Evaluation of Design Basis Pipe Break Loads of RCS Components in APR1400

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1. Introduction

The Design Basis Pipe Break (DBPB), as defined in SRP 3.9.3 [1], is the postulated pipe break other than a LOCA or MS/FWPB. This includes postulated pipe breaks in Class 1 branch lines that result in the loss of reactor coolant at a rate less than or equal to the capability of the reactor coolant makeup system. This is classified as Level C loads [1], but it is not used actually in the component evaluation or specifications. In this study, the reason why the DBPB is not applied in the design is provided. The evaluation results, such as loads and response spectra of the RCS components, due to the DBPB loads are also provided to show the actual effects of the DBPB in APR1400.

2. Concept of DBPB

The DBPB includes postulated pipe breaks in Class 1 branch lines that result in the loss of reactor coolant at a rate less than or equal to the capability of the reactor coolant makeup system. For APR1400, makeup flow can limit the loss of coolant from a break by installing 5.56 mm ID x 25.4 mm L orifice. In accordance with SRP 3.6.2 [2, 3], postulated pipe breaks in 25.4 mm diameter piping and smaller piping do not require the analysis of the dynamic system loading from a ruptured pipe. Therefore, the DBPB is not analyzed, and the Level C loading combination including the DBPB loads are not necessary to be considered in the design.

Though the dynamic loadings due to the DBPB are not used in the design, the system operating transients due to the DBPB, such as RCS temperature and pressure transient conditions, are considered as Level B condition

3. Evaluation of DBPB

In this section, the DBPB is actually analyzed to generate resultant loads and evaluated to identify its effects.

3.1 Analysis Model and Loadings

For the DBPB analysis, the typical lumped beam-mass models for RCS for APR1400 of Fig. 1 are used.

The locations of the DBPB are selected according to SRP 3.6.2 as shown in Table 1. The DBPBs in Table 1 are of the RCS branch lines, having 5.56 mm orifice, and the DBPB locations are the points right after the orifice. The thrust force, jet impingement load (JIL) and sub-compartment pressurization are considered as loading conditions. The thrust forces and JIL are calculated according to SRP 3.6.2, III.2.C [2]. The subcompartment pressurization are calculated according to SRP 6.2.1.2 [4].

As results of the analysis, the acceleration response spectra and support loads of main components are considered to evaluate the DBPB effects in the following sections.

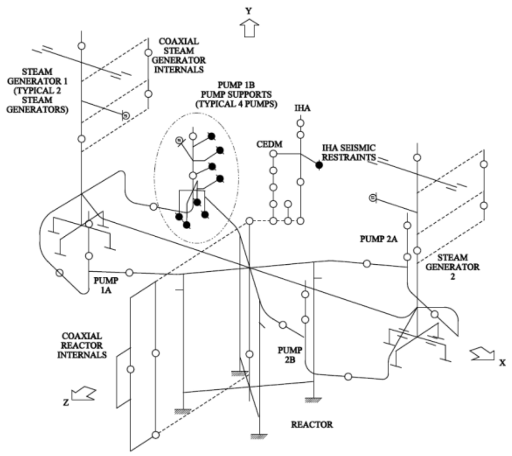

Fig. 1. RCS Analysis Model

Table 1: DBPB Locations

Break Location	ID (mm)	Pressure (MPa)	Temp (°C)
SG RCPB Cold Side Instrument Nozzle Break	17	154	290
Hot Leg Pressure Measurement Nozzle P-1	16	156	324
Hot Leg Pressure Measurement Nozzle P-10	16	156	324
Surge Line Sampling Nozzle5)	16	156	345
Pressurizer Upper Instrument Nozzle	16	155	345
Pressurizer Lower Instrument Nozzle	16	155	345
RCP Suction - Pressure Tap Nozzle Break	5	153	290
RCP Discharge - Pressure Tap Nozzle Break	10	154	290

3.2 Analysis Results: Response Spectra

The DBPB acceleration response spectra in the horizontal X direction and vertical Y direction for RCS main components of Reactor Vessel (RV), Steam Generator (SG), Reactor Coolant Pump (RCP) and Pressurizer are shown in Fig. 2 ~ Fig. 9. Each figure also includes spectra for SSE, BLPB and IRWST discharge for comparison.

