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CONCRETE DETERIORATION, CONSEQUENCES, INTEGRITY AND BEARING CAPACITY ASSESSMENT OF IN-SERVICE CONCRETE BRIDGES

RAZARANJE BETONA, POSLEDICE, PROCENA INTEGRITETA I KAPACITETA NOSIVOSTI POSTOJEĆIH BETONSKIH MOSTOVA

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Abstract

During their service life concrete bridges are exposed to the process of permanent aging. This process is accompanied by increasing traffic intensity (frequency and axle load). As a result, the concrete deteriorates, and damages of various kinds are taking place. The integrity of the bridge is jeopardised and its load bearing capacity can be significantly decreased.

Izvod

Betonski mostovi su tokom svog životnog veka izloženi procesu neprekidnog starenja. Ovaj proces je praćen povećanim intenzitetom saobraćaja (frekvencijom i osovinskim opterećenjem). Kao rezultat, nastupa razaranje betona i pojave raznih tipova oštećenja. Integritet mosta je ugrožen i njegov kapacitet nosivosti opterećenja bi mogao biti značajno umanjen.

INTRODUCTION

Concrete bridges are constructed today with the required high criteria regarding strength, waterproofing, resistance to frost and chloride action, and using a variety of different protective layers as well. The main goal is to provide the bridge durability and it is common today to consider the total bridge service life e.g. 100 years.

Unfortunately, the concrete ages during the time despite all these measures and it is subjected to deterioration which can be characterized as twofold: deterioration by aging which is taking place as a consequence of environmental and weather actions and structural deterioration, induced by the increasing traffic conditions (intensity and frequency). Both types of deterioration are not independent and mostly interact mutually, decreasing gradually the global load-bearing capacity of the bridge during their service life.

Having in mind as mentioned above, it is of significant importance for the bridge owners, not only to know about all kinds of concrete deterioration in concrete bridges, but the procedures for their inspection, testing, and the bridge integrity and load capacity assessment.

BRIDGE INSPECTION

All bridge owners in the world, that have or do not have particularly developed bridge management systems, are in charge to maintain the bridges. This relates not only to the maintenance of the bridge service conditions but to the measures of the bridge structure safety and reliability.

Bridge inspections differ depending on the volume and frequency of the bridge observation. Mainly, they are classified as:

Routine inspection – “passing by”

It is done as a routine, very often from a moving vehicle and without established time schedule.

General inspection

Visual inspection of only accessible members without devices (cranes, scaffolds, etc.) for access and closer inspection. They are performed every 2 years.

Main inspection

Detailed visual bridge inspection with a closer view of all structural members using special cranes and other devices for access (nowadays often by the help of drones and robots). It implies application of non-destructive and destructive testing methods. It is performed every 5/6 years.

Special inspection

Inspections with the particular purpose performed usually after some accidents (fire, explosion, floods, etc.).

Inspection for bearing capacity assessment

In fact, it responds to General inspection, but it comprises the application of relating non-destructive and destructive testing. It is performed on the request for bearing capacity assessment.

The bridge inspection is carried out as teamwork, but it needs to emphasize the role of the team leader who must be an experienced bridge engineer with good knowledge of the structural system and mechanical-physical characteristics of the material.

All mentioned types of inspections, implemented by most of the bridge owners, are based on the deterministic approach, i.e. they are applied according to the strict and inadvance predetermined schedule following a full set of activities. However, the contemporary concept, to make the bridge inspection more efficient and cost-effective at the same time, begins from the probabilistic principle - risk-based inspection. This concept, soon after few inspections, identifies the most critical member on the bridge, defines its limit state, and calculates the risk of reaching this state. Under these circumstances the key parameters appear as: *initial damage* and *damage function* (Fig. 1). After the first few bridge inspections, when the bridge is open for traffic, it is possible to observe the initial 'weak place,' initial damage which as a matter of a rule, has a progressive increase during the time. The functional dependence of the damage propagation, even having exponential character, cannot be expressed by the mathematically smooth curve, but after a few repeated inspections might be determined as the process described with discrete rows of points.

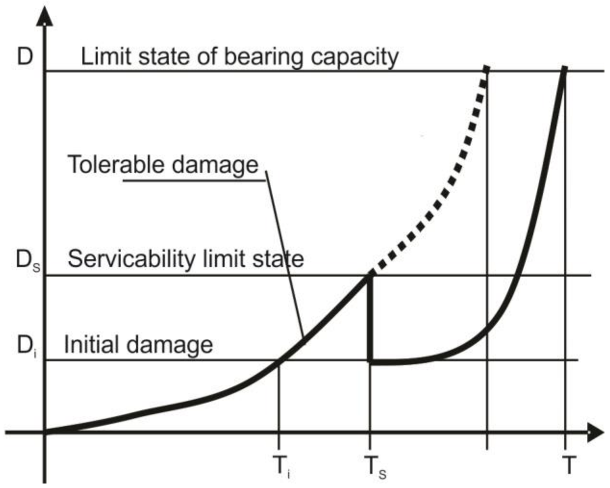

Figure 1. Damage function.

