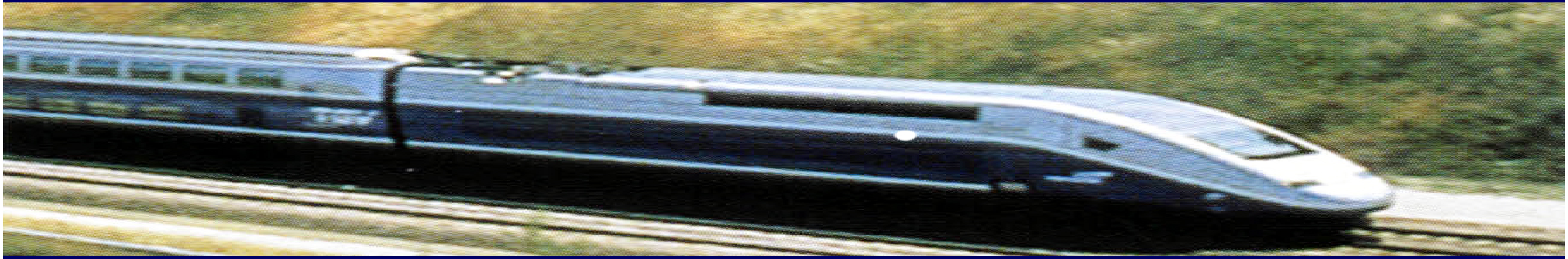
UNC 2008



Dynamics of Bridges Under Moving Loads

(Past, Present and Future)

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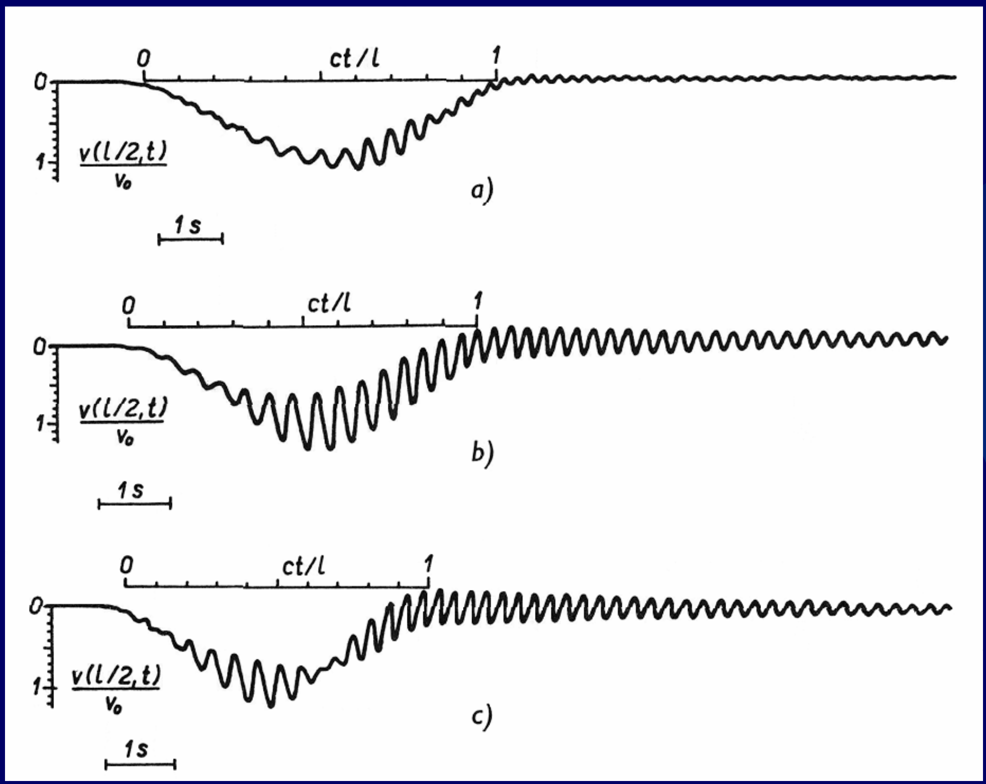
Contents:

1. Introduction

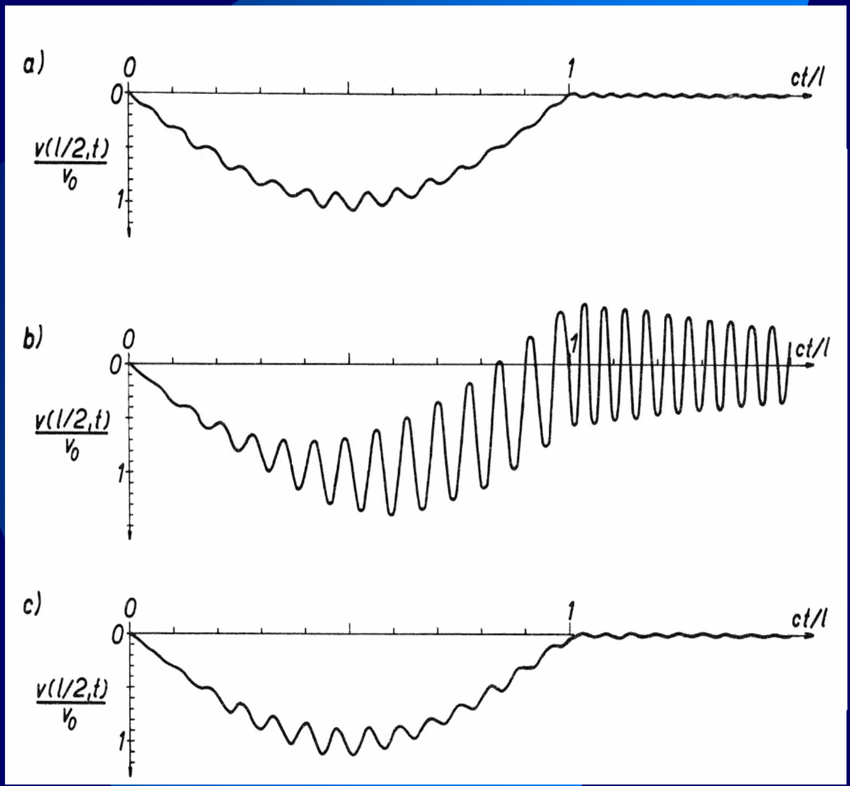
- First railway bridges in England
- First experimental and theoretical papers by Stokes (1849) and Willis (1849)
- Important progress by Timoshenko, Inglis and Kloušek

