Flutter analysis of an extradosed bridge in Hungary

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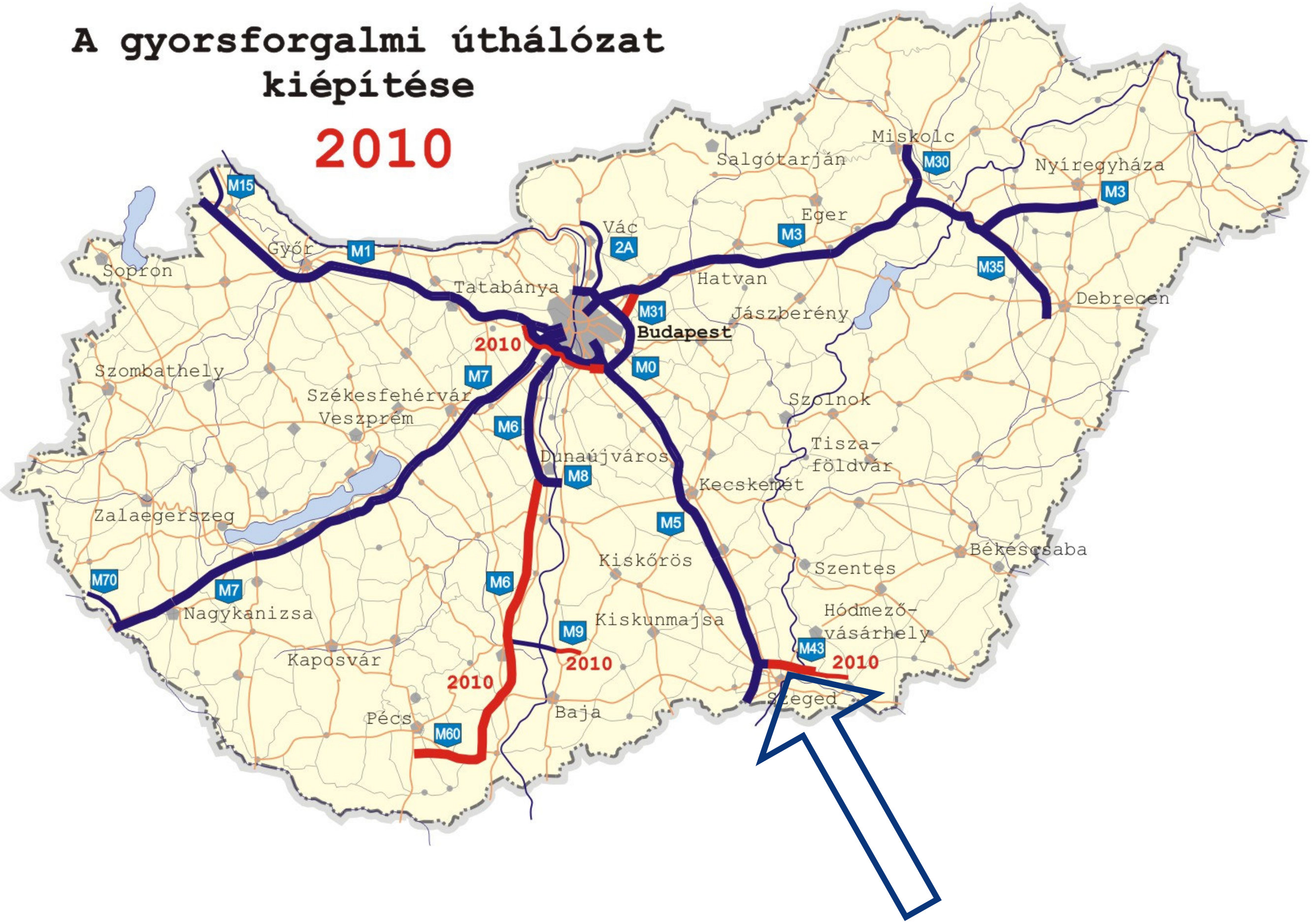
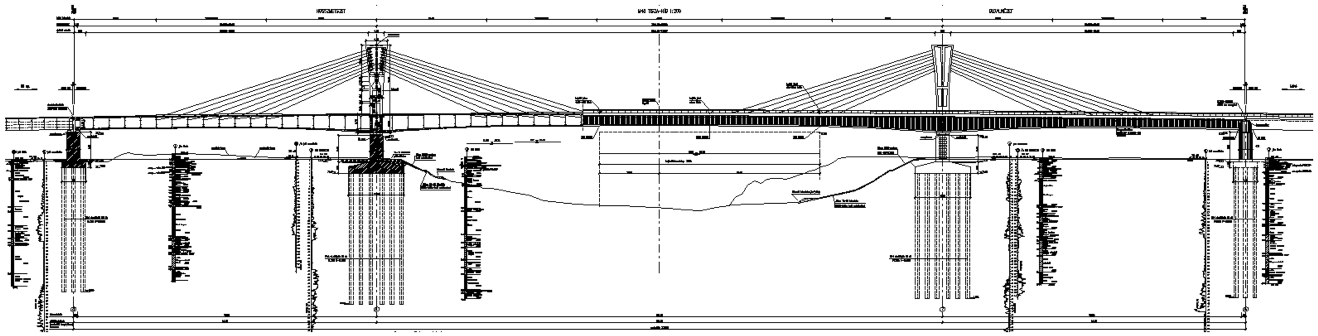
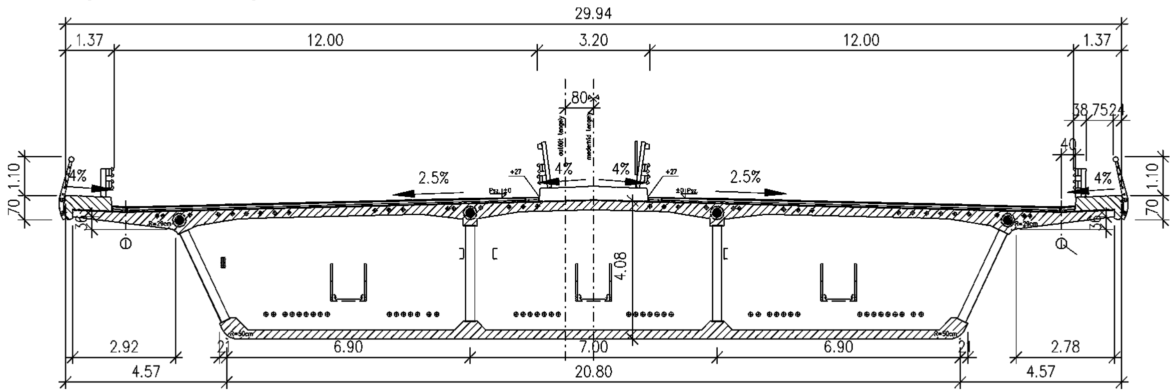
M43 motorway Tisza-bridge



