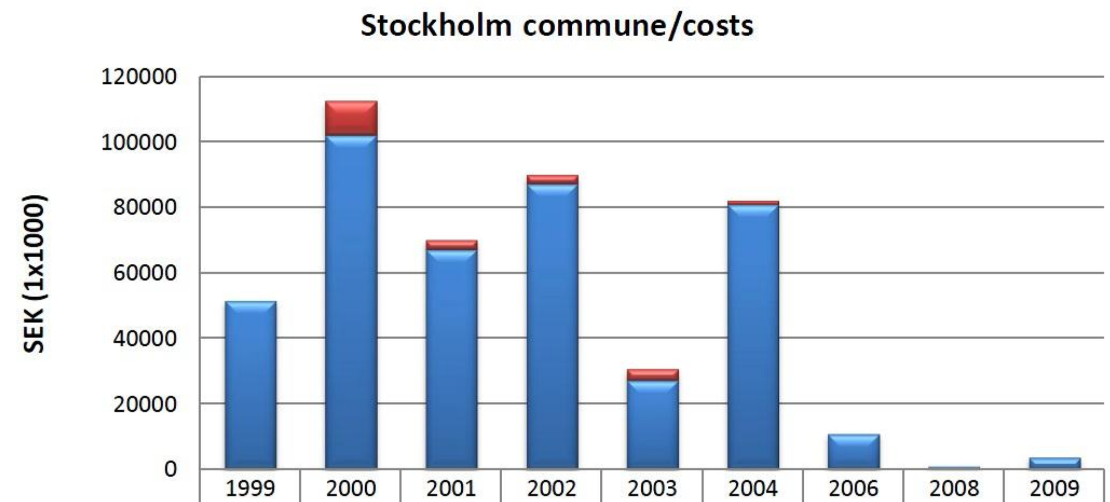
The cost breakdown for railway bridges is shown in figure A2.10.



	1999	2001	2003	2004	2005	2006	2007	2008	2009
Improvement	0	0	9440	3559	88420	17970	0	4343	0
Road measure	0	0	157	743	0	0	0	0	0
New construction	0	23557	13970	14480	17548	2006	1107	14395	248375
Maintenance	661	1010	3267	1162	2474	4136	6999	5557	2307

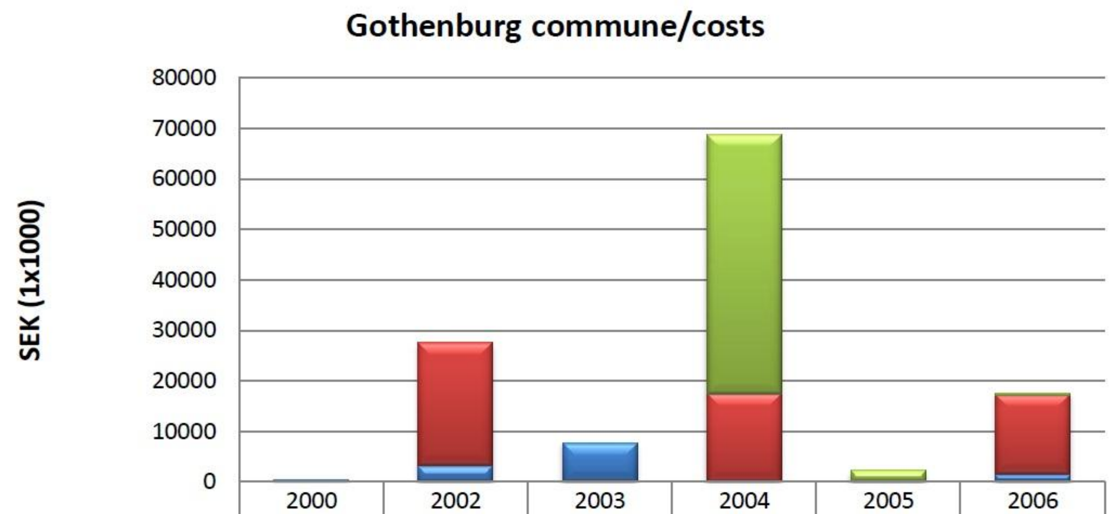
Figure 10 Cost breakdown of the investment done by TRV during 1999 to 2009 on railway bridges [3].

Figures A2.11 and A2.12 present the investment made by Stockholm and Gothenburg communes for both railway and roadway bridges, respectively.



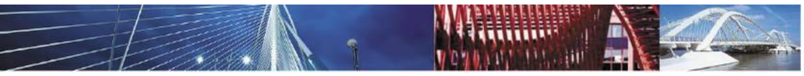
	1999	2000	2001	2002	2003	2004	2006	2008	2009
Improvement	0	10454	2928	2779	3534	1133	0	0	0
Maintenance	51431	102217	67206	87275	27165	80974	10838	943	3610

Figure 11 Investment distribution made by Stockholm commune for road and railway bridges [3].



	2000	2002	2003	2004	2005	2006
Improvement	0	0	0	51354	2244	433
New construction	0	24324	0	17370	0	15783
Maintenance	477	3237	7718	0	0	1408

Figure 12 Investment distribution made by Gothenburg commune for road and railway bridges [3].



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[1] Silfwerbrand J., Sundquist H., (2001), Drift, underhåll och reparation av konstbyggnader, Kungliga Tekniska Högskolan, 2001.

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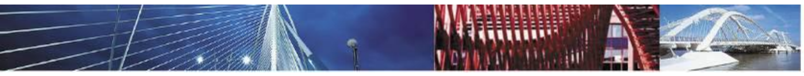
APPENDIX 4

Experience from concluded or on-going projects regarding the complexities and problems encountered during construction work.

Low-disturbance sustainable urban construction

PANTURA



Colophon

This publication is produced by Pantura work group: WP5

The main author is: Reza Haghani (CTH)

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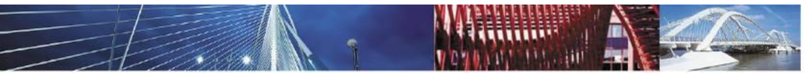

Table of contents

1. Introduction

The need for bridges maintenance and rehabilitation is increasing at present as the existing structures are near the end of their service life. Besides, other factors such as new codes requirements and other design deficiencies make the retrofitting a great business opportunity in the construction field.

One of the most promising techniques for the retrofitting of these obsolete structures is the use of carbon fiber reinforced laminates bonded with epoxy resin to the external surface of the elements to be strengthened. In this manner, it is possible to increase several times the flexural capacity of a bridge so that the resistant requirements are reached. However, there are some problems that workers have to deal with during the retrofitting works, which should be reduced as much as possible to improve this technique.

Finally, some case studies where this technique was applied to strengthen different types of structures are presented.

2. Condition and quality of bridge infrastructure

2.1 Condition of infrastructure in Western Europe based on Spanish case study

In Spain, bridges are made using a variety of construction materials. Often it is possible to find steel or concrete beams on masonry abutments or piles. Masonry bridges in Spain represent between 20 and 45% of the total number of bridges, depending on whether data are taken from the National network or from local administrations. Between 70 and 80% of bridges have been built with structural concrete (mass, reinforced or pre-stressed concrete), and only around 5% with steel. Composite bridges have not been very well defined inside the inventory of bridges [1].
Due to the use, the aging, the numerous impacts (hits, accidents, vandalism, etc.), the changes in the structures and the progress in the legislation, there is a continual evolution in the conservation status of bridges. The Highways Agency of the Ministry of Development have a Bridge Management System that have cataloged about 33000 bridges, of which 25000 have a span larger than 3 meters [2]. The Government manages the conservation and maintenance of the bridges which is responsible.

The Bridge Management System is an inventory of the structures that are in the highway network, and includes location data, typologies, dimensions, functionalities, elements and materials, photographs and existing documentation. Inspections in the structures are carried out, and deteriorations in their elements are evaluated, establishing the criteria to apply to determine the importance of the detected damage. In this way, the state of the bridges is estimated in order to prioritize repair.

The Spanish highway network was primarily developed during the 60's, and bridges were designed to have service lives between 50 and 100 years at most. As a consequence, significant maintenance, repair, rehabilitation, and replacement activities for the nation's highway bridge infrastructure are foreseen over the next few decades.

2.2 Condition of infrastructure in Central-East Europe based on Polish case study

The quality of transport infrastructure is one of the most important factors stimulating the economic development and competitiveness. If bad, it does not provide for proper quality of passenger and cargo traffic services and an effective allocation of industries and services. Bad transport infrastructure has a negative impact on foreign direct investments and mobility of labour force.

Between 2000 – 2009 year in Poland roads network has increased by 7,6%, while GDP has increased by 40,7%. Important fact is that the number of the vehicles have increased by 56,1%. Those factors show enormous lack of the new transport infrastructure in comparison with the rapid development of economy. The lack of national roads network of adequate standard appears nowadays as critical both for national and international transport. This situation can be extrapolated to other Central and Eastern countries like: Bulgaria or Ukraine that cope with the same issues. It need to be mention that polish infrastructure belongs to one of the weakest part of the polish economy. Additional drawback is the highways and express ways represent only 0,4% of the road system. Main disadvantages of polish transport infrastructure are:

> Lack of the efficient transport infrastructure between eastern and western border
> Pavements standard is not adjusted for the heavy trucks movements. The total
> length of roads accepting the load of 115kN/axle, being a basic European standard, is estimated as 20% of the total national roads network.
> The main cities suffer from the bottlenecks and traffic safety decrease. The main urban centres (Warsaw and Silesian agglomerations) are particularly affected by the road accidents, congestion and the environmental pollution.
> Almost 40% of the total national network are in poor quality and require immediate modernisation.

This results in additional economic, social and ecological costs of road transport, which is the most dangerous and expensive in terms of the human life. The human aspect can not be overvalued. Countries in Europe with the biggest urban road fatalities (as a percentage of total fatalities) are Poland, Greece, Portugal and Italy, it is worth mentioning that in Spain this factor does not exceed 18%.

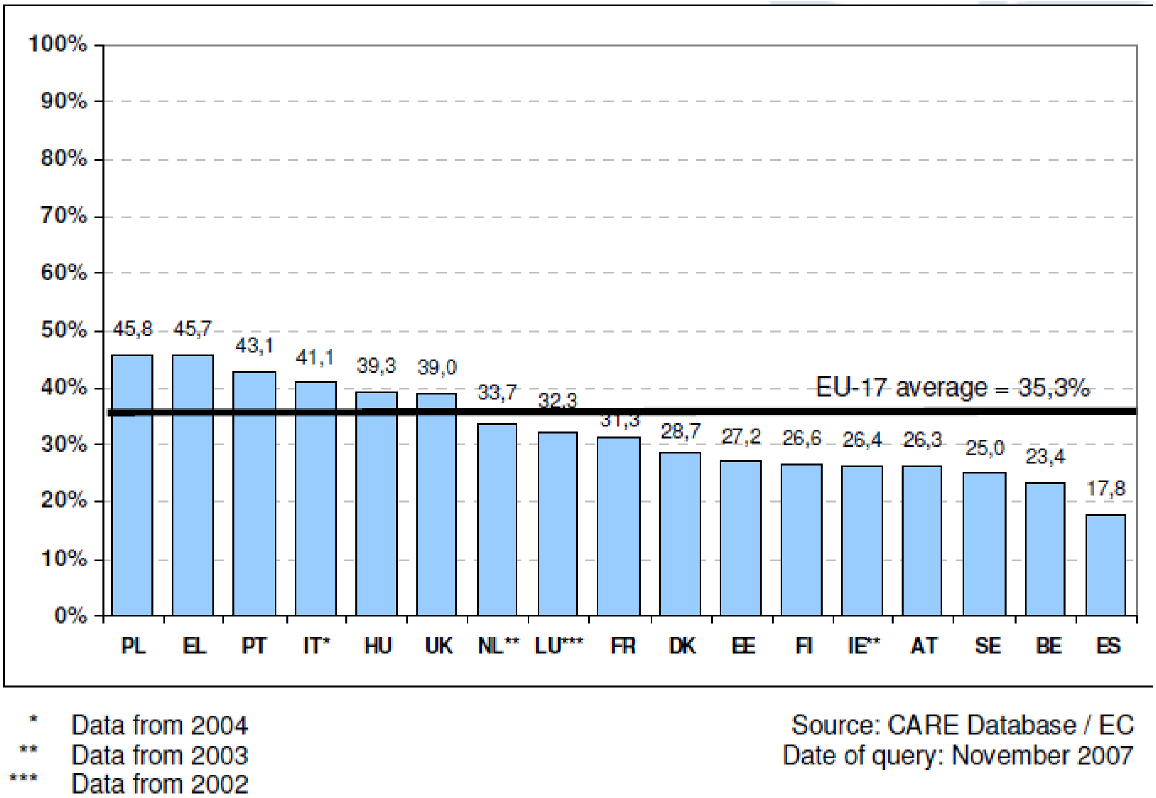

Figure 1 Urban road fatalities as a percentage of total fatalities. (CARE Database/EC) [3]

Bridge infrastructure in Poland mainly consists mainly of reinforced concrete bridges and pre-stressed concrete structures, together they state almost 80% of the bridges manage The General Directorate of Roads and Highways), Table 1.

Table 1 Features of the bridge infrastructure (General Directorate of Roads and Highways) [4]

Type of construction material	**Number**		**Length**		**Area**	
	No.	**%**	**m**	**%**	**m²**	**%**
Steel	623	13,82	48 595	25,51	619 391	26,41
Reinforced concrete	2 534	**56,20**	66 967	35,16	763 268	32,55
Pre-stressed concrete	1 263	28,01	73 965	38,83	951 664	40,58
Stone, brick, concrete	84	1,86	896	0,47	10 400	0,44
Other	5	0,11	63	0,03	471	0,02
Total	4509		190 487		2 345 194	

3. Most common problems during strengthening and repair of bridges

The most common problems that the working team should face and solve are:

- Restricted access: Many times the area to be strengthened not only has a restricted access but it also requires the use of special equipment in order to reach the place that needs to be repaired. In the case of bridges it is very common that these kinds of reinforcements are needed at the bottom of the beams or decks. This means that the strengthening operations are normally carried out at a considerable height from the ground and consequently it is mandatory the use of all protection measures to comply with the safety requirements. The problems focus on: lack of place for storage of construction material, lack of place for standby of large prefabricated elements, lack of place for installation of crane or scaffolding, lack of place for storage of demolished material from old bridge, lack of place for parking of workers and living area.
- Electricity cuts: It is usual that electricity is cut at the project site during the night when nobody works but some pieces of equipment work in order to cure the resin used for the execute of the reinforcement. This usually happens due to a lack of communication and coordination between the different people involved at the project site. This is a problem can be easily solve but nevertheless is very common to encounter.
- Weather conditions: Pending problem for the investors and contractors is winter time and associated with this low temperature and snowing. Winter construction is not a new problem however now new techniques and materials can lead to overcome barriers and continue construction investment in the winter time. Frequently due to the many investment that need to be performed in the cities, the summer time means significant traffic disruption. The issue is that all main constructions start at the same time what provoke many obstacles in every day transport and quality of life of the citizens. The goal of the stakeholders is to have the opportunity to execute new constructions and modernizations during all the seasons what will leverage the outcomes of the construction process. It need to be highlighted that the instability of the winter temperatures can results in lower quality of the construction works and slower construction time. Frequently the contractors begin the work in temperature above zero and unexpected reduction can stop the works, cause serious damages and lower the quality of already performed works. Therefore investors need to perform detailed construction supervision and to constantly monitor work progress. Also the rain can provokes problems, for example if it rains and there is the possibility the surface to be strengthened gets wet, the work need to be stopped with a consequent delay. For bridges that are strengthened with FRP tapes, the winter time also provoke problems, the resin increases its viscosity. Consequently, it is more difficult to work with it and it might need to be heated before or added with a catalyst. In some cases the surface needs

to be heated in order to let the resin cure. During summer time, the opposite situation happens, the resin viscosity is lower and resin drops fell from the reinforcement. The resin some times burns with the consequence that the fabrics are not properly glued to the surface.

