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DETERIORATION OF BRIDGE DECK ROADWAY MEMBERS. PART I: SITE INVESTIGATIONS

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Abstract. Bridge deck ancillary components such as surfacing, waterproofing, expansion joints, safety barriers, and drainage are important elements of highway bridges. These elements have an influence on either traffic safety and comfortability or the behaviour of the superstructures and substructures of a bridge. When they fail to function properly, the performance of bridges can be seriously affected. In this article deterioration and damages of deck components in highway bridges are analysed. The extent, causes and consequences of deterioration problems were investigated. A database analysis of field inspection results was performed. An investigation revealed that roadway members inevitably deteriorate over time at different rates. Illustrative examples of deteriorated roadway members are presented. The experience shows that lifetime of certain components is only about 5 to 7 years, sometimes less.

Keywords: road bridges, surfacing, waterproofing, expansion joints, safety and drainage systems, deterioration, damages, causes and consequences.

1. Introduction

Bridge engineers are challenged to construct and maintain bridges economically with a high performance level. Although engineers are confident about their bridge designs and maintenance, the deterioration of bridges in service due to ageing process, poor design and construction or lack of maintenance eventually cause the serious problems for bridge bearing structures as well as their ancillary components.

The bridge roadway or ancillary components include the deck members such as surfacing, waterproofing, expansion joints, safety system (parapets, handrails, median barriers), and deck drainage system.

The deck roadway members perform 4 main functions:

- to provide safe and comfortable traffic circulation;
- to prevent water and deck chemicals penetration into underlying structures;
- to transmit the live loads to the supporting elements or allow their free movements;
- to present a good appearance of a structure as a whole.

The bridge roadway components are exposed to rainfall, snow, temperature and moisture changes, sunlight, carbon dioxide, de-icing salts, and live-load effects. The interaction of these aggressive factors results in a significant degradation with time and requires sometimes a costly and extensive rehabilitation. Although most of these members are subjected to an intensive deterioration process in many cases, exclusively visual, insufficient attention to their condition leads to durability problems of a bridge as a whole and a considerable economic loss to society.

During the last decades problems of deterioration of bridge roadway components have been experienced in many countries and the methods of condition assessment and design have been proposed [eg 1–12]. However, statistical analysis for the causes and consequences of roadway member's deterioration or damages are still rather limited. As we know, statistics on this subject is lacking in many countries as well as in Lithuania.

The lives of existing roadway members are difficult to assess as all properties are the subject of varying standards of materials, construction and maintenance. Many of the design faults resulted from the shortcomings of new materials and techniques not being fully understood. The durability of components is strongly influenced by exposure conditions mentioned above. Frequently, repair and particularly replacement, for example, of surfacing or expansion joints cause considerable inconvenience to bridge users and losses of time and money due to traffic interruption [13].

Our surveys of bridges carried out over the past few decades also show that at present the roadway members of bridges in Lithuania show a serious deterioration and damage requiring an expensive replacement measures [14]. About 56 main urban bridges in City Vilnius were inspected and evaluated. Case studies showed that about 70 % of bridge roadway members have various deterioration problems and require remedial actions. About one-third of the maintenance work and expenditure involved in the bridges inspected could be avoided if a sufficient care had been taken at the design stage and during construction.

The objective of this paper was to analyse the current state of bridge roadway members on highway bridges and to evaluate their causes and consequences. This research examines condition for bridge pavement, expansion joints, safety barriers, and drainage. Illustrative examples of deteriorated roadway members will be the primary focus of the paper.

2. Types of deterioration and their causes

Deck roadway members are to provide safe and comfortable traffic circulation and to protect the underlying structures. The bridge engineer should be familiar with the general characteristics of the member's type and main requirements to find and assess the problems. General requirements for deck roadway members include the following.

Deck overlays:

- low permeability to water and de-icing chemicals;
- adequate skidding, abrasion and fatigue resistance;
- good bond to underlying concrete, steel deck or waterproofing;
- sufficient flexibility to avoid cracking caused by thermal and mechanical stresses;
- adequate surface profile.

Waterproofing:

- effectiveness as waterproofing;
- good adhesion to the concrete or steel support;
- resistance to punctures both during laying and in the finished pavement under heavy traffic;
- resistance to ageing.

Expansion joints:

- to allow the expansion or contraction in the superstructure caused by internal and external actions;
- to assure the discontinuities in the riding surface of the carriageway;
- to withstand the loads and displacements due to traffic, impact, vibration, settlement, shrinkage and creep of concrete, temperature gradient of bridge deck;
- not to give rise to an excessive noise of vibration;
- not to allow leakage of the water and debris.