M43 motorway Tisza-bridge



Spans: 96,30 + 180,00 + 96,30 m

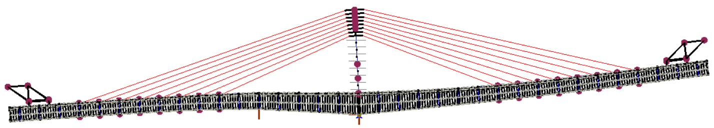


Courtesy of Pont-TERV

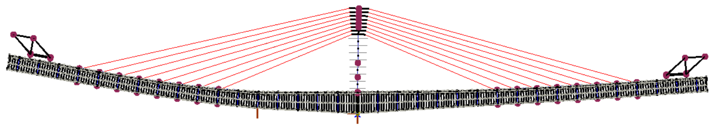
Flutter instability investigation:

- construction phase (cantilever stage)
- final phase

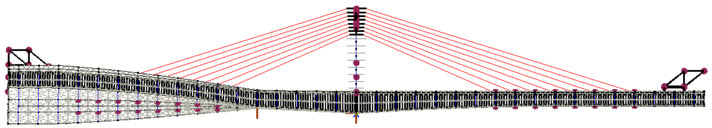
Mode shapes



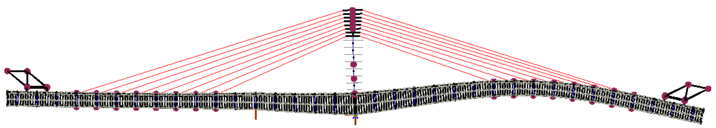
n_1=0,55 Hz



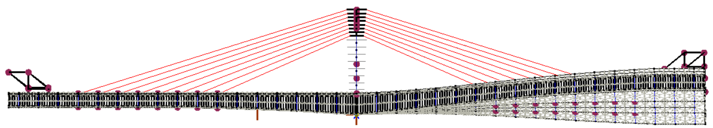
n_2=0,78 Hz



n_7=2,47 Hz



n_6=2,33 Hz

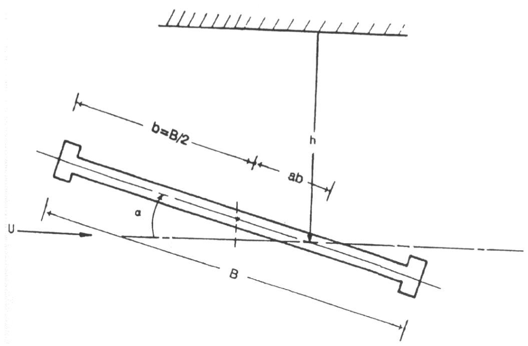


n_8=2,80 Hz

Szélhatások

- Kvázi-statikus állapot
  → erőtényező
- Dinamikus vizsgálat
  → átviteli függvény
- aeroelasztikus hatások
  (öngerjesztett erők)
  → derivatívumok

