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EXPERIMENTAL AND THEORTICAL INVESTIGATION OF STRESSES AND FLEXIBILITY COEFFICIENTS AT PIPE JUNCTIONS

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1. ABSTRACT

In the Primary Heat Transport system of Pressurised Heavy Water Reactors, the Tee Junction at the Header Pipe is a critical zone of stress and deformation. The junction unit cast monolithically has a complex geometry including varying wall thickness. The location and magnitude of maximum stress due to loads transmitted at the ends of the unit is required in design. Also the flexibility or stiffness coefficients of the unit are also important in the global analysis of the piping network. This article reports on a computational and experimental investigation on a typical Tee Junction regarding the above issues.

2.INTRODUCTION

Primary Heat Transport (PHT) system is a major sub-system in a Nuclear reactor which transports the heat generated in the reactor core by nuclear fission through the medium of the heavy water coolant to the steam generators. The intersection of main and branch pipes in Tee Junctions is a common structural feature in the Header Pipe of this system. These junctions have a very complex geometry including variation in wall thickness and a very large t/R ratio. Many times they will be mono–cast units and introduce an indeterminate amount of flexibility to the structural system. Very often, the piping network is considered as a framed system and analysed assuming the usual stiffness characteristics as those of solid structural members. The reduction in the stiffness due to the presence of the Tee junction is ignored. This may lead to unsafe design. It is clear that only a sophisticated theoretical tool like Finite Element Analysis and a well instrumented experimental study in the laboratory can yield satisfactory answers to the above problems.

Nataraj (1987), Rajender (1989), Himavan (1990) and Paramasivam (1991) carried out theoretical investigations on similar Tee junctions. Their studies were based on 20 node thick shell element, 4 node flat plate/shell elements. As these investigations did not consider the effect of shear-deformations, further investigation was necessary. Also, Robert (1971), Gwaltney (1976), Hayes (1977) and Moffat (1985) carried out experimental investigations on tee junctions for both static and fatigue loading. The pipes used in most of these investigations were thin. This article presents the investigation of stresses at junctions, flexibility coefficients and the 'stress amplification factors' (SAF) for moderately thick Tee pipe junction units both by experimental study and finite element analysis. A comparative study is also made between the theoretical and experimental investigations.

3. GEOMETRY, MATERIAL PROPERTIES & LOADING CONDITIONS

Fig. 1 shows the geometrical dimensions, the boundary and loading conditions of the Tee pipe junction unit. One end of the main pipe will be fixed and other end of the main pipe and that of the branch pipe is free from all restraints. Unit external load / moments will be applied in each of the possible 12 degrees of freedom separately. Table. 1 shows the material properties and Table. 2 shows the geometrical properties for the junction unit.

