Design of bridges made of precast elements

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Summary

Big construction projects such as construction of motorways impose unified type of structures that have to be designed and constructed. Mostly short deadlines force designers and contractors to use industrialized and typified solutions for these structures. This paper will show some observations of bridge design concerning primarily precast girders, describing phases from their production to construction of different types of structures such as bridges, viaducts, overpasses etc. Different type of girders used according to chosen structural system will be shown. Intention of this paper is also to give some observations on aesthetics of structures built from precast elements.

Keywords: design, construction, precast girders, production, transport, aesthetics

1. Introduction

In the last few years Croatia is one of the biggest construction sites in Europe. As a result of enormous efforts of all parties in construction, client, designers, contractors and supervisors, in June 2003 approximately 150 kilometres of modern motorways were opened to traffic. These also include all structures that appear along the motorway – bridges, viaducts, overpasses and underpasses, culverts, tunnels, retaining walls etc. Our company Civil Engineering Institute of Croatia is one of the major contributors to the “Croatian Motorway Project” which is the official title of the country′s plan for motorway development. Experts and engineers of Civil Engineering Institute of Croatia were involved as designers, supervisors and quality control managers in this project.

2. Building with precast elements

Due to country′s vital interest to complete construction of motorways as fast as possible, especially of those along the Adriatic coast (tourist season lasts up to six months through the year), it was quite a challenge for structural designers to design structures that would be built in a short period of time and also meet requirements of durability and quality that structure has to fulfil. The most suitable way to do it is to design structures made of precast elements. Parts of superstructure and furnishing of bridges and viaducts designed by Bridge Division of the Civil Engineering Institute of Croatia were designed as precast. Also parts of substructure could be designed as precast (i.e. precast segments of piers, pier foundations, etc.) but it wasn’t the case here.