Flutter analysis



- Middle-span cross section
- 2 DOF

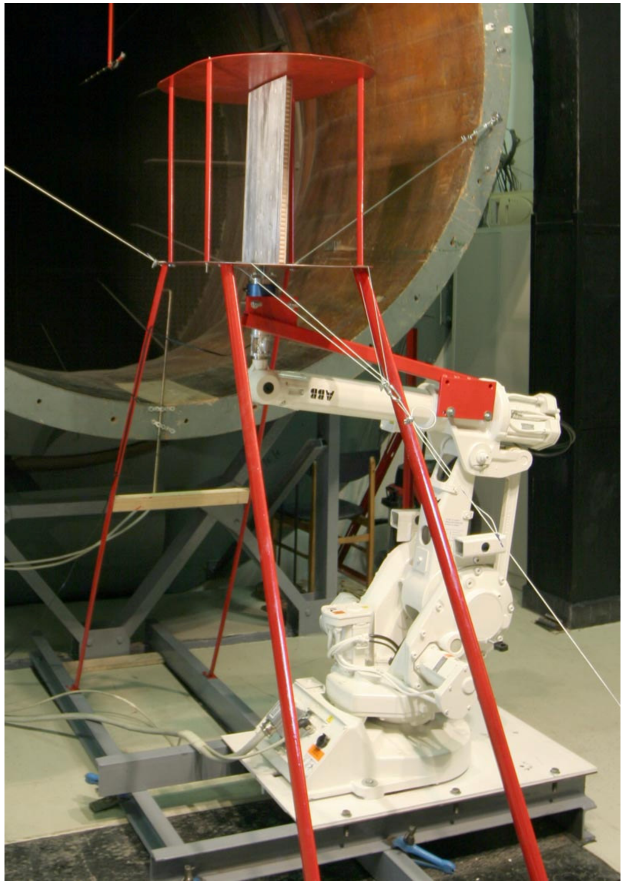
$$m\ddot{h}+c_h\dot{h}+k_h h=\frac{1}{2}\rho U^2 B\left(KH_1^*(K)\frac{\dot{h}}{U}+KH_2^*(K)\frac{B\dot{\alpha}}{U}+K^2H_3^*(K)\alpha+K^2H_4^*\frac{h}{B}\right)$$

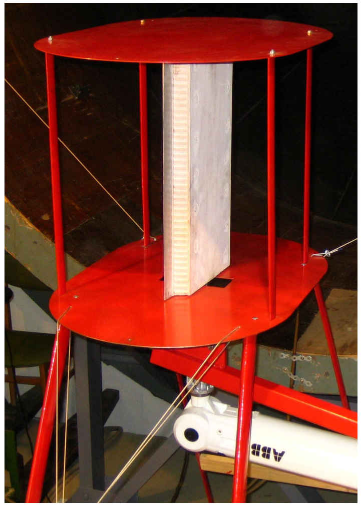
$$S\ddot{\alpha}+c_\alpha\dot{\alpha}+k_\alpha\alpha=\frac{1}{2}\rho U^2 B^2\left(KA_1^*(K)\frac{\dot{h}}{U}+KA_2^*(K)\frac{B\dot{\alpha}}{U}+K^2A_3^*(K)\alpha+K^2A_4^*\frac{h}{B}\right)$$

