SHELL STRUCTURE FOR A GAME CROSSING

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Abstract

The construction of a new railway line along a national highway and a state highway crossing a forest with rich wildlife has lead to the project of two game crossings, one over the railway line and one over the highways. The 100 m width (in direction of the roadways) of the game crossing over the highways as well as the large clear spaces above the roadways have conducted to evaluate different kinds of structures: a slab bridge, an arch, and a shell.

The shape of the shell was obtained by analogy with a suspended membrane. The resulting structure is characterized by two asymmetric spans of 33 and 18 m, a height of 9 m, a double curvature at any point and a concrete thickness of 0.2 to 0.4 m. Repeated shell elements of 12.5 m width are proposed in order to reuse the formwork.

Comparison of the three structures showed that the repeated shell one is the most economical mainly as it needs less material. Furthermore, the shell structure is beneficial for the wildlife because the overburden soil depth varies from 0.6 to 5 m allowing to plant large trees and to have a wavy surface reproducing the natural topography. Finally, the proposed shell structure reveals the special function of the crossing with an aesthetic construction.

1. Introduction

The railway network in Switzerland is now being improved by the project called "Bahn 2000". A new railway line between Berne and Olten is designed and the construction shall begin in 1996. North of Mattstetten crossing the forest "Birchiwald", the new railway line is located next to the national highway N1 Berne-Zurich and a state highway. As the new railway line separates the forest into two parts it represents an insurmountable obstacle for wild life. In order to provide a possibility for crossing this obstacle, two game crossings are proposed, one over the railway line and one over the highways.

The efficiency of a game crossing is mainly influenced by:

- *the environment*: geology, topography, vegetation, human activities, and weather conditions,

- *the obstacle*: length, width, depth, type of traffic and frequency, noise emission, light and vibrations diffusion,
- *the type of wild life.*

The game crossing in the forest "Birchiwald" is characterized as given bellow. The geology is composed of up to 4 m silty sand overlaying poorly to well graded gravel with a depth of up to 40 m. The existing topography, with a western slope of up to 15% and two high points next to the national highway is shown in figure 1. The forest is mainly composed of beech, pins and oaks. Minimum human activities are reported in the vicinity except on the railway and highways. The weather conditions are varying from cold winters with long periods of frost and heavy snow to hot dry summers with temperatures up to 35°C. The wild life is very rich and is characterized by species of large size as many roe deer were observed as well as some stags (reported in [4]).

