UPGRADING THE SEISMIC RESISTANCE OF THE VVER-400 PRESSURIZER BY JOINT SUPPORTS

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ABSTRACT

The pressure vessel of the pressuriser is supported by eight tube columns welded to the anchor plate and to the supporting shell ring. This support is found to be insufficient to safeguard the stability of the pressuriser in case of the Seismic Margin Earthquake with PGA_{RLE} = 0.100 g in a horizontal direction and PGA_{RLE} =0.067 g in the vertical direction. Computed by the spectral method the stress intensity in the supporting columns went up to 429 MPa. Originally assumed circumferencial sliding supports similar to those of the VVER-1000 pressurizer located in the vicinity of the ceiling circular opening (Fig. 1) due to spacing, accuracy and designing problems appeared as not applicable. A new supporting system consisting of struts with Cardan joints has been designed Left and right screw pairs allow to adjust the length of a joint strut (tie rod). The angles made by a strut with the radial direction and with the horizontal plane are taken to get the minimum tensile stress in the strut during heating a cooling the pressuriser. As the temperature conditions in the air stream in ceiling opening are uncertain, some tensile stress must be admitted. The joint strut supports behave like elastic constrains with gaps. Such a strut is modelled by the element SYSTUS 1602. To obtain the seismic response the floor displacement time histories were generated based on the given floor acceleration response spectra. The probable difference between column base and strut base displacements has been considered.

INTRODUCTION

The pressurizer KO-440 is a vertical pressure vessel of the height about 12 m and of the diameter 2710 mm. It is used to compensate volume changes of the cooling fluid. In normal working conditions it contains about 26 m^3 of fluid and 18 m^3 of steam at a temperature of 325 °C and at a pressure of 12,26 MPa. The pressurizer vessel passes through an opening in the concrete ceiling plate of thickness 1,4 m (Fig. 1).The pressurizer mass is about 127 000 kg and it is supported by eight columns, which were originally not designed to resist the seismic excitation during an earthquake. The vessel wall temperature varies from about 20 °C to 325 °C. Thus the vertical thermal dilatation as well as the diametric thermal dilatation are decisive as to the auxiliary supports design. These supports are assumed to be located on the concrete ceiling plate (elevation 18.9 m).

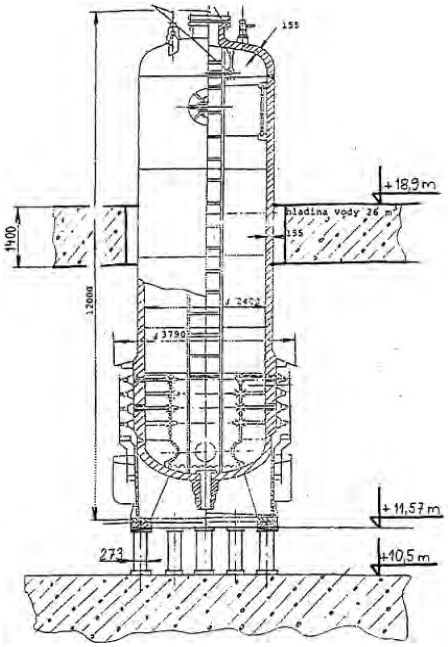

Fig. 1 Pressuriser KO-440

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Seismic resistance of the pressurizer vessel is to be achieved by sixteen auxiliary supports (struts, ties) each in a special form of a space five link kinematic chain with revolute or screw pairs only constituting an Assur group [1]. Such a kinematic chain behaves like a rigid system of links when joined to a frame or a system of links the positions of which are determined by the positions of two links (in our case AC and R) in between the the group is inserted and the positions of which are given. Here AC means an Anchored Casing and R the Ring of ⊐ shaped cross-section which encompasses firmly the presssurizer vessel.

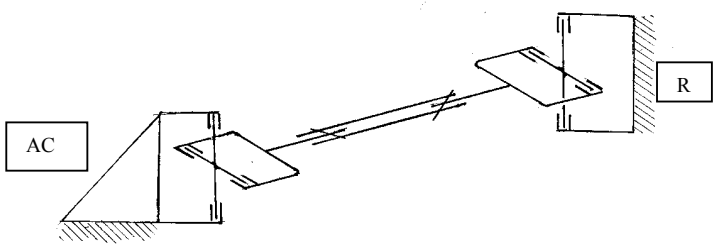

Fig. 2 Kinematic chain of the supporting strut (tie rod)

The first and second revolute pairs axes are perpendicular and intersecting, the fifth and sixth revolute pair axes as well. The middle srew pairs have a common axis is passing through the intersection points of the revolute pairs axes (Fig. 2). One screw pair has the right-hand thread, the other the left-hand thread. Thus the middle link has an internal mobility, which may be used to adjust the distance of revolute pair axes intersection points.