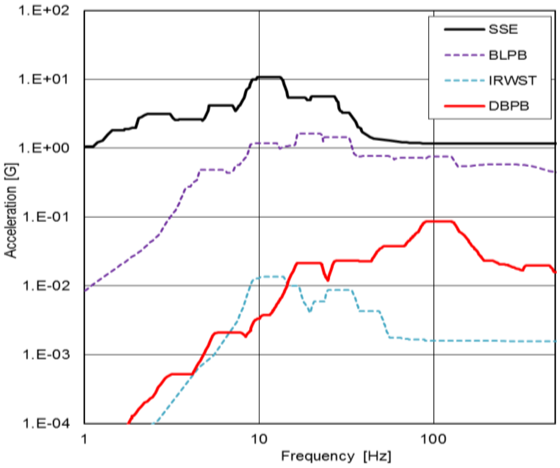

Fig. 2. Response Spectra for RV composite in X-direction

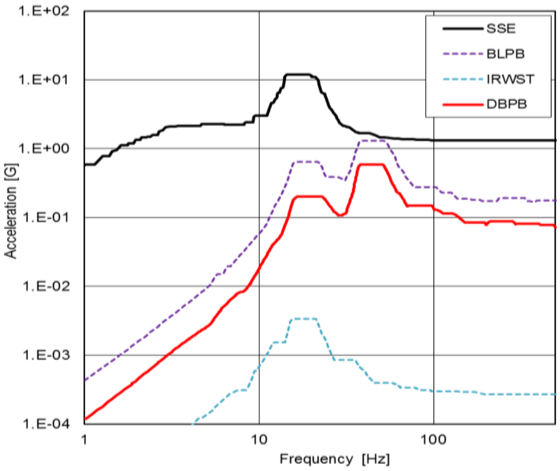

Fig. 3. Response Spectra for RV composite in Y-direction

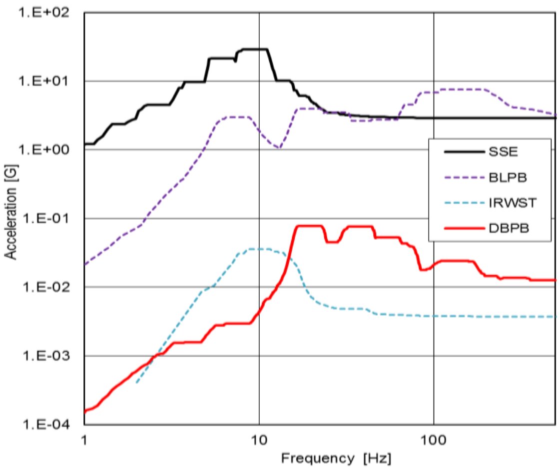

Fig. 4. Response Spectra for SG composite in X-direction

It is found that the acceleration values of DBPB are roughly 10^{-2} times less than those of SSE or BLPB on the whole. DBPB results could be neglected because they are smaller than the usual design margin of SSE or BLPB. The vertical Y value of RV shows a little large, but the peak acceleration value is still so small that it could not affect the overall response.

