HIYDRAULIC ANALYSIS OF BRIDGE PIERS REPLACEMENT

STAŠA VOŠNJAK
Institute for Hydraulic Research
Hajdrihova 28, Ljubljana, Slovenia

GORAZD NOVAK
Institute for Hydraulic Research
Hajdrihova 28, Ljubljana, Slovenia

Hydraulic analysis of bridge piers construction impacts was carried out on the Salzach river in Austria. The construction of a new bridge due to the expansion of the double track railway to three tracks foresees two new bridge piers in addition to the four existing ones. Since it is not possible to interrupt the traffic, a new parallel railway bridge has to be constructed first, and only afterwards the old piers will be removed. Since such a number of bridge piers will cause the conveyance reduction of the river, hydraulic modeling was demanded and performed at the Technical University Graz. A physical hydraulic model was constructed, and comparative mathematical modeling with two commercial two-dimensional, depth averaged mathematical models (SMS-RMA2 and Aquadyn) was carried out at the same time. Further on, an analysis was made of the impact of the necessary contraction of the river due to the construction pits for building of new piers or pulling down of the existing ones. A comparison of velocity magnitudes and distribution of velocities along the river section was made. The comparison showed deviations, which can be attributed to the locally higher three-dimensionality of the flow, as well as different transverse distribution of calculated velocities.

1 Introduction

An analysis was made of the hydraulic conditions at a section of the Salzach river, where there already exist four bridge piers for a double track railway. Due to the expansion of the railway to three tracks, a new bridge railway with two bridge piers will be constructed parallel. Since the traffic cannot be interrupted, a new bridge will be constructed first, and when the traffic has been diverted to it, the old bridge will be pulled down. A higher number of bridge piers cause local disturbances of the flow, conveyance reduction and erosion processes related to them. Since in such cases mathematical models are not yet sufficiently reliable, a (physical) hydraulic model was ordered. Moreover, model measurements carried out with both, 1D and 2D probes were also used to assess the applicability and reliability of two commercial 2D (ground plan) depth averaged mathematical models (Aquadyn and SMS-RMA2). Coupling and comparing physical and mathematical modeling should give additional information of flow phenomena around piers as well.

2 Physical hydraulic model

A physical hydraulic model built to an undistorted model scale of 1:40 according to Froude's Law of Similarity was constructed. The model comprises a section of the Salzach river, 1140 m in length and 120 m in average width. In most part of the section, the model has a fixed bed, only in the area of bridge piers and downstream of them, a mobile sand bed for informative tests was set up.

Figure 1: Physical model of the Salzach river section

The first measurements were performed on a model with a mobile bed in the narrow area of bridge piers (variant A). Since the erosion processes at the bridge piers proved to be too strong, bed enforcement needed to be foreseen. For further measurements, the physical model was remodeled in the area of bridge piers (variant B), i.e. consolidated with suitable stone granules, which represent the future bed and bank enforcement in nature.

Figure 2: Variant A – Local erosion of the bed

Figure 3: Variant B – Enforcement of the bed

For both variants of the physical model, measurements of water surface profile for 10-year and 100-year flood events were carried out, which were then used for calibration of both 2D mathematical models. Measurements of water surface profile were carried out on 12 cross-sections, in the axis of an individual cross-section. Measurements of local velocities of the flow were also carried out on the physical model, both with 10-year and 100-year flood events, using different measuring equipment.

In one case, velocities were measured with the equipment for measuring one-dimensional (primary) velocities, while in the other case, two components of velocities (longitudinal and transverse) were measured. The following instruments were used in measuring the velocities:

(1) 1D velocimeter of the manufacturer Höntzsch
(2) 2D Acoustic Doppler Velocimeter (ADV) of the manufacturer Nortek.

The first instrument, small current meter, allows measurements of water velocities from the direction, into which the probe is directed. The second instrument allows measurements of two components of velocities in a remote sampling volume, which is practically undisturbed by the presence of the probe. Being insensitive to water quality, probe is widely applicable (in a laboratory and in the field). For comparison purposes, directions of both longitudinal velocities were the same.

The velocity measurements were carried out on 12 cross-sections (Fig. 4) for two flood events. The first discharge was Q10 (1520 m3/s in nature, 150.2 l/s on the model), and the second discharge was Q100 (2200 m3/s in nature, 217.4 l/s on the model). In each cross-section, velocities were measured in three different points, in the axis of the cross-section and in two adjacent, symmetrically distributed points along the cross-section. In the vertical direction, probes were positioned 2 cm below the water surface due to the restrictions on the physical model.

