eJSE International

Electronic Journal of Structural Engineering, 7(2007)

Common pathologies in RC bridge structures: a statistical analysis

J. Santos, C. Nunes, C. Fernandes & H. Varum

Department of Civil Engineering, University of Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal

ABSTRACT: One of the main tasks in bridge engineering is to maintain the existing bridge stock according to current and predicted traffic and safety requirements. Bridges deterioration commonly occurs due to a wide variety of pathological factors, with origin in, for example: unexpected traffic loads, vehicle impacts, environmental factors, earth movements, chloride attack, carbonation effect, lack of maintenance, de-icing salts, degradation of the drainage systems, pavement quality. Considering this, a statistical analysis of the most common pathologies in bridge structures, their origin and consequences, was carried out. This analysis was performed considering the pathologies for the overall structure, and for each bridge component. A total of 85 reinforced concrete bridges, representative of the bridge stock in Portugal, were analyzed. Additionally, a comparison of the obtained results with a similar study for Germany was developed. The main differences between the results obtained for each country within this study are pointed out.

1 INTRODUCTION

Bridges are an important part of the country's patrimony and considerable financial effort is presently being made to maintain their safety and functionality (Brito et al. 1997). Nowadays, there are two main tasks in bridge engineering. One is the development of new projects, considering new construction technologies and new materials. The other, which is probably the most important, is the maintenance of existing bridges in order to prevent their fast deterioration and to keep their serviceability to the increasing traffic loads. Preventing deterioration should begin in the structure's project and execution stages, assuring the quality of the materials, of the project and of the execution, what implies the knowledge of the possible deteriorations and its causes (Johnson 1973). In the last decades, the fast deterioration of existing bridges has become a strong economical and technical issue, registered all over the world. In most cases, the rehabilitation of a bridge is far more expensive then its maintenance, a procedure that should be carried out correctly during all of the structure's life time. Many factors can lead to the deterioration of these structures. The most important ones, which have being affecting the bridges for the last 20~30 years, are (Radomski 2002, Patjawit & Kanok-Nukulchai 2005, Yang et al. 2006): i) The increasing traffic and loads of the vehicles, usually larger than the values considered at the original design; ii) The bad influence of environmental pollution over the construction materials; iii) The low quality of the used equipments, like in expansion joints, bearing equipment, drainage systems, among others; iv) Lack of maintenance; and, v) The use of de-icing salts, which are used only in some particular locations in Portugal. Bridges are also affected by other multiple hazards, such as floods and earthquakes (Adey et al. 2003), which are an important cause of damage and collapse of these type of structures. Earthquakes, such as the 1989 Loma Prieta and 1994 Northridge earthquakes in California, and the 1995 Kobe earthquake in Japan, have caused collapse or severe damage to a considerable number of major bridges that were at least nominally designed for seismic forces (Priestley et al. 1996).

2 INSPECTIONS, MAINTENANCE AND REHABILITATION

2.1 *Inspections*

Bridge inspection is immanently related with bridge maintenance and evaluation of the technical condition of bridge structures. The methodology and scope of bridge inspection are usually determined with regard to the relevant instructions, guidelines, standards or other official regulations. Bridge inspection can be classified into the following groups, depending on its scope and frequency (Radomski 2002): i) Cursory inspection, carried out by road maintenance staff during routine road inspections, normally every day; ii) Basic inspections, carried out usually at least once a year by local bridge inspectors; iii) Detailed inspection, carried out at least every five years on selected bridges by regional bridge inspectors; and, iv) Special inspections, carried out by highly qualified experts and researchers according to technical needs, normally as a consequence of questionable results from basic or detailed inspections. It is necessary to determine the capacity, and assess the safety, of a bridge after unexpected or accidental loads, in order to establish its ability to resist acting loads, or to indicate the rehabilitation and strengthening needs.

It is important to emphasize that each inspection is unique. The inspection process varies, depending on many technical, economic and regulatory factors (Branco & Brito 1996, Radomski 2002). Bridge inspection can be considered as the most important element of a bridge evaluation and assessment, and is directly related with bridge rehabilitation, because inspections are instituted to determine the existing condition of the structure from which recommendations for repairs, if necessary, can be formulated (Brinckerhoff 1993).