CONCRETE DETERIORATION

In general, concrete is a durable material. Assuming good design, construction carried out with strict quality control, and regular maintenance, it is justifiably to expect the bridge service life of 100 and more years. However, depending on the many circumstances - environmental and local climate conditions, maintenance procedure, traffic intensity and particularly of the presence of water and chloride ions, the concrete deteriorates. This deterioration takes place in many different ways but the most common are:
- *scaling* - the loss of the surface portion of concrete (or mortar) as a result of freezing and thawing;
- *disintegration* - the physical deterioration (results of scaling) or breaking down of the concrete into small fragments or particles;
- *erosion* - the deterioration of concrete surface as a result of particles in moving water scrubbing the surface;
- *corrosion of reinforcement* - the deterioration of steel reinforcement in concrete which can be induced by chloride or carbonation;
- *delamination* - a discontinuity of the surface concrete, substantially separated but not completely detached from concrete, below or above it;
- *spalling* - an extended delamination when the concrete fragments detach/fall off from a larger concrete mass;
- *alkali-aggregate reaction* - the internal cracking of concrete mass as a result of a chemical reaction between alkalis in the cement and silica in the aggregates;
- *cracking* - a linear fracture in concrete which extends partly or completely through the member.

The first task of any bridge inspection is to spot, locate, identify, and describe any observed kind of concrete deterioration/damage. The second step is the cause analysis, degree of hazard evaluation, and effect quantification to the general bridge condition.

Whichever type of the concrete deterioration is observed on the bridge structure, it does not mean that it is fatal, but must be carefully considered, rated, and included in the process of the bridge bearing capacity assessment. Once the concrete deterioration or damage is observed, it is up to the head of the inspection team to decide what kind of testing should be applied in order to define extent and cause of damage. The most common methods are:
- determination of the depth of protective layer,
- testing of the penetration depth of the chloride ions,
- testing of the penetration depth of the carbonation,
- determination of the degree of reinforcement corrosion,
- testing by potential field measurement,
- testing by rebound hammer,
- determination of the concrete strength on drilled cores,
- determination of the adhesion between repair layer and concrete.

If the test results show significant and jeopardizing effect of the bridge general conditions, a more detailed numerical calculation of the limit state of the bridge resistance must be performed. This calculation takes into account the bridge general conditions, the real material characteristics, rate of deterioration/damage and the result of the previous testing. The outcome is the exact assessment, stating the maximum permitted load on the bridge now.

This approach is presented here in several consecutive steps as follows.

Step 1. The first step in this process is the bridge structural analysis and bearing capacity calculation based on the primary code valid at the time when the bridge is designed (M0).

Step 2. The nominal heavy live load is evaluated based on the statistics obtained from the traffic axle load record. The heaviest vehicle (track) of 44 t (440 kN) has been determined – article 10 in /2/. However, this load must be multiplied with the coefficient of uncertainty, 1.50, according to the values given in Table 3, page 4 in /3/.

Step 3. The bridge resistance capacity is calculated with a load of $440 \times 1.50 = 660$ kN (M1). If the value M1 ≤ M0, the bridge bearing capacity is satisfactory. If the value M1 > M0, the next step must be taken.

Step 4. The bridge resistance capacity is calculated with the same load but taking into the coefficient of uncertainty as low as 1.00, i.e. $440 \times 1.00 = 440$ kN (M2).

If the value M2 ≤ M0, the bridge resistance is *conditionally satisfactory* (the value M0 refers to the new bridge structure but being in service many years the concrete structure deteriorates diminishing the initial structure resistance).

At this level of assessment, the bridge load test needs to be carried out. The main task of the testing is to discover possible hidden bearing reserve which an existing concrete bridge structure might possess. Based on the experience, this bearing reserve range is between zero to 20%. Anyway, as much as registered, it is included in the total bridge bearing capacity assessment.

Step 5. The final and most decisive step is the calculation of the limit state analysis of the bridge resistance. This procedure should be accomplished taking into account the real (as built) geometrical and material characteristics. However, keeping in mind the process of bridge aging and concrete deterioration, the outcome of the analysis is multiplied by the factor of engineer's general condition assessment $F_c < 1.00$ /1, 3/. This factor determines the head of the inspection team, and that is the only point within this procedure where the engineer's subjectivity cannot be excluded.

As a comment to that, the proper question here is: who else is more competent to define the general bridge condition, even with one single number?

Limit state resistance:

$$M_{RU} = M_R \times F_c \,, \tag{1}$$

Factor of capacity:

$$F_b = \frac{M_{RU} - 1.60(\mathrm{M2} + M_g)}{1.80 \times \mathrm{M2}} \,, \tag{2}$$

Bridge bearing capacity:

$$Q_b = F_b \times 440 \text{ [kN]}, \tag{3}$$

where: M_{RU} - real limit state resistance; M_R - calculated limit state resistance; F_c - factor of general bridge conditions; F_b - factor of capacity; M2 - bridge resistance for load type 440 kN; M_g - bridge resistance for self-weight; 1.60 and 1.80 - safety coefficients; Q_b - bridge bearing capacity.

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