The arrangement of all the supports with eight anchored casings and eight V pairs of joint struts in shown in Fig. 3. The constructional scheme of a joint strut in Fig. 4.

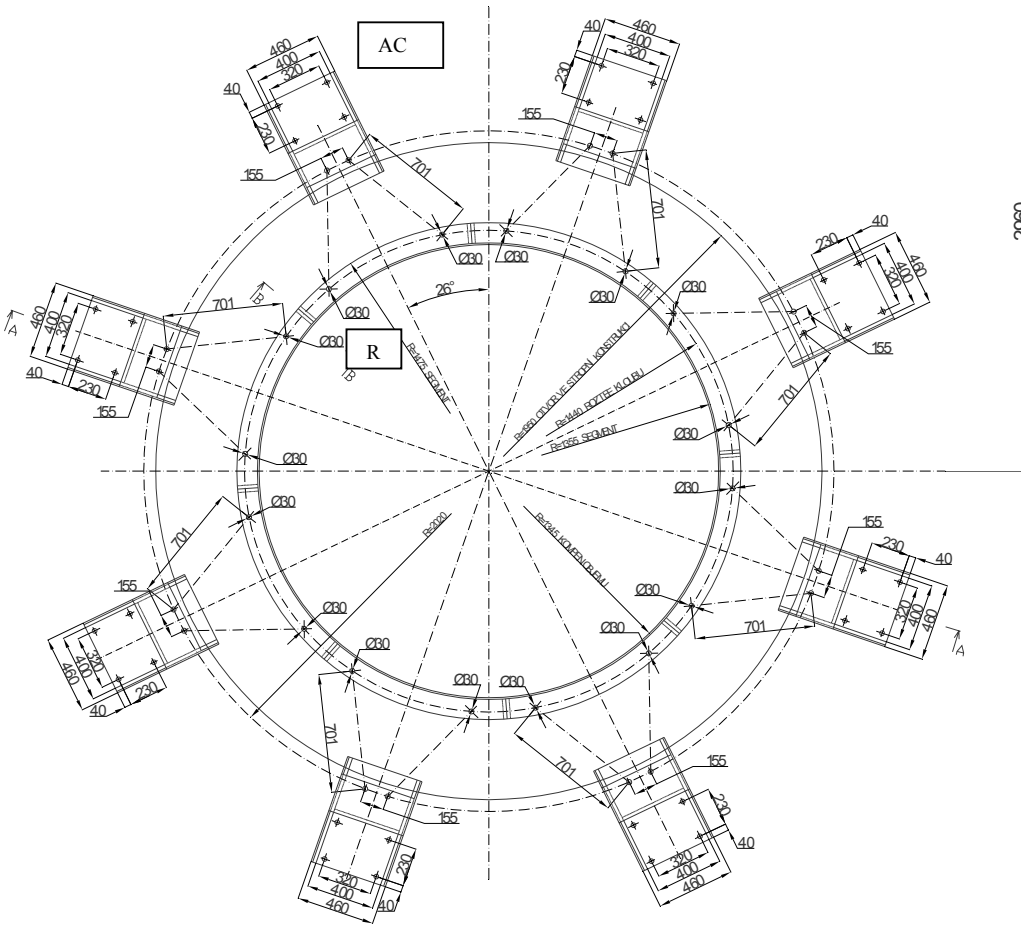

Fig. 3 Supporting system

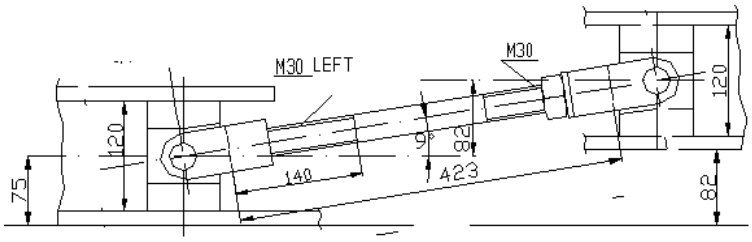

Fig. 4 Construction of the joint support

HEATING AND COOLING THE PRESSURISER.

