EVALUATIONS OF STRESS CONCENTRATION AT GIRTH BUTT WELD JOINT BETWEEN STRAIGHT PIPE AND ELBOW**

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1. Introduction

The design of class 1 piping for nuclear plants is performed in accordance with the ASME B & PV Code Sec. III by using stress index which have been defined at the center portion of elbow, since it has been generally believed that the highest stress will occur at this point. Consequently the stress evaluations at girth weld joint is not recognized contrary to the high stress concentration due to the weld irregularities. However, for LMFBR piping especially in high temperature services the stress evaluations based on the index at the center portion of elbow will not always provide conservative results from the stand point of piping design, especially for fatigue, because it requires to evaluate the stress or strain range by multiplying the square of the stress or strain concentration factor[1][2]. For thin wall and large diameter LMFBR piping following four items provide significant effects on the stress and strain at the girth weld joint between straight pipe and elbow,

(1) Stresses in weld joint due to ovalization of elbow, it is represented by "Carry over Factor".

(2) Stress concentration due to weld irregularities between straight pipe and elbow.

(3) Gross structural discontinuity due to radial deflection caused by weld shrinkage at joint.

(4) Increase of nominal stress due to decrease of nominal pipe wall thickness caused by counter bore machining.

This report presents proposed design factors to above four items in order to use in "Monju" FBR PHTS main piping and verify the structural integrity.

2. Carry Over Factor

This factor is defined as the ratio of the maximum stress component in any pipe section to that in the associated elbow. However, in this paper we have studied the factors at the girth weld joint from the four reasons explained above. The higher stresses induced by ovalization of elbow gradually decrease in proportion to the distance from the center of elbow along the pipe axis. But 20 ~ 60 % of its amplitude is still kept at the end of the elbow.

In this paper, two piping models were analized to establish the factors for use in Monju piping design. Fig. 1 shows the structural models and the dimensions and material are selected to consist with the Monju PHTS main hot leg piping. Fig. 2 shows one of the finite element models in the analysis, it was represented by elastic triangular flat shell elements of SAP IV. Fig. 3 shows stress distributions at $\phi = 30^\circ$ elbow section. The maximum stress components in the cross section perpendicular to the axis could be defined for each stress component from the figure.

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Fig. 4 shows these maximum stress distributions along the pipe axis. Point (A) gives the maximum stresses at the girth joint for Monju because the joint is planned to locate by 100 mm from the end of elbow.

Table 1 shows Carry Over Factors derived from the reference stress $\sigma c_2 = C_2 D_0 M/2I = 18.36$ kg/mm^2 which is based on code indice C_2 and shows a good agreement with the maximum inside hoop stress $\sigma_\theta = 18.15$ kg/mm^2. Note that the factors for U-bend connected by a short (1 D_0) straight pipe are larger than those for 180^0 elbow. This fact means that the both side elbows onto the short pipe affect to increase the stresses and make "a synergy".

3. Stress Concentration Factors

Stress concentrations at the girth weld joints were caused by weld irregularities and abrupt changes in contour due to misalignment. The exterior surface of the joint for piping can be ground but the interior can not be prevented from the excess stress concentrations. Therefore the selection of welding process and method is important to obtain a good interior surface as welded. TIG weld with Ar gas backed up shield is planned to be used for Monju piping. And comparatively long counter bore will be used to protect weld joint from stress concentrations.

To evaluate the stress concentrations for Monju main piping, measurement tests were performed concerning about trial productions for Monju.

Fig. 5 and Fig. 6 show cross sections parallel to the piping axis at the the girth weld joints.

Table 2 provides structural parameters and load conditions for analytical models. The dimensions and shape of joint contour for these models were selected and defined based on the measurement data and manufacturer's experiences. The FEM program MARC was used to analize, and the axisymmetric solid elements 28 for stress and 42 for heat transfer were used.

Fig. 7 shows one of the Mises equivalent stress contours at joint zoomed up and the stress concentration factors along the surfaces.

Table 3 shows summary of analyses and Table 4 defines proposed design stress concentration factors for Monju. From Table 4 the design factors for the interior joint surface, become 1.4 to axial stress and 1.1 to hoop.

4. Weld Shrikage

Generally, large weld shrinkage is observed on girth weld joint for thin wall and large diameter austenite stainless steel piping[3]. To obtain the radial shrinkage for Monju main piping, measurement tests were performed by using 24 in (609.6 mm) dia. mocked up pipe and elbow assemblies.

Fig. 8 and Fig. 9 show the measurement results. The amount of weld shrinkage is about 2 mm in radial direction and this deflection dies out in about 100 mm distance from weld joint. This gross discontinuity causes secondary bending stress at the joint in the wall thickness direction and the stress is proportional to the shrinkage Δ.

