

원통형 배관 지지대의 응력계수 개발

Development of Stress Indices for Trunnion Pipe Support

김 종 민* · 박 명 규** · 엄 세 윤**
Kim, Jong-Min · Park, Myung-Kyu · Eom, Sea-Yoon
이 대 희*** · 박 준 수****
Lee, Dae-Hee · Park, June-Soo

요 약

배관을 구축시키기 위한 원통형 배관 지지대(Trunnion Pipe Support)가 부착된 배관의 응력해석을 위하여 유한요소해석을 사용하였다. 해석결과로 부터 얻어진 응력은 두께에 대한 평균(막응력) 및 선형 응력(굽힘응력)으로 분류되었으며, 분류된 응력값은 압력에 의한 일차응력계수(B_1)와 이차응력계수(C_1), 모멘트에 의한 일차응력계수(B_{2R} , B_{2T})와 이차응력계수(C_{2R} , C_{2T})를 추정하기 위하여 ASME Code에 정의된 것과 일치하게 해석되었다. 무차원의 함수로써 응력 계수에 대한 경험식을 개발하기 위하여 여러 모델의 해석을 수행하였다.

Abstract

A finite element analysis of a trunnion pipe anchor is presented. The structure is analyzed for the case of internal pressure and moment loadings. The stress results are categorized into the average (membrane) and the linearly varying (bending) stresses through the thickness. The resulting stresses are interpreted per Section III of the ASME Boiler and Pressure Vessel Code from which the Primary (B_1) and Secondary (C_1) stress indices for pressure, the Primary (B_{2R} , B_{2T}) and Secondary (C_{2R} , C_{2T}) stress indices for moment are developed. Several analyses were performed for various structural geometries in order to obtain empirical representation for the stress indices in terms of dimensionless ratios.

Keywords : primary stress, secondary stress, stress index, trunnion pipe support, pressure, moment, finite element analysis

* 정회원 · 한국원자력연구소, 계통기계분야 연구원
** 한국원자력연구소, 계통기계분야 연구원
*** 정회원 · 한국원자력연구소, 계통기계분야 선임연구원
**** 한국원자력연구소, 계통기계분야 선임연구원

• 이 논문에 대한 토론을 1996년 12월 31일까지 본 학회에 보내주시면 1997년 6월호에 그 결과를 게재하겠습니다.

1. Introduction

The support of a piping system for dynamic loads such as seismic load or waterhammer often results in the requirement to weld an attachment to the pipe to form a part of the supporting structure. These types of configurations are commonly used in nuclear power plants to restraint or anchor the pipe. However, ASME Code Section III¹⁾ does not provide stresses indices for these types of configurations. The purpose of this paper is to identify the primary(B_1 , B_{2R} and B_{2T}) and secondary (C_1 , C_{2R} and C_{2T}) stress indices as defined by the welded trunnions attached to pipe.

The trunnion support is shown in Fig.1. It represents a cylindrical support pipe welded to a run pipe. The support pipe does not penetrate the run pipe as in a 90 degree branch connection, and the trunnion pipe is not pressurized. This type of component is similar to an integral attachment.

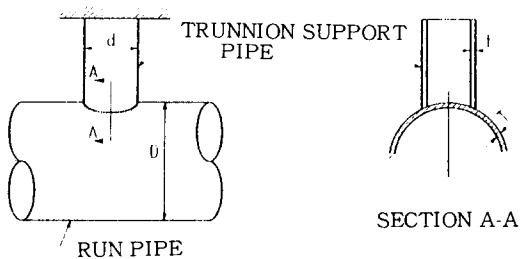


Fig. 1 Typical trunnion support

Stress indices were introduced into the first edition of Section III of the ASME Code(1963) for nozzles in pressure vessels subjected to internal pressure loading only. These indices were obtained from photoelastic tests and /or from steel model tests. Dodge²⁾ and Rodabaug-

