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SOME ASPECTS OF THE SPRING HANGER DESIGN PROCEDURE FOR PIPING FLEXIBILITY ANALYSIS

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ABSTRACT

Influence of the spring hanger design on the piping flexibility and stress analysis is considered in the presented paper. Three aspects of this procedure are discussed and illustrated by the numerical examples:

- load variation criteria: different interpretations of load variability could lead to different sizes and even types of selected springs. The key issue of this problem is definition of the cold load (theoretical installed load vs. actual cold load);

- influence of the different nonlinearities (hanger's side forces due to short rod length and support's friction) on the values of calculated piping thermal movements and hence on the type of selected springs;

- modeling and interpretation of spring hanger loads within calculation of sustained stresses.

Being differently realized in the commercially available programs for piping flexibility analysis these effects are significant for flexible hot pipes and could introduce a big scattering of results.

NOMENCLATURE

R_H	=	design (hot) load
R_C	=	cold load
R_0	=	theoretical cold load
k_S	=	spring rate
k_R	=	rigid stiffness
u	=	piping deflections for "restrained" load case
$u_H(u_0)$	=	piping deflections for operational (hot) load case
u_C	=	piping deflections for cold load case
var	=	load variation
K	=	stiffness matrix of piping system (without including spring hangers)
P	=	pressure
W	=	weight loads
T	=	thermal expansion loads
R_{MIN}	=	spring hanger minimal permissible load
R_{MAX}	=	spring hanger maximal permissible load

DEFINITIONS

For the subsequent discussion the following terms are defined:

Design Load (R_H) is a target hanger load that should balance weight of the piping. Design load is calculated as reaction of the vertical rigid restraint installed in the location of the designed spring hanger. For this case it is assumed that piping is subjected to sustained loads only (weight of insulated pipe with medium content). Sometimes Design Load is also referred to as Hot Load due to the fact that for most cases a weight balance should be achieved in the operational (hot) state.

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Cold Load (R_C) is reaction of spring hanger support in the cold state, when piping has an ambient temperature and no medium inside.

Hanger Travel characterizes vertical piping movement that could be measured in the location of spring hanger support between installed (cold) and operating (hot) positions.

Spring Rate (k_S) is a stiffness of spring hanger support. Spring Rate depends on the type and number of springs used for a given hanger support.

Theoretical Cold Load (R_0):

$$R_0 = R_H + k_S * u_0 \qquad (1)$$

Load Variation (var) is the maximum variation between the cold and hot loads:

$$var = \frac{|k_S \times travel|}{R_H} = \frac{|R_H - R_C|}{R_H} \qquad (2)$$

INTRODUCTION

Design of spring hanger supports is a routine procedure that each piping analyst performs many times during his engineering career. However, in spite of apparent simplicity of this process there are significant peculiarities that should be addressed in piping flexibility and stress analysis.

One of the most significant factors influenced on the overall results of spring hanger design is criterion for load variation. There are well-known requirements for limitation of spring variability values: according to western engineering practice load variation for variable spring hangers should not exceed 25% threshold [1]; otherwise constant load hangers should be installed instead. In Russia, where Constant Load Hangers practically are not used, this value is extended up to the level of 35% [2].

It is important to understand that requirement for load variation was derived based on the following factors:

1. Historically, limited value of load variation was a justification for not including spring stiffness in the thermal expansion range calculations.

2. Code compliance check for sustained stresses is normally performed for the hot state when design (hot) load is acted on the pipe. Limited value of load variation could guarantee acceptable level of sustained stresses for piping in the cold state without additional analysis.

3. Significantly unbalanced piping weight in the cold state could cause difficulties in adjustment of spring hangers during installation and also impact horizontal tangent deflection slope causing problems in pipe draining.

However, modern engineering tools and approaches allow more precise evaluation of these factors and could lead to the relaxation of sometime unduly restrictive limits for load variation.

SPRING HANGER DESIGN ALGORITHMS

Two commonly used spring hanger design algorithms are considered below:

- ***Conventional "one step"*** algorithm realized in the most commercial software packages, Figure 1;

- ***Iterative*** algorithm realized in some programs and used as standard in Russian engineering practice since the early 70's [3], Figure 2.