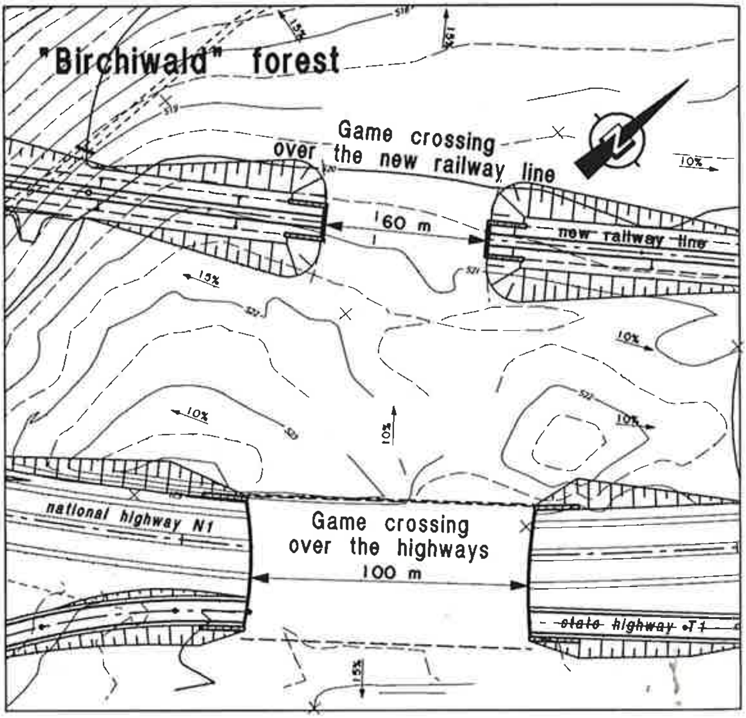

Fig. 1: Overview of the game crossings

The game crossing "Birchiwald" over the railway is 60 m in width and the one over the highways is 100 m in width as shown in figure 1. These significant widths are imposed by: the length of the obstacle, the high traffic frequency (traffic noise and traffic light are frightening wildlife), and the fact that roe deer and stags are very sensitive animals. These types of game crossings correspond to the "natural" or "ecological" bridge as described by Müller and Berthoud [3].

In the following, the game crossing over the new railway line will not be discussed as it is a standard concrete frame structure with a 12 m span. However, the design process of the game crossing over the highways is discussed here. This is due to its significant width (resulting in an area of about 5000 m^2). First, two standard game crossings are evaluated in section 2.2. Then an alternative shell structure is discussed in section 2.3. Finally, the three solutions are compared in section 3. and conclusions are presented.

2. Evaluated game crossing structures

2.1 Preliminaries

For a "natural" bridge it is usually accepted that the mean overburden soil depth is about 1 m. Therefore, typical game crossings are wide overpasses covered with vegetation using roof plantation techniques. Consequently, the main structural aspect for the design of game crossings is the heavy dead load due to the overburden soil. In most case live loads can be neglected.

2.2 Standard game crossings

In the preliminary design the crossing over the highways was proposed to be a multi-span slab bridge as shown in figure 2 (or a prefabricated T-beam).

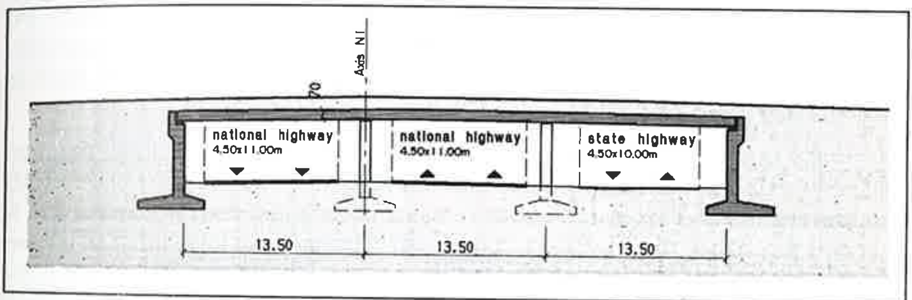

Fig. 2: Slab bridge for a game crossing

It is characterized by spans of 13.5 m, rectangular columns and a reinforced concrete deck of 0.7 m depth. During construction, traffic diversion is necessary due to the specific formwork cross-section (not required for the prefabricated T-beam solution). Since this structure did not satisfy functional and aesthetical requirements two other solutions were studied.

An arch bridge was elaborated as shown in figure 3. The two highways are crossed with one span of 55 m and a height of 10 m. The thickness of the arch is 0.5 m at the crown and 1 m at the bottom. The main disadvantage of this solution is the horizontal force implying the construction of large concrete foundation (lateral displacement has to be expected due to the gravel soil). Concerning the construction procedure, a formwork supported by two intermediate scaffolds located between highway lanes is required.

