# Design of Budapest New Danube Bridge, Hungary

## *Design and 3D CFD Simulation of River Piers of New Danube Bridge in Budapest, Hungary*

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*DOI: https://doi.org/10.14459/icbdb24.08*

**Abstract** New Danube Bridge in Budapest, designed by BuroHappold and UNStudio, along with the Hungarian specialist bridge designer firm CÉH, will be a stunning landmark cable-stayed bridge redefining the landscape of Budapest, while creating a long-awaited new connection between the South Buda districts and Csepel Island.

The bridge accommodates a 2x2 road, a 2x1 combined tram and bus, two-way cycle lanes and footpaths on both sides. The five-span cable stayed bridge will comprise two inclined pylons with aesthetically pleasing shape. It will have a main span of 246.00 m crossing the Danube navigation route, at a skew angle of 73°. The main span will be supported by fore stays arranged symmetrically and perpendicular to the bridge deck centerline. Backstays, each comprising 4 concentrated stay cables will connect the top of the pylons to anchorage piers on the riverbanks.

The design of the river piers was extensively studied at the very early design stages to provide both combined architectural and engineering solution. The design satisfies the navigation requirements, considers the hydraulic effects, and elegantly supports the bridge superstructure.

Departing from the rectangular competition geometry, early stage river pier variations were aligned to be more streamlined and elegant. These variations were investigated using two dimensional numerical hydraulic simulations and a small-scale physical model. Downstream vortex shedding was observed at one of the pier types.

In addition to conventional methods, state-of-the-art 3D CFD models were built to reveal the prevailing flow features and riverbed movements in the vicinity of the investigated river piers.

The results of detailed studies performed on the different pier variants, refuted the significant extent of vortex shedding observed in the small-scale experiment. However, they made clear that fine tuning of the pier angle would produce a better solution considering complex stream conditions and different water levels.

# 1 Introduction

In 2017, an architectural design competition was launched aiming to design the newest bridge over Danube River at the South side of Budapest, Hungary (figure 1). After a rigorous selection process, Buro Happold (U.K.) and UNStudio (NL) were chosen as winners. Recognizing the importance of local expertise, lead designer consortium commissioned the Hungarian bridge consultancy CÉH Inc. (H), as their sub-consultant bridge designer. Below paper content references to the tender design documentation content prepared by the design team.

**Figure 1:** Visual concept of the New Danube Bridge

The architectural competition design consisted of two river pier foundations, which due to their perpendicular orientation to the superstructure, did not optimally align with the flow line of the river, thus river pier geometry and alignment needed to be furtherly detailed.

The pier geometry optimization process started by reducing the width and adjusting the skew alignment to be paralell to the expected river flowline. To minimize the impact of hydraulic effects, the design team investigated various pier geometries through conventional two-dimensional hydraulic modelling, small-scale testing, and eventually, state-of-the-art three-dimensional Computational Fluid Dynamic (CFD) simulation.

# 2 Architectural Concept

The existing historical and modern bridges of Budapest are key to understanding the city’s rich history and modern age development from the mid 1800‘s to the present day. Each of the bridges offer unique insights into the architectural and social trends of its time, playing a vital role in the city’s growth by connecting different areas across the Danube.

In line with the Client’s requirements, the contemporary design of Budapest‘s New Danube Bridge

**Figure 2:** Rendered image of the proposed Budapest New Danube Bridge – © UNStudio

(figure 2) is meant to be a new landmark structure redefining Budapest's southern landscape, while trying to promote further urban development for the neighbouring districts.

## 3 General Structural Description

The five-span bridge consists of two asymmetrically shaped, backward-leaning pylons, a cable-stayed main span of 246.00 m over the navigation channel, two side spans of 111.00 m, and two approach spans of 29.28 m. Due to existing constraints of the adjoining roads, the bridge crosses the mean river flowline with the angle of 73.0° hence, resulting in a leftward skew alingment. The total length of the structure is 546.07 m.

The stiffening girder at main span is supported by 14 pairs of cable-stays arranged symmetrically in two planes and perpendicular to the bridge axis in a "fan" arrangement. The cable-stays anchored to the back consist of four concentrated cables that extend from the pylon heads to support the crossbeams on the anchorage piers located on the riverbanks. The pylon shafts are composed of closed steel box girders with varying cross-sections, featuring a distinctive break below the upper connection points of the cable stays, creating an aesthetically pleasing form.

