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EFFECT OF MANAGEMENT AND MAINTENACE ON BUILDING STRUCTURAL RELIABILITY

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Summary: *Appropriate controlling and maintenance of building structures during their service lifecycle represent actions of equivalent significance as suitable design and realisation quality. The paper would illustrate common imperfections and even fatal failures of especially bridge structures due to already presently underestimated activities.*

Keywords: *Inspections, structural imperfection, load carrying capacity, maintenance*

1. INTRODUCTION

With respect to construction industry, four principal activities can be distinguished, as research and development, designing, construction and management, but also maintenance and eventual retrofitting. *Science* and structural theory development is being executed simply by appropriately skilled research workers in the relevant subject. *Design* engineering is a process, which involves preparing a set of plans and specifications that defines the structure in its completed configuration. A considerable design engineering effort is required to prepare a good set of contract documents. Only experienced state certified engineers may be authorised to design specified types of buildings. *Construction* engineering involves governing and guiding the fabrication and erection operations needed to produce the structural members to the proper shape, and get them safely and efficiently in place in the structure, so that the completed assembly under the dead load conditions and at normal temperature will meet the geometric and stress requirements stipulated on the design. Building process can be realised only by approved company, adequately staffed, engaging experienced and trained key employees. During execution stage, a building is obviously properly supervised. In the case of adequate teamwork, remarkable buildings can be built without complications.
Inspections, maintenance and structural management provide quality assurance for construction and play either a very important role during entire and long-time exploitation. Regular maintenance is important factor influencing durability of structure. Generally up to now, little emphasis was given to structural inspection and maintenance.

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Although over the past three decades, the construction inspection program evolved into one of the most-sophisticated management systems.

2. BRIDGE MANAGEMENT SYSTEM

2.1 Maintenance Inspection

Each bridge document needs to have items such as structure information, structural data and history, description on and below the structure, traffic information and load rating. Regulations require that each bridge that is opened to public should be inspected at *regular intervals* not exceeding specified period. Inspection findings should be recorded in bridge document. The purpose of bridge inspection is to maintain the public safety, confidence, and investment in bridges. To this end, inspection staff should be knowledgeable in material and structural behaviour, bridge design, and typical construction practices. The frequency, scope, and depth of the inspection generally depend on several parameters such as age, traffic characteristics, state of maintenance, fatigue-prone details, weight limit situation level and known deficiencies. The specific frequency of inspections may be finally established based on the above factors. In the case of traffic accident, the extra-special bridge check must be executed. Some of the main responsibilities of a bridge inspection are especially identification of even minor problems that can be corrected before they develop into major repair, recognizing bridge components that require repairs in order to avoid total replacement, finding unsafe conditions, preparing accurate inspection records, documents, recommendation of corrective actions and providing bridge inspection program support. The findings and results of a bridge inspection are to be recorded on standard inspection forms. After inspecting a bridge, a reasonable conclusions should be communicated and practical recommendations to correct or preclude bridge defects or deficiencies advised. Whenever recommendations call for bridge repairs, the type of retrofitting, the scope of the work, and an estimate of the quantity of materials must be carefully described. The advice of more-experienced personnel should be sought, when the inspection findings cannot be interpret or the cause of a specific defect determined. All instructions for maintenance work, stress analysis, posting, further inspection, and repairs should be included in the recommendation. It is also important to recognize that these inspection reports are legal documents and could be used in future litigation.