steam locomotives $F(t) = F_0 \sin \Omega t$

Steel bridge, l = 56.56 m



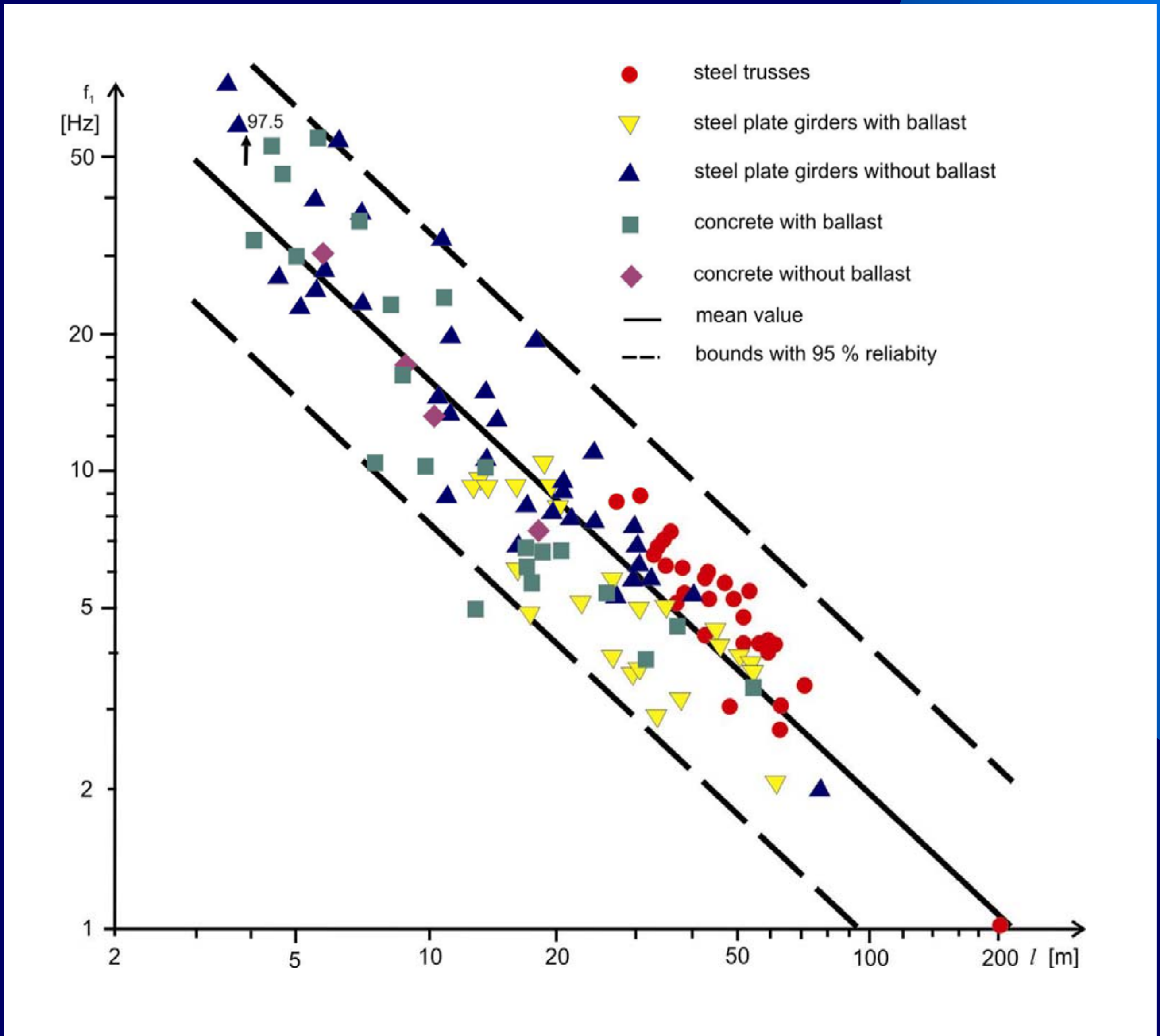
experiments



theory

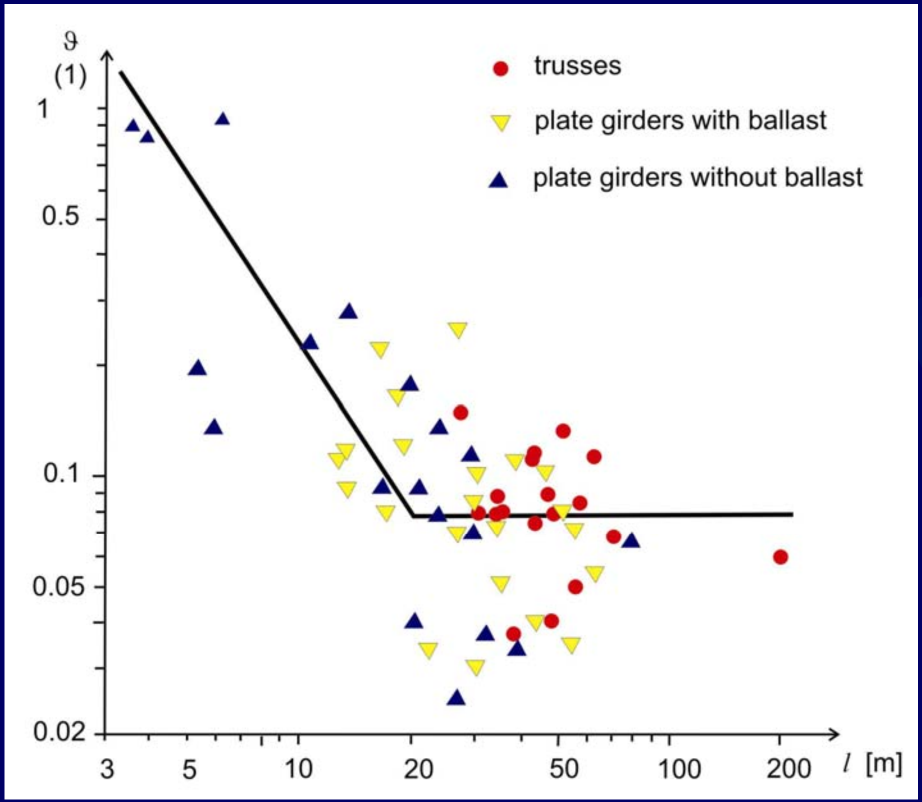
2. Past

- International investigations by ORE, ERRI and OSŽD
- Dynamic characteristics of bridges