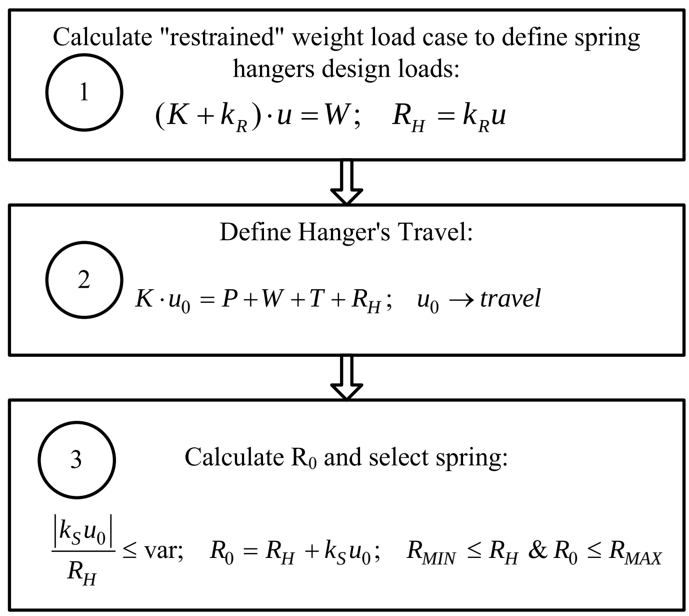

Figure 1
One step algorithm for spring hanger design

Numerical examples given below illustrate both these algorithms for design of spring hanger supports. A first example (Figure 3) is a fragment of the conventional power plant Main Steam Line located between two fix points: boiler header and turbine stop valve. This system, designed more than 20 years ago, has a typical floating design: heavy and flexible pipe is suspended between two anchor points by spring hangers only.

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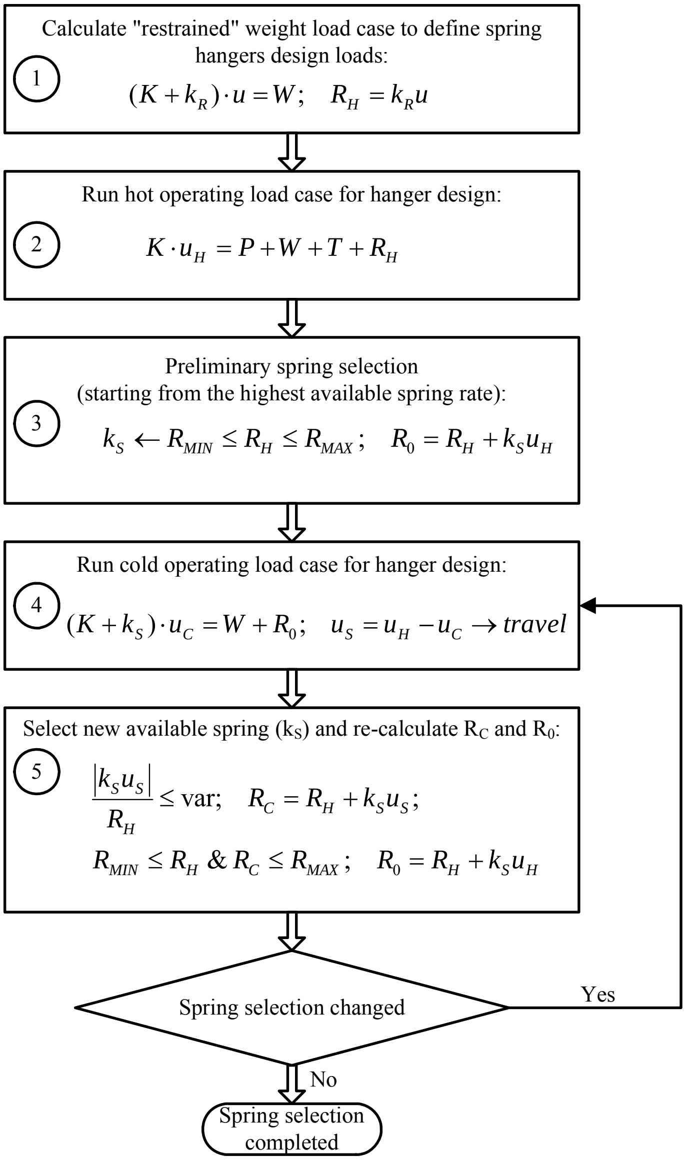

Figure 2
Iterative algorithm for spring hanger design

Tables given in Annex A demonstrate results of spring's selection procedure performed according to the above algorithms. Springs were selected from LISEGA 2010 Catalogue. In both cases a target load variation criteria was set to 25%. Each selected spring is designated as “X/Y”, where X – spring size, Y –travel range (i.e. designation “4/3” corresponds to LISEGA type number “21**43**28”).

Results of analyses show that in case of flexible piping (floating design) above algorithms lead to essentially different results:

According to the "traditional" one step algorithm (Table 1):

- spring hanger actual cold loads R_C significantly differ from the theoretical cold loads R_0;
- a most flexible and bulky springs were selected for supports NN 07, 08 ,09 and 14, but load variation criteria are still not satisfied for supports NN 08 and 09. It means that on practice designer most probably would prefer more expensive constant load spring hangers;
- most interesting result was obtained for spring hanger support N 12: computer check of R_0 vs. R_{min} does not indicate any problem, but actual cold load R_C is less than R_{min};
- satisfying load variation criteria for R_0 does not guarantee good weight balancing of piping in the real cold state (support N 12).