2.2 *Maintenance*

The term maintenance is usually limited to the current works performed systematically by maintenance services to ensure normal and safe utilization of bridge structures. These works consist mainly of inspection, maintenance, repair and replacement, if necessary, of expansion joints, bridge deck, drainage system, railings, balustrades and barriers, pavement, bridge bearings, etc, as well, as anti-corrosive protection of some elements, mostly by painting. In many cases, the maintenance of existing bridges, according to the determined technical and economical requirements, demands other essential actions, prior to the current maintenance itself. Therefore, the term maintenance may also be considered, more widely, as a multi-component process leading to the fulfillment of all conditions related to the safe utilization of existing bridges in the anticipated period of their future service (Frangopol 1999, Radomski 2002).

The actions of maintenance can be divided in two kinds, corrective or preventive actions. Actions of preventive maintenance should assure the normal operation of the bridge and respective equipment, being able to develop repair works or actions of little damages. Preventive actions applied to non deteriorated components are designated as proactive and their objective is to delay the time of damage initiation. Preventive maintenance actions applied to deteriorated components are denoted as reactive, and they aim at eliminating or reducing the effects of the deterioration process (Yang et al. 2006). Corrective maintenance consists in important repair actions, including reinforcement of some of the bridge components, with the objective of, at least, replace the initial conditions of service, or to ensure better ones (Nunes & Santos 2005).

2.3 *Rehabilitation*

Rehabilitation means to restore, to make suitable, to put back in good conditions, to re-establish on a firm basis, to bring back to full use, to reinstate, to renew and revive. Rehabilitation concerns mostly of the whole structure, including its primary structural members. However, it can also include works of modernization, which are a form of upgrading by adding new features, e.g. new traffic flow arrangement, new signs, new lighting, new barriers. This term is commonly applied to structures designed and constructed prior to availability of these modern features. However, modernization can also be considered in a wider meaning. For instance, the upgrading of a bridge requires in many cases its strengthening, new traffic flow arrangement requires the widening of the bridge deck, and so on (Radomski 2002).

3 PORTUGUESE STATISTICAL ANALYSIS

A statistical analysis of anomalies and pathologies detected in 20 to 30 years old existing reinforced concrete (RC) highway bridges (viaducts and over highways), in different locations of Portugal, was performed based in inspection reports of bridges, with the objectives of identifying: i) the most common pathologies in RC bridges; ii) the most affected components; and, iii) the probable causes of these pathologies. A total of 85 bridge structures were analyzed. The results of this statistical analysis were compared with a similar study made over 100 bridges in Germany.

3.1 *Results analysis*

From the inspection reports of the studied bridge structures, the most important results were analyzed. These global results obtained from the rapid screening inspection methodology can be a useful tool in alerting the responsible entities about the priority for a more detailed bridge inspection campaign, maintenance and rehabilitation.

Table 1 summarizes the basis for the global analysis of 85 RC bridge structures in Portugal, concerning the main pathologies that affect each of their components. Since each bridge structure is unique because of its function, technical restrictions in the construction, age, etc., some components do not exist in every bridge structures, as shown in left column of Table 1 (EP 2003, LUSOSCUT 2003). The pathologies identified at each bridge component (right column in Table 1) are presented in percentage relatively to the studied structures in which this component exists.

From the analysis of Table 1, the following conclusions can be drawn:

There are components of the bridge structures that stand out with high percentages of pathologies, such as the abutments, drainage systems, expansion joints and bearing equipment.

The high percentage of pathologies registered in expansion joints, bearing equipment and drainage system is probably due to the lack of maintenance or to a misuse of the structure.

The location of the bearing equipment in middle supports certainly justifies the small incidence of pathologies verified at these components, because they are usually better protected from the water action, particularly the ones located under continuous girders beams.

– All the deficiencies in the drainage systems, or the lack of some of its elements, normally lead to several pathologies in other bridge components, such as quick degradation of abutments and bearing equipment, as well as to deterioration of the concrete surface of the structural components and steel reinforcement corrosion.
– Superficial pathologies are also generally verified in the structure. Usually they have no major structural stability consequences. The less affected components with the superficial pathologies are the pavement and the bearing equipment in middle supports.
– Pathologies verified in secondary components such as footways, rail-guards or safety-guards do not affect the global structural safety. However, when they are very severe, like unstable cracking or broken fastenings of the guards, they should not be disregarded, because can even be a threat to pedestrians.