E.C. Rodabaugh et al[4]. proposed the following equations to estimate the stress;

$$C_1 = 1.0 + 0.7\,(\Delta / t)$$

$$C_2 = 1.0 + 2.9\,(\Delta / t) \text{ ------ } t > 3/16 \text{ in.}$$

$$C_2 = 1.4 + 2.9\,(\Delta / t) \text{ ------ } t \leq 3/16 \text{ in.}$$

In this paper, the validities of above equations were checked to use them for Monju. Table 5 shows structural models and load coditions. The FEM MARC and the axisymmetric shell element were used, Fig. 10 shows one of results. Fig. 11 presents the comparison between the given equation and analysis. It is obvious that the equations provide suitable and conservative results.

5. Counter Bore Machining

Counter bore machining is prepared to obtain good alignment of weld joint. The amount of decrease in wall thickness due to machining depends on the manufacturing tolerances of pipe and elbows. For Monju specification, the machining yields about 10 % reduction in wall thickness, consequently, this reduction in nominal wall thickness will be considered in the stress evaluation at joint.

6. Design Factors And Conclusions

Table 6 shows the design factors proposed in this study. The factors are given in each two principal directions, therefore designer should take care to obtain larger stress intensity and peak stress intensity in the last stage of the stress evaluations.

Table 7 shows results of trial use for Monju PHTS main hot leg piping. It is concluded that there is not any severer girth weld joint in strength than the associated elbow. Note that when a short (1 D_0) pipe is used to connect two elbows, the girth weld joints in the short pipe become severer than the connected elbows for fatigue evaluations. In this case, the designer should check the fatigue by using design factors proposed for the joints.

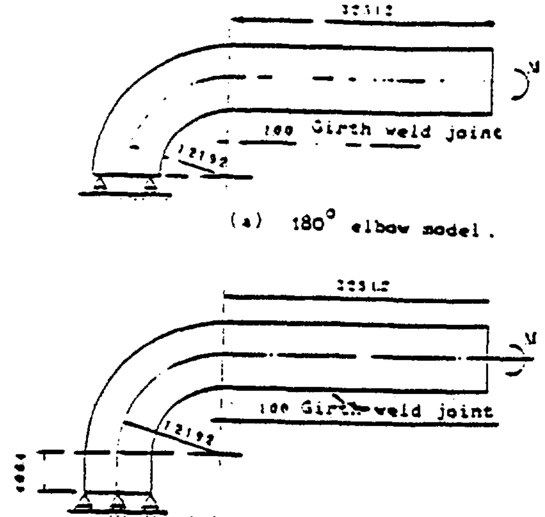
7. References

(1) Structural design guide for class 1 components of prototype Fast Breeder Reactor for elevated temperature service (Draft) Sep. 1980 PNC

(2) ASME B & PV Code Case N-47

(3) J.C. Downey, D.W. Hood, D.D. Keiser, "Shrinkage in Mechanized Welded 16inch Stainless Pipe" Welding J. Mar. 1975 p.170-175

(4) E.C. Rodabaugh & S.E. Moore, "Stress Indices for Girth Welded Joints, Including Radial Welded Shrinkage, Mismatch and Tapered Wall Transitions" NUREG/CR-0371, ORNL/Sub-2913/9 Sep. 1978



(a) 180° elbow model.

(b) U-bend model connected by a short (1D_o) straight pipe

Dia.of pipe	:	812.8 mm
Wall thickness	;	11.1 mm
Bend radius	;	1219.2 mm
Applied moment	;	10000 kg-m
Material	:	304SS