Fundamental Relations

The angles made by a strut with the radial direction and with the horizontal plane (Fig 3 and Fig. 5) are designed to get the minimum tensile stress in the strut (tie rod) during heating and cooling the pressuriser. As the temperature conditions in the air stream in ceiling opening are uncertain, some tensile stress must be admitted but minimized.

Let us denote *A* the fixed intersection point (AC) of the revolute pair axes (Fig. 2) and *B* the moving intersection point of the revolute pair axes (Fig. 2). Displacement of B is due to the dilatation of the ring R. At the temperature t_o the point *B* let be on the z axis of a cartesian coordinate system *Oxyz* (Fig. 5).

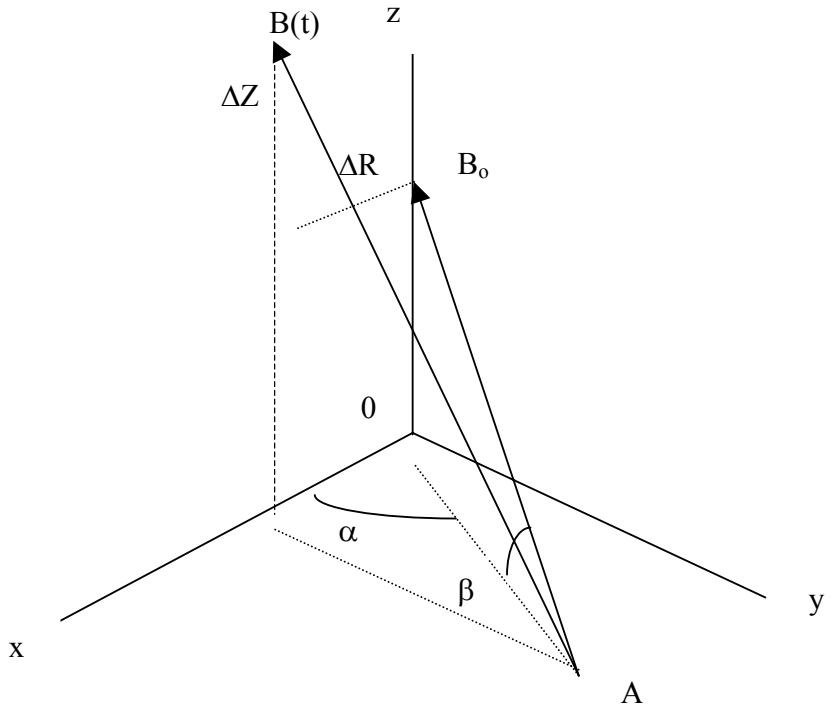

Fig. 5. Reference coordinate system.

Due to the temperature change *t* the point *B* is displaced to the position *B(t)*. The z axis is parallel with the pressurizer vessel axis so that the vertical displacement component ΔZ is equal to the thermal displacement of the vessel surface in the vessel axial direction. If the x axis is intersecting the pressurizer axis the displacement component ΔX is equal to the radial vessel surface thermal displacement ΔR (Fig. 5).

Let us denote $AB(t_0) = l_0$ and $AB(t) = l(t)$, where

$$l(t) = \sqrt{\left(l_0 \cos\beta\cos\alpha - \Delta R\right)^2 + \left(l_0 \cos\beta \sin\alpha\right)^2 + \left(l_0 \sin\beta + \Delta Z\right)^2} \quad . \tag{1}$$

If R is the radius of the pitch circle of the points B_o and α_t the thermal dilatation coefficient there is approximately

$$\Delta R = \alpha_t t\, R = kR\ ,\ \alpha_t t = k \quad . \tag{2}$$

If H is the altitude of the point B_o above the vessel supporting columns , there is approximately

$$\Delta Z = \alpha_t t\, H = kH\ . \tag{3}$$

The substitution to (1) gives

$$l^2(t) = l_0^2 - 2kl_0 R\cos\alpha\cos\beta + (kR)^2 + 2l_0 kH\sin\beta + (kH)^2\ . \tag{4}$$

The temperature variation of the middle links with screw pairs t_p is smaller than that of the pressurizer. The respective change of the distance AB due to this temperature variation is

$$\Delta l_t = \alpha_t t_p\, l_0 = k_p l_0\ ,\ \ \alpha_t t_p = k_p \quad . \tag{5}$$

