Experimentální Analýza Napětí 2004

EVALUATION OF BRIDGE CRANE SUPPORTING STRUCTURE WITH REGARD TO DYNAMICAL RESPONSE – QUESTION OF NECESSITY

KRITIKA POTREBY POSUDZOVANIA NOSNEJ KONŠTRUKCIE MOSTAVÉHO ŽERIAVA NA DYNAMICKÚ ODOZVU

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V ČR a SR od 1.1.1991 platná norma ČSN (STN) 27 0103 „Navrhovanie oceľových konštrukcií žeriavov. Výpočet podľa medzných stavov.“ Posudzuje podľa druhej skupiny medzných stavov pretvorenie a últlm kmitania konštrukcie žeriava. Príspevok sa zaoberá teoretickým rozborom a experimentálnym dokumentovaním pre návrh a vypostenie tohoto dôkazu, ak konštrukcia vyhovuje kritériám podľa skupiny medzných stavov.

Keywords: *oscillation, damping, energy, experiment, deflection, time.*

Introduction

Result of revision of former Czechoslovak technical standard ČSN 27 0103, which was valid from 1.1.1972 to 21.12.1990 is a new standard STN 27 0103 „Design of steel crane structure. Calculation according to limit deformation state“. It is valid today in Slovak republic from 1.1.1991.

In accordance with STN 27 0103 there are two groups of limit states. For the first group there are important criterions:

- strength and stability,
- fatigue strength,
- position stability.

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For the second group are important:

- static deformation (deflections, displacement, steering),
- dynamic response of structure (frequency, amplitude and structure damping).

The second group of limit state is evaluated in this standard in the Article X with recommendation to apply an Enclosure VIII.

The standard STN 27 0103 is based on a German standard DIN 15018 „Krane Gründsätze für Stahltragwerke Berechnung“, but there is no prescript in this DIN to perform the check of limit deformation and damping state.

Oscillation damping of supporting crane structure

For following calculation purposes it is necessary to make a simplification of real mass system.

Assumption is that on the body with mass **m** acts an external force **F(t)** given as a time function. Displacement of body is ξ and the spring rate is $\boldsymbol{\delta}$. Then the equation of motion is:

$$m.\frac{d^2\xi}{dt^2} + \frac{\xi}{\delta} = F(t), \tag{1}$$

where the first member in equation is an inertial force and the second member is a spring force.

This equation can be given in the form:

$$\frac{d^2\xi}{dt^2} + p^2\xi = \frac{F(t)}{m}, \tag{3}$$

where $\quad p = \dfrac{1}{\sqrt{m.\delta}}$.

General solution of (3) consists of homogenous and particular solution.

The homogenous solution of (3) presents a simple harmonic oscillation (4),

$$\xi = A\sin(p.t + \varphi) \tag{4}$$

where: **A** is an amplitude of oscillation,

φ is a phase of oscillation,

p is a rotation frequency

Interesting is the energy of oscillatory system according to (4). Kinetic energy of oscillating mass is:

$$E_k = \frac{1}{2}.m.\left(\frac{d\xi}{dt}\right)^2 = \frac{1}{2}m.A^2 p^2.\cos^2(pt + \varphi).$$

Because of $mp^2 = \frac{1}{\delta}$, the total energy of oscillatory system will be:

$$W = E_k + U = \frac{1}{2}.\frac{A^2}{\delta}\cos^2(pt+\varphi) + \frac{1}{2}.\frac{A^2}{\delta}.\sin^2(pt+\varphi)$$
$$W = \frac{A^2}{2\delta}. \quad (5)$$

Particular solution of (1) will be in the form:

$$\xi_p = \frac{1}{mp}\int_0^t F(\tau)\sin p(t-\tau)dt \ , \quad (6)$$

If there are taken into consideration also the resistance forces, the equation (1) will be:

$$m\frac{d^2\xi}{dt^2} + \frac{1}{\delta}\xi + \alpha\frac{d\xi}{dt} = F(t). \quad (7)$$

The final result of dynamic analysis of oscillatory system is determination of important mechanical characteristics, for example damping characteristics, evaluation of influence of resistance forces by means of energetic method, internal friction forces.

