The so-called arch lowering construction method offers a possibility to build large arch bridges. As a counterpart to the lowering construction method the "balanced lift method" is presented in this paper. The main advantages of this new bridge construction method are savings in construction time and construction materials. It is suggested to build the bridge girders in vertical position and rotate them into the final horizontal position afterwards. The bridge girders can be built in combination with the pier using climbforming techniques which will allow a considerable cost reduction in manufacturing and speed up construction time. The range of the span length for the application of the balanced lift method lies between 50 m and 250 m.

1 FROM LOWERING ARCH CONSTRUCTION TO BALANCED LIFT METHOD

1.1 The lowering construction process
In the lowering process, two arch rings are built in a nearly vertical position. Today they are constructed sequentially using self climbing formwork. Rotation shoes have to be installed for the lowering process. After completion of the concreting, both halves of the arches are lowered by means of tendons until they meet right above the center of the valley where they can be joined.

1.2 Lussia footbridge and Storms River Bridge
The first to use this method of building concrete arches was Riccardo Morandi who build the footbridge of Lussia’s torrent in Italy (Muñoz and Troyano 2004). After completing the lowering process the arch rings were supported by a central tower, which was removed after closing the arch. The bridge with a span of 70m was completed in 1953.

Morandi also designed the Storms River Bridge 1954 in South Africa with a span length of 100m. The lowering method was applied similar to the one of the Lussia footbridge, but without using a formwork tower in the middle. The rotation points were not at the base points of the arches. One fifth of each arch ring was built in the final position. The rotation points were located on the top of these arch segments.

1.3 Argentobel Bridge
The Argentobel Bridge in Germany with its reinforced concrete arch and an arch span of 145m is the world’s largest arch bridge constructed by means of a lowering method (Hünlein and Ruse 1985). The arch halves were built with self climbing formwork. The techniques for the raising and lowering with heavy forces to get the arch rings in the final position were already improved. Compared with the Storms River Bridge the new technique speeded up construction time, due to the little bending moments during the lowering process.

1.4 Lowering construction systems in Japan
Most of the existing arch bridges using the lowering construction process were built in Japan. These bridges advanced their span length step by step. In 1988, Uchinokura Bridge with 37m span length was built. In 1992, Senpiro Bridge with 60m span and in 1999, Sanganme Bridge with 90m span were constructed (Fukada et al. 2002). In March 2002 the Kobaru Keikoku Ohashi Bridge with a span of 135m was completed. It is the largest span among the bridges constructed by the lowering method in Japan. The construction site of the Kobaru Bridge is located at the entrance of the Sobo-Katamuki national park. The lowering method was adopted for this bridge because of the V-shaped valley. The height of the bridge surface is about 80m above the river bed.

1.5 Nervion Bridges
Two bridges over the Nervion, finished in 2001 and 2003, were also constructed by means of the lowering process (Troyano 2002). They are located on the stretch between the stations of Bolueta and Etxebarri on the metropolitan railway of Bilbao, that crosses
the river Nervion two times due to the river bends. The method of lowering the semi arches was chosen for two reasons: Because of the relatively small span length of approximately 60m it was possible to carry out an economic rotation of the arches. An assembly of the system with a construction of cantilevers held by cables would have been more expensive.

1.6 Comparison of construction methods for bridges
A comparison of erection procedures for bridge girders and arches should point out that the proposed new bridge construction method is analogous to the arch lowering method.

2 BALANCED LIFT METHOD
2.1 Patent situation
The German patent (No. 10 2006 039 551) for the balanced lift method was granted in September 2007. The international patent search by the European Patent Office has shown that the balanced lift method is indeed a new construction method and can therefore be patented worldwide.

2.2 Description of the method
This new bridge construction method consists in building the bridge girder in a vertical position and in rotating the bridge girder into the final horizontal position. The bridge girder can be built in combination with the pier using climbforming techniques which will allow for lower production costs and shorter construction time. Moreover, during the production no bending stresses are generated in the girders.

The proposed method will be especially advantageous for bridges with high piers. For an expedient application of this construction method the bridge span should lie between 50m and 250m.

Two different versions of this new construction method can be applied (Fig. 1), either the construction with a compression strut (Espinosa 2007) or the construction with a tension cable (Blail 2007).

The rotation of the bridge girders is either achieved by lifting the end points of the compression members or by a vertical lift of the end points of the bridge girders. For both construction methods standard heavy lifting techniques can be used for the forces which occur during the lifting process.