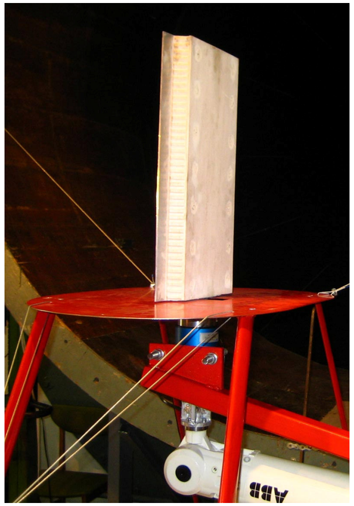
Instability criteria

- ω_{crit} , U_{crit}

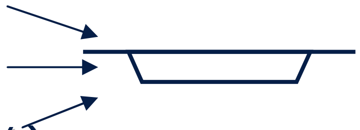
Wind tunnel investigation





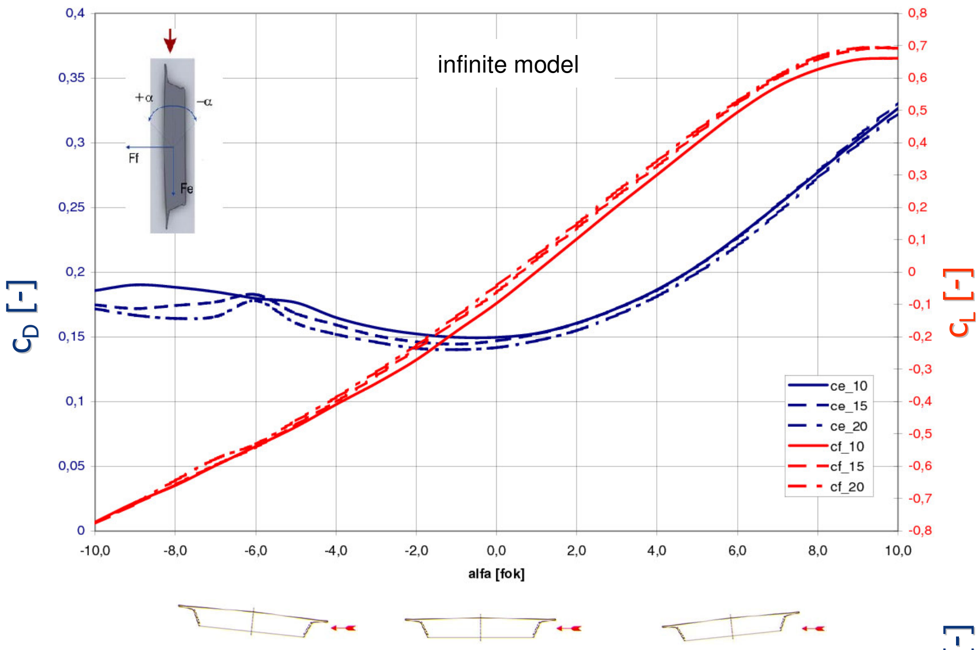


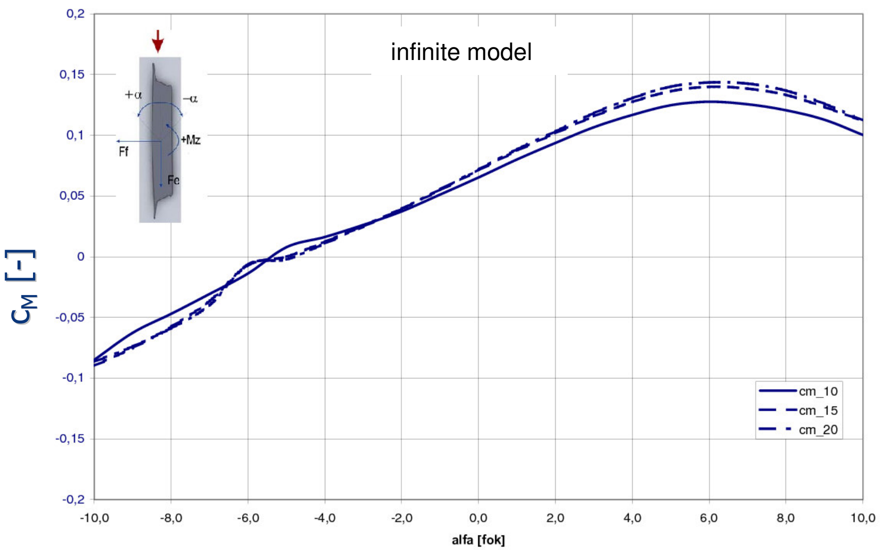
- scale 1:100
- forced 2 DOF model
- semi-finite and infinite models
- angles of attack: -6°, 0°, +6°



- small turbulent intensity ($I_u \leq 0{,}5\%$)
- separation of inertial forces, „no-wind” measures

