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Advantageous bridge construction with prefabrication

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Abstract

In comparison to the extensive period of time spent within the engineering and procurement stages, very short construction period is almost always required. The usual reasoning by the public highway agencies (i.e. project owners) for that is the effort to cut the construction costs, while the road user costs are usually ignored. This paper discusses the advantages of the prefabrication on the construction site over the traditional cast-in-place approach mainly regarding the speed of construction. Its advantages include the acceleration of construction due to parallel production of the lower structure and bridge's supporting structures, minimum impact on the existing transport network, i.e. lowering the road user costs to the possible minimum, better quality control, higher durability of the resulting structure and often also cost savings via the economies of scale. Paper further discusses the development of the bridge building with the usage of the prefabrication approach in the Czech Republic and how the system of prefabricated beams and segments have evolved till today. This newly improved way of building bridges has proved to be efficient even in the construction of the highway network's most demanding projects. Technological improvements, such as the use of high-quality concrete or new generation of prefabricated segments which provide new bridges with a long service life with minimal maintenance needs are assessed. Transferring the main construction activities after completion of the lower structure outside the bridged area is proposed. In a permanent production plant, high quality concrete elements can be achieved thanks to the high stiffness of the mold and considerable manufacturing accuracy. The classic method of constructing bridges with a medium span of mounting in symmetrical brackets from segments have successfully returned between frequently used technologies and especially the speed of construction gives this technology a good perspective to the future.

Keywords: precast concrete; prefabrication; segmental bridge; speed of construction.

1. Introduction

The current situation in the highway construction in the Czech Republic can be without any exaggeration defined as critical. The number of newly opened kilometres of highways stagnates at values of single digit of dozens. The construction of transport infrastructure is one of the long-term priorities of the Czech government and not even the financial crisis of 2008-9 and its many years lasting effects have not changed anything about it [1]. Although the impact of the crisis is still felt by the construction industry till today, money is not the problem regarding the highway construction, respectively governmental investments into it. After a very long period of time usually required for the approval of land use plans, verification of environmental performance, resolution of property relations and investment and project preparation, an extremely short construction period is almost always required. And bridges and tunnels are those objects that in particular limit the speed of construction. With the bridges of small and middle span, the prefabrication of the structural elements is the basic possibility how to deal with this requirement.

Precasting bridge parts and elements offsite is also very beneficial as bridges are generally among the most expensive objects constructed and also serve as a natural bottleneck for the traffic flows and so speeding up the construction process is beneficial again. It also brings substantial safety advantages, lowers disruption to traffic and increases overall convenience for the road users [2].

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2. Prefabrication of bridge constructions

The industrial production of concrete building elements can be applied to a significant part of the construction market. Prefabrication is a natural choice where high construction speeds are required where the auxiliary supporting structures coincide and formworks are for bridged transport routes and built or expensive land. While permanent factories with optimal work and the production conditions focus on simple or repeated standard designs; on the construction sites of large bridges, individualized molds for the production of large and heavy elements are needed [3].

2.1. Prefabrication on the site

The advantages of prefabrication on the construction site include the acceleration of construction due to parallel production of the lower structure and supporting structures, minimum impact on the existing transport network, better quality control and often also cost savings. Nevertheless, prefabrication at the construction site – unlike in other countries - has never started to be used much in the Czech Republic. Development in construction machinery and technology that uses heavy cranes, means of transport and assembly files, allowed extending of the prefabrication even to large bridges with melts and bridges with big spans, while maintaining its technical and economic advantages.

2.2. Possible negatives impacts

Prefabrication of bridge constructions can of course have negative impacts as well and careful consideration must always be given to the suitability of the system for any given environment. In particular, it is necessary to prevent monotone repetition, fine-tune the shape of the structures, solve the work and expansion joints and transfer of shear stress between individual elements.

3. Bridges using a system of prefabricated beams

Prefabricated composite beam systems are suitable for horizontal load-bearing structures of building structures and especially where considerable variability, fast construction without limitation of the underlying height, high payload and longevity are required. SSŽ (now Eurovia Group) construction company developed the systems of post-tensioned beams for the 12 to 27 m range and lightweight beams optimized for a 24 to 36 m, respectively for the 33 to 42 m range [4]. Bridge design is always optimized for each project with spatial arrangement, obliquity, continuity, load intensity, and other parameters. That is an important proof that the prefabrication expertise still remains in the Czech Republic, even though it is not being utilized in the same extent as it once was.

Supporting structures of beams with a coupled plate meet the current requirements of quality, durability and durability lifetime of the building work listed in european technical standards and in technical qualitative conditions. Beams are very suitable for different types of highway bridges and overpasses with a stand in the middle belt, but also for rail and tram bridges, pedestrian walkways, substructure of subways, excavated tunnels, underground garages and metro stations a heavily loaded ceilings of industrial buildings. The appearance of the bridges is aesthetically pleasing and design has a lighter look.