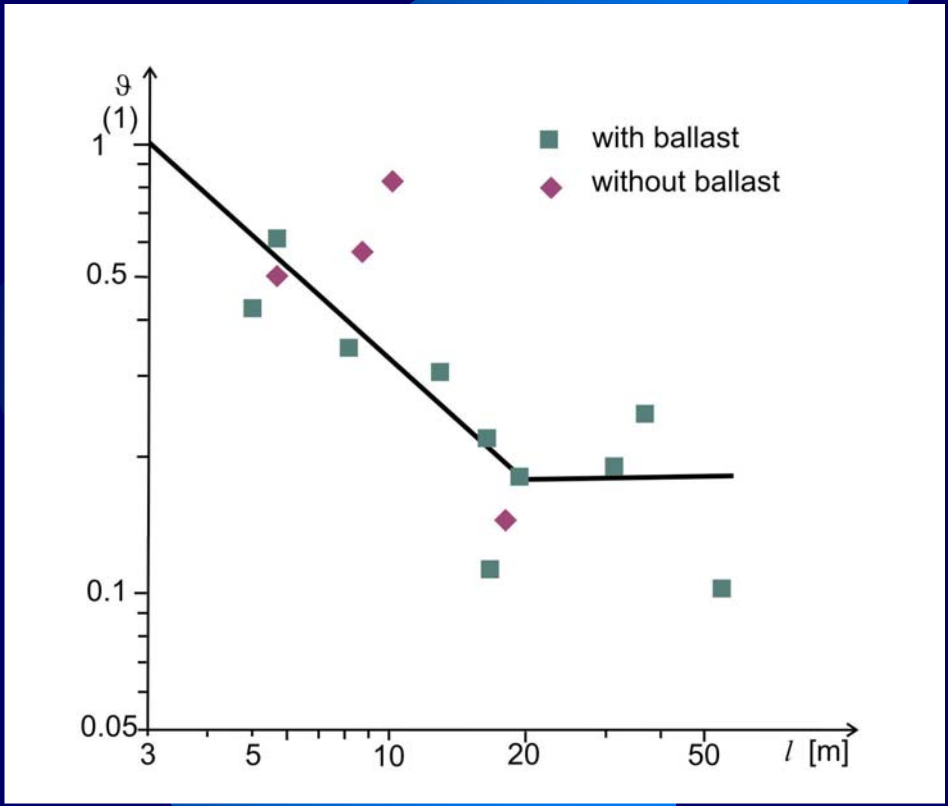


First natural frequencies of bridges

Logarithmic decrements of damping

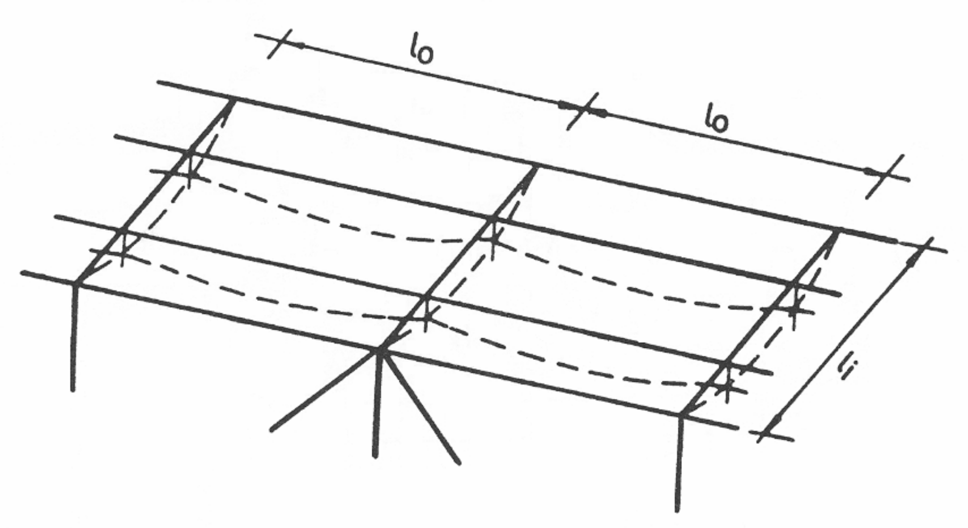


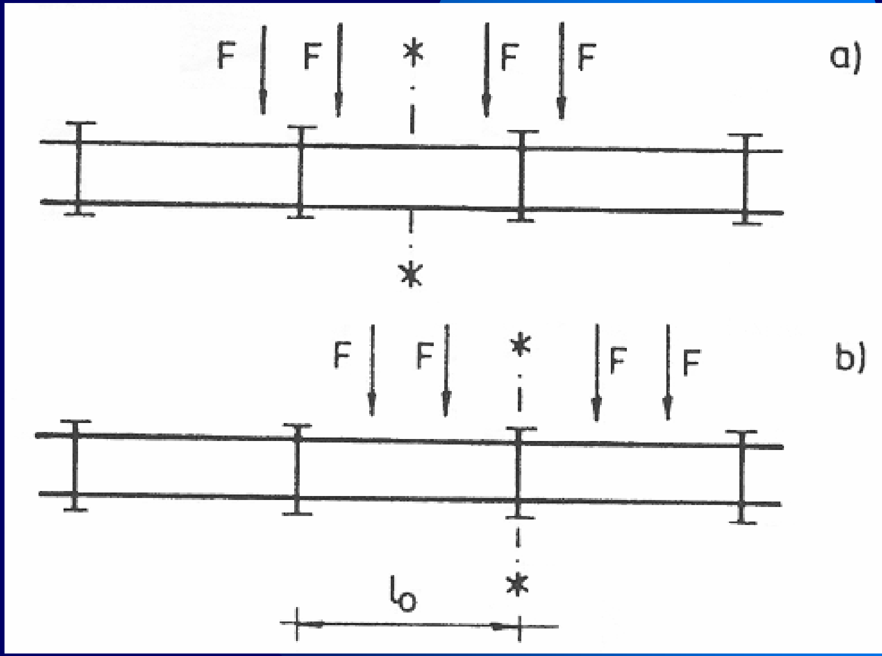
steel



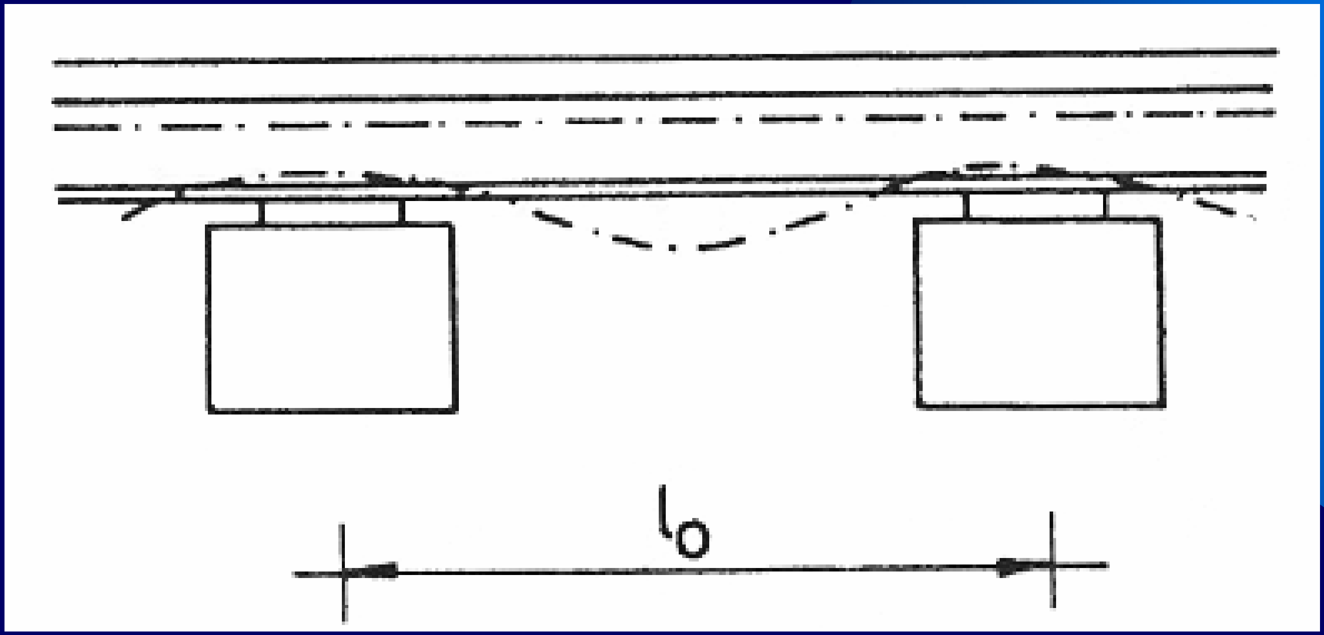
concrete

Cross girder effect

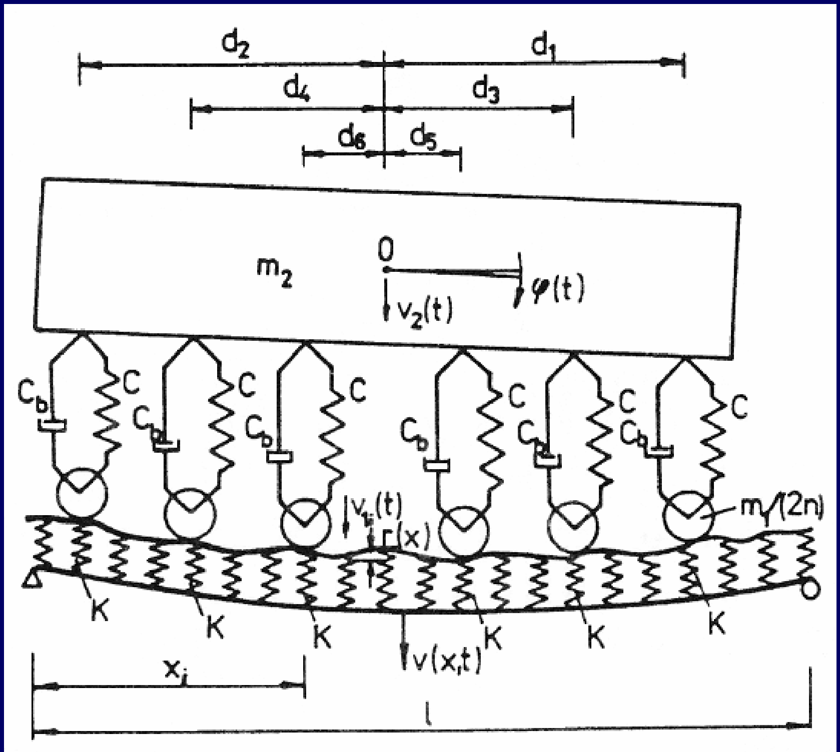




Sleeper effect



Theoretical model



$$-I\frac{\mathrm{d}^2\overline{\varphi}(t)}{\mathrm{d}t^2}+\sum_{i=1}^{2}(-1)^i D_i\left[Z_i(t)+Z_{bi}(t)\right]=0,$$

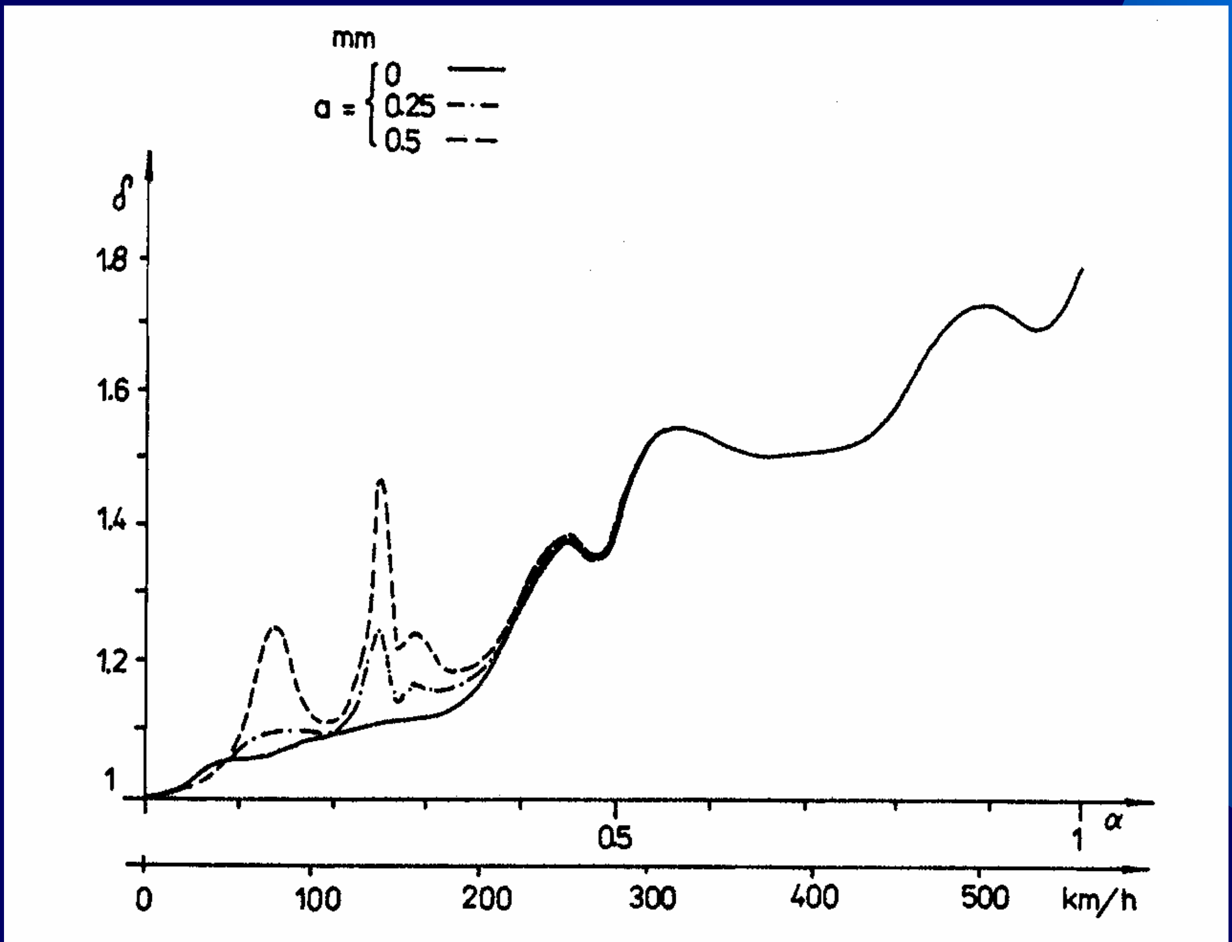
$$-m_3\frac{\mathrm{d}^2 v_3(t)}{\mathrm{d}t^2}-\sum_{i=1}^{2}\left[Z_i(t)+Z_{bi}(t)\right]=0$$

$$P_i+P_{3i}-m_i\frac{\mathrm{d}^2 v_i(t)}{\mathrm{d}t^2}+Z_i(t)+$$

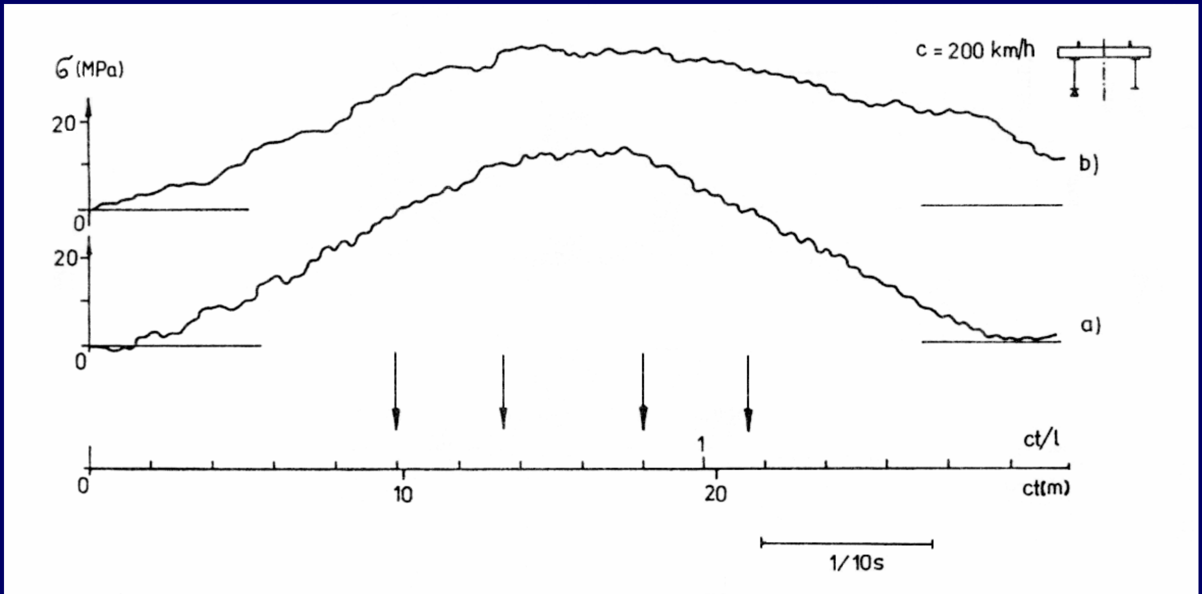
$$+Z_{bi}(t)-\overline{R}_i(t)=0;\quad i=1,2,$$

$$EJ\frac{\partial^4 v(x,t)}{\partial x^4}+\mu\frac{\partial^2 v(x,t)}{\partial t^2}+2\mu\omega_b\frac{\partial v(x,t)}{\partial t}=\sum_{i=1}^{2}\overline{\varepsilon}_i\overline{\delta}(x-x_i)\overline{R}_i(t).$$