Iterative algorithm (Table 2) in contrast to the traditional one utilizes real values of load variation and problems described above are not appear. Although the theoretical variability var(R_0) is much higher than 25%, the actual variability is in the specified limits. Moreover, comparison of results from Tables 1 and 2 leads to conclusion that iterative algorithm provides more compact and economic springs for hanger supports.

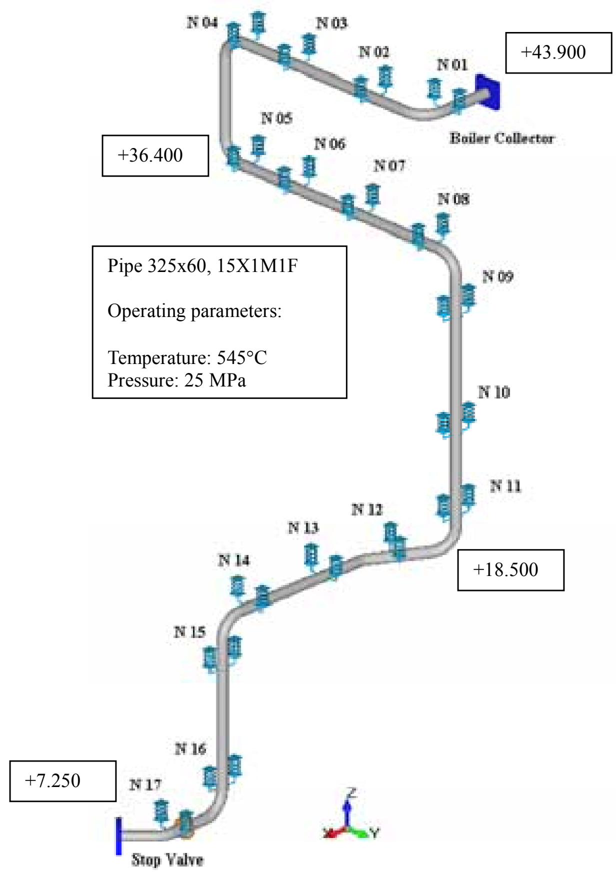

Figure 3
Example 1 (floating design)

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Same piping system but with changed support configuration is considered in Example 2. Rigid hanger supports are installed instead of spring hangers NN 07, 10, 13 and support N 06 is excluded as shown in Figure 4.

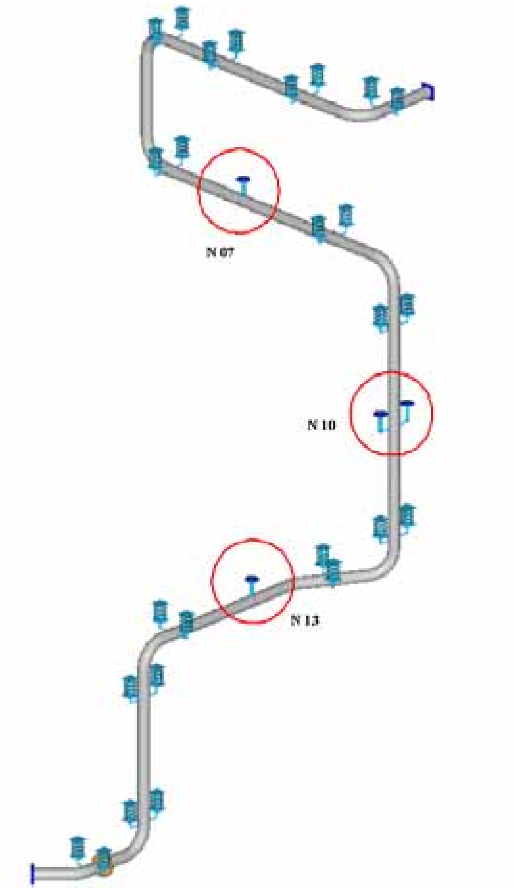

Figure 4
Example 2 (rigid design)

Unlike first example influence of spring stiffness on the vertical movements is significantly less.

Results for this case (Tables 3, 4) demonstrate invariance of selected springs to the implemented algorithm: both approaches lead to practically identical results. Only in one instance traditional algorithm selects more flexible spring (N 15)

INFLUENCE OF NONLINEARITIES ON ACTUAL SPRING HANGER LOADS

Once being designed spring hanger supports should be properly represented in the subsequent piping flexibility analysis. On this stage piping engineer should be aware that factors, which are usually not considered in analysis on the stage of spring hanger design (friction in sliding or guide supports, hanger lateral restoring forces caused by short rod length and also referred to as swing effect) could significantly influence on the final results.