4. Segmental construction approach

4.1. Segmental technology limitations

Segment technology is world-class to significant technologies for the construction of medium-range concrete bridges. It is very demanding for technological equipment companies to its professional level and adherence to technological discipline. It is therefore not appropriate to use segment technology anywhere in common cases. A typical example is a high altitude above the terrain, inaccessibility of the area under the bridge, a large variation of the directional route of the small radii, high demands on speed and construction in last but not least, limitations of the wet construction process ecological reasons. It is necessary to take in consideration increased costs due in particular to higher tensioning stress consumption, and contractor's investment in technology equipment.

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4.2. Necessary refinements

A large number of segmental bridges can be found, for example, in the Southwest and North Europe, North America or Southeast Asia. In the 70s and 80s of the twentieth century segment technology belonged to the most frequently used technology for the construction of bridges of medium range in the Czech Republic (and in former Czechoslovakia) and it was offered by most of the civil engineering contractors. Some of the then built segmental bridges, however, had to be costly reconstructed, especially due to insufficiently solved structural details in the project phase, lower quality of that era's materials and not fully dedicated and professional maintenance. Such improved segmental construction approach is being successfully used as can be seen on Fig. 1 below.

Fig. 1. Segmental construction approach applied at the D8 highway project in 2014. (Source: ŘSD ČR (Directorate of the roads and highways of the Czech Republic))

5. Innovation of the segment technology

5.1. Design's optimization

Above mentioned post-tensioned beams' system is built on the Freyssinet International system. Technological innovations made progressively on the basis of years of experience have eliminated the many shortcomings and problems in recent years. Great attention was paid to the deviators of the loose cord cables. In order to eliminate the risk of cracks in concrete after tensioning the cables, their shape, reinforcement and formwork technology have been optimized [4]. The free cable geometry is three dimensional in the implementation documentation and the conical outlets of the lifted cables are set in the exact direction, for example, by means of laser sighting. At the same time, optimization of the cable conduction, the bay reinforcement and the geometry of the internal prestressing channels are carried out during concreting. Furthermore, a complex of problems related to sealing of segments, watering of pockets and grouting of pretensioning cables was solved.

5.2. Design's modernization

The sealing of the cable ducts in the contact joints is solved by the determined technology of application of the certified putty in the joint. The injection and venting system has been optimized so that they do not pass through the seams between the segments, and the proposed pocket watering technology allows for perfect cavity filling. Complete renovation and modernization of molding techniques and assembly files were also carried out. A considerably complex problem of bridge behavior during construction is always solved by the designer on a spatial static model, considering the interaction between the foundation soil and the bottom structure. The calculation takes into account the progressive construction of the scaffolding over the pillars, their gradual joining and the influence of the rheological properties of the concrete and the filling of joints [5]. The aim is to minimize the differences between the theoretical level and the actual design of the load-bearing structure.

5.3. Design's lightening

The next phase of the innovation became generally used in practice after 2005. The visually lightened pillars with an X-shaped cross-section pass into an expanded head adapted to accommodate all the technological equipment for mounting and rectification of the load-bearing structure. Segments of the classic chamber cross section have rounded outer corners between the wall and the bracket. There is a maximum of one pair of bracket cables in each segment. The anchor is located in the area of the wall and the top plate, there are no cables in the walls. The result is small changes in the direction of the cable routing, thus improving the continuity of the cable path in the joints and evenly distributing the shear tooths along the entire height of the wall. Reducing the number of channels allows them to be sealed in seams with sealant. The above mentioned are actually only a part of all the currently applied innovations, just to prove the attention being paid to the possibilities of the prefabrication on the current market.

6. Conclusions

Beam bridges are being successfully used even at the long and heavy motorway estacades like the one on the D8 highway (see Fig.1) or on D3 highways in the Czech Republic [6]. The use of high-quality concrete provides these bridges with a long service life with minimal maintenance needs. Prefabricated beam structures of multiple fields are basically designed to be continuous. New generation of bridge segments of the Czech companies have proved its advantages even in the construction of the highway network's most demanding projects. Segmental technology is nowadays popular in the industry world-wide as for example around 500 segmental bridges have been built in the United States since the beginning of the 1970s [7]. The main advantage of the technology used is the high speed of construction - assembly takes place typically at a speed of four segments per day which is up to ten meters of bridge per day and as the segments are produced in advance, the assembly can keep up with construction of the lower structure.

Substantial differences can be also recognized with the prefabrication approach when comparing its life-cycle costs and an extent to which its construction process affects the public, environment and the local economy over the traditional cast-on-site construction. Prefabrication of any structure component off-site offers major construction time and user cost savings. Precast prestressed road pavements' technology and precasting bridges' parts and elements offers dramatic increase in durability, while it also substantially decreases construction time and resulting user costs [5]. High socio-economic importance of the road user costs is most often ignored by the public sector, i.e. by the project owner who decides its design. This can surely be identified as the main advantage of the discussed prefabricated segmental bridges and as a main recommendation to the state highway agencies together with the overall awareness about the road user costs importance.

Another benefit is the possibility of transferring the main construction activities after completion of the lower structure outside the bridged area (e.g. valley or a busy junction). In a permanent production plant, high quality concrete elements can be achieved thanks to the high stiffness of the mold and considerable manufacturing accuracy. The classic method of constructing bridges with a medium span of mounting in symmetrical brackets from segments have, after a certain decline, successfully returned between frequently used technologies and especially the speed of construction gives this technology a good perspective to the future.

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