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Paper # K07-5

SEISMIC SAFETY EVALUATION AND ENHANCEMENT AT THE PAKS NUCLEAR POWER PLANT

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ABSTRACT
A comprehensive program for the evaluation of seismic safety and increasing of seismic resistance of the Paks Nuclear Power Plant was started in1993 and now is in progress. In the first two years of the program the urgent and quickly realizable fixes were performed, seismic instrumentation was installed, and a procedure was elaborated for the activities to be performed after a possible earthquake. Re-evaluation of the site seismic hazard was finished in 1996. The adequacy of the evaluation was approved by micro-seismic monitoring results in 1998. A new concept has been established for the safe shutdown and cooling down of the reactor core, which is based on reinforcement of systems and minimizing system modifications. The systems, equipment and structures relevant for seismic safety have been determined. Seismic re-qualification of the main part of the equipment and structures has been completed. The most important safety-related measure, the seismic upgrading of the primary circuit was implemented on tall the four units in 1998. Until the end of 2002 the realization of the site seismic upgradings were finished on all the four units.

1. BACKGROUND

In 1996 a safety upgrading program was launched at Paks NPP. Main goal of the program were to improve the plant safety up to the internationally accepted level. Most extensive part of the general safety upgrading programme at Paks NPP is the seismic safety upgrading programme, which includes the following tasks:

- re-evaluation of seismic hazard of the site, which included the geotechnical survey of the site, analysis of the soil liquefaction, etc.
- establishing the safe shutdown and heat removal technology, and elaboration of the list of the structures, systems and equipment, which are essential to ensure seismic safety,
- installation of the seismic instrumentation and elaboration of the pre-earthquake preparedness and post-earthquake actions,
- evaluation of the seismic capacity of systems and structures relevant for safety,
- performing the necessary upgrading measures taking into account the priorities and the feasibility of the necessary corrective actions.

The re-evaluation of site seismic hazard was completed in 1996. The design base earthquake with 10^{-4} annual recurrence frequency has been determined by probabilistic method. The horizontal ground peak acceleration (GPA) of the design base earthquake is 0.25 g, which is ten times greater than it was assumed during the plant design.
Comprehensive evaluation of seismic capacity of safety related structures, systems and components resulted in excessive upgrading program. The steel frames of the reactor and turbine halls had to be fixed by new structural elements, i.e. x-bracing, improving of joints, etc. The total weight of new steel structures is close to 2000 tons. The main circulating loops and primary components have been fixed by viscous-dampers. On the piping and equipment fixes were improved, new fixes added or viscous dampers installed. The cabinets and racks, also the cable trays have been reinforced as well. The seismic evaluation and upgrading program of Paks NPP have been widely presented at SMIRT Conferences [1-n].
The industrial needs motivated the development of the design methods applicable for the solution of specific upgrading needs at operating nuclear power plant. In this paper some of these specific tasks and methods are described.

2. ENGINEERING TASKS IN THE REALIZATION OF THE SEISMIC SAFETY PROGRAM.

From the short summary given in the Background section it is clear that for the practical implementation of the additional seismic safety reinforcement of the power plant large quantity and high quality engineering tasks had to be resolved for such a short time (about 5 years). Without demand of perfection we will show only those of the above mentioned tasks that prepared the qualifications and confirmed the adequacy of the solutions.

- strength analysis and designing of reinforces of pipes,
- reducing vibration of high energy pipelines with viscous dampers
- thermal flow calculations for heating control of viscous dampers.

3. QUALIFICATIONS, STRENGTH ANALYSIS OF PIPELINES

The largest volume of engineering works for the supervision of seismic resistance of the power plant has been performed for the analysis of system, equipment, building and steel structures involved in the qualification, dimensioning and design of reinforcement of cooling technology required after earthquake. We would like to accentuate the part of this work related to the pipelines for the limited time available for the lecture.

