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INFLUENCE OF BAR SPACING AND FREE-STREAM TURBULENCE ON FLOW-INDUCED VIBRATION OF TRASHRACKS

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Abstract

Flow-induced vibrations are often a concern in the design and operation of trashracks. Trashracks are hydraulic structures, consisting of an array of bars. They are typical inlet devices of river power plants used to prevent large obstacles from hitting the turbines.

This paper experimentally investigates the oscillation of trashrack models with two degrees of freedom in the streamwise and the crossflow directions. The rack construction was made up of several rectangular shaped bars with a chord-to-thickness ratio of 10.

The mutual interaction of the formation of single vortices, the bar spacing, the angle of incidence and the free-stream turbulence affected the rack vibration characteristics. The hydraulic experiments covered a wide range of different bar spacings and flow incidence angles extending from 5° to 45°.

The qualitative response of the trashrack models due to flow-induced excitation was determined by plotting the entire rack motion appropriate to the directions of the main vibration modes.

Similar to measurements by Kerenyi (1997), the oscillation of the trashrack bars due to vortex-induced excitation was able to be suppressed by restricting the bar spacing to a value smaller than the length of a single bar.

Besides the variation of flow incidence angles and bar spacings, the influence of free-stream turbulence on the excitation of the trashrack models was object of the investigations. In order to prove a possible turbulence effect on the vibration behaviour of the rack, the turbulence intensity of the approaching flow was varied between 3.5% and 5.5%. It will be demonstrated, that with decreasing turbulence level, excitation due to turbulence occurs.

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The hydraulic model tests were carried out in the water channel of the Laboratory of Hydraulic Engineering at Vienna University of Technology.

INTRODUCTION

Trashracks are hydraulic structures used to prevent trash from entering a duct leading to a turbine or pump. These structures typically consist of an array of vertical prisms or bars and several horizontal members which are responsible for both the stiffness of the individual bars and the maintenance of equal distances between them.

Trashrack vibrations should strictly be avoided due to the risk of severe damage. Such vibrations are attributed to various causes referring to Naudascher et al. [2]:

- Buffeting due to free-stream turbulence or other extraneous sources of excitation,
- resonance with vortex shedding (alternate vortex shedding – AEVS) or impinging vortices (impinging leading edge vortices –ILEV), and
- galloping, wake breathing and plunging vibration.

In practice the flow approaches the trashrack bars at some incidence angles. Large angles can occur locally near side piers or accumulated trash. In case the rack being clogged with trash or obstructed by a tree trunk, one can imagine, that the flow is not only deflected but its velocity is larger in the unclogged parts. The combination of these two effects can lead to an increasing probability of excitation.

Individual structures of rectangular cross-section may generally vibrate in transverse or streamwise direction. The results of vibration testing on trashracks demonstrated, that both transverse and streamwise vibrations appear simultaneously with nearly the same eigenfrequencies.

Experimental investigations by Kerenyi [1] showed, that the bar spacing s between several rectangular shaped bars inclined to the approaching flow (cf. *Figure 1*) strongly affects the excitation of these bars.

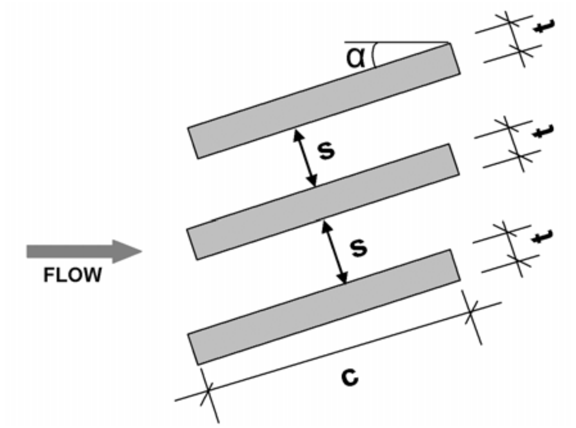

Figure 1 – Description of bar spacing s, chord-to-thickness ratio c/t and angle of incidence α

Kerenyi carried out investigations on trashrack models consisting of an array of three and five single bars. The chosen bars had a rectangular cross-section with an elongation ratio of c/t = 10 due to the circumstance, that cross-sections of prototype trashracks usually conform to this aspect ratio. It turned out that there was no difference between these two set-ups regarding flow-induced excitation. The chord of the bars was 5 cm and the thickness 0.5 cm.
A critical bar spacing was specified at a value of s_{crit} = 1.1c. Above this critical bar spacing excitation due to vortex shedding occurred, below this critical value no oscillations emerged.

