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Translated by: Name and Address	SCITRAN COMPANY 1482 East Valley Road Santa Barbara CA 93150 (805) 969-2413

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STRENGTH RATING STANDARDS OF NUCLEAR POWER EQUIPMENT
AND PIPING PNAE G-7-002-86

Rules and standards in nuclear power engineering. Approved by the USSR State Committee on Use of Nuclear Power. Approved by the USSR State Committee on Inspecting Safe Operation in Nuclear Power Engineering. Mandatory for all ministries, departments, organizations and enterprises that are planning, designing, fabricating and operating nuclear power plants, heating plants, experimental and research nuclear reactors and units under the control of the USSR State Committee for Inspection of Safe Operation in Nuclear Power Engineering. Put into effect 1 July 1987 with changes.

5.7. Calculation for Continuous Cyclic Strength /92*

5.7.1. The calculation for continuous cyclic strength is made as applied to structural components operating at temperatures causing /93
creep and with loaded repeated thermal or mechanical stresses.

5.7.2. The recommended method for calculating for continuous cyclic strength is presented in Appendix 7.

The calculation uses the characteristics of continuous strength and plasticity according to Tables A6.1 and A6.3.

5.7.3. The structural component calculated for continuous cyclic strength must satisfy:
1) strength conditions adopted in selecting main dimensions in the entire operating temperature interval;
2) strength conditions in the calculation for continuous static strength.

5.7.4. Other methods can be used on the condition that they have proper calculation and experimental substantiation for the materials employed, operating conditions and operating lifetime for

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*Numbers in margin indicate pagination in original foreign text.

the number of cycles and duration of loading.

5.8. Calculation for Brittle Failure Strength

5.8.1. General points.

5.8.1.1. Based on the points of this section a calculation is made for brittle failure strength of nuclear power equipment and piping at the planning stage.

5.8.1.2. The points of this section do not cover calculation of fastening parts.

5.8.1.3. The calculation for brittle failure strength of equipment and piping components is made for all operating conditions, including normal operating conditions (NOC), violation of normal operating conditions (VNOC), emergency situations (ES) and hydraulic (pneumatic) tests.

5.8.1.4. The main characteristics of the material used in the calculation are the critical coefficient of stress intensity K_k, critical brittleness temperature T_k and yield strength $R^T_{p0.2}$.

Change in the properties and materials during operation is taken into consideration by adding to the calculation shift in critical brittleness temperature because of various factors in the operating process.

5.8.1.5. If the thickness of the walls of the calculated components is less than the required thicknesses for determining that the values K_k according to the points of GOST 25.506-85, critical opening of cracks δ_c or other characteristics (K_c, J_c) that can be defined according to the aforementioned GOST may be used in calculations for brittle failure strength.

The calculation techniques using the indicated characteristics /94
must be agreed upon with the main organization for developing strength calculation standards.

5.8.1.6. Brittle failure strength is considered guaranteed if the following condition is fulfilled for the selected calculated defect in the form of a crack in the operating mode under discussion

$$K_1 \leq [K_1]_i,$$

where $[K_1]_i$ is the permissible value of the stress intensity coefficient.

The index i indicates that the permissible values of the stress intensity coefficients vary depending on the calculated conditions: i = 1 for normal operating conditions; i = 2 for hydraulic (pneumatic) tests and violations of normal operating conditions; i = 3 for an emergency situation.

5.8.1.7. In defining $[K_1]_i$ the values of neutron migration F_n and temperature T are assumed to be equal to their values at the point corresponding to the greatest depth of the selected calculated crack.

5.8.1.8. If it is necessary to make calculation of equipment and piping in operation, fabrication or assembly, or completed by working planning at the moment these standards are put into operation it is permitted that:

1) points of this calculation may be used;

2) for equipment and piping in operation, by agreement between the design (planning) organization, main materiology organization, enterprise that own. the equipment and piping parameters of defects may be defined that are permitted from conditions of guaranteeing strength and by monitoring to confirm the absence in the equipment

and piping of defects whose parameters exceed those permitted by calculation; the calculation should use actual properties of materials, while the actual calculation (including schematization of the defects detected during monitoring) must be made by techniques agreed upon with the main organization for developing strength calculation standards;

3) for equipment and piping in fabrication, assembly or finished by working planning, techniques may be used that differ from that described in this section by agreement with the main organization for developing strength calculation standards and the USSR State Committee on Inspecting Safe Operation in Nuclear Power Engineering.