The resulting middle link elastic elongation (shortening) Δl is

$$\Delta l = l(t) - l_0 - \Delta l_t\ . \tag{6}$$

Choice of the Angles α and β

At a given thermal state a relation between the angles α and β can be found corresponding to $\Delta l = 0$. Substitution from Eq. (6) to Eq. (4) if $\Delta l = 0$ gives

$$l_0^2(1+k_p)^2 = l_0^2 - 2kl_0 R\cos\alpha\cos\beta + (kR)^2 + 2l_0 kH\sin\beta + (kH)^2\ . \tag{7}$$

When introducing

$$\frac{R}{l_0} = r\ ,\ \ \frac{H}{l_0} = h\ . \tag{8}$$

we get

$$\cos\alpha = \frac{k^2r^2 + k^2h^2 + 2kh\sin\beta - 2k_p - k_p^2}{2kr\cos\beta} \quad . \tag{9}$$

At a certain temperature t of the pressurizer vessel there exist a value t_p of the joint strut temperature given by Eq. (10), which corresponds to $\Delta l = 0$.

$$\alpha_t t_{p1,2} = 1 \pm \sqrt{1 + \left(-k^2r^2 - k^2r^2 - 2kh\sin\beta + 2kr\cos\beta\cos\alpha\right)}\ . \tag{10}$$

Dependence of α(β) on the Pressurizer Temperature t and on the Joint Strut Temperature t_p if $\Delta l = 0$.

The following diagrams show how the function α(β) depends on the pressurizer vessel temperature variation ranging from 0°C to 300 °C and on the joint strut temperature t_p proportional to t ranging up to 75 °C (Fig. 6), up to 100 °C (Fig. 7), up to 125 °C (Fig. 8) and up to 150 °C (Fig. 9) for the elevation angle β equal 8, 8.5, 9, 9.5, 10 and 10.5 deg.

The lay out of the supporting link groups is shown in Fig. 5 for the design case when $\alpha = 40^o$ and $\beta = 9^o$. The designed angle $\alpha = 40^o$ cannot be changed during mounting on contrary to the angle β.

In Tab. 1 there are shown the values of t and β corresponding to zero elastic elongation (shortening) the joint strut (Δl=0) related to the maximum strut temperatures t_{pmax} = 75°, 100°, 125° and 150° if $\alpha = 40^o$. One can see that for $\beta = 8^o$ and $\beta = 8{,}5^o$ never Δl=0 if $\alpha = 40^o$. The majority of cases when Δl=0 and $\alpha = 40^o$ corresponds to $\beta = 9^o$ a 9.5°. At fully heated pressurizer and for t_{pmax}= 100° it ought to be $\beta = 9^o$. For $t_{pmax} = 125^o$ the most suitable value of β is 9.5°.

In Fig. 10 there are diagrams where red lines correspond to t_p rise proportional to t and by dark lines the ideal t_p rise when always $\Delta l = 0$.