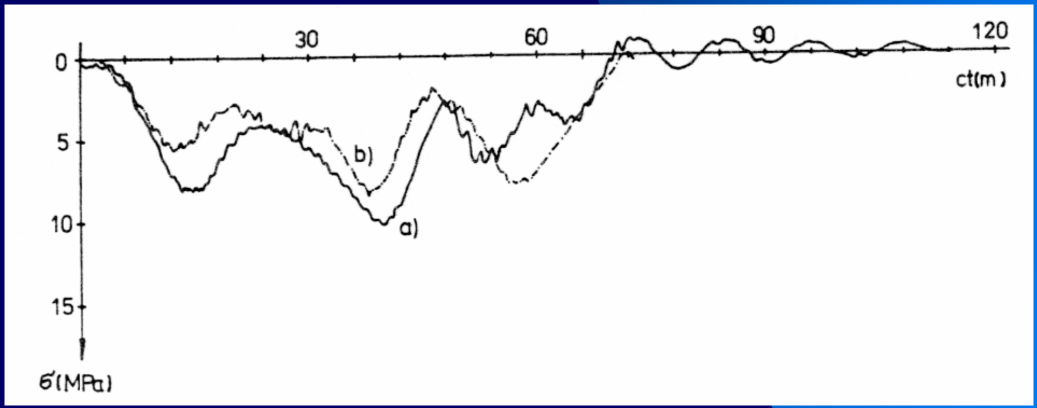
Effect of the speed



ORE experiments (DB, SNCF)



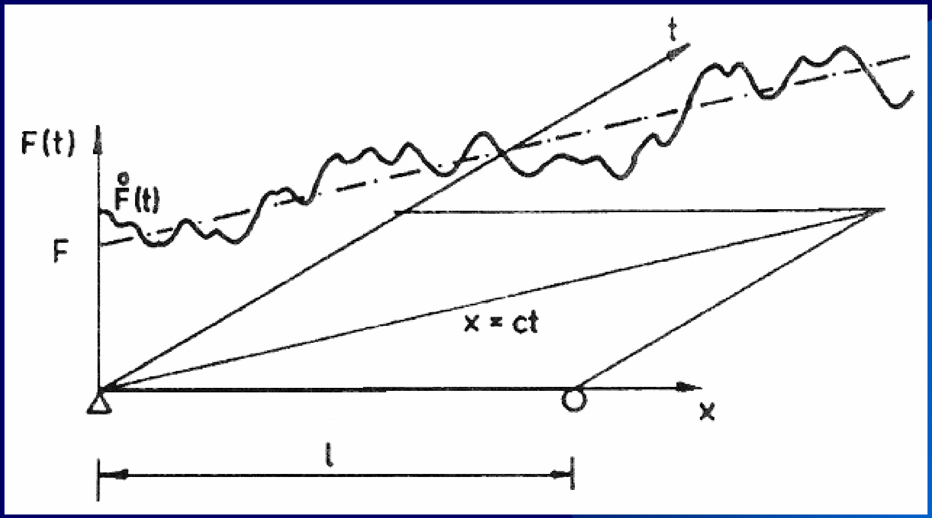
DB steel bridge, l = 19.6 m, 200 km/h



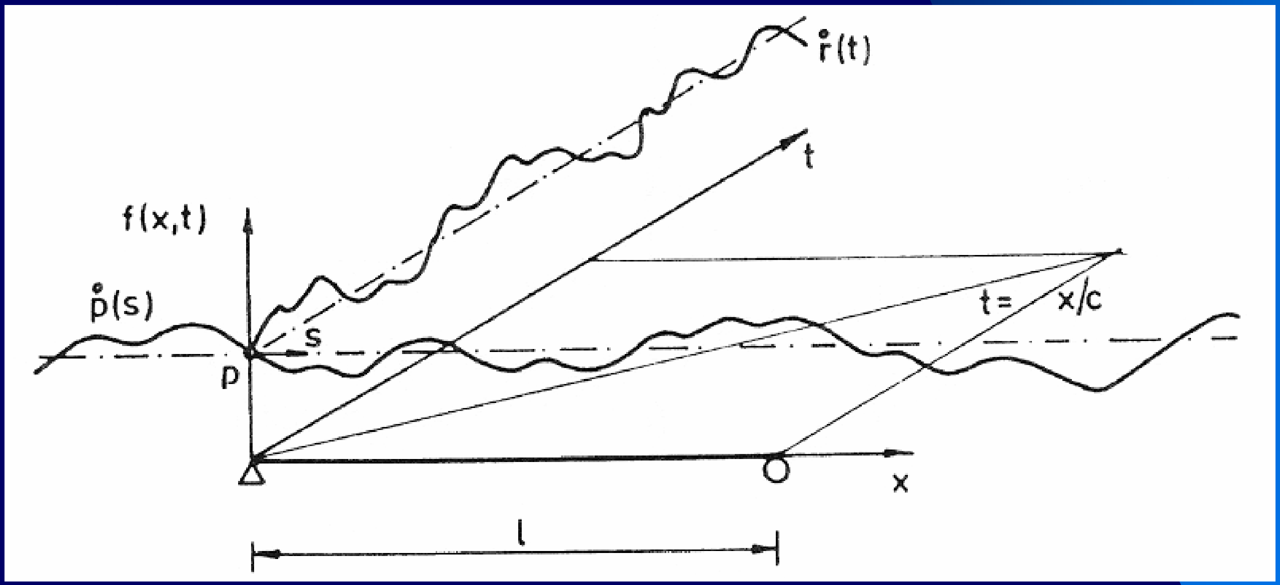
SNCF composite bridge, l = 26.4 m, 241 km/h

Stochastic concept

$$F(t) = F + \varepsilon \dot{F}(t),$$

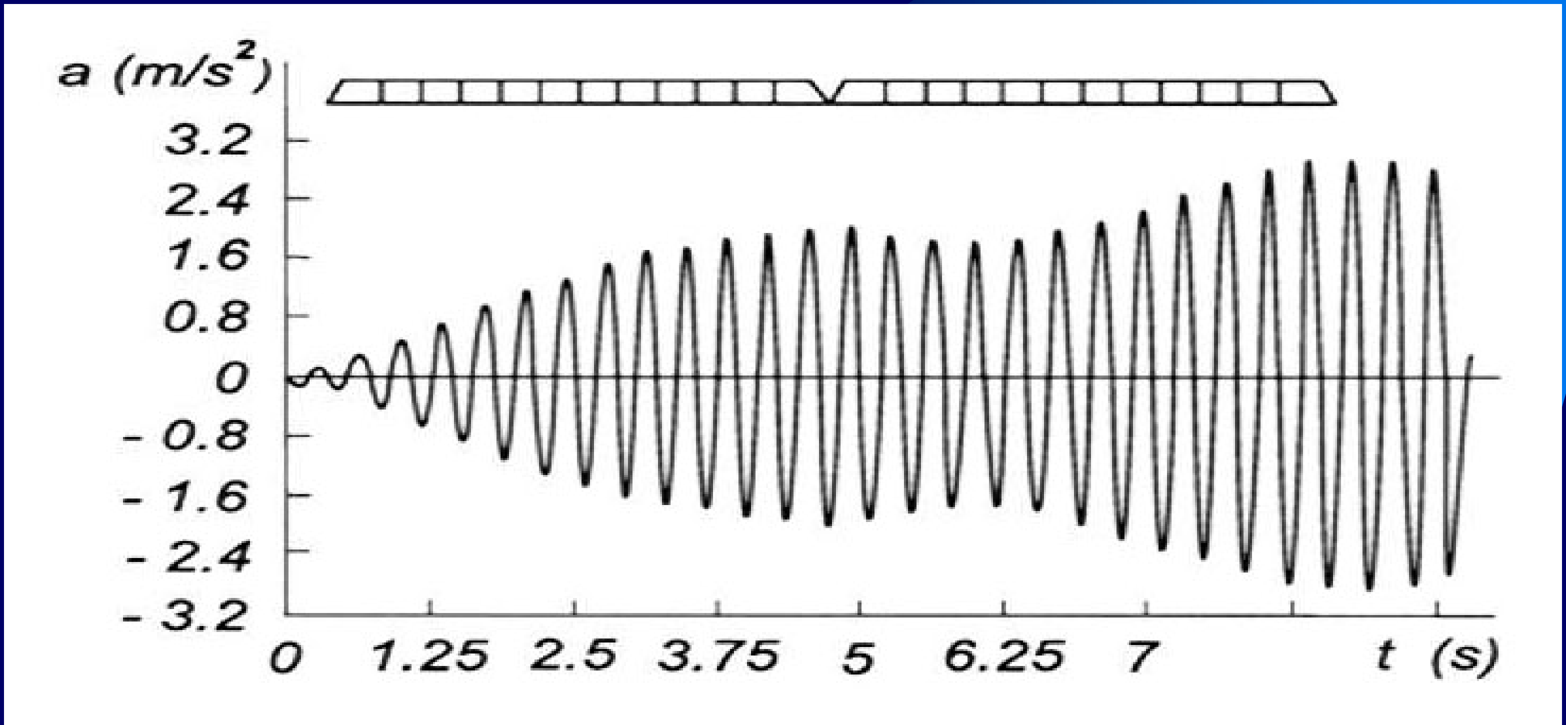


$$f(x,t) = \left[p + \varepsilon \dot{p}(s) \right] \left[1 + \dot{r}(t) \right]$$