5.8.1.9. Calculation for brittle failure strength may not be made for structural components that are not subject to neutron irradiation (or are subject to irradiation at temperatures 25 - 350°C until migration of no more than 10^{22} neutron/m² with $E \geq 0.5$ MeV) in the following cases: /95

1) structural components are made of corrosion resistant steels of the austenite class or colored alloys;

2) material of the structural components (including welding connections) have yield point at temperature 20°C less than 300 MPa (30 kg-f/mm²), while the thickness of the structural component wall is no more than 22 mm;

3) materials of the structural components (including welded connections) have yield point at temperature 20°C less than 600 MPa (60 kg-f/mm²), while the thickness of the structural component wall is no more than 16 mm;

4) the thickness of the wall of the structural component under discussion smm, satisfies the condition

$$s \leqslant 8 \cdot 10^3 \left(\frac{[K_I]_1}{R^T_{p_{0.2}}} \right)^2$$

with $[K_1]_1$ in MPa x $m^{\frac{1}{2}}$ and $R^Tp0.2$ in MPa (both characteristics are adopted with the least operating temperature and critical brittleness temperature T_k corresponding to the end of operation).

5.8.1.10. The calculated thickness of the wall of the components of equipment and piping does not include the thickness of the anticorrosion coating.

5.8.2. Coefficient of stress intensity.

5.8.2.1. The coefficient of stress intensity for the selected calculated cracks is defined analytically, numerically or experimentally by techniques agreed upon with the main organizations for developing strength calculation standards.

5.8.2.2. The coefficient of stress intensity, MPa x $m^{\frac{1}{2}}$ for cylindrical, spherical, conical, elliptical, flat components loaded by internal pressure and temperature factors may be defined from the formula

$$K_1 = \eta(\sigma_p M_p + \sigma_q M_q)\left(\pi \frac{a}{10^3}\right)^{1/2} / Q,$$

where η is the coefficient that takes into consideration the impact of stress concentrations; σ_p is the component of stretching stresses, MPa; σ_q is the component of bending stresses, MPa; $M_p = 1 + 0.12 (1 - a/c)$; $M_q = 1 - 0.64\, a/h$; a is the depth of the crack, mm; c is the half length of the crack, mm; h is the length of the zone in whose limits the component of bending stresses maintains positive value, mm;

$$Q = [1 + 4.6(a/2c)^{1.65}]^{1/2}.$$

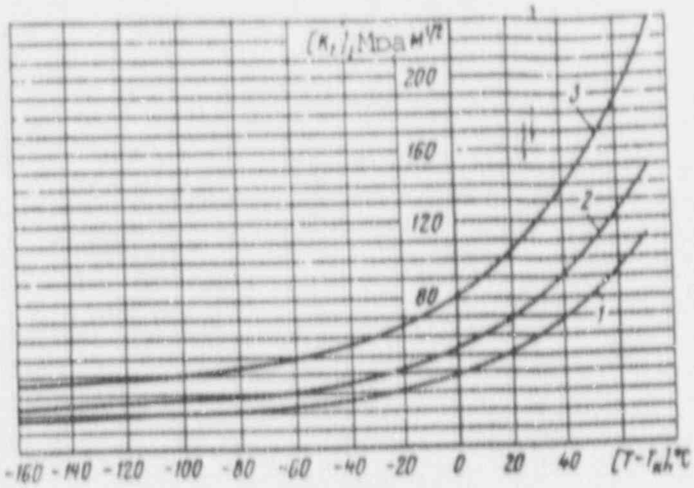

Figure 5.14. Steels of Grades 12Kh2MFA, 15Kh2MFA, 15Kh2MFA-A

Key:

1. NOC, $[K_1]_1 = 17.5 + 22.5\ c^{0.02(T-T_1)}$
2. VNOC and hydraulic (pneumatic) tests $[K_1]_2 = 23.5 + 30\ c^{0.02(T-T_1)}$
3. ES $[K_1]_3 = 35 + 45\ c^{0.02(T-T_1)}$

The formula is correct with $a \leq 0.25\ s$ and $a/c \leq 2/3$, where s is the thickness of the item wall. /96

In calculating the zones where stress concentration is missing $\eta = 1$ is assumed.

5.8.2.3. The stretching stress component (annular or axial) is defined from the formula

$$\sigma_{ip} = \frac{1}{s}\int \sigma_i \, dx.$$

where j is the θ or Z coordinate; σ_j is the function of stress change over the thickness of the wall; s is the thickness of the wall in the calculated section.

5.8.2.4. The value of the bending stress component is defined from the formula

$$\sigma_{ju} = \sigma_{jn} - \sigma_{jp},$$

where σ_{jn} is the value of the stress change function over the thickness of the wall at point n.

For elements without anticorrosion facing point n is located on the external or internal surface of the item in the zone of operation of the maximum stretching stresses. For components with anticorrosion facing point n is selected on the external surface of the item or on the interface of the anticorrosion coating and the base metal in the zone of operation of the stretching stresses.

