MARS-KS Code Analysis for SBLOCA Counterpart Test in ATLAS Facility

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1. Introduction

ATLAS test facility, which is an integral test loop for simulation of various thermal hydraulic phenomena in APR1400 (Advanced Power Reactor 1400 MWe), has been designed according to the three-level scaling method. [1,2] Scaling ratio of the facility is 1/2 in length and 1/144 in area.[3] To make the experimental data in the ATLAS scaled up reasonably, it is necessary to validate the scaling methodology and the design characteristics of the ATLAS by performing a counterpart test and comparing a reference test data.

In this study, a Small-Break Loss-of-Coolant Accident (SBLOCA) scenario was selected for the counterpart test in the ATLAS. The reference test data could be found from SB-CL-32 test in LSTF (Large Scale Test Facility), which simulated 1% cold leg SBLOCA in the full-height integral test loop. In prior to conduct the experiment, appropriate test condition was defined considering the scaling methodology and design parameter of the ATLAS. To validate the counterpart test condition in the ATLAS, MARS-KS code calculation result was compared to the LSTF test data.

2. Scaling Analysis and Test Condition

2.1 Scaling ratio of ATLAS test facility

The LSTF has a scaling ratio of 1/1 in a length scale and 1/48 in a volume scale.[4,5] Considering the design difference of the LSTF and ATLAS as shown in Table 1, the scaling ratio of the ATLAS test facility with respect to the LSTF was determined as 0.52 in a length (or height) scale (l_{oR}) and 0.20 in a volume scale. It means that the ratio of a diameter (d_{oR}) and a flow area (d_{oR}^2) is 0.62 and 0.39, respectively. Effective heating length in a core and total coolant volume in the primary system were selected as a reference length and a reference volume, respectively. The ratio of other geometric parameters for the length, area, and volume was in a reasonable agreement between two test facilities as listed in Table 1.

2.2 Test condition for counterpart test

From the scaling ratio in the length and flow area of the ATLAS, boundary conditions for the counterpart test can be determined according to the three-level scaling methodology. Those include the initial thermal power in the core, flow rate in the primary and secondary systems, and the collapsed water level in a pressurizer and steam generators. Initial pressure and temperature in the primary system of the ATLAS could be maintained equivalently to the LSTF test, so that there was no difference in the properties of working fluid.

Considering that thermal power of 10.08 MW was supplied in a steady state condition of the LSTF test and the scaling ratio for the thermal power in the core is 0.278 ($d_{oR}^2\ l_{oR}^{1/2}$) according to the scaling methodology, 2.81 MW is required for the ATLAS to perform the counterpart test. However, this condition is beyond capacity of the electrical heaters in the core, so that the initial condition for the core power was determined as 1.9 MW. According to the reduced thermal power, primary system flow rate and feedwater flow rate in the steam generator was reduced to maintain the equivalent pressure and temperature condition. Detailed test

Table 1 Comparison of geometry for LSTF and ATLAS test facilities

Parameter	Scaling ratio	Description	LSTF (P)	ATLAS(M)	Ratio(M/P)
Length (height)	l_{oR}	Total RPV	10.9572(m)	5.9579(m)	0.54
		Effective heating length	3.66(m)	1.905(m)	0.52
Diameter	d_{oR}	RPV inner wall D	0.640(m)	0.408(m)	0.64
		Core barrel inner D	0.514(m)	0.3175(m)	0.62
Area	d_{oR}^2	V_{core}/L_{core}	0.1112(m^2)	0.0524(m^2)	0.47
		V_{RPV}/L_{RPV}	0.2434(m^2)	0.0939(m^2)	0.39
		Core flow area	0.1134(m^2)	0.04521(m^2)	0.40
Volume	$l_{oR}\ d_{oR}^2$	Total RPV	2.6673(m^3)	0.5597(m^3)	0.21
		Core region	0.4069(m^3)	0.100(m^3)	0.25
		Primary inventory	8.14(m^3)	1.6366(m^3)	0.20

condition at the steady state will be described in Section 3 with comparing to preliminary code calculation result.

3. MARS-KS Code Calculation Result

3.1 Steady state condition

To validate the test condition for the counterpart test in the ATLAS, a thermal hydraulic system analysis code, MARS-KS, was utilized. It modeled the whole system of the test facility with one-dimensional volumes and junctions.

