THE BALTIC JOURNAL
OF ROAD
AND BRIDGE
ENGINEERING
2022/17(1)

ISSN 1822-427X/eISSN 1822-4288
2022 Volume 17 Issue 1: 167–188
https://doi.org/10.7250/bjrbe.2022-17.556

ASSESSMENT OF REINFORCED CONCRETE BRIDGE DEFICIENCIES UNDER SERVICE LOADS

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Received 10 July 2020; accepted 11 May 2021

Abstract. Conditions of existing bridges are often problematic issues and expensive to resolve for many countries. In order to anticipate and reduce these problems, the combination of various general and local factors causing degradation needs to be identified in the early stage. The identification of these problems reveals the need for local research and detailed inspection for bridges. Reinforced Concrete Bridges in Albania were built at different standards in different periods and were exposed to rapidly increasing and changing traffic loads in the last three decades. This situation made the structural assessment of the bridges inevitable in the local conditions. Although the existing condition of these bridges had not been clearly defined, after democratization and joining the European Council (the 1990s), new bridges were rapidly built and

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existing bridges were strengthened with different methods. In this context, the structural condition of existing reinforced concrete bridges in Albania was examined in this study. The condition of Albanian bridges was presented in this paper based on visual inspection of 104 bridges covering the total length of 7271.6 m along 263 km road from different parts of the country, concentrating on local causes of deteriorations. The main causes of the defects are figured out in the study as traffic load, natural force, aging, lack of maintenance, and last but not least construction and design deficiencies. The study concludes that the general physical condition of the bridges is poor, so the services provided by the bridges are potentially at risk. The results obtained at the end of this study may be valid for countries with similar features, e.g., other Balkan countries.

Keywords: assessment, bridges, defects, inspection.

Introduction

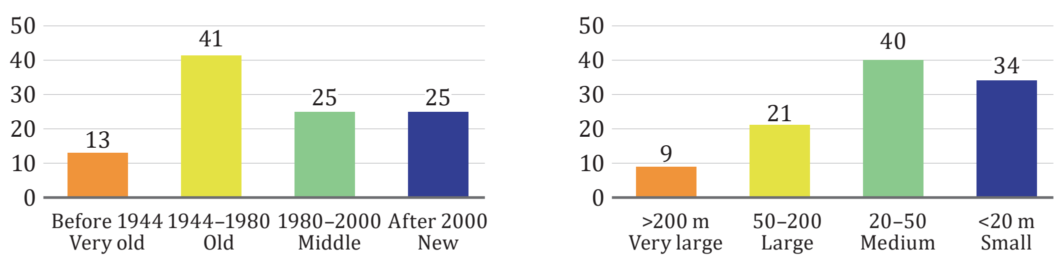
Bridges are a crucial part of modern life and their construction and maintenance are expensive practices. These structures need constant strengthening and maintenance due to the increased demand, code revisions, or damage incurred. Declining serviceability of bridges and maintenance costs are an increasing problem, especially as the bridge ages (Limongelli, Chatzi, & Anzlin, 2018; Melchers & Chaves, 2020). The collapse of Caycuma Bridge in Turkey is a tragic example and 14 people lost their lives because of this disaster. This disaster was caused by the wrong inspection as well as the wrong strengthening method that was applied to increase the capacity of the bridge (Dinçer, Aydın, & Gencer, 2014). Systematic assessment of bridges lowers the cost of repairs and makes the bridge operation safe within the service life, therefore, preventing possible collapse (Jaafar, Yardim, Thanoon, & Noorzaie, 2003). Inspection is needed to ensure that bridges serve efficiently and maintenance costs are maintained in the estimated budget during its lifespan. Otherwise, to prevent a catastrophe, many reinforced concrete bridges must be demolished in their middle age, repaired with much more than the initial construction budget or estimated maintenance budget. In addition, disturbance of the service provided by bridges may double the cost.

Successful, long-term repair and strengthening of reinforced concrete bridges depend on the efficiency of inspection and evaluation of deterioration levels. Therefore, most of the inspection guides pay special attention to an effective rating system (Valigura, Liel, & Sideris, 2019). There are many factors that have a role in a deterioration level, including temperature changes, loading, construction methods, and many more (Melchers & Chaves, 2020; Miśkiewicz, Meronk, Brzozowski, & Wilde, 2017). It is very difficult to identify the exact causes behind some types of deterioration, such as cracks and expansion joint failures. Furthermore, the roles of the associated distress on worsening the problem of reinforced concrete have been a major concern for the bridge inspector. The inspector's decisions on the distress level mainly depend on personal experience and play a vital role. With this complexity, bridge inspection is a cumbersome procedure without a trained person and most importantly computer help (Sein, Matos, & Idnurm, 2017).