Safety barriers:

- to prevent traffic and pedestrians from crashing and falling from the deck;
- to minimise the consequences of an accident.

Drainage:

- to assure the slope of the surface and the slope and size of drainage pipes;
- to avoid standing water on the deck;
- to avoid wetting of the superstructures and substructures.

All members have to be easy to inspect and maintain with a minimum initial and maintenance cost.

Bridge deck roadway members are constantly and directly affected by traffic wear, temperature extremities, moisture and chemicals; consequently, they deteriorate faster than other parts of the bridge. Their life is limited and they need regular field inspections, maintenance, and eventual repairs.

However, it would be useful to present a classification by importance of the deficiencies based on their frequency of occurrence. Table 1 summarises information of the author's observations on the frequency of the defects of roadway members. As can be seen, the deficiencies in most bridge roadway members are frequent and they are detected always fairly rapidly.

There are several types and several possible causes of deterioration and damages, which occur in bridge roadway members. Deterioration of roadway members can be classified according to the character of visible damage on road-

Table 1. Frequency of deficiencies in the bridge roadway members

Members	Actions	Frequency
Overlays on road and footway	Abrasion and impact, temperature changes, rain, snow, frost, chemicals, ultraviolet rays	high
Waterproofing: in roadway area in footway area	Impact forces, movement of underlaying structures	 locally locally
Expansion joints	Rain, snow, temperature changes, abrasion, impact forces, chemicals, ultraviolet rays	high
Safety system (barriers, handrails)	Weather and chemicals, impact forces	high
Drainage system	Weather and chemicals	high

Table 2. Types of defects and damages their causes of bridge roadway members

Types of defects and damages	Most common causes
Cracks, potholes, ruts of surfacing	• poor quality of materials, faulty mixing, spreading and compacting • climatic factors (solar radiation, bitumen oxidation, thawing) • heavy traffic, high intensity of circulation
Inadequate longitudinal or lateral profiles (pounding of water)	• wearing of surfacing • extra thickness of existing wearing overlay, patching
Leakage of waterproof membrane	• poor quality and ageing of materials, defective mix • deterioration of surfacing deformations of underlying elements • accumulation of water due to a faulty drainage system • distress at the edges and connections, perforated areas • daily or seasonal variation in temperature
Restriction of movements, leakage and deterioration of expansion joints and their components	• faulty conception or design • restraints at joint • ageing of materials • fatigue of steel details and their joints
Damage and corrosion of railings and safety barriers	• water and chemicals • vehicle accidents • low quality of paint system
Ineffective drainage (flooding on roadway, wetting of structures)	• insufficiently dimensioned and detailed, damaged or clogged scuppers, spouts, pipes

way or superstructure surface, the size and causes of appearance, influence on bridge durability and traffic circulation safety. It is always essential to identify whether the deterioration is critical or not. Deficiencies of bridge roadway members as well as their causes in most cases are exclusively visual.

General classification of defects and damages are presented in Table 2. Experience shows that the deficiencies encountered may generally not be attributed to only one cause, but are the result of a combination of unfavourable circumstances.

The service life of roadway members can vary considerably, depending on the design, quality of materials, construction, environmental effects, as well as on the quality of maintenance. Various types of roadway components have been developed and used in construction of new and rehabilitation of the existing highway bridges. A variety of types of deck members leads to numerous forms of member deficiencies and deterioration processes.

A review of the deck roadway members is given below when discussing mainly the mechanisms, causes and consequences of deterioration. Photos will illustrate the examples of roadway member's deterioration and its influence on the condition of state of bridge superstructures and substructures.

3. Field observations

3.1. Surfacing and waterproofing

A number of materials such as asphalt concrete, steel-fibre reinforced concrete and polymer concrete as well as retrofit techniques are in general used for bridge deck surfacing. Many old deck roadways in Lithuania as a rule were designed and built with an asphalt concrete wearing surfacing and either mastic asphalt or sheeting waterproofing protected by reinforced concrete layer. The use of asphalt materials is very useful for bridge deck members because of their low cost and excellent performance under usual conditions. It is recognised, however, that these materials can show severe damages under adverse traffic circulation and climatic conditions. As a rule, asphalt concrete is not sufficient to prevent the penetration of water containing chemicals from roadway surface to the deck.