Fig. 1 Analytical models

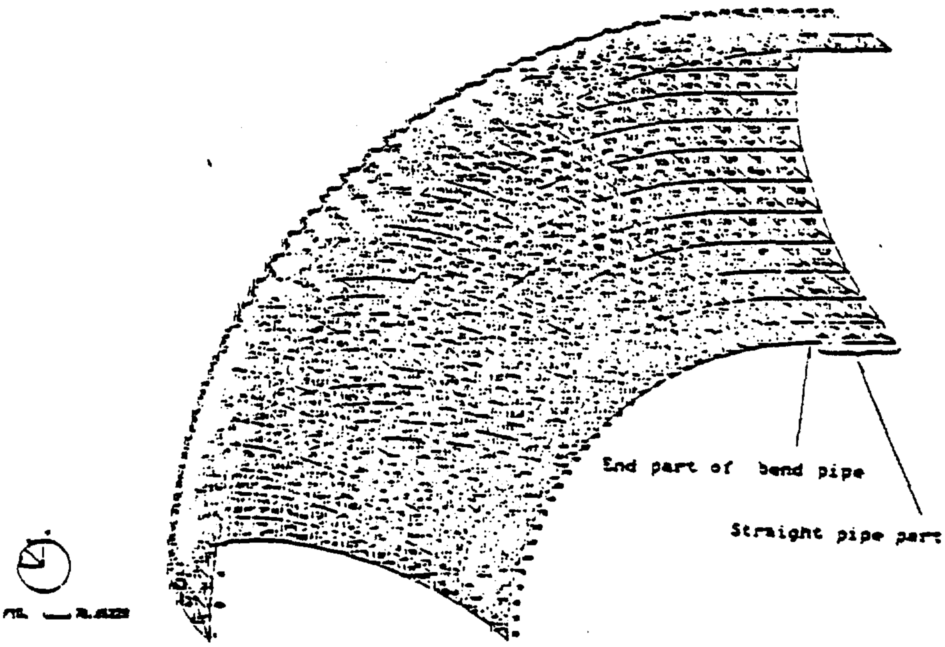


Fig. 2 FEM mesh model for 180° elbow (part)

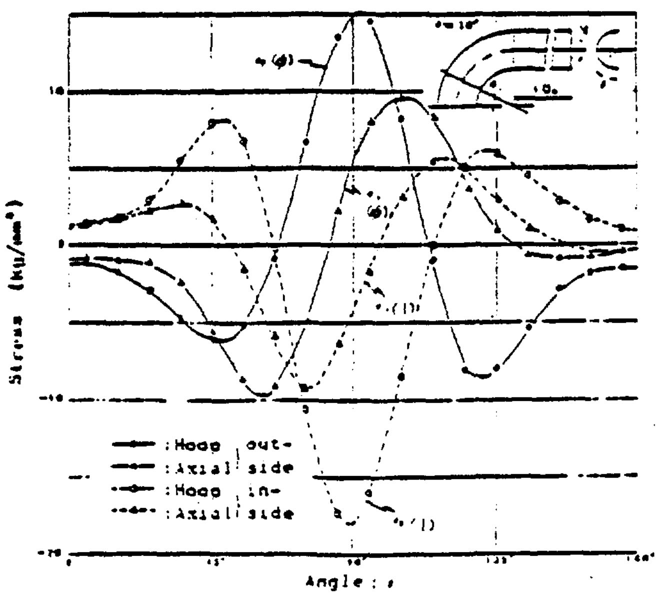


Fig. 3 Stress distributions at φ = 30° bend cross section

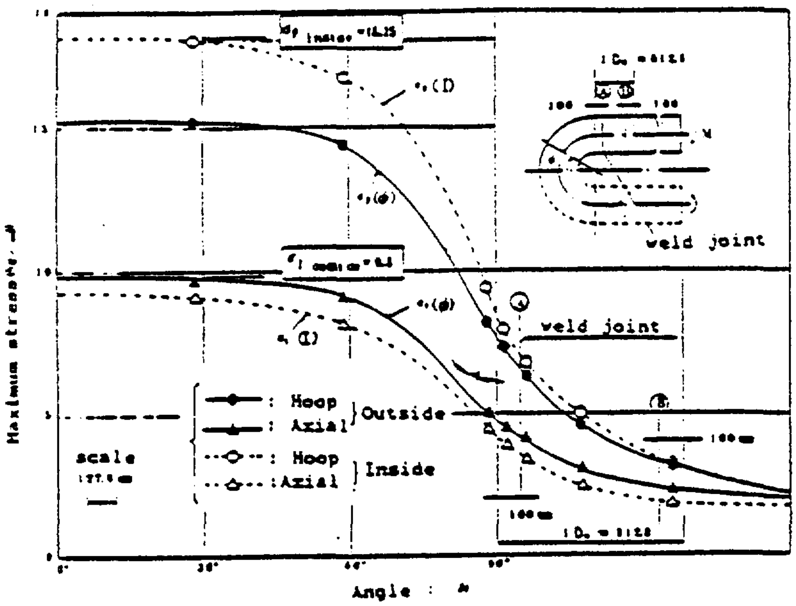


Fig. 4 Maximum cross section stress distributions along pipe axis

Table 1 Carry Over Factor

No.	Stress		Reference Stress σ_{C1}	180° Elbow: Stress: σ Ⓐ	180° Elbow: Ratio σⒶ/σ_{C1}	180° Elbow: Carry Over Factor: Fc	U-bend Connected by A Short Pipe: Stress: σⒶ'	U-bend Connected by A Short Pipe: Ratio σⒶ'/σ_{C1}	U-bend Connected by A Short Pipe: Carry Over Factor: Fc'
1	Inside Axial Stress	σ_1 (I)	18.36	3.6	0.20 (0.18)	0.23	4.6	0.25 (0.24)	0.34
2	Outside Axial Stress	σ_1 (ϕ)		4.2	0.23 (0.19)		6.2	0.34 (0.32)	
3	Inside Hoop Stress	σ_ϕ (I)	18.36	7.0	0.38 (0.36)	0.38	9.7	0.53 (0.53)	0.53
4	Outside Hoop Stress	σ_ϕ (ϕ)		6.6	0.36 (0.31)		9.0	0.49 (0.45)	

Note (1) Fc' indicates the results should be applied when the length of straight pipe between two elbows is about 1 D_0.