Before the tragic collapse of the Silver Bridge in 1967, bridge maintenance, repair, and rehabilitation were performed on an "as-needed" basis (Koteš & Vičan, 2006). This tragic event led to the development of bridge inspection and evaluation procedures. Computer-aided tools were employed by researchers to standardize and simplify the inspection under a Bridge Management System (BMS) (Janas, Miller, & Kaszyński, 2018).

This study is intended to identify and evaluate the common distresses on reinforced concrete bridges in Albania. The inspection of the reinforced concrete bridges in this study was generally based on visual data; in some cases, special tools were used to reach the pier, foundations, and beams of the bridges. It is a difficult and expensive task to examine all the bridges that span across the country. The bridge selection was made according to some previous reports and the strategic location of the bridges.

In this study, 104 bridges that cover a total length of 7271.6 m along 263 km road were inspected. This length corresponds to 37.7% of the entire bridge length in Albania. Inspected bridges were classified as shown in Figure 1. These selected bridges are located in the most strategic and sensitive part of the country's motor vehicle transportation route, such as ports, airports, and the key access to the most populous cities.



(a) Construction date **(b)** Bridge length (m)

Figure 1. Classification of inspected bridges

In addition, the study classifies the problems such as spalling of concrete cover, deterioration of reinforcement, failure of bearings, chemical attack and scouring according to bridge types, distresses location and severity of problems. The scope of this study is limited only to the evaluation of reinforced concrete bridges as most of the bridges in Albania are reinforced concrete.

The causes of problems and their effects on bridge structures are not part of this study, as these issues are covered in depth in many bridge inspection and maintenance manuals (Hawk & Small, 1998; Thompson, Small, Johnson, & Marshall, 1998; Wan, Foley, & Komp, 2010).

Over the last decades, many new bridges and roads were built in Albania. The construction of these bridges and roads was done in different periods and characterised by different types of construction codes. Albanian national road has 562 bridges with a total length of 19295 m over the whole country (Welch, 2010). These bridges were built in three different periods and in six different codes. The construction and design of the bridges were initially based on the Soviet Union standard, engineering understanding and knowledge, then it was continued with the Albanian Standard and Code (KTP 23-78). In the last two decades, United States Standards (AASHTO), British Standard (BS) and European Norms (EN) were used in bridge construction. Therefore, this study also compares the bridges which were designed and constructed according to various standards and in different periods.

While bridge codes emphasise that bridges require regular inspections (BS 5400-4 1990), there has not been a comprehensive and routine inspection practice in Albania until recently (2010). The effects of this situation are clearly demonstrated in this study: although many bridges in Albania are in the middle of their economic lives, the lack of inspection and monitoring has caused many problems with the bridge functionality and security. Due to this lack of inspection and low maintenance quality, some bridges, unfortunately, collapsed, such as the Peqin Bridge in 1996 (Paparisto et al., 2010), and Peshkatari Bridge in 2001 (Gega & Bozo, 2017), and some others are in danger of collapse.

Reinforced concrete bridges in Albania. Albania is a country in Eastern Europe which has over 85% of urban transportation and a very large percentage of freight transportation, within the country it carries through the terrestrial road (Welch, 2010). The modern history of road and bridge construction in Albania starts at the beginning of the 19th century. The construction of these bridges has been done under six different codes and in three representative periods.

1. Period 1912–1944; the time at which roads and bridges are designed by foreign engineers and implemented by local and foreign employees. During this time, the most influential countries

in road construction in Albania were Italy and Austro-Hungarian kingdom. Engineering intuition and knowledge of people responsible for the design have dominated these constructions.

2. Period 1944–1991; most of the bridges built in this period are one span reinforced concrete. Reinforced concrete science experienced rapid global development, which in Albania was not at the same rate as in other countries of Europe. Used standards in the construction of these bridges were those of the Soviet Union and later by Albanian Standard and Code (KTP 23-78). Voluntary works were common in this time period and they directly affected the quality of bridge construction.
3. Period 1991–present; after 1991 with the political changes, Albania was in urgent need for roads and bridges with new standards. These bridges are mainly reinforced concrete and in some cases are compositions of steel with reinforced concrete. In this period, standards used in design of these bridges are United State Standards (AASHTO), British Standard (BS), and European Norms (EN).

1. Methodology

In this research, which is based on visual inspection, a literature review was conducted first and then interviews were made with people who were part of the design and construction of the bridges. The scope of this study is to evaluate the existing situation of reinforced concrete bridges throughout Albania and to identify their deficiencies and damage situations. Before starting the visual evaluation, the previous examinations and research on these bridges were determined and examined. Within the scope of the study, more than 104 bridges selected from different regions of Albania were inspected. While selecting the sample bridges, they were chosen as similar copies that could represent the country in general. In the selection of the bridge, the construction period, the importance and the location of the bridge are the parameters that are considered. For this reason, it was preferred to select a road network carrying the heaviest traffic volume of the country and connecting the strategic nodes of the country such as port, airport and capital (Figure 2). In addition, it was decided to choose this road network and other bridges together with people who were interested in the design and construction of this road network. Considering all these criteria, the last selection was made among a total of 562 bridges reported in Albania.