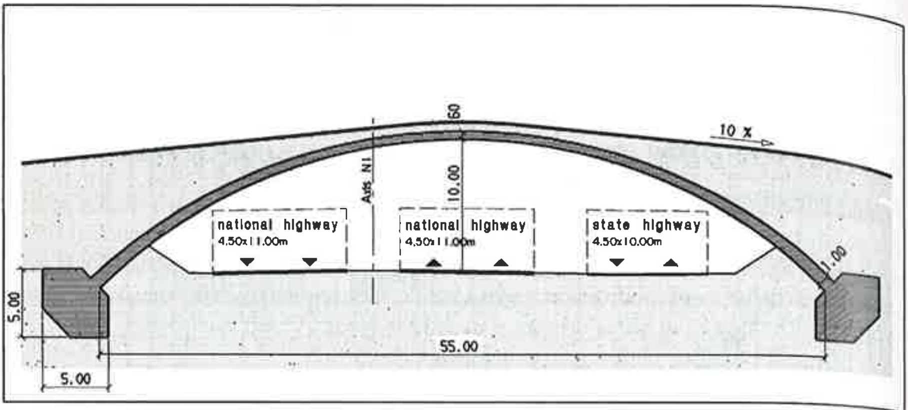

Fig. 3: Arch bridge for a game crossing

2.3 Development of a shell structure

In normal design process shell structures are often not considered because of the expensive formwork. However, for this game crossing, it is proposed to use repeated narrow shell elements. Therefore, one formwork is built and reused eight times so that its relative cost is reduced.

The shape of the shell is determined by experimental manipulation and the most adapted method is the hanging membrane one as developed by H. Isler and recently summarized in [2]. This method leads to membranes under tension stresses due to gravity load. Once the hanging membrane is "frozen" and inverted, the stresses change to compression. As mentioned, for a game crossing the main loading is the dead load. Therefore, the inverted hanging membrane is justified as it leads to a compression state of stress under the main loading.

The shape of the shell developed for the game crossing over the highways was determined by hanging a membrane coated with a hardener and supported so that the clear spacing of the highways was satisfied. It was chosen to support the shell between the two highways leading to an asymmetrical structure. The membrane has been inverted and the result is shown in figure 4.

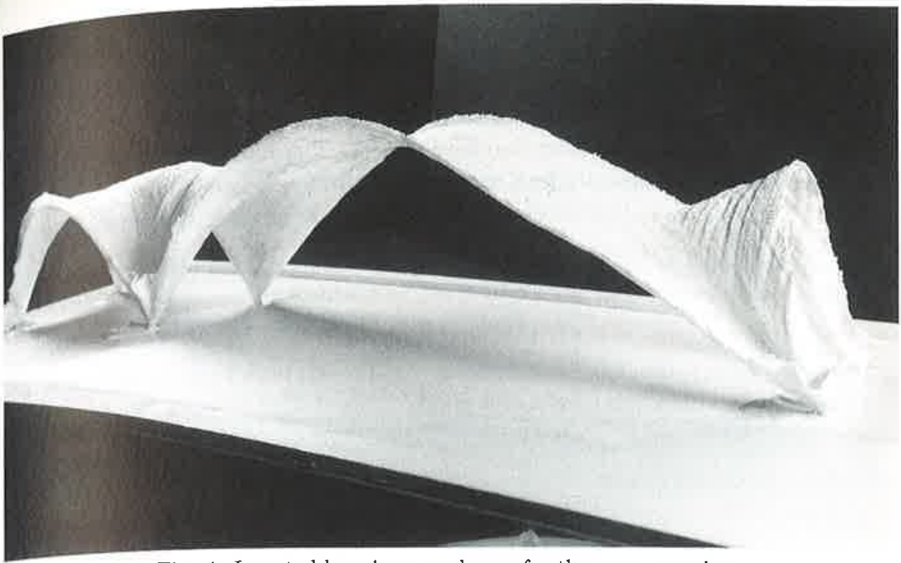

Fig. 4: Inverted hanging membrane for the game crossing

It is characterized by two asymmetrically curved spans in longitudinal direction. Transversely, the shell structure exhibits increasing curvature near the support. This increase in curvature raises the stability of the shell as mentioned by Scordelis [5]. Furthermore, in the middle of the main span, characterized by the smallest curvature, the shell is characterized by a negative gaussian curvature as defined by Billington [1]. This negative double curvature is of benefit for the shell stability. The shell stability should not be underestimated as the membrane mainly exhibits compression stresses. At this stage it was reviewed with empirical formulas but will be evaluated with a non-linear geometric numerical computation.