(2) The values in parenthes are the results by PNC using FINAS.

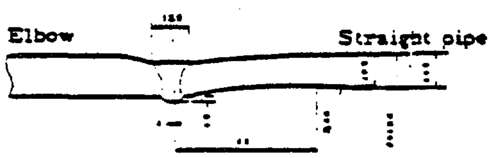


Fig. 5 Cross sectional contour of 32 inch elbow assembly

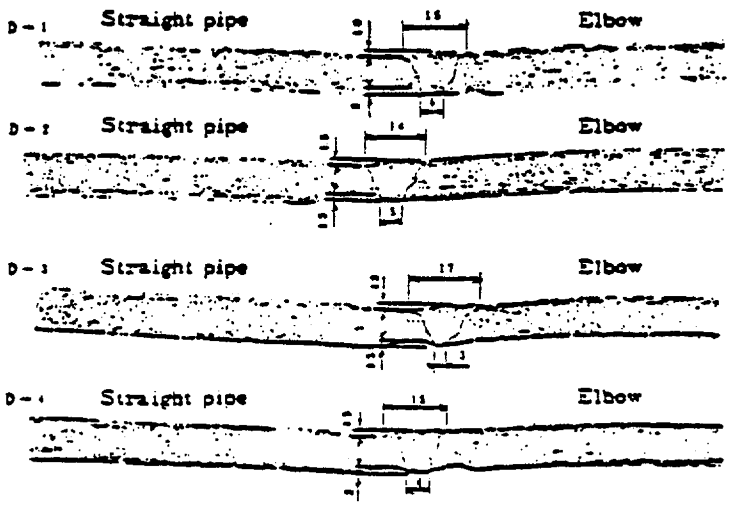


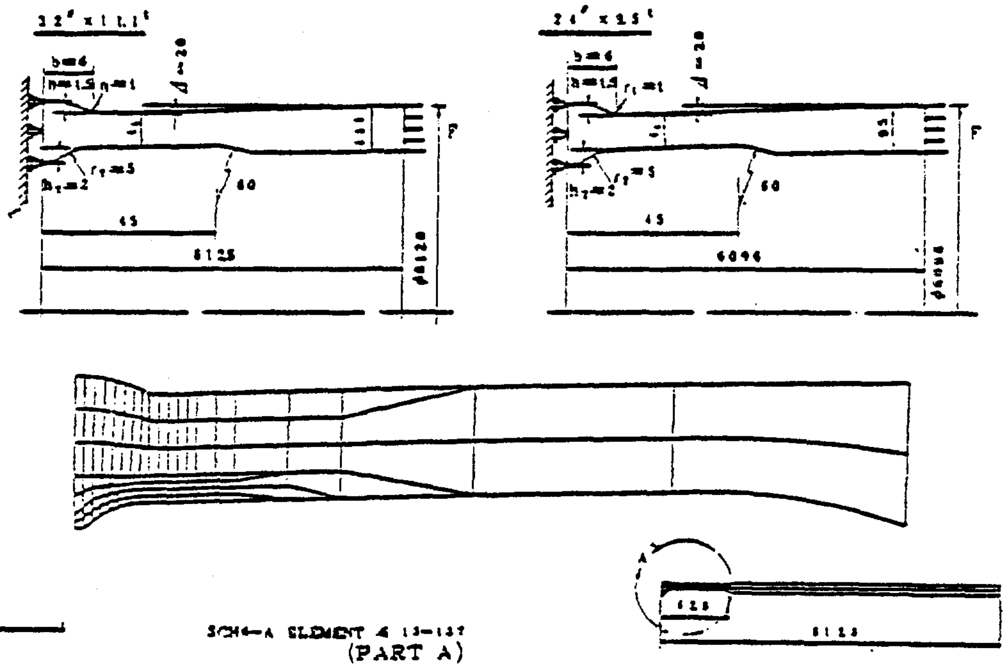
Fig. 6 Cross sectional contour (Specimen D)

Table-2 Parameters of weld joints for analyses

Unit : mm

CASE NO.		Shrinkage Δ (mm)	Thickness t_1	Outside Surface h	Outside Surface h_1	Inside Surface r_2	Inside Surface h_2	Applied Load[(1)] F	Applied Load P	Applied Load TT
32" ×11.1t	2-B	0	10.15	6.0	1.5	5.0	2.0	○	○	
	6-A	2.0	5.4	6.0	1.5	5.0	2.0	○	○	○
	3-A	3.7	5.4	6.0	1.5	5.0	2.0	○	-	-
24" ×9.5t	2-C	0	7.3	6.0	1.5	5.0	2.0	○	-	-
	6-C	2.0	7.3	6.0	1.5	5.0	2.0	○	-	○
	3-C	3.7	7.3	6.0	1.5	5.0	2.0	○	-	-