Outline framework of the adopted methodology is presented in Figure 3. A comprehensive literature review was carried out to identify the problems commonly encountered in reinforced concrete bridges. Data collection and relevant people interviews helped the authors to make bridge selection and prepare an adequate inspection check list. A preliminary inspection was carried out on 104 bridges in Albania to identify their current defects and distresses. Defects and distresses found in preliminary inspection were studied. Similar defects were defined from literature to enlighten the defect types and perform detailed inspection. Detailed inspection is the final stage of the field work and specified all the types of defects and distresses found on an inspected existing bridge structure.

The data obtained from the visual inspection were classified according to the importance of the defect severity. In order to classify

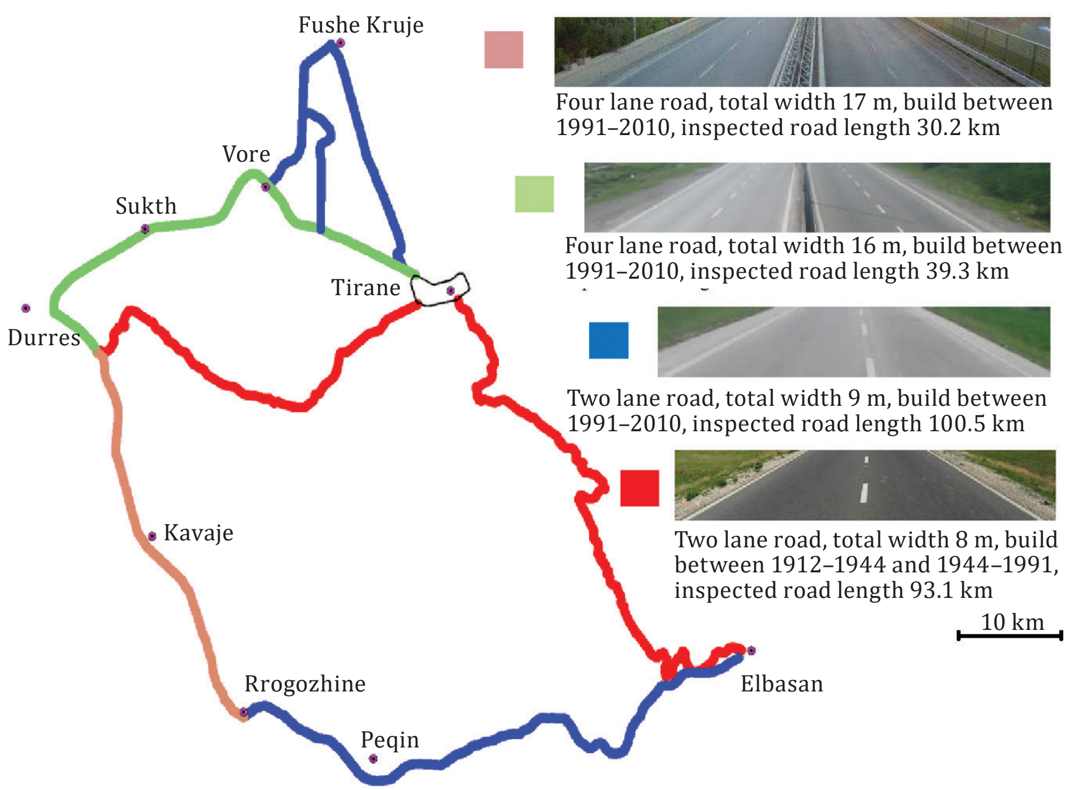


Figure 2. Inspected road network

this severity, a rating system from 1 to 5 was used. It is explained as follows:

No Risk (Rating 1): Damage has been identified. Observations on bridge is needed.

Low Risk (Rating 2): Damage has been observed clearly and a low risk potential is identified. Observation on a bridge is needed.

Medium Risk (Rating 3): Damage that has been observed is moderately critical and it is essential to accomplish typical maintenance work.

High Risk (Rating 4): Damage that has been observed is critical and thus it is essential to perform repair work. A serious technical review is required. Replacement work can be done.

Very High Risk (Rating 5): Very severe and critical damage exists and poses a high risk for safety. It is vital to carry out repairs or retrofits immediately. An exhaustive examination is essential.