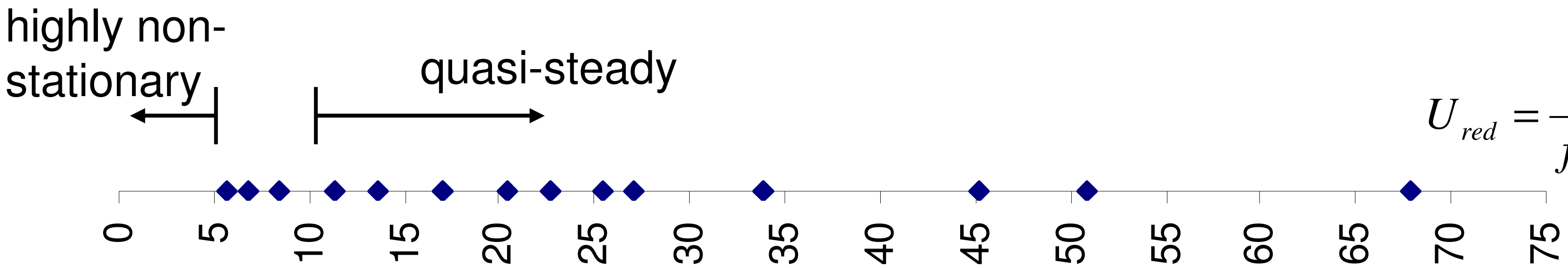
Force coefficients





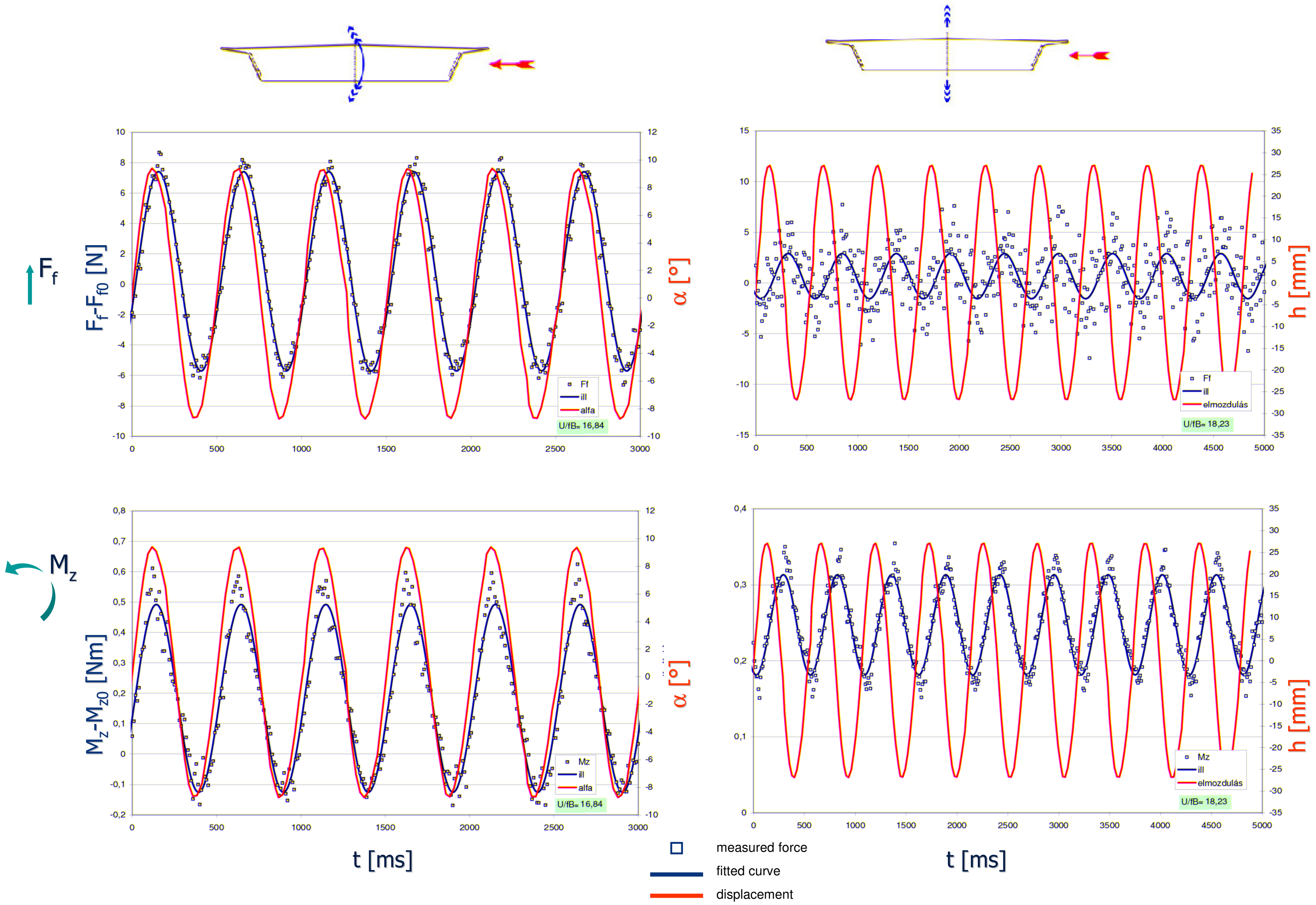
Wind tunnel investigation

- motion frequency f= 1,0; 1,5; 2,0; 2,5; 3,0 Hz
- wind speed U=5; 10; 15; 20 m/s
- model width B=295 mm (scale 1:100)
- measuring by 6 dynamometers
- oscillation $\alpha=0° \pm 10°$ +6,-6 ± 4°
  h= ± 30mm
- sampling rate 100 Hz

