Lightweight HPC beam OMEGA

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Abstract. In the design and construction of precast bridge structures, a general goal is to achieve the maximum possible span length. Often, the weight of individual beams makes them difficult to handle, which may be a limiting factor in achieving the desired span. The design of the OMEGA beam aims to solve a part of these problems. It is a thin-walled shell made of prestressed high-performance concrete (HPC) in the shape of inverted Ω character. The concrete shell with prestressed strands is fitted with a non-stressed tendon already in the casting yard and is more easily transported and installed on the site. The shells are subsequently completed with mild steel reinforcement and cores are cast in situ together with the deck. The OMEGA beams can also be used as an alternative to steel - concrete composite bridges. Due to the higher production complexity, OMEGA beam can hardly substitute conventional prestressed beams like T or PETRA completely, but it can be a useful alternative for specific construction needs.

1. Context – What was the problem to be solved?
Making ever longer spans of bridge superstructures from precast beams is a common practice. One major problem is the growing weight of the beams which complicates both transport and assembly on site. This problem is even bigger in case of difficult terrain on site and/or when assembly is done from greater distances, e.g. with the crane placed behind the abutment.

The proposed solution is based on an extensive use of high performance concrete (HPC), decreasing the beam weight very significantly. It not only helps to solve the usual problem of excessive weight of beams but has also a potential for improvements in overall economics of the structure, both during construction and long term maintenance costs. For example, transport can be arranged for pairs of beams on one truck, reducing transport costs and CO₂ emissions; service life can be extended thanks to increased durability of the material [1] etc.

2. What solution did we find?
The proposed “OMEGA” beam solves the problem of beam weight quite effectively. The cross section is a thin walled shell trough made of pre-tensioned pre-stressed high performance concrete in the shape of inverted letter Ω (Figure 1). This concrete shell has also all ducts and tendons for post-tensioning installed in the precast yard. After the transport and assembly of beams on site, the mild steel reinforcement is placed and the core of the beams as well as the composite deck with optional end crossbeams is cast in situ.

The “OMEGA” beam can be effectively used also as an alternative to the steel beams used in standard steel-concrete composite bridges.
3. Production of the beams
At first, the excessive weight of currently used precast beams was defined as the main problem to be solved. The target parameters were defined along with corresponding main dimensions of the new beam type, taking into account the practical technological possibilities in contemporary precast yards. The next step was the static analysis of proposed beams in all stages of the construction and service life according to the applicable codes. Also, a design of formwork for the first testing beams was prepared by formwork contractor Doka (Figure 2).

![Figure 1. "OMEGA" beam – typical cross section.](image1)

![Figure 2. Formwork of the beam.](image2)

![Figure 3. Test of the transport equipment cast into the surface of the beams.](image3)

![Figure 4. Detail of the beam end region.](image4)

![Figure 5. Omega beam – general view.](image5)
The first beam cast served to verify the technological methods used, including the transport equipment (Figure 3).
In the next phase, a group of four beams was cast (Figures 4, 5) and a set of loading tests was conducted on a selected beam.

4. **Loading tests**
The results of the static load-bearing test of a selected beam showed very good correlation with the calculated values (Figures 6, 7 and Table 1).
The basic requirement, i.e. no cracks while casting the composite 'in-situ' part of cross section, was also perfectly met, no temporary supports are needed on site. The total deflection during the static load test was measured together with other parameters.

![Figure 6. Loading test, general arrangement.](image)

| Load step            | Load [%] | Force [kN] | Deflection [mm] |
|----------------------|----------|------------|-----------------|
| Theoretical ULS      | 121      | 2x 172     | -               |
| Test ended           | 100      | 2x 142     | ~ 40            |
| Concrete tensile strength | 78      | 2x 111     | 24              |
| Decompression        | 63       | 2x 89      | 19              |
| Core and deck cast   | 60       | 2x 85      | 16              |
A test of the bond between the precast part of the cross section and the subsequently cast in situ core of the beam was carried out (Figures 8, 9, 10). The core on the left side (the side of active anchor) was separated from the composite deck to eliminate the effect of the deck. The prestressing tendon consisted of 19 strands Y1860-S7-15.7.

