The Effects of LOCA and SLB Accidents on Auxiliary Piping Attached to the Primary Loop

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Summary

The motion of the primary loop of a PWR due to the LOCA (Loss- of Coolant Accident) or the SLB (Steam Line Break) yields important dynamic effects in connected auxiliary lines.

Safety purposes require to maintain integrity of such lines during and after the postulated accident. Consideration of the dynamic LOCA and SLB effects as an ASME load case is then required.

Elastic calculations yield unusually high loads on the supports. It is shown that using inelastic analysis methods allows to take into account this load case without undue penalty in the support design. The major consequence at the support level is a ductility requirement.

1. Introduction

The motion of the primary loop of a PWR due to a LOCA (Loss- of Coolant Accident) or a SLB (Steam Line Break) yields important dynamic effects in connected auxiliary lines.

It may be required to maintain the integrity of such lines during and after the postulated accident for several safety purposes :

- the line may be needed for operational reasons (e.g. the safety injection),
- additional energy release in the subcompartments may be undesirable (pressurizer surge line),
- the lateral loads on the RC broken leg may be undesirable if such effects have not been considered in the RC loop restraint design.

In the past, the influence of the LOCA and SLB on connected auxiliary lines has been treated statically (static displacement at the primary nozzle). This method was the only one which could be applied because of the lack of displacement time histories (not usually produced by the NSSS supplier).

Since 1977, some papers (KASSAWARA /1/, PATEL /2/) evidenced the following points :

- a quasi-static treatment of LOCA and SLB in auxiliary piping systems is not correct and does not comply with ASME philosophy,
- the motion of the connected auxiliary piping is important, and the high frequency content may be significant,
- taking into account material non linearities in the piping and the supports (local yielding) allows a significant reduction of the load level.

2. ASME discussion

To treat the LOCA or SLB motion at the nozzle as a quasi-static load case is not in compliance with the ASME philosophy. In fact, the break of the primary piping may induce three main effects in a connected auxiliary line :

a) the displacement of the primary leg introduces anchor displacement effects,
b) the dynamic nature and frequency content of this motion yields inertia effects,
c) the auxiliary piping may be a target for jet impingement from the break.

In these three effects, the two last ones yield stresses which are primary stresses in the ASME sense, while the first one yields pure secondary stresses. If, as usual, the LOCA or SLB event is considered as a faulted condition for the auxiliary piping, primary stresses only are subject to ASME limitations.

If the LOCA or SLB event at the auxiliary piping nozzle is analysed only through a static displacement load case, it can be seen that the primary stress effects are omitted, when ASME limits exist, while secondary stresses are computed, which are not limited by the ASME code ; such a treatment appears to be not satisfactory.

3. Detailed analysis of a typical case

Several analyses have been performed on a specific auxiliary line (14" sch 140 RHR section on a 3-loop PWR Nuclear Power Plant). The piping system geometry is represented at fig. 1.

The NSSS vendor supplied for each rupture case, a time history of displacements (3 displacements - 3 rotations) at each theoretical nozzle location (intersection between run and branch axes).

From those data, accelerations are obtained through double derivation with spline functions, and nozzle response spectra are computed. Fig. 2 to 4 show displacement and acceleration time histories, and response spectra, at the considered nozzle for the analysed rupture case (steam line guillotine break after the steam generator outlet elbow).

Several analyses have been performed and are summarized in table I. The results are summarized in table II.

3.1. Static analysis (TEPIPE (+))

The first run is a static anchor displacement analysis (case 01).

3.2. Modal analysis and response spectrum calculation (TEPIPE (+))

In a first calculation (case 02), the piping system has been represented with its supports : the model used is valid until 100 Hz (finer mesh than for a seismic calculation) and the response spectrum analysis is also performed up to 100 Hz. A multiple support excitation technique is used , with separate computation of the effects of the three components of acceleration and absolute sum combination. The results emphasize the acceptable stress level (w.r.t. ASME criteria) in the piping and the high load level on the supports.

In a second calculation (case 03), the influence of the supports on the piping behaviour has been evidenced, through deletion of all supports in the primary nozzle neighbourhood : the fundamental frequency, of course, drops (from 7.91 to 1.31 Hz) ; the multiple support excitation spectral calculation again shows the acceptability of the event for the pipe,with a displacement at the deleted supports of 10 mm max.

The reason for performing this calculation is based on the following argument : if a configuration with some supports deleted can be demonstrated globally stable and thus acceptable for the piping, with respect to the ASME code, the loads obtained on the same supports when they are not deleted may be considered as secondary. However, the supports themselves must still be checked to insure that no uncontrolled failure mode (low ductility fracture) can happen. The case 03 is then aimed at computing this equilibrium and an upper bound of the correspondingly needed support ductility.