Computing and experimental application for bridge crane 50tx28,2m

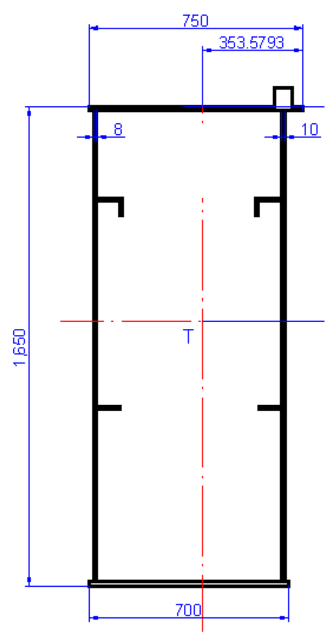
Technical parameters of crane:

- Lifting capacity Q = 500 000 N
- Crane span L = 28200 mm
- Lifting class H2
- Operation group J3
- Wheel base O = 7600 mm
- Travel speed of bridge v_p = 0,4167 m/s
- Travel speed of crane crab v_{pm} = 0,333 m/s
- Lifting speed v_z = 0,0333 m/s
- Track of crane crab z = 4500 mm
- Wheel base of crane crab s_1 = 1390 mm
- Lifting height H_z = 8788 mm
- Radius of bridge travel wheel D_z = 710 mm
- Radius of crane crab travel wheel D_m = 320 mm
- Weight of crane crab m_k = 6680 kg

WEIGHTS OF INDIVIDUAL CRANE PARTS

Main beam (2pcs.)	$G1 =$ 294800 N
Main cross beams (2pcs.)	$G2 =$ 41240 N
Travel unit of bridge (2pcs.)	$G3 =$ 7840 N
Driving travel wheels (2pcs.)	$G4 =$ 9260 N
Driven travel wheels (2pcs.)	$G5 =$ 7640 N
Cross trolley on the travel side	$G6 =$ 0 N
Switch device	$G7 =$ 3500 N
Resistors	$G8 =$ 0 N
Cabin	$G9 =$ 1500 N
Footbridge	$G10 =$ 20110 N
Service galleries	$G11 =$ 0 N
Buffers	$G12 =$ 896 N
Rails (2pcs.)	$G13 =$ 0 N
Cross trolley on the opposite side	$G14 =$ 1550 N

For the static values of beam cross-section see Fig.1:



$z_T = 812{,}5\text{mm}$

$A = 55\ 556\ \text{mm}^2$

$J_y = 2{,}2396.10^{10}\ \text{mm}^4$

$J_z = 4{,}396.10^9\ \text{mm}^4$

Fig.1 Cross-section of bridge crane beam

Damping calculation for crane supporting structure

According to STN 27 0103 „Design of steel crane structure. Calculation according to limit deformation state“, Article X, Annex VIII., it is necessary to determine the deflection of main bridge crane beam taking into consideration deflection values from Tab. VIII/1 caused by loadings from Article 14:

nominal load,

constant load,

loading from parts moving together with load.

In the case of bridge crane 50t x 28,2m with two main beams the maximum value of deflection has to be:

$$w_{\max} = \frac{L}{700} = \frac{28200}{700} = 40{,}28\,mm\,.$$

Damping time is given:

$$t_{tl} = \frac{\ln 2 z_{st}}{f.\upsilon}\,, \tag{8}$$

where **z_{st}** is a beam deflection from nominal load in [mm],

f is frequency of natural vibration in the beam [s^{-1}],

$$f = \frac{1}{2\pi}.\sqrt{\frac{c_o}{m_{red}}}\,, \tag{9}$$

υ is logarithmic decrement of damping

$$m_{red}(2) = \frac{m_2}{2} + \frac{m_k}{2} = 12539{,}7\,kg\,.$$

Based on a detailed analysis and several calculation steps the frequencies of natural vibration for individual beams are:

$$f_1 = 4{,}847\,Hz\ ,\ f_2 = 3{,}142\,Hz\ .$$

Damping times for both beams in the case of static deformation

$$z_{st} = \frac{Q.L^3}{48EJ_y} = \frac{25000.9{,}81.28200^3}{48.2{,}1.10^5.2{,}2396.10^{10}} = 24{,}36\,mm \text{ from nominal load}$$

is:

$$t_{tl}^{\ 1} = \frac{\ln 2.24{,}36}{4{,}847.0{,}1} = 8{,}02s\ ,\ t_{tl}^{\ 2} = \frac{\ln 2.24{,}36}{3{,}142.0{,}1} = 12{,}36s\ .$$

These time values are less than 15 seconds; therefore the support crane structure fulfils the damping requirement according to Article X, Annex VIII/2, from the standard STN 27 0103.