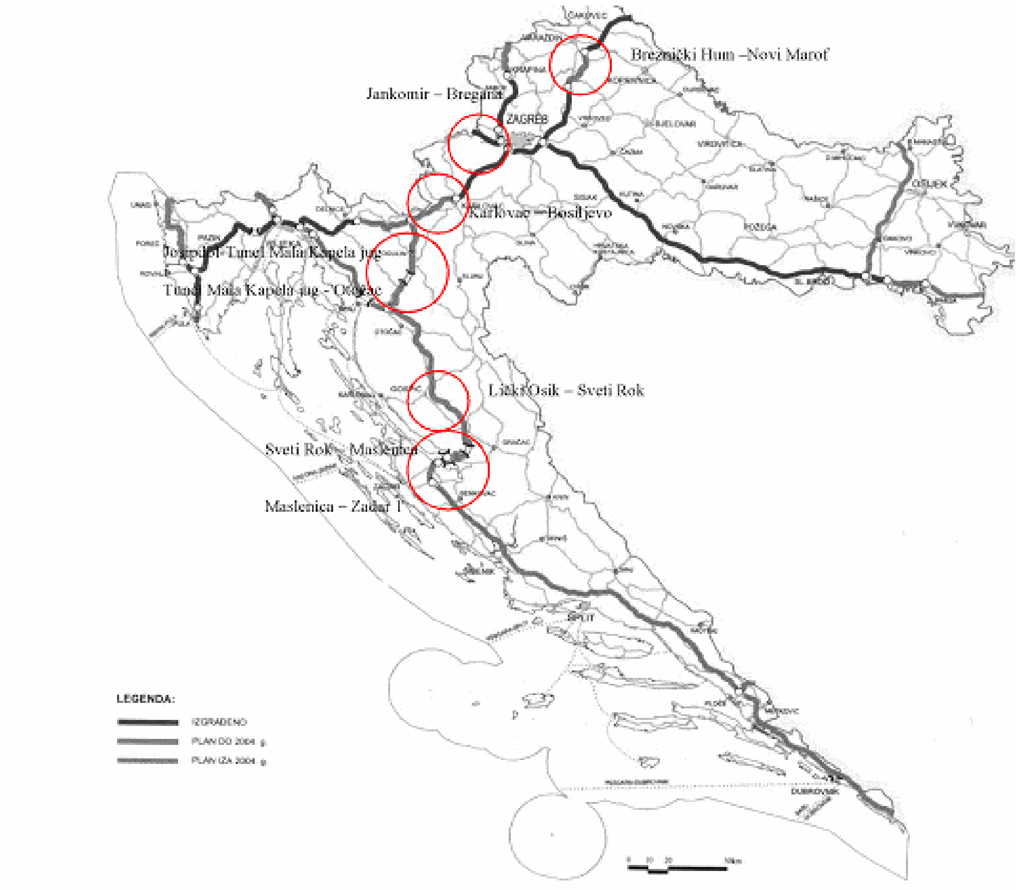

Figure 1: Map of Croatian motorway network

The clients requirements for structures are that they should be designed and constructed in such a manner which would also enable easy maintenance and repairs during structure's lifetime. As a result of this, standardized superstructures were designed. The idea was to implement U-shaped girders for all structures and simplify design and construction to a maximum degree. However this wasn't the most appropriate solution for skew structures. Therefore I-shaped were designed on skew structures and also for overpasses.

According to structural systems of structures made of precast girders can be divided in two groups: simple supported systems and continuous structural systems.

Construction of both structural systems is practically similar. Exception is a way of achieving continuity above piers [1].

2.1. Simple supported systems

Continuity of deck slab at simple supported systems (Fig.1) is achieved by link slab above piers. It is designed thinner than deck slab (designers' recommendation is to design link slab approximately 2 cm thinner than deck slab) because of different rotation angles caused by different outside loadings. Thinner link slab minimizes the probability of crack occurrence at the connection between the girders and link slab.

Link slabs are reinforced with minimum reinforcement and are strengthened on edges. Its reinforcement overlap with deck slab reinforcement. At the supports two cross girders were designed, which contribute to superstructure's stiffness.

Special attention is given to link slab waterproofing because of possible concentration of cracks. Waterproofing is done in at least two layers with special grounding underneath.

Main disadvantage of simple supported system is a number of bearings needed, especially for box girders, which are placed on four bearings each. Any difference in bearing bed height on site would cause unfavorable torsion effects. Therefore special attention has to be given to girder placing. Differential settlement of the grounds does not influence these structures.

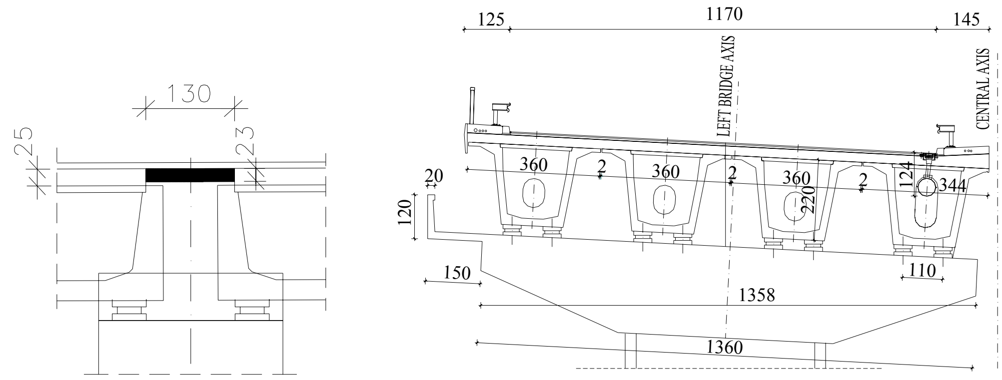

Figure 2: Continuity above pier for simple supported static system

2.2. Continuous systems

Continuity of continuous static systems (Fig.3) continuity at supports is achieved by sinking longitudinal girders in cross-girders. Superstructure is than supported on only two or three bearings and is not so sensible to differences between neighbouring bearing beds as simple supported systems. The disadvantages of this static system are that they are very sensible to differential ground settlement and appearance of negative moments on supports.

Big advantage of this static system is their durability. They have less “weak” points in sense of durability (less bearings) less connection, which can be damaged. Cross-girders are usually constructed in situ.

During all design phases special attention was given to the details of structures such as waterproofing, drainage details, bearings, expansion joints, etc [3], in order to design and build safe and durable structures as well to enable inspection and easy replacement of parts that need to be replaced during the lifetime of a structure.

Other structural parts produced as precast are cornices, curbs and New Jersey elements.