- Surface problems: The reinforcement fabrics should be placed on a clean and homogeneous surface. Many times the surface is in bad condition presenting holes and concrete spalling. In this case the surface needs not only to be cleaned and prepared but also needs reparation before the strengthening is placed.
- Working site: Some times reinforcing fabrics must be cut at the project site where there is not an adequate place to do it. Besides, the fabrics and the resin should be free of dust, which is a goal hard to reach at 100% in open sites.
- Impact on traffic: It is often required to let traffic remain as good as possible during all the period of construction works (e.g. working often at night to minimise traffic disturbance). Common problems are complains from road users, neighbours or client if traffic problems occur.
- Environmental problems: Problems related with noise emissions, dust emissions, waste generation, vibrations and other types of pollution.
- Health and safety of workers: Safety problem for workers due to nearby traffic during construction works; health of workers due to working environment (due to traffic noise and emissions, soil pollution, etc.); safety of workers in relation to the work performed (fall from height, etc.); heath of workers in relation to work performed (noise from machinery, dangerous products, etc.).

Main technical and design problems during strengthening and repair of bridges are listed below:

Technical problems	Design problems
Detection of new problems during the construction works that were not detected during the inspection/assessment prior to the conduction of repair/strengthening works	Differences between old standards and new standards
Residual stresses between new and old concrete (e.g. edge beams)	Missing information from original design
Need for physical and chemical compatibility between repairing material and material to be repaired	
New strengthening/reparation techniques are not well known so “classic” techniques are usually used instead	
Need to preserve the aesthetic aspect of the old bridge	

4. Case studies

4.1 Introduction

In Chapter 4 there are demonstrated case studies related to strengthening of the structures with FRP solutions.

4.2 Case study no.1

FRP strengthening of two reinforced concrete footbridges over the biological digester of the purifying plant in L'Alcudia

After an inspection performed on the two footbridges over the biological digester of the purifying plan in L'Alcudia, further studies were carried out in order to determine wheter strengthening of the structures was needed. The studies showed that the safety coefficients for positive flexion in some spans were under the limit value 1.5 given by the Spanish code. The analysis also showed that pathologies were caused by changes in the original design during the construction phase.

The two reinforced concrete footbridges were built in 2005 and the inspection was made in 2008. The final report recommended to increase the safety factors of the structures using carbon fiber laminates at the bottom of the spans where it was required. In these cases hand-lay-up process was used. The strengthening of the footbridge over the biological digester of the purifying plant in L'Alcudia in Spain was performed.

The Figures 4.1, 4.2, 4.3 show the footbridges, pathologies and the Figure 4.4, 4.5 and 4.6 show strengthening process.

Figure 4.1 Footbridge over the biological digester


Figure 4.2 Cracks in the abutments

Figure 4. 3 Deformations up to 4cm in the first span of one of the footbridges

Figure 4.4 Hand-lay-up process, impregnation of fibres

Figure 4.5 Curing of the CFRP reinforcement

Figure 4.6 Protection of the CFRP reinforcement during curing period

4.3 Case study no.2

Strengthening of a bridge along the motorway A-5 in Extremadura (2005)

The reinforcement of the bridge was needed due to an accident in which a truck hit the soffit of the bridge beams. The strengthening was done on a bridge along the motorway A-5 in Extemadura in Spain in 2005. Figures 4.7 to 4.10 show how the process looked like.

Figure 4.7 Resin impregnation of the surface

Figure 4.8 Fiber placement

Figure 4.9 Fiber placement

Figure 4. 10 Installation of vacuum system

4.4 Case study no.3

FRP strengthening of the Structure 2 PI – North east motorway A-2 km 64+800

The structure consists of a buried box of two cells with a width of 19.4m and a height of 6.8m (see Figure 4.11). The strengthening is needed due to a load increase coming from the increase in the ground level over the lintel.

Figure 4. 11 Initial situation of the project site (Motorway A-2 in Spain)

The strengthening process used was the hand-lay-up. The process started with the treatment of the surface with sand-blasting in order to get better cohesion and roughness that guarantees good adherence of the product to be glued. The next step was the surface and laminate impregnation with resin. After that, the fabrics are placed on the surface and the hand lay-up process is carried out. The resin cured for a minimum period of 24 hours at ambient temperature. Figures 4.12 to 4.16 show how the process looked like.

Figure 4.12 Surface preparation and impregnation

Figure 4.13 Preparation of resin for laminate impregnation

Figure 4.14 Preparation and placement of laminate and formwork

Figure 4.15 Laminate and props placement

Figure 4.16 Final FRP reinforcement with carbon fiber and epoxy resin

4.5 Case study no.4

FRP strengthening in residential building in Warsaw (Poland)

The strengthening was performed in newly constructed residential building on Pańska street in Warsaw in Poland. The problem was the opening for the stairs (in order to connect two flats) that was not designed primary. However change of the static scheme provokes additional bending moments and it was necessary to reinforce/strengthen the floor. For the reinforcement carbon woven 600g/cm² and epoxy resin were used. The strengthening was done in technology way-lay up. Firstly the surface was prepared, dust, dirt, oil, existing coatings and cement layer, and any other matter that could interfere with the bond of the FRP system to the concrete were removed. Then the primer was applied and the saturated woven with epoxy resin was placed.

Figure 4.17 FRP reinforcement with carbon fiber and epoxy resin on the floor and opening in residential building.

4.6 Case study no 5

Case study describes strengthening of historic brick-wall situated on Ordynacka street in Warsaw (Poland). The wall was linked with reinforced concrete retaining wall with carbon FRP bars with diameter Φ10mm, Figure 4.18. Bars were glued within two structures with epoxy adhesive Hilti HIT-HY 70 330/2.

Figure 4.18 Strengthening of historical brick-wall with FRP carbon bars in Warsaw.

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APPENDIX 5

Strengthening and repair of steel bridges-Case studies

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Strengthening and repair of steel bridges-Case studies

Type of report, Version, 28 December 2011

Colophon

This publication is produced by Pantura work group: WP5

The main author is: Reza Haghani (CTH)

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Table of contents

1. Case study 1

Midland Links-bearing stiffeners [1]

Bridge	**Midland Links Motorway Viaducts.**
Introduction	The Midland Links Motorway Viaducts carry the M5 and M6 motorways around the outskirts of Birmingham. They mainly comprise simply supported steel RC decks of 15-27m spans. The spans of up to 21m are supported by universal beams and those above are supported by plate girders. Simple rocker bearings were provided, with the bottom flange of the steel beams sliding directly on the top plate of the bearing. Bearing stiffeners were not provided, the transverse forces on the deck ends being carried by 150 mm thick RC shear walls supporting the deck ends. These are cast monolithically with the RC cross-beams supporting the decks, and hinged at the deck soffit. A study of buckling of the webs of the universal beams and plate girders established that there was a reasonable factor of safety against buckling of the universal beam webs, but a limited factor of safety against buckling of the plate girder webs.
Weakness	Bearing stiffeners were not provided on steel composite universal deck beams and plate girders.
Strengthening limited	Following a review of web buckling capacity ratios a departure from standard was obtained permitting omission of bearing stiffeners from the universal beams. The review comprised an assessment to BS 5950, a review of testing at Aston University which showed that BS 5950 could be unconservative but only for knife edge loading, and an assessment to the AISC code. This demonstrated usage factors of about unity for the universal beams and about 1.35 for the plate girders, using the BS 5950 partial safety factor of 1.05 for materials.
Strengthening installed	Bearing outstand stiffeners were welded in place at all plate girder ends. At abutments stiffeners were bolted due to lack of access for welding.
Alternatives considered	Cheek (i.e. web) plates were rejected as providing insufficient support due to the bottom weld being overstressed in shear immediately above the bearing in transferring vertical load from the bottom flange into the web.
Prior inspection	The height, inclination and bow of webs were measured before works.
Prior testing	Ultrasonic examination of webs was carried out to detect laminations to avoid lamellar tearing on welding. Chemical analysis was carried out to determine a welding procedure. A mock-up of the restricted access was built for the welding trial in advance of the contract (see Figures 1.2 and 1.3). A mock-up was built at the start of the contract to check that welding procedures would not result in unacceptable strains on the shear connectors. A sample at each geographical location was taken and tested to ensure that the carbon content was not excessive for the welding procedure adopted.
How fasten?	By fillet welding. Buttering (coating with weld metal) over laminations.
How fit?	By grinding to close tolerances to permit fillet welding to the webs and fitting to the bottom flanges. The stiffeners were held by G-clamps during welding.
Traffic management	Loading restrictions from 45 to 25 units of HB were invoked during welding to avoid overstress while the steelwork was hot and therefore at

	reduced strength. Welding was carried out under normal working hours.
Testing afterwards?	MPI and ultrasonics on welds. Not many failures were identified.
Within programme?	Generally yes, although the grinding was a longer job than the contractor allowed for.
Within costs?	Generally yes.
Problems revealed?	The difficulty of fitting the stiffeners required careful supervision. At the occasional location where the web was significantly bowed the web would not straighten when the bolted stiffeners were tightened. The gap was filled with epoxy mortar.
Anything went badly?	No.
What changes if do again?	No major changes

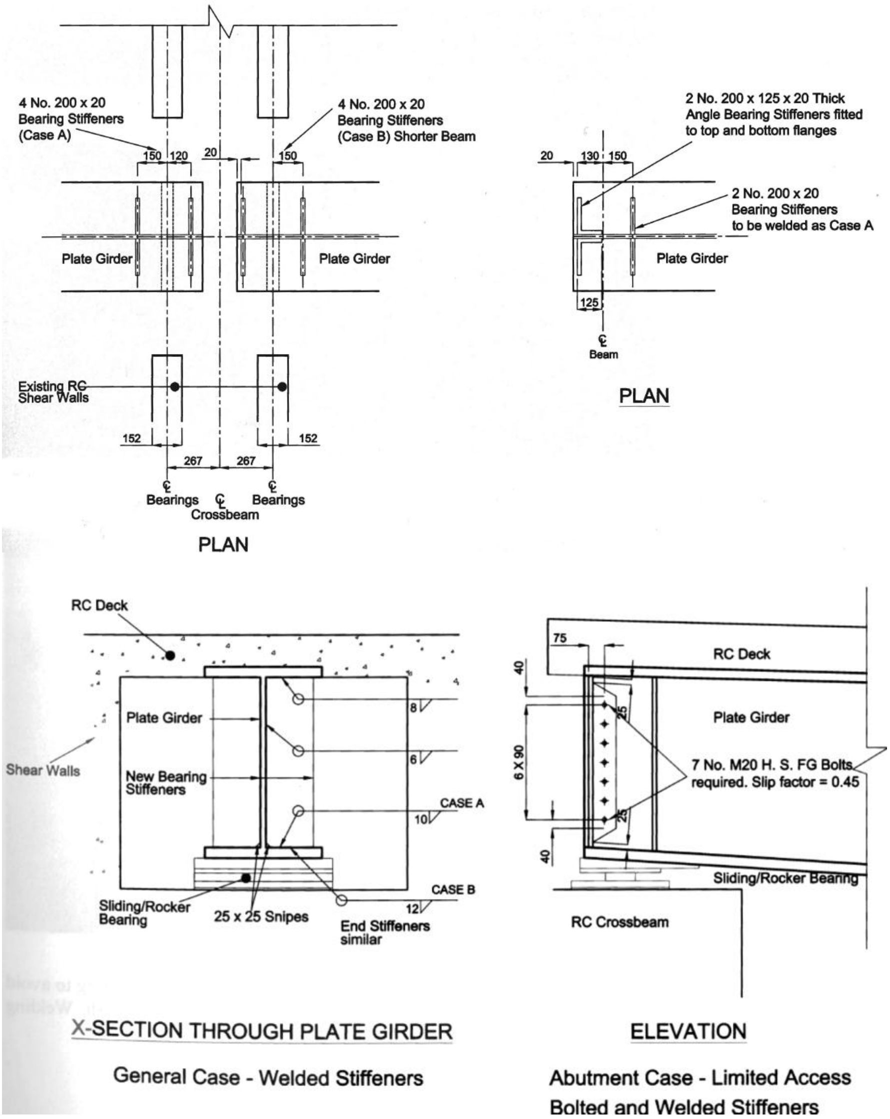


Figure 1.1 Midland Links-bearing stiffeners

Figure 1.2 Bearing stiffener welding trial

Figure 1.3 Bearing stiffener welding trial

2. Case study 2

Rakewood Viaduct-prestressing [1]

Bridge	Rakewood Viaduct is a six span continuous viaduct of composite construction carrying the dual three lane M62 Motorway over a steep-sided valley at a maximum height of 36m (see Figure 2.2).
Introduction	Prone to high winds as well as snow and ice in the winter and carrying a high proportion of heavy vehicles on a steep gradient, the hardshoulder was to be converted to an additional climbing lane. A P6 parapet was to be added. The bridge. was assessed to BS 5400 whereas it had been designed to BS 153 and consequently the live loading had increased. The bottom flanges of the main girders in the hogging zones over the piers were found to be heavily overstressed.
Weakness	The bottom flanges in the spans between the points of contraflexure were prestressed in order to induce a reduction in the hogging moments over the piers.
Strengthening limited	The bottom flanges in the spans between the points of contraflexure were prestressed in order to induce a reduction in the hogging moments over the piers.
Strengthening installed	The prestressing was provided by prestressing bars. The anchorages for the bars were HSFG bolted to the bottom flanges and bearing stiffeners were added to resist induced local vertical forces.
Alternatives considered	It would have been difficult to add bottom flange plating at the piers because of the obstruction by the bearing stiffeners above and by the bearings below. With self-weight stresses alone near allowable, adding flange and web plates would have worked only with jacked unloading.
Prior inspection	A comprehensive prior inspection was carried out in order to measure tolerances for plate panel and stiffener stability assessment. A thorough check of all welding was undertaken.
Prior testing	The method is based on earlier American practice. Comprehensive welding trials were undertaken together with testing of steel quality to guard against brittle failure.
How fasten?	By HSFG bolts and welding of 1967 high tensile steel.
How fit?	As above.
Traffic management	No traffic management was required for the prestressing which was carried out from hanging scaffolds.
Testing afterwards?	Permanent strain monitoring was carried out on the bars during stressing and thereafter. This ensured adequate prestress was applied and maintained.
Within programme?	Yes.
Within costs?	Yes.
Problems revealed?	Prestressing caused contra-rotation and problems at the end bearings.
Anything went badly?	No.
What changes if do again?	The prestressing bars are exposed and easily inspected for corrosion and corrosion protection. However high strength fibre composite tendons could be considered.