Table 1. Pathologies of each component in bridge structures analyzed.

Bridge component	Bridges where this component exists (out of 85)	Pathologies identified (%)
Deck	85	57
Abutment	85	73
Wing wall	82	22
Expansion joints	62	64
Bearing equipment	65	62
Intermediate bearing equipment	67	17
Slopes	83	54
Drainage system	59	71
Cornice	85	37
Guard-rail	85	57
Safety-guard	79	53
Pavement	83	10
Footways	82	48
Other components	85	54

3.2 *Most common pathologies*

Table 2 summarizes the most common pathologies observed at each component of the bridges under analysis.

The main pathologies verified in RC components, namely in decks, abutments and wing walls are concrete cracking and delamination with consequent concrete spalling, and reinforcement exposure and corrosion. These pathologies may have their origin in a poor finishing of the concrete surfaces, or in an inadequate arrangement of the steel reinforcement or even by an inadequate concreting or demoulding. The pathologies related to the drainage systems, like garbage and fragments accumulation, are essentially due to improper use and to the absence of maintenance (EP 2003, LUSOSCUT 2003).

Graphics in Figures 1-4 show the pathology incidence that affect decks, abutments, expansion joints and slopes, respectively.

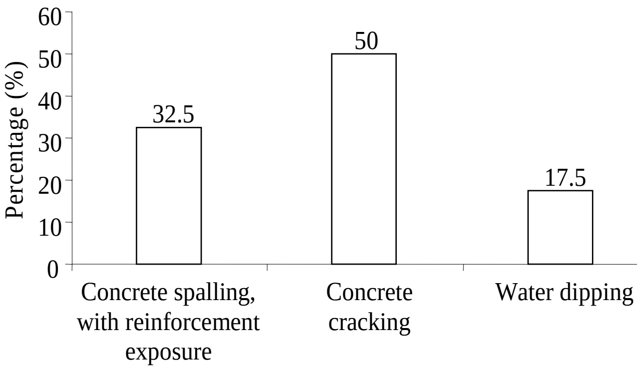

Figure 1. Pathologies in decks.

Table 2. Main pathologies at each component of the analyzed bridges.

Affected components	Pathologies
Deck	Concrete spalling with reinforcement exposure Cracking Water dripping
Abutments	Concrete spalling with reinforcement exposure Cracking Water dripping
Wing walls	Cracking and/or spalling with reinforcement exposure Reinforcement exposure
Expansion joints	Accumulation of fragments over expansion joints Deformation of the expansion joint Cracking parallel to the joint, allowing the infiltration of water to the abutment
Bearing equipment	Protective sleeves damaged Corrosion of the metallic elements Partial or total degradation of the bolt's massive protection
Bearing equipment at intermediate support	Affixing publicity Water dripping caused by lack of protective sleeves Concrete delamination
Slopes	Slope's covering damaged Slope covered with vegetation causing the obstruction of the drainage elements Erosion of the vegetable slope
Drainage systems	Accumulation of fragments Lack of certain elements Broken elements
Cornices	Cracking, spalling and delamination of concrete Concrete spalling due to impacts Bending mortar's detachment
Guard-rails	Corrosion Car impacts Lack of restrains, or restrains damaged with corrosion
Safety-guards	Car impacts Lack of restrains, or restrains damaged with corrosion Lack of elements
Pavement	Damaged pavement covering
Footways	Accumulation of fragments Lack or cracking of the floor covering Lack of protection plates on the expansion zone
Other components	Garbage Lack of barrier Growing vegetation near the bridge structure

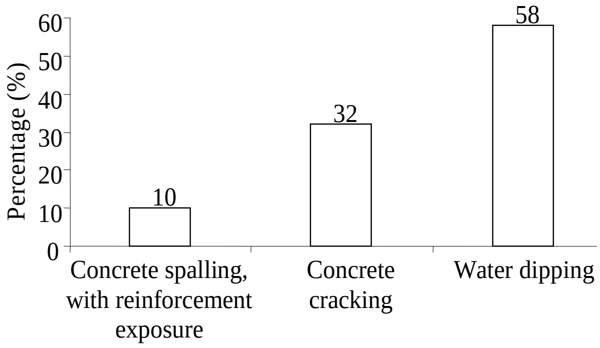

Figure 2. Pathologies in abutments.