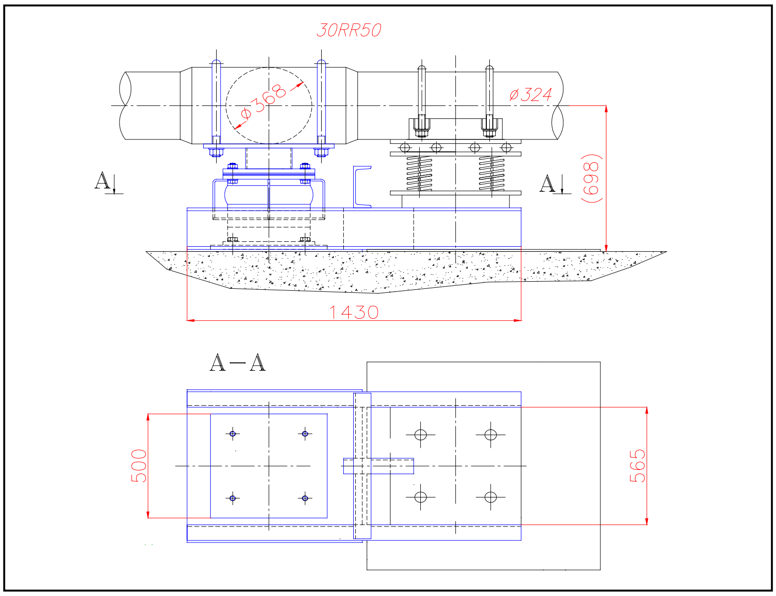
The supervision of pipelines is performed as follows:

- strength analysis of the assigned systems to effect of the earthquake response spectrum defined for their environment,
- in case of inadequacy the definition of required reinforcements
- detailed design of reinforcement
- control of strength calculation for the reinforcing structures.

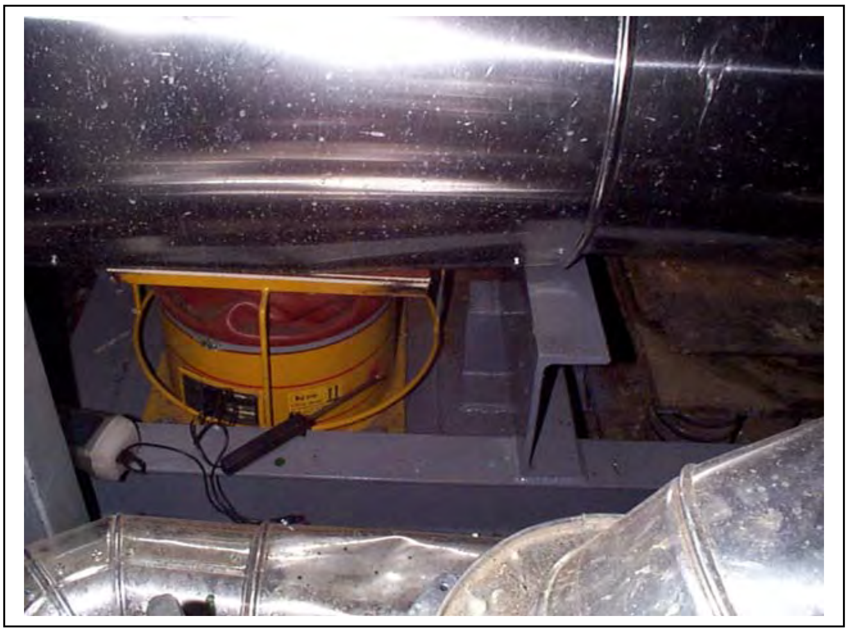
The first two tasks have been mostly performed by the Czech and Russian offices of the S&A company and by the Siemens Nuclear Office. The detail design and the control calculations have been executed by Hungarian engineers.

We would like to show a characteristic example for this part of work where the built in viscous dampers are applied together with the control calculation of new pipe supporting structure and the calculation of thermal flow.

