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CFD Simulations of Vortex Shedding for single and interacting Sections

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SUMMARY:
CFD simulations are gaining some importance for bridge design. Most important values are the quasi-static force and moment coefficients dependent on the angle of attack and the Strouhal number and lateral force coefficient clat for the vortex induced vibrations. The classical URANS turbulence models may deliver all these values, but there remain questions on obtaining reliable results.
Very interesting is the effect of two sections where the second one is within the wake of the first. This paper deals with some backgrounds for CFD simulations, shows some “simple” validation cases from the literature and results for a large bridge with two adjacent decks where simulations and wind tunnel tests are compared and some useful conclusions for the construction stages have been drawn.

Keywords: CFD, URANS, Vortex shedding

1. STROUHAL NUMBER AND LATERAL FORCE COEFFICIENTS

The definition of these values may be found in EN 1991-1-4 Appendix E. The common approach is based on a fitting of the parameters n_a and B from the spectral response of the measurements:

$$\frac{S_L(n)\cdot n}{\sigma^2} = \frac{n/n_a}{\sqrt{\pi}} \cdot e^{\frac{1-n/n_a}{B}} \quad (1)$$

And then the Strouhal number is obtained by:

$$St = \frac{n_a \cdot b_{ref}}{v_m} \quad (2)$$

While the lateral force coefficient c_{lat} is obtained from the RMS value of the response of the lift force divided by the sectional height b_{ref} and the mean reference pressure q_m. Sometimes d_{ref} is used instead, creating wrong values if not treated properly.

The simulation techniques for turbulent fluid flow vary from RANS, URANS, LES to the full simulation with DNS. For the typical range of Reynolds numbers and the available computing equipment only LES or URANS are applicable. As URANS will still work with mean values within every time step, we do not obtain a spectrum of the response but in most cases a single value for a given wind speed with a dominant frequency.

2. TURBULENCE PARAMETERS

The turbulence parameters used in the experiment and in the simulation have a considerable impact on the results. In the wind tunnel it is common practice to use different velocities and turbulence parameters. The dependency of mean values on the turbulence intensity and length scale especially for bluff bodies has been published by many authors long ago, e.g. (Laneville, Williams, 1979) or (Bearman, 1968). For 2D cases a measure of $I \cdot L/b_{ref}$ seems to be appropriate.

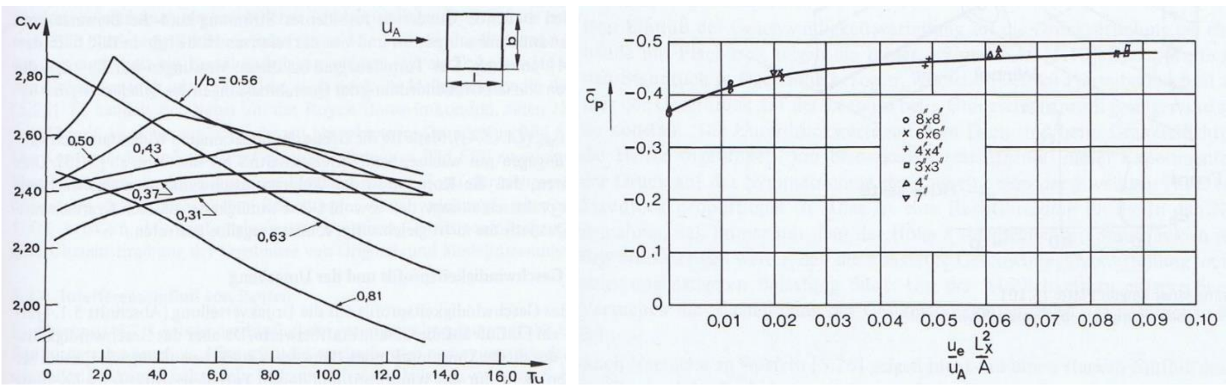


Figure 1. Turbulence dependencies (Laneville, Williams, 1979), (Bearman, 1968)