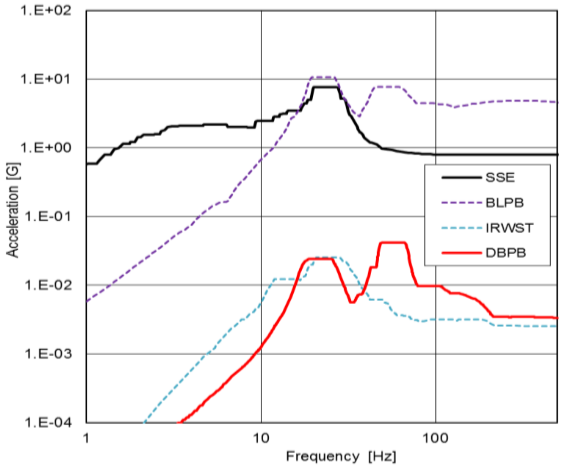

Fig. 5. Response Spectra for SG composite in Y-direction

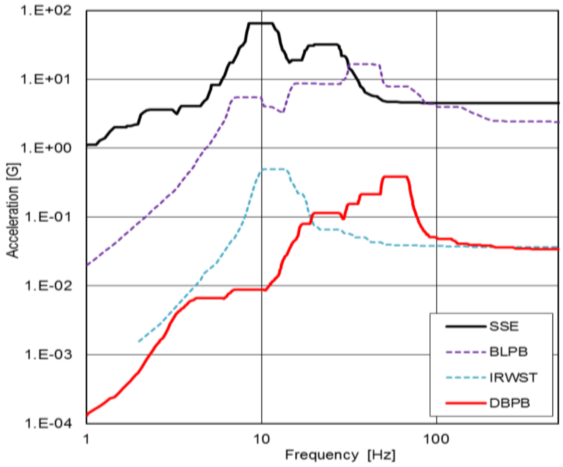

Fig. 6. Response Spectra for RCP composite in X-direction

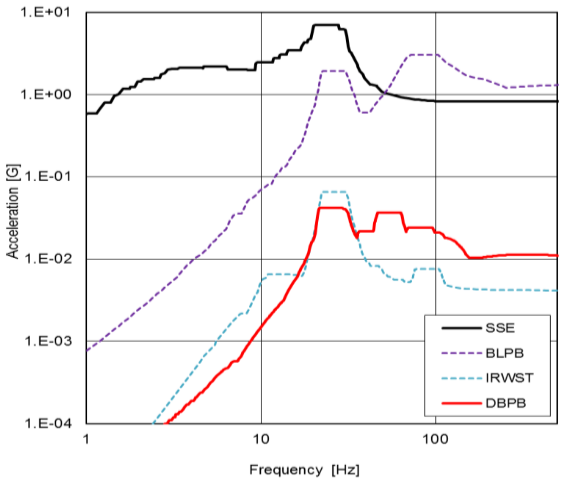

Fig. 7. Response Spectra for RCP composite in Y-direction

The shapes of DBPB response spectra are similar to those of BLPBs, because the load characteristics, such as thrust force, JIL and subcompartment pressurization, are similar to each other. The level of DBPB response is similar to that of IRWST discharge.