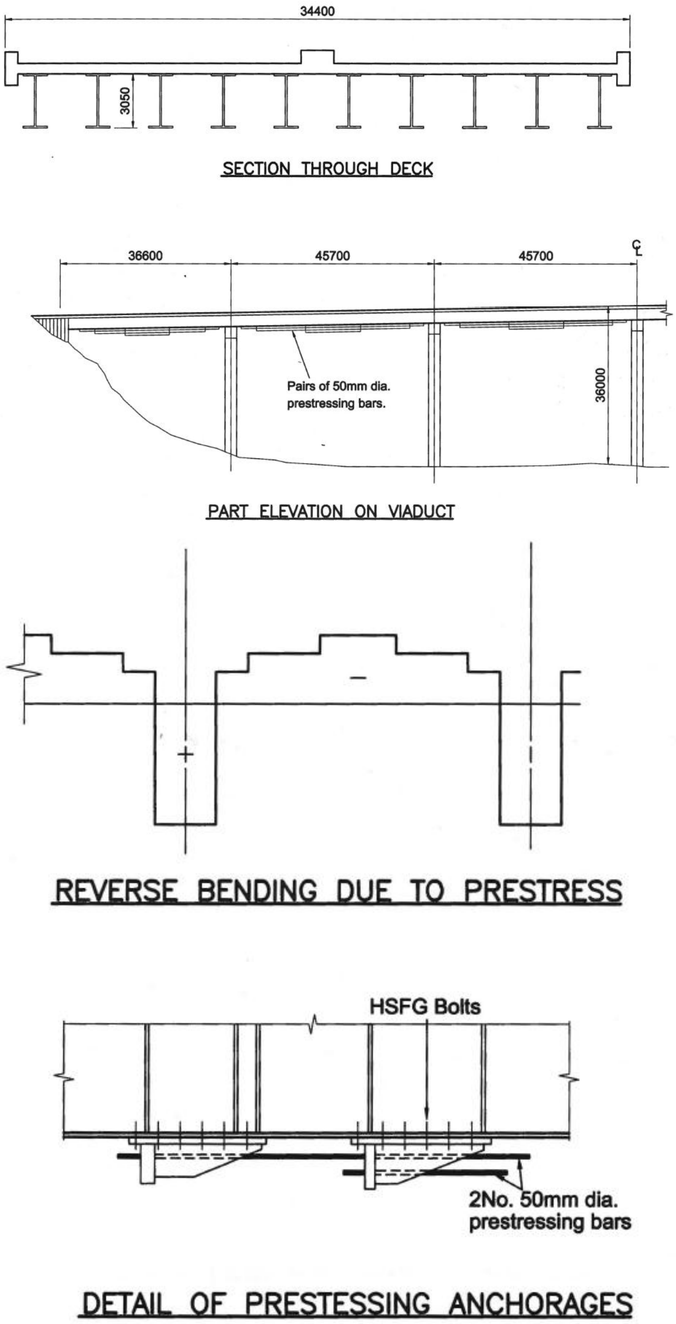


Figure 2.1 Rakewood Viaduct-prestressing

Figure 2.2 Rakewood Viaduct

3. Case study 3

Huntworth Viaduct-steel box strengthening [1]

Bridge	Huntworth Viaduct, M5, twin steel box girder.
Introduction	Huntworth Viaduct is a 17 span steel box girder bridge carrying the M5 Motorway over the mainline railway, a main river, a canal and two minor roads. One of its steel roller bearings had cracked and a piece had broken away and fallen to the ground (see Figure 3.3). The viaduct was inspected and assessed. In addition to the roller bearings several aspects failed the assessment. A fast-track programme of designing new bearings and strengthening measures for the boxes was instigated and imple-mented through to installation on site.
Weakness	The roller bearings were found to be prone to low cyclic fatigue failure, and some had already cracked. No jacking points were provided to enable the bearings to be replaced. The bottom longitudinal stiffeners failed their assessment in flexural bending over the pier supports (see Figure 3.4). The box girder web failed in shear at the first large panel 12m from each support.
Strengthening limited	A 9 m length of longitudinal stiffeners along the bottom flange in the region of the piers was encased in concrete to reduce the effective length and thereby pass the assessment. This was much more economical than strengthening the stiffeners in steel and avoided welding in a confined space. The unrestrained web plate 12m from the support was reclassified as restrained by bolting on an additional T-stiffener. This allowed the web to pass its assessment in shear. It was more economical than strengthening the web in shear say by the addition of a doubler plate, and again avoided welding in a confined space.
Strengthening installed	Doubler plates were welded to the existing transverse stiffeners to provide jacking points which would enable the bearings to be replaced. Defective diaphragm/web welds were strengthened. The roller bearings were replaced with inverted pot bearings (see Figure 3.5) using existing fixing positions on the box girder. These removed the eccentricity from the diaphragms of the box girder under thermal movement and applied the eccentricity to the piers instead (see Figure 3.6). The sliding surfaces were covered with a flexible hood to prevent detritus from damaging the polished surface. The tops of the RC piers were strengthened against bursting at the time the bearings were replaced (see Figure 3.7).
Alternatives considered	Direct strengthening would have been much more expensive.
Prior inspection	The condition of the existing welds was inspected using MPI and ultrasonic techniques.
Prior testing	The condition of the existing welds was tested. Acoustic emission was used to detect fatigue cracking in the roller bearings under movement of a known heavy load. Materials testing was undertaken to determine the notch toughness.
How fit?	The box was jacked up on temporary supports to replace the bearings. Welds were repaired while stress was removed.
Traffic management	The welds were strengthened while the box was jacked onto temporary support to replace the bearings.
Within programme?	Yes.

Within costs?	Project was completed generally within cost.
Problems revealed?	The biggest oversight in the design was not realising at the design stage that the original bridge bearings were not in the position indicated on the as-built drawings, and were at the maximum extent of their travel before the minimum bridge temperature was reached. This meant that the new bearings had to be individually placed, not necessarily on the centreline of the pier. A pre-contract survey is recommended.
Anything went badly?	Negotiations with Railtrack regarding access over a level· crossing (to get access under one half of the bridge).
What changes if do again?	Pre-contract survey of the bearing positions. It is believed that at the ends of the bridge (410 m from fixed bearing) the bridge was approximately 30 mm too short, and this was due to shrinkage in the butt welds joining the box sections together. This may not have been considered in the original design and caused the bearings to be beyond their allowable travel before the minimum bridge temperature was achieved.