Next numerical examples show influence of above factors on the values of the actual load variation. For evaluation of both these effects a horizontal high temperature pipe rested on sliding supports (Figures 5) or suspended by rod hangers (Figures 6) is considered as example. At the end of its length pipe makes a loop, where two variable spring hangers are located. In case of sliding supports friction coefficient was assumed to be equal 0.3. For rod hanger case length of rods equal to 1.5 m was selected to meet requirements for non-exceeding of 4° angularity limit.

Table 5 summarizes results for spring hanger loads derived from the analyses. Load variation coefficients ***var_hot*** and ***var_cold*** were calculated against design hot load. On the design stage desired variability was set to not exceed 35 % limit. However, from the real operational load cases it achieves value of 38 % in case of friction. Moreover, difference between design and actual hot loads achieves 22 % for friction case and 11 % for swing effect. It should be noted that such weight imbalance for the operation hot state could be dangerous for pipes operated at elevated temperature in creep conditions.

This discrepancy between design and actual hot loads could be avoided considering friction or swing effects on the stage of spring hanger design. However, taking into account the uncertain nature of these nonlinearities, it appears that more robust solution is the fulfillment of certain actions to reduce the impact of these effects on the system. At the same time piping software must clearly indicate these effects for designer to perform follow-up measures.

Table 5
Influence of friction and swing effect on spring hanger loads.

Parameters	Spring Hanger Design	Operational Load Cases	
		Friction	Swing
Support N 01			
Hot Load, R_H	12.22 kN	9.54 kN	10.92 kN
Cold Load, R_C	16.18 kN	16.91 kN	16.24 kN
var_hot	0 %	**22%**	**11%**
var_cold	32 %	38%	33%
Support N 02			
Hot Load, R_H	11.74 kN	9.62 kN	10.77 kN
Cold Load, R_C	14.72 kN	15.29 kN	14.76 kN
var_hot	0%	**18%**	**8%**
var_cold	25%	30%	26%

As the next step of this study influence of the above effects on the calculation of sustained stresses is considered. Before

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doing this we need once again come back to the most commonly used algorithms realized in popular piping software.

<u>**Cold** support configuration algorithm.</u>

According to this algorithm several load cases (LC) should be performed for stress analysis:

LC1: $(K + k_S) \cdot u = W + R_0$ → **SUST COLD**
LC2: $(K + k_S) \cdot u = P + W + T + R_0$ → **OPER HOT**
LC3 = *LC2 – LC1* → **EXP**

In the above equations LC1 corresponds to sustained loads applied to the system in the cold state. Sustained stresses (SUST) are calculated directly from this equation taking into account an operational internal pressure and hot allowable stress limits. LC2 defines an operational hot state (OPER) and could be used to calculate an actual hot loads acted on supports and equipment. Expansion stresses (EXP) are calculated as difference between hot and cold loads (LC3).

<u>**Hot** support configuration algorithm</u>

LC1: $(K + k_S) \cdot u = W + R_0$ → **OPER COLD**
LC2: $(K + k_S) \cdot u = P + W + T + R_0$ → **OPER HOT**
LC3: $K \cdot u = T$ → **FREE THERMAL**
LC4 = *LC2 – LC3* → **SUST**
LC5 = *LC2 – LC1* → **EXP**

This algorithm performs first two load cases for cold (LC1) and hot (LC2) loads. Then, additional "free thermal case" is executed (LC3). This load case assumes weightless piping. Sustained stresses (LC4) are calculated as difference between LC2 and LC3. And simultaneously expansion stresses (LC5) are calculated as difference between hot and cold loads.

<u>**Modified Hot** support configuration algorithm</u>

LC1: $(K + k_S) \cdot u = P + W + T + R_0$ → **OPER HOT**
$R_H = R_0 - k_S u$ *save status one-way supports*
Actual Spring Hot Load

LC2: $K \cdot u = P + W + R_H$ → **SUST HOT**
(no friction & no lift-off supports)

LC3: $(K + k_S) \cdot u = W + R_0$ → **OPER COLD**
LC4 = *LC3 – LC1* → **EXP**

This algorithm is used in Russia for the design of power piping since middle seventies [3]. Analysis starts from the hot operational load case LC1 taking into account all kinds of nonlinearities existing in piping supports. Spring hanger actual hot load R_H is calculated and status of one-way supports is checked and saved for the next step. LC2 is performed to calculate sustained stresses. No friction or swing effects are included in solution. One-way supports with lift-off may be excluded or may be not from this load case depending on the lift-off criteria (1/16" is a good practice). It should be noted that piping displacements calculated on this stage are fictitious and the main purpose of this analysis is assessment of piping weight balance for operational hot state. Cold loads are calculated as LC3 and expansion stresses are defined as difference between LC1 and LC3.