## 4 Riverbed and geotechnical Conditions

The planned bridge will cross Danube River international water transportation route at 1641+350 r.km section. The estimated maximum and reference water level is the flood level for the Danube at this location, which is 103.22 meters above sea level.

At beginning of the design work, detailed riverbed and geotechnical survey were carried out on site. The explored subsoil consists of very hard Oligocene clay starting directly from the riverbed, interspersed with lens-shaped layers of compact sand and gravel of varying thicknesses (figure 3). The riverbanks are composed of sandy-gravelly fill layers above the riverbed (figure 4). The proposed foundation for the bridge can be constructed applying pile foundation.

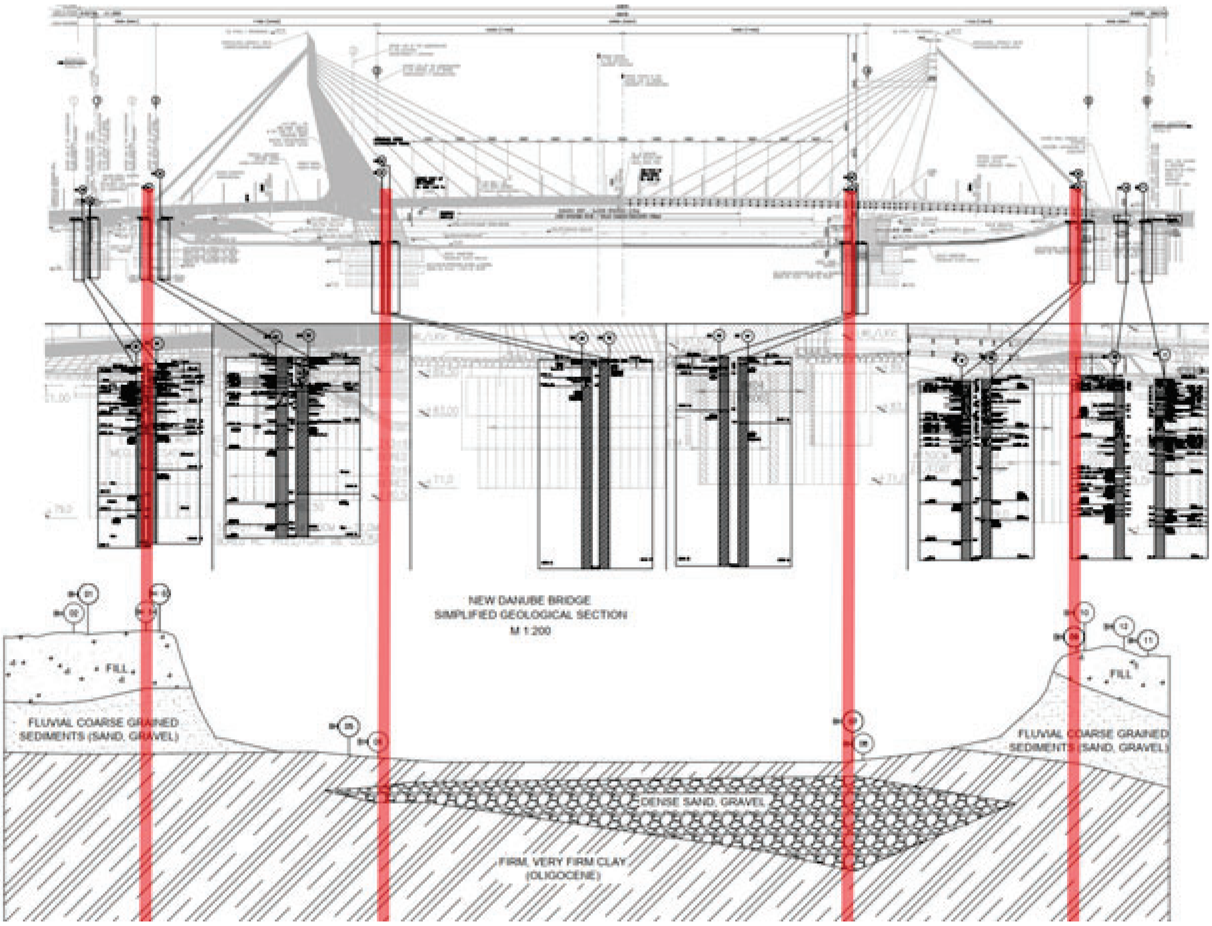