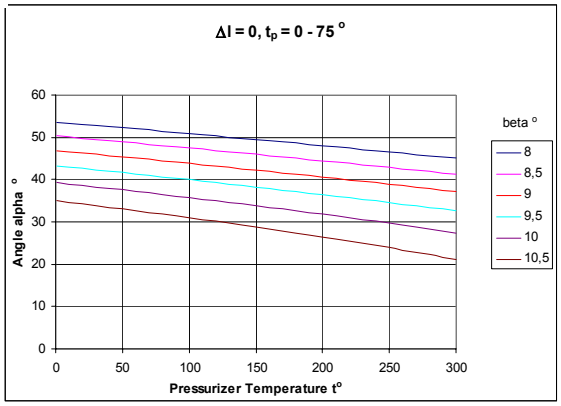

Fig. 6 Variation of $\alpha(\beta)$ with t and $t_p = 1/4$ t

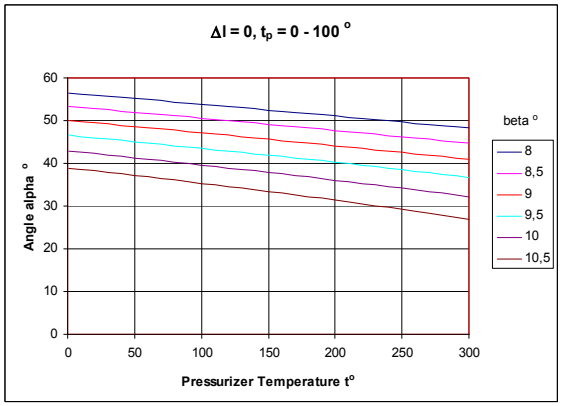

Fig. 7 Variation of $\alpha(\beta)$ with t and $t_p = 1/3$ t

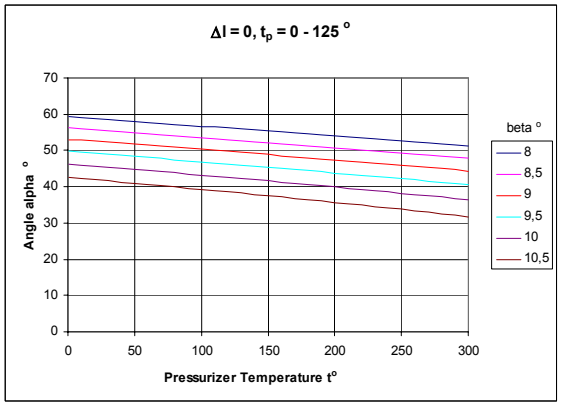

Fig. 8 Variation of $\alpha(\beta)$ with t and $t_p = 1/2.4$ t

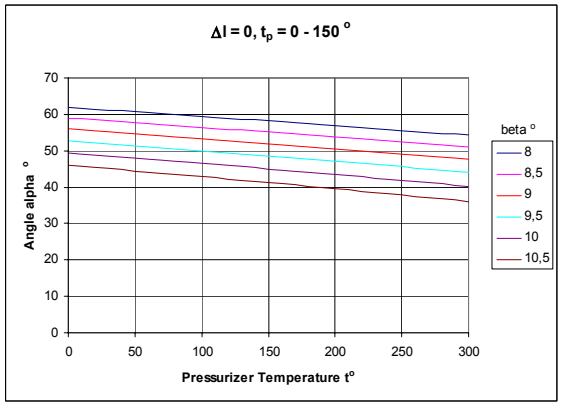

Fig. 9 Variation of $\alpha(\beta)$ with t and $t_p = 1/2$ t

Tab. 1 The values of t_k and β for Δl=0 and t_{pmax}= 75°, 100°, 125° and 150°

$\alpha = 40^o$	$\beta^o =$	8	8,5	9	9,5	10	10,5
$t_p = 0 - 75^o$	$t^o =$			230	100		
$t_p = 0 - 100^o$	$t^o =$			300	210		
$t_p = 0 - 125^o$	$t^o =$				300	200	80
$t_p = 0 - 150^o$	$t^o =$					300	190

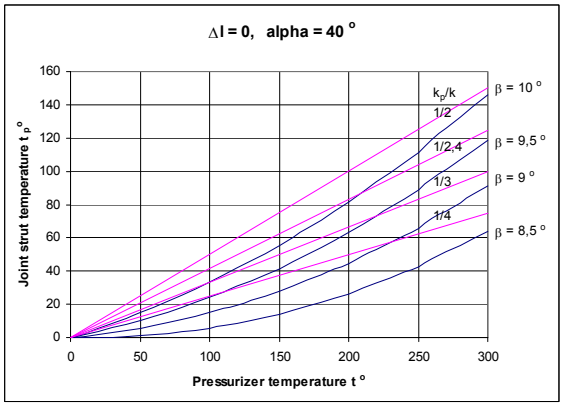

Fig. 10 Strut temperature (Ideal-dark, proportional–red)

The function $\Delta l(t)$ if at A Given Value of t_i $\Delta l = 0$

Let be $\Delta l = 0$ at the angle $\alpha(\beta)$ corresponding to the given temperature t_i = 0, 100, 200 and 300 °C (Fig. 11). We can see that a minimum of Δl is achieved in the last case. The $\Delta l(t)$ does not depend on the elevation angle β.

