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압력과 모멘트 하중을 받는 원통형 배관 지지대의 응력계수 개발

Stress Index Development of Trunnion Pipe Support for Pressure and Moment Loads

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요약

배관을 구속시키기 위한 원통형 배관 지지대 (Trunnion Pipe Support)가 부착된 배관의 응력해석을 위하여 유한요소해석을 사용하였다. 해석결과로 부터 얻어진 응력은 두께에 대한 평균 및 선형 응력으로 분류 되었으며, 분류된 응력값은 압력에 의한 일차응력계수(B_1)와 이차응력계수(C_1), 모멘트에 의한 일차응력계수(B_2)와 이차응력계수(C_2)를 추정하기 위하여 ASME Code에 정의된 것과 일치하게 해석되었다. 무차원의 함수로써 응력계수에 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 as average and linearly varying(through the thickness) stresses. 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_2) and Secondary(C_2) stress indices for moment are developed. Several analysis were performed on various structural geometries in order to determine empirical relationships for the stress indices as a function of dimensionless ratios.

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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 part of the supporting structure. These types of configurations are commonly used in nuclear power plants to restraint or anchor the pipe. But ASME Code Section III [1] does not provide stresses indices for these types of configurations. The purpose of this paper is to identify the primary(B_1, B_2) and secondary(C_1, C_2) stress indices as defined by the welded trunnions attached to pipe.

The trunnion support is shown in Fig.1 and 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.

(Fig. 1)

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. Dodge [2] and Rodabaugh, Dodge, and Moore [3] 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 Avent [4] 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, B_2, C_1 and C_2 were developed as a function of d/D and D/T, t/T and d/D, D/T, and d/D respectively. Hankinson, Budlong and Albano [5] were developed the secondary stress indices of trunnion elbow support as a function of the 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_2) and the secondary stress indices (C_1, C_2) of the trunnion pipe support as a function 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 [6].

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

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 membrance 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.

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

(Table 1)

Displacement plot was obtained for the Model No. 10 using the 3 dimensional solid element post-processor (POST 1) of ANSYS. The displacement plot about pressure is shown on Figure 2.

(Fig. 2)

3. Stress - Index Development

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

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

where 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 pressure, 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

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

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

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 intensity σ is defined to be twice the maximum shear stress or simply the difference between the algebraically largest and smallest principal stresses.

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 allowed a simple categorization of the total stress into average and linear components. Consequently, the average membrance values were used to determine B_1 , B_{2R} and B_{2T} , while the average plus linear portion was used to determine C_1 , C_{2R} and C_{2T} .

The following relationship was used to derive stress indices for pressure and moment loadings:

$$B \text{ or } C = A_0 \, (D/T)^{m1} \, (d/D)^{m2} \, (t/T)^{m3} \tag{4}$$

The first step requires establishng a relationship between the calculated B (or C) from finite element analysis, for one applied 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 $(t/T)^{m3}$ and do this as a function of the next variable d/D. The process is repeated until all exponents are determined. The final step also defines the constant A_0.

In order to determine the B_1, B_{2R}, B_{2T}, C_1, C_{2R}, and C_{2T} indices as functions of the dimensional parameters given in Table 1, the maximum primary membrance and maximum primary and secondary stress intensities were chosen for each model. The following equations for the B_1, B_{2R}, B_{2T}, C_1, C_{2R}, and C_{2T} indices were derived from the results of numerical data:

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

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

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

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

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

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

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

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

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

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

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

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

4. Summary and Conclusion

Stress anlysis 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 Sectionary). The B_1, B_{2R}, B_{2T}, C_1, C_{2R}, and C_{2T} indices shown on Table 2 were estimated from the average or membrance stress values.

a. The stress indices, B_{2T} and C_{2T}, of trunnion pipe support is higher than B_{2R} and C_{2R} of run pipe.