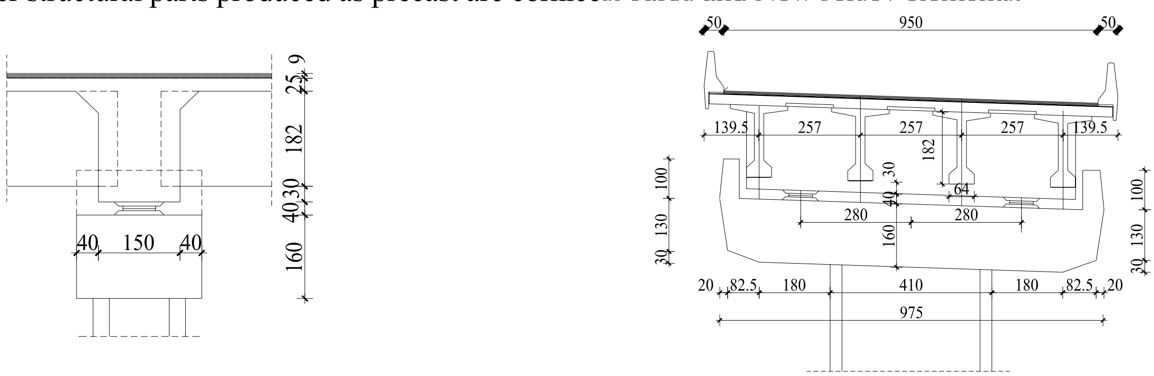

Figure 3: Continuity above pier – continuous static system

3. Precast element production

Both kind of structures mentioned before, along motorways that are already built (or will be in the next four years under "Croatian Motorway Project") are made of precast elements. To illustrate the size of precast element production several motorway sections are still under construction, and in 2003 approximately 150 kilometres of motorways was completed and opened to traffic. The total of 7500 precast girders and more than a million other precast elements (curbs, New Jersey elements, cornices, etc.) has been produced in a four-year period. These numbers show what kind of precast element production has to be organized to meet construction site requirements.

3.1. Organizing precast element production

There are two ways of organizing precast element production in this kind of construction. Concrete plants for production of precast elements can be located away from construction site or it can be located at construction site and be moved due to construction requirements.

3.1.1. Permanent concrete plant

Croatian construction companies in business in these parts for more than 60 years and with more that 50 years experience in precast element production, have their own concrete plants, located near companies headquarters. This kind of precast element production is better for continuous production for different construction sites and requires only one concrete plant with bigger production capacity. In these kind of concrete plant where production is continuous, staff doing the works is highly qualified, production process is optimized, it can cover more than one construction site at the same time and precast element production can't be influenced by construction site delays. Organizing scheme of any kind of concrete plant for precast element production is shown on Fig. 4.

Permanent concrete plants, which were mentioned before have more than one production line and have larger storage areas. Problems with this kind of concrete plants are storage of produced precast elements (mass production requires large girder storage which is rare in permanent concrete plants) and their transportation to construction site (this impacts total cost). These two facts are the limiting factors for precast elements production in such concrete plants. Usually these concrete plants are built near railways so that transportation of produced precast elements can be easier and cheaper. But if the construction site is not close to railway there has to be organized transportation from railway line to construction site. These are factors that enlarge costs of production of precast elements away from construction site.

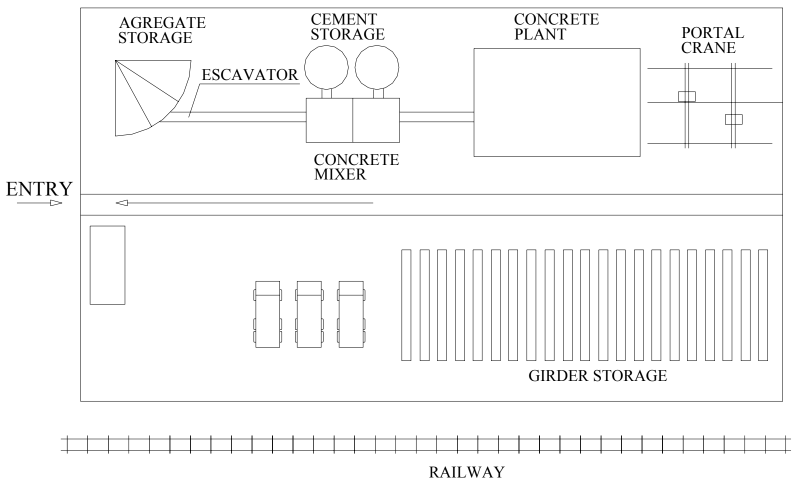

Figure 4: Organizational scheme of concrete plant

3.1.2. Temporary concrete plant

It is reasonable to organize temporary concrete plant on construction site for big projects like motorway construction. In this way transportation time and costs are minimized. Organization of temporary concrete plant is the same as the permanent one, only they are easier to move and remove according to construction needs (i.e. location of these plants is connected to the sections of "Croatian Motorway Project" which is currently under construction). Their disadvantages are smaller production capacity and problem with storage space. For construction of 3A2 section on Bosiljevo-Sveti Rok on route of Zagreb-Split motorway additional grounds had to be purchased for girder storage as shown on Figure 5. Figure 6 shows transportation of precast girder on Capperi