Damping time values can be calculated by means of energetic method, as well. In this case there are obtained following results:

- logarithmic decrement of damping is $\upsilon = 0{,}12088$
- periods of oscillation for both beams are $T_{(1)} = 0{,}2063$ s, $T_{(2)} = 0{,}3183$ seconds
- damping times are:

$$t_u^{(1)} = \frac{\ln 2.24{,}36}{4{,}847.0{,}12088} = 6{,}63\ s\ ,\ t_u^{(2)} = \frac{\ln 2.24{,}36}{3{,}142.0{,}12088} = 10{,}23\ s$$

Again it is evident that both time values are less than 15 seconds.

What it is necessary to say, that there is a very important influence of internal friction losses for determination of damping characteristics. Real values of internal friction resistance as well as logarithmic decrement of damping are higher than theoretical values. From this reason the to Article X, Annex VIII/2, from the standard STN 27 0103 is useless.

Tensometric measuring and results

There was suggested a tensometric measurement for electric bridge crane 50tx28, 2m with box beams according to Fig.2. This measurement enabled to determine not only tension values, but also deflections from hanging load, amplitude of oscillating crane bridge during the process of lifting and the damping time.

There is illustrated an arrangement of tensometers in Fig.2.

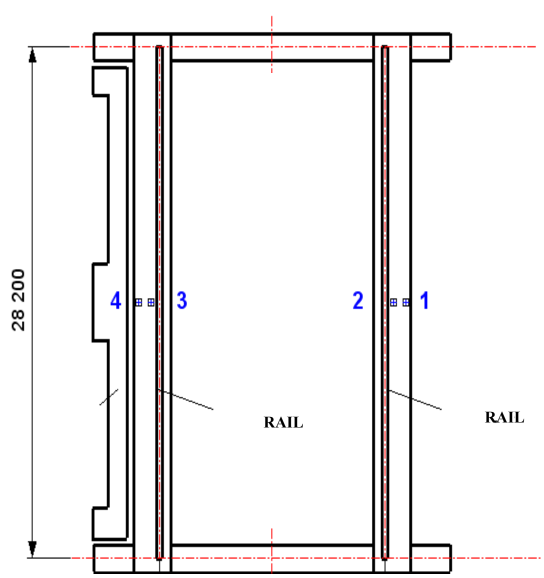


Fig.2 Scheme of the crane bridge and arrangement of tensometers

There were applied tensometers HBM XY91 with resistance value 120 Ω and with constant of deformation sensitivity 2,05 using tensometer bond HMB X60. Tensometers were connected with tensometer plant SPIDER 8..

There were processed and evaluated the measured values of relative deformations and normal stresses by means of a CATMAN software in the given measured points, see Fig.2.

The loading state of crane was following:

Loading of crane with crane crab without load,

Loading with the load 48 000 kg

Time behaviours of stresses

From the measured relative deformation there were calculated values of normal stresses in the main beam.

There are illustrated in diagram D1 time behaviours of stresses during the intermittent lifting process of

48 000 kg load in the measured points 1, 2, 3 and 4 from the Fig.2.