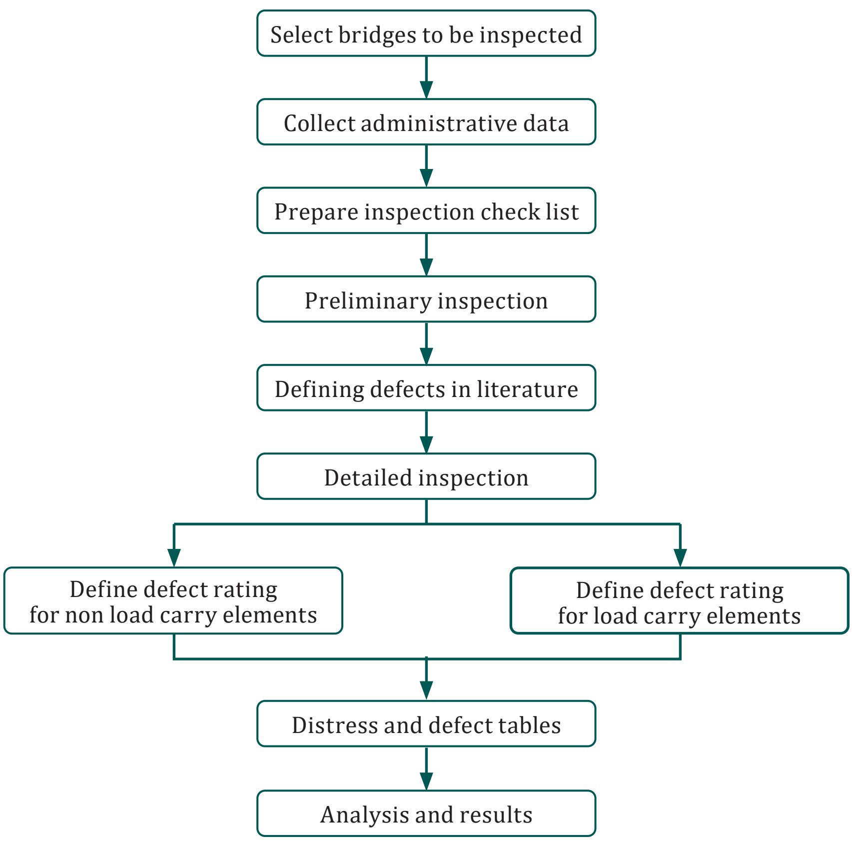


Figure 3. Outline of the methodology

2. Distresses on the bridges

Existing reinforced concrete bridges in Albania are in poor or very poor physical condition. The main reasons causing this poor physical condition are s lack of maintenance, harsh environmental conditions, design inaccuracy, problems during construction period, load increasing because of high traffic flow and aging. Many of the visual and accessible elements of the bridges have little or no major underlying problems for different reasons.

2.1. Scouring

Despite structural defects, substructure of reinforced concrete bridges in Albania is suffering from scouring problems. Base level of stream, protection methods against scour, types of streams and rivers, foundation properties, flood and etc. are the factors which play a role on scour on bridge foundations. Especially major floods volume and velocity cause considerable scouring. As the stability of the entire bridge structure varies inversely with foundation conditions, a scour in certain height will cause serious deficiencies in bridge functionality.

Most of Albanian rivers have an aggressive flow regime, due to this aggressive regime they carry a lot of river material toward sea, thus endangering the bridge safety in Albania.

The number and percentage of bridges having a scour risk are summarised in Figure 4. From all inspected bridges, 82 bridges pass over water environment; 22 of them or 26.8% are recorded as not causing a scour risk, 52 of them or 63.5% have a low or moderate scour risk and 8 bridges or 6.7% are in high or very high risk.

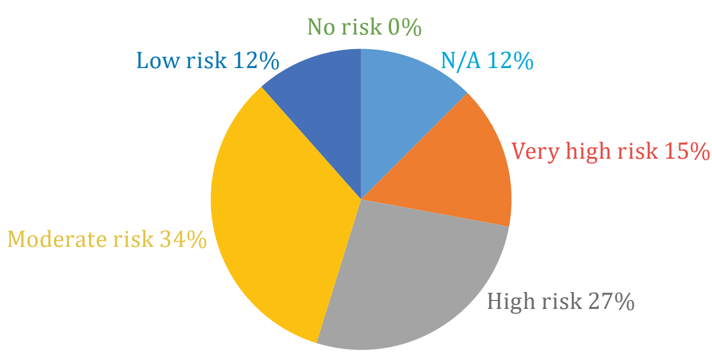


Figure 4. Rating of bridge distresses (Scouring)

During the investigation of some bridges, heavy scours were reported mainly. The high flow rate, lack of design detail, poor workmanship and last but not least lack of maintenance result in a different level of scour in 60 inspected bridges. Bridges that have shallow foundations are the ones in the worst conditions. Due to scouring, differential settlement of foundation have caused problems to substructure and superstructure. Scouring problems are seen in deep foundations as well. One of the most sever scour problem was recorded at Mat Bridge. Scour height on these piles changes from 0.5 m to 4.5 m. Heavy scouring was monitored at some part of the foundation as shown in Figure 5a. Due to insufficient concrete cover and poor workmanship, reinforcements of pile cap were exposed and rusted. Additionally, significant amount of soil was observed in pile cap; a significant amount of soil was observed in pile concrete, proving poor construction workmanship. Exposed steel bars were detected because of concrete deteriorations on piles (Figure 5b). Insufficient foundation depth, human intervention, high river flow are detected as the main causes of scouring.