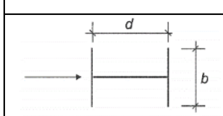
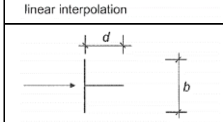
In general, both values are not specified for published force coefficients. While rather low intensities (2 to 4 %) are used in wind tunnels, higher values of turbulence intensities are present in the atmospheric boundary layer according EN 1991-1-4 some shown in the following table:

	z = 10 m	z = 30 m	z = 300 m
$z_o = 0.05$	I = 18.9 %	I = 15.6 %	I = 11.5 %
$z_o = 0.01$	I = 14.5 %	I = 12.5 %	I = 9.7 %

The integral length scale given in the design code is the longitudinal value, for isotropic turbulence as used in most CFD codes the mixing length equal to $0.41 \cdot z$ ($L_v = 0.8 \cdot z$) matches a vertical integral length scale of $0.2 \cdot L_x$ quite well and should be considered as input parameter.

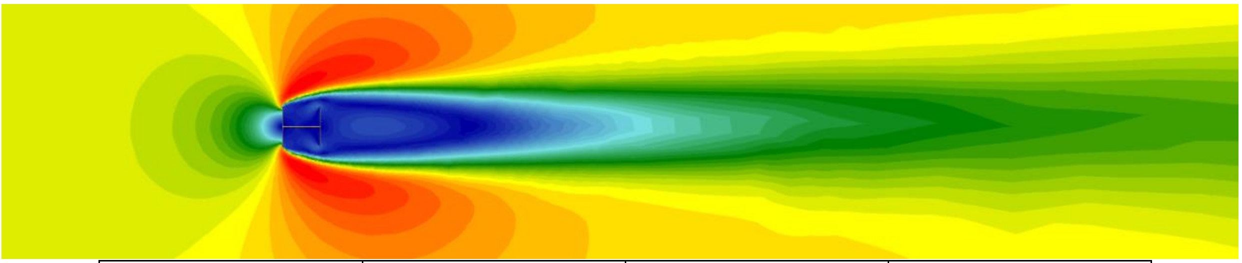
3. VALIDATION CASES T AND DOUBLE T SECTIONS (EN 1991-1-4)

The following table shows results obtained for some reference values given in tables E.1 and E.2.

Section	d/b	C_d			C_{lat}		St	
		Ref.	steady	transient	Ref.	CFD	Ref.	CFD
 linear interpolation	1.0	1.70	1.60	2.00	0.8	0.76	0.12[1]	0.122
	1.5	1.80	1.42	1.94	1.2	1.26	0.10	0.077
	2.0	1.60	1.42	1.55	0.3	0,36	0.09[1]	0.085
 linear interpolation	1.0	2.00	1.91	2.83	1.6	1.31	0.13	0.147
	2.0			2.06	2.3	2.22[2]	0.08	0.082
	[1] Values according to other literature, especially the third line is not correct in EN. [2] Values are obtained from the superposition of two frequencies.							

Dependencies on the mesh size, the Reynolds number, the CFL number, the mesh size and the turbulence parameters are given in the full paper.

Steady state CFD Results show small variations with different turbulent intensities:



Section 1	I = 10 %	I = 15 %	I = 20 %
c_D (d/b=1.0)	1.603	1,592	1.584

Figure 2. Turbulence dependencies for steady state solutions with L_{mix} = b/2

For the transient analysis, in some cases there are dominant frequencies in some cases there are multiple frequencies.