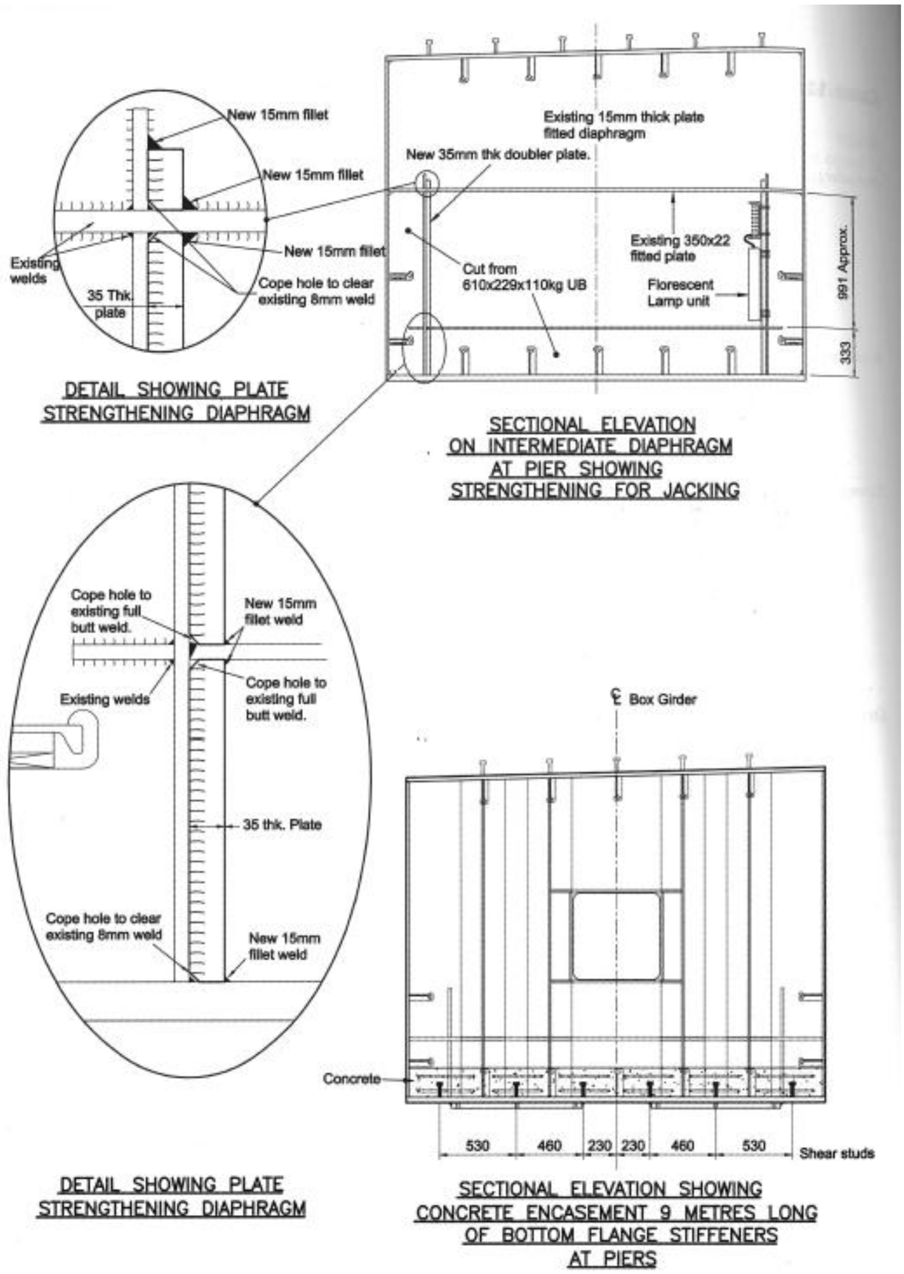


Figure 3.1 Huntworth Viaduct-steel box strengthening

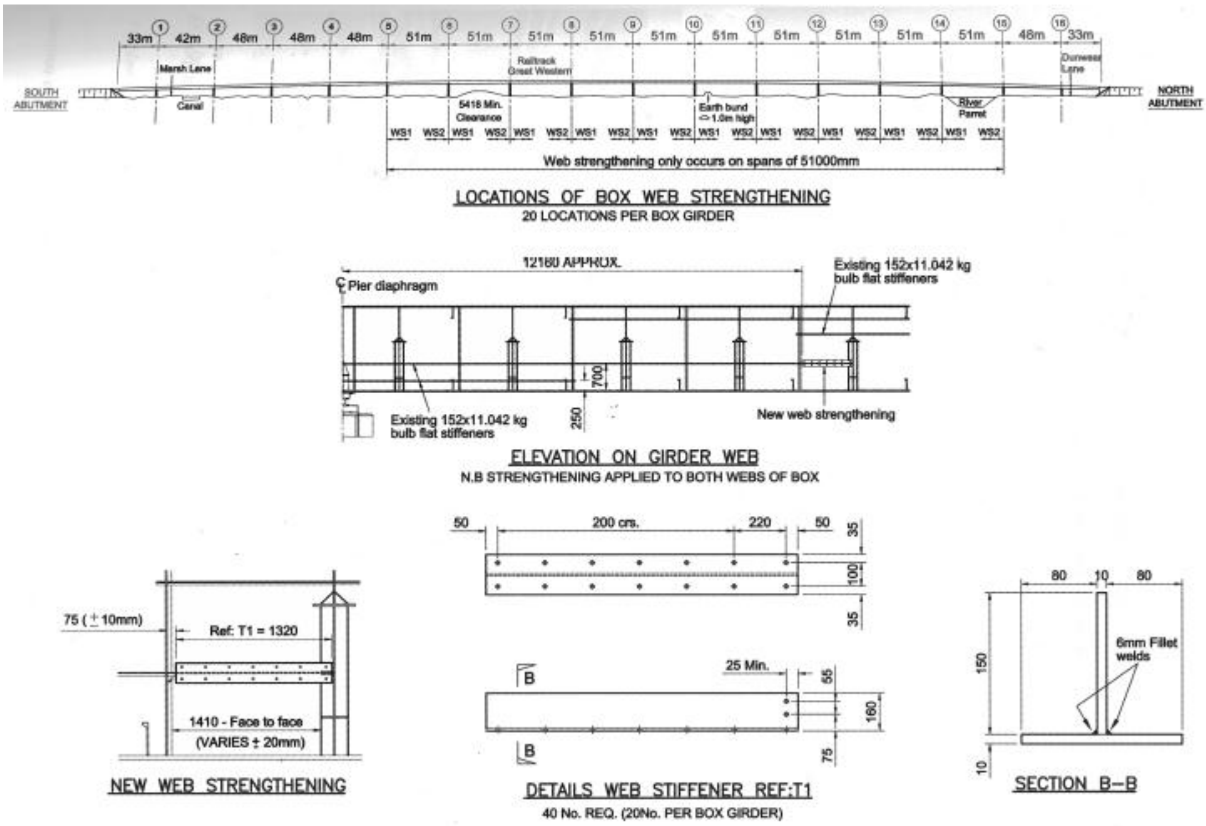


Figure 3.2 Huntworth Viaduct-steel box strengthening

Figure 3.3 Existing roller bearing

Figure 3.4 View in box showing bottom flange stiffeners

Figure 3.5 Installation of new bearing

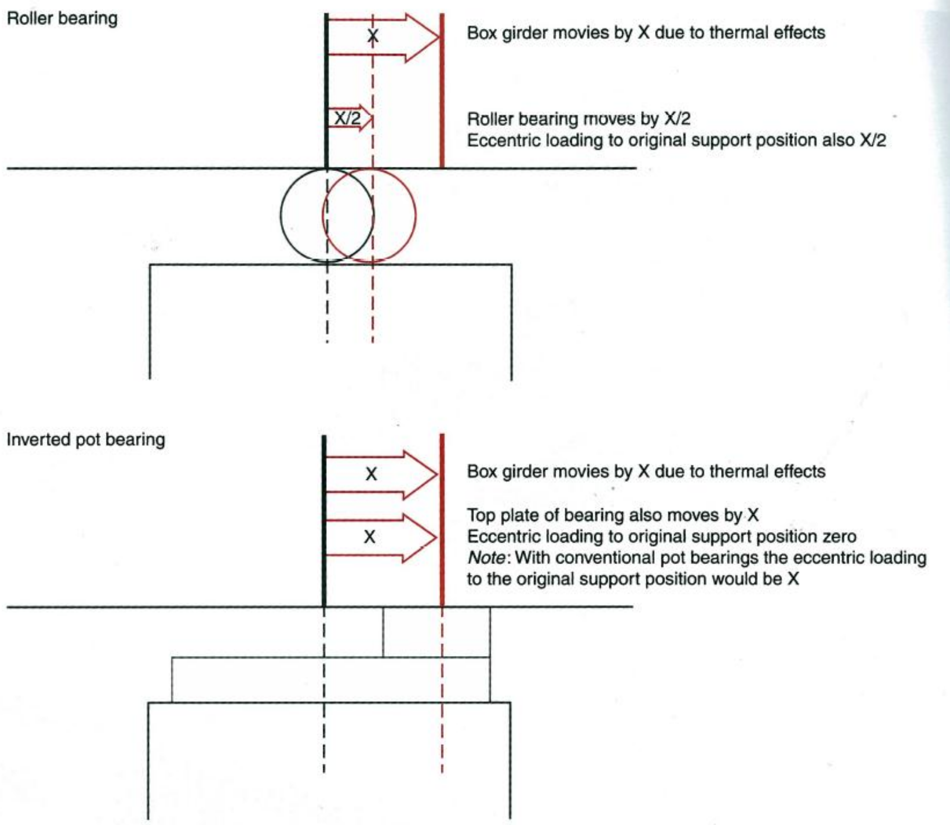


Figure 3.6 Bearing eccentricity

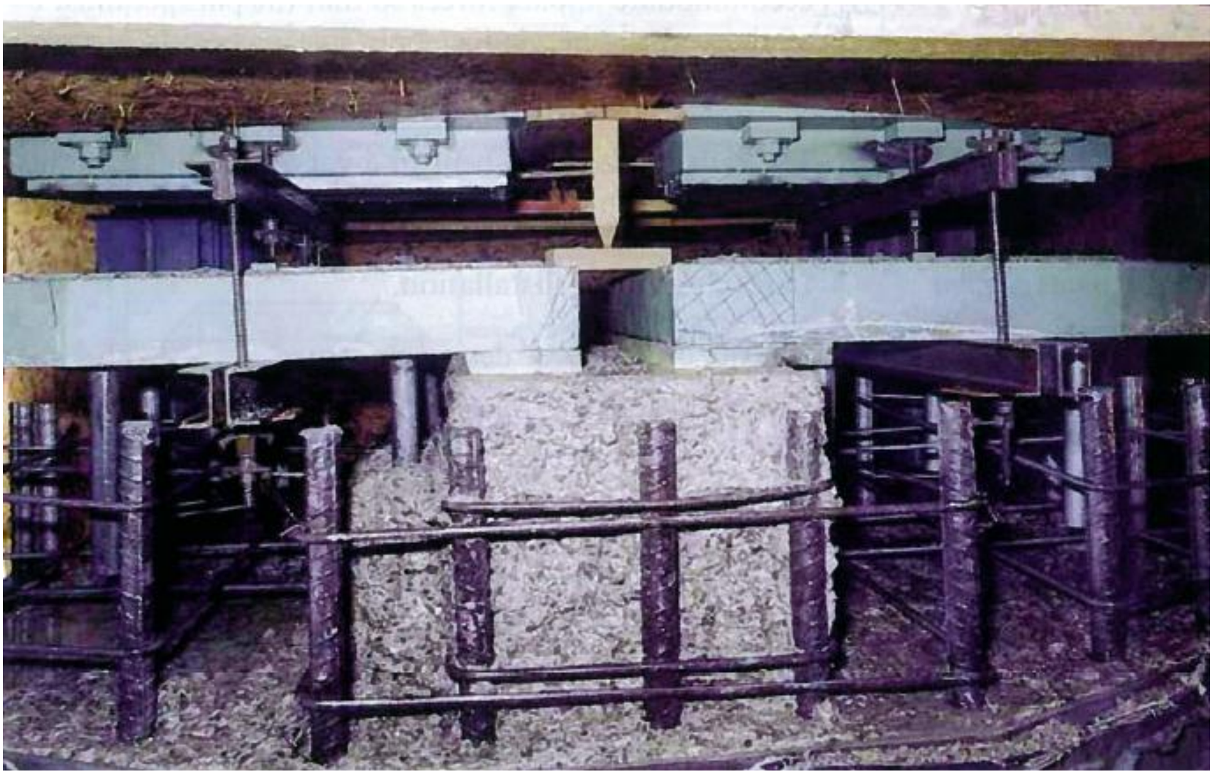


Figure 3.7 Pier top after hydrodemolition

4. Case study 4

Friarton Bridge-prestressing [1]

Bridge	Friarton twin steel nine-span box girder with lightweight concrete deck across the River Tay with 174m main span
Introduction	Current standards and increase in loading have led to excessive tensile stresses in the top flange at the internal supports and inadequate factors of safety against buckling of the webs and flanges.
Weakness	The shear studs fail to satisfy the distance between the underside of the stud head and the longitudinal reinforcement, the longitudinal spacing of the studs exceeds the maximum allowed and the diameter of the studs at certain locations is greater than one-and-a-half times the flange thickness. However, the shear studs are adequate with regard to strength and fatigue. The contact width of the diaphragms above the bearings exceeds one-quarter of the depth of the diaphragm.
Strengthening limited	Departures from standard were accepted for the shear studs on the basis that dynamic monitoring work had demonstrated the slab and girder to be acting compositely, and the shear studs are not fully utilised with usage factors of 85% at Serviceability Limit State (SLS), 45% at Ultimate Limit State (ULS) and a maximum fatigue stress of 70%. A departure from standard was accepted for the diaphragm on the basis that an FE model showed the diaphragm stresses to be within acceptable limits.
Strengthening installed	External prestress used to reduce tensile stresses in top flange. Stiffeners added to increase the factor of safety against buckling of webs and flanges.
Alternatives considered	Inclined cables would have overstressed the bottom flange and the diaphragms. Bolting plates outside the bottom flange would have been too heavy for installation by the maintenance gantry and in carrying only live load would have operated inefficiently. Installing tensioned cables at the top flange over the supports would have relieved the top flange but not the overstressed compression flange. Welding longitudinal stiffeners to the top and bottom flanges in the hogging zones at the supports could provide sufficient capacity, but in carrying only live load would act inefficiently, increasing the weight to be man-handled along the bridge and to be lifted to considerable height to the top flange above the pier.
Prior inspection	A pre-tender paint survey was carried out by tenderers to define the scope of girder maintenance painting to be included in the contract.
Prior testing	Vibration measurements were made of the viaduct to quantify its in-service dynamic behaviour, allowing determination of the viaducts natural frequencies of vibration, location of the neutral axis, amount of shear lag, extent to which the deck slab and boxes are acting compositely, and the degree of cracking in the deck slab.
How fasten?	Cables anchored to 150mm thick plates welded to two longitudinal stiffeners welded to the top flange and existing longitudinal and transverse stiffeners. Anchorage points staggered.
Traffic management	One lane of traffic or a single 150t load during strengthening. No live load during welding. Girders strengthened consecutively. Tenderers priced for full closure of carriageway over girder being strengthened and

	for closure only at night. Allowing for traffic delay costs the second option was cheaper and was chosen.
Testing afterwards?	Monitoring of the modes of vibration at regular intervals during strengthening enabled the behaviour of the structure to be compared with the modelled predictions.
Within programme?	The contract progressed well.
Within costs?	Lump sum contract. Modified ICE 5th conditions. Bill of quantities prepared by tenderers to assist evaluation of any variations and facilitate interim valuations.
Problems revealed?	None indicated.
Anything went badly?	Contract progressed well.
What changes if do again?	None indicated.

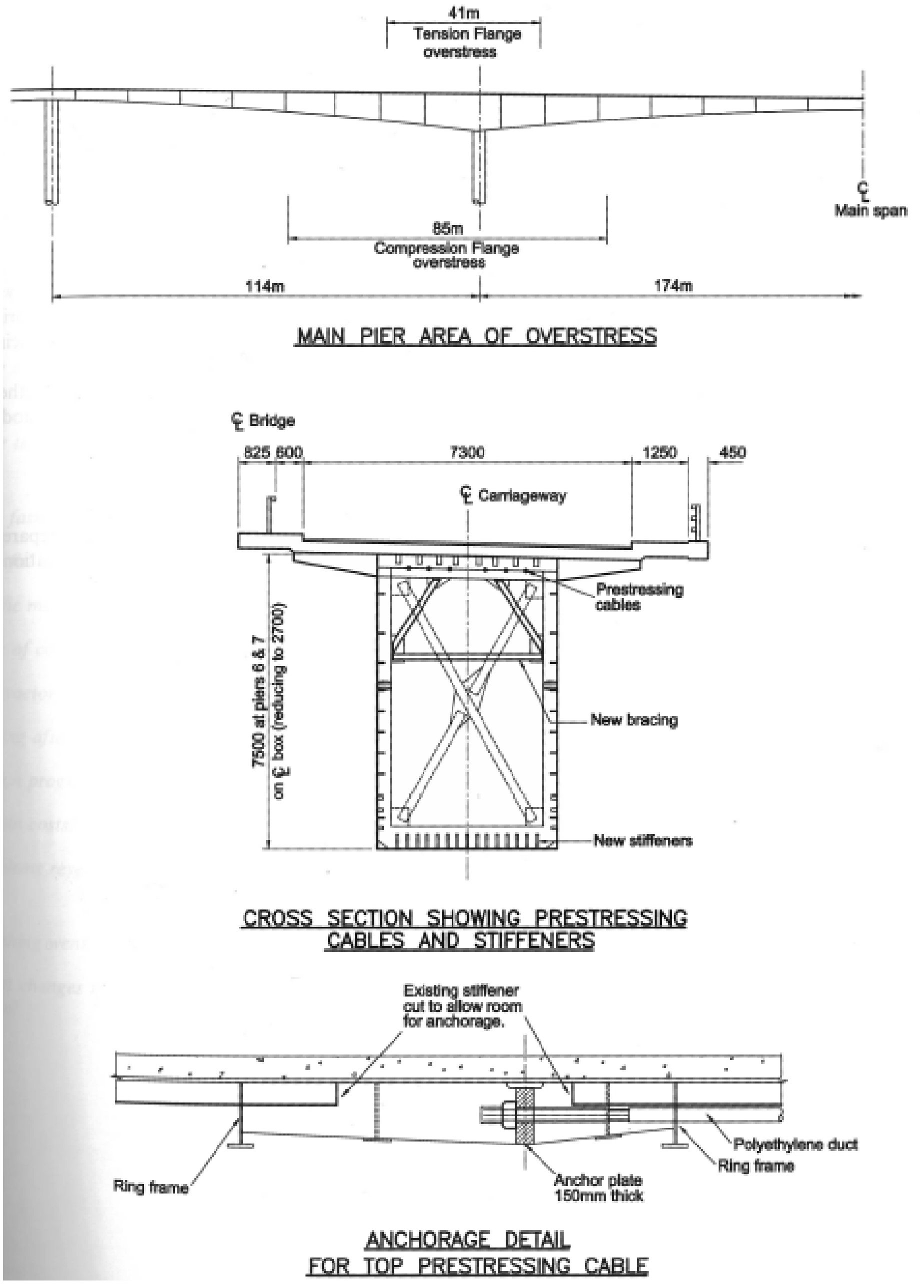


Figure 4.1 Friarton Bridge-prestressing

5. Case study 5

Conwy Bridge-diagonal brackets [1]

Bridge	Conwy Bridge, A55. The main river span is a two-pin arch spanning 94.5 m between pedestal steel pin bearings, and consists of four spandrel braced arch ribs of riveted steel box section (see Figure 5.2). It carries a single 6.7 m wide carriageway supported on steel buckle plates, and a 1.8 m footway on the northern side supported on trough flooring. The north elevation is faced with cast-iron panelling, and cast-iron parapets are provided on both sides. A service bay is located under the footway and is accessed through manholes in the hollow bastions at each abutment. The abutments are masonry faced mass concrete founded on rock. The ends of the deck upper chords are supported off the abutment shelf by a steelwork frame on rocker posts, which is connected to the deck steelwork by pin joints.
Weakness	The assessment of the bridge showed that although the main arch structure was adequate for the standard assessment loading, cross-members supporting the deck plates were overstressed due to local wheel load effects. The footway was also overstressed by accidental wheel loads.
Strengthening limited	A new vehicle/pedestrian parapet was installed along the edge of the footway to prevent accidental wheel loading on the footway. In order to reduce water leakage, the existing deck concrete was removed along the edge of the footway adjacent to the carriageway, and over the abutment linkage areas. The steelwork was waterproofed with a sprayed waterproofing membrane and the concrete replaced. The complete deck and footpath was then waterproofed and resurfaced, and new expansion joints provided. A full maintenance painting contract was not necessary at this time, and worst areas only where leaks had occurred were treated. As a trial, the area directly under the linkages was painted with a 1 mm thick specialist urethane coating to give a greater durability as 100% sealing of this deck area was thought unlikely to be achieved. In the event, a substantial reduction in leakage was achieved with leaks occurring in isolated areas only.
Strengthening installed	Knee brackets were designed to support the cross-members supporting the deck buckle plates. These brackets (300 in number) were of varying geometry to cater for the changing height of the spandrel bracing. An initial contract to install these as a matter of urgency was necessary because Welsh Water had programmed to install a new water main and sewer through a new service bay located between the two ribs on the south side. Because of lack of space at the centre of the bridge, it would have been impossible to have installed the brackets after pipe installation.
Alternatives considered	None.
Prior inspection	Team of abseilers was used to inspect the internal lattice structure.
Prior testing	The grade of steel was established by testing.
How fasten?	Gusset-type brackets were fixed to either truss verticals or lower rib by HSFG bolts. Variable length struts comprising back-to-hack angles were fixed to the cross-member web and new brackets by HSFG bolts (see Figures 5.3 and 5.4). Parapet anchorages were fixed to new strengthening brackets by prestressing bars.

How fit?	Templates were used to determine varying angles and lengths for fabrication. Existing rivets needed to be removed and packing plates were required on the riveted arch rib.
Testing afterwards?	MPI on welding stiffeners to the lower rib.
Within programme?	Phase 1 was successfully carried out to a very tight programme to enable a new sewer and water main to be installed prior to the main contract. Overall there were no delays due to the principal strengthening work.
Within costs?	Generally yes within 10% for steelwork elements.
Problems revealed?	The variable geometry was even more complicated than anticipated, but the templates worked well.
Anything went badly?	The parapet anchorage system needed modifications in Phase 2 by lengthening the prestressing bars and bedding the system on mortar to overcome lack of fit steel to steel.
What changes if do again?	No major changes. It is essential to design the system for maximum flexibility to cater for the existing steelwork geometry for similar bridges.