5.8.3. Permissible values of coefficients of stress intensity. /97

5.8.3.1. Permissible values of stress intensity coefficients depend on the relative temperature $(T-T_k)$ and the calculation case. The dependence of $[K_1]_i$ on $[T-T_k)$ is obtained as the envelope of two curves defined from the initial temperature relationship K_k. One of these curves is obtained by dividing the ordinates of the original curve by the coefficient of the strength margin n_k, the other is obtained by shifting the original curve along the x-axis onto the value of the temperature margin ΔT.

It is assumed:
for normal operating conditions $(i = 1)$ $n_k = 2$, $\Delta T = 30°C$;
with disruption in normal operating conditions and hydraulic (pneumatic) tests $(i = 2)$ $n_k = 1.5$, $\Delta T = 30°C$;

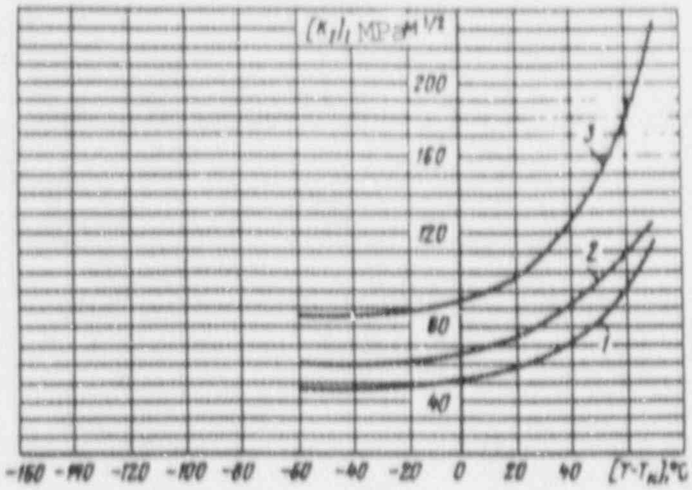

Figure 5.15. Steels of Grades 15Kh2NMFA, 15Kh2NMFA-A

Key:

1. NOC, $[K_1]_1 = 37 + 5.5\, e^{3.85\times10^{-2}(T-T_1)}$
2. VNOC and hydraulic (pneumatic) tests, $[K_1]_2 = 50 + 5.1\, e^{4.1\times10^{-2}(T-T_1)}$
3. ES, $[K_1]_3 = 74 + 11\, e^{3.85\times10^{-2}(T-T_1)}$

for emergency situations ($i = 3$) $n_k = 1$, $\Delta T = 0°C$.

5.8.3.2. The original temperature relationships K_k are adopted from data presented in the appropriate certification reports on materials (base metal, welded connections) or for technical decisions agreed upon with the USSR State Committee on Inspecting Safe Operation in Nuclear Power, the main materiology organization and the main organization for developing strength calculation standards.

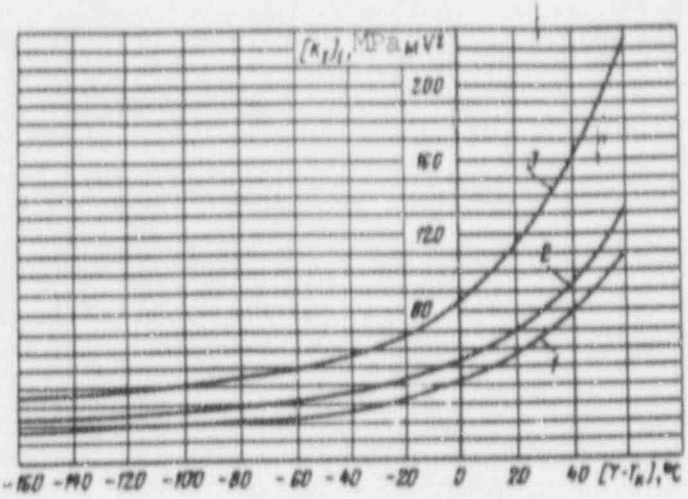

Figure 5.16. Welded Connections of Steels of Grades 15Kh2MFA, 15Kh2MFA-A, 15Kh2NMFA, 15Kh2NMFA-A

Key:

1. NOC, $[K_1]_1 = 17.5 + 26.5\ e^{0.0217(T-T_1)}$
2. VNOC and hydraulic (pneumatic) tests, $[K_1]_2 = 25 + 27\ e^{(2.35\times10^{-2}(T-T_1)}$
3. ES, $[K_1]_3 = 35 + 53\ e^{0.0217(T-T_1)}$

5.8.3.3. Temperature relationships $[K_1]_i$ for steels of grades /98
12Kh2MFA, 15Kh2MFA, 15Kh2MFA-A, 15Kh2NMFA, 15Kh2NMFA-A and their welded connections are presented in Figures 5.14 - 5.16.

