Structural Modelling of the Railway Station “Stuttgart 21”

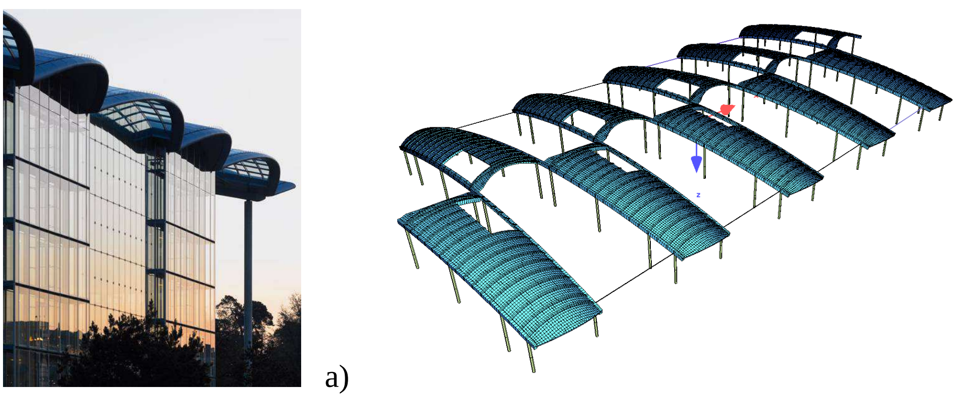
Lucio Blandini, Torsten Noack, Albert Schuster, Werner Sobek

Abstract:

Contemporary architecture often asks for complex double curved surfaces while the engineering of such structures often becomes a challenge. This paper illustrates the tasks that emerged and the methods developed during the engineering process of the new railway station “Stuttgart 21”. One of the main challenges in generating a structural finite element model out of the architectural design was the definition of the middle surface for the concrete structure and the need to obtain a meshed system with continuously varying shell thicknesses. Such tasks were solved using RhinoScript for the preprocessing phase and an open modular finite element program as Sofistik in the processing and postprocessing phase.

1 INTRODUCTION

It is often surprising how light and elegant concrete can appear once used for spatially curved surfaces. However the engineering of such complex structural elements is an extremely challenging task. Several computational tools and fabrication concepts have been developed at Werner Sobek Stuttgart over the last ten years in order to support the engineering and fabrication of complex double curved concrete structures. At the Lufthansa Aviation Centre [1], ten modular “fingers” are roofed with double-curved reinforced concrete shells. Each roof module is different in geometry but all of them have been derived parametrically in AutoCAD from the same typology. Since the shells have constant thickness, the main challenge in the preprocessing phase was the generation of the middle surfaces and the transfer of the geometrical information from AutoCAD to Sofistik.

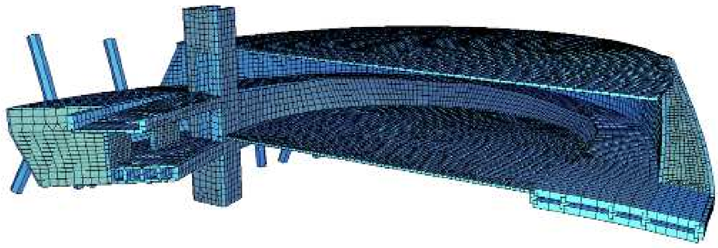


a) b)

Figure 1.1 Lufthansa Aviation Centre. a) View of the corner (H.G. Esch) b) Structural model (Werner Sobek Stuttgart)

In the new Mercedes-Benz Museum [2], Stuttgart, the most complex concrete elements, the “ramp” and the “twist” were engineered as curved hollow box girders with varying sections (Fig. 1.2b). In order to determine the concrete sections, the middle surfaces of the shells were derived based on the original outer surfaces, which were imported from the architectural Rhino model. The middle surface model was then meshed, analysed and structurally optimized with Sofistik. The thickness of the concrete walls was kept constant to 50 cm.

a)



b)

Figure 1.2 Mercedes-Benz Museum. a) View from inside (Brigida Gonzalez) b) Myth ramp structural model (Werner Sobek Stuttgart)

The modelling of the railway station “Stuttgart 21” took advantage of the experience gained in the two described projects. However the modelling of the railway station was in many ways more challenging because of the constantly varying concrete shell thickness. New tools had to be developed in order to precisely define the thicknesses at each node of the finite element mesh.

2 STUTTGART 21: DESIGN AND GEOMETRY

The railway station “Stuttgart 21” is the core project in an effort to modernize the connection between Munich and Paris. The present terminus station in Stuttgart will be replaced by a 450 m long and 80 m wide underground through station designed by Ingenhoven Architects, Düsseldorf. The space is characterized by 28 doubly curved concrete columns; the so called “chalices”.