**Figure 3:** Simplified geotechnical longitudinal section – © CÉH

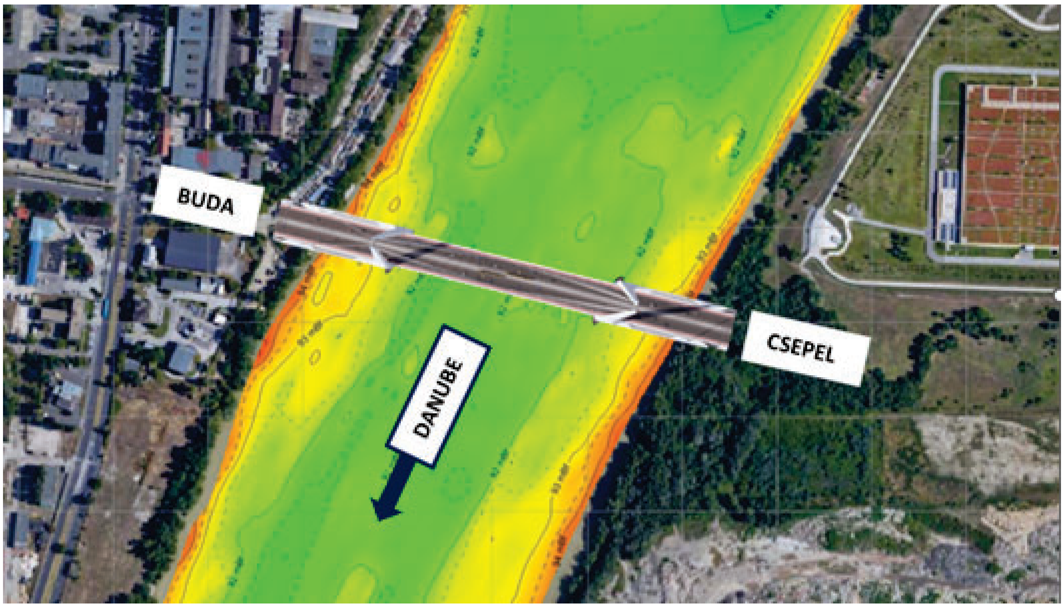

**Figure 4:** Riverbed topography with schamatic bridge layout – © CÉH

## 5 River pier geometry variations

In order to maintain the architectural concept while further detailing the pier geometry, three different pier variations had been studied in details (figure 5). The conventional shaped first variant featured an 8.00 m wide and 52.00 m long pier geometry. The second variant introduced a unique “boat-like” pier design with a varying width and length along it’s height. The third variant was identical to the second variant, but slightly longer and the piers moved 3.00 m both sides toward the riverbanks increasing the span of the bridge by 6.0 m.