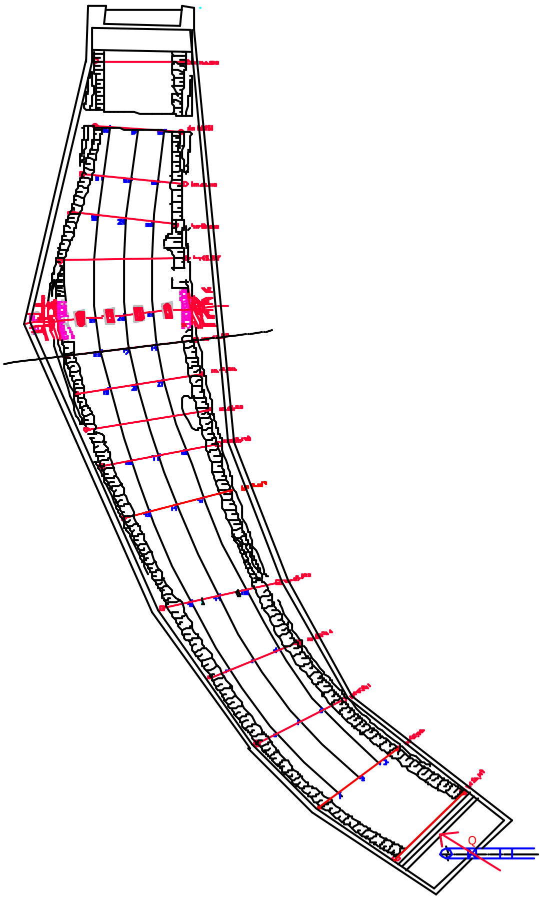

Figure 4: Cross sections on the model

The measured velocities were compared among themselves, as well as with the velocities calculated with the mathematical models, previous calibrated to the measured water surface profile. However, since the 2D mathematical models provide depth averaged velocities, a recalculation was required between the measured velocities and the velocities from the mathematical model by adopting a logarithm distribution of velocities along the vertical. Such a distribution assumption slightly reduced the deviations in the comparison of the results obtained by different models regarding the magnitude of velocities in individual points or the spatial variation of velocities along the cross-section.

3 Mathematical model

Hydraulic analysis was carried out by means of two mathematical models SMS-RMA2 and Aquadyn, which are depth averaged numerical simulations based on the finite element method. Using this method, the water body is divided into elements, which can be either triangular or quadrangular in shape with parabolic sides. Values of variables within a finite element are approximated using the nodal values and interpolation functions. A quadratic interpolation is used for velocities, and linear interpolation for depths, according to the Newton-Raphson method. The calculations are based on the Reynolds averaged Navier-Stokes equations for turbulent flow.

The easiest way of entering the geometric data in the model is by a digital relief model, to which other (e.g. measured) data on geometry are added. To enter the geometry, a SMS graphic interface was used, and the area discussed was covered with a mesh composed of 7136 triangular finite elements, which was the same for both hydrodynamic mathematical programs Aquadyn and SMS-RMA2. Boundary conditions need to be added, so for the inflow and outflow cross-section, the model RMA2-SMS (for subcritical flow) requires two boundary conditions: discharge and water surface elevation. The same boundary conditions are required also by Aquadyn, which is a hydrodynamic package and allows also modeling of steady and unsteady flows in supercritical and subcritical flow regimes, taking into account the bed elevation of the water course (bathymetry), water friction with the bed, gravity force, wind stress, Coriolis force and turbulence dissipation.

A graphic interface allows presenting the distribution of velocities along the discussed section, either to give an overview of the whole river section or the situation in the narrow area of bridge piers.

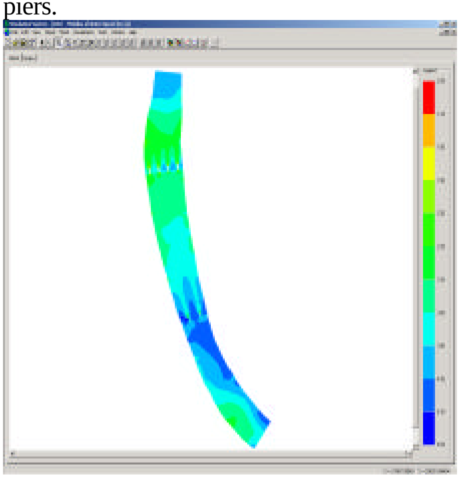

Figure 5: Spatial depth averaged velocity distribution along whole river section calculated with Aquadyn software for the Q100 flood event.

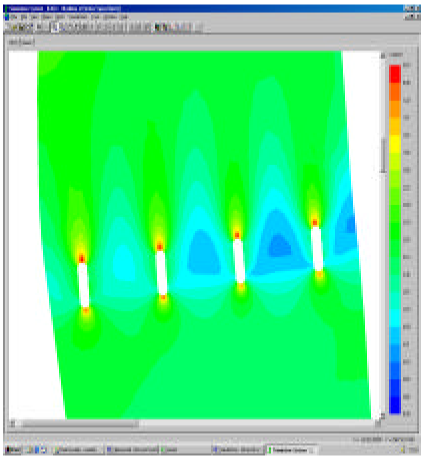

Figure 6: Spatial depth averaged velocity distribution in narrow area of the bridge piers, calculated at the Q100 flood event.