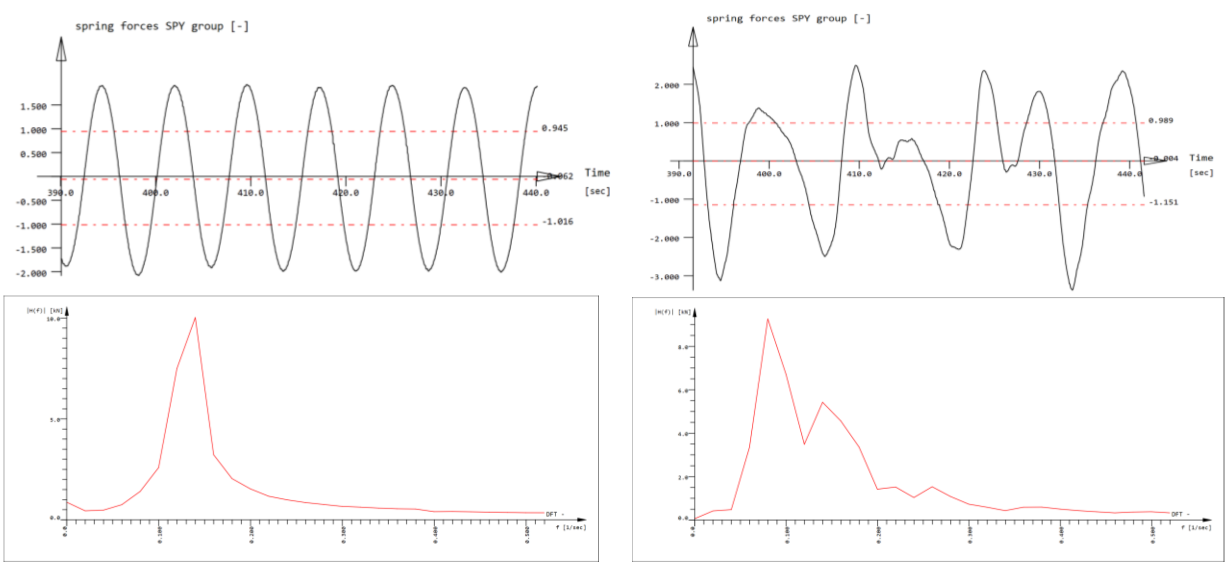


Figure 3. Forces over time and their Fourier transforms for I=5% and L_{mix} = b/2 (left) versus b/20 (right)

Especially for the longer sections (d/b=2.0) the end of the section has a significant influence on the behaviour of the flow, strongly depending on the turbulence parameters.

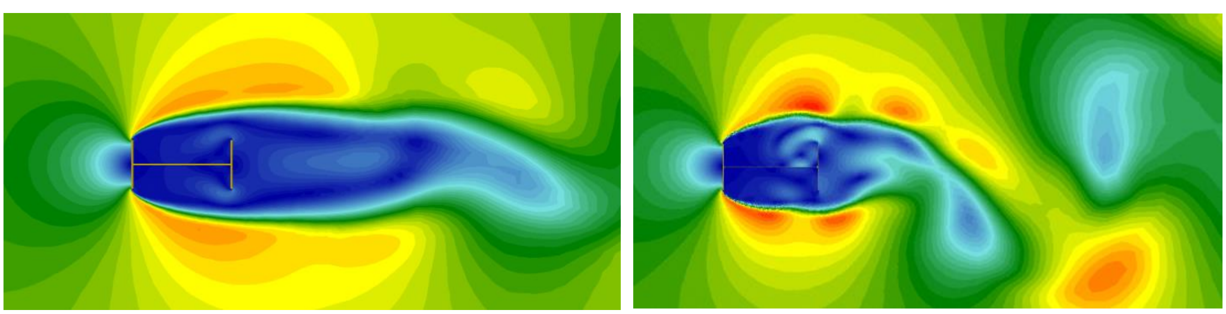


Figure 4. Different wake characteristics (d/b=2.0)

For the longer single T-section very interesting back flow patterns may be observed.