h, Dodge, and Moore³⁾ determined stress indices for small lug attachments, and proposed the modified term to be added in ASME Code equation to analyze such attachments. Sadd and Avent⁴⁾ developed the primary and secondary stress indices for trunnions attached to straight pipe subjected to internal pressure and moment loadings, and these stress indices B_1 , C_1 , B_2 , C_2 were developed in terms of d/D and D/T , d/T , t/T and d/D , d/D respectively. Williams and Lewis⁵⁾ provided the primary stress indices B_1 and C_1 of trunnion elbow supports for internal pressure. Hankinson, Budlong and Albano⁶⁾ developed the secondary stress indices of trunnion elbow supports in terms of D/T , d/D and t/T for in-plane moment, out-of-plane moment and torsional moment, respectively. This paper developed the primary stress indices(B_1 , B_{2R} and B_{2T}) and the secondary stress indices(C_1 , C_{2R} and C_{2T}) of the trunnion pipe support in terms of the dimensionless ratio(D/T , d/D , t/T , d/t) for pressure and moment loadings.

2. 3-D Finite Element Analysis

The finite element mesh was generated using the 3-D isoparametric solid element(solid 45 of ANSYS) which is defined by eight nodal points having three degrees of freedom at each node, except one region between run pipe and trunnion supports where solid 45 tetrahedra element was used. Because of the symmetry of the model about the longitudinal Y-Z plane(Fig. 2), a half symmetric finite element mesh was generated to reduce the wave front used in the matrix solution. The ANSYS preprocessor(PREP7) was used in generating the overall mesh. This preprocessor is an extended capability version of the node and element gen-

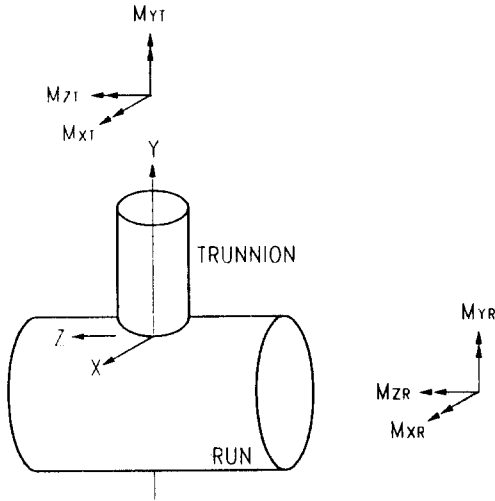


Fig. 2 Moment loadings for trunnion component

eration routine in the ANSYS program.⁷⁾ The mesh was generated in several segments. The three elements through the thickness were used in all regions except in the trunnion support where 2 elements through the wall were considered. In the circumferential(θ) direction, the run pipe consisted of one element every 10 degrees and the trunnion support had one element every 5 degrees. In the longitudinal direction, the run pipe had 18 element and trunnion support consisted of 10 segments.

For the elastic analysis of the trunnion pipe support, a modulus of elasticity 'E' of 206839.5 Mpa(30×10^6 psi) and a Poisson's ratio ' ν ' of 0.3 were used for both cases of the loadings : internal pressure and moment.

A pressure of 6.895 Mpa(1000 psi) was applied on all exposed internal surfaces of the run pipe. The moment of 1130 N-m(10000 lb-in-) was given on run pipe and trunnion support. The boundary membrane forces were applied as a negative(tensile) pressure at the right end of the run pipe. For the bending moment

loadings, linear varying loads producing the proper statically equivalent effect were applied at the ends of the run pipe and trunnion support. Twisting moments were generated by a uniform distribution of tangential loading at the ends. A half symmetric model was utilized for all analyses. This modeling technique exploited each structure's geometrical symmetry with respect to the plane of the pipe's longitudinal axis. Compatibility of the nodal deformation between the half and equivalent whole models was maintained by specifying symmetric displacement fields.

3. Stress Results

The run pipe and trunnion support dimensions for the representative models under consideration are given in Table 1. From the dimensional parameters outlined by Table 1, stress indices are later developed in terms of selected dimensionless ratios.