Surface roughness (wear), longitudinal, transverse or map cracking, depressions, ruts, potholes are the major defects of overlays. In practice the deterioration processes are not uniform at any point of time. Different parts of an asphalt overlay will be in different states. The deterioration always starts by cracking and debounding from the concrete in the areas along the expansion joints, safety barriers, curbs, and at locations of the truck way. The water and detritus enter the cracks and in winter frozen water causes spalling of the surfacing edges. The risk of spalling is aggravated by the traffic. If the overlays are not repaired in time, the damages especially in the areas of cracks and joints reach critical value and the deterioration progresses rapidly. Intensive traffic and poor maintenance contribute to development of potholes, ranging from cup size to square metres in area. Surface deterioration too far advanced is very often observed in practice (Fig 1). The distressed surface areas were evident after 5–7 years after construction and have been patched.

The causes of overlay deterioration may generally be attributed also to an insufficient understanding of the overlay behaviour on the bridge decks. It should be stressed that traditional methods of highway structural analysis and design cannot be applied to overlay of concrete bridge decks [1]. This is also commonly recognised for the bridges with steel orthotropic decks. Surfacing on orthotropic decks act compositely with the steel deck plate and must be regarded as an integral structural deck system. Surfacing on orthotropic steel deck bridges have a limited life span and fatigue cracking is a common type of damage in the deck system. Details of structural behaviour of such a system with relevant references can be found in [3].

Wearing surface in poor condition will eventually affect integrity of the underlying deck. Deterioration of surfacing leads to the increasingly severe impact forces under traffic to the underlying elements and often reflects on the wear of the underlying waterproofing layer. It is well recognised that roadway surface irregularities and imperfections are significant factors affecting the dynamic responses of bridges under moving heavy vehicles [eg, 4–7]. The dynamic impact factor can be 2 to 4 times higher for pavement irregularities greater than 14 mm [5].

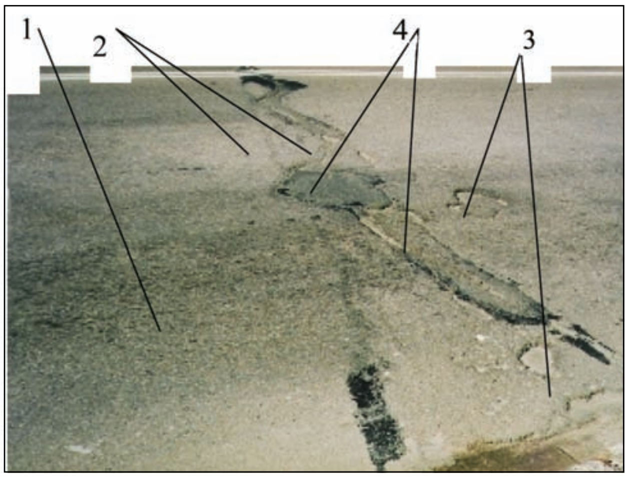

Fig 1. Bridge surfacing deterioration: 1 – surface wearing; 2 – cracks; 3 – potholes; 4 – patches

Fig 2. Deterioration of precast concrete overlay in bridge footways

Fig 3. Polymer surfacing on footbridge deck

Surfacing in footways differs from that in the carriageways. Three types of surfacing are practiced: bituminous concrete surfacing (40–60 mm thick), overlays in cement concrete (40–80 mm), and thin resin-based overlays (10–20 mm thick). The first two types of surfacing are often more permeable and poorly drained. This results in water stagnancy which may accelerate damage of underlying layers. In general, the problems raised in footways sufacings are similar to those encountered with carriageways surfacing (Fig 2).

In North America and some European countries the polymer surfacing was developed and is used for bridge decks. Repaving of concrete footbridge in City Vilnius proposed by the author is a recent example of such application (Fig 3). Performance of this type of surfacing remains to be determined.

Waterproofing is mandatory for all concrete bridge decks. The widespread use of waterproofing on bridge decks is perceived as providing decks with a good protection against climatic factors and de-icing salts.

The waterproofing of bridge decks most commonly adopted in Lithuania are synthetic asphalt mastics, bituminous sheets prefabricated in rolls or thin membranes of synthetic resins. The latter were used only experimentally due to its sensibility to surface humidity and irregularities, high costs. Experience shows the disadvantages of these types. Waterproofing deteriorates with time, losses its characteristics. Defects in the waterproofing system (cracking, rutting, excessive creep) sometimes result from poor materials and construction or from deterioration of surfacing. Waterproofing is susceptible to damage during resurfacing operations. It was observed the cases when the fabric membrane edges were not adhered well to each other allowing water penetration. The design fault observed on majority of old bridges is the absence or interruption of protective system near the safety barriers or curbs. In many cases waterproofing is not used beneath sidewalks, ie alone the edge beams with the result of intensive water seepage, which sets off the process of deterioration of the edge structures (Fig 11). The edges of waterproofing membrane always are the very vulnerable points.