(+) TEPIPE is the Tractionel proprietary piping analysis program.

3.3. Time history analysis

The study of the influence of the support ductility upon the piping response is possible only with a tool capable of modelling this ductility : the PIPERUP (++) program has this capability and appeared very suitable for our purpose.

The displacement time history at the primary nozzle has been imposed to a PIPERUP model of our piping system, with the following structural data :

- case 04 : linear model identical to case 02 above
- case 05 : linear model identical to case 03 above
- case 06 : same model as in case 04, but without nozzle rotations
- case 07 : fully non linear model
- case 08 : fully non linear model with smaller ($1.75\ 10^{11}$ instead of $2.\ 10^{11}$) Young's modulus

Each support is represented with two one-directional restraints, capable of (perfectly) plastic deformation in the cases 07 and 08.

The main results are summarized in table I and can be detailled as follows :

- as expected, time history calculations (case 05 with respect to case 02, case 05 with respect to case 03) yield less pessimistic results than the corresponding modal spectral calculations ;
- the error obtained when neglecting rotations (case 06) is not significant, except at the nozzle itself ;
- plastic yielding in the piping system is not significant in this case ;
- allowing a small amount of plastic deformation in the supports yields a significant reduction in the pipe response (at the yielding supports, but also at the other supports and in the pipe itself). The needed ductility is quite lower thant that obtained from the elastic calculation (case 03) ;
- lowering the piping stiffness decreases the stresses in the pipe but increases the support loads (yielding of support 192 Z).

4. Conclusion

From the above results, the following procedure is proposed for the treatment of the LOCA/SLB in the auxiliary lines :

1° sizing of the supports on basis of the usual loads (gravity, thermal, earthquake, external hazards, fluid transients) ; "oversizing" of the support will be avoided (which would induce higher anchor loads in the step 3 and 4 below)

2° selection of rupture load cases to be computed

3° non linear analysis of the auxiliary line with provision for elastic-plastic capability in both piping and supports.

(++) PIPERUP is a program developed by Quadrex Corp. for non linear analysis of piping systems subjected to postulated ruptures.

In this calculation, the supports for which a significant (greater than 1 mm) elastic deformation is expected (snubbers e.g.) are modeled with this value at yield ; the other supports are sized with the minimum yield deformation compatible with numerical stability (0.2 to 0.5 mm typical). The supports are modeled as elastic, perfectly plastic components, with a yield load corresponding to the design load (envelope of level A + B multiplied with 1.5 and level D).

An ASME verification of the piping system is performed with respect to criteria given in Appendix F (Ref. /3/).

4° support ductility check

- bending deformation process instead of traction-compression,
- anchor verification (the anchor and/or expansion bolts must be ductile in the sense of Ref. /4/).

Should the check lead to a negative conclusion, a specific standard device with controlled ductility (GERAETS /5/) is interposed.

References

/1/ KASSAWARA, R.P. et al : The effects of Reactor Coolant System Pipe Rupture Motion on Tributory Piping and Attached Equipment
CE-TIS-6321, Combustion Engineering, Windsor, 1979

/2/ PATEL, M.R. : Auxiliary Line Evaluation of Loss-of-Coolant Accident using Time-History Plastic Analysis
Dynamic Analysis of Pressure Vessels and Piping Components, (C. Sundararayan, ed.), ASME-PVP-PB-022, New York, 1977

/3/ ASME Boiler and Pressure Vessel Code, Section III, div. 1, 1980

/4/ ACI 349-76 : Code Requirements for Nuclear Safety Related Concrete Structures, App. B, (+ Commentary on App. B)
ACI Journal, August 1978.

/5/ GERAETS, L.H. : Définition d'un élément dissipatif mécanique à ductilité contrôlée,
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TABLE I : DESCRIPTION OF ANALYSED CASES

CASE N°	PROGRAM USED	ANALYSIS TYPE			PIPING MODEL		SUPPORT MODEL			NOTES
		STATIC	DYNAMIC		LINEAR ELASTIC	ELASTIC PLASTIC	LINEAR ELASTIC	NO SUPPORTS	ELASTIC PLASTIC	
			MODAL SPECTR.	TIME HISTORY						
01	TEPIPE	X								
02	TEPIPE		X		X		X			
03	TEPIPE		X		X			X		
04	PIPERUP			X	X		X			
05	PIPERUP			X	X			X		
06	PIPERUP			X	X		X			(1)
07	PIPERUP			X		X			X	
08	PIPERUP			X		X			X	(2)

Notes : (1) No nozzle rotations.