EXPERIMENTAL SET-UP

The experimental rig was designed to permit the coupling of streamwise and transverse vibrations of freely oscillating prisms in a water channel. Arrays of three trashrack bars were positioned vertically in a free surface channel with a cross-section width of 0.955 m and a water depth of 0.4 m. The Plexiglas test bars had sharp-edged corners and were free to oscillate in the directions corresponding to its main bending axis. The free oscillator was constructed as a perpendicular pendulum. This pendulum was suspended with three swing arms. In order to allow perpendicular vibration, cardan joints were used (*Figure 2*).

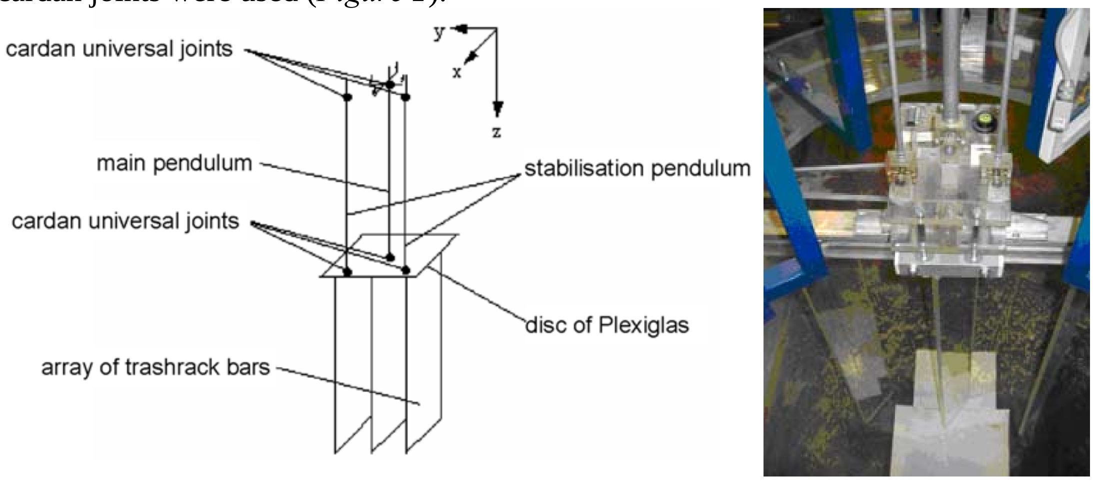

Figure 2: Experimental rig

To enable the simulation of inclined flow, the experimental rig was connected with a rotatable disc.

In addition to the sharp-edged rectangular trashrack bars with a chord of 5 cm and a thickness of 0.5 cm one more trashrack twice as large was added to the model set-up of the present study (cf. *Table 1*). To simplify matters, the larger array of bars will be referred to as “prototype” and the smaller one as “model”. In practice trashrack bars absolutely correspond to the dimensions of the chosen “prototype” set-up.

The test series were initiated with an angle of incidence of 35°. Of vital interest was the effect of bar spacing on the vibration behaviour of the trashracks. Therefore the conducted experiments covered a range of s = c up to s = 2c.

Table 1 – Relevant data of the investigated trashrack bars

RECTANGULAR SHAPED BARS c/t = 10	CHORD c [cm]	THICKNESS t [cm]	TURBULENCE LEVEL Tu [%]	MEAN FLOW-VELOCITY v_0 [cm/s]
PROTOTYPE	10	1	3.5%, 4.5%, 5.5%	17
MODEL	5	0.5	3.5%, 4.5%, 5.5%	12

In contrast to Kerenyi's model tests, special emphasis was given to the influence of free-stream turbulence on the excitation of the trashrack bars by varying the turbulence level of the approaching flow.