For all models, displacements(U_x , U_y and U_z) were calculated at all nodal points. In addition, stress components(σ_x , σ_y , σ_z , σ_{xy} , σ_{yz} and σ_{xz}), principal stresses and the maximum shear stresses were calculated at all nodal points. Displacements and stress contour plots were obtained for the Model No. 10 using the 3 dimensional solid element post-processor(POST 1) of ANSYS. These plots are intended to provide an understanding of the pattern of stress distribution in the model. Displacement plot under internal pressure loading is presented in Figure 3. In all of the displacement plots, the dashed lines show the undeformed or original configuration and the solid lines indicate the deformed shapes. The stress intensity(σ) is defined to be twice the maximum shear stress or simply the difference between the al-

Table 1 Dimensional Parameters

Model No.	Run Pipe					Trunnion Support					d/D	t/T
	NPS mm(inch)	Sch No.	D mm(inch)	T mm(inch)	D/T	NPS mm(inch)	Sch No.	d mm(inch)	t mm(inch)	d/t		
1	101.6(4)	40	114.30(4.500)	6.02(0.237)	19.0	76.2(3)	80	88.9(3.500)	7.62(0.300)	11.7	0.78	1.27
2	152.4(6)	40	168.30(6.625)	7.11(0.280)	23.7	101.6(4)	80	114.3(4.500)	8.56(0.337)	13.4	0.68	1.20
3	152.4(6)	80	168.30(6.625)	10.97(0.432)	15.3	101.6(4)	80	114.3(4.500)	8.56(0.337)	13.4	0.68	0.78
4	203.2(8)	40	219.08(8.625)	8.18(0.322)	26.8	101.6(4)	120	114.3(4.500)	11.13(0.438)	10.3	0.52	1.36
5	203.2(8)	80	219.08(8.625)	12.70(0.500)	17.3	101.6(4)	40	114.3(4.500)	6.02(0.237)	19.0	0.52	0.47
6	254.0(10)	40	273.05(10.750)	9.27(0.365)	29.5	152.4(6)	80	168.3(6.625)	10.97(0.432)	15.3	0.62	1.18
7	254.0(10)	60	273.05(10.750)	12.70(0.500)	21.5	152.4(6)	40	168.3(6.625)	7.11(0.280)	23.7	0.62	0.56
8	304.8(12)	40	323.85(12.750)	10.31(0.406)	31.4	254.0(10)	80	273.1(10.750)	15.09(0.594)	18.1	0.84	1.46
9	304.8(12)	60	323.85(12.750)	14.27(0.562)	22.7	203.2(8)	60	219.1(8.625)	10.31(0.406)	18.1	0.68	0.72
10	304.8(12)	120	323.85(12.750)	25.40(1.000)	12.8	203.2(8)	80	219.1(8.625)	12.70(0.500)	17.3	0.68	0.50
11	355.6(14)	30	355.60(14.000)	9.53(0.375)	37.3	152.4(6)	80	168.3(6.625)	10.97(0.432)	13.9	0.47	1.15
12	355.6(14)	30	355.60(14.000)	9.53(0.375)	37.3	203.2(8)	120	219.1(8.625)	18.26(0.719)	12.0	0.62	1.92
13	406.4(16)	60	406.40(16.000)	16.66(0.656)	24.4	203.2(8)	40	219.1(8.625)	8.18(0.322)	26.8	0.54	0.49
14	508.0(20)	40	508.00(20.000)	15.09(0.594)	33.7	254.0(10)	80	273.1(10.750)	15.09(0.594)	18.1	0.54	1.00
15	508.0(20)	40	508.00(20.000)	15.09(0.594)	33.7	406.4(16)	30	406.4(16.000)	9.53(0.375)	42.7	0.80	0.63