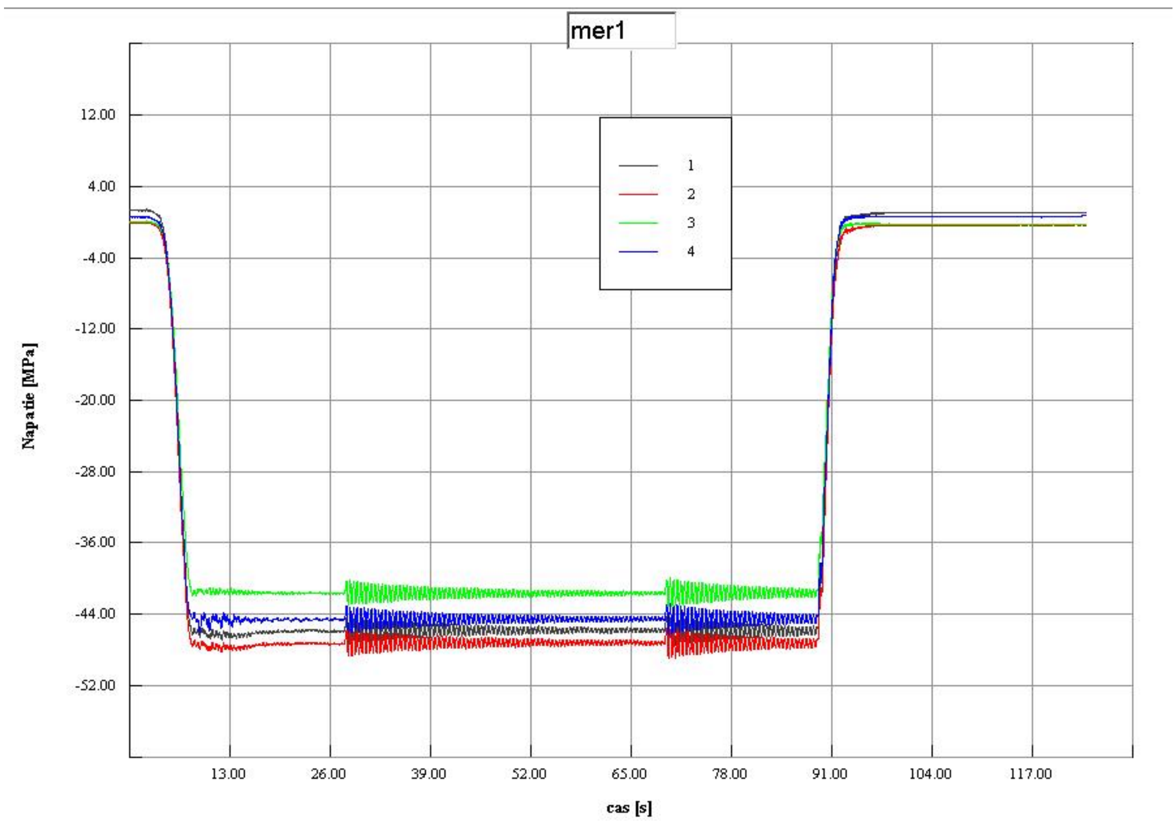


Diagram D1

Time behaviours of deflections

There are time behaviours of stresses in beams in diagrams from D1 to D5. It is necessary to transform these behaviours from the values of stress into the values of deflection, i.e. it is important to obtain time behaviours of deflections in beams.

The deflection in the middle of beam is:

$$w = \frac{F.L^3}{48.EJ_y} = \frac{L^2}{12.z}.\varepsilon = \frac{L^2.\sigma_o}{12.E.z}, \qquad (10)$$

where F – weight of one half load Q = 470 880 N,

L – bridge span 28 200 mm,

z – distance from neutral axis to upper table, ε – relative deformation in the point of tensometer measurement,

E – modulus of material elasticity,

σ_o – stress value in the point of tensometer

$$\sigma_o = \frac{F.L}{4.J_y}.z \quad [\text{MPa}]. \qquad (11)$$

There are in diagram D1.1 time behaviours of crane beam deflections form the load 48 000 kg obtained from the measured values in the points 1,2,3 and 4 (Fig.2) based on stress values from diagram D1. In diagram D1.2 is selected time interval from 0 to 91 seconds from D1.1, measured point 2.

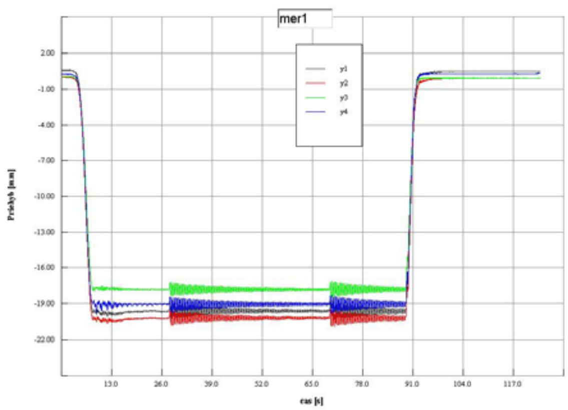


Diagram D1.1

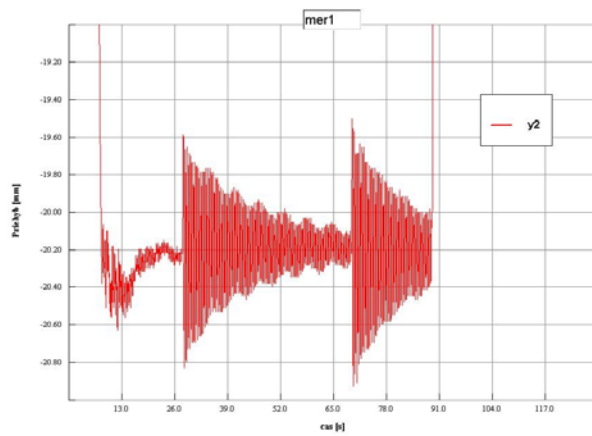


Diagram D1.2

Data evaluation from tensometer measurement

There are extended time behaviours of deflections in diagrams from D2 to D5 according to stress values during lifting process. In this way it is possible to determine the main important dynamical characteristics of given system, i.e. the natural angular frequency with regard to damping, natural frequency and period of natural oscillation taking into consideration damping in beams.