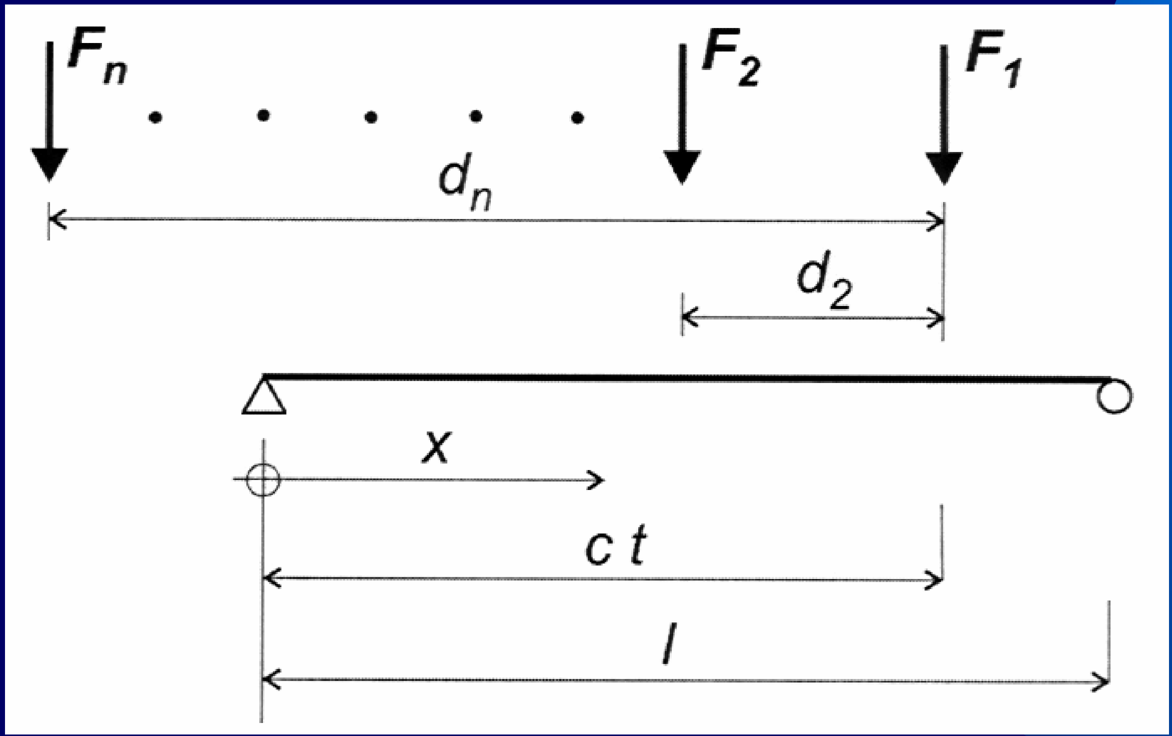
3. Present

Resonant vibration

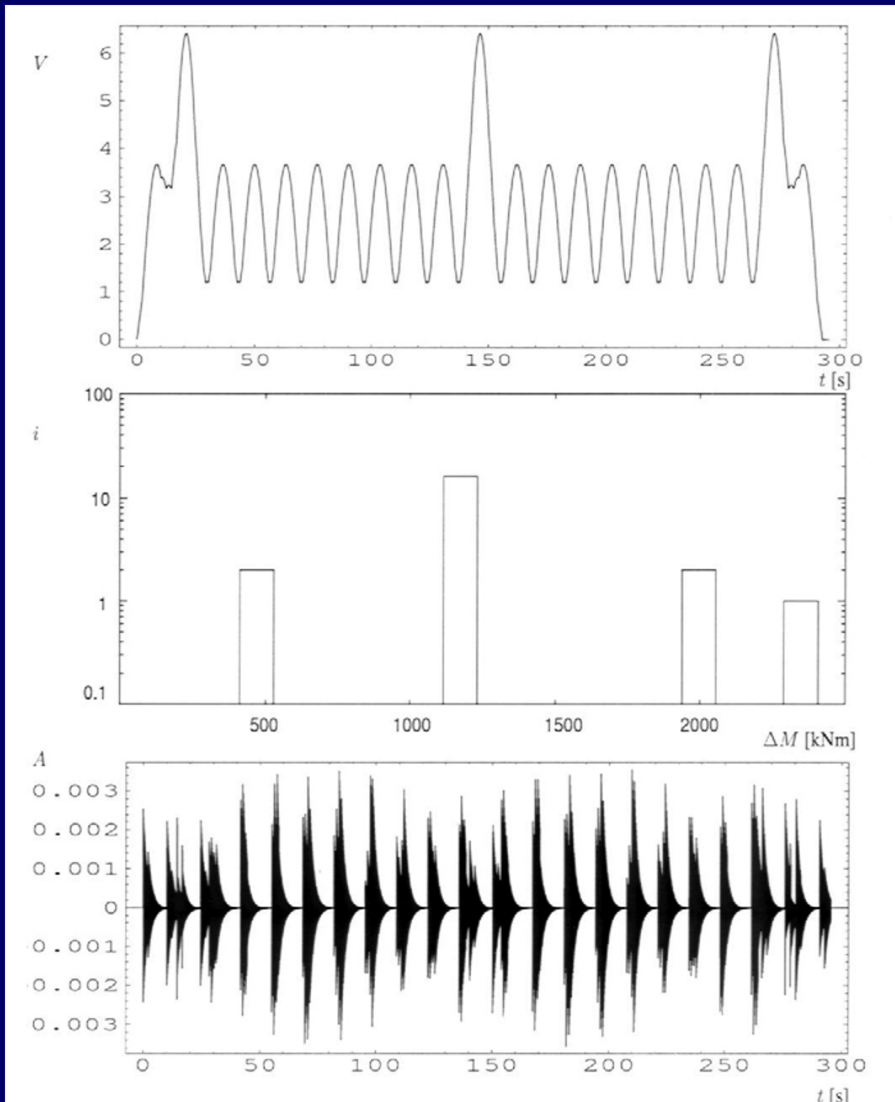


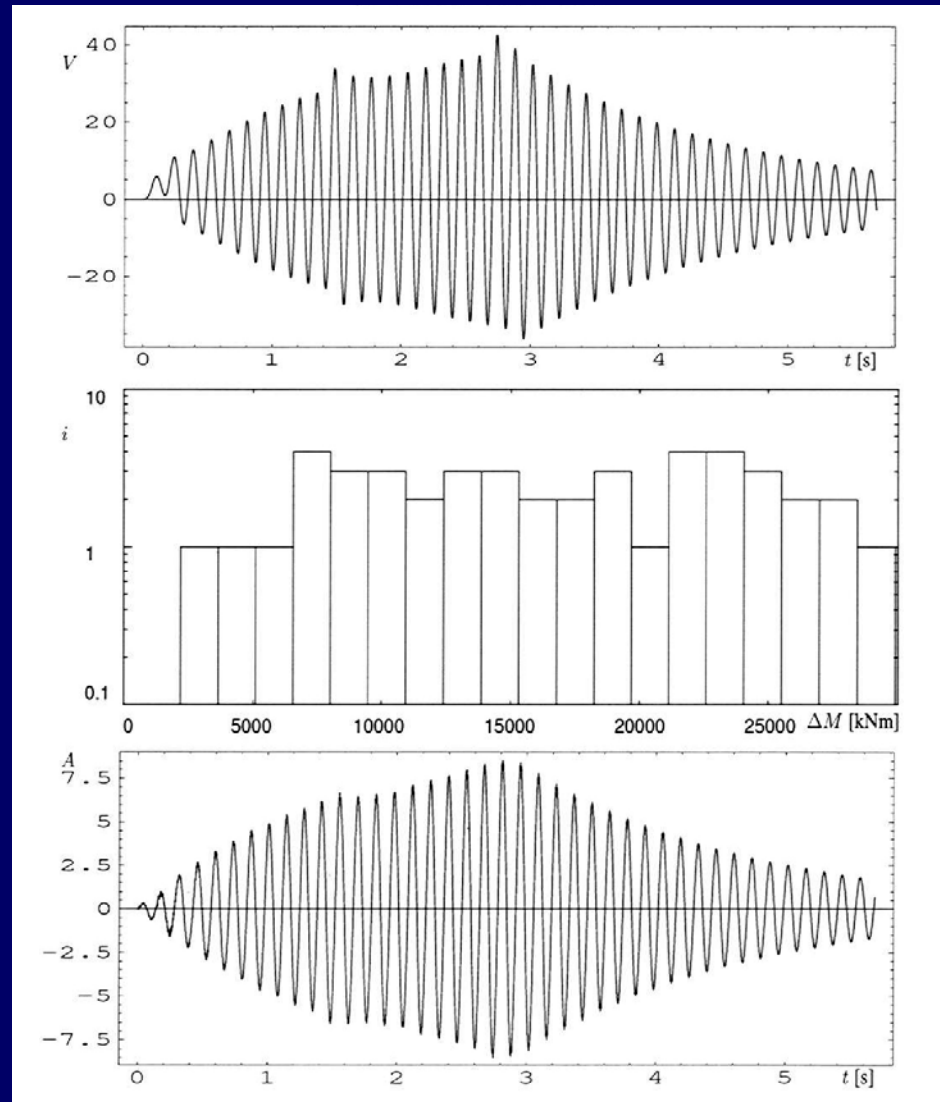
SNCF bridge, l = 38 m, TGV, 192 km/h

Theoretical idealization

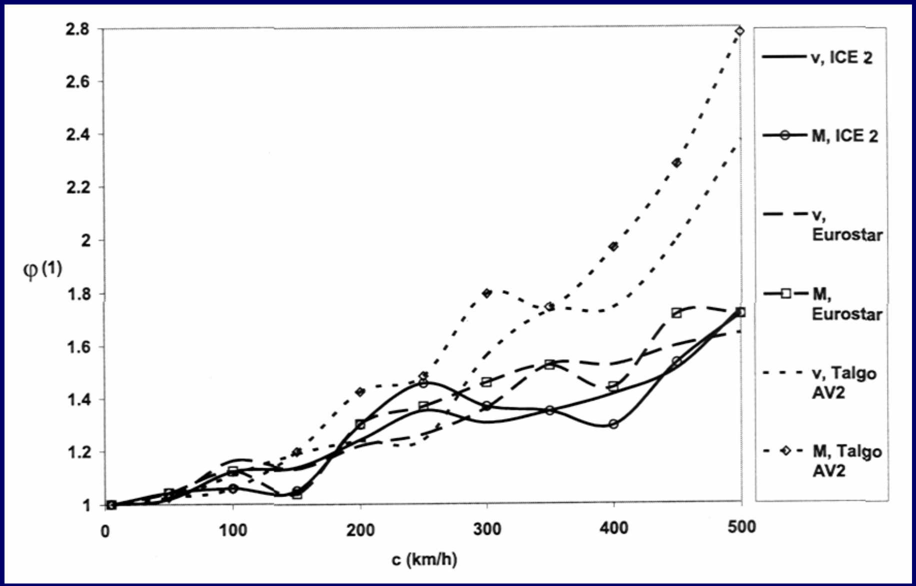


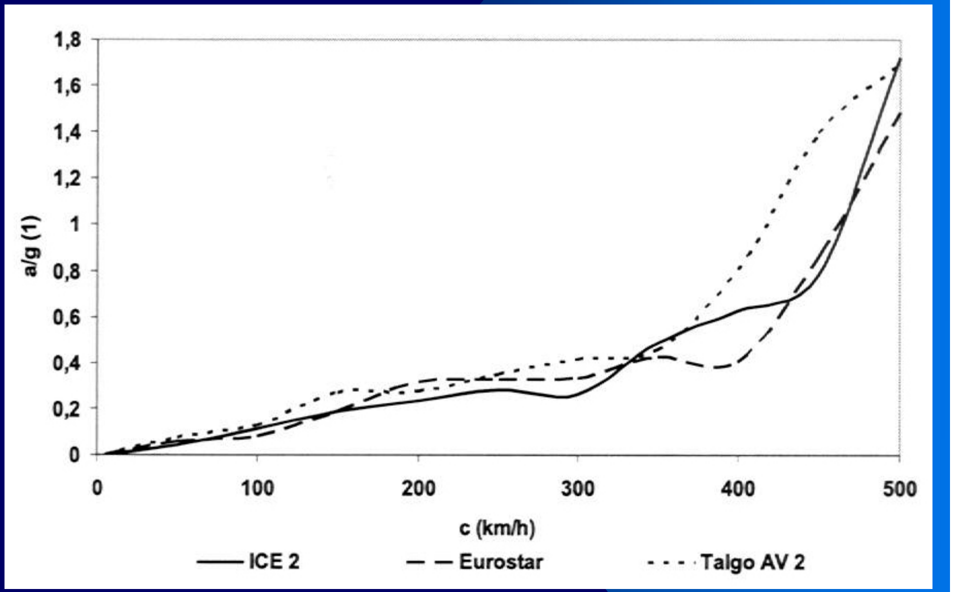
$$EI\frac{\partial^4 v(x,t)}{\partial x^4}+\mu\frac{\partial^2 v(x,t)}{\partial t^2}+2\mu\omega_d\frac{\partial v(x,t)}{\partial t}=\sum_{n=1}^{N}\varepsilon_n(t)\delta(x-x_n)F_n$$