(2) Low pipe Young's Modulus

TABLE II : RESULTS

Case		01	02	03	04	05	06	07	08
a) load on supports in kN ; (displacement in mm)									
support	dir.								
132	X	62	544	(4.29)	109	(4.6)	106	77 *	77 *
137	X	66	506	(6.57)	127	(3.7)	100	103	128
	Z	23	519	(9.87)	105	(3.5)	81	73	74
192	X	7	181	(7.01)	36	(3.9)	40	65	43
	Z	3	191	(9.99)	45	(3.2)	46	46	48 *
198	X	8	275	(10.10)	49	(3.9)	46	93	84
232	X	1	70	(0.76)	20	(2.8)	23	18	25
	Y	3	103	(3.63)	14	(2.5)	16	7	38
	Z	(0.32)	46	(1.23)	(0.8)	(1.1)	(0.8)	(0.5)	(0.5)
105	X	56	639	598	577	300	345	419	449
(prim.	Y	30	367	513	150	193	193	174	106
nozzle)	Z	61	373	279	89	85	85	77	131
b) maximal piping stresses (MPa) : the highest stress appears always at the node number 110 (piping to nozzle weld)									
		50	105	115	38	64	39	36	31

* Specified plastic limit.

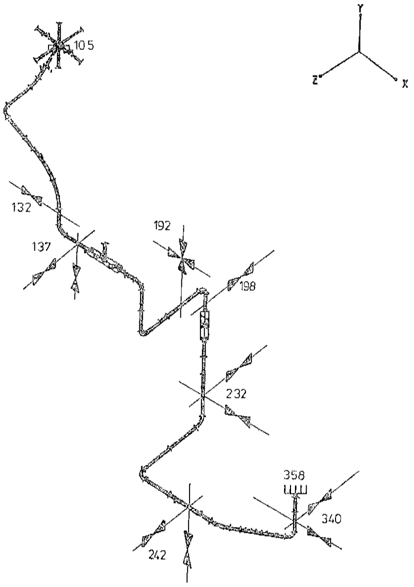

Figure 1 Piping isometrics

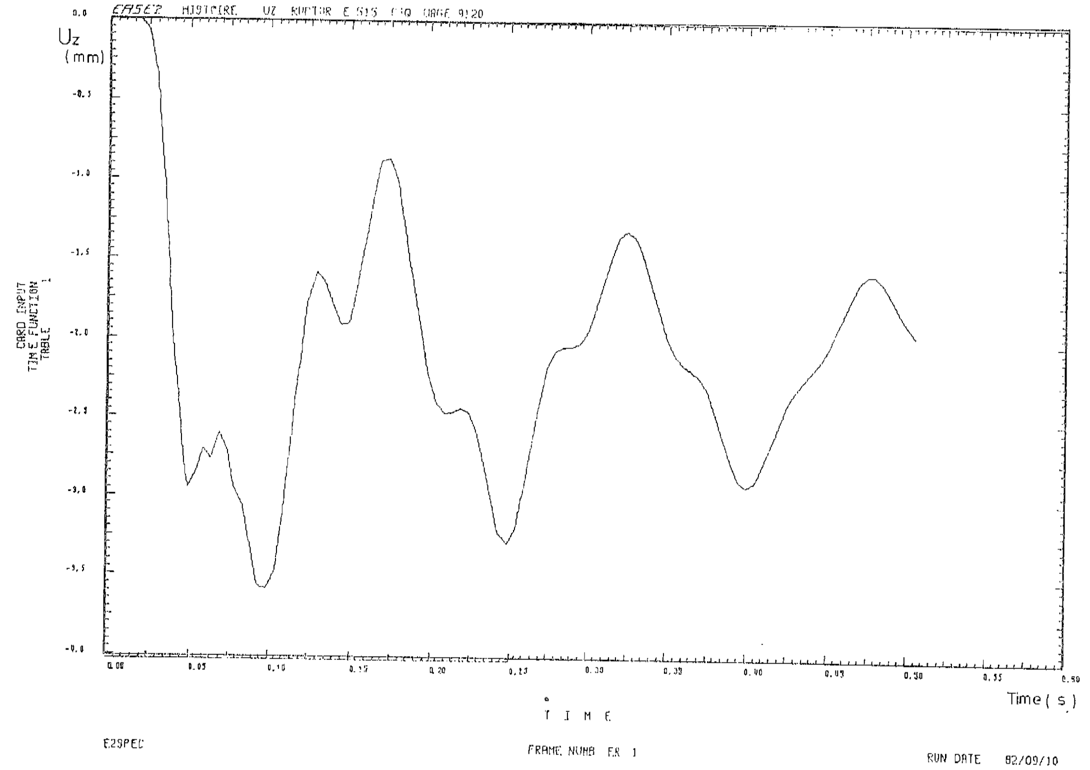

Figure 2 Nozzle displacement (Z direction)