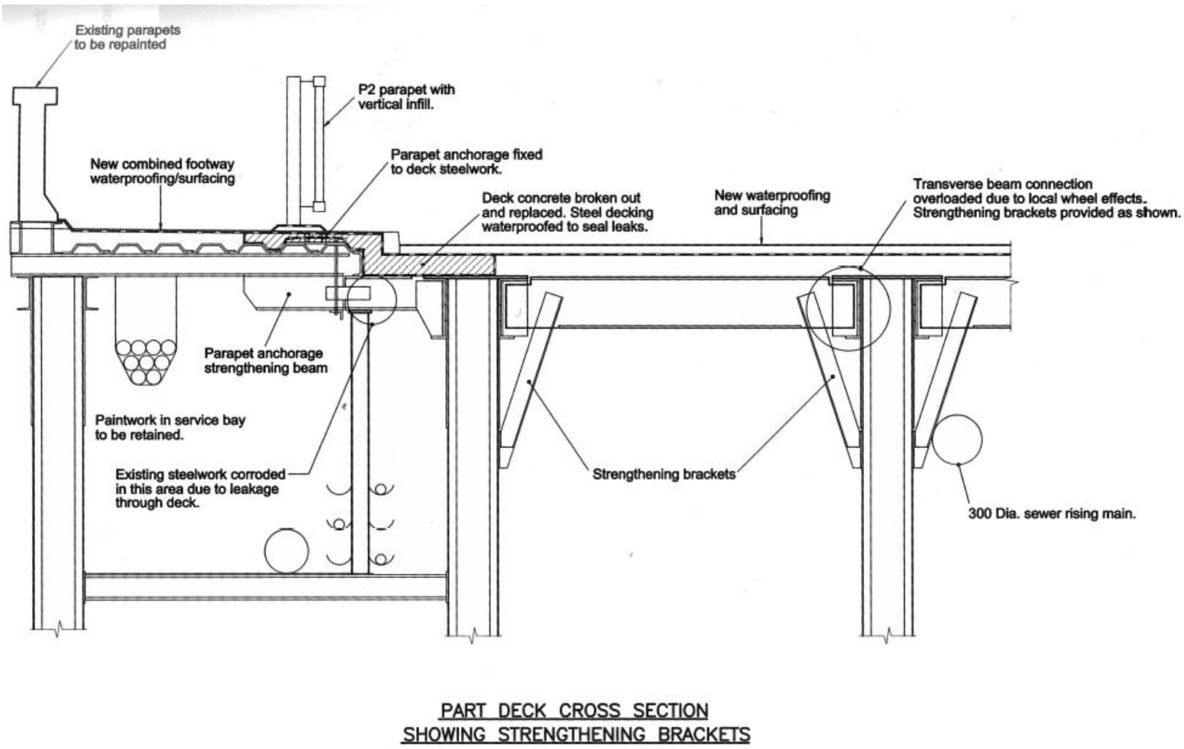


Figure 5.1 Conwy Bridge-diagonal brackets

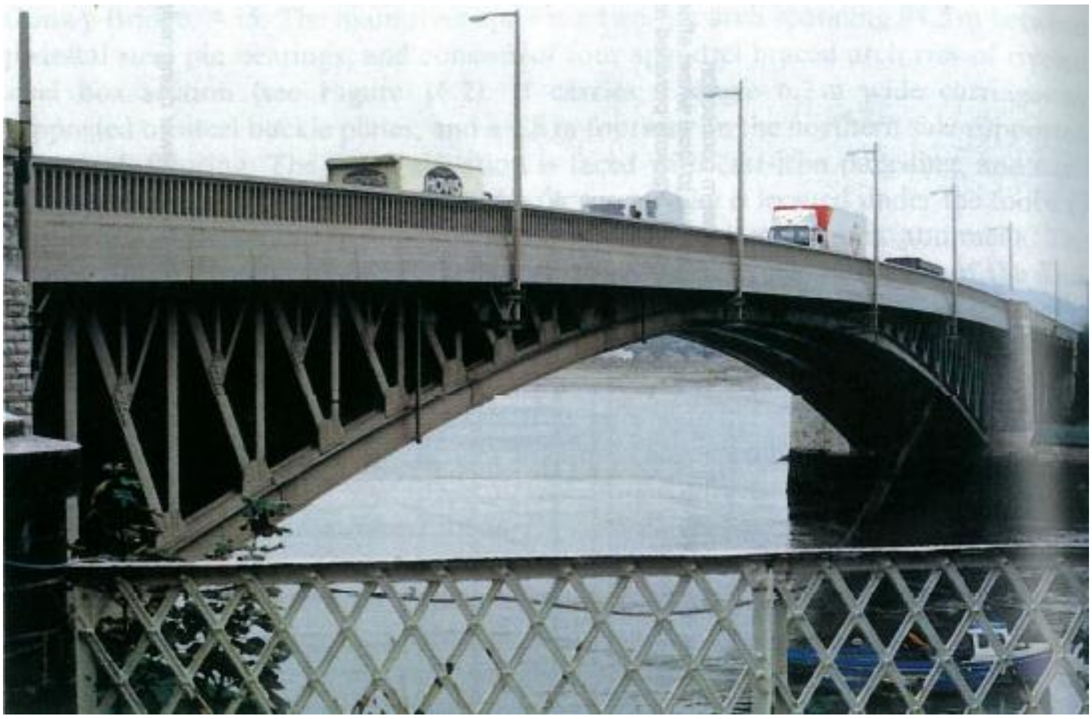


Figure 5.2 Conwy Bridge elevation

Figure 5.3 Diagonal struts

Figure 5.4 Diagonal struts

6. Case study 6

Wave Bridge-flange plates [1]

Bridge	Wave Bridge, Maldon is a single span bridge built circa 1910 which carries a very busy single carriageway road over a navigable canal (see Figure 6.2). The structure is located in a built-up area with buildings in close proximity on all sides. The deck comprises riveted steel troughs on brick abutments. The canal is used predominantly by leisure craft and is maintained by a private company.
Weakness	The bridge was assessed as part of the national assessment programme and failed to achieve 40 t assessment loading. The failure mode was mid-span sagging of the troughs.
Strengthening limited	Due to the lack of an alternative route for the large numbers of heavy vehicles using the road over the bridge a weight restriction was not a viable option. The close proximity of buildings on all sides and the need to maintain two-way traffic flows meant that deck replacement or schemes involving changes to the carriageway layout were not suitable options. Strengthening measures below the deck were restricted by the need to maintain a clear waterway opening with adequate headroom for vessels using the canal. Support for the working platform from the canal bed was not possible due to the risk of damage to the puddle clay forming the bed.
Strengthening proposed	An option study was made and it was decided to strengthen the bridge by welding steel plates to the bottom flanges of the steel troughs to increase their moment capacity (see Figure 6.3). As well as strengthening the deck the existing paint system was to be removed and a new system installed.
Strengthening works	From discussion with the contractor it was agreed to overcome access difficulties by means of a working platform suspended from the underside of the deck. This was preferred to using a floating pontoon as it offered greater stability for welding operations. The platform was designed with a section which could be removed to allow vessels to pass (see Figure 6.4). Arrangements were made to divert the footpath from under the bridge for the duration of the work. Once the access platform had been erected the steel plates were tack welded into place and subsequently fixed by continuous fillet welding. The deck was then blast cleaned and a new paint system applied. On completion of the work the platform was removed but the fixing sockets were left in place for use in subsequent maintenance operations.
Prior inspection	Prior to developing a strengthening scheme a site inspection was made to locate services, accesses, and check the condition of the existing steel and paint system. Steel samples were taken and tested for strength and weldability. Paint samples were taken and tested for lead content in view of the risk of contamination of the watercourse. Masks and/or other precautions would normally be required when removing lead based paint.
Traffic management	None required beyond limiting delivery times to outside of peak hours.
Testing afterwards?	The welds were tested using MPI. The paint system was checked using an electronic thickness gauge.
Within programme?	The work was finished within programme and with minimal disruption to traffic.

Within costs?	The work was completed within the cost targets set. The cost of deck replacement was not investigated as this option would have caused unacceptable traffic disruption. Deck replacement would have been much more expensive than the strengthening carried out.
Problems revealed?	Whilst work was in progress it was noticed that large vibrations of the deck occur when large vehicles pass over.
Anything went badly?	The bridge crosses over the canal a short distance upstream of a lock where the canal opens into a tidal estuary. When the working platform was first erected incorrect operation (by others) of the lock gates between canal and estuary at high tide caused a water surge which lifted working platform boards from the support system. The boards were subsequently clamped in place. No further surges were experienced.
What changes if do again?	It would have aided the welding operation to have tapered and curved the ends to the steel plates. This would also reduce the risk of future fatigue problems.

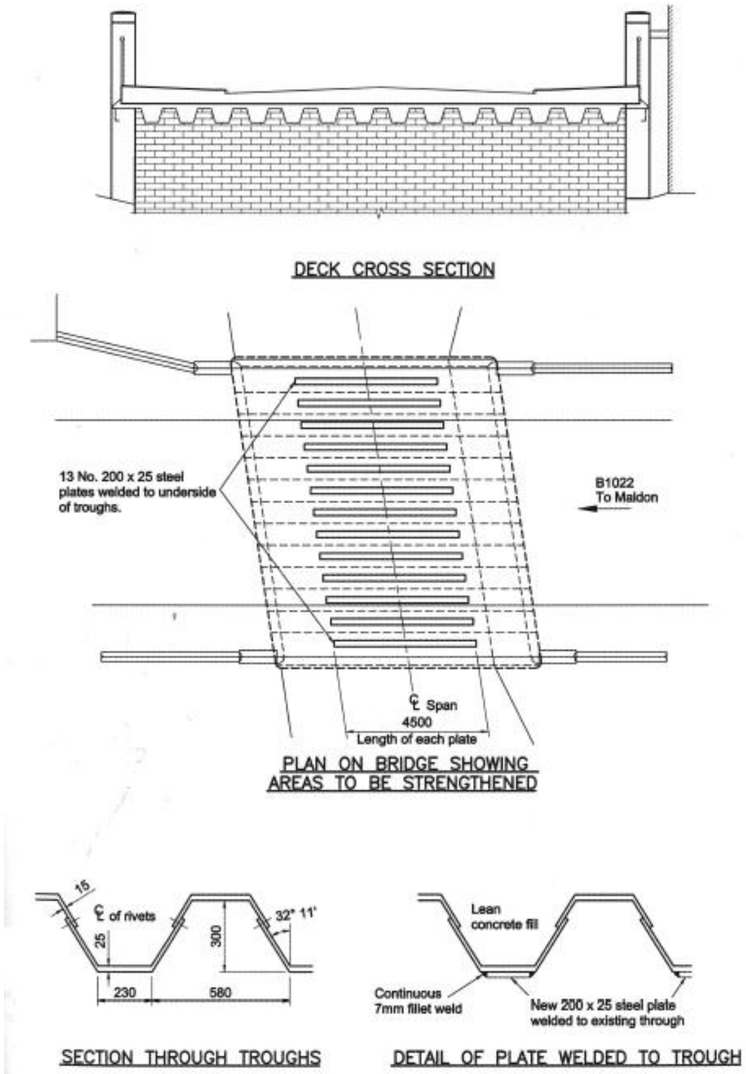


Figure 6.1 Wave Bridge-flange plates

Figure 6.2 Wave Bridge

Figure 6.3 Flange plates

Figure 6.4 Canal boat passing under Wave Bridge

7. Case Study 7

Honey Lane Bridge-flange channels to steel I-beams [1]

Bridge	Honey Lane Bridge, Waltham Abbey is a single-span bridge which carries a very busy single carriageway road over a channelised watercourse located in a built-up area (see Figure 7.2). The area is prone to flooding. The deck comprised riveted built-up !-section beams with a concrete slab. The deck is supported by brick clad concrete abutments.
Introduction	
Weakness	The bridge was assessed as part of the national assessment programme and failed to achieve 40 t assessment loading. The failure mode was mid-span sagging of the steel beams.
Strengthening limited	Due to the lack of an alternative route for the large numbers of heavy vehicles using the road over the bridge a weight restriction was not a viable option. The need to maintain two-way traffic flows meant that deck replacement or schemes involving changes to the carriageway layout were not suitable options. Strengthening measures below the deck were limited by the need to maintain the waterway opening. The Environment Agency restricted any lowering of the soffit level to a maximum of 25mm.
Strengthening proposed	An option study was carried out and it was decided to strengthen the bridge by welding additional steel plate to the underside of the existing beams. To achieve the required capacity steel troughs were required as the capacity could not be achieved with steel plate alone within the imposed restrictions (see Figure 18.3).
Strengthening works	The steel troughs were tack welded into place and subsequently fixed by continuous fillet welding. The deck was then blast cleaned and a new paint system applied.
Prior inspection	Prior to developing a strengthening scheme a site inspection was made to locate services, accesses, and check the conditions of the existing steel and paint system. Steel samples were taken and tested for strength and weldability. Paint samples were taken and tested for lead content in view of the risk of contamination of the watercourse.
Traffic management	None required beyond limiting delivery times to outside of peak hours.
Testing afterwards?	The welds were tested using ultrasonic and MPI. The paint system was checked using an electronic thickness gauge.
Within programme?	The work was finished within programme and with minimal disruption to traffic.
Within costs?	The work was completed within the cost targets set. The cost of deck replacement was not investigated as this option would cause unacceptable traffic disruption. Deck replacement would have been much more expensive than the strengthening carried out.
Anything went badly?	The contractor experienced difficulty with welding the trough to the bottom flanges of the existing beams.
What changes if do again?	No major changes.

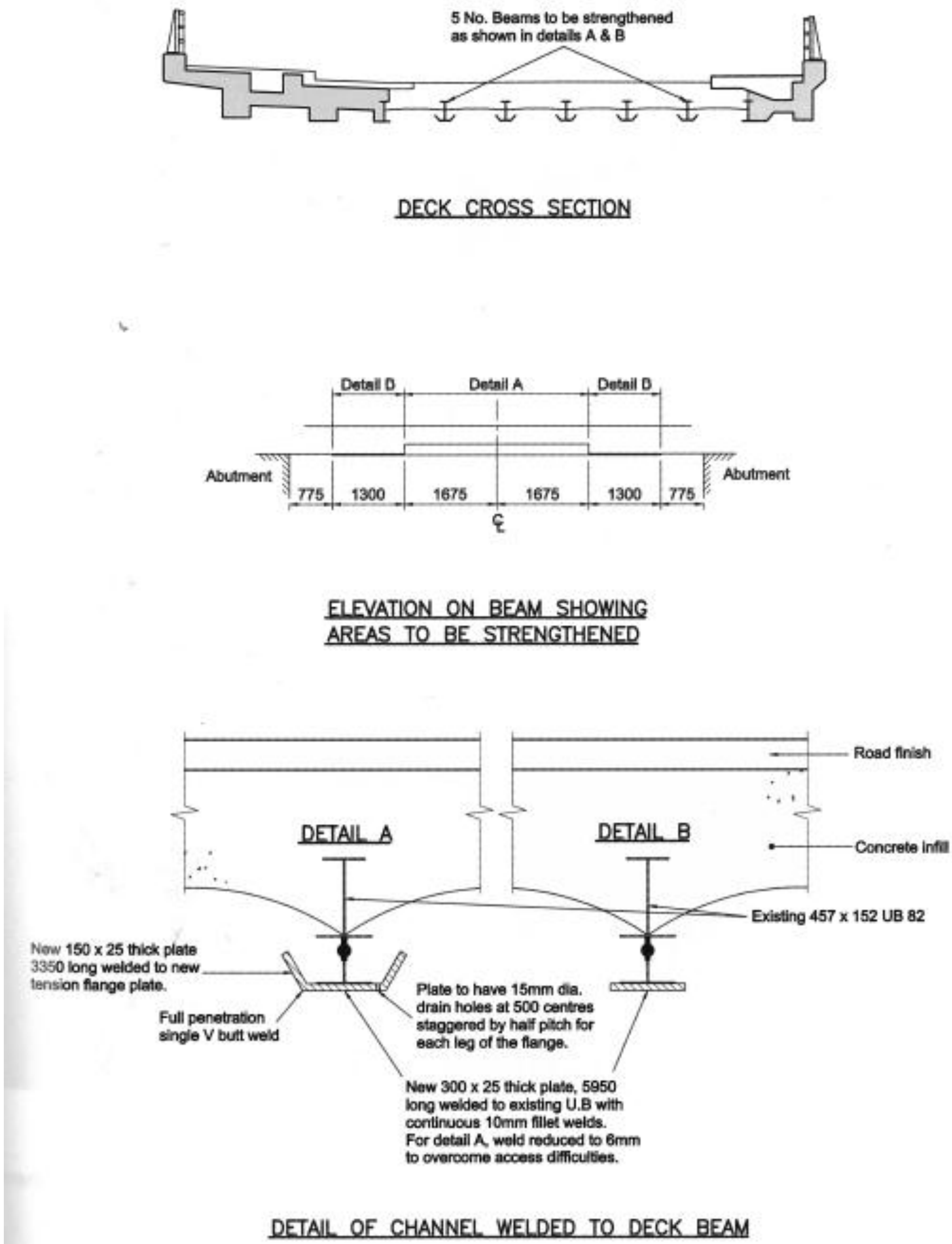


Figure 7.1 Honey Lane Bridge-flange channels to steel I-beams

Figure 7.2 Honey Lane Bridge

Figure 7.3 Flange channels

8. Case study 8

North Bridge-additional beams [1]