On the figure there are shown the original spring pipe support that proved too soft for the case of earthquake and the additional viscous dampers supported by the new pipe supporting elements welded to the concreted supporting plate.



The installed viscous damper and steel structure can be seen on the following photos.



3.1 Strength analysis of pipe supports

The reinforcement of pipe systems has been calculated for level *SSE (Safe Shutdown Earthquake)*. The *ASME III level D* service limits are to be used for the evaluation. Concerning the strength analysis, the prescriptions of *ASME*

III Div. 1 NF [1] and *ASME III Div. 1 Appendix F* [2] have to be used. In case of welded joints the acceptability criteria of base material can be used.
The categorization of pipe supports according to *ASME*:

1./ Plate- and Shell-Type Supports: fabricated from plate and shell elements and is normally subjected to a biaxial stress field.

2./ Linear-Type Supports: acting under essentially a single component of direct stress. Examples of such structural elements are tension and compression struts, beams and columns subjected to bending, trusses and frames. Such elements may also be subjected to shear stresses.

3.1.1 Plate- and Shell-Type Supports

The criteria pertain to primary stresses only. The primary membrane and membrane plus bending stress intensities have to be calculated and compare with the allowable values. The average primary shear stress has to be also evaluated. In case of elastic system analysis, the acceptance criteria of *Appendix F-1332* shall be used.

3.1.2 Linear-Type Supports

In case of elastic system analysis, the acceptance criteria of *Appendix F-1334* shall be used.

4. DETERMINING OF THERMAL BOUNDARY CONDITIONS

4.1 Thermal Conductivity

Thermal conductivity of materials was determined using the appropriate references [5] [6] and GERB catalogue.

Material	Thermal conductivity W/mK
S235JRG2 (steel)	43
S355J2H (steel)	43
ISOPLAN insulation	0.13

Table **-1: Thermal conductivities

4.2 Heat Transfer Coefficient Between the Structure and the Surrounding Air.

Calculating the heat transfer coefficients produces the basic data for the finite element heat analyses. The heat transfer coefficient is a function of the effective temperature, which is the arithmetical mean of the temperatures of the structure surface and the air. So the effective temperature depends on the surface temperature, which we get as a result of the heat transfer analysis. At first we take an approaching value for the effective temperature. The finite element heat transfer analysis serves the result of surface temperatures, so the effective temperature can be approached more exactly. Using an iterative procedure the surface temperature can be calculated with adequate accuracy. Conservatively stationary air condition is assumed for the calculation. The characteristic length and the position of the damper element to the supporting structure and the pipe are also taken into consideration when calculating the heat transfer coefficient. The characteristic length is the one, which is in line with the heat flow of the air.

Sample calculation:

Characteristic length: $L := 100 \cdot \mathrm{mm}$

Effective temperature: $t := \frac{270 + 30}{2} \cdot \mathrm{C}$ $\quad t = 150 \circ\mathrm{C}$

Heat transfer coefficient:

$$\alpha_{air} := \frac{Nu_{air} \cdot \lambda_{air}}{L} \qquad \alpha_{air} = 7.85 \circ \frac{\mathrm{W}}{\mathrm{m}^2 \cdot \mathrm{C}}$$

4.3 Verification of supporting structure 30RR50-DR50

Supporting structure	Type of loading	Loads [N]		
		F_x (N-S)	F_z (E-W)	F_y (vertical)
30RR50-DR50	R1	37800		14000
	T1	0		0

The criteria of *linear type supports* were used for the evaluation of standard beam elements (hollow squared section 200×200×8), and the criteria of *plate and shell type supports* were used for the evaluation of the connecting plates and 'U' channel beams.

A finite element model of the supporting structure was made. The model can be seen in figure-1.