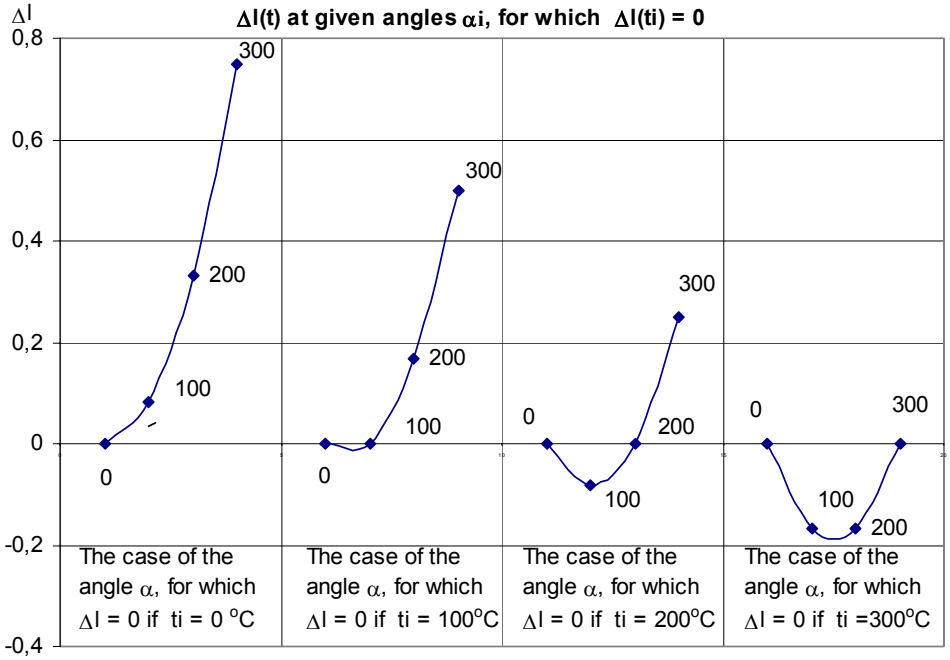

Fig. 11 $\Delta l(t)$

SEISMIC RESPONSE OF THE PRESSURISER

Model of the joint strut

Due to clearances in kinematic pairs the joint struts (tie rods) behave like elastic constraints with gaps (Fig. 12). In the computational model such a constraint is modelled by the element SYSTUS 1602. Its variable stiffness k for $k_{max} = 10^9$N/m and the gap of d =0,15 mm is shown in Fig. 13.

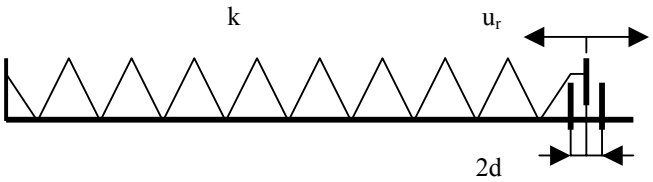

Fig. 12 Model of an elastic support with a gap

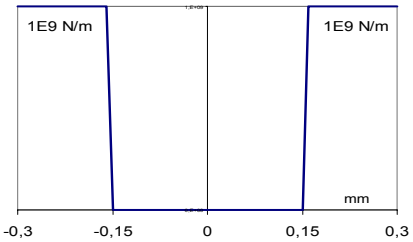

Fig. 13 Stiffness of a SYSTUS element 1602

Floor acceleration and displacement time histories

To obtain the seismic response the floor displacement and acceleration time histories were generated by the program ACCLGS based on the given floor acceleration response spectra [3] as a sum o harmonic series components Eq.(11) [4]. The possible difference between column base and strut base displacements (Fig. 1) has been considered approximately. Following Fig.14 shows the given horizontal response spectra and the generated displacement time histories.

$$u(t) = -\sum_{j=1}^{n} a_j (-1)^j \sin \Omega_j t\,,\ a(t) = \sum_{j=1}^{n} a_j (-1)^j \Omega_j^2 \sin \Omega_j t \tag{11}$$