From the diagrams D2, 3,4,5 it is evident that periods of natural oscillations for individual beams are:

$$T_{(1)} = 0{,}4 \text{ s},$$

$$T_{(2)} = 0{,}47 \text{ s}.$$

Next possible step is calculation of logarithmic decrements of damping depending on oscillation amplitudes influence and stiffness of steel wire crane rope.

The cycle periods of oscillations are higher than values obtained from analytic calculations.

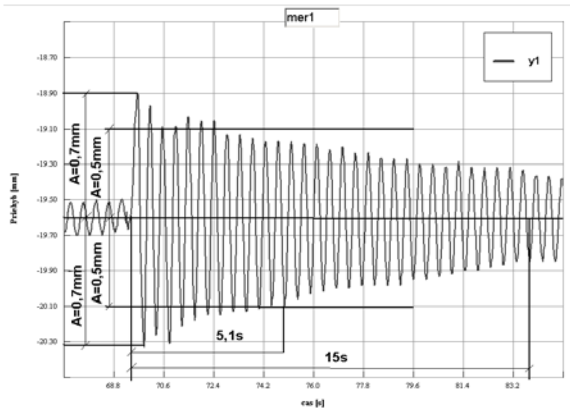


Diagram D2

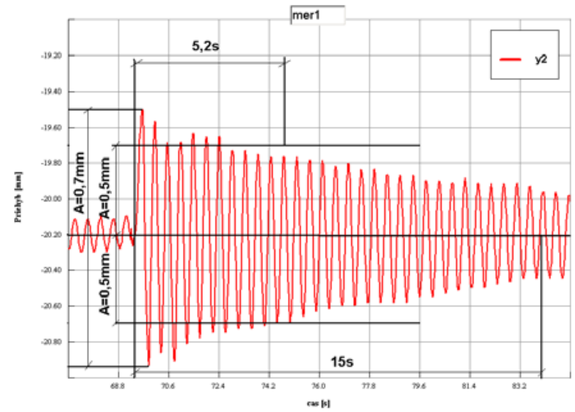


Diagram D3

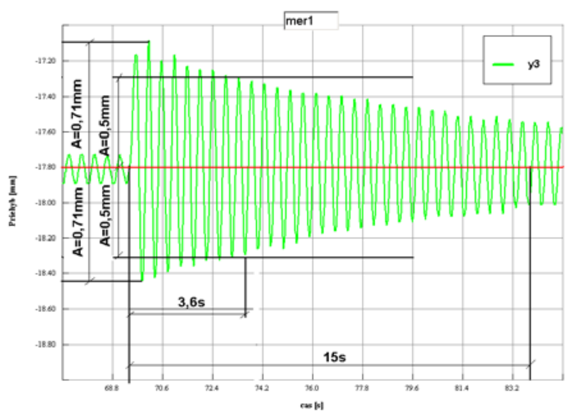


Diagram D4

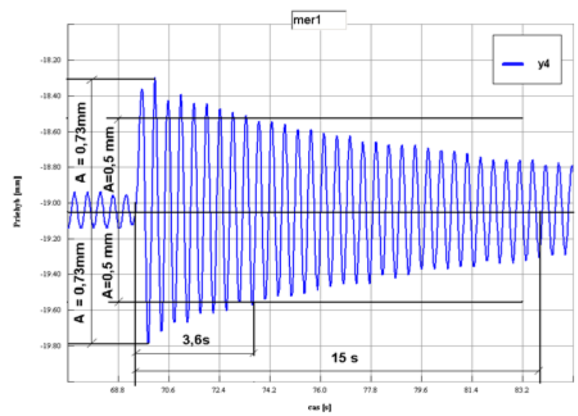


Diagram D5

Conclusions

During the design process of crane supporting structures it is necessary to take into consideration the ergonomic point of view, i.e. to eliminate such oscillation frequencies which are unacceptable for the crane-operator as well as to avoid the resonance frequencies because of fatigue loading.

According to the standard STN 73 1401 „Design of steel structures“ from the year 1998 there are two limit values of natural frequency: 3 Hz and 5 Hz.

For beams with the span $L \leq 10$ m deflections have to be less than 10 and 28 mm.

Values of acceleration and frequency are limited with regard to ergonomic criterions and function of system.

The final decision is: Article X and Enclosure VIII in standard STN 27 0103 does not make sense because in the case that supporting crane structure is fit from the strength point of view, it is also convenient with regard to limit deformation state.

References

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