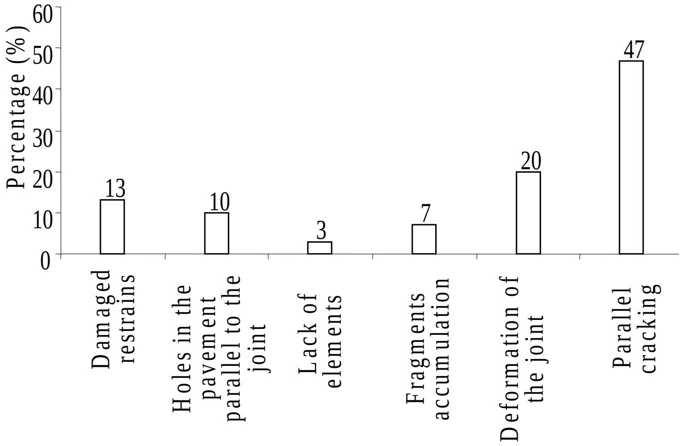

Figure 3. Pathologies in expansion joints.

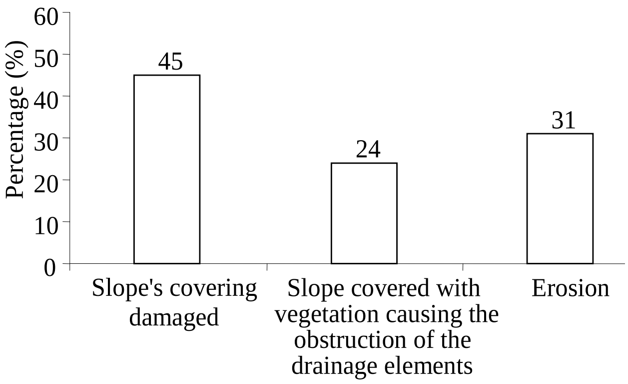

Figure 4. Pathologies in slopes.

From the 85 RC bridge structures analyzed in Portugal (see Tables 1 and 2, and Figs 1-4), the following can be observed:

57% of the bridges evidenced pathologies in the deck. 83% of those pathologies are related to concrete: spalling and consequent reinforcement exposure (33%), or cracking (50%). Water dripping was also observed in 18% of the structures with pathologies in decks.
73% of the 85 analyzed bridge structures show deficiencies in the abutments. In these structures the most common pathologies observed were: water dripping (58%), concrete cracking (32%) and spalling with reinforcement exposure (10%).
54% of the structures show problems regarding the expansion joints. Parallel cracking represents 47% of those pathologies, 20% are excessive deformations, 13% are referred to the joint's restrains, 10% are fissures and holes in the pavement parallel to the joint, and 3% are related to the lack of elements in the joints.
54% of the analyzed structures have pathologies in the slopes. 45% of those pathologies are related to the damaged covering. In 31% of the bridges it was verified erosion in the slopes. Slopes covered with vegetation causing the obstruction of the drainage system was verified in 24% of the bridges under analysis.

4 STATISTICAL ANALYSIS OF THE COMMON PATHOLOGIES IN GERMANY

The main results of a study made over 100 over highways bridge structures in Germany (less than 50 years old) are summarily presented in Table 3 (Favre 1989).

Table 3. Main pathologies registered in the German survey.

Main pathologies	Percentage of affected structures (%)
Reinforcement's corrosion	17
Concrete cracking	11
Concrete degradation	13
Expansion joints degradation	31
Bearing equipment's degradation	14
Drainage systems degradation	27
Rail-guard's degradation	58
Pavement's degradation	32
Degradation of the waterproofing materials	21
Degradation of the substructure	27

The elements affected with higher number of pathologies are rail-guards, pavements, expansions joints and substructures. Concrete spalling is frequently detected, probably due to exposure to de-icing salts, commonly used on Germany.