Figures 7 & 8 show results for sustained and creep range stresses. Calculations were performed according to provisions of EN 13480-3 "Metallic industrial piping - Part 3: Design and calculation". Above algorithms were implemented for Example 3 piping (Figure 5). Analysis of these results leads to the following conclusions:

- ***Cold support configuration algorithm***. The disadvantage of this algorithm is incorrect treatment of the spring hanger loads: cold loads are applied to the system instead of the actual hot loads. In case of big load variation or significant nonlinearities R_H and R_C could vary considerably that will lead to incorrect stress calculations. For the given system it appears in the nodes 105 and 106: sustained stresses in these points are underestimated. Moreover, in case of supports lift-off these effects may increase.

- ***Hot support configuration algorithm***. As can be seen from the results, the application of this algorithm leads to a substantial overestimation of stress values. The main reason for this is that the free thermal load case is performed for a weightless piping and secondary friction forces are transferred to the primary sustained loads, which is contrary to the nature of these loads. The appearance of this discrepancy can be seen in the horizontal section of the piping (nodes 195 - 225): sustained stresses exceed the allowable values, although the weight of this part is well balanced and there is no such problems should arise in principle.

- ***Modified Hot support configuration algorithm***. It seems that this approach is more robust to handle above effects: algorithm provides appropriate treatment of spring hanger loads and accounting of nonlinearities is more consistent.

- In case of linear systems both Hot and Modified Hot algorithms lead to identical results.

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CONCLUSION

Approaches for quantitative evaluation of spring hanger supports in frame of piping flexibility analysis, starting from the design stage and ending with stress analysis, were evaluated and presented in this paper. Examples were shown where currently available commercial software products, with different underlying algorithms, produce significantly different results. Therefore this paper presented alternative approaches which were shown to produce consistent results for all considered cases.

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2. RTM 24.038.12-72, Spring hanger design for Power and Nuclear Piping, Technical Guidance Material, CKTI, 1972
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ANNEX A

TABLES AND FIGURES FROM NUMERICAL EXAMPLES

Table 1
Example 1. Selection of springs according to one step algorithm (floating design).

Support №	Designation	Spring Rate, N/mm	R_{min}	R_{max}	R_H	R_C	R_0	var (R_C)	var (R_0)	
			kN					%		
01	4/1	133.4	3.33	10	9.52	9.41	9.56	1	0	
02	5/2	133.4	6.66	20	12.99	13.92	14.95	7	15	
03	4/3	33.3	3.33	10	7.16	7.99	8.52	12	19	
04	5/3	66.7	6.66	20	16.26	18.55	19.79	14	22	
05	5/1	266.8	6.66	20	17.21	13.60	19.09	21	11	
06	4/3	33.3	3.33	10	5.32	5.55	6.45	4	21	
07	5/5	33.3	6.66	20	12.25	13.57	14.81	11	21	
08	5/5	33.3	6.66	20	9.38	11.98	13.52	28	**44**	**variation !**
09	5/5	33.3	6.66	20	13.93	16.02	17.65	15	**27**	**variation !**
10	5/4	44.5	6.66	20	12.63	13.06	15.22	3	20	
11	5/3	66.7	6.66	20	10.68	8.81	12.05	18	13	
12	5/2	133.4	**6.66**	20	9.40	**6.05**	11.27	36	20	**$R_c < R_{min}$!**
13	5/3	66.7	6.66	20	11.65	12.32	14.10	6	21	
14	5/5	33.3	6.66	20	9.98	11.84	12.26	19	23	
15	5/4	44.5	6.66	20	12.85	15.03	15.35	17	19	
16	5/1	266.8	6.66	20	14.36	13.06	14.98	9	4	
17	5/1	266.8	6.66	20	16.50	15.31	15.79	7	4	

Table 2
Example 1. Selection of springs according to iterative algorithm (floating design).

Support №	Designation	Spring Rate, N/mm	R_{min}	R_{max}	R_H	R_C	R_0	var (R_C)	var (R_0)
			kN					%	
01	4/1	133.4	3.33	10	9.52	9.38	9.56	2	0
02	5/1	266.8	6.66	20	12.99	13.92	16.90	7	30
03	4/2	66.7	3.33	10	7.16	8.21	9.87	15	38
04	5/2	133.4	6.66	20	16.26	19.18	23.31	18	43
05	5/2	133.4	6.66	20	17.21	13.68	18.15	21	5
06	4/1	133.4	3.33	10	5.32	4.61	9.86	13	85
07	5/3	66.7	6.66	20	12.25	14.05	17.37	15	42
08	5/5	33.3	6.66	20	9.38	11.52	13.52	23	44
09	5/3	66.7	6.66	20	13.93	17.15	21.36	23	53
10	5/1	266.8	6.66	20	12.63	11.32	28.13	10	123
11	5/4	44.5	6.66	20	10.68	8.79	11.59	18	9
12	4/3	33.3	3.33	10	9.40	8.11	9.87	14	5
13	5/1	266.8	6.66	20	11.65	11.68	21.46	0	84
14	5/4	44.5	6.66	20	9.98	12.26	13.02	23	30
15	5/3	66.7	6.66	20	12.85	15.95	16.60	24	29
16	5/1	266.8	6.66	20	14.36	12.38	14.98	14	4
17	5/1	266.8	6.66	20	16.50	15.13	15.79	8	4

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Table 3
Example 2. Selection of springs according to one step algorithm (rigid design).