Variation of free-stream turbulence

In order to obtain a general view of the water channel, *Figure 3* schematically illustrates the construction of the channel including adopted measures to control free-stream turbulence.

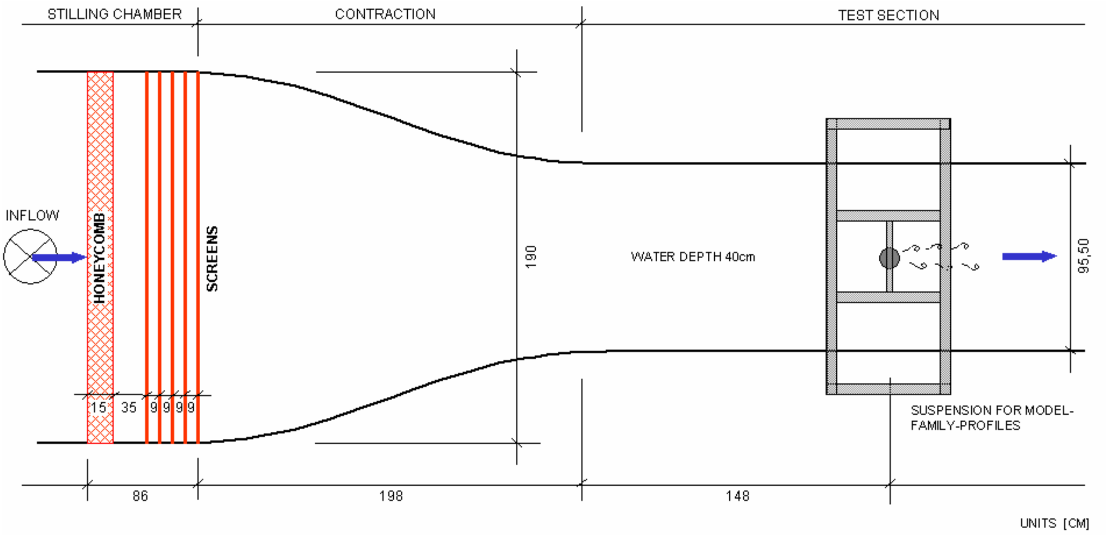

Figure 3 – Water channel [3]

The upstream flow conditioning was achieved by using a honeycomb flow straightener, a series of five damping screens in tandem arrangement - each with a solidity ratio of 34% - and a carefully designed trumpet-shaped contraction [3]. By varying the number of screens it was possible to adjust three turbulence intensities –

3.5%, 4.5% and 5.5%. The turbulence level was measured by means of an ADV probe (acoustic Doppler velocimetry). The side and bottom walls of the test section were made of Plexiglas, allowing flow visibility from all angles.

Kerenyi did not consider the influence of free-stream turbulence – his experiments were only subject to the condition of very low turbulence (less than 1%). However constructional elements are faced to effects which may be caused by the influence of high turbulence.

Vibration-ellipse

The qualitative response of the trashrack models due to flow-induced excitation was determined by plotting the entire rack motion appropriate to the directions of the main vibration modes (in and against flow direction). *Figure 4* sketches the record of this motion, which will be henceforth designated as “vibration-ellipse”:

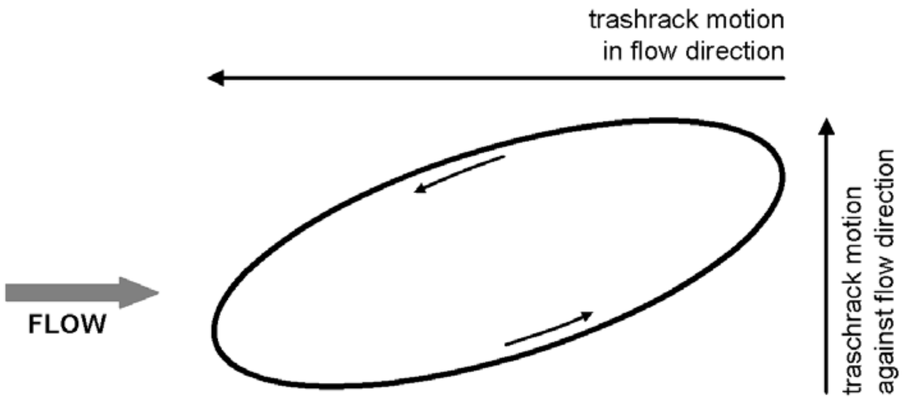

Figure 4 – Vibration-ellipse

The vibration-ellipse was recorded with orthogonally arranged laser displacement sensors.

In case the trashrack models were not excited from rest due to flow induced mechanisms, an initial push (manual excitation) should ensure, whether vibrations could be initialized and hold up, or not.

Regarding the influence of free-stream turbulence, it turned out, that the “model” vibration-ellipses at turbulence intensities of 3.5% and 4.5% looked alike, whereas the “prototype” ellipses showed different behaviour for all three investigated turbulence levels.

EXPERIMENTAL RESULTS

The following paragraph illustrates the recorded vibration-ellipses of “model” and “prototype” depending on bar spacings ranging from s = c up to s = 2c and turbulence intensities varying between 3.5% and 5.5%. The trashrack bars were inclined to the approaching flow at an angle of 35°.