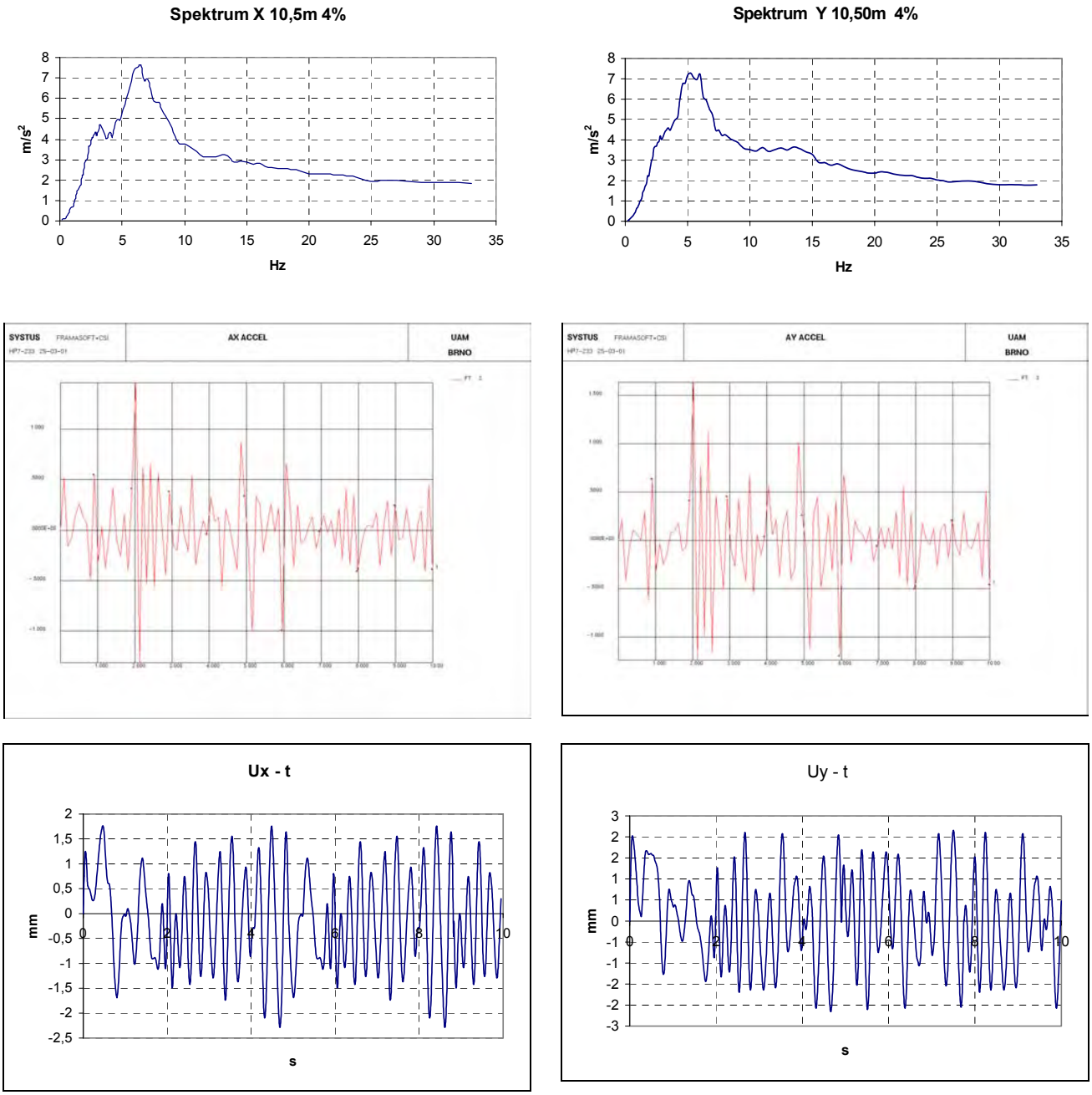

Fig. 14 Horizontal response spectra, generated acceleration and displacement time histories

Response to the seismic loading

According to [4] Fig. 15 shows the excited displacements of a pressuriser node related to time by a thick blue line. Green line describes the floor displacement – time relation at the elevation of 18.9 m and red line the floor displacement – time relation at the elevation of 10.5 m (Fig. 1) during the initial time period of the seismic excitation up to about 1.1s. In Fig. 16 there are the corresponding support reaction – time relations.

Greatest reaction magnitudes can be observed in the time interval between 2.1s and 2.6s (Fig. 17). Maximum reaction appears at the time of 2,255s (Fig. 18).

