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### **DESIGN, EXECUTION AND MAINTENANCE ASPECTS OF REINFORCED CONCRETE BRIDGES EFFECTING ON DURABILITY AND SAFETY**

*Bridge structures are particular building objects because of the importance of such facilities in the national economy and multiplicity of factors that need to be considered in design and construction. These factors affect on durability and operation of bridges. The article considers bridges that are part of highways. As these structures are operated in open environment, exposed on atmospheric conditions the special treatment in design and during construction and operational - maintenance periods is required. This paper describes the author's experience in the scope of factors affecting on the safety, durability of bridge structures related to design, execution and operation. The paper also includes the review of most popular types of reinforced concrete bridge structures currently implemented in Poland.*

### **WYBRANE ASPEKTY PROJEKTOWANIA, REALIZACJI I EKSPLOATACJI TYPOWYCH ŻELBETOWYCH OBIEKTÓW MOSTOWYCH MAJĄCYCH WPŁYW NA TRWAŁOŚĆ I BEZPIECZEŃSTWO KONSTRUKCJI.**

*Konstrukcje mostowe są szczególnymi konstrukcjami budowlanymi ze względu na ważność tego typu obiektów w gospodarce narodowej oraz z punktu widzenia projektowania i realizacji ze względu na mnogość czynników wpływających niekorzystnie na ich trwałość i eksploatację. W artykule przedmiotem analizy są obiekty mostowe będące elementem dróg szybkiego ruchu i autostrad. Ponieważ konstrukcje te są eksploatowane w otwartym terenie, narażone są na niekorzystne oddziaływania czynników atmosferycznych, co ma wpływ na ich eksploatację. Wymaga to szczególnego traktowania mostów podczas etapu projektowania, zachowania reżimów technologicznych podczas realizacji oraz konsekwentnego i dokładnego działania serwisowego i konserwacyjnego podczas eksploatacji. Przedmiotem omówienia niniejszego artykułu są doświadczenia autora w zakresie czynników wpływających na bezpieczeństwo i trwałość konstrukcji mostowych, a związanych z ich projektowaniem, wykonawstwem i eksploatacją. Dokonano przeglądu ciekawszych typów obiektów mostowych realizowanych aktualnie w Polsce.*

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## 1. INTRODUCTION

It is generally accepted that structural elements determining the safety of bridge should fulfill the requirements throughout whole period of operation. Durability of each element should correspond to sustainability of the entire facility [1,2]. Similar treatment of all elements of the structure however could result in the need for high sustainable construction elements and therefore significantly increase the costs of implementations. For this reason it is assumed that some parts of bridge components or products may have less durability than the bridge as a whole structure and will require replacement, repair or maintenance. Of course without affecting on the safety and reliability of the bridge as a whole [11].

From the point of durability and safety of the bridges elements the structure can be divided into several categories. First of them includes all elements of bridge that lifetime is shorter than the lifetime of the bridge as a whole and which should be replaced within the given time. These are not structural-bearing elements of the structure.

The second category includes the bridge elements whose life is shorter than durability of whole structure, but they are kept in the technical state to retain properties at the required level by use of some additional treatments such as corrosion protection, water proof membrane, etc.

The third category are the elements which may endanger the safety of structure when are destroyed, and cause repair excessive costs. Their durability should be equal to the sustainability of the whole structure of the bridge. Foundations, pillars, supporting girders can be classified in this group.

Due to numerous advantages and after eliminating the major drawbacks, the reinforced concrete monolithic and precast structures of bridges dominate in bridge industry. For example precast methods allow for implementation of complete structural assemblies in production factories bringing assembly only to make on construction site [3]. This method significantly reduces the execution time of bridge, increases productivity, improves quality and lowers the overall cost of structure. Improvement of technological processes of production of steel and concrete gives the possibility of using the materials of higher quality, and thereby allows for less material consumption and thus to reduce the weight of the structure. Further possibilities of using high-strength concrete and steel creates the pre-compression technique. In addition making easier to merge various elements in a single structural unit [4].