2.2. Chemical attack

Chemical attack is an effect of outer aggressive elements or inner material elements. Mainly all bridge structures suffer from carbonation, chlorides attach, alkaline silica reaction and sulfate. The water in cement pores is generally alkaline.

The carbon dioxide in the air reacts with the alkaline and makes more acidic environment. Carbonation reaction starts from concrete surface and penetrates into. If the reinforcement is too close to concrete cover, early failure due to corrosion may occur.

(a) Heavy scour **(b)** Exposed steel bars

Figure 5. Scour problems in Mat bridge

Concrete cover is specified in bridge standards. However, the main reason of carbonation observed on inspected bridges in Albania is insufficient concrete cover and poor concrete quality. Poor concrete quality has allowed the water to penetrate into; as a result, steel bars have been corroded. Corroded steel bars have then led to the spalls in concrete. Out of 104 inspected bridges, only 5 or 4.8% have no chemical attack risk, 69 of them or 66.3% have a low or moderate chemical attack risk and 30 bridges or 28.9% are at a high or very high risk (Figure 6). Chemical attack on a reinforced concrete bridge can be seen in Figure 7.

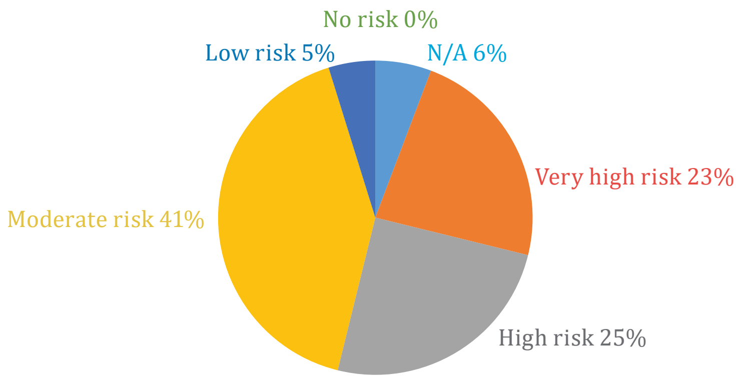


Figure 6. Rating of bridge distress (Chemical attack)

Figure 7. Chemical attack on a reinforced concrete bridge

2.3. Water leakage

Water leakage is caused from bridge non-functional elements, especially drainage systems and expansion joint. Out of all inspected bridges, only 1 has no water leakage risk, 72 of them or 69.2% have a low or moderate water leakage risk and 31 bridges or 29.8% are at a high or very high risk (Figure 8). Water leakage resulting from non-functional drainage systems and expansion joint has led to extreme rust on steel bars, spalls in concrete and complex problems to bridge elements. The main causes of water leakage are the following: totally out of function drainage systems, non-functional expansion joints, lack of design details and maintenance. A typical water leakage is shown in Figure 9.

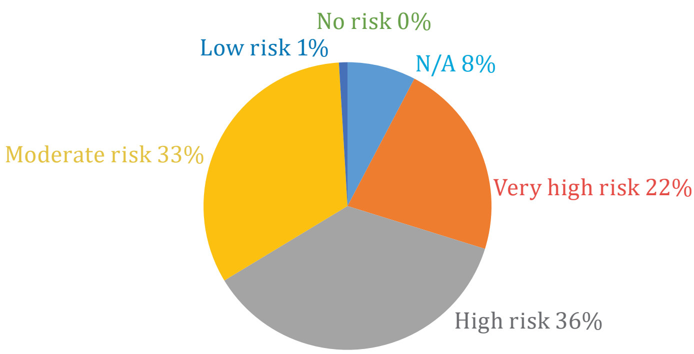


Figure 8. Rating of bridge distress (Water leakage)

Figure 9. A typical water leakage

2.4. Cracks

Cracks are the language of a reinforced concrete structure. It is very important to analyse them in order to understand behaviour and defects of the structures. Special attention needs to be paid to structural cracks. From exposed steel bars (Figure 10a), it is seen that the Albanian bridges are over-reinforced. Therefore, it is not common to meet flexural cracks. Types of cracks mostly seen in the bridges are shear cracks, long-term shrinkage crack and plastic shrinkage cracks. Shear cracks are the most delicate structural cracks found on the inspected bridges (Figure 10b). The steel bars used in design to resist moment are very dense but not the same attention is shown to stirrups. They are far from each other, sometimes more than 50 cm, and are of small diameter. Long-term plastic shrinkage cracks are mostly seen in abutments and sometimes in piers (Figure 10c).