Note (1) F : equivalent axial force, P : internal pressure, TT : thermal transient



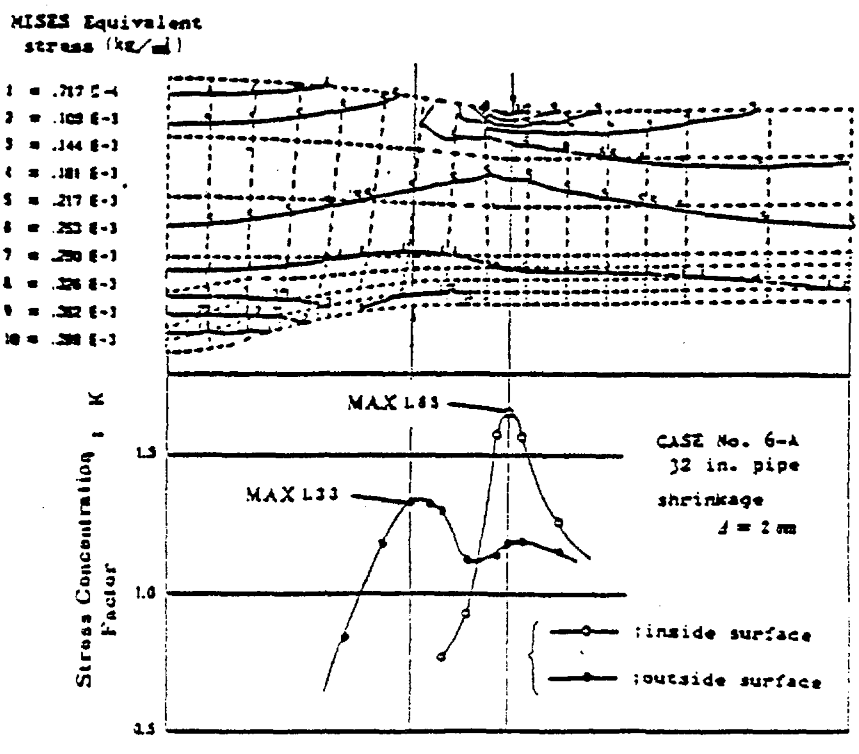


Fig. 7 Stress concentration at weld joint

Table 3 Calculative Results of Stress Concentration Factor

Pipe Size	Case No.	Load Condition	Radial Shrinkage : Δ (mm)	Stress Concentration Factor : K Inside	Outside	Associated stress component
32″ (11.1t)	2−A	Axial Force	0	1.43	1.53	σ_l
	6−A		2	1.33	1.65	σ_l
	3−A		3.7	1.26	1.66	σ_l
	2−B	Internal pressure	0	1.33	1.46	σ_l
				1.04	1.10	σ_θ
	6−A		2	1.27	1.21	σ_l
				1.03	1.09	σ_θ
	6−A	Thermal Load	2	1.13	1.48	σ_l
24″ (9.5t)	2−C	Axial Force	0	1.26	1.56	σ_l
	6−C		2	1.25	1.60	σ_l
	3−C		3.7	1.22	1.66	σ_l
	6−C	Thermal Load	2	1.12	1.45	σ_l

σ_l : Axial Stress σ_θ : Hoop Stress

Table 4 Design Stress Concentration Factor for Inside Joint Surface

No.	Load Condition	Stress Component		Design Stress Concentration Factor : K
1	Bending Moment	Axial	σ_l	1.4
		Hoop	σ_θ	1.1
2	Internal pressure	Axial	σ_l	1.4
		Hoop	σ_θ	1.1
3	Thermal Load	Axial	σ_l	1.2
		Hoop	σ_θ	1.2