5.8.3.4. For steels of the perlite class and high-chrome steels and their welded connections with yield strength at temperature 20°C established from the instructions of point 3.7 of these standards and not exceeding 600 MPa (60 kg-f/mm²) generalized curves of permissible stress intensity coefficients presented in Figure 5.17 can be used.

5.8.4. Critical brittleness temperature.

5.8.4.1. The critical brittleness temperature of a material is defined from the formula

$$T_k = T_{k0} + \Delta T_T + \Delta T_N + \Delta T_F,$$

where T_{k0} is critical brittleness temperature of the material in the original condition; ΔT_T is shift in critical brittleness temperature because of temperature aging; ΔT_N is shift in critical brittleness temperature because of cyclic failure; ΔT_F is shift in critical brittleness temperature because of the influence of neutron irradiation.

5.8.4.2. The values of T_{k0}, ΔT_N, ΔT_T and ΔT_F (or the coefficient of radiation embrittlement A_F) are adopted from the data of appropriate certification reports on materials (base metal and welded connections), specification data for materials or based on technical solutions agreed upon with the USSR State Committee on Inspecting Safe Operation in Nuclear Power, the main materiology organization and the main organization for developing strength calculation standards. /99

The techniques for defining the value T_{k0}, ΔT_T, ΔT_N, ΔT_F (or A_F) are presented in Appendix 2.

5.8.4.3. Values T_{k0}, ΔT_T, and A_F presented in Table 5.11 can be used.

5.8.4.4. Values ΔT_N can be defined from the formula

$$\Delta T_N = 20 \sum_{i=1}^{i=m} N_i/[N_i],$$

where N_i is the number of loading cycles in the i-th operating mode; $[N_i]$ is the permissible number of cycles for the i-th operating mode; m is the number of conditions.

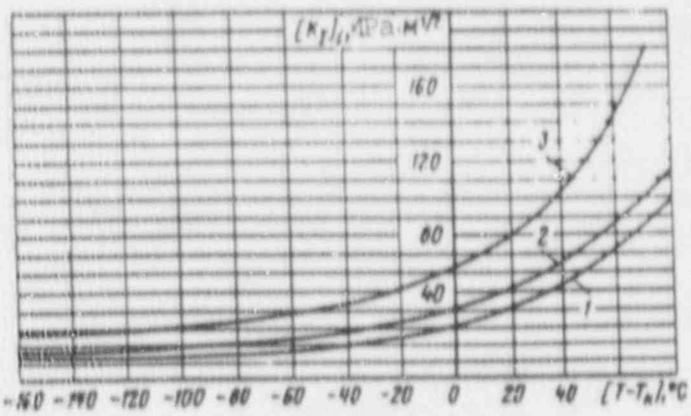

Figure 5.17. Generalized Relationships of Permissible Stress Intensity Coefficients

Key:

1. NOC, $[K_1]_1 = 13 + 18\ e^{0.02(T-T_1)}$
2. VNOC and hydraulic (pneumatic) tests, $[K_1]_2 = 17 + 24\ e^{0.018(T-T_1)}$
3. ES, $[K_1]_3 = 26 + 36\ e^{0.02(T-T_1)}$

5.8.4.5. Values ΔT_F can be defined from the formula

$$\Delta T_F = A_F (F_n/F_0)^{1/3},$$

where A_F is the coefficient of radiation embrittlement, °C; F_n is neutron migration with $E \geq 0.5$ MeV, neutron/m²; $F_0 = 10^{22}$ neutron/m².

The formula is correct with

$$10^{22} \leq F_n \leq 3 \cdot 10^{24} \text{ neutron/m}^2$$

The values A_F are adopted from documented data f-om point

5.8.4.2 or Table 5.11.

5.8.4.6. In calculating structural components made from steels of grades 12 Kh2MFA, 15Kh2MFA, 15Kh2MFA-A, 15Kh2NMFA, 15Kh2NMFA-A and their welded connections subject to neutron irradiation with /107
$F_n \geq 10^{22}$ neutron/m² ($E \geq 0.5$ MeV) at temperatures 250 - 350°C $\Delta T_T = 0$ may be assumed.

5.8.5. Calculation under normal operating conditions.

5.8.5.1. Brittle failure strength should be considered guaranteed if the following condition is fulfilled

$$K_1 \leq [K_1]_1.$$

5.8.5.2. In defining K_1 a superficial semielliptical crack of depth $a = 0.25$ s with correlation $a/c = 2/3$ is adopted as the calculated defect.

5.8.5.3. Dimension h can be adopted as equal to 0.5 s.

5.8.5.4. With regard for the instructions in points 5.8.5.2 and 5.8.5.3 we obtain

$$K_1 = \eta(0,7\sigma_p + 0,45\sigma_q)(s/10^3)^{1/2}.$$

where σ_p and σ_q are in MPa; s is in mm; K_1 is in MPa x $m^{\frac{1}{2}}$.