Figure 2.1 Rendering of the new station from inside (Ingenhoven Architects, Düsseldorf)

The railway station was modelled architecturally using Bentley Microstation. The top surface of the station has five different slopes. The platform level has two different slopes in the longitudinal axis. These boundary conditions require different heights of nearly each chalice. Nevertheless a concept was implemented to achieve a maximum amount of geometrically common elements in the model. The geometric description of the doubly curved roof has been split at level -6m (Fig. 2.2). This allows the upper part of the standard chalices to be described in a way that more or less follows one type of geometry. The different heights at each chalice are mitigated by three types of pedestals which connect the lower end of the chalices with the inclined platforms. Nevertheless each pedestal has to be adapted to the height of each chalice, by sectioning the pedestal at the upper surface of the platform.

Through this approach, a high number of geometrically similar chalices were achieved: 23 so called "standard-chalices", 4 "flat-chalices" and one special chalice. Still, several chalices present local changes as they are partly cut at the junction with the sidewalls and at the kinks of the roof. The grouping of the pedestals also leads to a high number of identical surfaces, as they only differ in the lower portion.

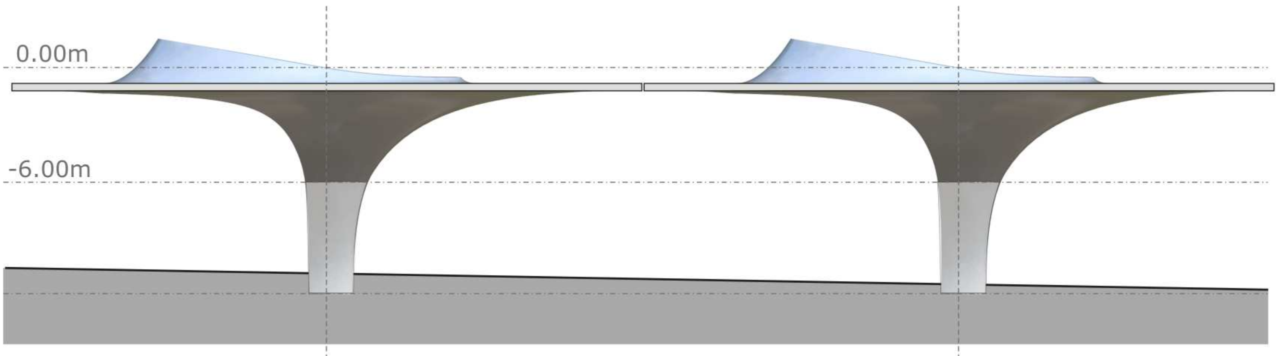
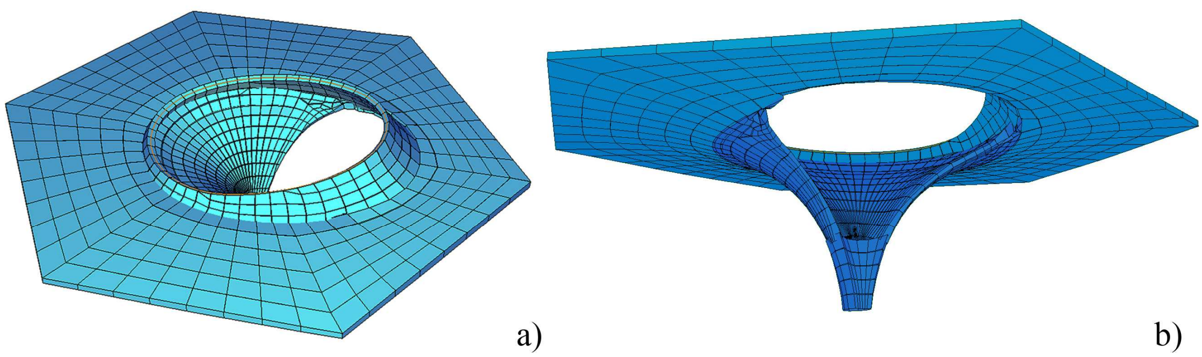


Figure 2.2 Section showing the division line for the chalices (Werner Sobek Stuttgart)