Support №	Designation	Spring Rate, N/mm	R_{min}	R_{max}	R_H	R_C	R_0	var (R_C)	var (R_0)
			kN					%	
01	4/1	133.4	3.33	10	9.52	9.37	9.43	2	1
02	5/1	266.8	6.66	20	13.01	13.81	14.23	6	9
03	4/2	66.7	3.33	10	7.09	8.04	8.09	13	14
04	5/2	133.4	6.66	20	16.48	19.12	18.91	16	15
05	5/2	133.4	6.66	20	17.09	13.21	12.90	23	24
06	Excluded								
07	Rod Hanger								
08	5/3	66.7	6.66	20	13.43	16.33	16.43	22	22
09	5/3	66.7	6.66	20	16.00	18.98	18.98	19	19
10	Rod Hanger								
11	5/3	66.7	6.66	20	15.00	11.92	11.92	21	21
12	4/3	33.3	3.33	10	9.56	8.21	8.19	14	14
13	Rod Hanger								
14	5/4	44.5	6.66	20	10.07	12.40	12.48	23	24
15	5/4	44.5	6.66	20	12.80	14.92	15.01	17	17
16	5/1	266.8	6.66	20	14.35	12.68	13.22	12	8
17	5/1	266.8	6.66	20	16.52	15.25	15.38	8	7

Table 4
Example 2. Selection of springs according to iterative algorithm (rigid design).

Support №	Designation	Spring Rate, N/mm	R_{min}	R_{max}	R_H	R_C	R_0	var (R_C)	var (R_0)
			kN					%	
01	4/1	133.4	3.33	10	9.52	9.37	9.43	2	1
02	5/1	266.8	6.66	20	13.01	13.81	14.23	6	9
03	4/2	66.7	3.33	10	7.09	8.04	8.09	13	14
04	5/2	133.4	6.66	20	16.48	19.12	18.91	16	15
05	5/2	133.4	6.66	20	17.09	13.20	12.90	23	24
06	Excluded								
07	Rod Hanger								
08	5/3	66.7	6.66	20	13.43	16.33	16.43	22	22
09	5/3	66.7	6.66	20	16.00	18.98	18.98	19	19
10	Rod Hanger								
11	5/3	66.7	6.66	20	15.00	11.92	11.92	21	21
12	4/3	33.3	3.33	10	9.56	8.21	8.19	14	14
13	Rod Hanger								
14	5/4	44.5	6.66	20	10.07	12.38	12.48	23	24
15	5/3	66.7	6.66	20	12.80	15.93	16.12	24	26
16	5/1	266.8	6.66	20	14.35	12.47	13.22	13	8
17	5/1	266.8	6.66	20	16.52	15.18	15.38	8	7

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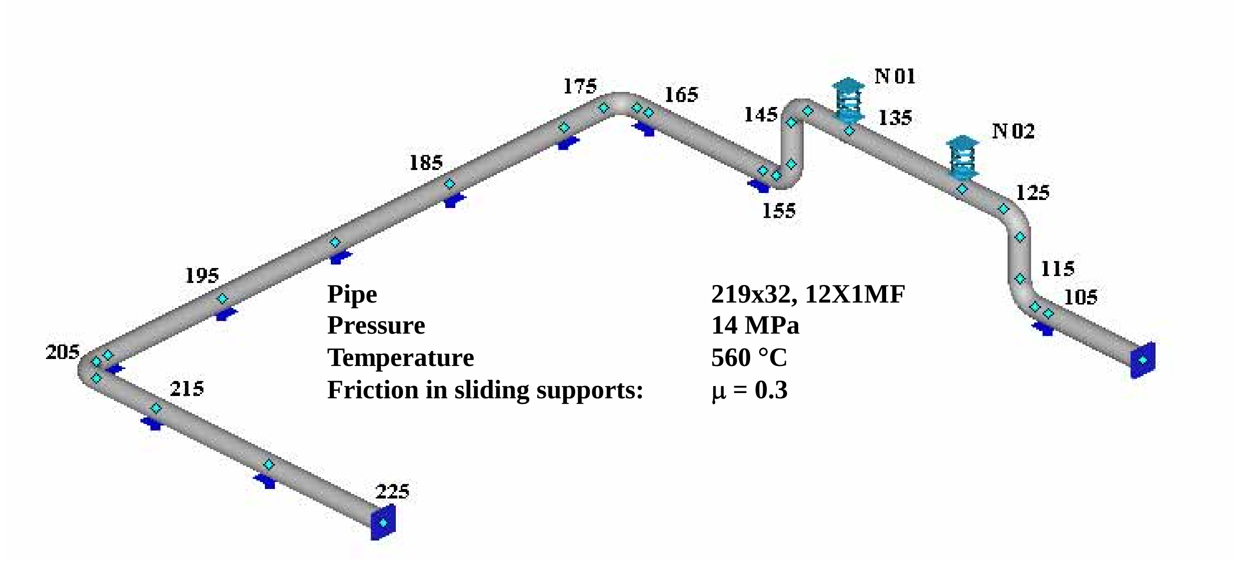