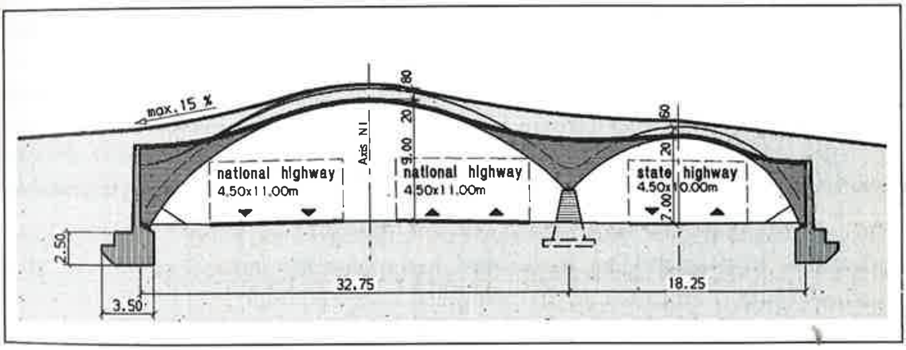

Fig. 5: Cross-section of the shell structure

The experimental membrane is then slightly modified in order to optimize construction. The height of the shell is reduced by elevating the middle bearing. A retaining wall is foreseen at the extremities of the shell to retain the soil. The shell structure is supported at the base of this retaining wall. The resultant shell structure is shown in a cross-section in figure 5. The crown profile of the shell structure is shown in a longitudinal section in figure 6.

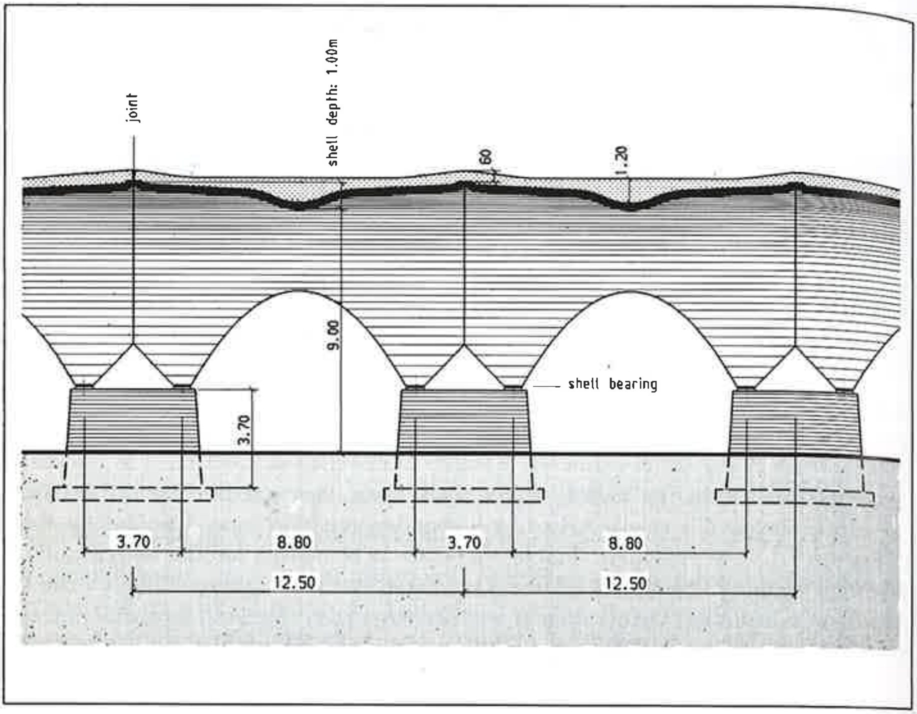

Fig. 6: Crown profile of the shell structure

The longitudinal curvature is characterized by a rise of 1 m. The depth of the overburden soil varies from 0.6 m to 1.2 m (at the crown). The narrow shell elements are repeated eight times to cover the whole width. Between the shell elements a joint ensures the continuity. At the borders special shell elements should be considered.