As in any field of construction so in bridge industry, precast method has its special advantages giving its priority comparing to structures cast in situ: bridge span and width, different classes of load, different local conditions, independence from weather conditions, better control of production [5,6].

## 2. EXAMPLES OF ONGOING TYPES OF REINFORCED CONCRETE BRIDGES IN POLAND

Currently in Poland number of concrete bridges in line of highways are carried out in the system of:

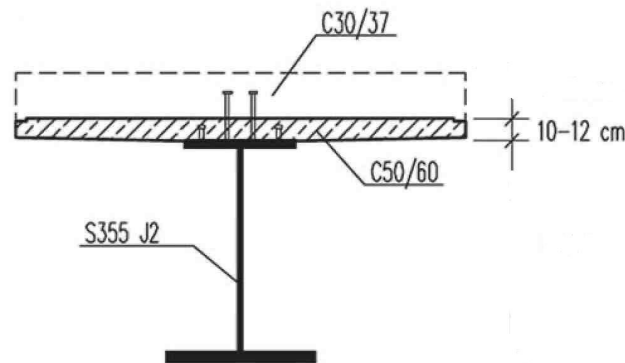
1. rigid frame (type PG-6, PG-8, PG-12) with slabs cast in situ
2. rigid frame (type WD-12, WD-13) with slabs on prestressed beams named Kujan
3. rigid frame closed box (type WA-10) with slabs cast in situ

#### 4. steel-soil structures type SUPER COR and MULTI PLATE

Prestressed girders type Kujan are the most common supporting structure of typical bridge structure applicated within highways. Assembly of these elements are relatively easy to do. These beams have the shape of an inverted 'T' cross section and they are designed on load class A and B according to [9]. They are made of concrete C35/45 or C45/C55 and depending on the span of the beam, the number of strings is from 11 up to 20.

Kujan NG has increased capacity in comparison with Kujan, and they are designed for load class A and special vehicle class 150. Beam class 'T' are produced for moving load, class A.

VFT girders are prefabricated composite steel beams with concrete flange, that are development of "T" beam (Fig.1.).



*Fig.1. Cross section of VFT girder*

Typical precast prestressed beams can be replaced by soil-steel structure also known as ground-coating. This alternative can be used for structures of small or medium span, especially for local roads, but more often for railway or highway. Furthermore this structure is being used as transition for animals. For steel-soil the corrugated sheets called Super Cor, Stren Cor, Multiplate, Vario-sec, Tubosider czy Voest are used, which differ among themselves mainly corrugated sheet dimensions. Shapes that are used in longitudinal directions are: box, curve, circular, elliptical, circular arc. Load capacity of these structure is therefore a combination of cooperation of steel structure and surrounding soil.

### 3. DESIGN PHASE

Design phase allows for proper selection of sections in order to satisfy the conditions of load capacity and deflections. Inclusion of all loads is most important, especially dynamic load when needed. In addition to long-term static load (weight of structure) bridges are subjected to loads such as vehicles or pedestrians and wind. The effects of these loads are vibrations of structures. Depending on the type of structure and size of loads vibrations can have different frequencies and amplitudes, to be more or less

noticeable to users or dangerous for safety. Depending on directions of excitations bending and torsional vibrations are important or combination of both. If the excitation frequency corresponds to natural frequency of the structure, the resonance can appear, often leading to accidents or disaster. Therefore the structural characteristic is needed to be calculated, especially the free vibrations frequencies. Moreover, vibrations may be the source of fatigue.

Load coming from moving vehicle occurs during normal use of the bridge. The key parameter determining the impact of traffic on the structure is the speed of the vehicle. If the construction of the bridge (surface) is new and there is no broken pavement the critical velocity causing the resonance of beams are very high, i.e. for steel structure over than 1000 km/h, in the case of concrete structure 2000 km/h and with the decreasing span of the beam these values are increasing. The situation is different when the wheels hit the irregularity of the surface. If the irregularities are in the form of threshold and located in the middle of the span of simply supported beam and if the wheels of the vehicle hit these irregularities in regular intervals that correspond to the own vibration period of the beam, the value of the critical velocity is then more real. In some cases the velocity is in the range of 50-100 km/h. This situation is unique but gives some idea of the occurring cases. The obvious conclusion resulting from this example is the need to eliminate any irregularities in road's surface on the bridge.