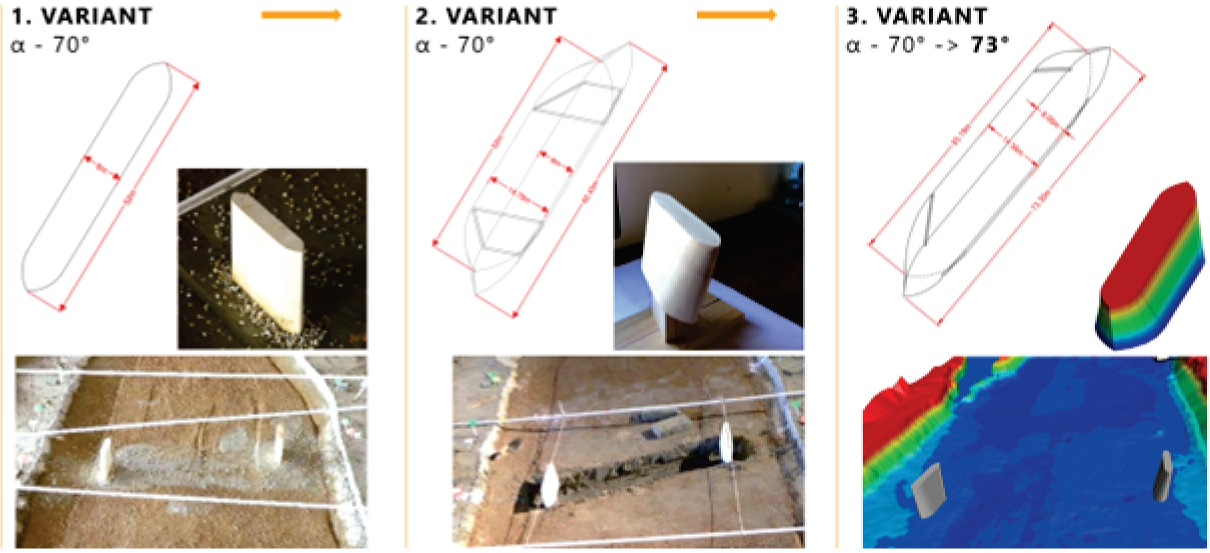

**Figure 5:** Main investigated pier variants, evolution of geometry – © CÉH

Initially, based on visuals, the mean river flowline in relation to the piers was determined to be a 70° skew angle however, as the design progressed with the studies, a parametric sensitivity analysis using the 3D CFD simulations allowed for further optimization hence, a final 73° skew angle was determined.This is discussed in more detail in chapter 8.

## 6 2D hydraulic modelling

During the early design stages, initial hydraulic studies were carried out on the river Danube for the newly proposed bridge. The objectives of these studies were to evaluate the backwater effect of the piers, identify changes in flow patterns and evaluate the changes in the condition of the navigation (figure 6).

For the first variant, the backwater effect was between +0.5 – 2.0 cm higher. For the second variant it was between +1.2 – 4.0 cm, and for the third variant, it was between +1.3 – 5.0 cm, which were values considered to be acceptable.
Due to the planar nature of the 2D hydraulic modelling method, it is limited in its ability to accurately represent the full hydraulic behavior within the riverbed. As a result, small scale testing and 3D CFD analysis was performed.

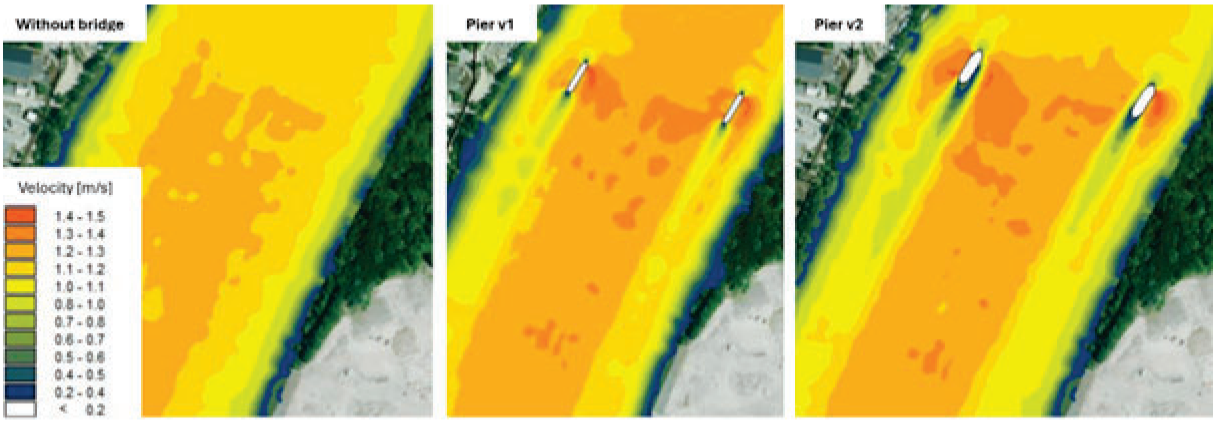

**Figure 6:** 2D hydraulic modelling – flow velocities with different settings (without bridge / pier v1 / pier v2) – © CÉH

## 7 Small-Scale Experiment

Performed in parallel to the 2D hydraulic modelling, small-scale testing was also carried out according to the Client's requirements. This test led to several additional conclusions regarding the three pier variants. For the first variant, the piers did not disrupt the flow pattern significantly. The shape of the upstream edge allowed ice floes to pass by easily, preventing the formation of ice blockage. Vortices generated by both piers were observed within appr. 500 m at downstream side, which at the Csepel side found to be acceptable, but at the Buda side river pier, irregular vortex detachment was observed also reaching the navigation route.