(a) Dense reinforcement

(b) Shear crack at beams

(c) Plastic shear crack at abutments

Figure 10. Concrete cracks

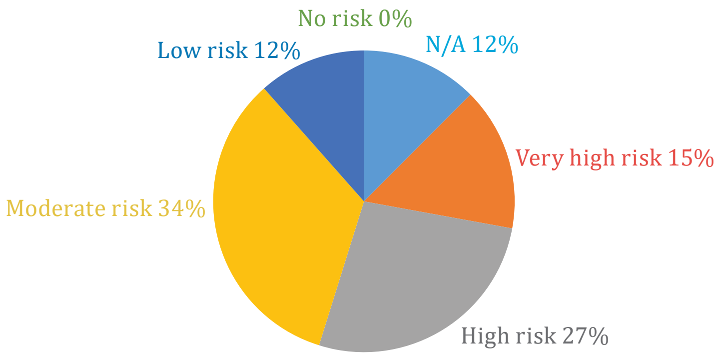


Figure 11. Rating of bridge distress (Cracks)

Out of 104 inspected bridges, 28 or 26.9% have no crack risk, 67 of them or 64.4% have a low or moderate crack risk and 9 bridges or 8.7% are at a high or very high risk (Figure 11). The main causes of cracks are the following: overload, poor workmanship and lack of design details. Despite of structural and non-structural cracks, problems met in almost every bridge are concrete spalls.

3. Bridge element defects

Various defects have been observed in the upper structure in many examined bridges. More serious defects have been identified especially in the bridges built before 1990 due to the aging factor. It has been determined that many bridges have poor workmanship problems, including obvious false frame work and insufficient concrete coating (Figure 12).

(a) Wrong connection and slope

(b) Poor workmanship misalignment

Figure 12. Superstructure defects

Diaphragms which are essential components should be positioned on beams on a line. Nevertheless, it has been observed that the position of some diaphragms in the examined bridges deviates. More than 50 mm eccentricity failure of alignments has been monitored on some of the diaphragms.

As a result of poor concrete replacement, several gaps remain in the concrete. Additionally, due to insufficient concrete cover, water leakage remains in the concrete. Therefore, reinforcements in concrete are exposed to heavy rust damage for pouring the concrete in these bridge elements.

The reinforcement diameter was reduced to 4 mm at some rusty place.

Chemical attack is a common problem on superstructure elements in bridges. Additionally, spalling and delamination have been detected all over the bridge superstructures. Bridge superstructure elements are classified as expansion joints, bearings, wearing surface, drainage system and parapets.

3.1. Expansion joints

Expansion joints help absorb movement that occurred because of temperature change. Since these joints work very actively and directly affect the traffic and traffic safety on the bridges, they must be replaced a couple of times during the service life of the bridge.

(a) Out of function expansion joint **(b)** Partly missing expansion joint

Figure 13. Expansion joint defects

Problems occurring in these members are gaps and spacing that can create extreme danger, level difference between road and joint, too much noise, water leakage and cracks on the pavements. During traffic flow, if there is a level difference between the joint and the road, these expansion joints will cause disturbing noise. However, it is known that some bridges do not have expansion joints.

It has been determined that the elements that provide the fixing of expansion joints such as bolts and welds are non-functional (Figure 13a). In addition, cracks and spalls were reported on the edges of asphalt or concrete adjacent to these joints. In addition, the lack of many expansion joints or its elements that create unexpected problems to other components such as bearings and other infrastructure elements was noted (Figure 13b).

Expansion joint defect was recorded for all inspected bridges. 39 of inspected bridges do not have any expansion joints at all, 39 of them or 60.0% have a low or moderate expansion joint defect risk and 26 bridges or 40.0% are at a high or very high risk (Figure 14). The main causes of expansion joint defects are the following: maintenance, poor workmanship and lack of design details. In order to get rid of the problems caused by expansion joints, new studies are carried out to minimise the number of joints by providing continuity on the asphalt (integrated bridges). For this reason, new types of expansion joint such as “Tarko”, “Thorma Joint”, “Serviflex” have been developed (Kamaitis, 2006).

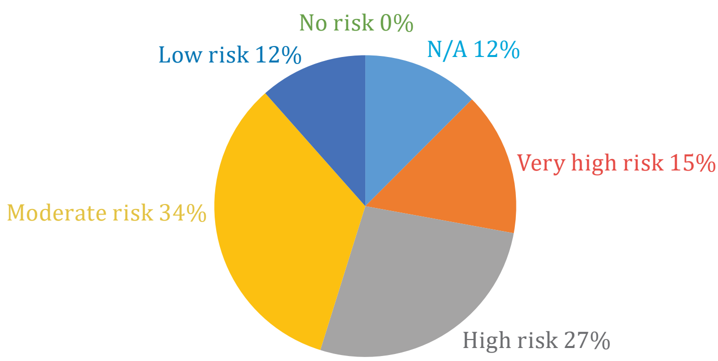


Figure 14. Rating of Expansion joint defects

3.2. Bearings

Bearings, whose task is transferring loads from the superstructure to the infrastructure, is the boundary between the infrastructure and the superstructure. These different types of elements allow rotation due to deflection and also lateral movement of beams because of temperature changes. Bearing failure to perform its functions for any reason will result in additional stresses on the superstructure that can increase inner forces steadily.