5 COMPARISON BETWEEN THE PORTUGUESE AND THE GERMAN RESULTS

The global results obtained from the analysis of pathologies in 85 RC bridges in Portugal were compared with a similar study from a German survey. Analyzing the data from the Portuguese inspection reports it can be concluded that the survey is very extensive, pointing out even the first sign of the pathologies. Even if clear differences in both studies, related to the degree of detail in the inspection procedures, were recognized, the comparative analysis is assumed valid based on the similarities in terms of bridge typologies and problems.
Figure 5 compares the obtained global results, from the Portuguese and German surveys, for the more significant and challenging pathologies. The pathologies were arranged into two groups, concerning if they affect or not principal structural components. In both studies, it was evident a significant number of pathologies that may lead to consequences in some important bridge components with structural safety implications at long term, and not only with aesthetical consequences.

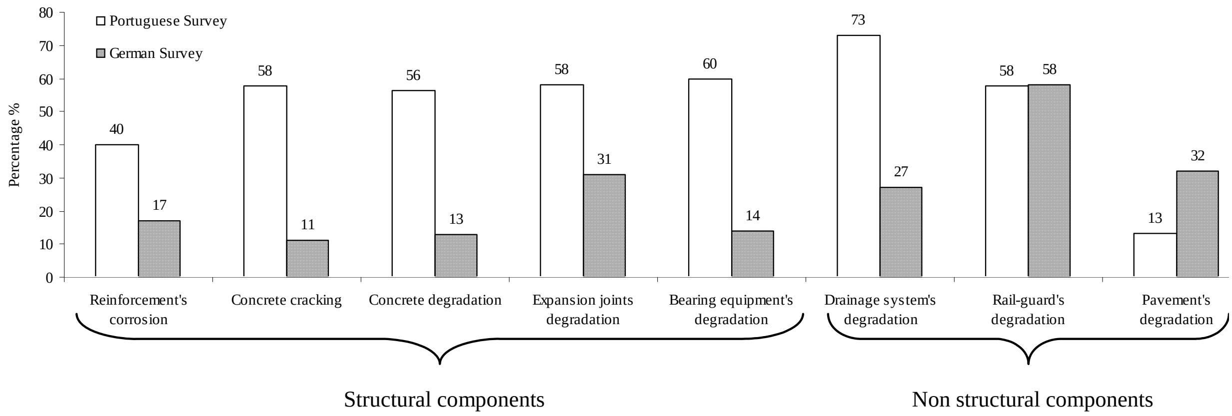

Figure 5. Main pathologies detected in bridge structures in Portugal and Germany.

The pathologies represented in Figure 5, assembled into two groups, depending if they affect or not structural components, allow the following conclusions:

In Portugal, the main pathologies are due to the high exposure of the bridge structures, and particularly of some of their components. For example, non structural components, such as the elements of the drainage system are affected in 73% of the cases, and the bearing equipment in 60%. The concrete surfaces are affected in 58% of the studied bridges with cracking, and in 56% with general degradation.

In the German survey the pathology with the highest incidence is the rail-guard degradation, verified in 58% of the analyzed cases. Generally, the pathologies that affect non structural components have the highest percentages, having smaller implications in terms of safety of the structure at long term. The severe climatic conditions, certainly, have direct implications into a strict quality control during the concrete manufacturing, concreting and demoulding of the structural elements, adoption of larger concrete covering thicknesses, a good protection of the final concrete surface with waterproofing materials and a proper resistance to freeze-thaw cycles. The bridges designed and constructed with this level of exigencies result into structures with a higher durability.

6 VISUAL INSPECTION: RESULTS IN RECENT BRIDGE STRUCTURES

In parallel to this research work on the pathologies in existing bridges, visual inspections made over new bridge structures with just eight months of service, were performed.

Even if they are new, the inspected bridges already show various pathologies, due essentially to misuse and lack of thorough in the finishing works of the concrete surfaces, pavements, drainage systems, etc. Among other pathologies, it were observed accumulation of construction waste and other fragments over the expansion joints, and reinforcement without proper concrete cover already with signs of the beginning of corrosion process. Figures 6-10 show examples of the pathologies and defects detected in the inspections to these new bridge structures.

Figure 6. Bearing equipment.

Figure 7. Expansions joints.

Figure 8. Drainage grids.

Figure 9. Cracked abutment wings.

Figure 10. Concrete surfaces improperly finished.