Bridge	North Bridge, Colchester.
Weakness	The bridge was overstressed in the side spans which still contained cast-iron plates and beams. In the centre span, replacement steel beams could not carry the full load as a result of a potential failure in buckling due to the unrestrained top flange.
Strengthening installed	Additional universal column sections were provided between the cast-iron beams. Transverse rectangular hollow sections were provided to transfer load from the cast-iron plates.
Alternatives considered	Re-decking with a 300 mm RC slab would have caused traffic problems. Structural steelwork underneath was also considered as was spray concrete to the underside of the bridge.
Prior inspection	Full principal inspection.
Prior testing	Grade of steel/welding capabilities.
How fasten? How fit?	Additional UC beam on the underside of the side spans supporting Rectangular Hollow Sections (RHSs) to carry the deck. The UC beams were supported by stub beams cast into the abutment and pier walls. Additional welding was carried out on the centre span to restrict the movement of the top flange.
Traffic management	Not required and not allowed (except Sundays for loading and unloading).
Testing afterwards?	MPIs
Within programme?	4 weeks overrun.
Within costs?	£15 000 overspend (extra unforseen problems).
Problems revealed?	Additional welding and plating was required to the existing steelwork where it was badly corroded.
Anything went badly?	The dry packing between the new steelwork and the existing soffit.
What changes if do again?	Amend the dry packing specification.

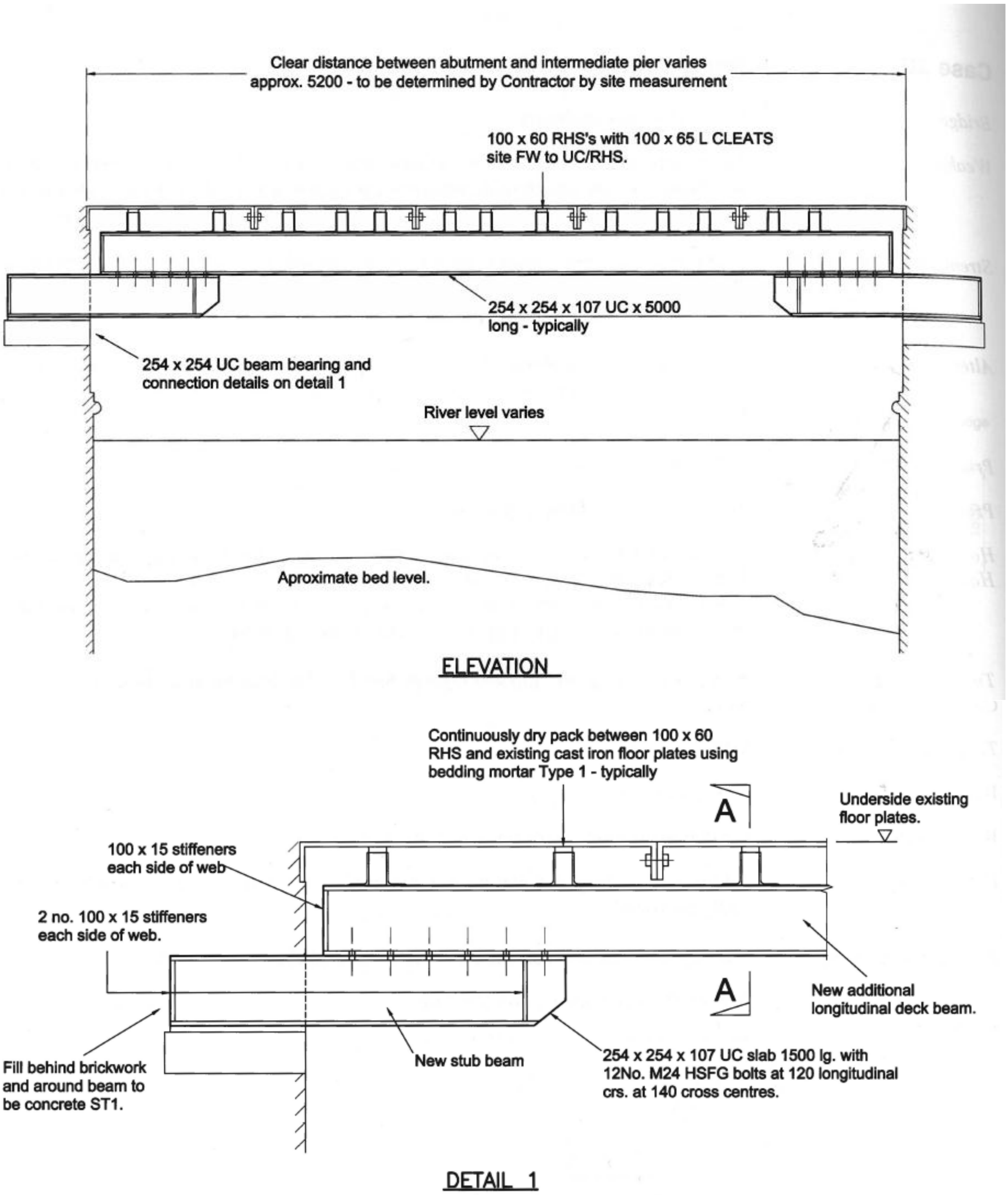


Figure 8.1 North Bridge-additional beams

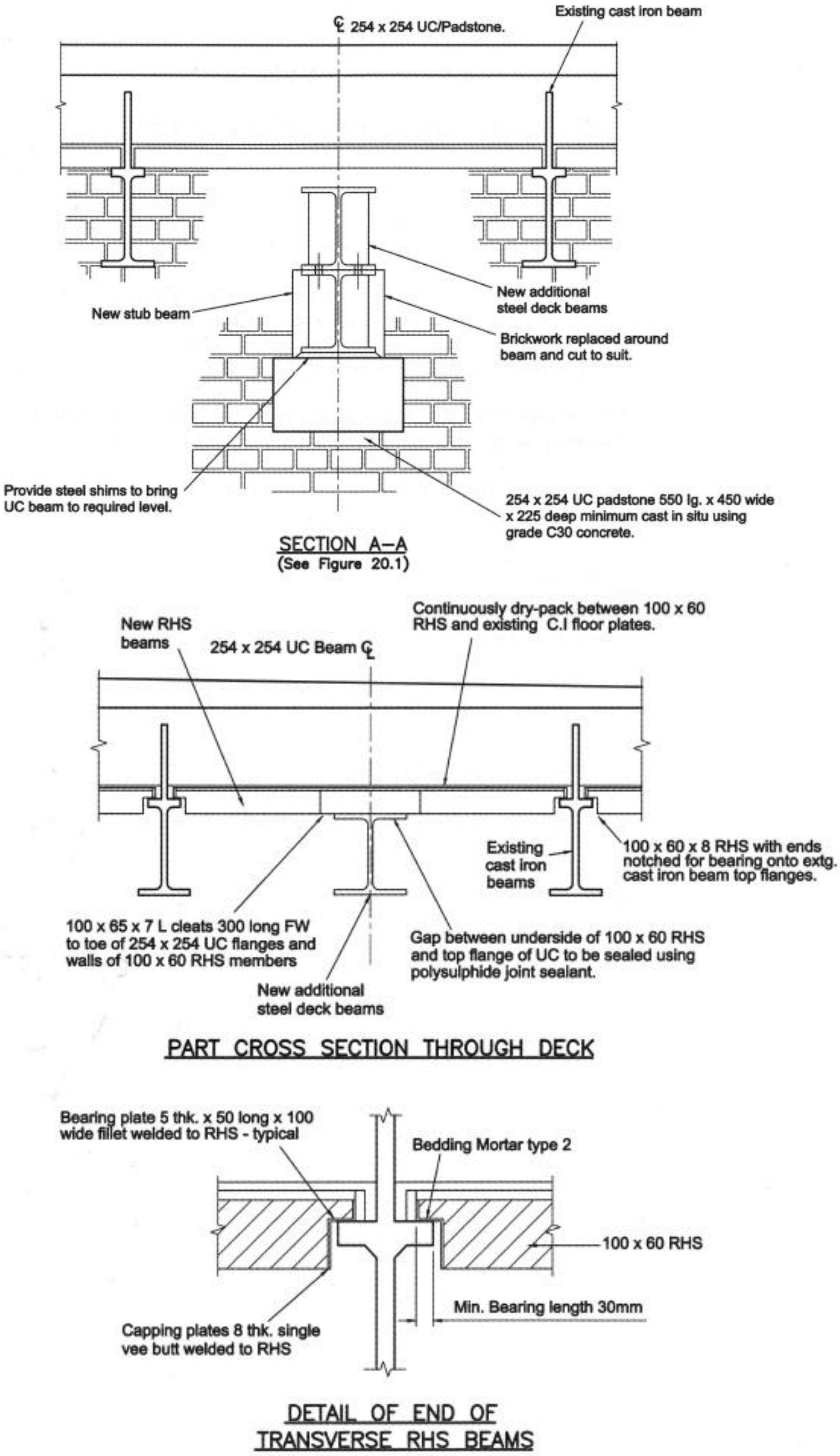


Figure 8.2 North Bridge-additional beams

9. Case study 9

Avonmouth Bridge-prestressing [1]

Bridge	Avonmouth Bridge, M5, 1400m twin steel box girder with composite concrete deck on the approach spans and an orthotropic steel deck on the haunched 174m main span and side spans (see Figure 9.3). The superstructure is supported on steel knuckle bearings fixed to longitudinally slender concrete columns. The bridge is fixed at its abutments with the slender columns allowing longitudinal movement due to temperature effects. A single movement joint at the steel deck/concrete deck interface allows for the ±600 mm movement.
Weakness	Having been designed to BS 153 and carrying dual three-lane road plus hard-shoulder, the bridge was to be strengthened to BD 37/88 to carry dual four-lane carriageway plus hardshoulder and a combined cyclewayjfootway within the existing overall width. Due to the additional loading, for which the bridge had to now be designed, the distorsional bending stresses, tension and compression flange stresses and the web shear stresses within the box girders were all above acceptable limits. BS 5400: Part 3 showed the V-troughs of the orthotropic deck not to comply with the shape limitation requirements, implying a reduced effective section and no allowance for their torsional stiffness. The cross-girders linking the two box girders also had insufficient stability and bending resistance.
Strengthening limited	Mill certificates were used to provide actual yield stress which was reduced by 10 N/mm2 to provide nominal yield stress. BD 37/88 footway loading reduced. During an event on the River A von likely to produce a crowd loading, the hardshoulder would not be used as a running lane. Partial load factor on surfacing taken as 1.2 at ULS with specified tolerance on new and future surfacing thickness as +5 mm.
Strengthening installed	In the approach spans a set of Macalloy bars anchored near the top of each pier diaphragm fans out to support the bottom flange, thereby reducing the hogging movement over the piers and relieving some of the shear in the webs (see Figure 9.4). Surfacing was removed, and trestle supports at the third points of both adjacent spans were also used to temporarily jack up the deck, reducing locked in dead load and "background" live load effects prior to any strengthening works. In the main spans, circular hollow steel section struts were laid on the bottom transverse stiffener between the pier diaphragm and the third point of the span. Here a prestressing tie was installed leading to a saddle near the top of the pier diaphragm hence reducing global moments and shear forces within the boxes (see Figure 9.5). Where the effects of the prestressing could not remove overstresses within the existing box girders, web plating and additional stiffening was utilised. Adding additional plating and lateral restraint members strengthened the cross-girders. Increasing the torsional and distorsional resistance of the boxes was achieved by the addition of X-shaped bracing members.
Alternatives considered	Plating and adding new stiffening to the box girders, without the use of the third point propping system or cable support system, was considered. This however would have increased the weight of the strengthening by approximately 3000 t. External plating of the box girders was considered, but because of concerns regarding safety during installation, and future inspection and maintenance issues this was discarded.

Prior inspection	Detailed fatigue assessment based on strain gauging of critical details. A Radar survey of the surfacing thickness, concrete cores to determine strength and thermal expansion of the structure. Straightness and flatness checks of the existing plating and stiffeners.
Prior testing	Strain gauge readings taken under the passage of abnormal loads.
How fasten?	The Macalloy bars were attached to brackets welded to the diaphragms and to transverse and longitudinal bottom flange stiffeners. The prestressing tendon saddles were built into the diaphragms which were stren-gthened vertically. The tubular struts were tied down to bottom flange transverse stiffeners by brackets which allowed longitudinal movement.
Traffic management	Three lanes of traffic in each direction were maintained. A weigh-in-motion system combined with a number plate recognition system computed the weight of traffic on the bridge and rang an alarm on the limited occasion when loading exceeded that assumed during welding. In the event no special corrective measures were required.
Testing afterwards?	The Macalloy bars and prestressing cables have strain gauges and load cells fitted respectively, enabling monitoring to be carried out and comparisons to be tp.ade with the anticipated loadings.
Within programme?	Major programme delays took place at the start of the project resulting from forced changes due to the unforeseen condition of the structure. The revised programme has been achieved.
Within costs?	The traditional ICE 5th contract, was subsequently modified and a secondary agreement based on fair value linked to a target price for specific elements.
Problems revealed?	Following paint removal a number of fatigue cracks were found in existing welds in the bridge overall. Minor defects were also found in existing box girder welds, which although not an immediate problem, would be covered up by strengthening works and hence needed to be repaired.
Anything went badly?	Site team and associated personnel from their respective organisations acted profess-ionally and together, with a team approach.
What changes if do again?	For work of an unusual nature where intricate fabrication changes could exist a target price contract would be preferable.