5.8.5.5. The coefficient η for transition zones of hardness (connection of flanges with the cylindrical part of a vessel, fillets, etc.) is defined from the formulas:
with $0 < s/R_2 \leq 5$

$$\eta = 1 + (K_\sigma - 1)^{0,7} \cdot 1,8/(s/R_2);$$

TABLE 5.11. VALUES OF FAILURE STRENGTH CHARACTERISTICS

Grade of Base Material	Type of Welding, Grade of Welded Material	Standard or Specifications	T_{k0}, °C	ΔT_T, °C (see note 1)	Irradiation Temperature, °C	A_F, C (see note 2)
15Kh2MFA	-	TU 5.961-11060-77, Ed. 6-90-3315	0	0	250 270 290	22 18 14
15Kh2MFA-A	-	TU 108.131-75, Ed. 479	0	0	270 290	12 9
15Kh2NMFA	-	TU 108.765-78, Ed. 4-83	0	0	290±15	109
15Kh2NMFA-A	-	TU 108.765-78, Ed. 4-83	-25	0	290±15	23
15Kh3NMFA	-	TU 24-3-15-223-75, Ed. 480, TU 5.961-11021-79, Ed. 6-90-3305	-10	0	-	-
10KhN1M	-	TU 14-1-2587-78	10	10	-	-
22K	-	TU 108-11-543-80	40	30	-	-
10GN2MFA	-	TU 108.766-78	15	10	-	-
15Kh2NMFA	EShS, wire Sv-16Kh2NMFTA	TU 14-1-3633-83	20	0	-	-
	Flux OF-6	-				
	RDS, electrodes RT-45A, RT-45AA, RT-45B	OST 108.948.01-80	0	0	-	-
15Kh2NMFA-A	ADS, wire Sv-12Kh2N2MAA (including VI, VD)	TU 14-1-2502-78	0	0	290±15	20
	Flux FTs-16A	TU 108.949-80				
	Wire Sv-09Kh GNMTA-VI	TU 14-1-3675-83	0	0	290±15	20
	Flux KF-30	TU 5.965-11090-80				
	RDS, electrodes RT-45 AA, RT 45B	OST 108.948.01-80	0	0	290±15	20

TABLE 5.11. Continued:

15Kh3NMFA-A	ADS, wire Sv-09KhGNMTA-VI	TU 14-1-3675-83	0	0	-	-
	Flux KF-30	TU 5.965-11090-80				
	RDS, electrodes RT-45B	-	0	0	-	
	EShS, wire Sv-16Kh2NMFTA	TU 14-1-3633-83	20	0	-	-
	Flux OF-6	-				
15Kh2MFA	ADS (see note 3), wire Sv-10KhMFT, Sv-10KhMFTU	GOST 2246-70	40	0	250 270	see note 2
	Fluxes AN-42, AN-42M	-				
	KF-30	TU 5.965-1190-80				
15Kh2MFA-A	ADS (see note 3), Sv-10Kh MFTU	TU 14-1-3034-80	20	0	270	15
	Flux KF-30, AN-42M	TU 5.965-11090-80			290	12
	RDS (see note 2), electrodes N-3, N-6	TU 5.965-4052-73	20	0	270 290	15 12
15Kh2NMFA	ADS (see note 3), wire Sv-12Kh2NMFA, Sv-12Kh2 NMFA-A (including VI, VD)	TU 14-1-2502-78	0	0	-	-
	Flux FTs-16, FTs-16A	TU 108.949-80	0	0	-	-
	Wire Sv-09KhGNMTA	TU 14-1-3675-83	0	0	-	-
	Flux KF-30	TU 5.965-11090-80				
15Kh3NMFA-A	ADS, wire Sv-09KhGNMTA-VI	TU 14-1-3675-83	0	0	-	-
	Flux KF-30	TU 5.965-11090-78				
	RDS, electrodes RT-45B	-	0	0	-	-
	EShS, wire Sv-16Kh2NMFTA	TU 14-130-168-75	20	0	-	
	Flux OF-6	-				
10KhN1M	ADS, wire Sv-10NMA	GOST 2246-70	10	0	-	-
	Flux AN-42, AN-42M	-				
	Flux KF-31	-				
	Wire Sv-08KhNM	GOST 2246-70	10	0	-	-
	Flux KF-31	-				
	RDS, electrodes UONII-13/45A, UONII-13/55	-	20	20	-	-
	Electrodes N-25	-	0	0	-	-
10KhN1M (VK-1A)	ADS, wire Sv-10NMA	GOST 2246-70	0	0	-	-

(Table continued next page)

TABLE 5.11. Continued:

	Flux AN-42, AN-42M	-				
	Flux KF-31	-				
	Wire Sv-08KhNM	GOST 2246-70	0	0	-	-
	Flux KF-31					
	RDS, electrodes N-25	-	0	0	-	-
22K	ADS, wire Sv-06A	TU 14-1-1569-75	0	0	-	-
	Fluxes AN-42, AN-42M	-				
	Wire Sv-08GSMT, Sv-10GSMT	GOST 2246-70	40	20	-	-
	Flux AN-42	-				
	Wire Sv-08GS	GOST 2246-70	15	30	-	-
	Flux FTs-16	TU 108.949-80				
	Wire Sv-08GSMT, Sv-08GS	GOST 2246-70	0	0	-	-
	Flux KF-30	TU 5.965-11090-78				
	RDS, electrodes UONII-13/45, UONII-13/45A, UONII-13/55	-	20	20	-	-
22K	EShS, wire Sv-10G2	GOST 2246-70	40	20	-	-
	Flux AN-8M	GOST 9087-81				
10GN2MFA	ADS, wire Sv-10GNMA	TU 14-1-2860-79	15	10	-	-
	Sv-10GN1MA	TU 14-1-2860-79				
	Flux AN-17M	GOST 9087-81				
	FTs-16	TU 108.949-80				
	RDS, electrodes PT-30	GOST 108.948.01-80	15	10	-	-
	EShS, wire Sv-10GN2MFA	TU 14-1-2860-79	15	10	-	-
	Flux OF-6	-				

Notes:

1. Values T_t are presented for temperatures up to 350°C.
2. Values A_F are defined from correlations $A_F = 800\ (P + 0.07\ Cu)$ with irradiation temperature 270°C, $A_F = 800\ (P + 0.07\ Cu) + 8$ with irradiation temperature 250°C, where P and Cu are the content of phosphorus and copper, %.
3. ADS--automatic flux arc welding; RDS--arc welding; EShS--electroslag welding.

with $s/R_2 > 5$

$$\eta = 1 + (K_\sigma - 1)^{0.7} \cdot 9/(s/R_2)^2.$$

With $\eta > K_\sigma$ $\eta = K_\sigma$ is assumed.

The quantity η can be defined by the graphs in Figure 5.18.

In the formulas R_2 is the radius of the curvature of concentrator in the calculated cross-section; K_σ is the theoretical concentration coefficient (it is permitted to assume that it is equal to the value K_σ during stretching).

5.8.5.6. The coefficient η for zones of holes (connections of sleeves, pipe unions, pipes) is defined by the formulas:
with $s/R \leq 0.8$

$$\eta = [1 + 5(K_\sigma - 1)\exp(-0{,}86 s/R_1)]^{1/2};$$

with $s/R > 0.8$

$$\eta = [1 + 2(K_\sigma - 1)/(s/R_1)]^{1/2},$$

where R_1 is the radius of the hole.

The quantity η can be defined by graphs in Figure 5.19.

5.8.5.7. A calculation needs to be made only to the relative temperature $[T - T_k]^*$ whose greatest value on the graph $[K_1]_1 = f[T-T_k]$ corresponds to the value $[K_1]^*_1$ defined by the formula

$$[K_1]_1 = 0{,}35 R^T_{p0.2} (s/10^3)^{1/2},$$

where $R^T_{p0.2}$ is in MPa; s is in mm, $[K_1]^*_1$ is in MPa x $m^{\frac{1}{2}}$.

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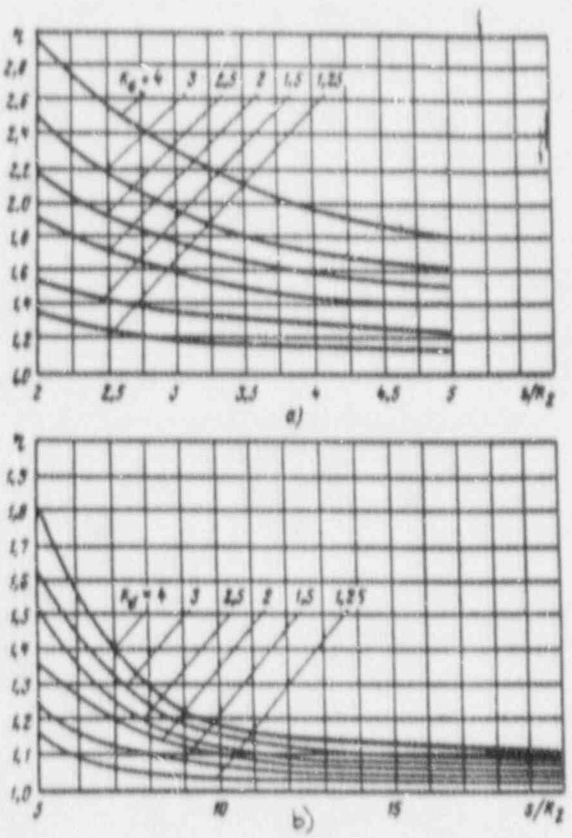

Figure 5.18. Dependence of Coefficient η on Ratio s/R_2 for Transition Zone of Hardness

Key:
a. $2 \leq s/R_2 \leq 5$
b. $s/R_2 > 5$

5.8.6. Determination of minimum permissible construction temperature during hydraulic (pneumatic) tests.

5.8.6.1. Hydraulic (pneumatic) tests must be conducted under such conditions that the minimum construction temperature during the hydraulic (pneumatic) tests T_h is greater than or equal to the minimum permissible construction temperature $[T_k]$ defined from a calculation of brittle failure strength.