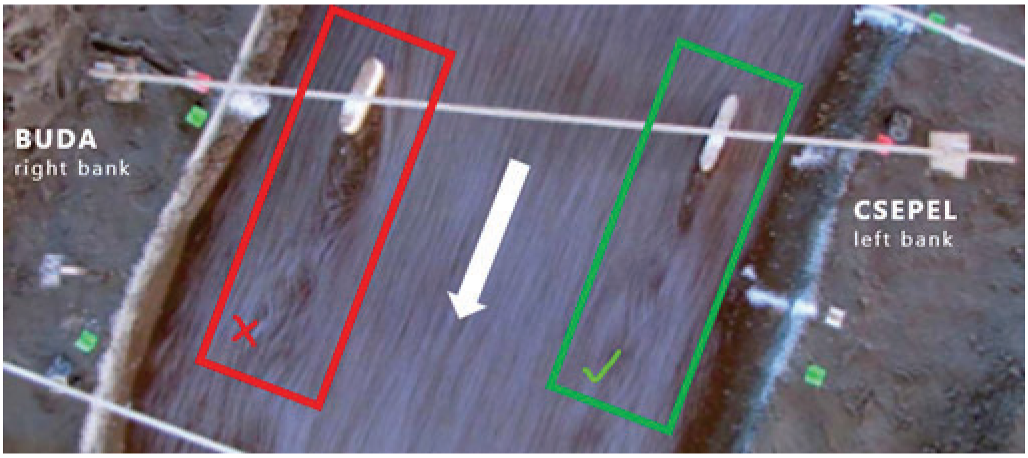

**Figure 7:** Small scale testing – irregular vortex detachment at right bank side riverpier (left side with red) – © CÉH

In order to clarify the flow anomaly (figure 7), 3D CFD simulation was requested to be carried out by the National Water Management Directorate, which is considered as the most appropriate and cost-effective method for such purposes nowadays.

## 8 3D CFD Simulations

Commissioned by CÉH, 3D CFD simulations were carried out by Budapest University of Technology and Economics (BME), Department of Hydraulic and Water Resources Engineering. As state-of-the-art 3D numerical flow simulations via Computational Fluid Dynamics (CFD), first a large-scale CFD model was built, then a fine-scale CFD model was assessed aiming to evaluate the influence of the planned bridge piers. The geometrical models for the detailed numerical simulations were generated using the riverbed survey data and 3D CAD pier models provided by CÉH (figure 8).

**Figure 8:** Additional site measurements - ADCP instrument (left) fixed to the BME's measurement vessel – © BME / CÉH

The large scale CFD model was built (also validated with the small-scale test results, figure 9) to analyze global flow dynamics between Danube River sections of 1644-1639 r.km, including the flow-disturbing Lágymányosi Bay and nearby canals. Fine-scale CFD modells were applied to reveal and assess the transient hydrodynamic behavior of the various pier setups under varying hydrological conditions. To improve the accuracy near the bridge piers, a nested grid approach was applied, enhancing resolution in areas with significant flow changes.

As validation of the CFD model, the simulated flow considering additional site measurements was compared to the small scale flow test results showing good correlation between the two approach.

The flow analysis assessed navigational conditions across different water levels (figure 10). At low water conditions, velocities at the planned bridge increased by about 20% due to the piers, also affecting downstream and upstream reaches. Mean water conditions showed smaller increases in velocity, while flood conditions (high water) resulted in significantly higher velocities but did not impact the navigation route.