2.2 Bridge superstructure rating

Once a bridge is constructed, it becomes the property of the owner or state agency. The evaluation of existing bridges under operation is a continuous activity to ensure the safety of the public. First of all, because bridges were built gradually in different time periods. Thus they were designed according to time-knowledge and live-load, which reflected the level of transport technique. There are even presently bridges from the beginning of the previous century designed for the roller of 8 t but also completely new structures designe for two axales load model weighing 60 t. Even if bridges are designed for the standard load model specified in codes, actually EC1 [1], they might not have adequate capacity to handle the actual traffic. Some changes in a few details during the construction phase, failure to attain the recommended strength or properties, unexpected settlements of the foundation and unforeseen damage to a member could influence the capacity of the bridge. Also, the live-load-carrying capacity of the bridge structure may have altered as a result of deterioration, damage to its members, aging, added dead loads, or modification to the structural member. The most important parameter ensuring the reliable service of a bridge during its service life is the load carrying capacity. It is defined as a maximum momentary weights of vehicles, which can pass through the bridge under certain conditions. According to type of idealised vehicle moving load on highways, roads and local communications, three types of load carrying capacities can be determined [2]. Normally, vehicles can cross a bridge without special limits in number, location at the road pavement and speed. Corresponding *normal* load carrying capacity is given as the weight V_n of one of six identical lorries representing the load model. Obviously only the *exclusive* load carrying capacity is interesting in the case of current bridge failures. It is given by maximum momentary weight V_e of a four-axle vehicle. Except of this variable action is no moving load at the bridge. In relevant structural analysis, actual geometric parameters of elements, real material properties and the most probable bridge behaviour and contempory conditions should be considered. The data are provided by technical diagnostic and investigation report. Sometimes, an industry would like to transport their heavy machinery from one location to another site. These heavy haul trailer would weigh much more than the design vehicles and thus the bridge owner may need to determine the *extraordinary* live-load-carrying capacity of the bridge. Load capacity limited by critical section can be determined from equation

$$\gamma_G \,.\, E_G + \phi .\, \gamma_Q .\, E_\theta(V_i) = f_{yd} \qquad (1)$$

with γ_G and γ_Q are partial safety factors, E_G means the effect of all dead load and $E_\theta(V_i)$ effect of variable action, produced by relevant load model. The dynamic coefficient ϕ depends on structural element span. Yield strength f_{yd} is output of material standard tests. The latest approaches for assessment of railway bridges have been incorporated into the guideline established by our department [2]. The reglementation is based on the limit state concept and live load is taken in accordance with the ideal train scheme *UIC - 71*. Load carrying capacity Z of critical section can be determined from the modified condition

$$\gamma_G \,.\, E_G + Z.\phi .\, \gamma_Q .\, E_\theta(UIC) = f_{yd} \qquad (2)$$

In this relation Z is ration of remaining resistance to the theoretical requirements for the *UIC – 71* train [1]. Depending on actual load, vehicles in operation are classified by railway authorities in eight effect categories. For practical assessment, the ratio of a given vehicle to *UIC – 71* train effects is of interest and denoted λ_{UIC}. The passage of certain group of railway vehicles ca be allowed, it the loading bridge carrying capacity is greater than maximum vehicle effect λ_{UIC}. Thus, the following criterion should be satisfied

$$\psi .Z = \lambda_{UIC} \qquad (3)$$

where ψ is factor taking into account real dynamic actions in the case of reduced vehicle velocity.

Bridge inspection and the strength evaluation process are two integral parts of bridge rating. The evaluation provides necessary information to repair, rehabilitate, close, or replace the existing bridge.

However, when a bridge is found to have inadequate capacity for legal vehicles, engineers need to look at several alternatives prior to closing the bridge to the public. Some of the possible alternatives are imposing speed limits, reducing vehicular traffic, limiting for vehicle weight, restricting the vehicles to certain lanes, recommending possible small repairs to improve the problem. In addition, when the evaluations show that the structure is marginally inadequate, frequent inspections to monitor the physical condition of the bridge and traffic flow may be recommended.

Although engineers may recommend one or a combination of the alternatives described above, it is the owner, not the engineer, who ultimately makes the decision. Many times, bridges are assessed for reasons other than structural evaluation, such as posting at a lower weight level to limit vehicular or truck traffic.

Load limit may cause inconvenience and hardship to the public. In order to reduce troubles to the public, the owner needs to look at the weight limit as a last option. In addition, it is sometimes in the public interest to allow certain overweight vehicles such as firefighting equipment and snow removal equipment on a bridge. This is usually done through the use of special permits, as a higher weight level means a greater level of risk. But standard evaluation methods above described may be overly conservative. When a more accurate answer is required, a more-detailed analysis, such as three-dimensional analysis or physical load testing can be performed. In the following sections, establishing the live load-carrying capacity and the bridge rating will be discussed using sellected case studies.