Vibration of a steel bridge at low and resonant speed





Effect of the speed on deflection and bending moments

steel bridge, l = 5 m

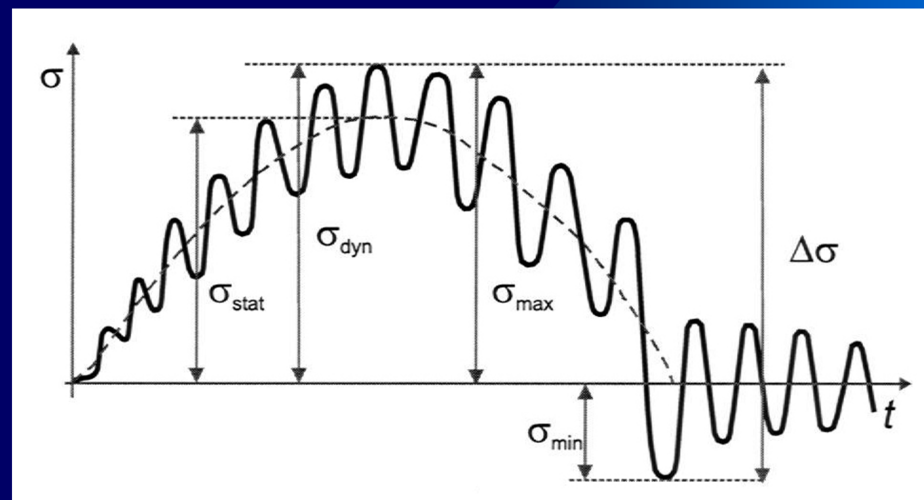
Effect of the speed on vertical acceleration