5.8.6.2. Temperature $[T_h]$ is defined using the condition

$$K_1^h \leqslant [K_1]_2,$$

where K_1^h is the coefficient of stress intensity and the cross-sections of the structure under discussion during hydraulic (pneumatic) tests.

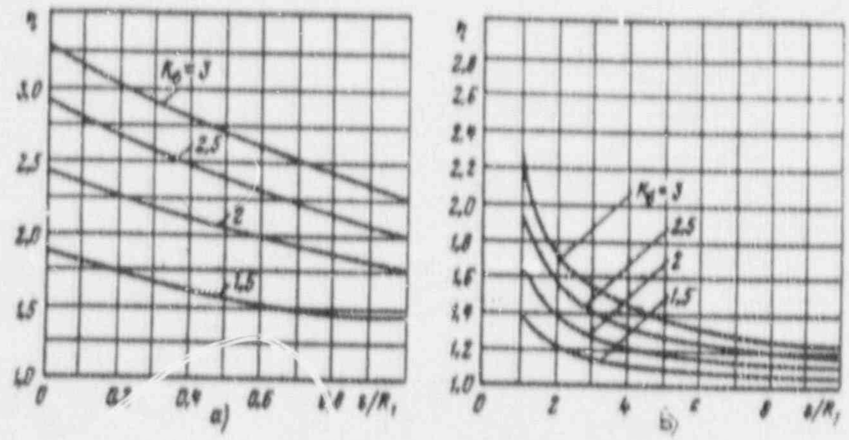

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Figure 5.19. Dependence of Coefficient η on Ratio s/R_1 for Zones Where There are Holes

Key:

a. $s/R_1 \leq 1$

b. $s/R_1 > 1$

5.8.6.3. Values K_1^h are defined according to the instructions in points 5.8.2, 5.8.5.2 and 5.8.5.3.

5.8.6.4. The value $[K_1]_2$ is adopted equal to the value K_1^h defined from point 5.8.6.3 and using relationship $[K_1]_2 = f[T-T_k]$ we find the value $[[T_h] - T_k]$ and then, by knowing the value T_k we establish the value $[T_h]$.

5.8.6.5. Condition 5.8.6.2 must be fulfilled during the pressure delay during hydraulic (pneumatic) tests, during delay for inspection of equipment and piping and during heating to the testing temperature.

5.8.6.6. It is permitted that a complete calculation to determine temperature $[T_h]$ not be made and it is assumed it equals 5°C in any of the following cases:
1) conditions of point 5.8.1.9 are fulfilled (except point 4);
2) the following condition is fulfilled for the element under discussion

$$s \leq 4{,}5 \cdot 10^3 \left(\frac{[K_1]_2}{R^T_{p0{,}2}}\right)^2$$

with s in mm; $[K_1]_2$ in MPa x $m^{\frac{1}{2}}$; $R^T{}_{p0.2}$ in MPa; value $[K_1]_2$ is defined with relative temperature $(5 - T_k)$, where T_k corresponds to the moment of conducting hydraulic tests, while the value $R_{p0.2}$ is adopted at temperature 20°C.

5.8.7. Calculation in VNOS and ES modes.

5.8.7.1. Brittle failure strength is considered guaranteed if the following conditions are fulfilled

$K_1 \leq [K_1]_2$ for VNOC;
$K_1 < [K_1]_3$ for ES.

5.8.7.2. The calculation is made in the following sequence: /110
1) for different moments in the occurrence of VNOC and ES modes the temperature fields and stresses defined in the calculated cross-sections and for the components exposed to neutron irradiation the distribution of neutron migration through the wall thickness is also defined;
2) according to the instructions in point 5.8.2 for each of the

stress fields σ_p, σ_q and h are defined;

3) zone h is divided into intervals whose boundaries are designated by coordinates 0, x_1, x_2 ..., x_n; the length of one interval of division must be no more than 1 mm on sections where the stress gradient is over 70 MPa/mm, and no more than 2 mm in sections where the stress gradient is over 30 MPa/mm;