Figure 5
Example 3. Influence of Friction

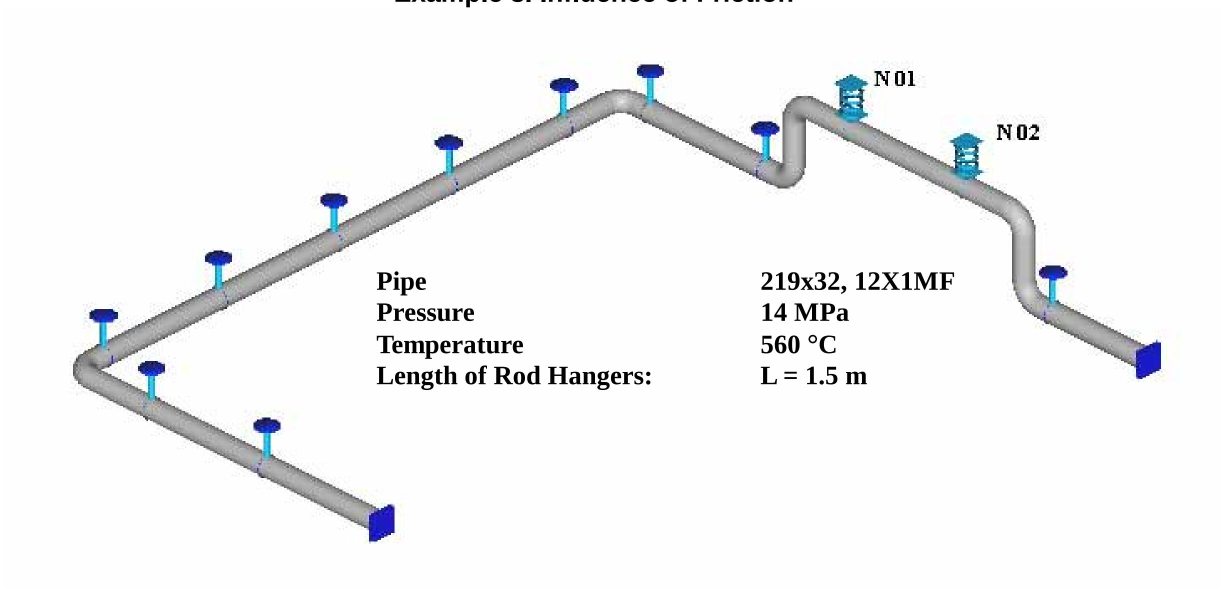

Figure 6
Example 4. Influence of Swing

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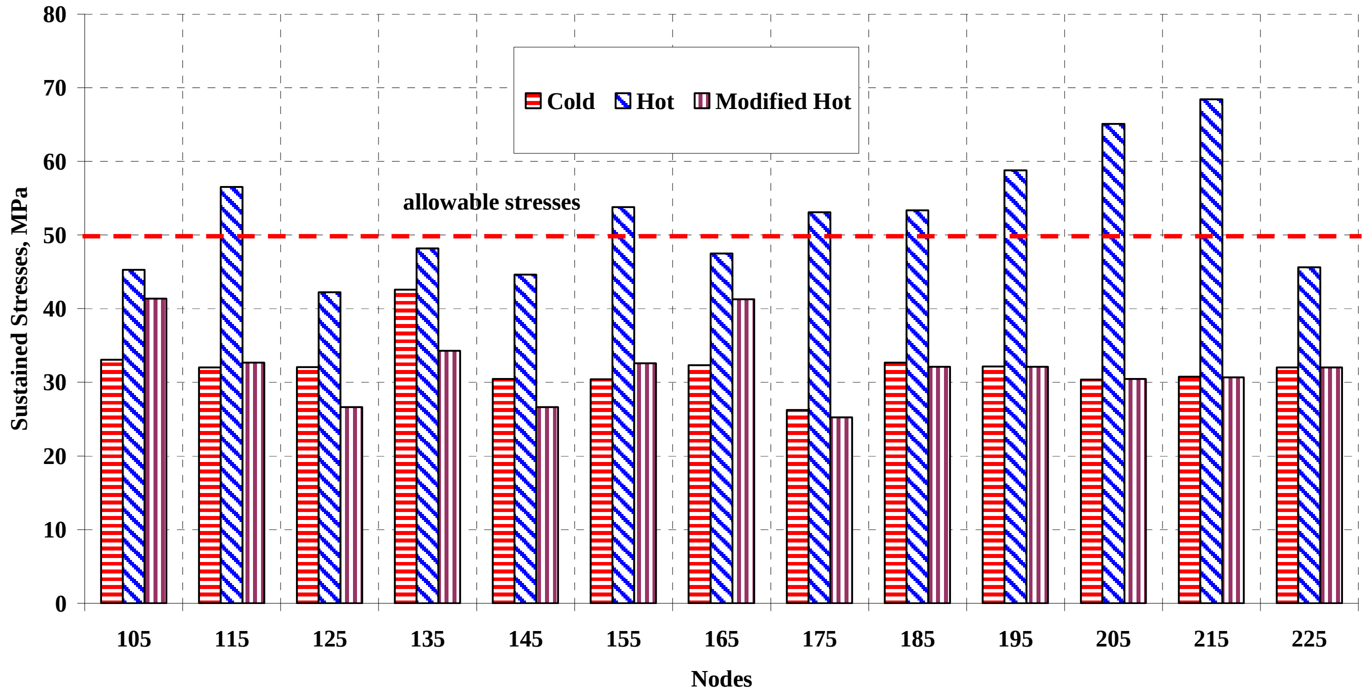

Figure 7