3 STRUCTURAL MODELLING

The key in setting up a structural model that comprised so many variations of the same typology was the automation of generating the finite element meshes. This was achieved directly through RhinoScript. The meshed model contains all the information necessary for the finite element analysis and the data could be exported directly from Rhinoceros into Sofistik.
The structure was divided into areas which could be better modelled by means of beam elements (lower area of the chalices) and areas which had to be modelled by means of shell elements (upper area of the chalices). The differentiation led to the coding of two sets of scripts to derive the information. One of the key issues for both sets of scripts was the geometrical definition of the centre axis respectively the middle surface. The centre axis was modelled by sectioning the surfaces which describe the lower area of the chalices and by connecting the gravity centres of the sections. The axis geometry information was exported into Sofistik dat files with the adequate node and bar definitions. The necessary bar section definitions were also generated by the script and directly exported into Sofistik aqua text instruction files. The generation of the middle surface of the shell-meshed regions was more complex. The outer and inner surfaces were pre-processed, defining different sub-regions to be later analysed in detail in Sofistik. These surfaces constitute the input for a script which determines the shortest distance between the two surfaces at a discrete number of nodes and within a certain range of approximation. All the necessary information, including all the Sofistik commands and the required parameters (i.e. quad numbers, node numbers and thickness, etc.) was exported into a dat file, which could be directly implemented in SOFIMSHA.



a) b)

Figure 3.1 Structural model of a chalice. a) View from above b) View from below (Werner Sobek Stuttgart)

This process was developed and checked for one single chalice first, and then further implemented to model the whole station, thereby accounting for all the local variations from the standard geometries. The subdivision of the model in groups according to the area and the structural function enabled an easy control of all the parts during and after the calculations. The quad local axes have been set specifically in each region depending on the chosen reinforcement layout [3].

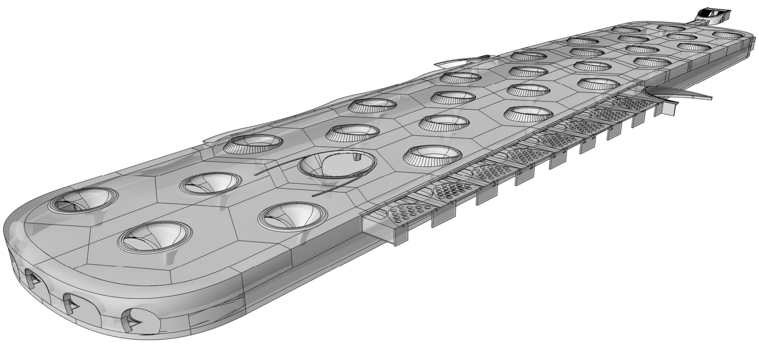


Figure 3.2 Architectural model of the railway station in Rhinoceros (Werner Sobek Stuttgart)

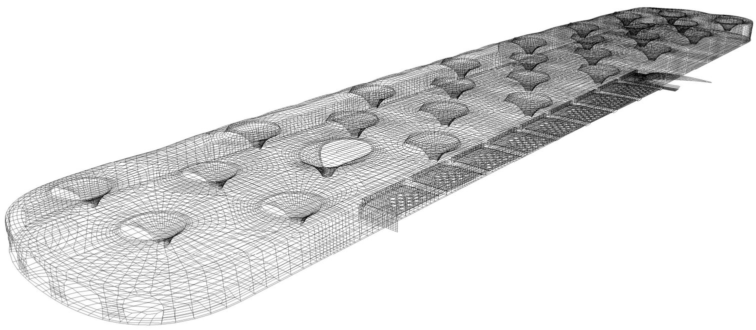


Figure 3.3 Meshed model of the railway station in Rhinoceros, middle surface (Werner Sobek Stuttgart)

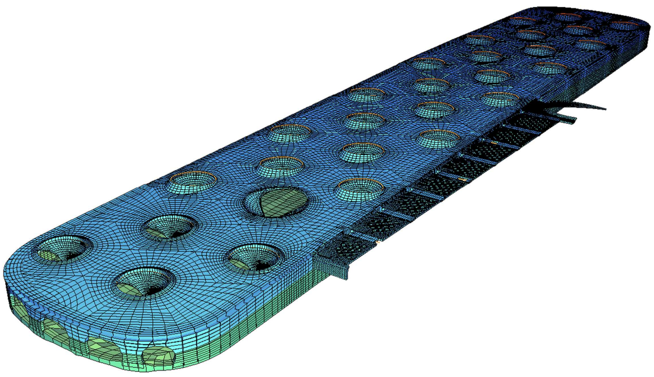


Figure 3.4 Finite element model of the railway station in Sofistik (Werner Sobek Stuttgart)

The whole SOFISTIK program code was controlled by a main dat file calling several external files (i.e. geometric information, loads, etc.), in order to minimise the total file size and to keep a better control of the different parts. The integration of additional tasks during the planning process was much easier to control this way.