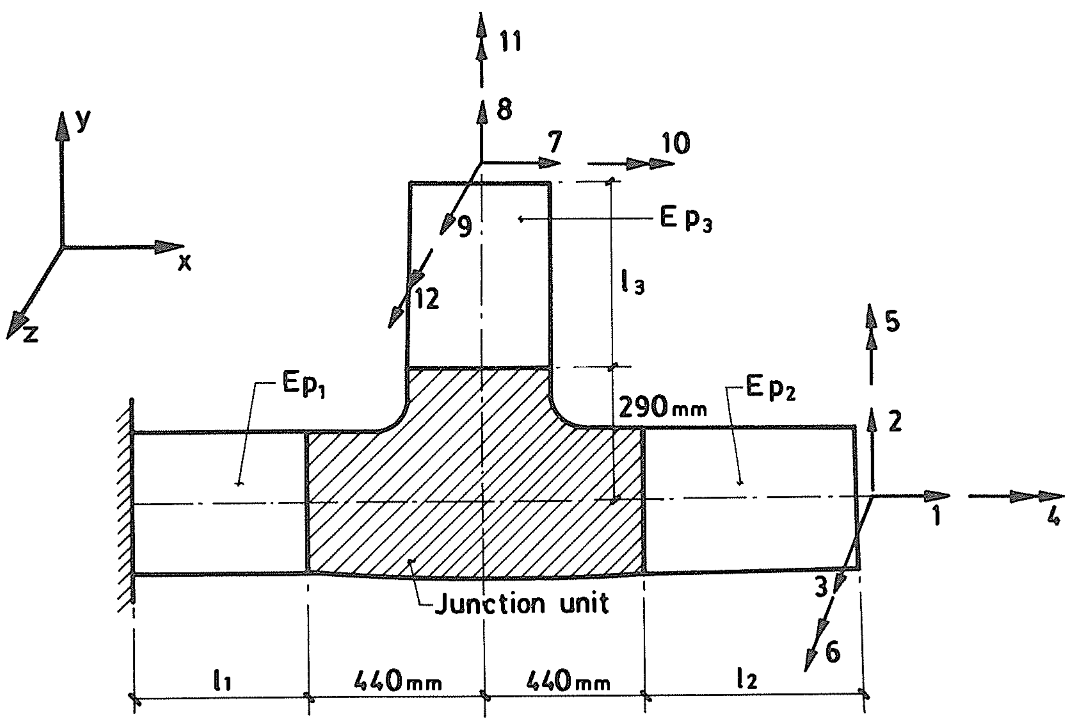

Fig.1. Tee pipe junction

Table 1. Material properties of the test specimen

Type of material	:	Carbon Steel SA106, Grade B
Young's Modulus of Elasticity (E)	:	192.37 kN/mm^2
Poisson's Ratio (ν)	:	0.3
Material density (ρ)	:	77.00 kN/m^3
Coefficient of Thermal Expansion (α)	:	6.07×10^{-6} per degree F

Table 2. Geometrical properties of the test specimen

Pipe	Outer dia.	Thickness	D_{mean}/t
Main	410 mm	55.0 mm	6.455
Branch	410 mm	47.5 mm	7.632

4. EXPERIMENTAL INVESTIGATION

4.1 Instrumentation

The prototype tee junction has been instrumented with 59 electrical resistance rectangular rosette strain gauges, 12 linear strain gauges for the measurement of strains. It is also fitted with 17 mechanical dial gauges for the purpose of measurement of deflections. Load cell, reaction frame, hydraulic jack, calibration jack, load indicator, hydraulic pumps, data logger, IBM PC etc. are the other necessary accessories.

4.2 Measurement of strains and displacements

The junction unit has been pasted with 59 rosettes. Locations were decided based on the information available from the literature and also form the preliminary theoretical investigations. Both the rosettes and linear gauges were connected to data recording system which is having a capacity of 200 channels with a measurement speed of 500 channels per second. The complete system was interfaced with IBM PC/AT through RS 232 in which strain data for each increment of loading was stored. The deflections and rotations were directly measured and recorded manually.

One end of the main pipe was firmly fixed to the 1.2m thick RC testing floor by using 4 high strength bolts. Each one was prestressed up to 20 tons. The load / moment was applied at each dof separately in increments and the strains and deflections were recorded for each increment. The Fig. 2. shows the method of application of load at ends of main and branch pipes. This also shows the instrumentations. The strains recorded were further processed for the computation principal strains and stresses. The location and magnitudes of the major and minor principal stresses were recorded. From the recorded displacements measurements, the flexibility coefficient a_{ij} has been calculated as the displacement at j^{th} degree of freedom due to unit load at i^{th} dof. Further the 'Stress Amplification Factor' (SAF) which is the ratio of experimentally measured maximum stress to the calculated stress from the Strength of Materials approach in a pipe without branch connections is also calculated.