3. BRIDGE WITH TWO GIRDERS

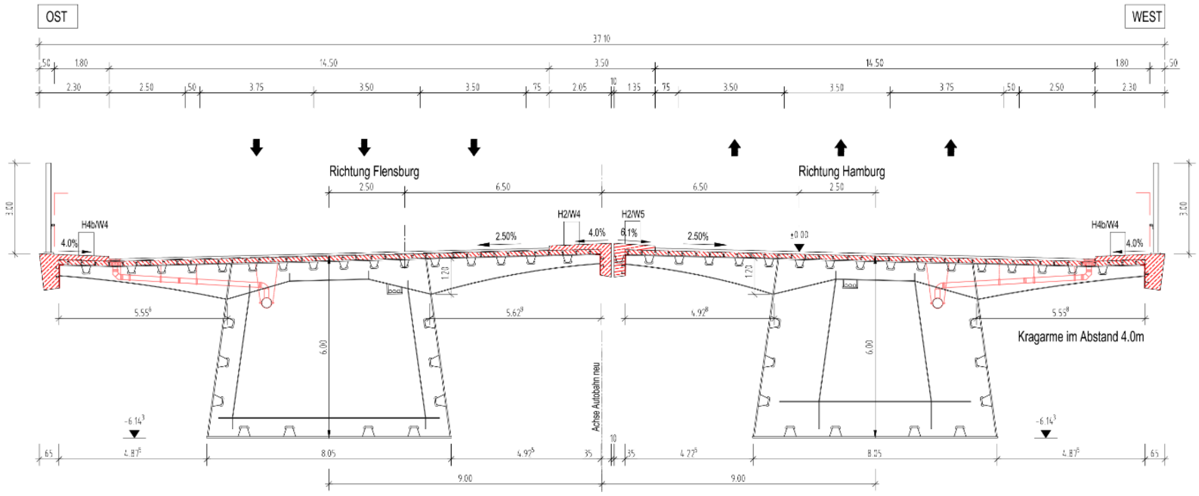


Figure 5. Main span final bridge sections of new Rader High Bridge

A motorway bridge over the North Sea and Baltic Channel is replaced. Thus, at any phase of the construction there are two girders interfering with each other. The quasistatic force coefficients have been evaluated with CFD in the preliminary design phase. For the final design a validation of these values has been done via wind tunnel tests showing excellent matches (Katz,2021).

While these quasistatic coefficients have been obtained with a turbulence of 14 % and a mixing length derived from the turbulence generating grid, the dynamic properties have been obtained with a rather low turbulence of 3.5 % and an empty wind tunnel. Details in the full paper.

There was a considerable impact observed of the second section in the wake of the first in the wind tunnel and the CFD-Analysis. Special studies have been performed for variant constructions of the launching nose. Details to be found in the full paper.

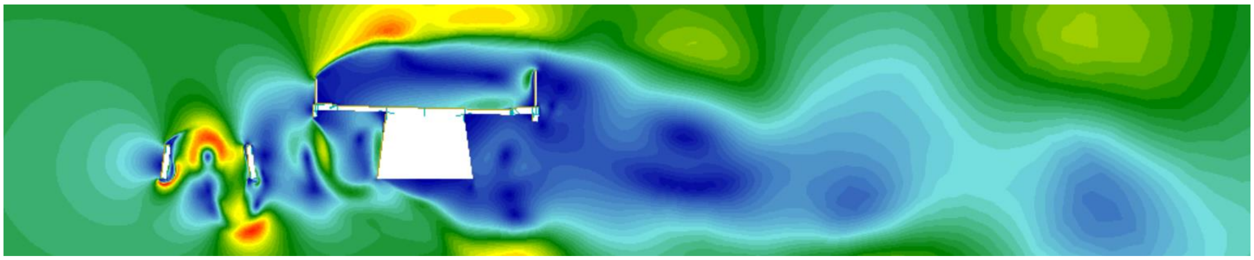


Figure 6. Bad variant of the launching nose with favourable effect of the second bridge

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