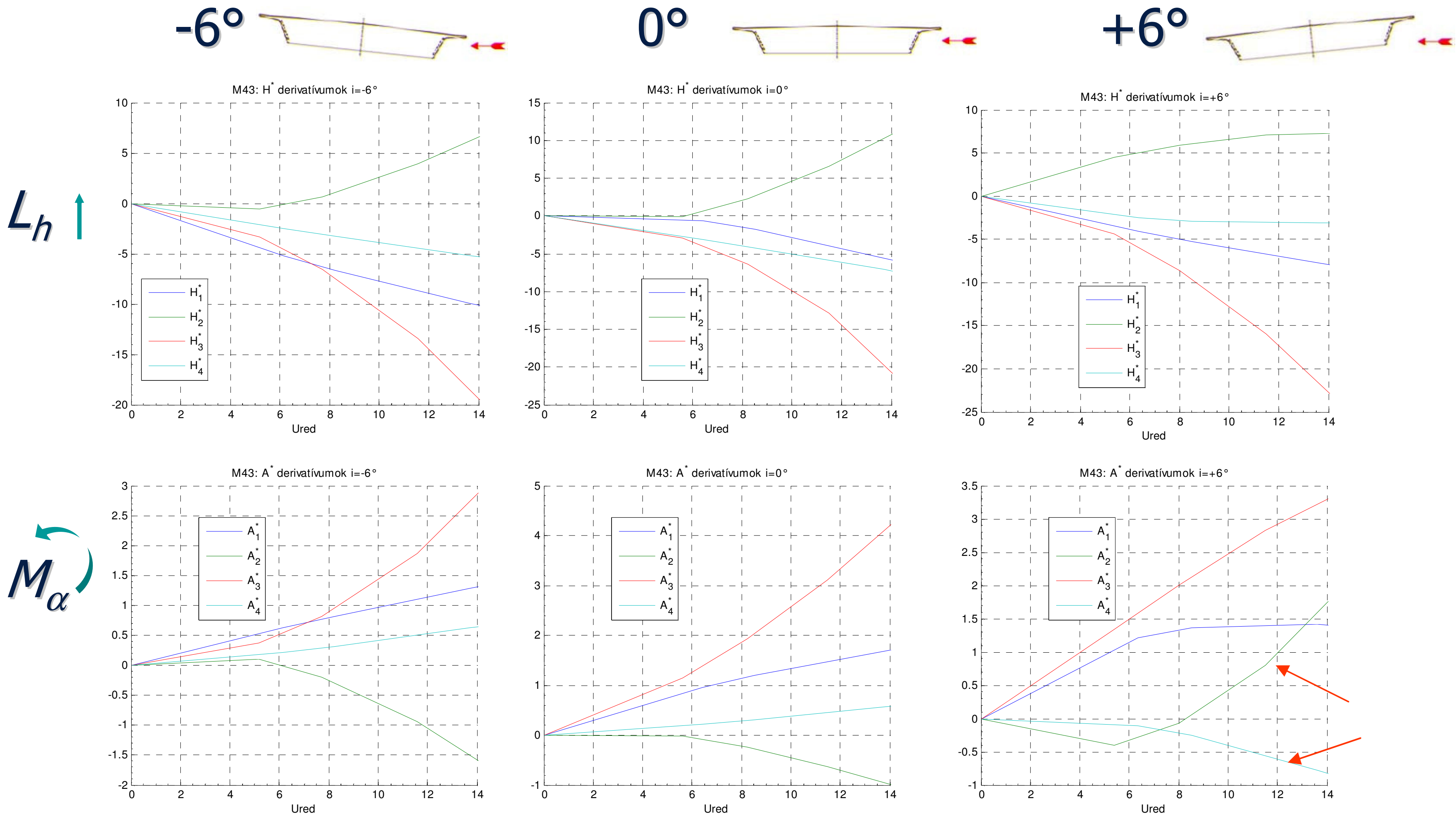


$$U_{red} = \frac{U}{f\,B}$$

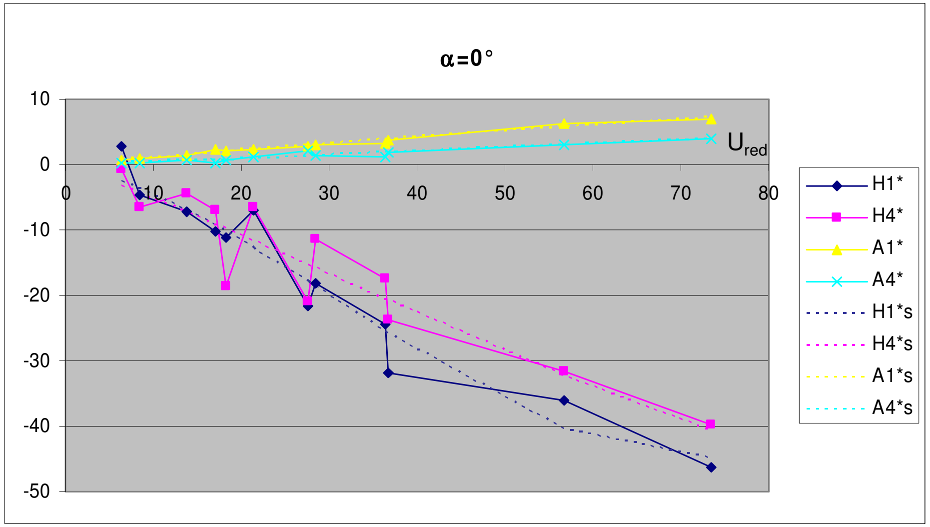
α=0 f=2 Hz U=10 m/s

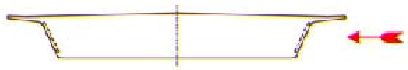


Flutter derivatives

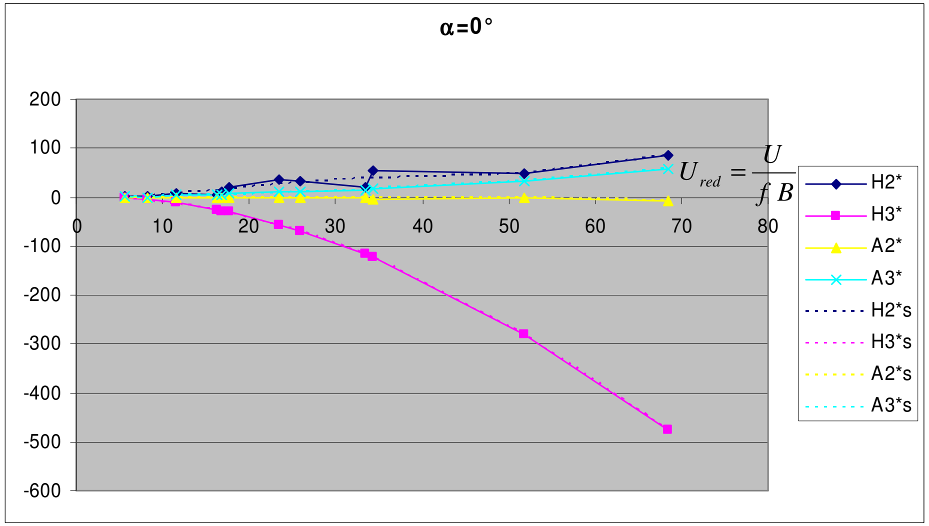


Flutter derivatives





Polynomial fitting of 3rd order



$$L_h = \frac{1}{2}\rho U^2 B\left(KH_1^*(K)\frac{\dot{h}}{U} + KH_2^*(K)\frac{B\dot{\alpha}}{U} + K^2H_3^*(K)\alpha + K^2H_4^*\frac{h}{B}\right)$$