The difficult ground conditions in Stuttgart required the consideration of the possible local loss of bedding caused by the formation of dolines. A set of iterations was necessary to calculate the most disadvantageous bedding configurations for each area. Moreover a second model was generated to check the different construction stages by means of the construction stage manager. The mesh was refined by Rhino according to the specified construction sequence and the group definitions were adapted. The load bearing behaviour of the temporary structure significant differs from the one of the whole model, so that temporary additional supports were foreseen for several construction stages.

All the information gained during the calculations was used to check and locally optimize the concrete thickness and to define the necessary amount of reinforcement. Because of the highly automated workflow, optical and analytical control strategies have been developed to check the correspondence between the given architectural geometry and the finite element model.

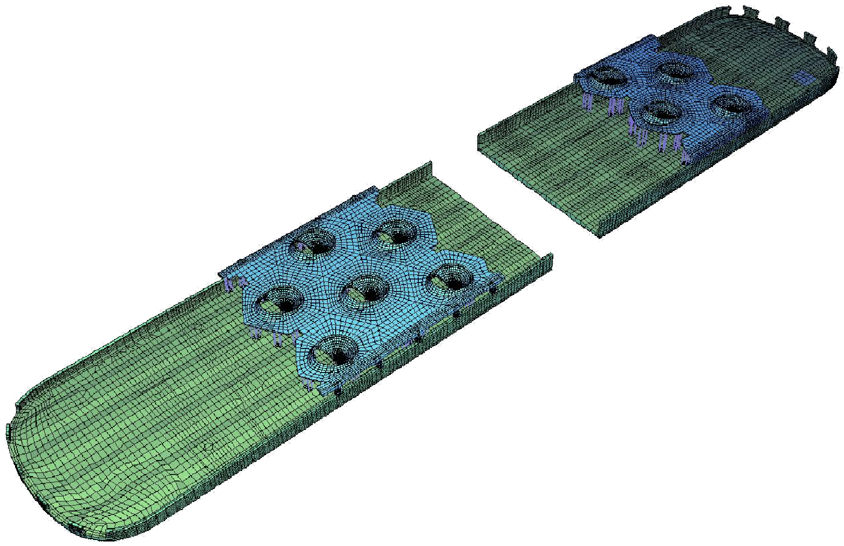


Figure 3.5 Construction stage phase 8 (Werner Sobek Stuttgart)

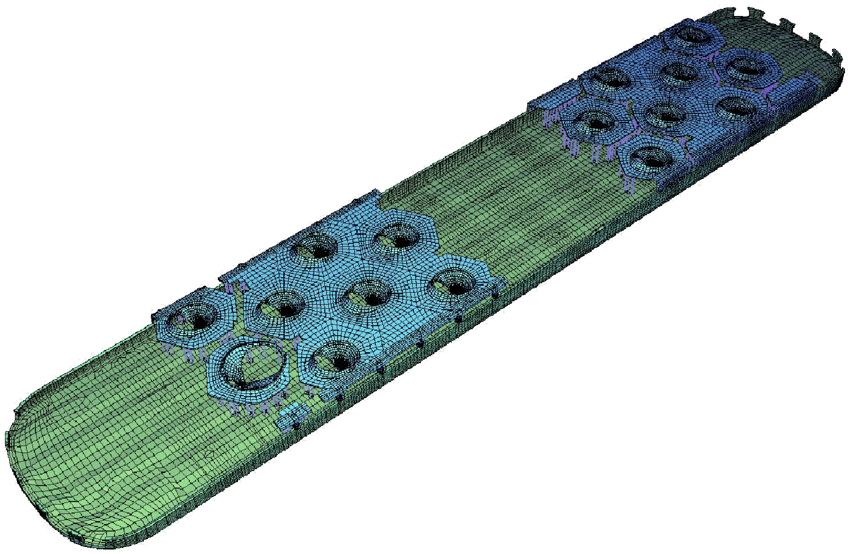


Figure 3.6 Construction stage phase 9 (Werner Sobek Stuttgart)

4 CONCLUSIONS

The experience gained over the last 10 years in engineering the Lufthansa Aviation Center and the Mercedes-Benz Museum was the basis for the structural design process of the High Speed Railway Station “Stuttgart 21”. This design process has been set up with a highly automated workflow, making use of specially developed algorithms to allow for an iterative structural optimization. During the structural design, one of the main challenges was the generation of several complex finite element models with constantly varying thickness, defined on the basis of the architectural 3D-model. Further challenges were the definition of different bedding configurations and a proper modelling of the construction stages. The use of an open and modular finite element program as Sofistik has given a very powerful frame to integrate preprocessing information, which has been generated through RhinoScript. Moreover it has contributed to an improved workflow between the different professionals involved.

5 ACKNOWLEDGMENTS

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