Development of transport includes increase of traffic flow with high speed of movement. Development of structures is associated with reduction of weight of the bridge beams and supports.

All these changes cause the dynamic influences and increasing damages, scratches and cracks. These cases require solutions at the phase of design. Analysis of bridges under the dynamic excitations indicates that most of the cracks in concrete structures come from shear and notches, as in these sections the deformities are more focused and less suppressed by deformations. Dynamic issues can not be restricted only to certain subjects or locations, such as vibrations of the span. Dynamic excitations cause vibrations of all parts of the bridge and impulse or reflections that can cause damages to any of them. In the selection of bridge structure, material and dimensions is therefore necessary to consider all dynamic effects which may cause damage to any part of the bridge.

Impulse load plays specific role because it very often causes shear damages rather than throughout tension or compression damages. Stresses or deformations caused by these destructive impulses are not equally proportional to the stresses and strains of destructive static load.

Analyzing the dynamic load effecting on bridge structures one need to pay attention to the effects of dynamic changes caused by reflected waves, that are concentrated in discrete sections as nodes, corners, connections, on the surface of bars and aggregates. The effects of these changes increase with the size of discontinuities and differences in dimensions of connected parts, bars and aggregates. These conclusions state requirements of proper shaping of sections and sizing to avoid these discontinuities. In concrete bridges structure should preserve as much continuity of reinforcement as possible, reducing of its diameter and spacing. Also dimensions of aggregate should not be big in relations to the size of elements, webs, slabs, flanges, etc. All these recommendations are well known but they do not have their counterparts in the analysis of dynamics and therefore there is no basis of calculations.

Proper forming of reinforcement is connected to the stresses cumulations as the bridges are exposed to corrosion due to weather conditions and chemicals e.g. based on salts which are used in order to properly maintain the roads in the winter [7,8]. The chloride corrosion can appear. The design should provide such solutions to avoid increasing the moisture content in concrete, as well as the expansion of soluble salts. The shape of the structure is essential for resistance to frost and corrosion protection (Fig.2.).

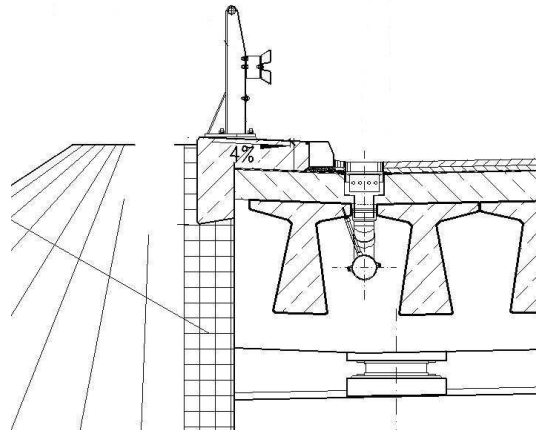


Fig.2. Section detail

The risk of damage due to the freezing is largely dependant on the damp of the concrete, hence it is need to use solutionsthat enable to rapid outflow of water. Water that is discharged from one part of the structure should not flow down to another part.