Distribution of sustained stresses along pipe (Example 3)

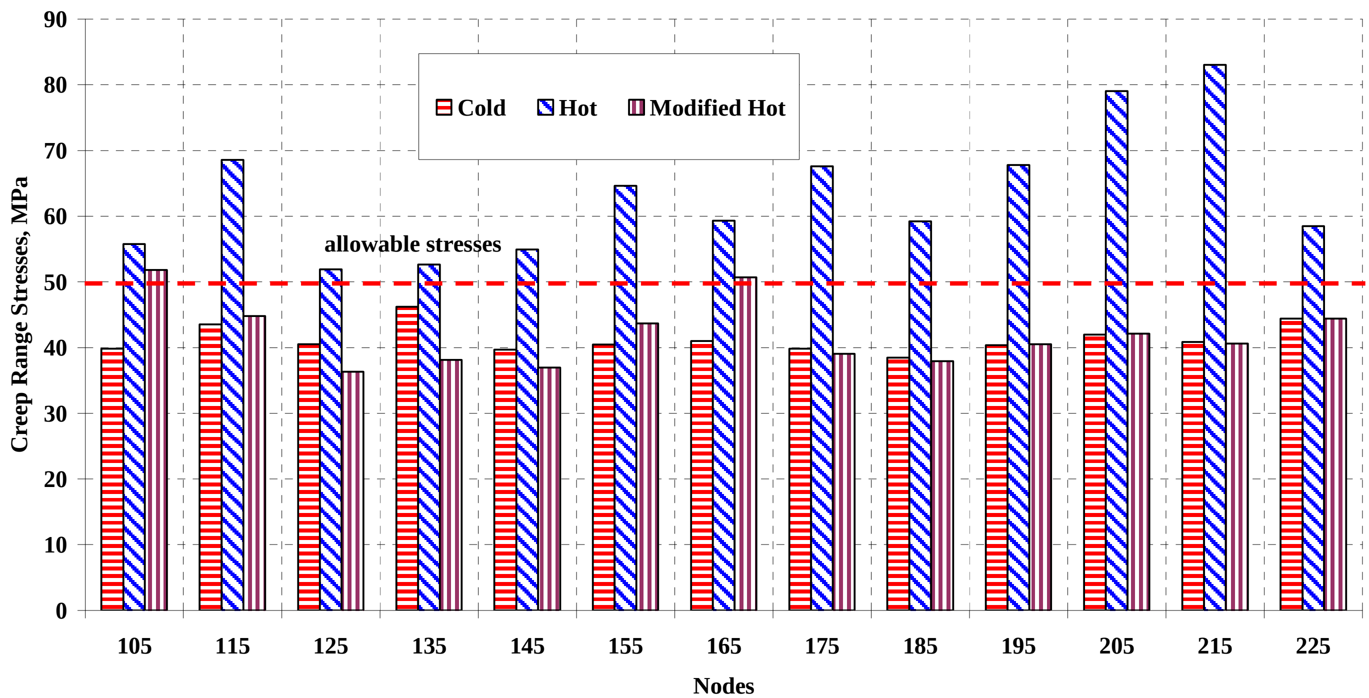

Figure 8
Distribution of creep range stresses along pipe (Example 3)

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