3. SUPERSTRUCTURE RATING EXAMPLES

3.1 Simply Supported Railway Bridge

The assessment procedure can be illustrated on the example of a railway overpass. A failure of lower flange of its main girder was developed by an important impact of a trailer to the bridge structure. The crack through flange was partially propagated into the web (Fig. 1).

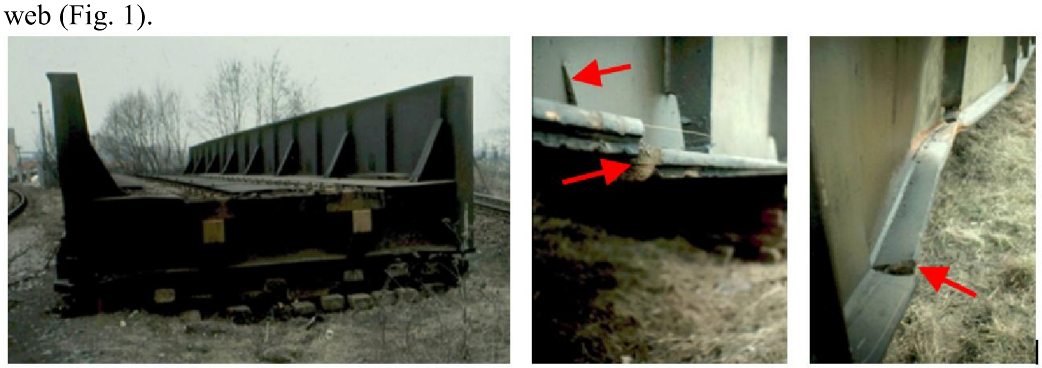


Figure 1. Trough passed bridge with fractured flange and web by lorry impact.

Public exposure to danger was a conclusion of the bridge evaluation. Since railway operation was not stopped immediately after the bridge damage due to collision [4]. The reduced ratio of load carrying capacity $Z = 0{,}38$ was totally insufficient for ensuring the reliable service of the damage bridge for the effect of engines operating on the track.

3.2 One Span Road Truss Bridge

The case of truss road bridge can illustrate that simple judgement, alone, is generally insufficient. Especially through passed road bridges may have imperfections due to lorry impact to the main girder, critical for load carrying capacity. The adequate periodical inspections managed discover the structural deterioration of the vertical strut [5]. Truss Pratt bridge has a span of 70,7 and was only 6,40 m width. The upper chords are curved limiting the forces due to bending and buckling length of diagonals carrying shear. Both upper and lower horizontal bracing provide rigidity to structure and transmit the main part of the wind load to the bridge portals. The conventional roadway of the asphalt lay and concrete slab was supported on three interior and two edge stringer 0,60 m high, made of built – up beam by riveting. The floor beams 0,75 m high, rigidly connected to the vertical post thus provide lateral rigidity to the bridge as a whole. The bridge was built 85 years ago (Fig. 2). The original structural analysis was simplified by breaking it down into planar and linear components such as the main trusses, floor beams, stringers and bracing frames. Thus the computed internal forces represented only an approximation of the actual ones.

