Stress Analysis of Piping Systems In Nuclear Power Plants

Thesis

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BY

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CHAPTER 4

ELASTIC BEHAVIOUR OF PIPING UNDER STATIC LOADING

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Notation:

F.	Constant Hanger Force.	N
ΔF	Imbalance Force Component	N
M.	The Resultant Bending Moment	Nm
SFF	Support Force Factor	
Δz^n	Vertical Deflection (in Z direction) measured at constant hanger position n under dead-weight	mm
DZ^n	Vertictal Deflection (in Z direction) as a result of piping design calculations under dead weight.	m
$D\Delta^n$	Deviated Vertical Deflection (in Z direction) from the design vertical deflection under dead-weight.	mm
R_e	Yield Strength	N/
R_m	Ultimate Strength	N
A_s	Reduction of Area at Rupture	mm²
U_o	Ovalization Percent	%
D_{max}	Major Diameter of Ovalized Elbow	mm
D_{min}	Minor Diameter of Ovalized Elbow.	mm
$M_{b,test}$	Bending Moment at the Middle of the Tested Elbow	N.
M_{FPL}	Bending Moment for Fully Plasticity of Straight Pipe.	N.m
R	Support Reaction	N
D_o	Outside Diameter	mm
θ	Arc Length of Elbow	
R	Bend Radius of Elbow	mm
t	Wall Thickness	mm
$\bar{A}$	Additional Thickness	mm

A	Area of Cross-Section	mm^2
L1,L2	Length of Adjacent Straight Pipe	mm
A1	Reduction of Area Percentage	%
F	Force	N
SX	Snap Load Case in X Direction	N
SZ	Snap Load Case in Z Direction	N
$\bar{S}_x (\bar{S}_y)$	Shear Force in X Direction (y Direction) due to Force Balance of the System	N
$\bar{\bar{S}}_x (\bar{\bar{S}}_y)$	Shear Force in X Direction (y Direction) due to Moment Balance of the System	
N	Normal Force	N
Mb	Bending Moment	Nm
Mx (My)	Bending Moment in X Direction (y direction)	Nm
T	Torsional Moment	Nm
τ	Shear Stress	N/m^2
ε	Strain	m/m
σ	Stress	N/m^2
N_{ab}, (M_{ab})	Stress Resultant referred to an arc length where the first suffix gives the direction of the stresses and the second gives the direction of the normal to the plane (a or b = X, Y or Z)	$(\frac{Nm}{m})$
E	Young's Modulus	N/m^2
G	Modulus of Rigidity	N/m^2
μ	Poisson's Ratio	
φ	Circumferential Angle	Degree
α	Arc Angle of Elbow	"
R	Bend Radius of the Elbow	mm

Suffix equiv.: Equivalent

Suffix 0 Outside

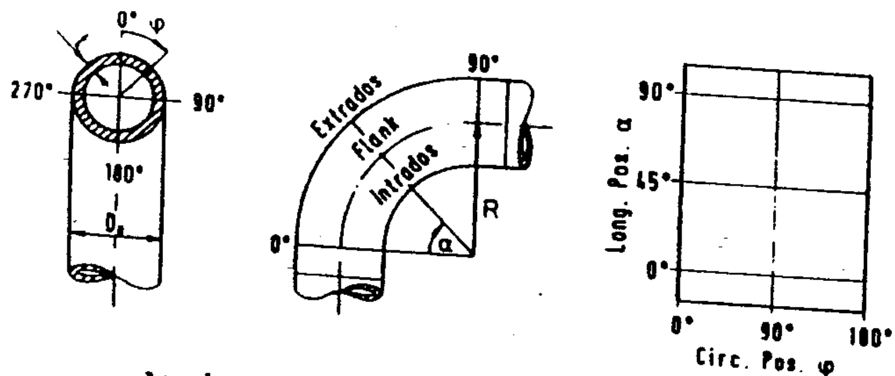
Suffix I Inside

Suffix U_a Circumferential Strain or Stress at Outside Surface.

Suffix U_i Circumferential Strain or Stress at Outside Inside Surface

Suffix L_a Longitudinal Strain or Stress at Outside Surface

Suffix L_i Longitudinal Strain or Stress at Inside Surface.



Angle convention and single plane orthomorphic projection of the bend surface

- Abbreviation

MPA: Material Testing Centre, Stuttgart University, Germany
KTA: German Nuclear Safety Standards
RCC: French Nuclear Safety Standards
NDT: Non Destructive Testing

ABSTRACT

Stress analysis of safety related piping systems in nuclear power plant were investigated under various loading conditions to verify safety principles and to show that catastrophic failures can be excluded.

The effect of boundary conditions on the reliability of piping was studied. For instance, the presence of significant deviating constant hanger load ratings which are frequently used for supporting the piping showed unexpected additional stresses on the piping .Such deviation is not taken into consideration during the design phase.

Several examples of piping models were studied to illustrate such deviating constant hanger load rating cases. According to such studies, it is recommended to review the state of stress under the actual load rating of the used constant hangers. For determining such actual load rating some suggested iterative methods were developed.

Experimental tests using an actual feed water piping system of decommissioned reactor (Heissdampfreaktor, HDR) in Germany were performed. Parallel to this experimental work, theoretical computations of the stresses were achieved by using advanced finite element codes such as ASKA and ABAQUS Codes. For validation purposes a comparison of experimental and theoretical results were performed. Member programme caculations provide a conservative estimation for piping behaviour. However, more advanced 3 dimensional analysis programmes give more realistic evaluation of highly stressed components than using simplified analysis as cited in the American Society of Mechanical Engineering ASME Boiler and Pressure Vessel Code. A coupled experimental-theoretical method was developed to provide more accurate analysis of highly stressed components in case of unknown boundary conditions.

Elastic-Plastic behaviour of highly stressed components could lead to plastic deformation under faulted conditions.

Thus, experimental investigation for elastic —plastic behaviour of the simulated elbows of HDR feed water piping under predominant in-plane bending moment in opening mode was undertaken. The results showed that the bend zones were subjected to cross-sectional deformation (ovalization) as a result of elbow geometry. These results were also proved to be extended to the adjacent straight pipes. This deformation led to high stresses particularly in the inner surfaces. Also, plastic deformation of such elbows was initiated locally at elbow flank in the inner surface and then in the outer surface . It has been shown that the elbows under in-plane bending moment in the opening mode are not amenable to collapse under practical service conditions. This complies with the basic safety approach in which a catastrophic failure is excluded.