Figure 6 shows the first signs of corrosion in the bearing equipment and also a drainage trench that conduct the water towards the equipment. In Figure 7, the accumulation of construction waste and other fragments evidences the faster degradation of the expansion joints, inhibiting its correct structural function. This indicates the lack of maintenance and misuse of the structure. In Figure 8 it can be observed that the grid spacing is not proper. Thus, waste and fragments will get into the drainage system causing eventually its malfunctioning. Figure 9 shows the cracked wing of an abutment, which allows the water infiltration, instead of conducting it to the drainage system, and possibly affects the structural behavior and soils stability. Figure 10 presents an example of concrete surfaces not accurately finished, leading to potential problems, such as steel reinforcement corrosion and concrete's degradations.

7 FINAL COMMENTS

In both, Portuguese and German surveys, the analyzed bridges are very similar in terms of structural geometry and materials. The pathologies observed are also analogous.

Although being very important to the global safety of the superstructure, foundation's pathologies were not considered in this work, since they were not mentioned in the analyzed surveys.

The comparison made over the main global results, suggests that the incidence of pathologies verified in existing bridge structures is higher in Portugal than in Germany. This is probably due to the combination of important aspects, such as: detailing in the design projects without concern on durability concepts and the absence of a systematic inspection, maintenance and repair of the first superficial pathologies detected in the bridges, preventing their development to a more severe scenario.

An integrated management system which guides the regular assessment inspections and alert to the bridge structures pathologies which can develop more serious damages can certainly help in reducing the observed high pathologies incidence in bridges verified in Portugal. The development of an integrated bridge management system and the implementation of a maintenance policy can reduce the costs in future repair operations.

A more detailed study should be conducted, considering not only the presence of the pathologies visually detected, but also with its categorization according to specific intensity classification. This method can contribute to the bridge prioritization for strengthening measures, and even to identify the bridges in need of an urgent intervention.

8 ACKNOWLEDGEMENTS

The authors would like to acknowledge Engineer Romana Ribeiro from EP – Estradas de Portugal, and Engineers Adan Monteiro, Luís Trabulo and Hélio Costa from LUSOSCUT, for their precious help in the supplied material and guided visual inspections to the bridges.

REFERENCES

Adey, B., Hajdin, R., and Bruhwiler, E., "Risk-based approach to the determination of optimal interventions for bridges affected by multiple hazards", *Engineering Structures*, Vol. 25, 2003, pp. 903-912.

Branco, F. A., and Brito, J. 1996. *Bridge management from design to maintenance*.

Brito, J., Branco, F.A., Thoft-Christensen, P., and Sorensen, J. D., "An expert system for concrete bridge management", *Engineering Structures*, Vol. 19, No. 7, 1997, pp. 519-526.

Brinckerhoff, P. (ed. L. G. Silano) 1993. *Bridge inspection and rehabilitation*. New York: John Wiley & Sons Inc.

Estradas de Portugal [EP] 2003. Annual report of bridge structures inspections.

Frangopol, D. M. 1999. *Application of life cycle reliability-based criteria to bridge assessment and design*.

Favre 1989. *Maintenance et reparation des ouvrages d'art*. École Polytechnique Fédérale de Lausanne.

Johnson, S. M. 1973. *Deterioro, conservacion y reparacion de estructuras*. Madrid: Editorial Blume. Barcelona: Editorial Labor.

LUSOSCUT 2003. *Annual report of bridge structures inspections*.

Nunes, C., and Santos, J. 2005. *Patologias em obras de arte de betão armado e pré-esforçado*. University of Aveiro (in Portuguese).

Patjawit, A., and Kanok-Nukulchai. W., "Health monitoring of highway bridges based on a Global Flexibility Index", *Engineering Structures*, Vol. 27, 2005, pp. 1385-1391.

Priestley, M. J. N., Seible, F., and Calvi, G. M. 1996. *Seismic design and retrofit of bridges*. New York: John Wiley & Sons Inc.

Radomski W. 2002. *Bridge rehabilitation*.

Yang, S., Frangopol, D. M., and Neves, L. C., "Optimum maintenance strategy for deteriorating bridge structures based on lifetime functions", *Engineering Structures*, Vol. 28, 2006, pp. 196-206.