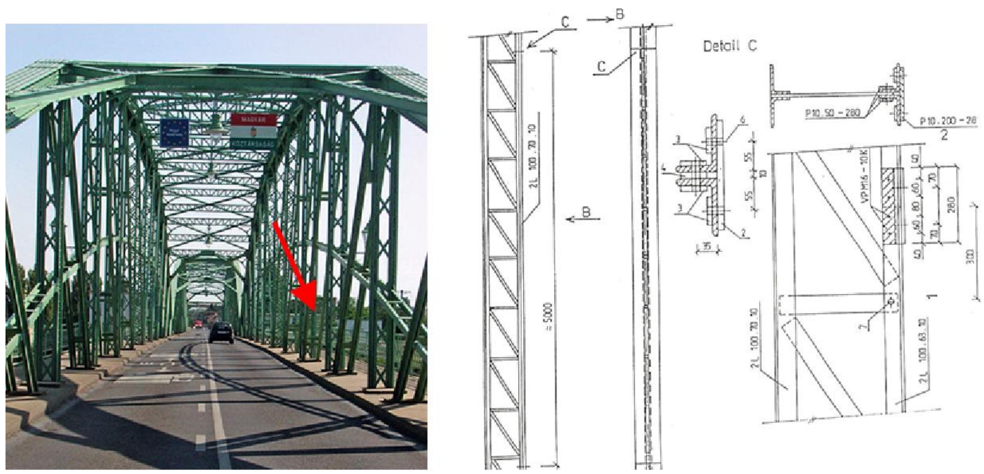
3 

Figure 2. Damaged vertical post of a truss bridge, refiting by strenghtening.

The large extra deflection about 100 mm of the originally straight vertical post developed by the impact to the bridge girder exceeded greatly the standard initial in perfection given in standard EC 3 [3]. The stress analysis as space structure, with real member end fixity and the truss joints behaviour was carried out by the computer program based on the finite element model. Even though the resulting more real distribution of stresses among the members, the normal bearing capacity of bridge was reduced at Vn = 22,0 t. This value represented only the halt of the original magnitude.

Taking into account the importance of the transport traffic passing through the bridge, it was decided to repair the limiting member. Its damaged part was cut out and replaced by the new one, connecter by high friction bolts. The reconstruction operation necessitated closing the bridge for one day, because the works had to be executed at the bridge structure without one live load.

3.3 Single span trusses as temporary road bridge

A truss bridge was used to provide the temporary river crossing during construction [6]. Such a system consisted of bridge edge abutments, stringers, joists, and forms. The superstructure was assembled from obvious standard subcomponents of triangular configuration. The single 41.5 m span bridge consisted of double truss girders of constant height of 3.2 m joined by bolted framing at both chords. The superstructure with restrictive carrying capacity at one lorry of 20 t had only the 4,0 m clearance space required for passage construction-site traffic. Timber deck comprised lumber plank 60 mm thick and 250 or 300 mm wide placed side by side and attached with large spikes to the supporting laminated standard stringers I 120. The entire deck was nailed together to act as a composite section and oriented such that the lumbers were laid transverse to the bridge span across the supporting built-up stringers 0,36 m high, axially 0.38 m spaced. A lower lateral bracing under deck was needed to hold system in stable condition during erection and operation (Fig. 3). The crossing was designed by the contractor and approved by the inspector to resist vertical live loads, as well as longitudinal and transverse horizontal loads. No special hydraulic bridge design was executed to consider flood and its potential negative impacts. When high water flow was obstructed, the superstructure was pushed out from bearings and the horizontal upstream mid-span deflection nearly 1,5 m was dveloped.

Figure 3. Concept of truss bridge, horizontal deflection caused by flood, bridge finite element modelling

As conclusion of the exeptional inspection but somewhat vague one, special pads were employed at abutments and the bridge superstructure was placed back in the previous position, but 0,8 m higher. Unfortunately, imperfections of the upper chord alignment were underestimated. Furthermore, several bolted framings of the upper chord were detached. Originally, built-up members, made by bolting together two standard structural U120 chanels acting as one component, started to work as individual units shapes. But only cross frames consisting of truss vertical and floor beams, compatible with their locations can provide lateral stability of top flanges. The more-detailed three-dimensional analysis confirmed that the above intervantion increased the upper chord buckling length from the value 3,0 m at 4,14 m. While a 20 t heavy lorry passed through bridge, buckling collapse of the upper chords occurred and the superstructure fallen down in the river. A combination of an improper repairs and incorrect inspection led to this structural failure.

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ЕФЕКТИ УПРАВЉАЊА И ОДРЖАВАЉА ОБЈЕКАТА НА ПОУЗДАНОСТ КОНСТРУКЦИЈА

Резиме: *Адекватна контрола и одржавање конструкција објеката током њиховог употребног века представља активности које су једнаке по важности као и добро пројектовање и извођење. Овај рад илуструје уобичајене имперфекције па чак и фаталне грешке нарочито код мостовских конструкција услед подцењених активности управљања и одржавања.*

Кључне речи: *Прегледи, имперфекције конструкције, носивост, одржавање*