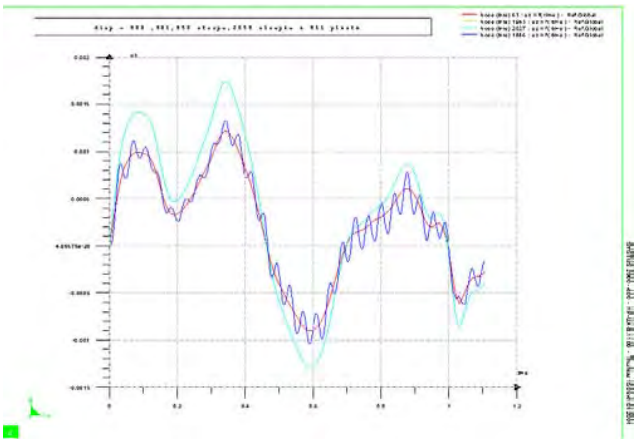

Fig.15 Displacements

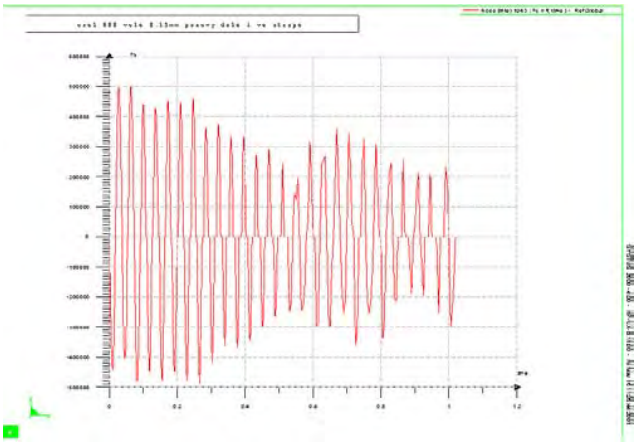

Fig. 16 Reactions

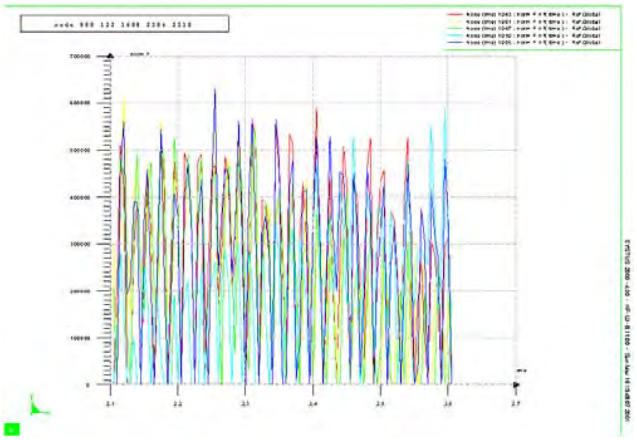

Fig. 17 Reaction magnitudes

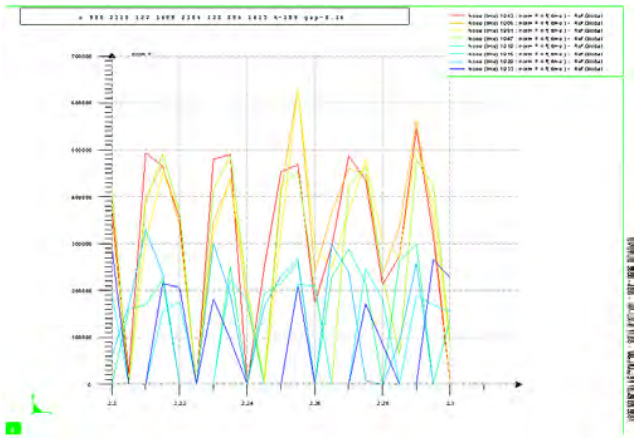

Fig. 18 Reaction magnitudes-detail

CONCLUSIONS

The seismic stability of the pressurizer can be achieved by intruducing auxiliary supports in a form of particularly shaped five link groups. The support is characterised by the angles α and β (Fig. 5). These angles are to be chosen to get minimum strain in the links of the joint strut and minimum action on the pressurizer vessel during the heating up and cooling . In case of a total linkage clearence of about 0,2 mm no strain would be imposed to the joint strut links at all. Nonlinear response analysis of the pressuriser vessel as of a system with gaps in elastic constraints to seismic loading given by generated displacement time histories based on defined response spectra proves the seismic resistance of the pressurizer.

REFERENCES

[1] Novotný J. : Kinematics of Space Assur Groups, University of Oulu, Laboratory of Machine Design Research Papers, Oulu, 1990.

[2] Novotný J., Novotný J. jun.: Upgrading the pressurizer KO EDU seismic resistance by joint struts, Rep UAM ltd. No. 3946/06, Brno 2006 (in Czech).

[3] Floor response spectra, seismic qualification design NPP Dukovany, DAVID, engineering and consulting office rep. No. 087-006 Praha 1996 (in Czech).

[4] Novotný, J., Novotný j., jun.: Optimum Design of the Pressurizer Vessel. Upgrading the pressurizer seismic resistance, rep. ÚAM ltd., No. 3082/01, Brno, 2001 (in Czech).