Morphological assessment highlighted that the riverbed is primarily clay, which made complicated to make predictions of sediment changes. Increased bed shear stress near the piers was noted,

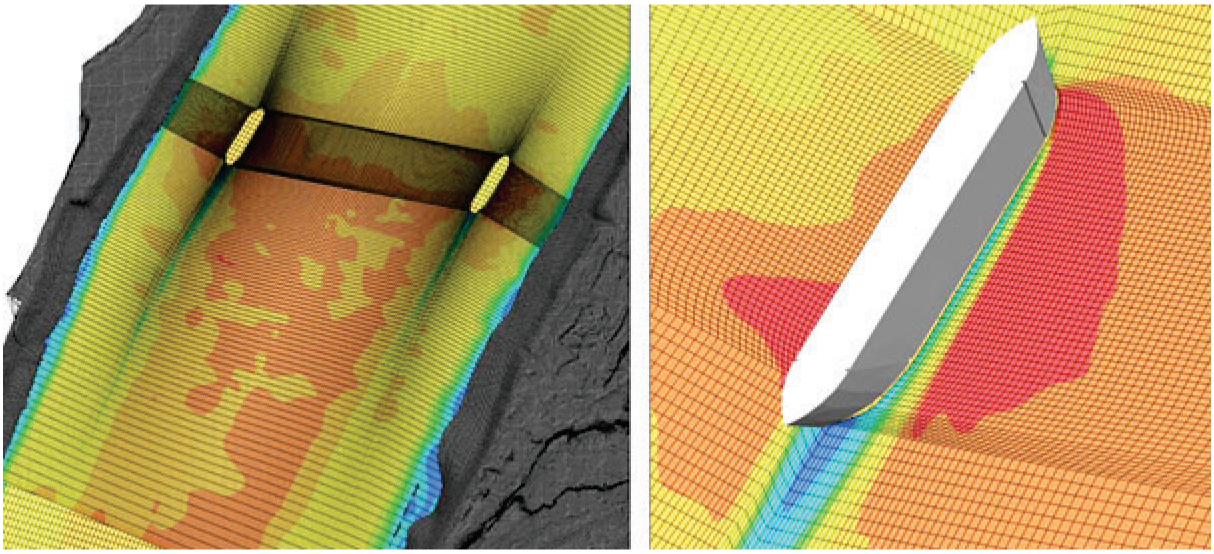

**Figure 9:** Numerical grid in the vicinity of the planned bridge (left) and at the bridge pier – © BME / CÉH

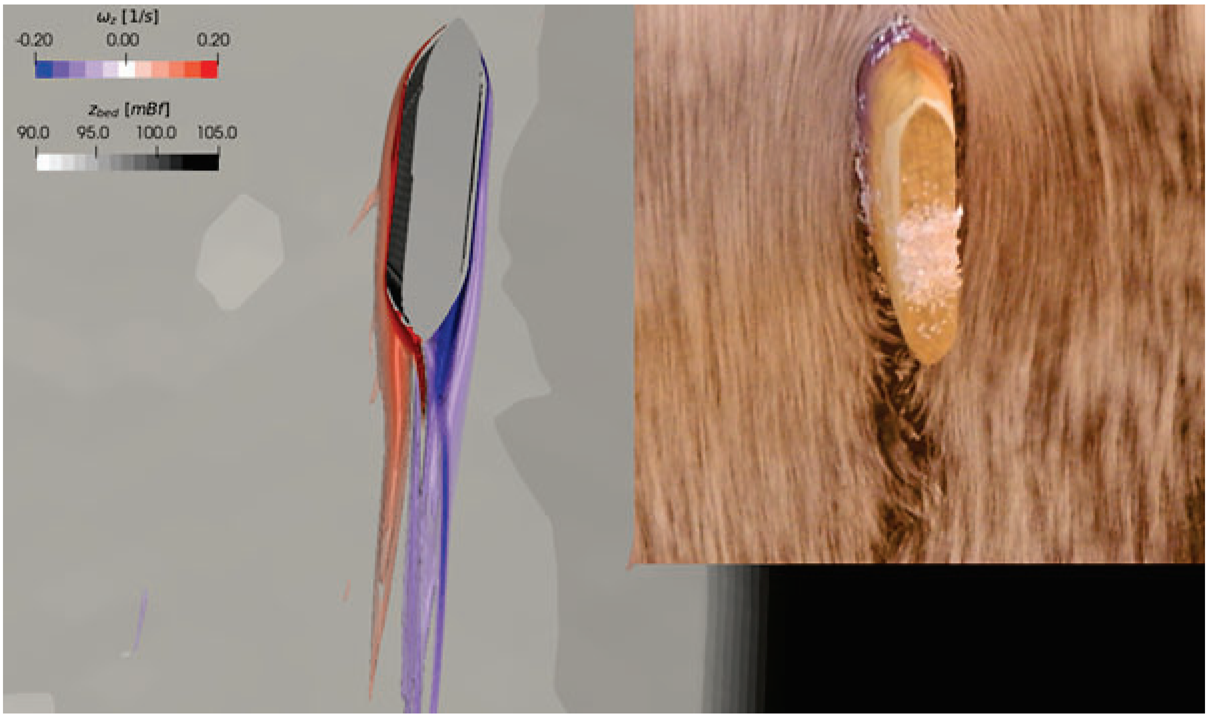

**Figure 10:** Comparison of small-scale test and CFD model results in the vicinity of the left bank pier (design variant 2), river flow to be considered from the top to the bottom – © BME / CÉH

suggesting localized erosion but not significant impacts on sediment deposition zones. Eventually, riverbed stabilization (scour protection) was recommended in areas with increased erosion capacity, especially during floods.

The 3D CFD analysis did not identify any adverse unsteady flow features that would significantly impair navigational conditions, confirming the acceptability of the architecturally preferred third variant pier geometry. Due to the inability to perfectly align both piers to the actual flowline, while optimising the pier alignment, sensitivity analysis on skew angle of piers (the deviation angle between the pier longitudinal axis and the actually determined flow direction at piers) had been performed. One of the key condition was, that longitudinal axis of both left and right riverbank piers needed to stay paralell to eachother.

This analysis revealed a slight sensitivity in the flow field, with a local increase in flow velocity around the left pier and a decrease around the right pier by about 10%. As a result, the final pier geometry was defined with a rotation from the initially determined value of 70°. This was also tested and found to be a good value between the original (70°) and most extremely rotated versions (75.5°), and was particularly favourable under high water conditions. The final skew angle of both side bridge piers was found to be optimal at an angle of 73° (figures 11 & 12).