In the gap between both cores a set of displacement sensors was installed for measuring a possible movement of the core relative to the shell. The force in the tendon was gradually increased in steps of 400 kN with a time step of 1 minute. The test was finished after the maximum force 4.1 MN was reached. The results of the test showed that only elastic deformations occurred (Figures 11, 12) and sufficient bond was achieved.

Figure 7. Loading test, theoretical and measured deflections during test.

Figure 8. Test of bond.

Figure 9. Test of bond, displacement sensors (LVDT displacement sensors).
Figure 10. Test of bond between core and shell – general arrangement.

The resulting product meets all requirements defined at the first stage. Therefore, the development of the new type of beam is considered finished. The idea of a lightweight precast concrete beam was fulfilled and the design is currently protected as a registered design no. 29825 at the Czech Office of Industrial Intellectual Property. A registration of invention was also filed under no. PV 2016-410.

The article of Petr Bílý from ČVUT (Czech Technical University, Prague) called “FEM simulation of static loading test of the Omega beam” [2] presents the numerical simulation of static loading test of the beam.
Figure 11. Test of bond – displacement measured on particular sensors. 1: Bottom, right; 2 – bottom, left; 3 – top, right; 4 – top, left.

Figure 12. Test of bond – prestressing force applied.

5. Wider adoption of the innovation
The described OMEGA beams will be seen first in the situ use on the project of a utility bridge in a quarry of the Eurovia kamenolomy company located at the village Třebnůška in the Czech Republic. Two of the beams will be equipped with strain gauges which will allow further investigation and measurements to be done both during the construction period and in service.

Assembly of 4 OMEGA beams was carried out on above mentioned bridge (Figures 13, 14) on 2.3.2017. Typical cost comparison is shown in Tables 2 and 3.

Table 2. Comparison of weights for various dimensions of beams.

| Beam depth [mm] | 550 | 650 | 750 | 850 |
|-----------------|-----|-----|-----|-----|
| Span [m]        |     |     |     |     |
| T – beam [t]    | 14.7| 20.7| 27.6| 35.5|
| Omega beam [t]  | 6.4 | 8.6 | 11.0| 13.7|
Table 3. Comparison of cranes required for various beams.

| Single span | $\Omega 15$ | $T 15$ | $\Omega 21$ | $T 21$ | $\Omega 24$ | $T 24$ |
|-------------|------------|--------|------------|--------|------------|--------|
| 1 span      | LTM 1055   | LTM 1200 | LTM 1100   | LTM 1200 | LTM 1200   | LTM 1300 |
|             | 810 EUR    | 3890 EUR | 1670 EUR   | 3890 EUR | 3890 EUR   | 5470 EUR |
| 2 span      | $2 \times \Omega 21$ | $2 \times T 21$ | $2 \times \Omega 27$ | $2 \times T 27$ | $2 \times \Omega 24$ | $2 \times T 24$ |
|             | LTM 1200   | LTM 1500 | LTM 1500   | LTM 1500* | * Including 2 assembly positions |
|             | 5520 EUR   | 7470 EUR | 9260 EUR   | 11260 EUR |           |        |

The cost comparison is done on a fictitious site with travel distance 50 km. For 2xT27 T beams it is necessary to move the crane behind the other abutment due to beam weight, thus further increasing the costs. The cost estimate for crane transfer behind the other abutment is EUR 3,000. For conversion, the ratio 27 CZK/EUR is used. Further savings could be achieved by transport of 2 OMEGA beams on one truck.

Figure 13. OMEGA beams used on site. Figure 14. Finished bridge in Třebnůška Quarry.

6. Conclusions
The newly proposed shell beam, able to withstand all loads during construction, offers some financial savings in transport and construction costs. Feasibility of the design was verified on a real bridge in Třebnůška, Czechia, finished in May 2017 (Figures 13 and 14).

Acknowledgements
This paper was prepared thanks to the support of the Technology Agency of the Czech Republic (TAČR), project “Centre for Effective and Sustainable Transport Infrastructure (CESTI)” (no. TE01020168).

References
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