NPS : Nominal Pipe Size

Sch. No. : ANSI B36.10 steel pipe schedule numbers

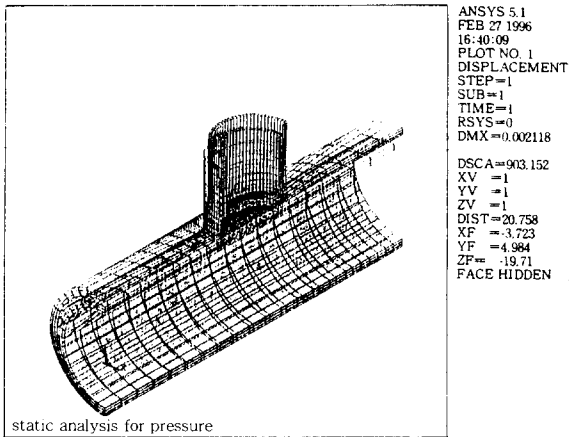


Fig. 3 Deformed and undeformed plot

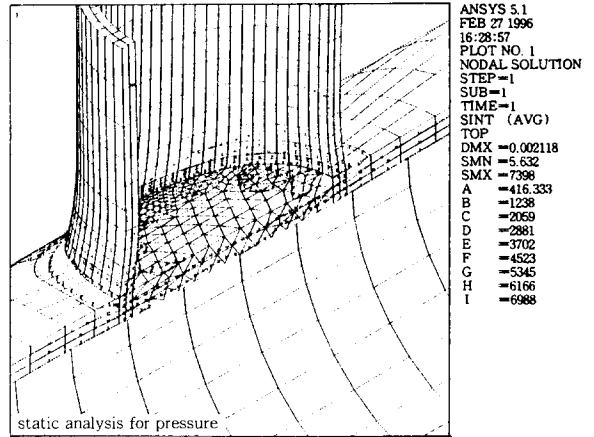


Fig. 4 Stress intensity plot

gebraically largest and smallest principal stresses. The stress intensity contour about pressure is shown on Figure 4. The maximum and minimum stress values based on extrapolated values are indicated on the plots by 'MN' and 'MX', respectively.

4. Stress-Index Development

To provide designers with a rapid approximate analysis, the ASME Code Sec. III, recommends a stress-index and stress-intensity method. These methods categorize the total

stress at any point in the structure into primary, secondary and peak stress components. Loadings are also classified into pressure, moment and thermal types. These simplified design stress formulas involve terms containing a stress index multiplied by a nominal stress. Hence with previously computed stress indices, these formulas allow a designer to rapidly check for allowable stresses.

The definitions of primary stress and secondary stress are included in reference¹⁾; Primary stress is any stress developed by an imposed loading which is necessary to satisfy the laws of equilibrium. The basic characteristic of a primary stress is that it is not self-limiting. Secondary stress is a stress developed by the constraint of adjacent material or by self-constraint of the structure. The basic characteristic of a secondary stress is that it is self-limiting.

ASME Code Section III of the ASME Boiler and Pressure Vessel Code provides the definition of a stress index to be

$$B, C \text{ or } K = \sigma / S \quad (1)$$

where B=Primary stress index

C=Secondary stress index

K=Peak stress index

σ =Elastic stress intensity due to a load

S=Nominal stress due to a load

The three types of stress indices represented by B, C and K are defined by the Code to be primary, secondary and peak indices, respectively. Each of the three categories of stress indices are further subdivided according to the manner of loading and are identified by the subscripts 1, 2 and 3, which signify press-

ure, bending and thermal loads, respectively.

For B indices, σ represents the stress magnitude corresponding to the limit load. For C or K indices, σ represents the maximum stress intensity due to applied load. Values of the nominal stress for isothermal conditions are

$$S = PD / (2T) ; \text{ pressure loading} \quad (2)$$

$$S = M_i D / (2I) ; \text{ moment loading} \quad (3)$$

where P=Internal pressure,

D=Outside diameter of run pipe,

T=Thickness of run pipe

M_i =Applied moment,

I=Area moment of inertia of pipe cross section

The stress values computed by finite element analysis simply give a total stress which is composed of the primary, secondary and peak components. For the present study, the ANSYS Solid 45 element allow to categorize of the total stress into membrane and bending components(LPATH command in ANSYS classifies membrane, bending and peak stress.). Consequently, the membrane values were used to determine B_1 , B_{2R} and B_{2T} , while the membrane plus bending portion was used to determine C_1 , C_{2R} and C_{2T} .