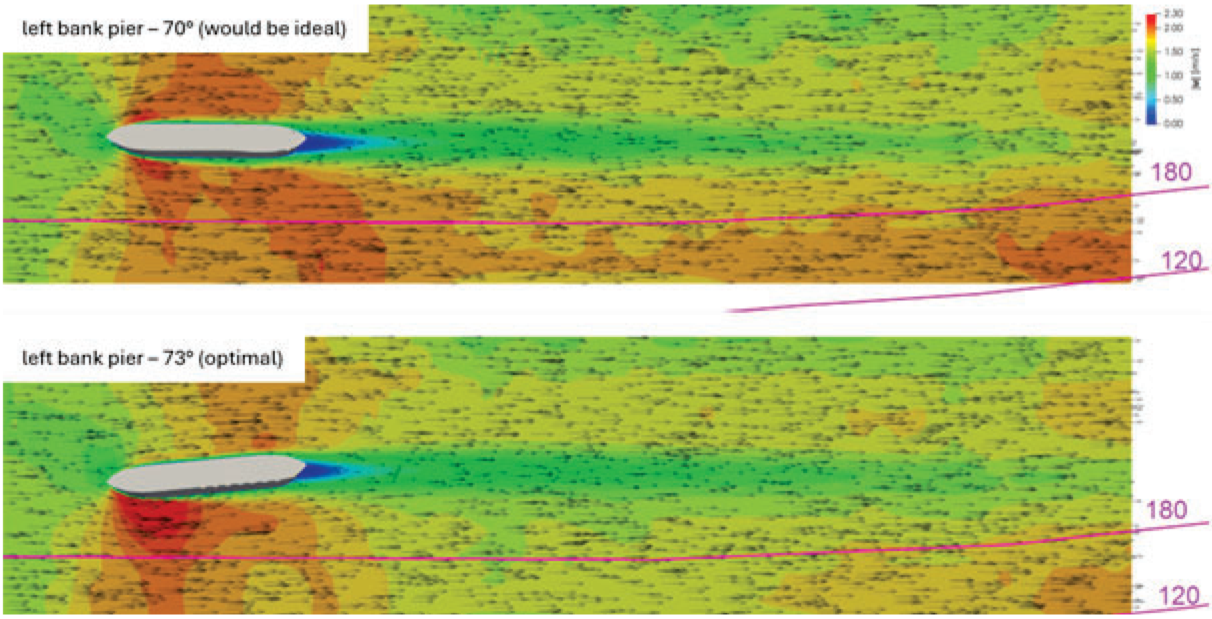

**Figure 11:** Left bank pier - near surface velocity contour and vector field, mean water level – © BME / CÉH

## 9 Summary of the optimization of riverbed piers

The river pier design of Budapest‘s New Danube Bridge was studied extensively to provide the perfect architectural and engineering solution whilst satisfying navigational requirement, consideration for known hydraulic effects, and being able to accommodate the bridge superstructure. Various constraints were considered with the major influence being the impact on the river’s hydraulic behaviour and transient water levels.

The main design development was to align the parallel river piers with the slightly differing flow lines of the river at the cross section and provide hydraulically favoured ‘pointed arch’ leading

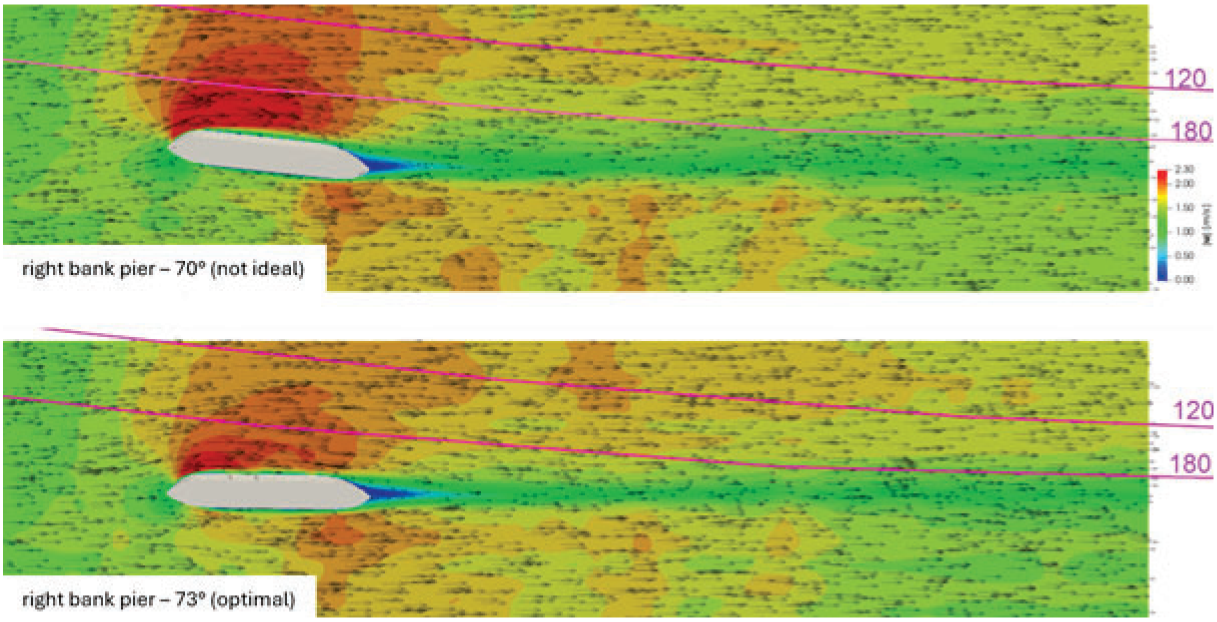

**Figure 12:** Right bank pier - near surface velocity contour and vector field, mean water level – © BME / CÉH

**Figure 13:** Rendered image of the final variant river pier and pylon structure – © UNStudio

and trailing edges of the custom shaped piers. The optimisation was carried out by performing extensive riverbed and hydraulic surveys, 2D hydraulic studies, small-scale physical testing and state-of-the-art 3D CFD simulation. In addition, a focus on associated matters such as scour protection. The engineering design aslo considered foundations based on site-specific ground investigation and construction methodologies.

As a result of the river pier geometry development, the final and optimal geometry of the substructures were determined, while maintaining the originally sought architectural integrity of the bridge (figure 13).