4) in limits of zone h values K_1 are defined assuming that the depth of the crack equals in value x_1, x_2, ..., x_n, while the correlation of semiaxes a/c = 2/3; the value x_n must not exceed 0.25 s;

5) the sequence of moments in time t_1, t_2, ..., t_n are selected so that the values K_1 calculated for one depth x_i of two subsequent moments in time differ from each other by no more than 10%;

6) at the points corresponding to the end of each interval x_1, x_2, ..., x_n the values of the temperatures T_1, T_2, ..., T_n are established and (for structures subject to irradiation) values of neutron migration F_1, F_2, ..., F_n;

7) for temperature values found T_1, T_2, ..., T_n with regard for values of critical brittleness temperature T_k relative temperatures are defined $(T_1 - T_k)$, $(T_2 - T_k)$, ..., $(T_n - T_k)$ and from the temperature relationship

$$[K_1]_2 = f[T - T_k] \text{ or } [K_1]_3 = f[T - T_k]$$

for each of the points x_1, x_2, ..., x_n values $[K_1]_2$ or $[K_1]_3$ are established;

8) at each point x_1, x_2, ..., x_n a comparison is made of the values K_1 defined from point 4, and values $[K_1]_2$ or $[K_1]_3$ defined from point 7 and fulfillment of the condition of point 5.8.7.1 is verified;

9) the calculation should be made in limits to relative temperature whose greatest value corresponds from the graph $[K_1]_2 = f[T-T_k]$ to the value $[K_1]_2 = {}_1R^T_{p0.2}(s/10^3)^{\frac{1}{2}}$ or on the graph $[K_1]_3 = f[T-T_k]$ to the value $[K_1]^*_3 = {}_2R^T_{p0.2}(s/10^3)^{\frac{1}{2}}$, where $[K_1]_2$ or $[K_1]_3$ is in MPa x $m^{\frac{1}{2}}$; $R^T_{p0.2}$ is in MPa, s is in mm, while the values β_1 and β_2 are defined from Table 5.12.

TABLE 5.12. VALUES OF COEFFICIENTS β_1 AND β_2

a/s	0,05	0,10	0,15	0,20	0,25
β_1	0,267	0,360	0,405	0,445	0,465
β_2	0,40	0,54	0,61	0,67	0,70

5.9. Calculation for Continuous Static Strength /111

5.9.1. In the verification calculation for continuous strength all operating modes should be examined which occur at temperatures exceeding T_1, including violations of normal operating conditions. The conditions of strength of the structural components are presented in Table 5.13 and are clarified in the following points.

5.9.2. A structural component calculated for continuous static strength must satisfy:
1) conditions of strength adopted in selecting the main dimensions in the entire interval of operating temperatures;
2) conditions adopted in calculation for static strength in the entire interval of operating temperatures.

5.9.3. Relative stresses of categories $(\sigma)_2$ and $(\sigma)_{RV}$, $(\sigma)_{RK}$ in calculating for continuous static strength of shells and piping must satisfy the following conditions:

$$(\sigma)_2 \leq K_t[\sigma] \text{ \& } (\sigma)_{RV},\ (\sigma)_{RK} \leq K_t'[\sigma],$$

where $[\sigma]$ is the nominal permissible stress,

$$[\sigma] = R_{mt}^{T}/n_{mt};$$

n_{mt} is the safety margin adopted according to section 3.4; K_t is the coefficient of reduction of stresses $(\sigma)_2$ to membrane defined in the zones of membrane or low membrane stresses by the formula

$$K_t = 1,25 - 0,25(\sigma)_m/[\sigma] \text{ or } K_t = 1,25 - 0,25(\sigma)_{mL}/[\sigma];$$

K'_t is the coefficient of reduction of stresses $(\sigma)_{RV}$ and $(\sigma)_{RK}$ to membrane defined in the zones of membrane or local membrane stresses by the formulas

$$K'_t = 1,75 - 0,25(\sigma)_m/[\sigma] \text{ or } K'_t = 1,75 - 0,25(\sigma)_{mL}/[\sigma].$$

Ultimate continuous strength R^T_{mt} in defining [6] is selected for the total duration of loading by stresses under discussion at the calculated temperature.

If the operating lifetime of the shell includes two or more loading modes that differ in relative stress or calculated temperature, then a condition must be fulfilled for accumulated continuous static damage

$$\sum_i^k \frac{t_i}{[t]_i} \leq 1.$$

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Continuous cyclic strength is calculated, as applied to structural components operating at temperatures causing creep. A method is recommended for calculating continuous cyclic strength using the characteristics of continuous strength and plasticity. It is noted the main characteristics of material used are the critical coefficient of stress intensity, critical brittleness temperature and yield strength. It is found that a structural component designed for continuous static strength must satisfy strength conditions adopted in selecting the main dimensions in the entire operating temperature range, and conditions adopted in calculating static strength.

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