The construction procedure of the game crossing is as follows: (1) setting a cylindrical steel scaffolding across the highways, (2) assembling of the glue-laminated timber formwork on the cylindrical steel scaffolding, (3) setting two layers of reinforcement, (4) concrete pouring, (5) dismantling the glue-laminated timber formwork, (6) sliding the cylindrical steel scaffolding for the next stage.

3. Comparison of structures

The three different structural solutions were compared and summarized in table 1 revealing that the shell structure is the most interesting one mainly because of the five following reasons:

1. The shell structure requires less material quantities (concrete and reinforcement) compared to the others due to its optimized shape.
2. The foundation of the shell structure is small compared to the one of the arch-bridge because of the diminished horizontal force due to transverse curvature and reduced dead load.
3. The amount of overburden soil over the shell structure is also reduced compared to the one over the arch-bridge. This is also due to the transverse curvature at the extremities of the shell.
4. The shell structure offers space for storage of maintenance or emergency equipments under the transverse curvatures.
5. The shell structure is the most beneficial structure for the wild life as the overburden soil depth varies from 0.6 to 5 m allowing to plant large trees and to have a wavy surface reproducing natural topography.

	slab-bridge	**arch-bridge**	**shell**
Cost (1995):	7'600'000 SF	7'300'000 SF	6'900'000 SF
Material quantities:			
• structural concrete	3'500 m^3	4'200 m^3	2'300 m^3
• concrete for foundat.	2'400 m^3	4'600 m^3	2'700 m^3
• steel reinforcement	740 t	750 t	500 t
• overburden soil	4'500 m^3	13'500 m^3	8'000 m^3
Wild life:			
• topography	horizontal	max. slope 10%	wavy slopes up 15%
• vegetation	low vegetation	large trees plantation	large trees plantation
Highway traffic:			
• during construction	highway diversion	little disturbance	little disturbance
• exploitation	standard	large clear space	space for storage
Structure:			
• construction	standard	large foundations	complex formwork
• durability	water sealing, minimum reinforcement	water sealing, uniaxial compression	unsealed sol. poss., biaxial compression
• aesthetics	not satisfying: tunnel-like	interesting: large clear space	optimum: shape and function are related

Tab. 1: Comparison of the structural solutions for the game crossing

The three first reasons indicate that the shell structure is the most economical solution being nowadays the most determinant argument. The particular shape of the shell structure also leads to an aesthetic structure. The developed shell reveals that the function of the structure is different from a regular bridge or tunnel; clear distinction can be made between a bridge for human activities and a game crossing for the wild life. Based on this comparison, it should also be mentioned that the main disadvantage of the shell structure is the construction procedure as it requires complex formwork. However, with the present state-of-the-art it should be considered as a challenge with limited risk.

4. Conclusions

The construction óf a game crossing over highways with large dimensions has lead to the development of different kinds of structures: a slab bridge, an arch, and a shell. The special shape of the shell was obtained by analogy with a suspended membrane. It is characterized by two asymmetric spans, a double curvature at any point, and a concrete thickness of 20 to 40 cm. A repeated shell structure is foreseen in order to build one formwork only.

By comparing the three structures, it is shown that the repeated shell is the most economical one, mainly as it needs less material. Furthermore, the developed shell structure is beneficial for the wildlife as the overburden soil depth varies from 0.6 to 5 m allowing to plant large trees and to have a smooth wavy surface reproducing the natural topography.

The presented discussion clearly shows that conceptual design of structures allows to reduce costs, improves the functionality of the structure and leads to an aesthetic structure with a clear distinction of its function through its shape.

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