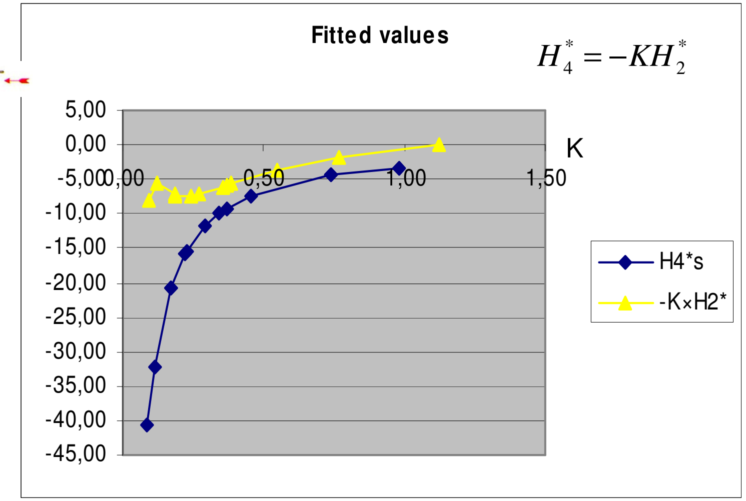
$$M_\alpha = \frac{1}{2}\rho U^2 B^2\left(KA_1^*(K)\frac{\dot{h}}{U} + KA_2^*(K)\frac{B\dot{\alpha}}{U} + K^2A_3^*(K)\alpha + K^2A_4^*\frac{h}{B}\right)$$

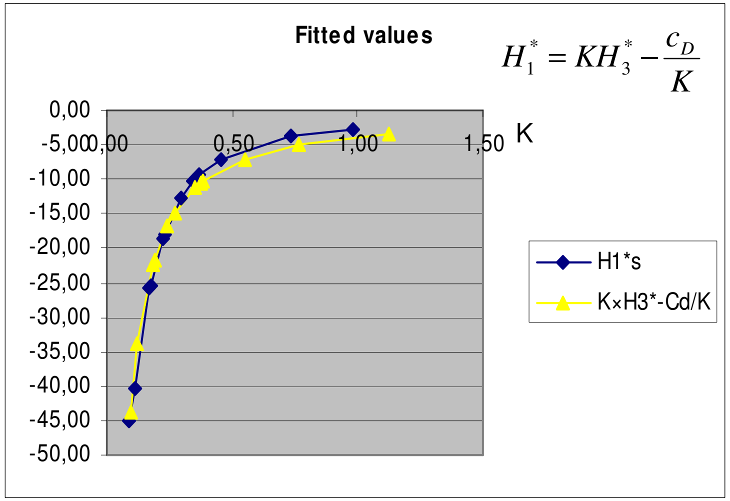
$$U_{red} = \frac{U}{f\,B} \qquad K = \frac{2\pi f\,B}{U} = \frac{2\pi}{U_{red}}$$