concrete bridge, l = 10 m

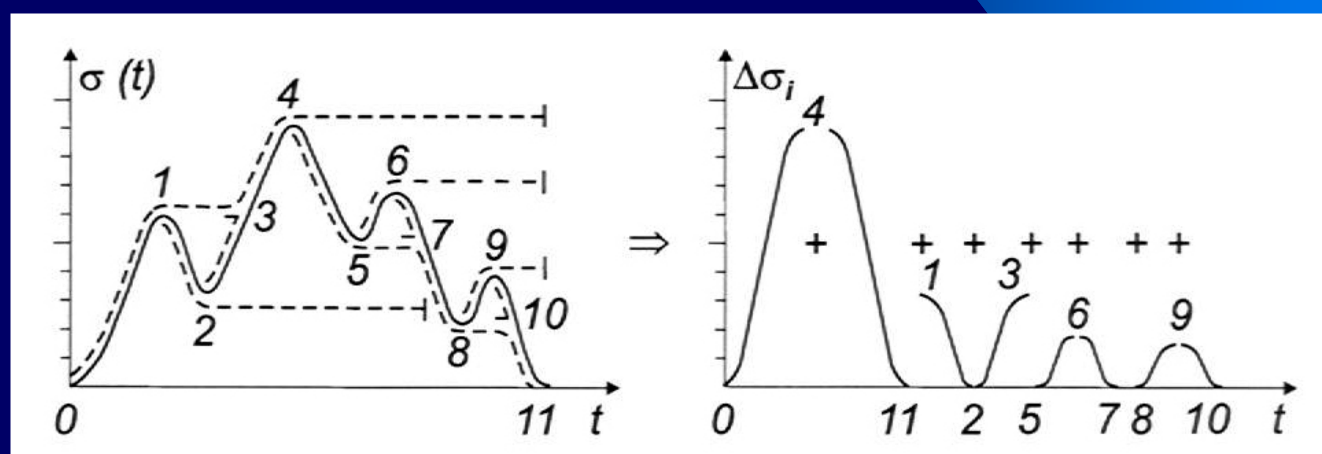
Stress spectra

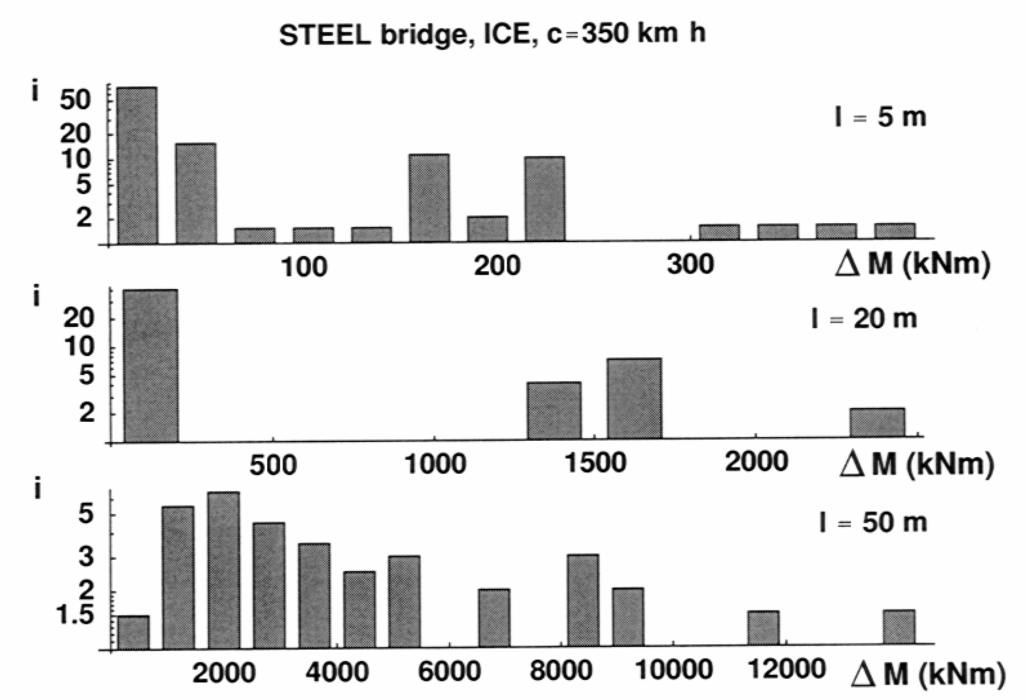
stress range

$$\Delta\sigma = \sigma_{\max} - \sigma_{\min}$$

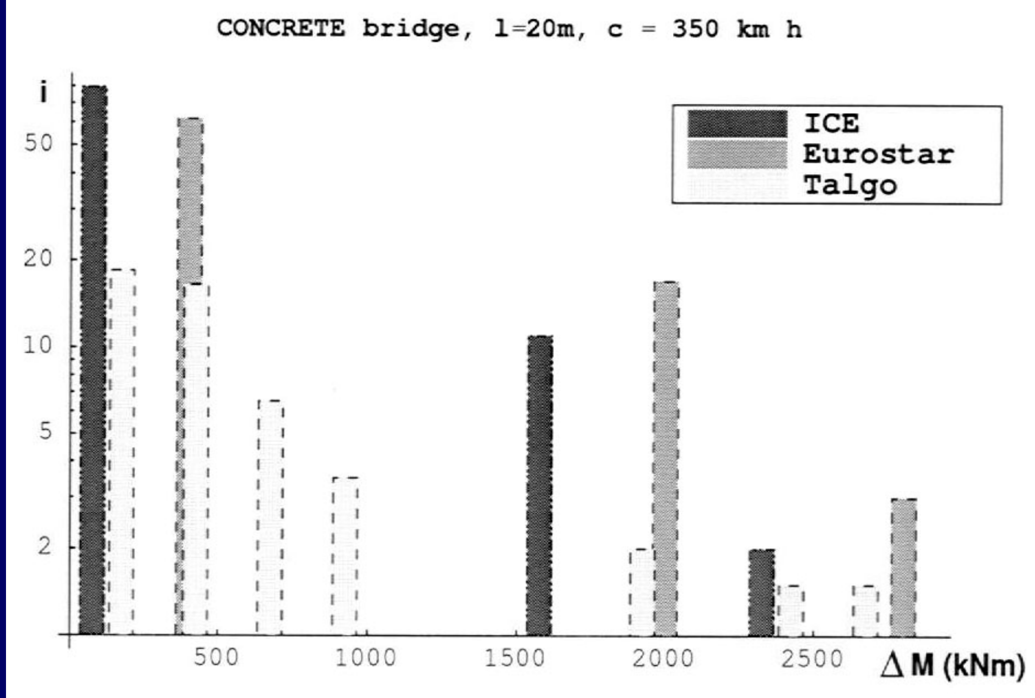


rain-flow





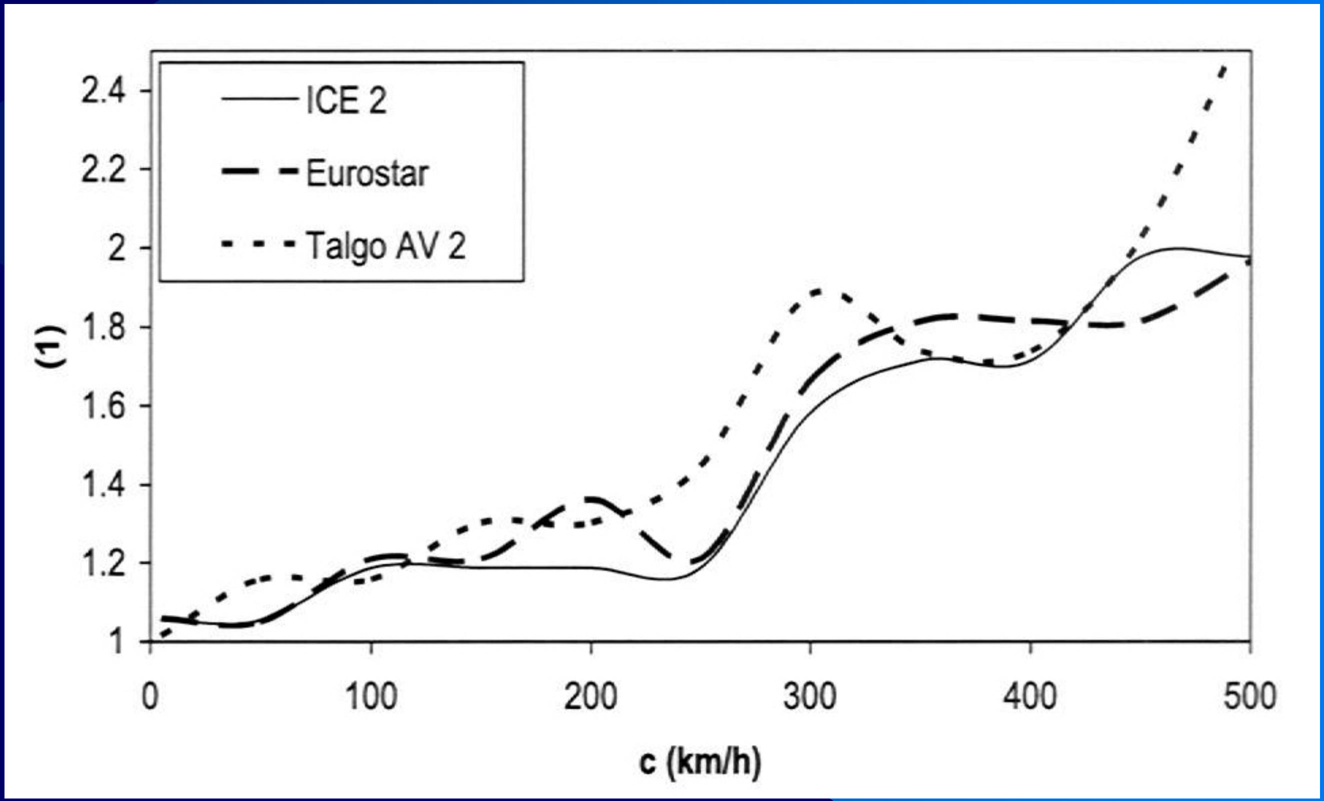
Stress spectra for steel and concrete bridges



Stress ranges

Effect of the speed

concrete bridge, l = 5 m

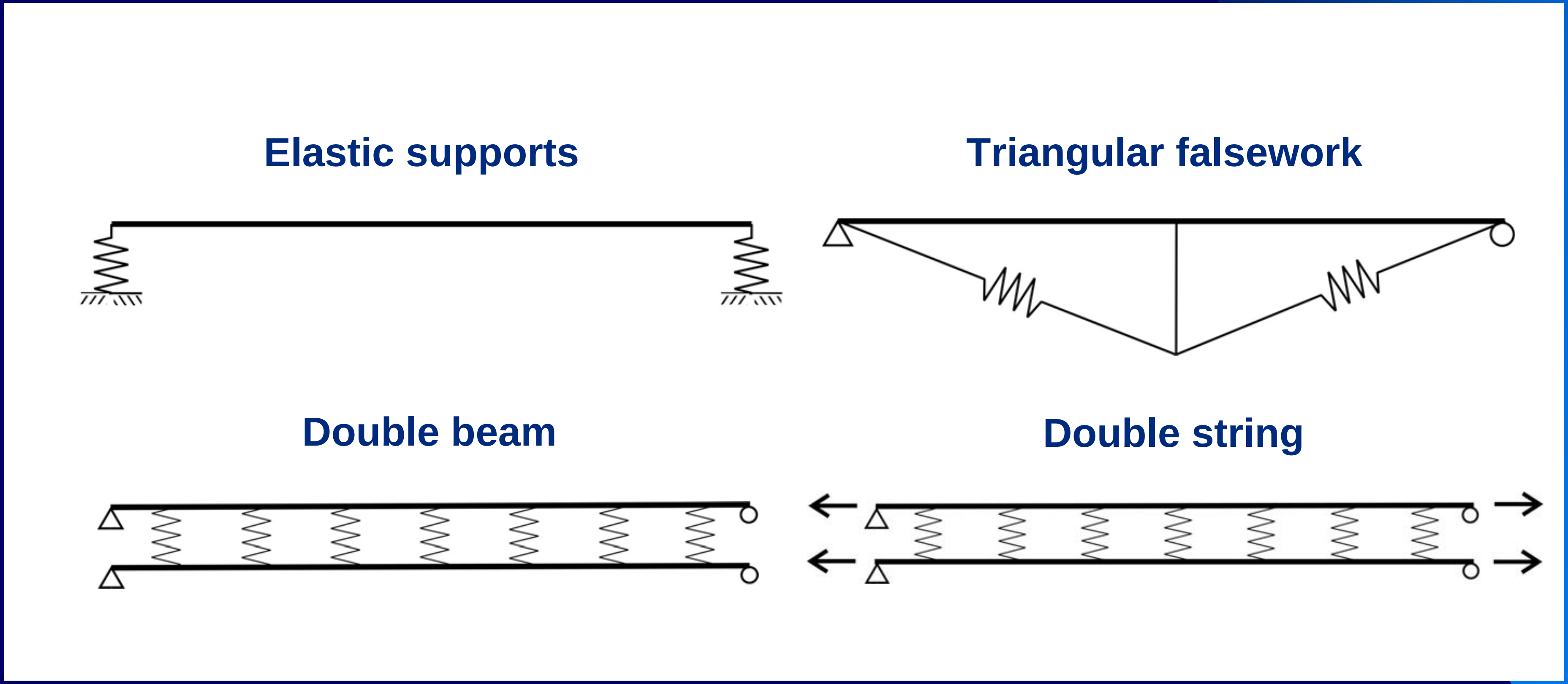


Critical speeds

$$c_{cr} = \frac{df_j}{k}, \qquad j = 1, 2, 3, \ldots, \qquad k = 1, 2, 3, \ldots, 1/2, 1/3, 1/4, \ldots$$

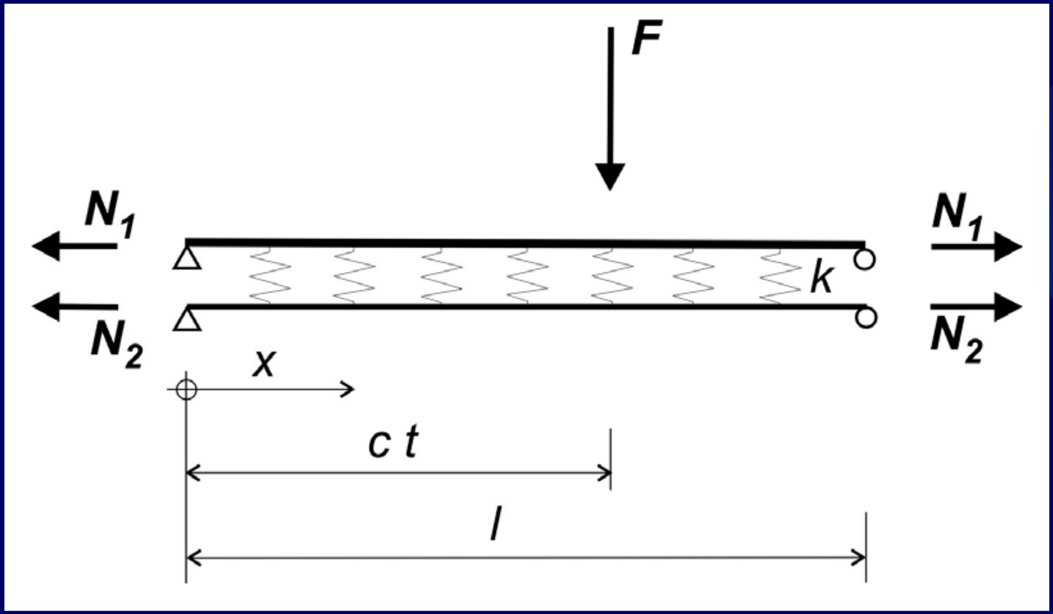
$$c_{cr} = \frac{2lf_j}{j}, \qquad j = 1, 2, 3, \ldots$$

4. Future



Elastic supports
Triangular falsework
Double beam
Double string

Beam coupled with a string



$$EI\frac{\partial^4 v_1(x,t)}{\partial x^4} - N_1\frac{\partial^2 v_1(x,t)}{\partial x^2} + \mu_1\frac{\partial^2 v_1(x,t)}{\partial t^2} + k\left[v_1(x,t) - v_2(x,t)\right] =$$
$$= \varepsilon(t)\,\delta(x - ct)\,F$$