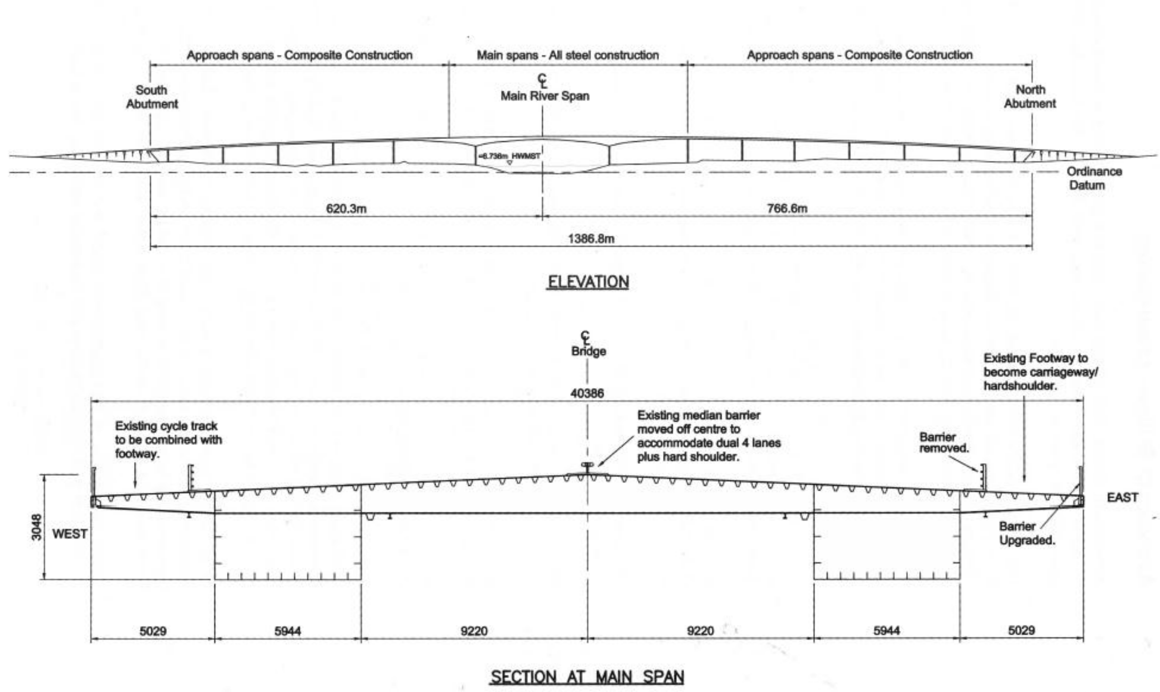
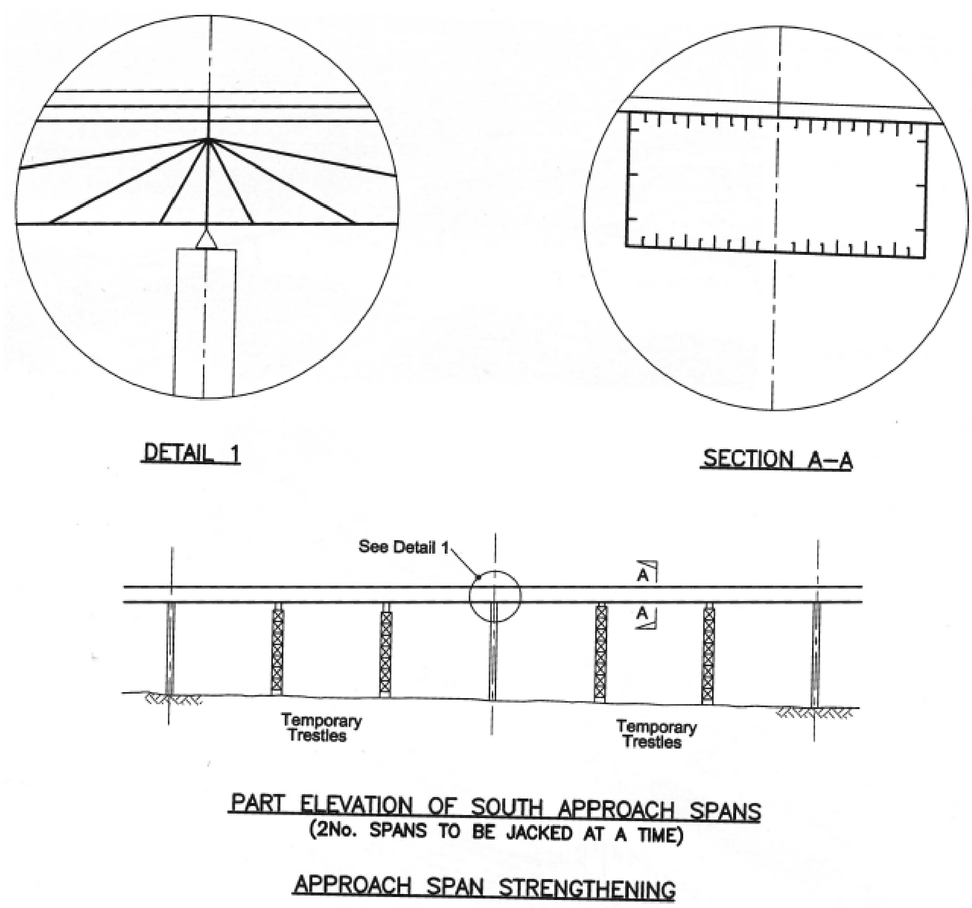


Figure 9.1 Avonmouth Bridge-prestressing



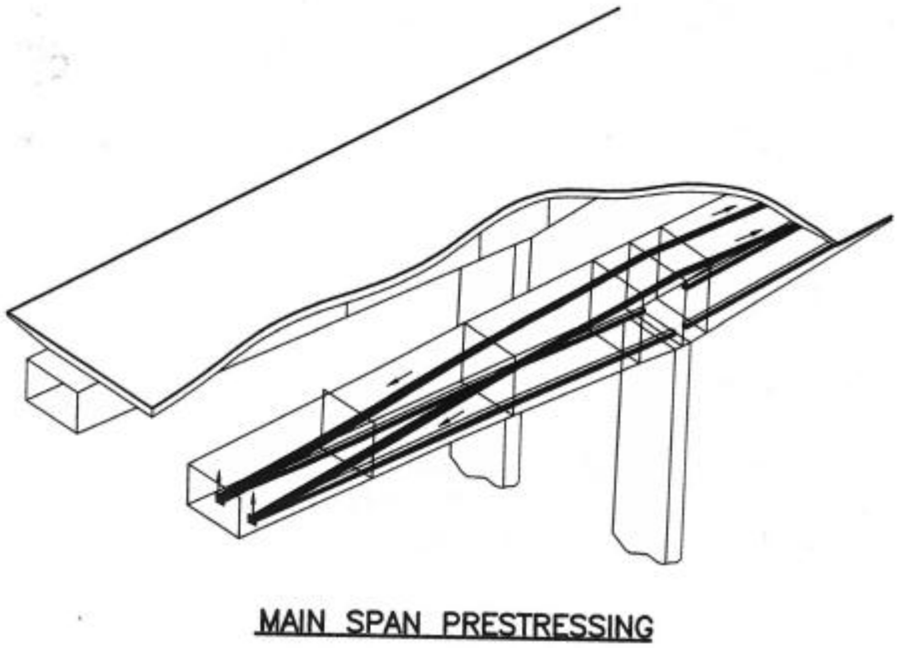


Figure 9.2 Avonmouth Bridge-prestressing

Figure 9.3 Avonmouth Bridge

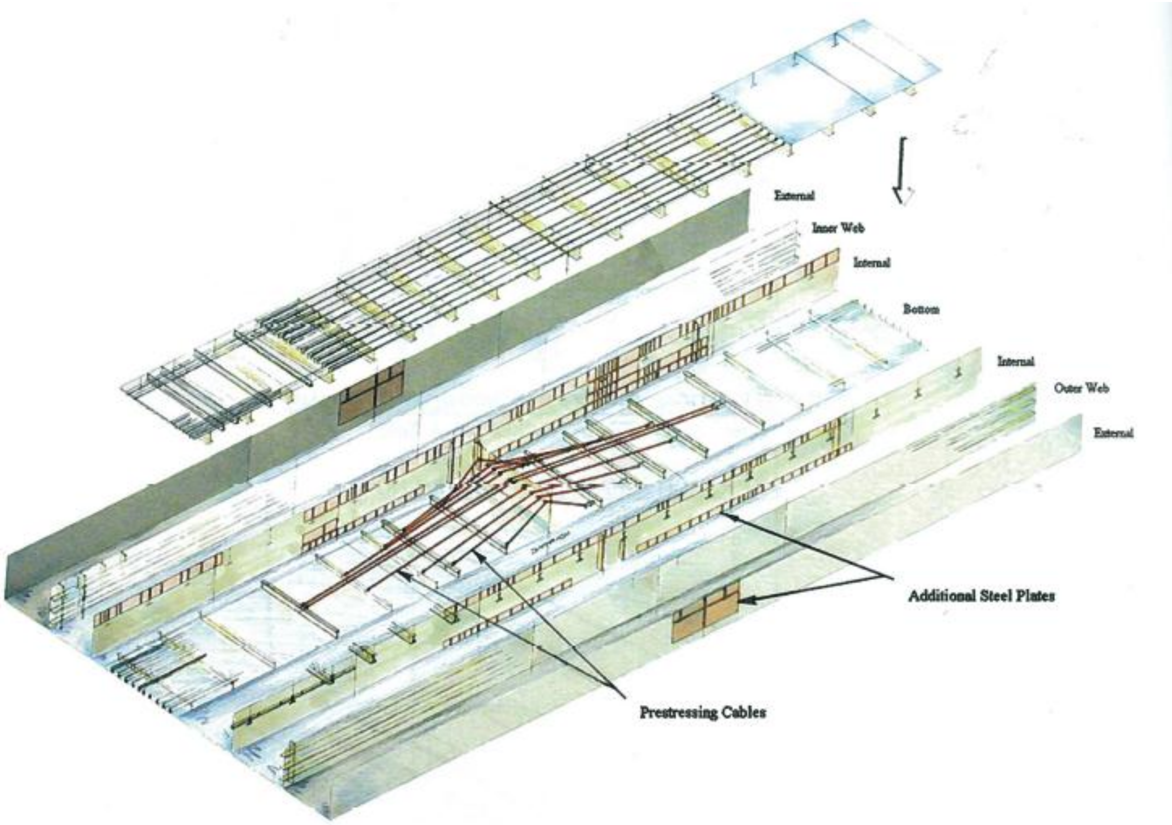


Figure 9.4 Avonmouth Bridge side spans

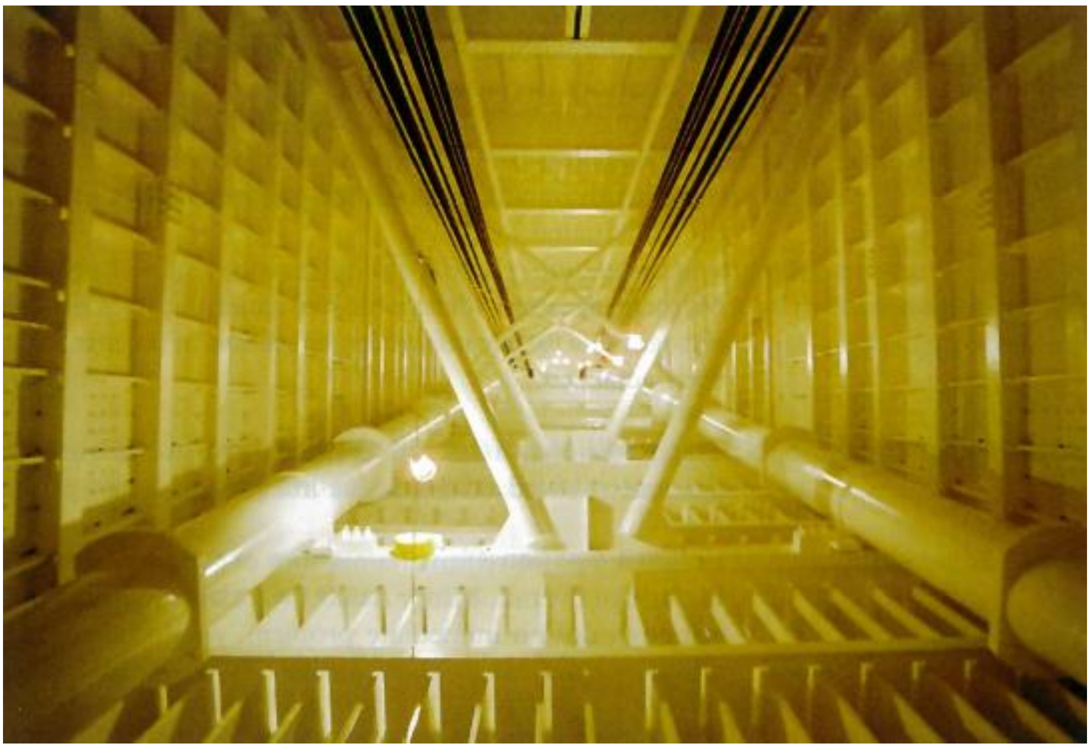


Figure 9.5 Avonmouth Bridge main span

10. Case study 10

New Road Overbridge-heat straightening [1]

Bridge	This is a four span continuous structure supported on three intermediate piers, with bank seats all on piled foundations. The structure carries an unclassified road over the M5. The superstructure consists of four universal beams in pairs, spliced on top of the piers, cast in situ with the concrete deck to act compositely.
Weakness	The southern most beam on the North bound carriageway was struck over lane 1 by an articulated tipping container resulting in displacement of the bottom flange over the entire three lanes. The maximum displacement over lane 1 was approximately 500mm.
Strengthening limited	Access over the bridge had to be maintained overnight. The quickest possible repair was required to keep traffic management costs to a minimum.
Strengthening installed	The damaged beam was heat straightened (see Figure 10.4). Two bracings and two web stiffeners were also fitted.
Alternatives considered	Replacing the entire beam was considered, but rejected as too costly and too long a duration. A cut out and welded replacement of the damaged section was also con-sidered but rejected as more expensive than the heat straightening. The cut out and weld option was adopted as a contingency option should the heat straightening fail.
Prior inspection	The damaged beam was measured during night-time lane closures. The shear studs in the concrete deck were exposed and MPI tested. The major damaged areas of the beam were MPI tested.
Methodology	The basic concept of heat straightening is relatively simple. Heat is applied with a torch to plate elements of a member at localised regions in a progressive fashion. The heat is applied in an unsymmetrical manner such that the internal redundancy of the plate elements impedes longitudinal expansion while expediting expansion through the thickness so that plastic deformations occur. During the cooling phase, the longitudinal contraction is less restrained and thus greater than the original expan-sion. The net effect is that curvature is produced. By applying the process cyclically and controlling the external restraint conditions, the temperature variation, the size and location of heats, and the number of heating cycles, permanent modification to the geometry of structural steel members can be achieved in almost any form. Heat straightening repair of a damaged steel member involves applying a limited amount of heat in specific patterns to the plastically deformed regions in repetitive heating and cooling cycles to produce a gradual straightening of the material. The process relies on internal and external restraints that produce thickening during the heating phase and in-plane contraction during the cooling phase. Force is not used as the primary instrument of straightening, which distinguishes it from other methods.
How heated?	Twenty-four heating cycles consisting of various V-shaped heats in bottom flange, line heats to the convex side of the yield zone at the top of the web and vertical strip heats to the web to coincide with the V heats to the bottom flange. Research shows that the steel properties will remain unchanged at temperatures below 650°C. In practice the steel was heated to between 550 and 600°C. The temperature was controlled by visual inspection of the colour of the heated steel below the oxy-acetylene flame.
How	Four jacks initially used. Two at impact points (the corners of the

restrained?	articulated trailer) and two points midway between the impact points and the ends of the beam. The outer restraints were removed after heat cycle 8. The jacks were used for restraint purposes only during heating. The jacks were not used to "bend" the beam straight.
Traffic management	Contraflow installed on the M5 for a period of 3 weeks. Removed after 2 weeks due to early completion of the works. The lane over the damaged beam had been closed since the accident. This was protected by TVCBs and traffic controlled by temporary traffic lights. No traffic was allowed over the bridge while work was underway.
Testing afterwards?	MPI of entire beam. Two cores from bottom flange and one from web subject to chemical analysis, microstructural examination, grain flow determination, hardness, Charpy impact test and tensile strength. No significant defects or alterations to the steel were found.
Within programme?	Finished after 2 weeks of a 3-week programme.
Within costs?	Completed within the estimate.
Problems revealed?	The bent beam was considerably stiffer than expected.
Anything went badly?	No.
What changes if do again?	More initial analysis of damaged beam. More equipment on standby on-site.