Polynomial fitting of 4th order

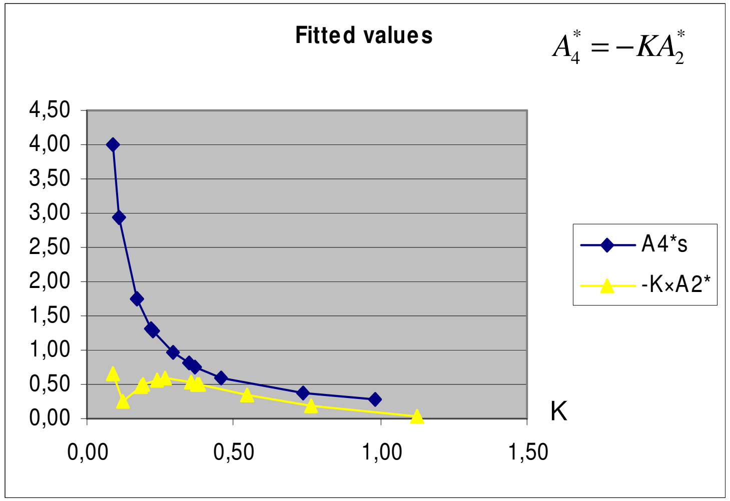
Verification

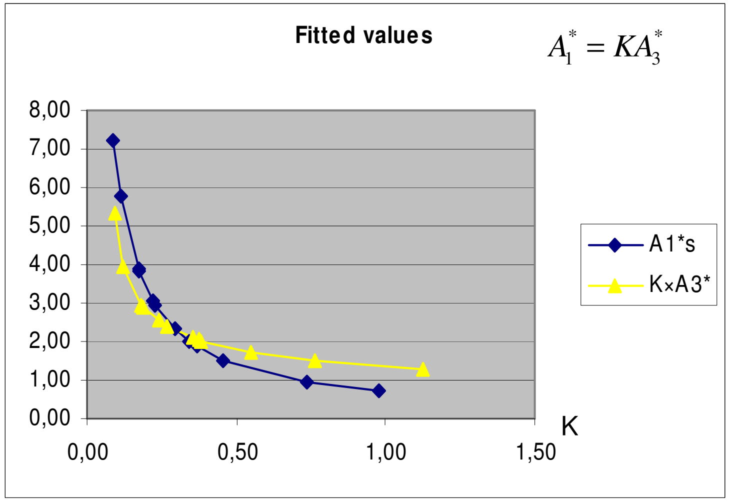
a=0°





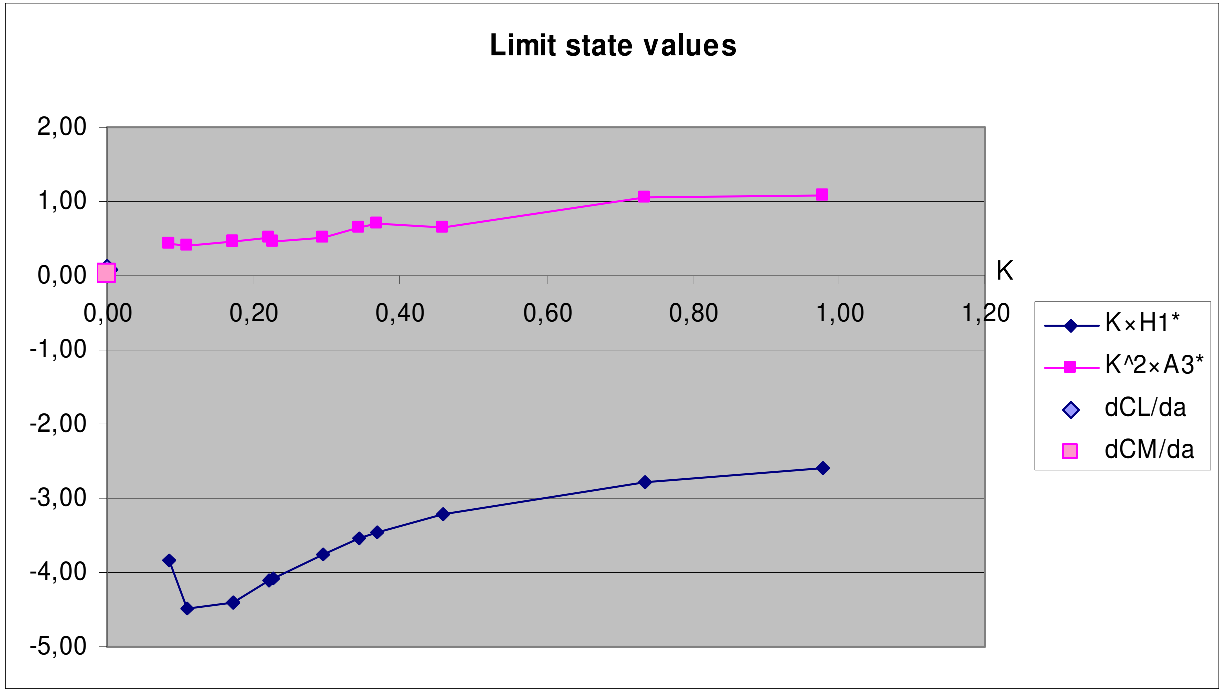
$$K = \frac{2\pi}{U_{red}}$$





Force coeffs. - derivatives

a=0°

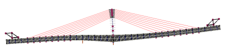
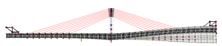
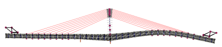
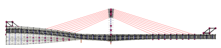


$$KH_1^* \xrightarrow{K \longrightarrow 0} \frac{dc_L}{d\alpha}$$

$$K^2 A_3^* \xrightarrow{K \longrightarrow 0} \frac{dc_M}{d\alpha}$$

Flutter condition

Damping factor: 3,5%

α [°]	f_B [1/s]	f_T [1/s]	Φ	$U_{red,crit}$ [-]	ω_{crit} [1/s]	U_{0crit} [m/s]
+6				0,59	3,47 *	12,87*
0	0,55	2,80	1,00	2,20	3,46 B	**47,9**
-6				0,62	14,40 T	**56,12**
+6				0,04	15,28 *	3,84*
0	2,33	2,47	0,90	2,45	15,30 B	226
-6				4,85	14,30 T	435

Affinity in the cross-terms: $\Phi A_1^*, \Phi A_4^*, \Phi H_2^*, \Phi H_3^*$

Max. wind speed

- Lack of wind map for Hungary → middle-Germany
- 10 min average wind velocity
- 20-30 oscillations for instability → duration of 5 sec
- p=0,02 annual probability of exceedence
- maximum wind speed 35,5 m/s
- safety against flutter instability $(U_{crit}/U_{max})^2 = (47{,}9/35{,}5)^2 =$ **1,82**

Conclusion

- Enough safety against flutter instability
- More measures in the highly non-stationary domain, at low reduced velocities
- Acceptable set-up, but a special test rig could be designed
- More verification during the wind tunnel test

Thank you for your kind attention

Acknowledgements

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