Damage to the waterproofing membrane can only be detected when water leakage with de-icing salts occurs through the structure. Water-saturated areas and efflorescence at the underside of the bridge deck are the indicators of insufficient waterproofing membrane (Fig 4). The leakage is observed also where the waterproofing membrane is perforated by the anchor bolts of bridge rails or luminance supports, in the connection of waterproofing layer and the drain (Fig 5). It is necessary to note that the leakage of water not always coincides with the position of defects in the waterproofing membrane.

Presently, the trend is toward the use of flexible rubber bitumen sheet membranes as a waterproofing protection system. They can accept hot rolled asphalt without a special protection.

3.2. Expansion joints

A serious concern facing bridge engineers is the maintenance and repair of expansion joints, which causes problems in all countries. The deck joints are of primary importance to the durability of the riding surface and underlying members as well as for the overall behaviour of the superstructure.

The types such as filled, sliding or fingerplate, elastic sheet seal are typically used as expansion joints. The deck joint systems are made up of a variety of materials with different physical and chemical properties susceptible to ageing and deterioration. It is necessary to stress that an expansion joint is subjected to the direct loading of vehicles causing the effects of contact pressure, impact and fatigue of joint members as well as severe weather conditions, moisture and de-icing salts leading earlier or later to its damage. All common types of joints always cause large or small problems. As a result of the authors' field investigations during few decades, it is concluded that the main defects in expansion joints are due to locking, water leakage, and irregularity of vertical profile, damage or loose of expansion joint members and as a result of improper joint functioning.

Sealed deck joints should seal the deck surface completely and should prevent the accumulation of water and debris. The sealer formed-in-place usually has a limited service life because of poor installation conditions. In this type of joints the cracking often occurs in the sealer or at interface between the joint material and the surfacing. The cracks quickly multiplies, potholes are formed. The loose, torn, split or hardened seals are also observed. The first signs of distress occur within 5–7 years, together with deterioration of the deck overlays. To do nothing led inevitably to the result shown in Fig 6.

In construction of new bridges and in the rehabilitation of existing expansion joints new types of preformed sealers are used.

In the sliding plate and fingerplate joints damaged or missing steel plates, shapes, and bolts are frequently found (Fig 7). In the finger plate joint due to small tolerance between apposing fingerplates accumulation of debris contributed to the openings clogging. Leakage and excessive noise are the common problems in the sliding plate joints.

In all types of expansion joints, the irregularity of the vertical profile will cause additional impact forces under traffic loading. The piling up of dirt in the joint or the rusting of drainage elements may result in the locking of the joint. Where deck joints leak, contaminated water reaches the ends of concrete beams, exterior anchorages of prestressing cables, end diaphragms, bearings, and substructure, where moisture tends to collect and remain in contact with concrete over a period of years (Fig 8). As a result, the concrete cracking and spalling, rusting of reinforcement steel in many cases is observed.

Fig 4. The effect of leaching on the underside of concrete deck of box-girder due to poor waterproofing

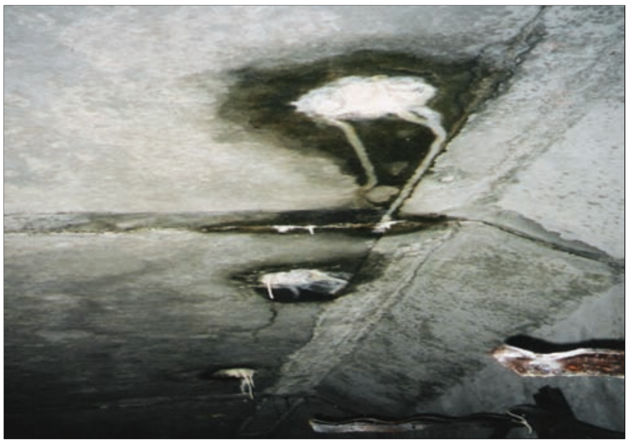

Fig 5. The effect of leaching on the underside of concrete deck due to perforated waterproofing

Fig 6. Deterioration of sealed deck expansion joint

Because expansion joints are recognised problem areas, the current trends are to minimise the number of joints or to their elimination providing continuity in the asphalt carriageway (integral bridges) and by reworking the connections between the deck and substructures. A number of new types of expansion joints have been developed, such as "Tarko", "Thorma Joint", "Serviflex" and used for rehabilitation of Lithuanian highway bridges. Through the implementation of new joints, significant savings can be realised due in part to the possible decrease in maintenance works.