As mentioned, it is desired to compute the largest stress index for each component studied, and then to develop an empirical equation expressing this controlling index in terms of particular dimensionless ratios. Table 2 shows the maximum stress indices for the various loadings. Results are given for both the trunion(T) and run(R) pipes. Locations of these maximum values generally occurred near the intersection zone.

The following relationship was used to de-

Table 2 Stress Index Results

Model No.	B ₁	C ₁	B _{2R}	C _{2R}	B _{2T}	C _{2T}
1	0.981	1.210	1.011	1.191	3.845	9.112
2	0.975	1.229	1.018	1.175	4.038	11.279
3	0.958	1.145	0.992	1.176	2.680	5.330
4	0.962	1.250	1.028	1.171	3.900	12.565
5	0.953	1.149	0.992	1.126	2.447	4.067
6	0.972	1.270	1.024	1.156	4.297	13.524
7	0.971	1.135	1.006	1.131	2.795	5.473
8	1.010	1.278	1.025	1.149	6.125	16.220
9	0.979	1.143	1.009	1.145	3.118	7.192
10	0.953	1.137	0.976	1.146	2.380	3.723
11	0.972	1.285	1.038	1.136	4.076	14.453
12	0.974	1.286	1.040	1.165	7.212	25.346
13	0.971	1.155	1.014	1.112	2.748	5.259
14	0.980	1.280	1.029	1.138	3.905	12.581
15	1.008	1.192	1.019	1.107	3.503	8.854

rive stress indices for pressure and moment loadings:

$$B \text{ or } C = A_0(D/T)^{m_1}(d/D)^{m_2}(t/T)^{m_3} \quad (4)$$

where D=Outside diameter of run pipe
d=Outside diameter of trunnion pipe support
T=Thickness of run pipe
t=Thickness of trunnion pipe support
A₀=Constant
m₁, m₂, m₃=Exponent

The first step requires establishing a relationship between the calculated B(or C) from finite element analysis, for a given load, and one of the variables. The logarithmic regression analysis is performed to establish the best-fit curve. From this analysis, the exponent m₃ is determined. The next step is to normalize the calculated B(or C) from finite element analysis with $(t/T)^{m_3}$ and do this in terms of the next variable d/D. The process is repeated until all exponents are determined.

The final step also defines the constant A₀.

In order to determine the B₁, B_{2R}, B_{2T}, C₁, C_{2R} and C_{2T} indices in terms of the dimensional parameters given in Table 1, the maximum primary and maximum primary plus secondary stress intensities were chosen for each model. The following equations(Eq. 5 to 16) for B₁, B_{2R}, B_{2T}, C₁, C_{2R} and C_{2T} indices were derived from the results of numerical data in Table 2. All results presented here are proposed only for the dimensional ranges $10 \leq D/T \leq 40$, $0.47 \leq d/D \leq 0.84$, $0.5 \leq t/T \leq 2.0$. Fig. 5 to 10 show the comparison between finite element analysis and equations 5 to 16 curve-fitted.⁸⁾

$$B_1 = 0.953(D/T)^{0.0169}(d/D)^{0.0543}(t/T)^{0.00915} \quad \text{for } (t/T) \geq 1 \quad (5)$$

$$B_1 = 0.953(D/T)^{0.0169}(d/D)^{0.0543}(t/T)^{0.0319} \quad \text{for } (t/T) < 1 \quad (6)$$

$$C_1 = 0.829(D/T)^{0.111}(d/D)^{-0.0445}(t/T)^{0.0185} \quad \text{for } (t/T) \geq 1 \quad (7)$$

$$C_1 = 0.829(D/T)^{0.111}(d/D)^{-0.0445}(t/T)^{0.00829} \quad \text{for } (t/T) < 1 \quad (8)$$