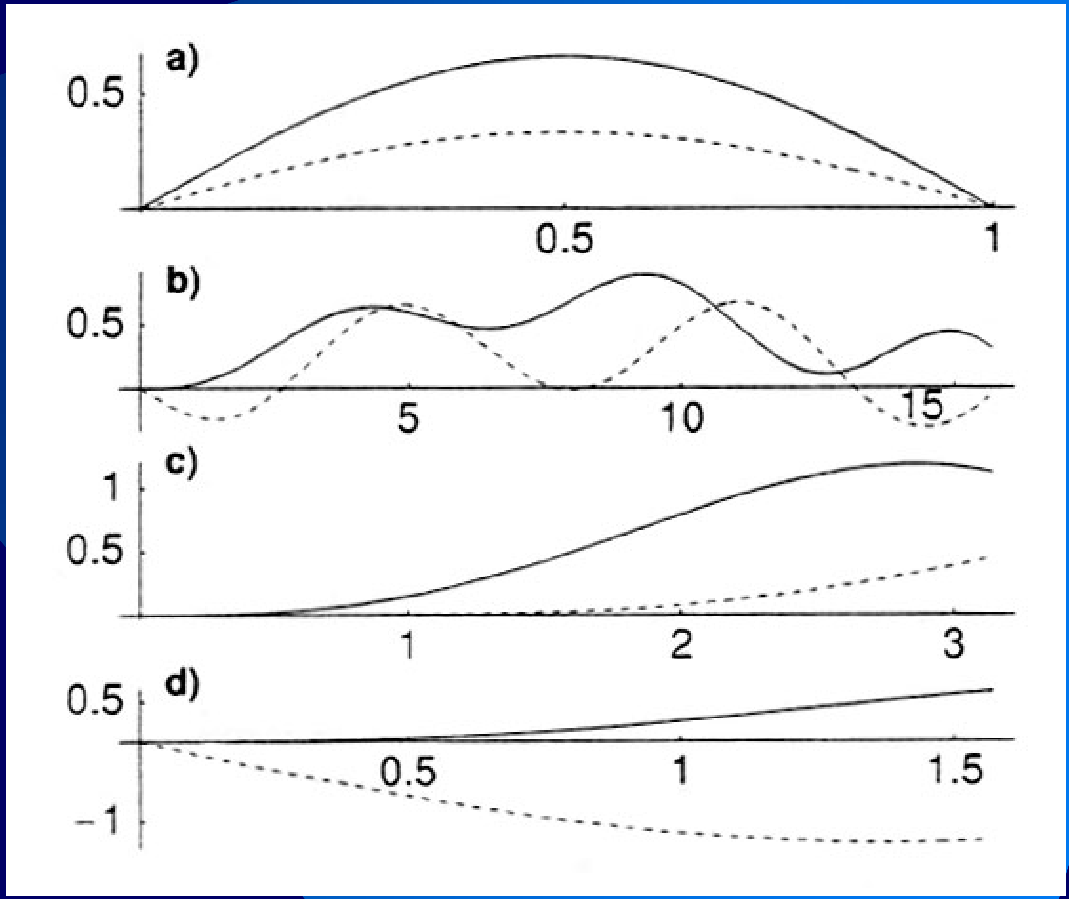
$$-N_2\frac{\partial^2 v_2(x,t)}{\partial x^2} + \mu_2\frac{\partial^2 v_2(x,t)}{\partial t^2} + k\left[v_2(x,t) - v_1(x,t)\right] = 0$$

α = 0

α = 0.2

α = 1

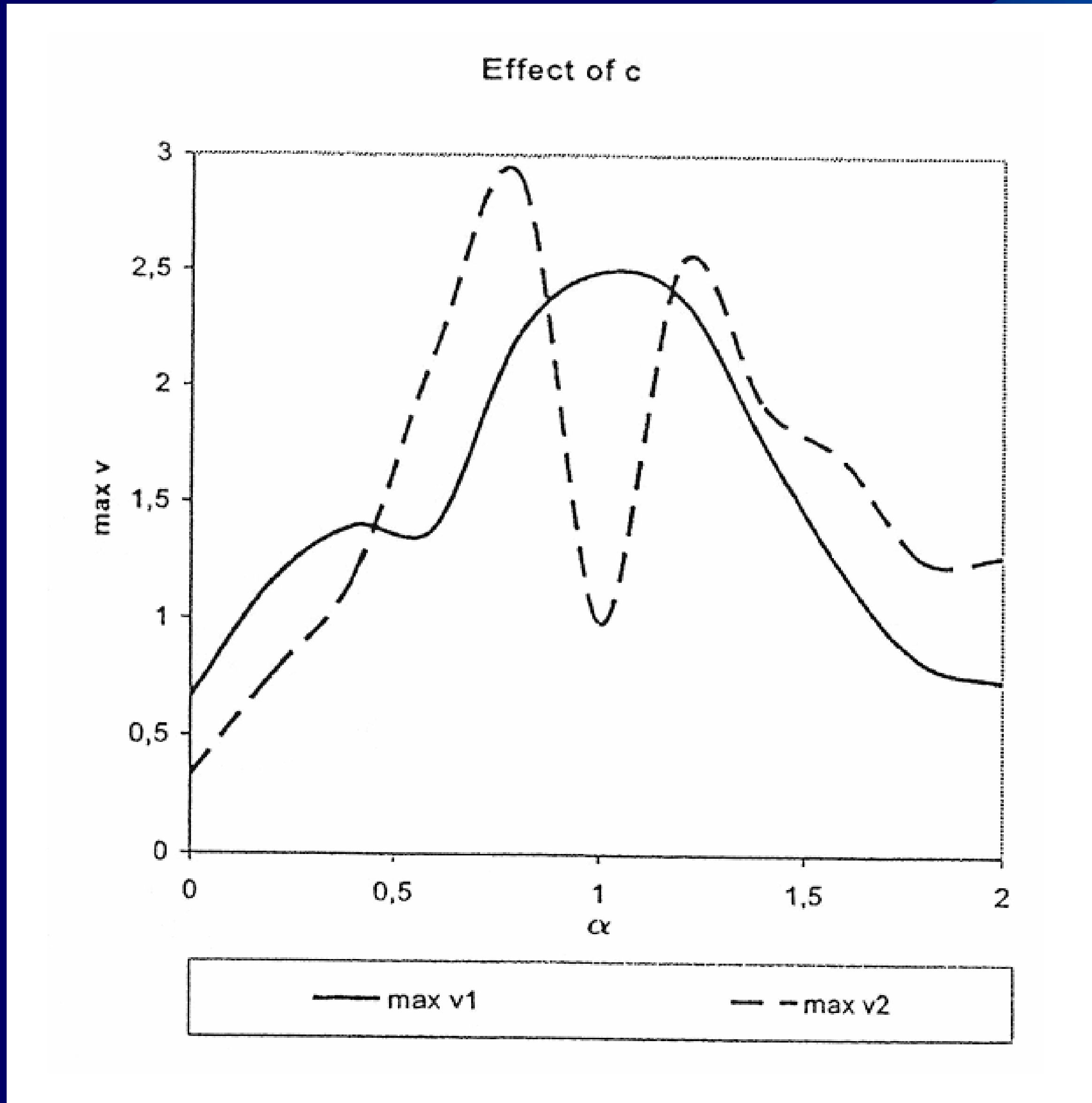
α = 2

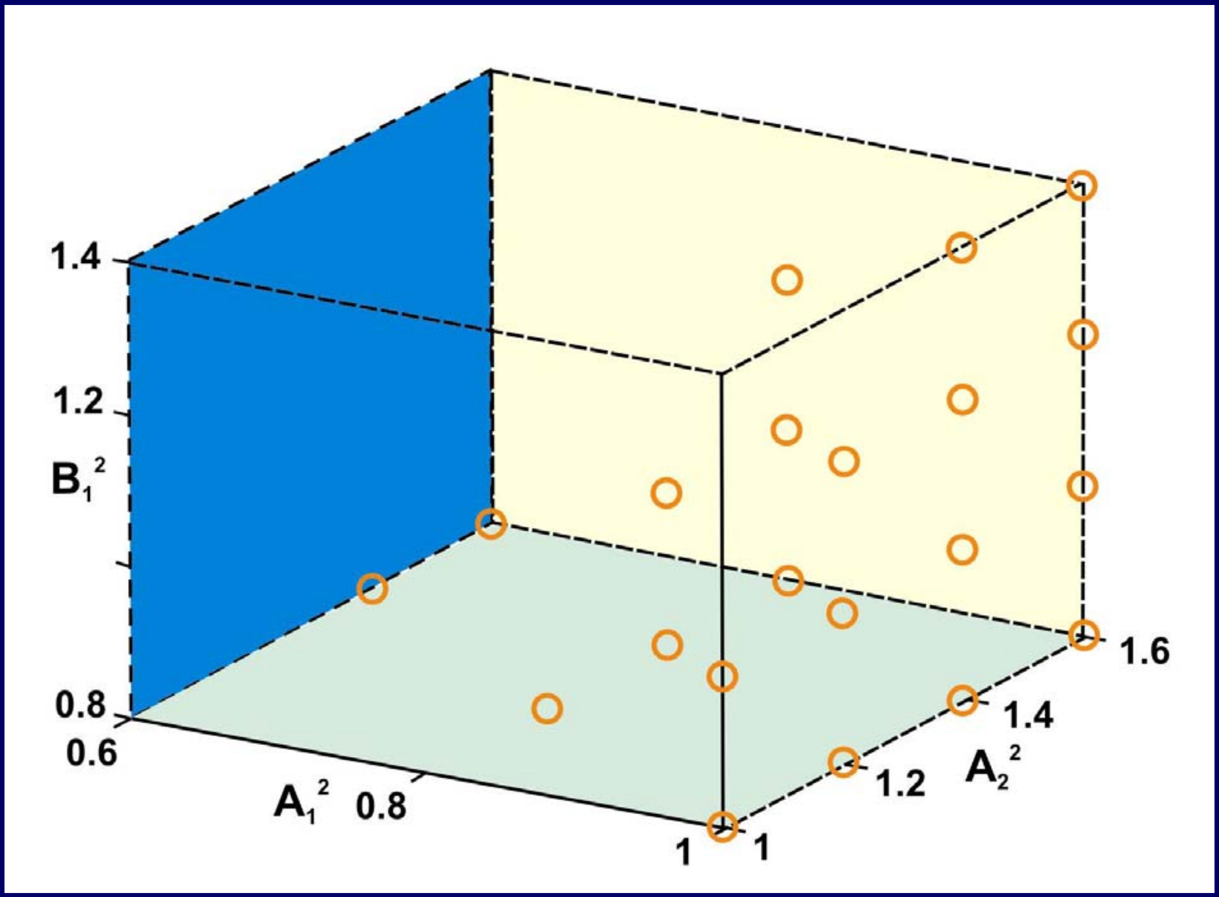


beam deflection

string deflection

α = dimensionless speed


Effect of c
3
2,5
2
1,5
1
0,5
0
max v
0
0,5
1
1,5
2
α
max v1
max v2



At $\alpha = 0$:

$v_1(x) < 1$ for $B_1^2 < A_1^2 A_2^2$

$v_2(x) < 1$ for $B_2^2 < A_1^2 A_2^2$

5. Conclusions

- Dynamic effects on bridges rise with increasing speeds of trains
- The dynamic response of concrete bridges is a little lower than steel ones due to their different mass and damping ratios
- Stress spectra present important data for the assessment of bridges at fatigue
- Vertical accelerations of bridges may be a limit state for the design of new high speed lines
- The diminishing of bridge dynamic response could be achieved with dampers or by interconnection of prestressed beams with pretensiled strings