2.3 Feasibility studies
Two models in a scale of 1:200 of actual bridges (height of piers 85m, span lengths 160m and 180m) were created to demonstrate the movement of the bridge girders and compression struts or stay cables (Blail 2007), (Espinosa 2007). The relevant cross-sections were dimensioned and the joints were designed to prove the applicability of this method in practice. Curved steel plates serve as a formwork for the bridge girders along the contact surfaces.

The joint, where the tension cable is connected to the bridge girder is designed with a rolling up hinge and a transversal beam. The transversal girder of the tension strut bridge induces the forces in the webs of the box girder, where the cable can unroll in a groove. The radius of the winding hinge is supposed to be 2,4m in Figure 2. Inclined cables with 55 strands and a diameter of 200mm are used.

2.4 Geometric restrictions
For both versions of the balanced lift method the surrounding area has to fulfil a few conditions.

The admissible form of the territory for the tension cable bridge is defined by the envelope of those lines which are defined by the different positions of the bridge girders during the lifting process. The parameter representation of this envelope \( c(t) = \left( (x(t), y(t)) \right) \) is as follows (Blail 2007):

\[
x(t) = -\frac{1}{f'(t)}
\]
\begin{align*}
y(t) &= -\frac{f(t)}{f'(t)} + t \\
\text{with}

f(t) &= \frac{-t^2 + 2at + 2b}{-2t + 2a + 2b} - t - \sqrt{b^2 - \left(-t^2 + 2at + 2b - a - b \right)^2}
\end{align*}

and \( t \in [0, a + b - \sqrt{b^2 - a^2}] \). The values \( a \) and \( b \) are given as shown in Figure 3.

The limiting curve for the lifting process of the compression strut bridge can be defined by the equation of the circle

\[ x^2 + (y - l)^2 = (c + d)^2. \]  

The values \( c \), \( d \) and \( l \) are given as shown in Figure 3.

3 FIELD TESTS FOR THE BALANCED LIFT METHOD

In December 2007 we started the field tests at the Vienna University of Technology. At first, the pier with a height of 8m was built. We intended to use this pier for both bridges, the tension strut bridge and the compression strut bridge. To be as close to reality as possible, the joints were simulated by steel mounting parts.

The lifting process was carried out by four hydraulic jacks positioned on the pier. Threaded bars connected them with the endpoints of the girders to be lifted. One stroke of the jacks was equal to 25cm.

With the aid of these tests the practicability of the hinges could be demonstrated also for large rotations.

3.1 Tension strut bridge

The two bridge girders with lengths of 8,5m each were assembled on the pier. In the next step tension struts consisting of stress bars with 30mm diameter were installed. The pier, the bridge girders and the tension struts constitute a statically determined mechanism whose geometry can be changed by lifting the base points of the bridge girders. The rotation process of the bridge girders from the tension strut bridge can be seen in the Figures 4 and 5. During the lifting process, the end points of the bridge girders rotated against each other with an angle of \( 90^\circ \). This was accomplished by cylindrical shaped end points which rolled almost frictionless against each other.

3.2 Compression strut bridge

For this bridge we first assembled the compression struts and then hooked the bridge girders into the pier. A steel mounting plate was placed in the pier and a toggle link socket in the bridge girder, so that it could be fixed with a bolt. Figure 6 shows the detail in the closed and the opened position of the girders. In reality the joint of a bridge, for example with a 85m high
pier and 160m span, will be constructed as shown in Figure 7. In the bridge girders, the cables 3 should be two post-tensioning cables (type VSL 6-12) in top flange and ten of the cables 2 are placed in the bottom flange. The cables 1 (16 VSL 6-12) are fixed on both girders and allow for rolling up on the pier.

An auxiliary steel plate was placed at the node where the strut and the bridge girder meet each other so that the compression struts could not slip at the beginning of the lifting process. The steel plate was welded to the mounting part of the bridge girder whereas the plate was doweled at the endpoint of the compression strut, as can be seen in Figure 8. On this plate strain gauges were installed to measure the strains. Moreover we built in strain gauges at the lowest points of the threaded bars to observe the forces during the lifting process.

The rotation process of the bridge girders reaches from the nearly vertical starting position to the final horizontal position is shown in the Figures 9 and 10.

4 OUTLOOK

In the field tests it was demonstrated that the rotation of the bridge girders from the nearly vertical to the final horizontal position can be accomplished without any problems. In a direct comparison with the balanced cantilever method and the new balanced lift method, we calculated material savings of about 30%.

REFERENCES