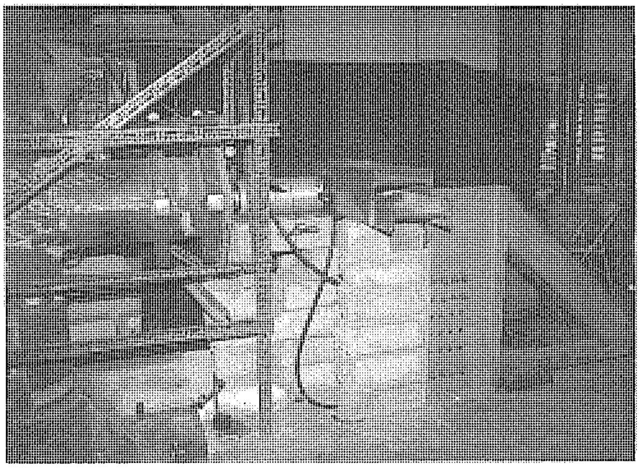

Fig.2. Experimental set-up

5. THEORETICAL INVESTIGATION

The prototype tee pipe junction on which experimental study was carried out was also analysed by the finite element method using ANSYS code. The shell element available in ANSYS package program called STIF93 was used. This element is having eight nodes and 6 dof per node with the consideration of shear deformation. From Table 2 it is clear that the pipe junction is of moderately thick type and the consideration of effect of shear deformation is necessary. The method of selective integration technique was incorporated in the element formulation to over come 'shear-locking'. The version of the package program has limitation on the size of the wavefront. The prototype was discretised with 160 elements and 503 nodes incorporating approximately 3000 active dofs. The facilities available in preprocessing was utilised in modeling the structure. Unit mechanical load was applied separately at each dof and the shape of the deformed structure and the plots of direct and principal stresses were plotted.

6. COMPARISON

The direct and principal stresses were evaluated form the experimentally measured strains and also they were computed by FE analysis. The stress amplification factors were also computed for each of the loading cases. Table 3. shows the comparison of maximum stresses. The flexibility coefficients were also calculated both experimentally and by FE analysis and Table 4. shows flexibility coefficients for some selected loading cases.

Table 3. Comparison of major principal stresses

case No.	Major Expt.(1)	Principal ANSYS (2)	Stresses SM (3)	Ratio (1)/(2)	SAF (1)/(3)
1	3.974e-5	3.914e-5	1.656e-5	1.015	2.400
2	2.288e-4	1.970e-4	2.209e-4	1.157	1.036
3	2.845e-4	2.781e-4	2.209e-4	1.023	1.288
4	5.211e-7	4.440e-7	1.047e-7	1.173	4.980
5	2.121e-7	1.910e-7	2.094e-7	1.110	1.010
6	2.954e-7	2.520e-7	2.094e-7	1.172	1.410
7	5.028e-4	3.940e-4	2.119e-4	1.276	2.370
8	5.707e-5	5.338e-5	3.312e-5	1.069	1.720
9	6.104e-4	5.310e-4	1.308e-4	1.149	4.670
10	4.823e-7	4.830e-7	1.047e-7	1.000	4.670
11	7.874e-7	6.080e-7	2.094e-7	1.295	3.760
12	2.705e-7	2.150e-7	2.094e-7	1.260	1.292

Table 4. Comparison of flexibility coefficients

dof		1	4	6	9
1	Expt.	2.550e-4	0.0	-3.150e-7	0.0
	ANSYS	2.230e-4	0.0	-1.930e-7	0.0
4	Expt.	0.0	1.770e-8	0.0	8.250e-6
	ANSYS	0.0	1.730e-8	0.0	8.130e-6
6	Expt.	-3.150e-7	0.0	8.060e-9	0.0
	ANSYS	-1.930e-7	0.0	8.480e-9	0.0
9	Expt.	0.0	8.250e-6	0.0	1.250e-2
	ANSYS	0.0	8.130e-6	0.0	1.170e-2

7. CONCLUSION

- In most of the loading cases the maximum stresses will develop along the intersection line of main and branch pipe where discontinuity in slope of the structure occurs.
- The ratio of maximum stresses between experimental and theoretical study varies from 1.0 to 1.27.
- The flexibility coefficients derived from experimental study are higher than theoretical study. As expected the theoretical study shows stiffer or lower bound results compared to the experimental results.
- The Stress amplification factor varies from 1.0 to 4.98. The maximum SAF is found in the cases where the main pipe will be subjected to torsion.

- When an axial compressive load was applied at the free end of main pipe, tensile stresses were observed of the same order at the same locations both in experimental and theoretical analysis.
- The maximum stresses developed due to in–plane shear or moment bending are more than that of out of plane loading cases. This is because of the opening at the junction.

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