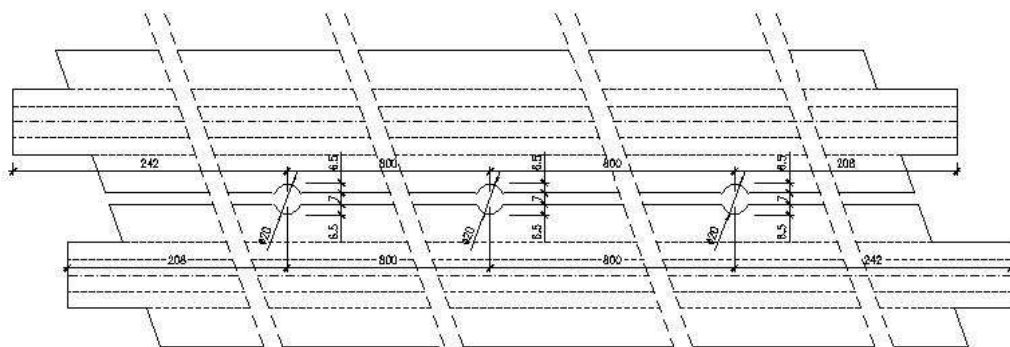


Fig.3. Outlets drainage

This is the case when we deal with water containing dissolved salts and other aggressive ingredients. In extreme cases when opportunities are limited, the concrete of higher quality should be used together with proper thickness of concrete around the bars [10].

#### **4. OPERATION PHASE AND MAINTAINANCE.**

Operation phase of bridge requires the permanent maintainance and control. Reinforced and prestressed concrete elements are ductile; such elements show deformation prior to failure. Concrete elements are often internally and externally redundant. It usually takes the failure of more than one internal component such as a reinforcing bar or prestressing strand to lead to failure of the member. It usually takes the failure of more than one member to lead to failure of the bridge. Cracks are not necessarily a sign of damage. Components of concrete bridge can maintain load-carrying capacity while obviously in a severely cracked and deteriorated state [8].

The failure of an unreinforced concrete elements. in bending or shear can be sudden without being preceded by large deformations.

Identification of a crack on the tension side or in the shear zone of a properly reinforced beam is not necessarily cause for alarm. Observation of the same crack in an unreinforced beam could be justification to close the bridge.

Verification of the location and size of embedded reinforcing steel or prestressing is difficult. Steel which is relatively close to the concrete surface can be located with a variety of instruments. Deeper layers of steel and steel in underground, underwater, or otherwise inaccessible is more difficult to assess.

The most visible effect of the corrosion of embedded steel is the cracking and delamination of the concrete cover, loss of steel area can be structurally significant. In prestressed concrete, oxidation of the steel may not generate enough corrosion product to crack the concrete, but may cause enough pitting to fracture wires.

In such circumstances reinforced or prestressed concrete member has no more protection against sudden, brittle fracture than an unreinforced member, and failure will not be preceded by large deformations

Reinforcing and prestressing steel provide strength and ductility only through bond and anchorage to the concrete, and the effectiveness of such connection can be reduced through deterioration of the steel, concrete, or both. The loss of prestressing anchorages due to corrosion has led to the loss of unbonded bars.

Concrete shows a wide variety of patterns of cracking due to combinations of effects which may include freeze-thaw damage, alkali-aggregate reactions, sulphate attack, drying shrinkage, thermal movement and the corrosion of embedded steel bars or wire. Some such cracks signal that the structure or component is in damage, many of the resulting cracks are of minimum structural significance if properly maintained. However, assessing the origin of cracks in the field, and sorting the critical cracks from the non-critical cracks, is a difficult task.

#### **5. CONCLUSIONS**

Nowadays bridges of concrete structure are executed very frequently, both in monolithic and perhaps even more often performed as precast constructions. Concrete as a

material in the opinion of the author is most suitable for these types of structures. It is very durable material, on the other hand free to shape. Also concrete is proper in creating the dynamic characteristic of the structure. This feature is especially useful in the light precast reinforced concrete. Further technological progress allows to use precast elements in areas that previously were reserved for monolithic structures. Versatility of precast structure is possible owing to new nodal connections and solutions.

To fully exploit the benefits of reinforced concrete bridge structures the requirements for proper forming of sections, combining reinforcement, compression in prestressed structures, concrete with optimum composition, technology of execution ensuring continuity of the process must be complied. To keep the facility safe, reliable the requirements of proper maintainance and operation must be fulfilled, under the supervision of experienced staff that is able to diagnose of visible and invisible symptoms on the working structure, e.g. deflections and cracks. Hence the natural criteria of requirements that are related to the design phase, execution and maintainance have been highlighted in the article.

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