The horizontal loads act in direction 'z'.
Loads:

F_y = 14000 N
F_z = 37800 N

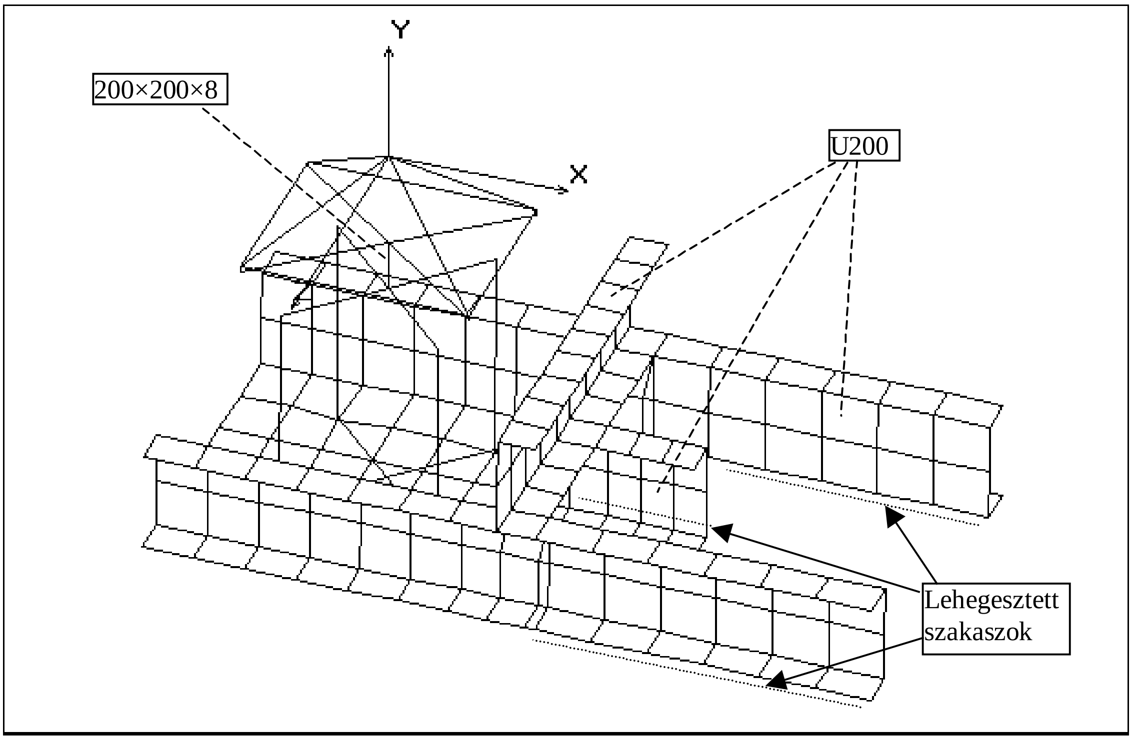


Figure -1. Finite element model

Model make up and its features:

Item 1: M22 bolts
Elements: 25-28

Items 5., 12.: M24 bolts
Elements: 29-39

Item 16.: 200×200×8 squared section
Elements: 37-38

Items 3., 4., 8., 9., 11.: U200 channel beam + plates (*SHELL*)
Elements: 39-253

Results:

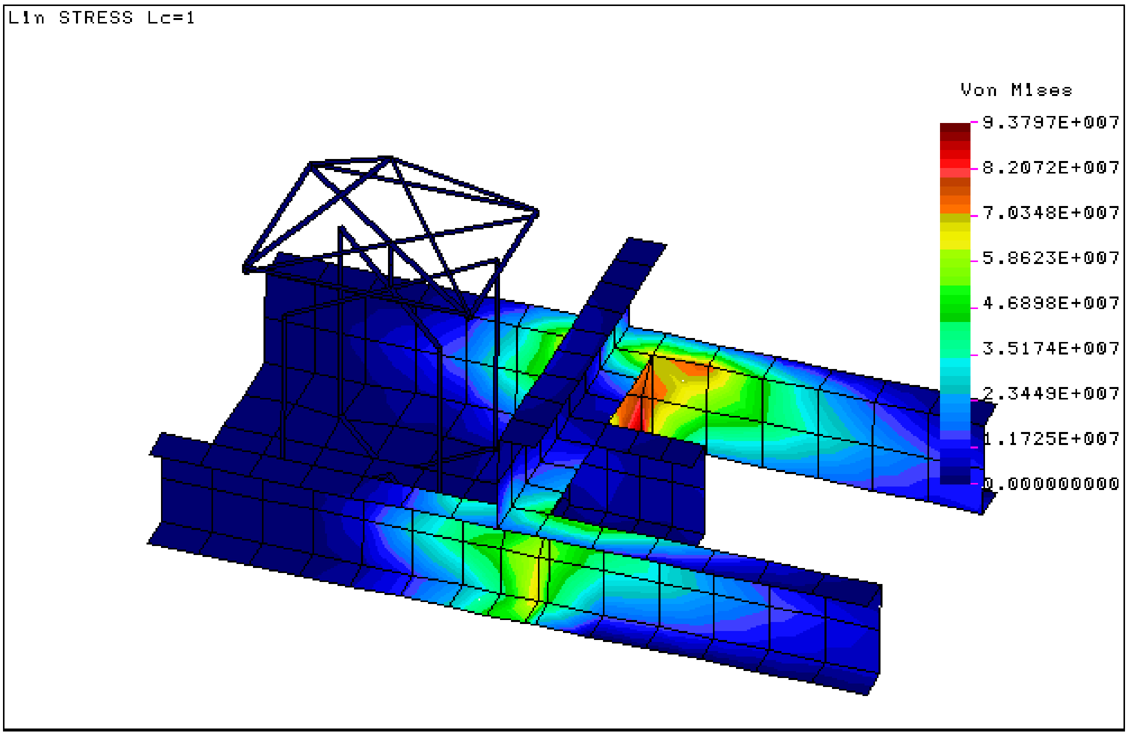


Figure -2. Von Mises stress distribution (membrane stresses) [Pa]