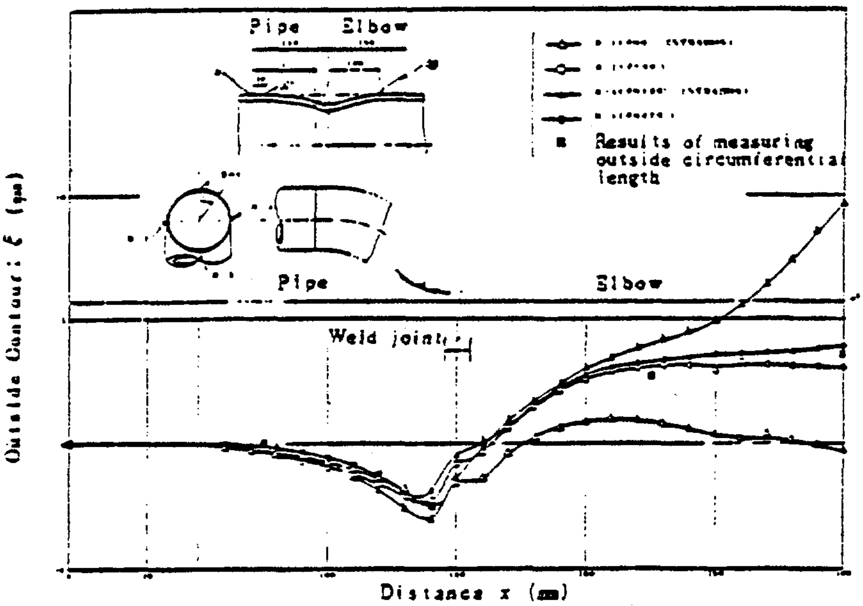


Fig.8 Outside contour of Specimen D

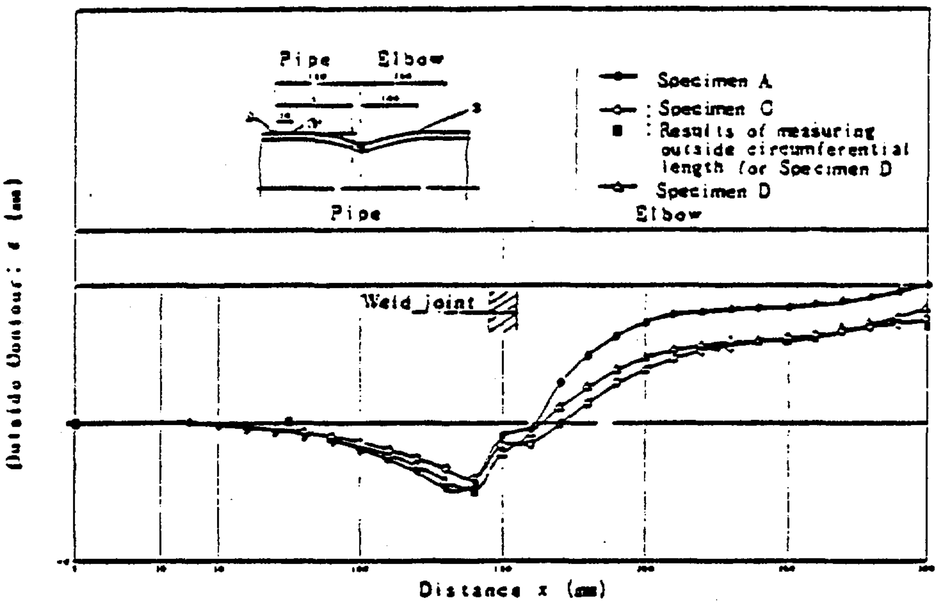
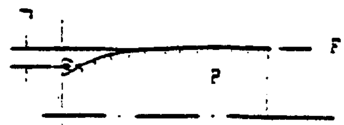


Fig.9 Outside contour of Specimens A, C and D

Table-6 Cases for Analyses and parameter

No.	Load	Shrinkage δ (mm)	Pipe Dimensions	Analytical Model
1	Axial Force : F	2.0	32"×11.1t	 F: Axial Force P: Internal pressure
2	Axial Force : F	1.7	32"×11.1t	
3	Internal pressure : P	2.0	32"×11.1t	
4	Internal pressure : P	1.7	32"×11.1t	