motor trailer. Total weight of this girder is more than 200 tons, which means that each part of trailer has 100 tons loads. These are very big loads for existing roads.

Figure 5: Girder storage at site

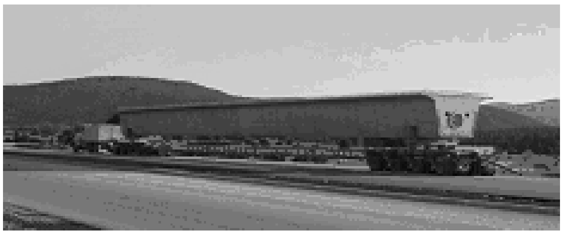

Figure 6: Girder transportation on Capperi trailer

4. Placing of precast elements

After girders were produced they have to be placed on their place in structure. This is done in several ways and the most used are shown here.

On structures which level line is designed low above ground surface girders are placed with car cranes [2]. This method of girder placing (Fig. 7) requires mostly horizontal grounds under car cranes and if it is not the case special plateau to insure safe grounds for car cranes are constructed. Girder placing with car cranes can be used also in cases where using any other method is not economically justified.

Figure 7: Girder placing at Kupa River

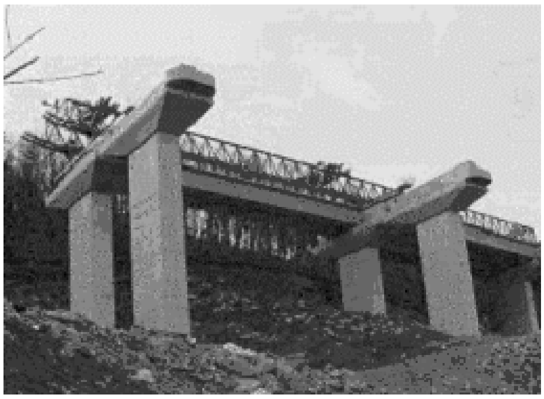

Figure 8: Girder launching – Viaduct Dreznik

For structures built on severe ground configuration and on those that have highly designed level line girders were placed with launcher (Fig. 8). This is very slow method of girder placing since every time launcher has to go all the way back to the abutment to pick up another girder.

This problem emerges especially during construction of long viaducts (more than 500m).

To overpass this problem after first several spans were placed, deck slab was concreted and when it had achieved required strength, girders were transported over completed deck slab. A special calculation of deck slabs for loads that occur during girder transportation was conducted and needed reinforcement was added. Figure 8 shows launching of girders on viaduct Krajine on Zagreb – Split motorway.

Due to contractor's technology in some cases piercaps had to be designed in a way to ensure enough space for launcher supports which demanded some modifications of original design.

5. Aesthetics of structures made of precast elements

During bridge design it is not only important to give attention only to the technical and economical aspects of the process but also try to incorporate structure into the surroundings in the most acceptable manner. Nowadays number of completed bridges is increasing every day so their aesthetic value becomes their mark, a kind of added value of a structure. As we all know bridges are remarkable structures that often become a landmark of a city or an area. But when it comes to bridges and similar structures on motorways, aesthetic aspect of design is rarely as highly considered as on city bridges. Designers are limited with terms, technology that contractors own, cost etc. Standardization of girders and elements that are incorporated in a structure are another limitation to achieve aesthetically acceptable solutions.

Figure 9: Dobra Bridge

Figure 10: Driver's view on overpass

Therefore, details as important parts of structures are very important to be designed in a way to primarily ensure function. Best examples for this are structures where clear load transfer can be seen (Fig. 9, 10).

Overpasses are structures that passenger can clearly see while driving along the motorway. That is why they should be designed to visually ensure safe passage under structure (Fig. 10) avoiding any discomfort for passengers (not causing the effect of "closing space").

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