It has been found out that basically four types of bearings such as roller bearing, linear rocker bearing, plane plain bearing and elastomeric laminated bearing are used in the Albanian bridges.

It has been observed that metal bearings in some bridges are corroded and the horizontal movement is limited by soil debris (Figure 15a).

Moreover, it has been found that some sliding bearings are not properly aligned and thus lose their functionality.

As it is clearly seen in Figure 15b, the contact between the bearings and the slide plates has disappeared and this essential system, which is the support joint of the bridge, has become inoperable. Many of

(a) Corroded and clogged bearing

(b) Misalignment of sliding bearing

(c) Offset on elastomeric bearing

Figure 15. Common bearing defects

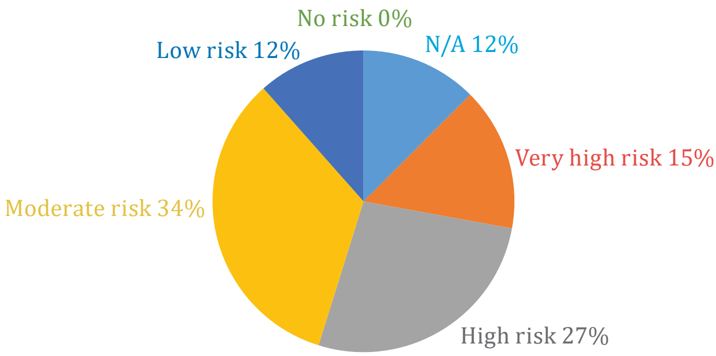


Figure 16. Rating of Bearing defects

the problematic elastomeric laminated bearings had offset problems (Figure 15c) and it was measured that the offset angle in the elastomeric bearings ranged from 15° to 20°.

Out of 104 inspected bridges, 64 have common bearings. Among those bridges, 8 or 12.5% have no bearing defect risk, 34 of them or 53.1% have a low or moderate bearing defect risk and 22 bridges or 34.4% are at a high or very high risk (Figure 16). There are 40 bridges where bearing is not applicative. The main causes of bearing defects are overload, maintenance, poor workmanship and lack of design details.

3.3. Wearing surface defects

Wearing surface is a top layer of highway and it protects the deck surface from water leakage and other atmospheric agents. All wearing surfaces of the Albanian bridges are asphaltic. Defects found on a wearing surface are asphaltic cracks and holes. In many cases, wearing

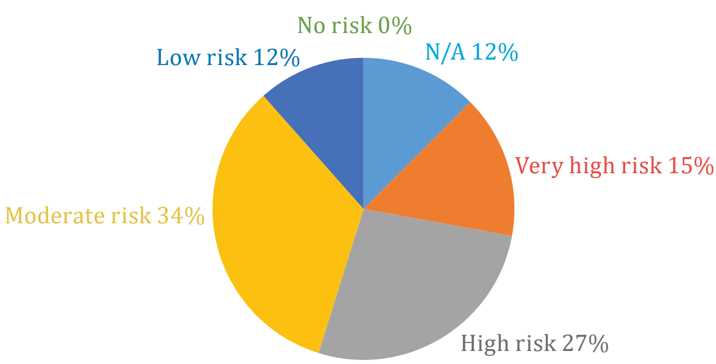


Figure 17. Rating of Wearing defects

surface is totally destroyed and deck surface is opened directly to traffic flow. Out of the inspected bridges, 7 or 6.7% have no wearing surface defect risk, 86 of them or 82.7 % have a low or moderate wearing surface defect risk and 11 bridges or 10.6% are at a high or very high risk (Figure 17). The main causes of wearing surface defects are low material quality, maintenance and poor workmanship. It is known that in some European countries and in North America polymer surfacing is used as surface wearing for waterproofing (Kamaitis, 2006).

3.4. Drainage system

Drainage systems may cause some durability problems to steel and concrete, which is one of the main supporting materials of the bridge, if it is not maintained. Removing water from the bridge superstructure and infrastructure is a function expected from the drainage system that has shorter design life than that of structures, so in periodic times they need to be checked and replaced. Condition of the drainage system in all inspected bridges has serious defects. In some cases, it has been observed that after the construction of the deck, drainage holes were opened by destroying part of the building element, even by cutting steel reinforcement bars or damaging the concrete cover. In fact, it has been found that there are no drainage pipes in some bridges and, therefore, the structure is constantly exposed to rainwater. As a result, the decks have problems such as poor chemical defects under the surface, continuous moisture and moisture-related algae formation. Drainage system is the worst bridge element found in the inspection process; 22 of them or 21.2% have a low or moderate drainage defect risk and 82 bridges or 78.8% are at a high or very high risk (Figure 18). Even young bridges that are not older than 10 years have serious drainage defects.