Fig 7. Deterioration of sliding joint

Fig 8. Deterioration of bridge beam ends and abutment due to leakage of expansion joint

Fig 9. Typical concrete barrier deterioration

3.3. Safety system

Bridge roadway safety system includes mainly barriers (parapets), handrails, and rails for the containment of pedestrians and cyclists. Roadway safety members are very important for road safety. They can be damaged due to traffic impact in case of accident, corrosion of steel or reinforcement due to spray of chloride solutions from vehicles.

Safety barriers (parapet beams and curbs) are generally made of prefabricated concrete or reinforced concrete members. Reinforced concrete barriers may be subject to defects and deterioration such as cracks, spalling, and reinforcement corrosion (Fig 9). It seems that chloride induced corrosion is the main problem of reinforced concrete barriers. It is commonly recognised that chlorides do not directly cause damage to the concrete. This statement is based on diffusion of chlorides and ignores the deterioration of concrete due to freezing and thawing in presence of salt solutions. The first signs of reinforcement corrosion were reported after 8–12 years in service. In some cases most concrete barriers perform well despite being exposed to spray of traffic. It is observed that other members of the same structure prefabricated in the same factory are in excellent condition. Numerous examples of heavily salted security parapets in areas of severe exposure that show no spalling or either deterioration after 20 years of service lead to the conclusion that the quality of concrete (mixing, compacting, steam curing) and concrete cover to reinforcement has an important impact on durability of prefabricated members.

Metal railings and fences can be damaged due to traffic impacts in the case of accidents, corrosion of steel. Faults include also slippage and corrosion of connecting bolts or welds.

Rigid concrete and flexible metal safety barriers are designed to resist impacts from vehicles. Barriers have to absorb some of the impact energy, to prevent errant vehicles from falling of the deck and to redirect the vehicle along the line of the barrier so that it does not turn over. Barriers minimum heights normally are specified in the codes such as the designed barrier is to take the entire traffic load. Vehicle safety barriers with a height of about 1,0 meter and taller arrest the heavy vehicles (cargoes). With a smaller height vehicle overturning or crashing through the barrier can occur (Fig 10). Thus, the insufficient height of barrier can increase risk for bridge users.

3.4. Drainage system

A properly designed drainage system is to remove water quickly from bridge roadway surface. Drains can cause troubles in different ways.

Where gullies and down pipes are not properly positioned, insufficient in number, inadequately maintained, the water is accumulated on the roadway, which combined with frost action, may accelerate the degradation of surfacing, parapets and curbs, waterproofing membrane. Inadequate longitudinal or lateral profiles of bridge deck lead to pounding of water at joint nosing, curbs, in service ducts and will cause seepage and unacceptable spread of contaminated water on bridge structures for prolonged periods of time and, as a result, an intensive deterioration of bearing structures (Fig 11). If the drainage system is damaged, water with de-icing salts may flow over the anchorages of prestressing cables, the bearings and substructure. If the spread water encroaches into the travel line, it can cause dangerous hydroplaning and increase the risk of road accidents.

Drainage inlets or typical bridge scuppers are easily clogged by debris and dirt. They should be inspected and cleaned periodically. Drains and downspouts generally are made of iron, which have not performed well in the presence of de-icing salts. Another poor drainage impact is erosion of the earths' surface by water flowing away from the bridge deck (Fig 12).

Fig 10. The truck carrying logs hit and crashed through the barrier and left the carriageway of the bridge over river Nemunas (courtesy of "Lietuvos Rytas")

Fig 11. Intensive deterioration along footway deck slab and exterior beam due to seepage of water with de-icing salts from bridge deck

Fig 12. Erosion at the abutment base due to a poor drainage

4. Conclusions

In this study the extent, causes and consequences of deterioration and damages of bridge roadway members have been investigated. The roadway components are important elements of bridge structures and have an influence on the durability of bridge bearing structures and the operation of the bridge itself. The main causes of bridge roadway member's deterioration have been from an intensive heavy traffic circulation, water carrying de-icing salts, weather conditions. Leaking waterproofing and expansion joints, restriction of deck movements, corrosion of steel and reinforcement, excessive wearing of overlays and ineffective drainage are the main defects of bridge roadway components. Experience shows that the life time of certain components is only about 5 to 7 years, sometimes less. Consequently, a more careful maintenance of bridges preventing any impact due to damages of deck roadway members is required. Unfortunately, there are no systematic surveys on condition states of bridge roadway members in Lithuania. Future research is needed to determine the effects of varying traffic and ambient conditions (weather) on materials and components, to detect problem areas with new types of expansion joints, waterproofing and surfacing, as well as criteria for state assessment and the cost of maintenance related to repair and replacement of roadway members, together with the nature of failures and their underlying causes.

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