To allow the comparison of calculations obtained by the two programs, the mesh of elements and the entire digital relief model were made by the SMS graphic interface and then transferred also to the Aquadyn program. The mesh points are thus the same in both programs, as are also the boundary conditions.

2 Results

On the basis of the measured water surface profiles, both 2D mathematical models were calibrated. When calibrating the mathematical models, Manning's roughness coefficient was being changed, but so that it had constant value within the calculation area. Their (numerical) results were then compared with both types (1D, 2D) of the measured velocities on the physical model. The calculated velocities correspond (by size) quite well to the measured velocities, however, one can observe differences both in the spatial distribution of velocities (e.g. location of highest velocities) as well as in the trends (e.g. higher velocities at the concave bank of curve, etc.).

In the majority of points, the calculated magnitudes of velocities are within the limits of the measured velocities and are, as a rule, higher than the 1D measured velocities and lower than the 2D measured velocities. The distribution of velocities calculated with the Aquadyn software does not correspond to the measurements only in the cross-sections at the bridge piers (which are, however, the most interesting). An interesting result is also that in individual cross-sections the distribution of 1D measurement corresponds to the distribution of velocities calculated by the Aquadyn software, while the 2D measurements showed different distributions. The second interesting point is that the spatial distribution of velocities is the same in the calculation with the Aquadyn software and the 2D measurements, while the 1D measurements show different distributions. As well as with the Aquadyn software, the velocities calculated with the SMS-RMA2 software correspond by size quite well to the measured velocities, with only the distribution along the cross-section being quite different, since also with the SMS software, the magnitude of the calculated velocities are, in the majority of points, within the measured velocities, and, as with the Aquadyn software, mainly higher than the 1D measured velocities and lower than the 2D measured velocities.

On the Fig. 7 comparisons between measured and calculated velocities for three locations in two cross sections are given, just indicate the variety in spatial distribution.

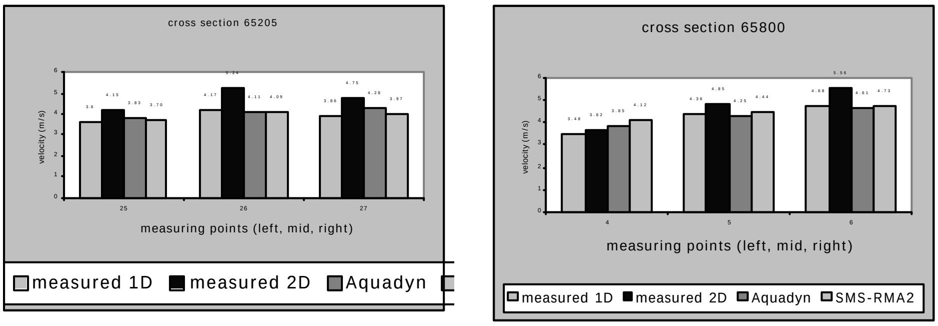

Figure 7: Two measured and two calculated velocities in three measuring points (left, mid, right) in cross sections (results of 1D probe, 2D probe, Aquadyn and RMA2 software given from left to right at each point)

The mathematical models show the areas with the highest velocities, however, there are such differences between the two that these results cannot provide any basis for the analysis of the eroding forces nor the dimensioning of consolidation in the area between the bridge piers. This confirms the necessity of constructing a physical model. The measurements on the latter will also be valuable in the further work, when more attention will be paid to the analysis of causes for different distributions of velocities obtained by individual mathematical models.

3 Conclusion

Hydraulic analyses are to a large extent based on an experiment since equations for water flow descriptions are not analytically soluble. In the past, hydraulic problems could be solved only by means of physical models, whereas afterwards a (too) large emphasis was laid on mathematical models, which, however, always required a certain extent of measurements. Nowadays, problems are solved by a balanced combination of numerical models and experiments on a physical model (or in nature). Despite the use of the most advanced computers and equipment, hydraulics still poses problems which can be solved only experimentally. Ones again, necessity of constructing a physical model was confirmed.

A practical example was used for a comparison between the hydrodynamic quantities measured on the physical model and the quantities calculated with 2D mathematical models (calibrated with water surface profile). The comparison took into account the fact that the velocities measured 2 cm below water surface theoretically would be higher than the calculated, depth averaged velocities in individual points. The comparison to the velocities calculated with both, Aquadyn and the SMS-RMA2 mathematical models shows good correspondence regarding the magnitude of velocities, but also deviations in the distribution of velocities in a horizontal plane of the discussed section.

Further work will require also calculations for dealing with the situation in case of a mobile bed, which will require additional software module(s). The differences between the results of both mathematical models (also with fixed bed) prove that the physical model was necessary. Further measurements of variant conditions at different construction phases will be used for additional analyses of suitability of mathematical models available on the market.

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