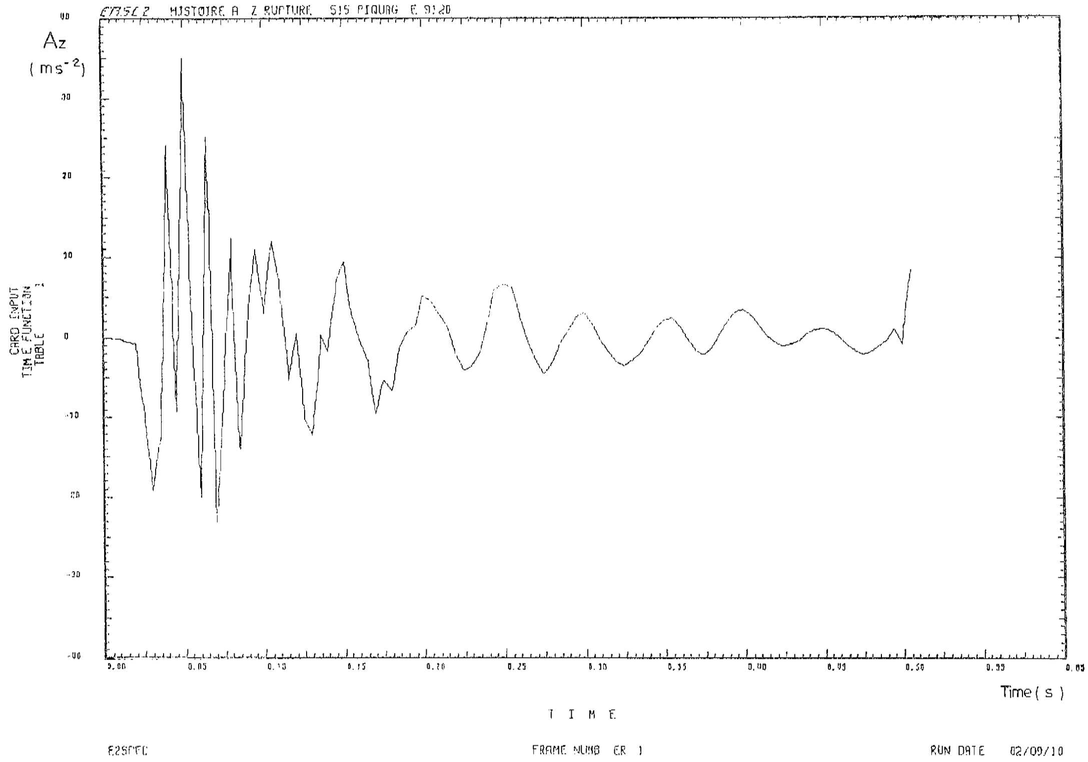

Figure 3 Nozzle acceleration (Z direction)

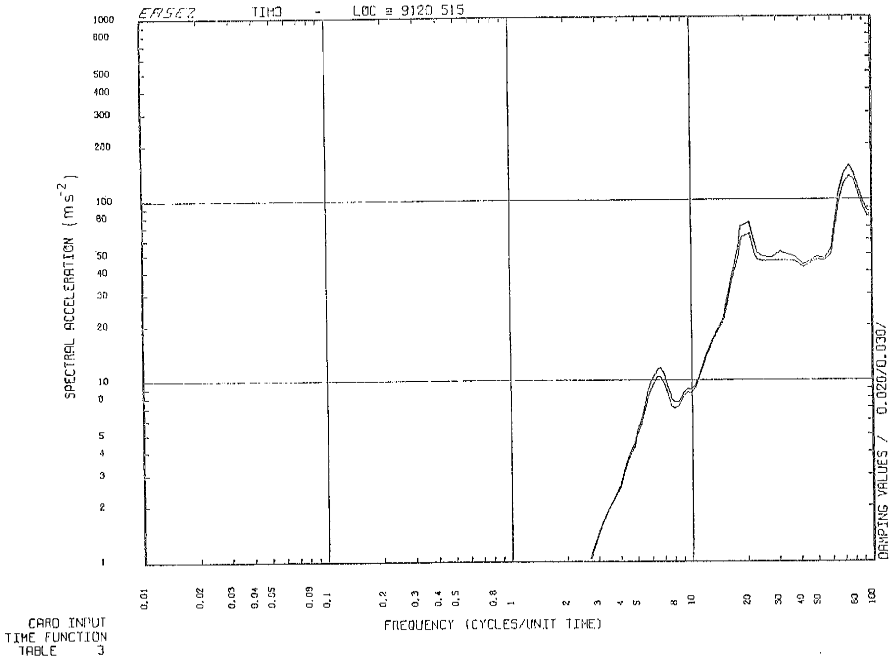

Figure 4 Nozzle response spectrum (Z direction)