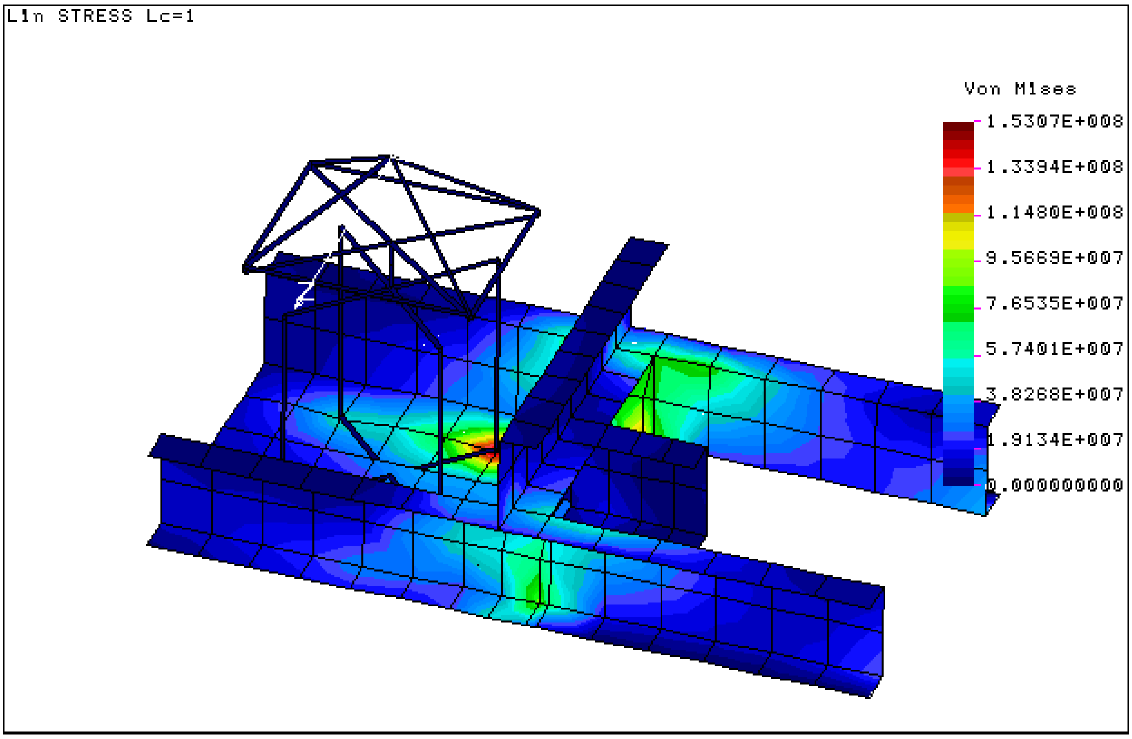


Figure -3. Von Mises stress distribution (membrane + bending stresses) [Pa]

Evaluation:

200×200×8 hollow squared section (*Linear type*):

Material: S355J2H

Element loads: tension/compression, shearing, bending

Allowable shear stress: F_v = min.{0.72S_y; 0.42S_u} = 205.8 MPa	Allowable tensile stress: F_t = min.{1.2S_y; 0.7S_u} = 343 MPa	Allowable bending stress (Compact section): $F_b = f \times S_y$ = 351 MPa

Maximum stress due to tension/compression plus bending is 31.7 MPa. Maximum shear element loads are two times more than tensile loads. Maximum stress due to tension/compression is 2.3 MPa. The acceptance criteria are met.

U200 + plates, (*Shell type*):

Material: S235JRG2

Element loads: tension/compression, bending

Acceptance criteria:

Primary membrane stress intensity *(Figure-2)*:

$P_m < \max.\{1.2S_y; 1.5S_m\} = 282$ MPa

and

$P_m < 0.7S_u = 238$ MPa

Primary membrane plus bending stress intensity *(Figure-3)*:

$P_m + P_b < 1.5\times\max.\{1.2S_y; 1.5S_m\} = 423$ MPa

és

$P_m + P_b < 1.05S_u = 357$ MPa

Calculated membrane plus bending stress intensity:

$P_m + P_b = P1 – P3 = 174$ MPa

The calculated stresses are less then the stress limits, so the acceptance criteria are met.

M22 bolts:

Material: 5.6

Cross section: A = 292 mm^2

Element loads: tension

Acceptance criterion:

$f_t < F_{tb}$

Allowable tensile stress:

$F_{tb} = \min.\{S_y; 0{,}7S_u\} = 300$ MPa

Calculated tensile stress:

$f_t = F_r/A = 45$ MPa $< F_{tb}$; acceptance criterion is met.

M24 bolts:

Material: 5.6

Cross section: A = 338 mm^2

Element loads: tension, shearing

Acceptance criterion:

$$\frac{f_t^2}{F_{tb}^2} + \frac{f_v^2}{F_{vb}^2} \le 1.0$$

Allowable tensile stress: $F_{tb} = \min.\{S_y; 0.7S_u\} = 300$ MPa	Allowable shear stress: $F_{vb} = \min.\{0.6S_y; 0.42S_u\} = 180$ MPa
Calculated tensile stress: $f_t = F_r/A = 223$ MPa $< F_{tb}$	Calculated shear stress: $f_v = \sqrt{V_s^2 + V_t^2} / A = 94.6$ MPa $< F_{vb}$

$$\frac{f_t^2}{F_{tb}^2} + \frac{f_v^2}{F_{vb}^2} = 0.83 < 1.0\text{; acceptance criterion is met.}$$

4.4 Thermal analysis of supporting structure 30RR50-DR50

Concerning heat transfer the connecting ’T’ section is of primary importance. Only parts of the supporting structure outside the pipe insulation were taken into consideration when calculating heat rejection. The supporting structure is connected to the cover plate of the GERB damper. There are two insulation plates between the damper and the connecting structure. The bottom plate of the damper has to be connected without insulation so that the temperature of the GERB element decreases to the level required.