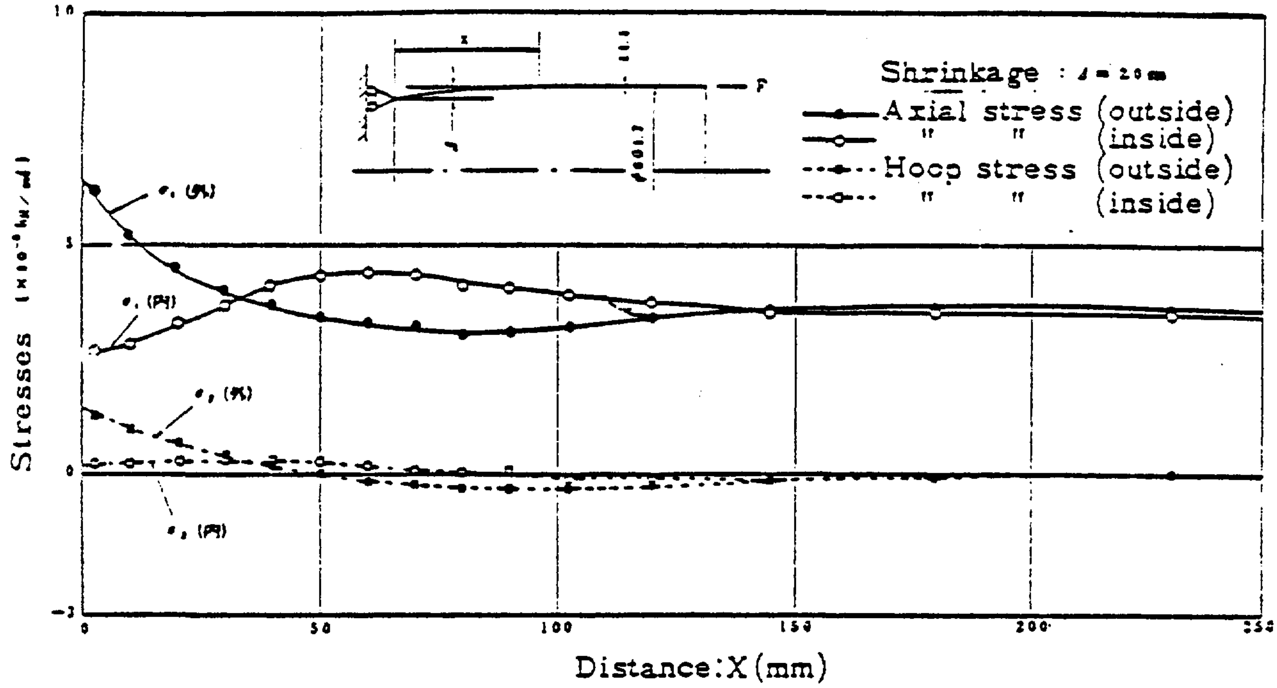


Fig. 10 Stress Distribution

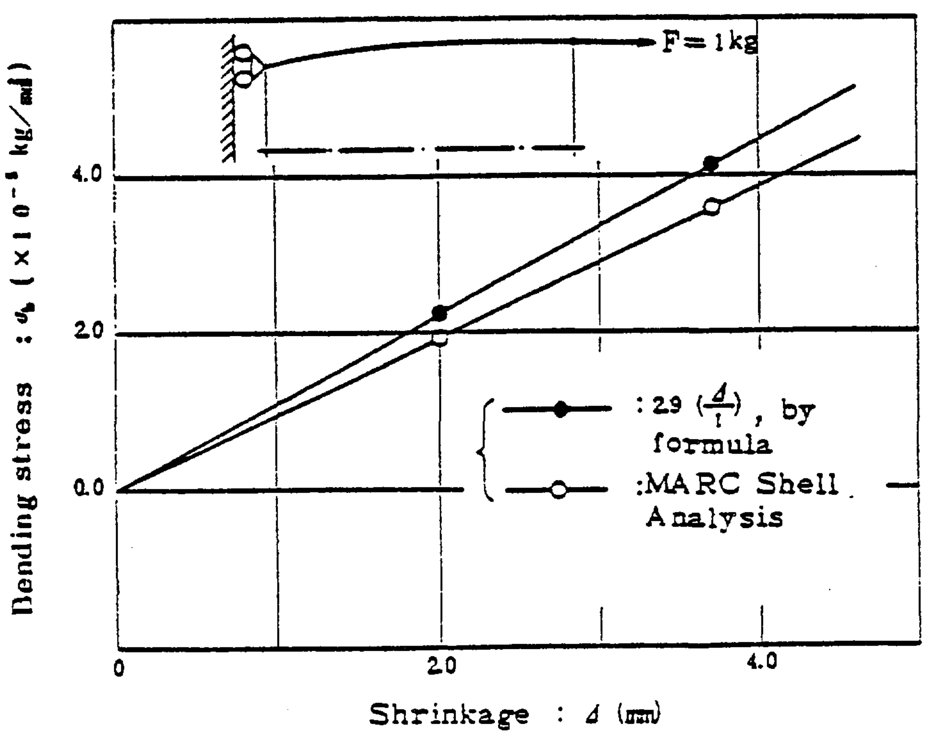


Fig. 11 Bending stress at a fixed end by welding shrinkage

Table 6 Stress Indices at Girth Weld Joint between Elbow and Straight Pipe for Monju PHTS Main Hot Leg Piping.