$$B_{2R} = 0.891(D/T)^{0.0369}(d/D)^{-0.0284}(t/T)^{0.0160} \quad \text{for } (t/T) \geq 1 \quad (9)$$

$$B_{2R} = 0.891(D/T)^{0.0369}(d/D)^{-0.0284}(t/T)^{0.0113} \quad \text{for } (t/T) < 1 \quad (10)$$

$$C_{2R} = 1.377(D/T)^{-0.0510}(d/D)^{0.0156}(t/T)^{0.0266} \quad \text{for } (t/T) \geq 1 \quad (11)$$

$$C_{2R} = 1.377(D/T)^{-0.0510}(d/D)^{0.0156}(t/T)^{0.0608} \quad \text{for } (t/T) < 1 \quad (12)$$

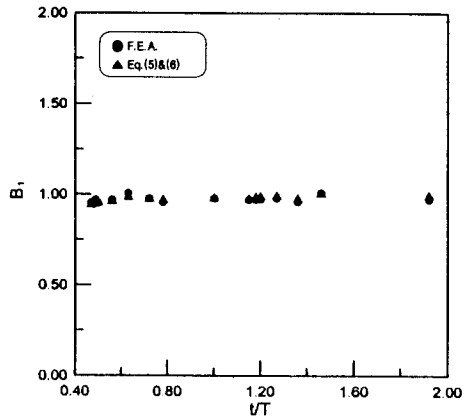


Fig. 5 Comparison of F.E.A. vs Eq.(5) & (6) for B_1

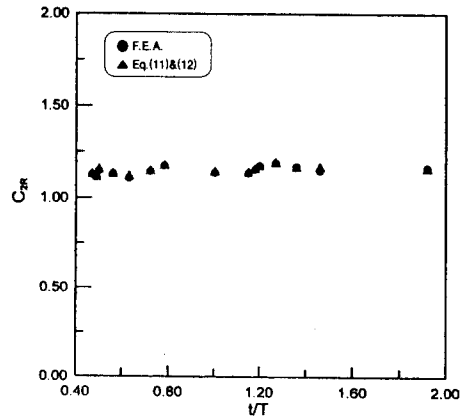


Fig. 8 Comparison of F.E.A. vs Eq.(11) & (12) for C_{2R}

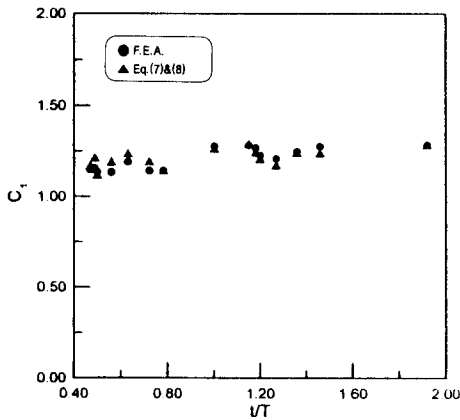


Fig. 6 Comparison of F.E.A. vs Eq.(7) & (8) for C_1

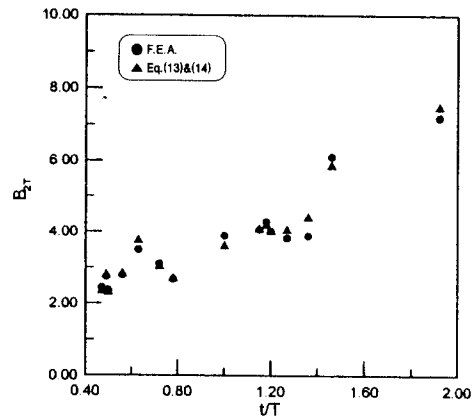


Fig. 9 Comparison of F.E.A. vs Eq.(13) & (14) for B_{2T}

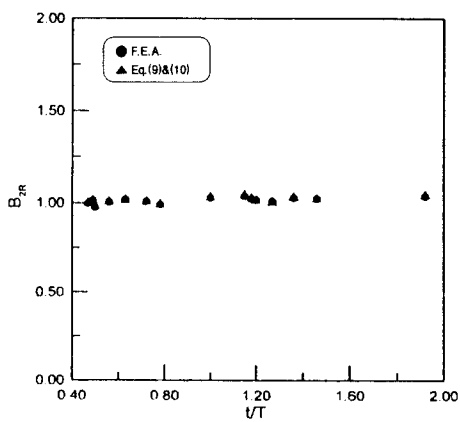


Fig. 7 Comparison of F.E.A. vs Eq.(9) & (10) for B_{2R}

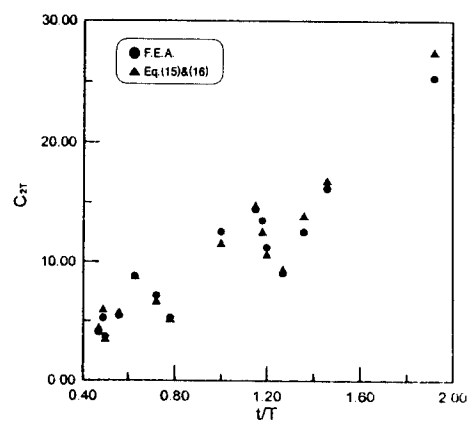


Fig. 10 Comparison of F.E.A. vs Eq.(15) & (16) for C_{2T}

$$B_{2T}=1.03(d/t)^{0.154}(D/T)^{0.257}(d/D)^{0.159} \\ (t/T)^{1.145} \quad \text{for } (t/T) \geq 1 \quad (13)$$

$$B_{2T}=1.03(d/t)^{0.154}(D/T)^{0.257}(d/D)^{0.159} \\ (t/T)^{0.332} \quad \text{for } (t/T) < 1 \quad (14)$$

$$C_{2T}=0.582(d/t)^{0.195}(D/T)^{0.645}(d/D)^{-0.247} \\ (t/T)^{1.402} \quad \text{for } (t/T) \geq 1 \quad (15)$$

$$C_{2T}=0.582(d/t)^{0.195}(D/T)^{0.645}(d/D)^{-0.247} \\ (t/T)^{0.75} \quad \text{for } (t/T) < 1 \quad (16)$$

where B_1 =Primary stress index due to internal pressure

B_2 =Primary stress index due to moment