In *Figure-4*. the temperature distribution of the supporting structure outside the pipe insulation, and the connecting cover plate of GERB damper can be seen.

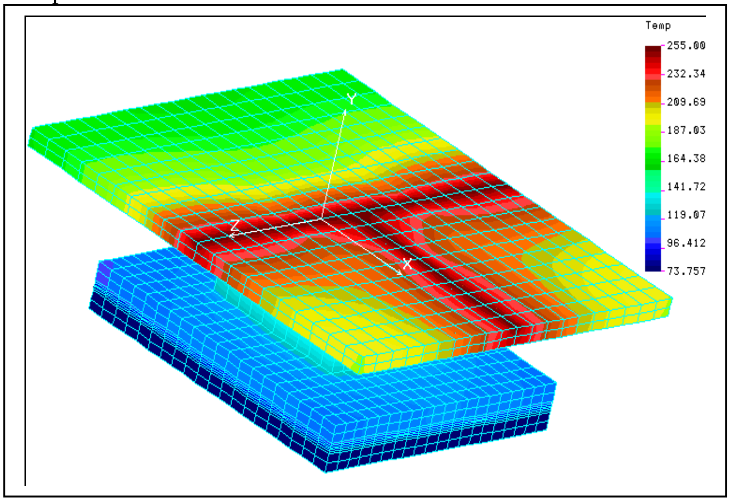


Figure-4: temperature distribution of supporting structure 30RR50 DR50 between the pipe insulation and the GERB damper

Results:

Supporting structure	T_{pipe} °C	$T_{ambient}$ °C	T_{Gerb} °C (Cover / bottom)
30RR50 DR50	255	27	74 (Cover)

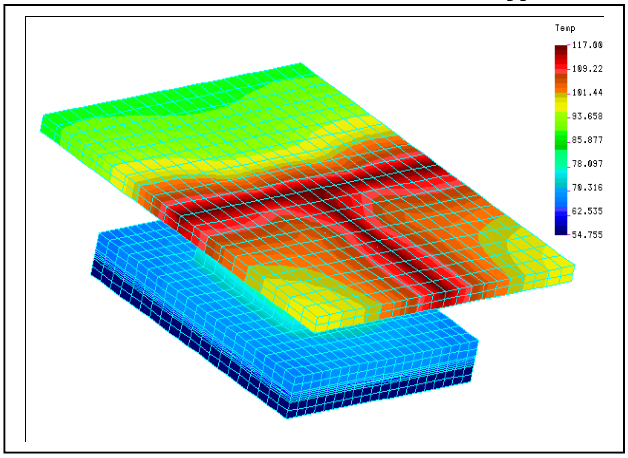
Acceptance criterion:

The service temperature of the selected viscoelastic medium of damper has to be lower than or equal to the limit value (in this case 60 °C). In case of connecting to the cover plate of damper, the temperature of the connected region may be higher (max. 20 °C, according to the manufacturer) because of the heat rejection of the GERB damper itself.

After the installation during operation of the system, when the photos were made, we measured the temperatures of the following elements:

wall of the pipe the temperature was 117 °C
ambient air the temperature was 33 °C
cover of damper the temperature was 55 °C

Using the above measures we recalculated the heat transfer of the support.



According the recalculation the temperature of the cover was 54,7 °C. This result is very conform of the measured value demonstrated the suitability of the calculation.

REFERENCES

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[2] Guidelines for Evaluation of Equipment Anchorage; Report rep21-97.pks. Stevenson and Associates, Plzen 1997

[3] M.A. Mihejev: The Basics of Empirical Calculation of Heat Transfer

[4] ASME Boiler and Pressure Vessel Code, Section III, Division 1, Subsection NF – Supports; 1998

[3] ASME Boiler and Pressure Vessel Code, Section III, Division 1, Appendices; 1998

[5] ASME Boiler and Pressure Vessel Code, Section II, Part D, Properties; 1998