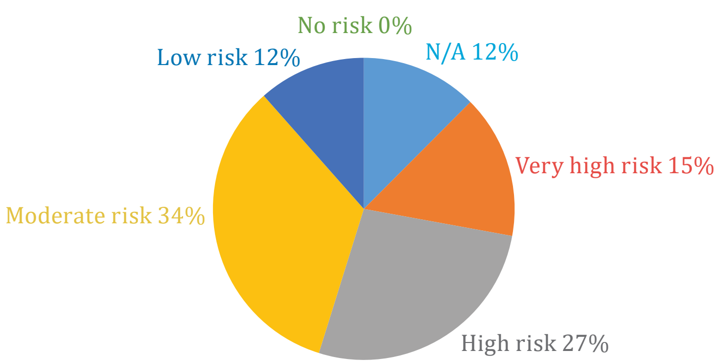


Figure 18. Rating of Drainage defects

The main causes of drainage defects are maintenance and lack of design details.

3.5. Parapet defects

One of the bridge rail functions is to reduce the consequences of vehicles leaving the bridge/road. Therefore, bridge parapet has a direct relation to life safety of the bridge users. Missing and under-design of bridge parapets cause few fatal accidents in Albania.

Defects found on bridge rail are broken connections and missing elements. Bridges built in the period of 1944–1911 have generally concrete parapets. Due to concrete degradation, the parapets were defected seriously. A parapet defect can be seen clearly in Figure 19. Bridges built in last two decades have metallic rails. Among the inspected bridges, 12 or 11.5% have no bridge rail defect risk, 63 of them or 60.6% have a low or moderate bridge rail defect risk and 29 bridges or 27.9% are at a high or very high risk (Figure 20). A phenomenon met in some cases is the destruction of these rails for informal profit from careless ruthless. The main causes of bridge rail defects are human intervention, maintenance and lack of design details. Rigid, high strengthened, innovative composite concrete has been designed to resist

Figure 19. Parapet defect on reinforced concrete beam

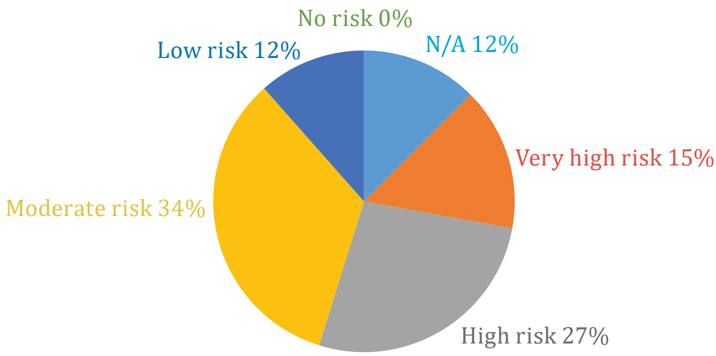


Figure 20. Rating of Parapet defects

impacts from vehicles nowadays in order to absorb impact energy and redirect the vehicle along the line of the road (Kamaitis, 2006; Köroğlu, 2016; Köroğlu, 2018; Köroglu & Ashour, 2019; Köroğlu & Özdöner, 2016).

Conclusion

In this study, a series of investigation studies have been carried out to determine the common problems of reinforced concrete bridges and deterioration levels of bridges. In this context, 562 bridges in Albania were examined using the previous review reports, and 104 critical bridges that were exposed to intense traffic loads were selected and examined in detail. The main aim of the visual inspection studies on these selected bridges is to predict possible problems in these bridges and to prepare a road map for more detailed investigations. These visual inspection studies on 104 critical reinforced concrete bridges show that the reinforced concrete bridges in Albania are under poor or very poor physical conditions. In line with these examinations, the main causes of defects in the bridges investigated in this paper were determined as the increased traffic load, harsh environmental conditions, the aging in the bridges, the lack of maintenance and repair, as well as the lack of project design.

Considering the increasing traffic loads in the light of these examinations, it is recommended to take immediate action to carry out emergency maintenance works for bridges under heavy traffic and to create a maintenance team. In this context, a more detailed examination and research should be carried out to prepare a maintenance plan schedule for all bridges. To investigate the assessment of reinforced concrete bridges deficiencies deeply, it is suggested for future studies to use various non-destructive testing methods, such as visual inspection, ultra-sonic pulse velocity (uspv) test, cover meter, rebound hammer test for concrete, half-cell potentiometer test, carbonation tests and chemical analysis. On the other hand, unmanned aerial vehicle (drone) technologies combined with digital image processing, which can be applied for visual inspection, are also suggested for future studies.

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