B_{2R} =Primary stress index due to moment in run pipe

B_{2T} =Primary stress index due to moment in trunnion pipe support

C_1 =Secondary stress index due to internal pressure

C_2 =Secondary stress index due to moment

C_{2R} =Secondary stress index due to moment in run pipe

C_{2T} =Secondary stress index due to moment in trunnion pipe support

5. Discussion

When the attachments, such as lugs or trunnion supports, are attached to the piping, the ASME Code Case⁹⁾ is recommended to evaluate the integrity of the piping system. Eq.(17) shows the primary plus secondary stress intensity except the thermal term in ASME Sec. III NB-3653.1. To use the stress indices derived in

this paper, Eq.(17) shall be modified into Eq.(18). Eq.(19) used in the ASME Code Case N-391-1 represents the evaluation equation for attachments on piping.

$$C_1(PD/2T)+C_2(M_iD/2I) \quad (17)$$

$$C_1(PD/2T)+C_{2R}(M_iD/2I)_R \\ +C_{2T}(M_iD/2I)_T \quad (18)$$

$$C_1(PD/2T)+C_2(M_iD/2I)+S_{NT} \quad (19)$$

where S_{NT} =Local stress for attachments

To evaluate the above equations, the pressure of 6,895 kPa(1 psi) and moments of 0.113 N-m(1 lbs-in) are applied. Two models(model 7 & 13) shown on Table 3 are selected from Table 1. The maximum deviation in the Table 3 is the below than 10 %. The comparisons appear to be reasonably good.

The data between proposed equations and analyses results, shown on Fig. 5 to 10, have some deviations(+, -). Therefore, Table 3 shows that the results of Eq.(19) are not always bigger than that of Eq.(18).