Load	Stress Indices	Stress Indices for elbow	Stress Indices for straight pipe	Stress Concentration Factor at Weld Joint	Carry Over Factor	Secondary Stress due to shrinkage	Stress Indices at Girth Weld Joint: Expression	Stress Indices at Girth Weld Joint: Figure (2)
Internal Pressure	B_1	1.0	(σ_t) 0.5	—	—	—	(σ_t) 0.5	0.5
	C_1	$C_{1e}=1.24$	(σ_θ) 1.0	—	(σ_θ) $1.0\,C_{1e}$	(σ_θ, σ_t) $1.0+0.7(\Delta/t)$	(σ_t) $0.5(1+0.7\Delta/t)$ (σ_θ) $1.0\,C_{1e}(1+0.7\Delta/t)$	0.6 1.4
	K_1	1.0	(σ_θ) 1.1 (1)	(σ_t) 1.4 (σ_θ) 1.1	—	—	(σ_t) 1.4 (σ_θ) 1.2	1.4 1.2
Moment	B_2	$B_{2e}=7.61$	1.0	—		—	1.0	1.0
	C_2	(σ_θ) $C_{2e}=10.15$	(σ_t) 1.0	—	(σ_t) $0.23\,C_{2e}$ (σ_θ) $0.38\,C_{2e}$	(σ_t) $1.0+2.9(\Delta/t)$	(σ_t) $0.23\,C_{1e}(1+2.9\Delta/t)$ (σ_θ) $0.38\,C_{2e}$	3.67 3.86
	K_2	1.0	1.0	(σ_t) 1.4 (σ_θ) 1.1	—	—	(σ_t) 1.4 (σ_θ) 1.1	1.4 1.1
Thermal Load	C_3	1.0	(σ_θ, σ_t) 1.0	—	—	—	1.0	1.0
	C_3'	0.5	0.5	—	—	—	0.5	0.5
	K_3	1.0	1.0	(σ_θ, σ_t) 1.2	—	—	(σ_t) 1.2 (σ_θ) 1.2	1.2 1.2

Remarks

(1) Near longitudinal weld, but Stress Indices = 1.0 at the point which is apart from longitudinal weld.

(2) Stress Indices are calculated by Δ = 2 mm, t = 10.2 mm.

Table 7 Fatigue Evaluation For Monju PHTS Piping

Stress	Ratio of Stress Index between for elbow and for girth weld joint [(2)]	$\sigma_t = K_e \sigma_n + K_T \sigma_T$					
		$S_n^* = \frac{C_2 D_o}{2I}(M_i^* + M_i^{***})_n$		$S_n = F_{1a}\frac{C_1 P_o D_o}{2t_n} + \frac{C_2 D_o}{2I}(M_i + M_i^* + M_i^{**} + M_i^{***})$			
		Hoop Stress	Axial Stress	Based on 180° elbow analysis		Based on U-bend connected by a short pipe	
				Hoop Stress σ_θ	Axial Stress σ_ℓ	Hoop Stress σ_θ	Axial Stress σ_ℓ
Pressure stress : σ_P	$\left(\frac{K_e^g \sigma_n^g}{K_e^e \sigma_n^e}\right)_{C_1} \quad \frac{K^g \sigma_n^g}{\sigma_n^e}$	–	–	$\frac{1.2 \cdot C_1^g}{C_1^e}\eta = 1.78$	$\frac{1.4 \cdot C_1^g}{C_1^e}\eta = 1.04$	1.78	1.04
Moment stress : σ_M	$\left(\frac{K_e^g \sigma_n^g}{K_e^e \sigma_n^e}\right)_{C_2} = \frac{K^g \sigma_n^g}{\sigma_n^e}$	$\frac{1.1 \cdot C_2^g}{C_2^e}\eta = 0.51$	$\frac{1.4 \cdot C_2^g}{C_2^e}\eta = 0.78$	$\frac{1.1 \cdot C_2^g}{C_2^e}\eta = 0.51$	$\frac{1.4 \cdot C_2^g}{C_2^e}\eta = 0.78$	0.71	1.14
Thermal stress : σ_T	$\left(\frac{K_T^g \sigma_T^g}{K_T^e \sigma_T^e}\right)_T = \frac{K \sigma_T^g}{\sigma_T^e}$	–	–	$1.2 \times \frac{1}{\eta} = 1.1$	$1.2 \times \frac{1}{\eta} = 1.1$	1.1	1.1
Ratio of total stress: [(1)] $\sigma_P\left(\frac{K_e^g \sigma_n^g}{K_e^e \sigma_n^e}\right)_{C_1} + \sigma_M\left(\frac{K_e^g \sigma_n^g}{K_e^e \sigma_n^e}\right)_{C_2} + \sigma_T\left(\frac{K_T^g \sigma_T^g}{K_T^e \sigma_T^e}\right)_T$		0.51	0.76	0.78	0.66	0.92	1.12

Note (1) Stress ratio of $\sigma_P : \sigma_M : \sigma_T = 1 : 5 : 1$ was assumed in above evaluation.

(2) Affixes g and e represent stress indices for girth weld joint and elbow respectively

(3) η provides the effect of stress induction due to reduction of nominal pipe thickness caused by counter bore machining.