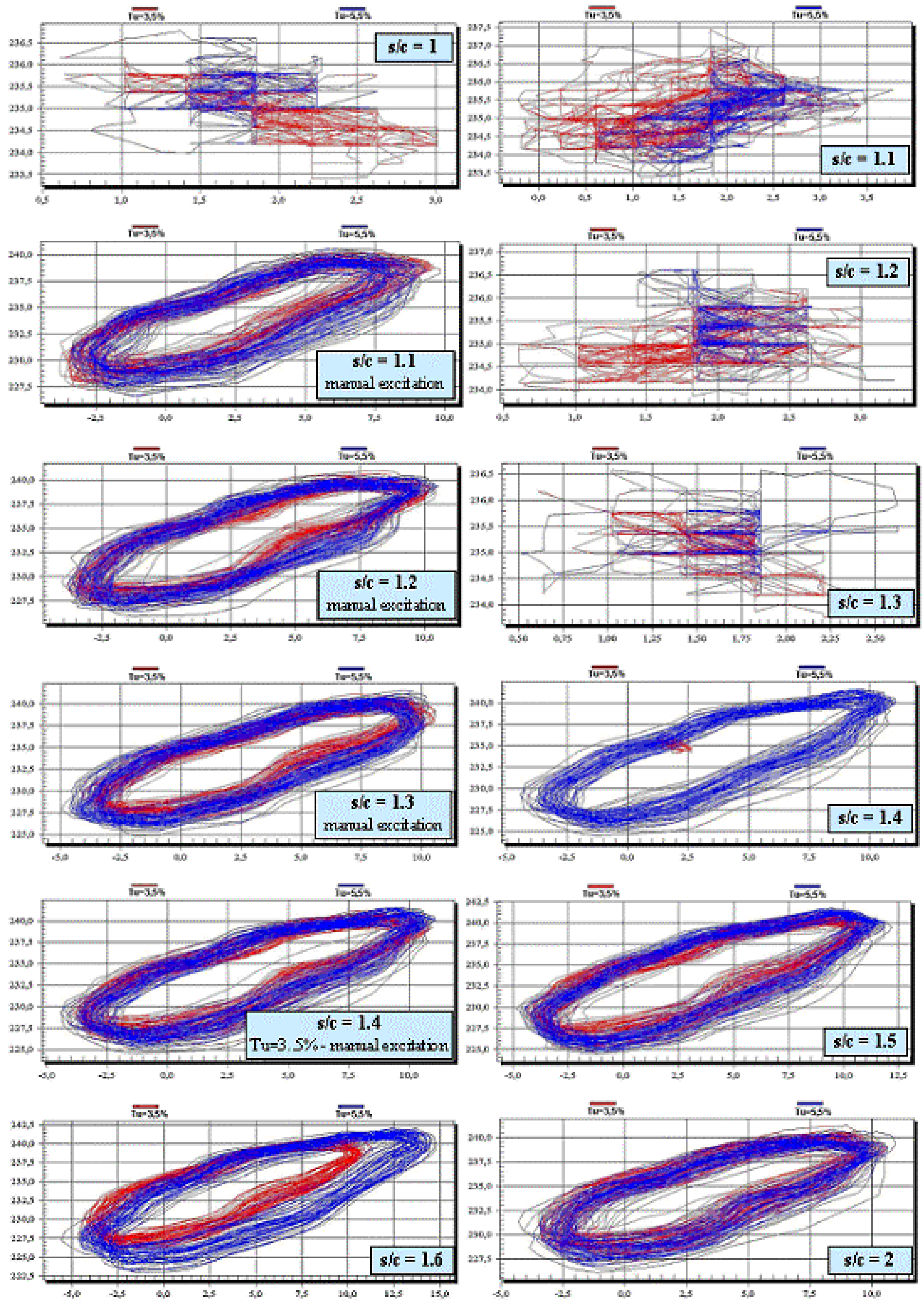

Figure 5 – Vibration-ellipses of "model" [3]

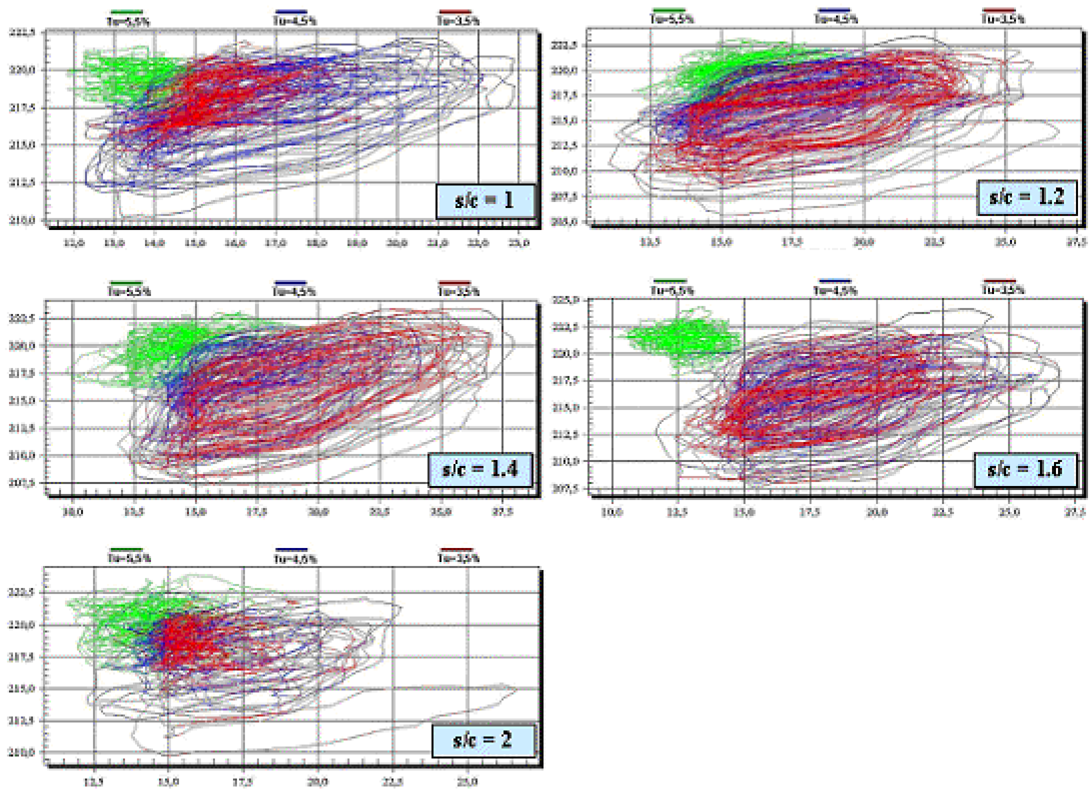

Figure 6 – Vibration-ellipses of “prototype” [3]