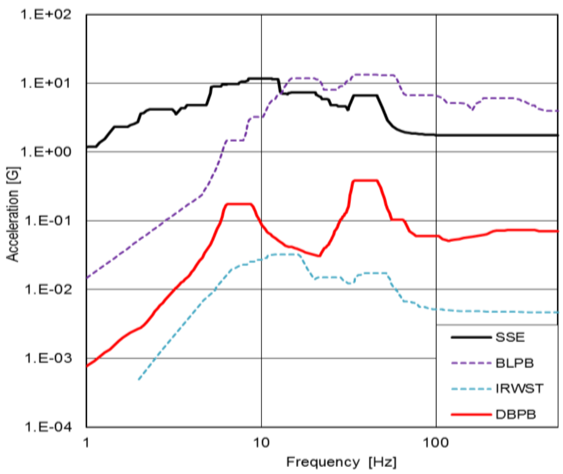

Fig. 8. Response Spectra for PZR composite in X-direction

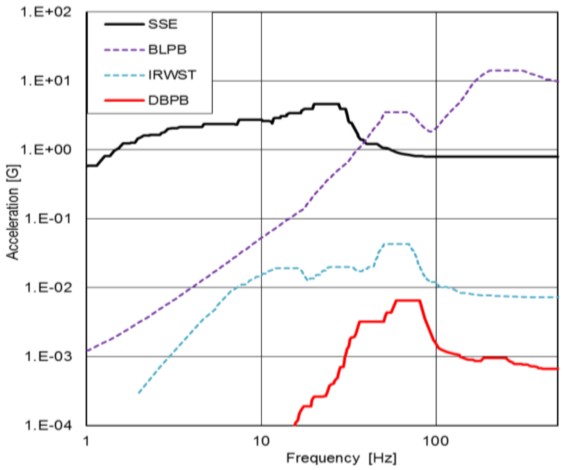

Fig. 9. Response Spectra for PZR composite in Y-direction

Table 2: RV Support Loads

Case	Fx	Fy	Fz	Mx	My	Mz
NOP	37	531	10	35	0.8	124
BLPB	2.8	56	58	47	31	9.4
SSE	50	473	120	34	81	16
IRWST	0	0.5	0.3	0.1	0.2	0
DBPB	0.1	7.4	0.2	0.7	0	0.3
R	1.00	1.01	1.00	1.02	0.81	1.00

(unit: 10^3 kgf, 10^3 m·kgf, except R)

3.3 Analysis Results: Support Loads

In order to check the static and dynamic effect together, the support loads for main components due to DBPB are compared to other loading cases in Table 2 ~ Table 4. The results show that the DBPB case is about 10^{-2} times less than other cases in general, and similar to IRWST discharge case.

Table 3: Support Loads for SG and RCP

Case	SG Sliding Base (vertical)	RCP Vert. Support	RCP Hor. Support
NOP	555	117	102
BLPB	738	22	42
SSE	518	64	48
IRWST	1.5	0.3	0.3
DBPB	2.8	0.4	1.0
R	1.002	1.001	1.008

(unit: 10^3 kgf, 10^3 m·kgf, except R)

Table 4: PZR Support Loads

Case	Fv	Fh	Mt	Mb
NOP	217	26	33	270
BLPB	142	91	31	439
SSE	121	132	172	876
IRWST	1.1	0.8	0.2	2.6
DBPB	0.1	2.7	0	25
R	1.00	1.07	0.99	1.08

(unit: 10^3 kgf, 10^3 m·kgf, except R.
v: vertical, h: horizontal, t: torsional, b: bending)

3.4 Evaluation of Level C Condition

The loading combination and stress limit for Design condition and Level C condition are as follows:

Design: PD + DW + IRWST,
$P_m \leq Sm$, $P_L+P_b \leq 1.5\ Sm$,

Level C: PO + DW + DBPB,
$P_m \leq 1.2Sm$, $P_L+P_b \leq 1.8\ Sm$,

where PO is operating pressure, PD is design pressure and DW is dead weight. The ratio of Level C limit to Design limit is 1.2. The ratio of Level C to Design, R, is expressed as follow:

$$R = \frac{PO + DW + DBPB}{PD + DW + IRWST} < \frac{PO + DW + DBPB}{PO + DW + IRWST}, \quad (1)$$

In the sections of 3.2 and 3.3, it is acknowledged that DBPB or IRWST is much smaller than PO+DW. Then, if Design condition is satisfied and R is always smaller than 1.2, we can say that Level C is always satisfied and may not be considered in the design. In Table 2 ~ Table 4, R for each component support load is provided to show that it is less than 1.2. So the evaluation for Level C condition can be excluded during design if Design condition is met in APR1400.

3. Conclusions

For typical APR1400, DBPB locations and loadings are selected and DBPB loads are evaluated. The DBPB results are about 10^{-2} times less than those of SSE and BLPB, and similar to IRWST discharge. It is also evaluated that Level C condition may be excluded from design, if Design condition is met.

REFERENCES

[1] U.S. NRC Standard Review Plan Section 3.9.3, ASME Code Class 1, 2 and 3 Components and Component Supports, and Core Support Structures, Rev. 2, 2007.
[2] U.S. NRC Standard Review Plan Section 3.6.2, Determination of Rupture Locations and Dynamic Effects Associated with the Postulated Rupture of Piping, Rev. 2, 2007.
[3] U.S. NRC Standard Review Plan BTP 3-4, Postulated Rupture Locations in Fluid System Piping Inside and Outside Containment, Rev. 2, 2007.
[4] U.S. NRC Standard Review Plan Section 6.2.1.2, Subcompartment Analysis, Rev. 3, 2007.