The present procedure of evaluating the local stress for attachments is followed ;

First, the piping system stress is determined by ASME Code NB-3653 for straight pipe(except attachments). Second, the result of

Table 3 Comparison between Eq.(18) and Eq.(19)

	Eq.(18)	Eq.(19)	Deviation
Model 7 pipe : 10" sch.80 sup't : 6" sch.40	13.95 psi	14.12 psi	1.2 %
Model 13 pipe : 16" sch.60 sup't : 8" sch.40	15.36 psi	14.29 psi	7.5 %
pipe : 8" sch.40 sup't : 4" sch.40	20.88 psi	22.72 psi	8.1 %
pipe : 12" sch.60 sup't : 6" sch.40	14.82 psi	14.68 psi	1.0 %

straight pipe is used to perform the local stress for attachments. The complicate equation for the local stress is given in ASME Code Case N-391-1. Therefore, the evaluation of local stress is determined by two steps.

Because the pipe and attachment are analyzed with together, the empirical equations derived in this paper contain the result of the local stress. If the dimensional parameters of the pipe and attachment are given, the integrity of piping systems with attachments is evaluated directly. Therefore, the use of empirical equations(Eq. 5 to 16) can simplify the procedure of evaluating the local stress.

6. Conclusion

Stress analysis and stress index results have been presented for a trunnion pipe supports when loaded by internal pressure and moment. The component was analyzed as a three-ended branch component, and the stresses were categorized by loading type and Code decomposition(Primary and Secondary).

The empirical equations were developed for the B_1 , B_{2R} , B_{2T} , C_1 , C_{2R} and C_{2T} indices. The maximum error between proposed equations and analysis results is below than approximate 10 percent. All results presented here are proposed only for the dimensional ranges $10 \leq D/T \leq 40$, $0.47 \leq d/D \leq 0.84$, $0.5 \leq t/T \leq 2.0$.

Based on the comparison between stress indices derived in this present study and ASME Code Case N-391-1, the empirical equations for stress indices are effectively used in the piping stress analysis.

The present procedure of evaluating the local stress for attachments is determined by two steps. But, the empirical equations(Eq. 5 to 16) evaluate the local stress directly. There-

fore, the use of empirical equations can simplify the procedure of evaluating the local stress, and save the time of issuing design documents.

References

1. ASME Boiler and Pressure Vessel Code, Section III, Division 1, "Nuclear Power Plant Components", American Society of Mechanical Engineers, New York, 1989 Edition.
2. W. G. Dodge, "Secondary Stress Indices for Integral Attachments to Straight Pipe", Welding Research Council Bulletin 198, Sept. 1974.
3. E. C. Rodabaugh, W. G. Dodge, and S. E. Moore, "Stress Indices at Lug Supports on Piping Systems", Welding Research Council Bulletin 198, Sept. 1974.
4. M. H. Sadd and R. R. Avent, "Stress analysis and stress index development for a trunnion pipe support", ASME Journal of Pressure Vessel Technology, Vol. 104, No. 2, May 1982, pp. 73-78.
5. D. K. Williams and G. D. Lewis, "Development of B1 and C1 stress indices for trunnion elbow supports", ASME Journal of Pressure Vessel Technology, Vol. 106, No. 2, May 1984, pp. 166-171.
6. R. F. Hankinson, L. A. Budlong and L. D. Albano, "Stress indices for piping elbows with trunnion attachments for moment and axial loads", ASME PVP-Vol. 129, 1987, pp 43-49.
7. ANSYS Engineering Analysis System User's Manual for Revision 5.1, Swanson Analysis System, Houston, Pa., 1994
8. C. F. Gerald and P.O. Wheatley, Applied Numerical Analysis, pp 530-576, 3th ed., Addison Wesley, 1984
9. ASME Code Case N-391-1 "Procedure for Evaluation of the Design of Hollow Circular Cross Section Welded Attachments on Class 1 Piping", July 1989

(접수일자 : 1996. 3. 19)