b. The stress index, C_1, for trunnion pipe support is increased the maximum 30% than that for straight pipe which is not attached trunnion support.

c. The stress index, C_{2R}, for trunnion pipe support is increased the maximum 20% than that for straight pipe which is not attached trunnion support. (The stress indices, C_1 and C_2, for straight pipe which is not attached trunnion support are 1.0) [1]

Stress index results shown in Fig. 3 to 5 were curve-fitted [7] and empirical equations 5 to 16 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 $10 \leq D/T \geq 40$, $0.47 \leq d/D \geq 0.84$, $0.5 \leq t/T \geq 2.0$

(Table 2)

(Fig.3) (Fig.4) (Fig.5)

References

1. ASME Boiler and Pressure Vessel Code, Section III. Division1, "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 Bulletion 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 Bulletion 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. 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.

6. Ansys Engineering Analysis System User's Manual for Revision 5.1, Swanson Analysis System, Houston, Pa., 1994

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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

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

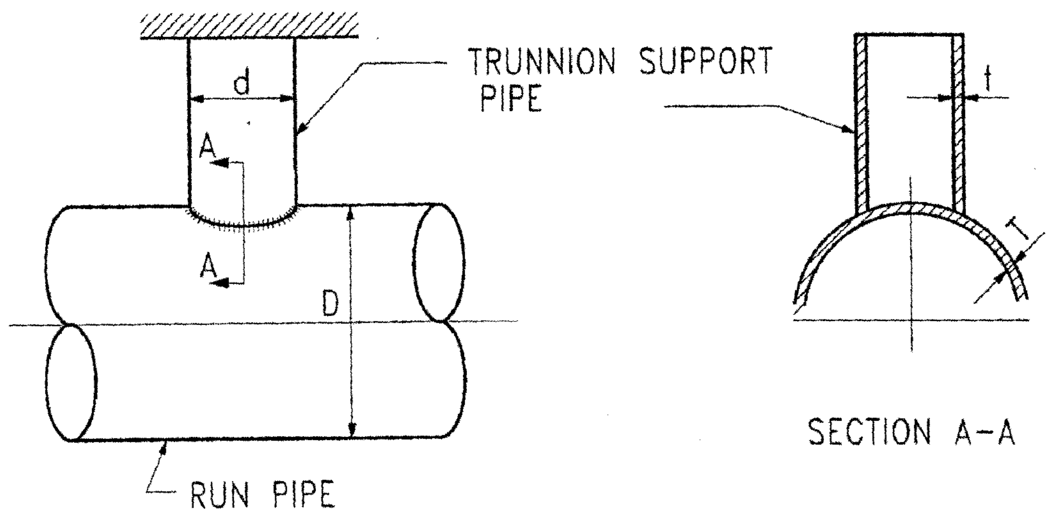

Fig. 1 Typical Trunnion Support

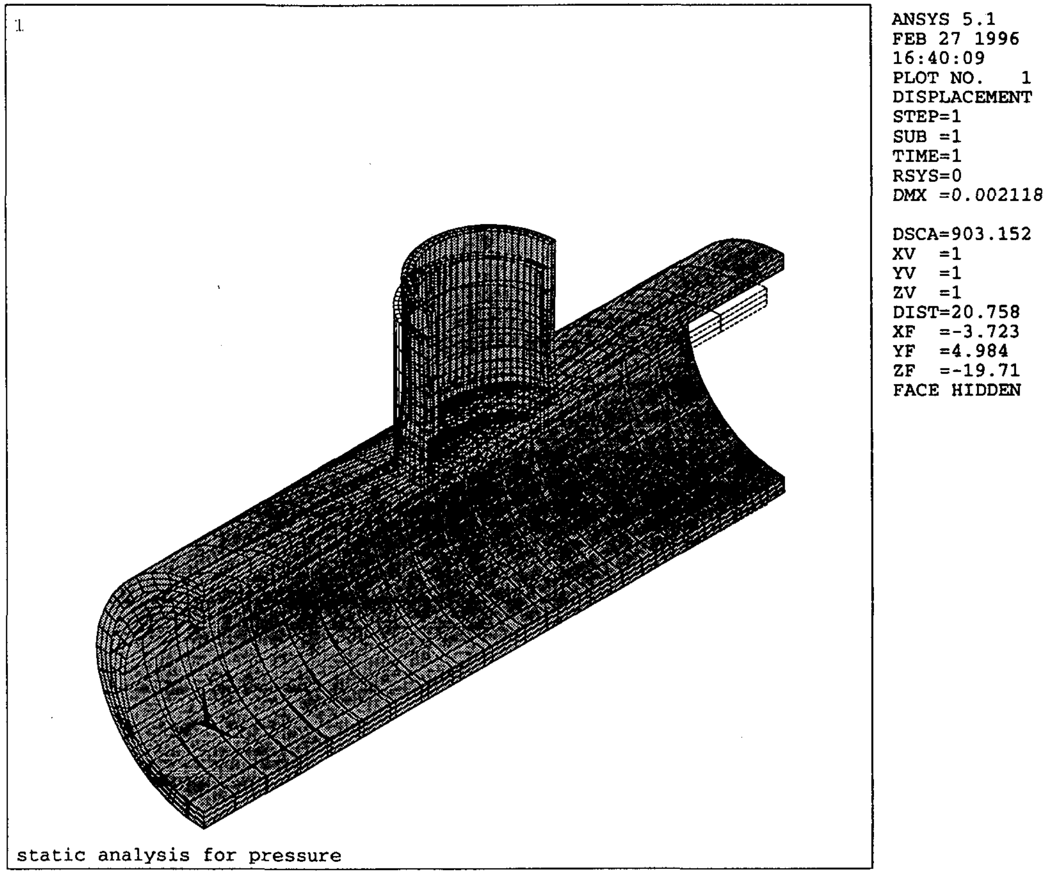

Fig. 2 Deformed and Undeformed Plot

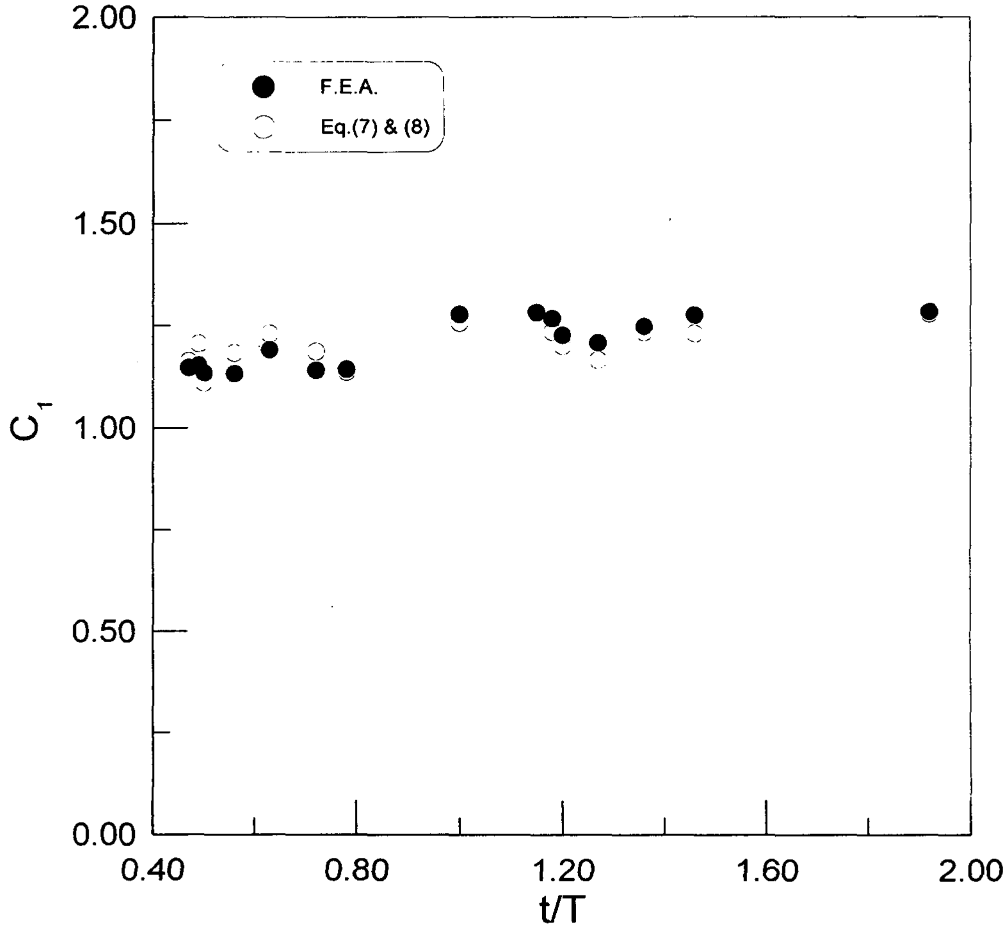

Fig. 3 Comparison of F.E.A. vs Eq.(7) & (8) for C_1

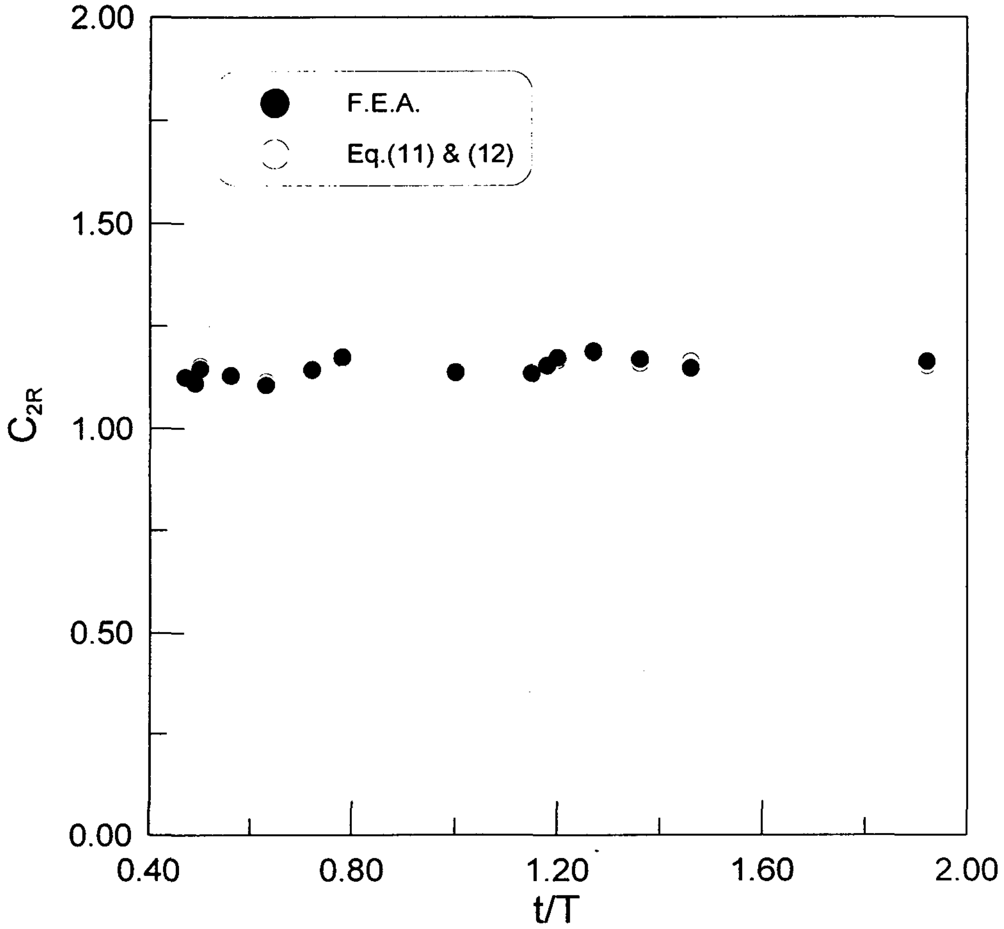

Fig. 4 Comparison of F.E.A. vs Eq.(11) & (12) for C_{2R}

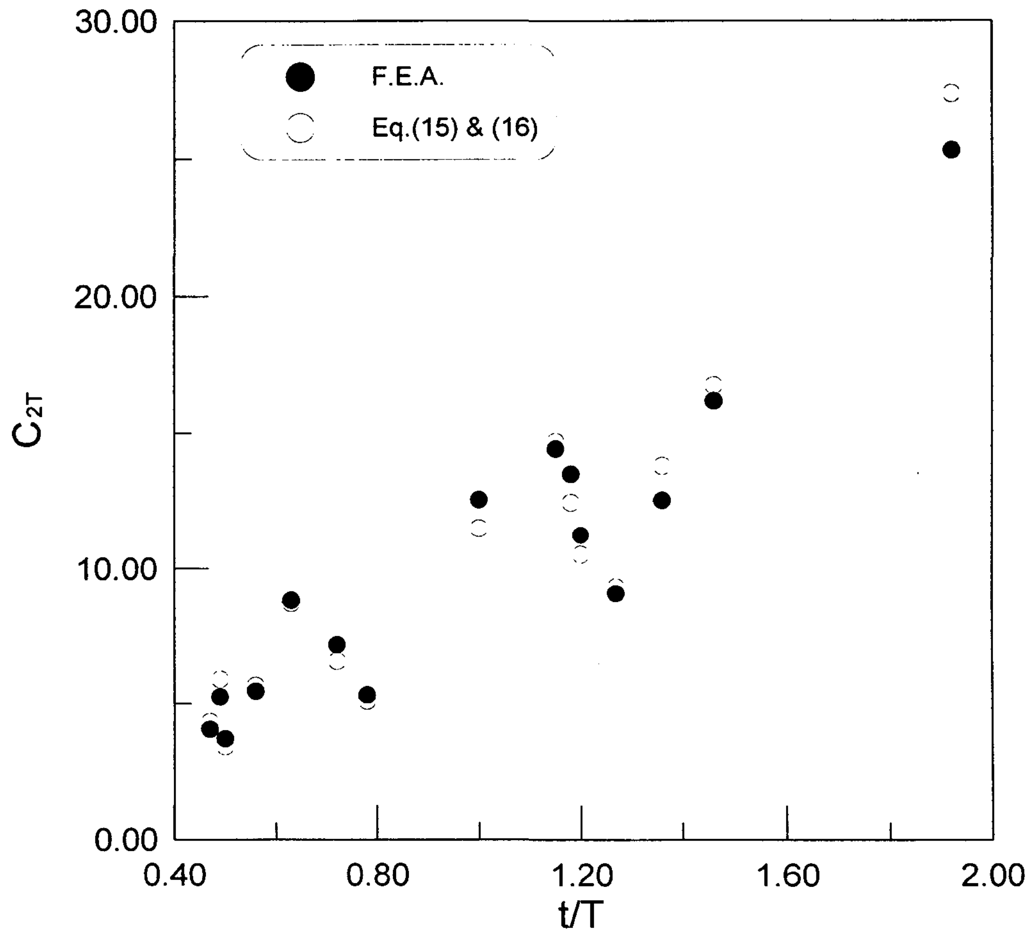

Fig. 5 Comparison of F.E.A. vs Eq.(15) & (16) for C_{2T}