For both “model” and “prototype” the following conclusions can be drawn:

- Similar to Kerenyi’s investigations [1] three main characteristic flow phenomena could be observed:
  - Alternating vortex formation (AEVS),
  - the formation of further vortices emerging from the trailing edges (similar to trailing edge vortices – TEVS),
  - and wake breathing.
- If the bar spacing s is limited to a value less than or equal to the chord c of a single bar, both “model” and “prototype” remained unaffected towards vortex induced excitation. This observation applied to additionally investigated flow incidence angles ranging between 5° and 45°.
- The main source of excitation concerning the “prototype” (*Figure 6*) is obviously caused by turbulence buffeting at turbulence intensities of 3.5% (red ellipse) and 4.5% (blue ellipse). Referring to *Figure 6* it can be recognized, that the oscillation is not stable and does not represent a precise vibration-ellipse compared to the motion records of the “model” in *Figure 5*. The oscillations of the “prototype” built up slowly and broke down shortly. It was not possible to excite the “prototype” with an initial push, independent of different bar spacings and angles of incidence. At a turbulence level of 5.5% (green ellipse) no oscillation occurred.
- The vortex induced self-excitation (excitation from rest) of the “model” could be observed at a bar spacing close to 1.5c. Paradoxically “high” turbulence intensity

(5.5% - blue ellipse) at a bar spacing of 1.4c already led to an earlier self-excitation of the “model”, whereas at a “low” turbulence level of 3.5% (red ellipse) the “model” was not able to be excited from rest. For bar spacings between 1.1c and 1.3c vortex induced excitation could only be initialized with a push.

- Unlike investigations by Kerenyi, the critical bar spacing was found at $s_{crit} = c$ – above this value the “model” rack could be excited with an initial push, which did not break down. Practically this might represent a trunk hitting the structure.

The evaluation of the trashrack motions is summarized in *Table 2* according to the ratio of bar spacing s to chord c of the single bar and the turbulence intensity Tu.

Table 2 – Evaluation of the vibration-ellipse records

s/c	MODEL	PROTOTYPE
1,0	no oscillation	Tu=4.5%: turbulence excitation Tu=3.5% / 5.5%: no oscillation
1,1	oscillation due to manual excitation only	Tu=4.5%: turbulence excitation Tu=3.5% / 5.5%: no oscillation
1,2	oscillation due to manual excitation only	Tu=3.5% / 4.5%: turbulence excitation Tu=5.5%: no oscillation
1,3	oscillation due to manual excitation only	Tu=3.5% / 4.5%: turbulence excitation Tu=5.5%: no oscillation
1,4	Tu=3.5% / 4.5%: oscillation due to manual excitation Tu=5.5%: vortex-induced vibrations	Tu=3.5% / 4.5%: turbulence excitation Tu=5.5%: no oscillation
1,5	vortex-induced vibrations	Tu=3.5% / 4.5%: turbulence excitation Tu=5.5%: no oscillation
1,6	vortex-induced vibrations	Tu=3.5% / 4.5%: turbulence excitation Tu=5.5%: no oscillation
2,0	vortex-induced vibrations	no oscillation

SUMMARY

In order to avoid excitation due to flow-induced mechanisms, such as vortex shedding and turbulence buffeting, the present paper showed, that the bar spacing of trashracks consisting of sharp-edged rectangular bars (c/t = 10) should be limited to a value smaller than the chord of the single bar and the influence of free-stream turbulence may not be neglected.

REFERENCES

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[3] Reibenwein C., “Einfluss der Turbulenz auf die Wirbelablösefrequenz bei kreisförmigen und rechteckigen Stäben“, PhD-Thesis, Institute for Hydraulic Engineering, TU-Vienna, (2005).