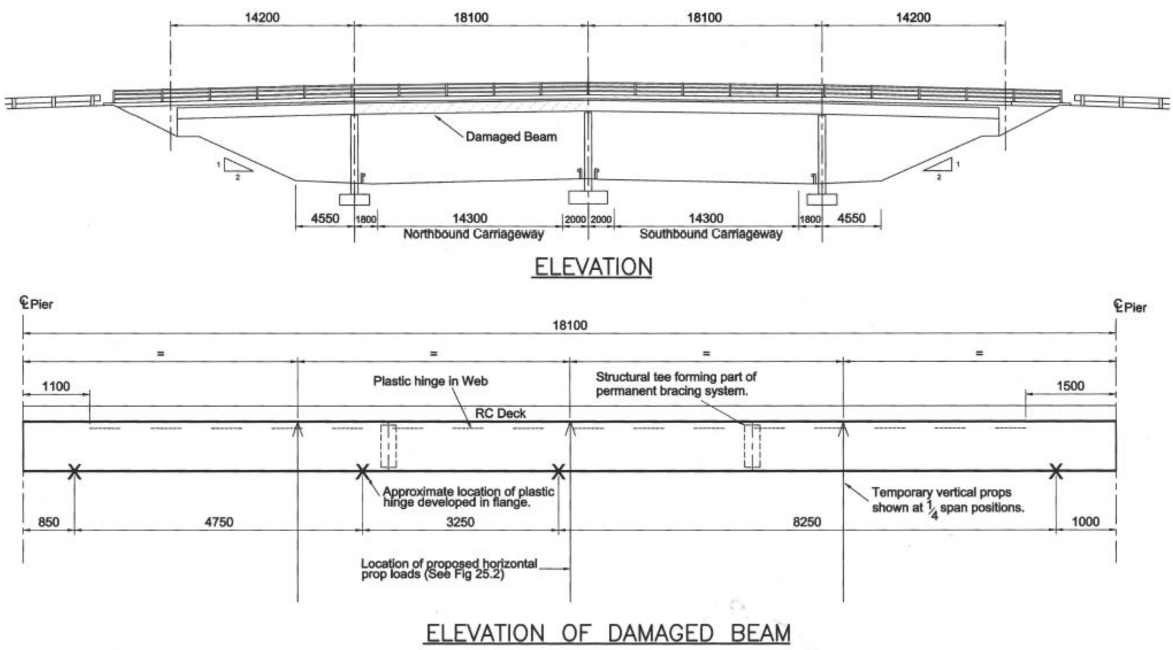


Figure 10.1 New Road Overbridge-heat straightening

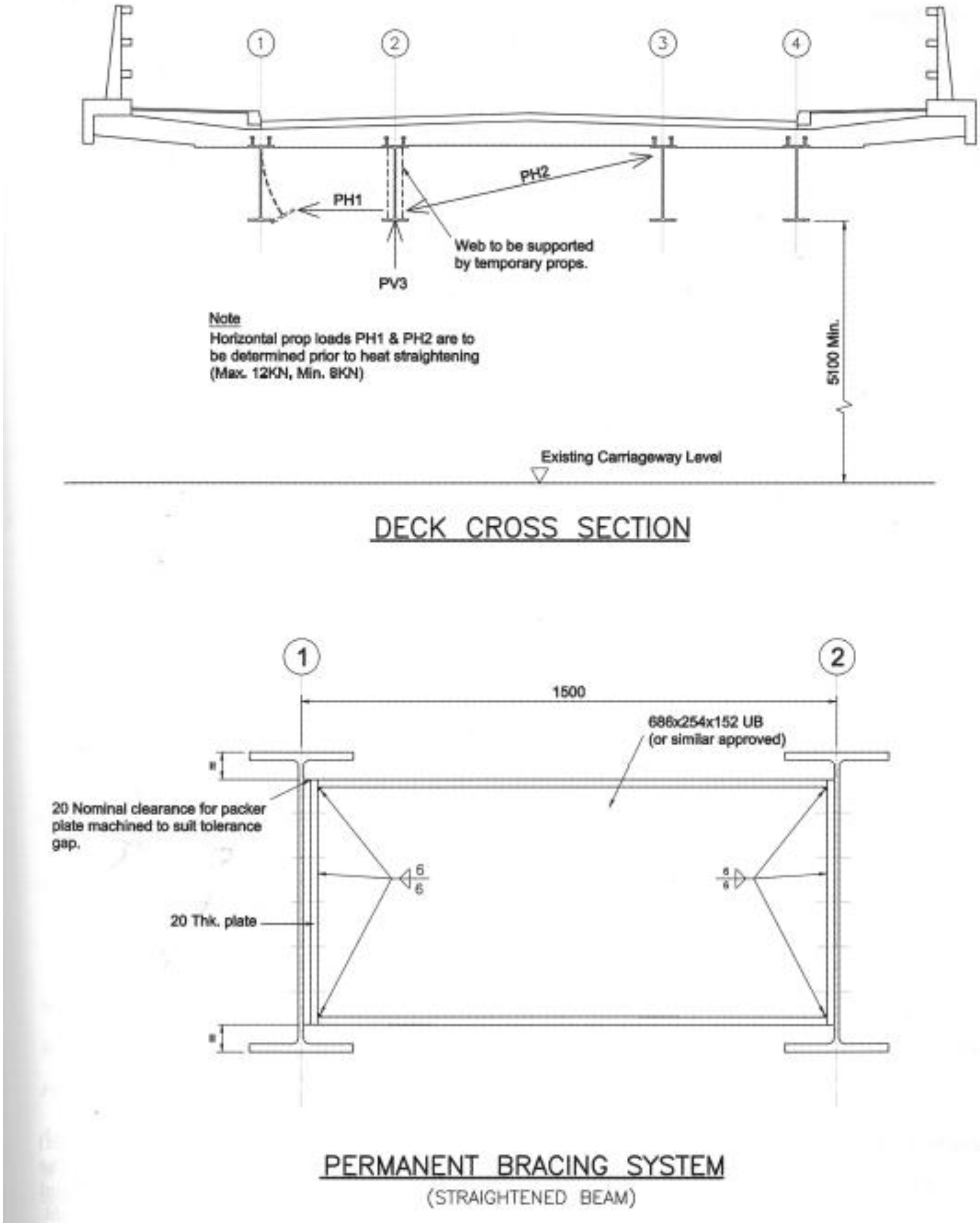


Figure 10.2 New Road Overbridge-heat straightening

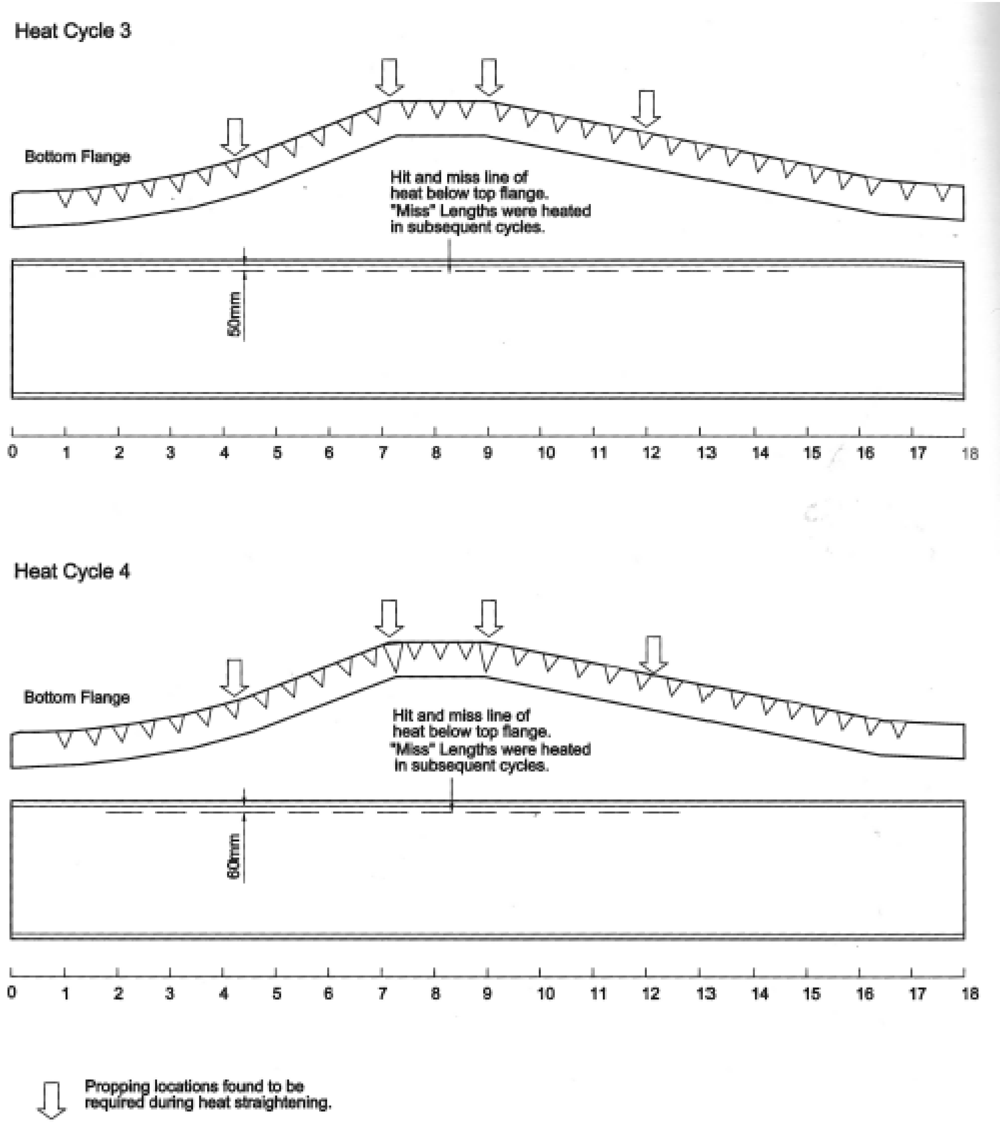


Figure 10.3 New Road Overbridge-heat straightening

Figure 10.4 New Road Overbridge-heat straightening

11. Case study 11

Erskine Bridge collision damage [1]

Bridge	Erskine Bridge carries the A898 across the River Clyde 9 miles west of Glasgow. The bridge comprises 15 spans of continuous longitudinally stiffened steel box girder with a cable-stayed main span of 305m and an overall length of 1321 m (see Figure 11.1).
Introduction	
Weakness	The bridge was struck near mid-span by an oil rig (which was being towed up the Clyde) in August 1996. The pulley at the top of the rig punctured the base of the web and scored a groove in the bottom flange as it passed below. The impact occurred adjacent to an intermediate diaphragm which was badly buckled across its lower edge in the collision. The longitudinal flange stiffeners were also badly distorted and some of the stiffener-flange welds had failed.
Strengthening limited	The strengthening was confined to the areas of damage.
Strengthening installed	Temporary steel "eggbox" frame was bolted around the tear to allow the bridge to be reopened to 3 t vehicles (see Figure 11.2). Holes were drilled at the ends of cracks to prevent further propagation. Permanent strengthening comprised external doubler plates bridging across the deformed bottom flange area. The voids between doubler plates and distorted flange plates were filled with injected polysulphide sealant. The damaged bulb flats were cut away and replaced by steel flats bridging the gap. Two additional transverse stiffeners were installed either side of the damaged region. The lower buckled portion of the damaged diaphragm and starter plates was cut away and the remainder of the diaphragm was strengthened by the addition of horizontal and diagonal steel angles to create a "truss" spanning between webs (see Figures 11.3 and 11.4).
Prior inspection	A detailed internal and external survey was carried out to determine the extent of damage and the size of distortions. The external survey was carried out initially by abseilers and later in more detail using a suspended gantry.
Prior testing	MPI around damaged areas.
How fasten?	High friction grip bolts were generally used to minimise further distortion.
How fit?	All internal components were made small enough to be man-handled and for transport through access holes. Outer doubler plates were lifted from inside the box via strands through holes in the bottom flange. Templating was used for all steelwork.
Traffic management	One carriageway of the bridge was kept open to 3 t vehicles once the temporary strengthening had been installed. The carriageway that was kept open depended on which portion of the diaphragm was undergoing repair.
Testing afterwards?	Draw-wire displacement sensors and strain gauges were installed at critical points around the damaged areas to warn of unexpected movement. These sensors were left in place after the bridge was reopened to heavy vehicles to monitor behaviour. MPI testing of the weld reinforcement to existing diaphragm starter plate welds was

	carried out.
Within programme?	Yes. Work completed within 30 weeks.
Problems revealed?	Grit blasting could not be used to remove the lead-based paint due to the likelihood of damaging the prestressed bars in the vicinity of the repair zone. Solvents were used to remove the paint.
Anything went badly?	Nothing significant.
What changes if do again?	No major changes.

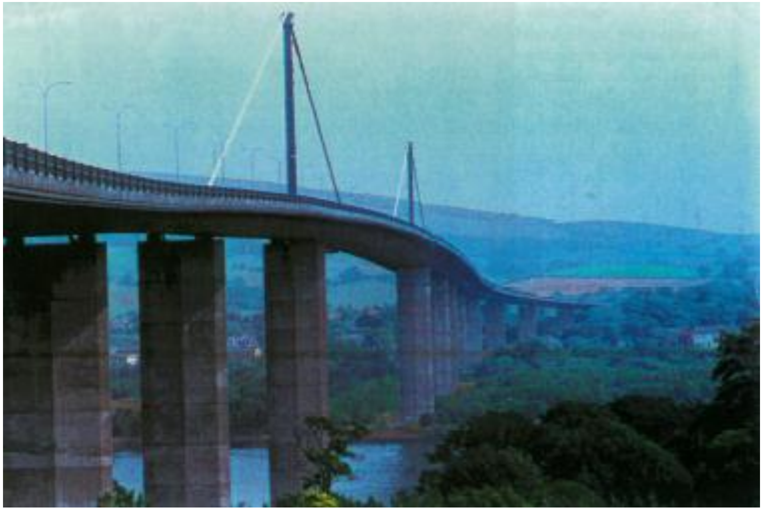


Figure 11. 1 Erskine Bridge (the photos of Erskine Bridge repairs are produced by courtesy of The Flint and Neill Partnership)

Figure 11.2 Temporary repair

Figure 11.3 Internal permanent repair

Figure 11.4 External permanent repair

References

[1] Reid I.L.K., Milne D.M., Craig R.E (2001): Steel bridge strengthening: A study of assessment and strengthening experience and identification of solutions, London, 2001.