Table 2 summarized the steady state condition from the MARS-KS code calculation comparing to that of the SB-CL-32 test in the LSTF. As noted in Section 2, a core flow and feedwater flow was reduced according to the scale of the normal power in the core. The calculation result showed that the ATLAS test facility could reasonably simulate the steady state condition with scaling down the LSTF test condition.

3.2 Calculation result for transient simulation

Table 3 listed a sequence of the major events which were predicted by MARS-KS code calculation during the transient simulation for cold leg SBLOCA. The event time was compared to that of the LSTF test in the ATLAS scale. Since the ATLAS has a reduced length scale (l_{oR} =0.52), time scale in the LSTF should be reduced according to the time ratio ($t_R = l_{oR}^{1/2}$ =0.72) for comparison to the ATLAS. In the code calculation, a reactor trip was occurred due to reduced pressure after the break initiation. At the equivalent time to the LSTF test after the break (456.7 seconds), relief valves on the steam generators were opened as accident management (AM). When the downcomer pressure is reduced lower than 4.51 MPa, a safety injection through accumulator (ACC) was initiated to cool down the reactor coolant system (RCS) and quench the core in the reactor pressure vessel. Low pressure injection (LPI) supplied emergency core cooling water after the pressure decreased lower than 1.2 MPa. As shown in the table, the counterpart test in the ATLAS could simulate the LSTF test reasonably with reduced length and time scale. A delayed injection through the LPI in the ATLAS was due to a different behavior of the pressure decrease in a later period of the transient.

Figure 1 compares the system pressure in the counterpart test simulation in the ATLAS test facility to the LSTF test data. After the break, the primary system pressure rapidly decreased to around 8.0 MPa, where a pressure plateau could be observed. Opening relief valves on the steam generator as the accident management contributed to decrease the pressure. From the result, the scaled test condition in the ATLAS counterpart test could simulate the test data in the full-height integral test loop very well.

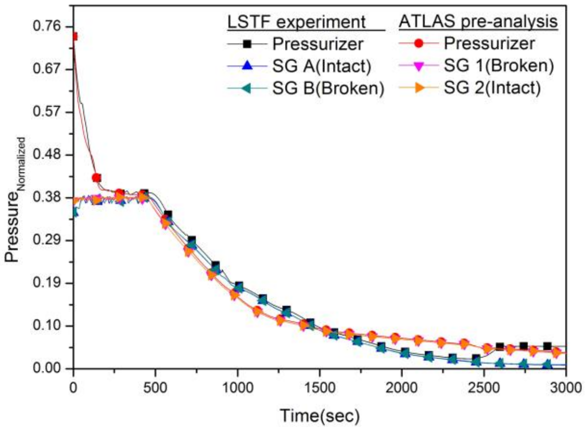

Fig. 1. System pressure in counterpart test of ATLAS

Break flow rate was compared in Fig. 2 for MARS-KS code calculation of ATLAS and the LSTF test data in the ATLAS scale. According to the three-level scaling methodology, the break size should be scaled down to preserve the mass flow rate at the break. Considering choking phenomenon at the break, velocity scale becomes unity in the ATLAS. So that, the break area should be scaled according to the flow area ratio,

Table 2 Comparison of steady state condition in MARS-KS calculation

Parameter	LSTF	Ideal ATLAS	MARS Calculation	Remark
Normal Power (MWth)	10.08	2.810	1.9	~68%
Pressurizer Pressure (MPa)	15.55	15.55	15.55	
Pressurizer Level (m)	7.28	3.64	3.77	
Core Inlet Temperature (K)	563.1	563.1	563.1	
Core Outlet Temperature (K)	598.6	598.6	598.6	
Total Core Flow (kg/s)	48.92	13.64	9.29	~68%
SG Pressure (MPa)	7.32	7.32	7.89	Difference in heat removal of SG
SG level (m)	10.24	5.3	5.27	
SG FW flow (kg/s)	2.7	0.753	0.55	~73%
SG FW temperature (K)	495.4	495.4	495.4	

Table 3 Sequence of events in SBLOCA simulation for ATLAS counterpart test

Events	Time after break (sec)		Remark
	ATLAS Simulation result	LSTF Exp. in ATLAS scale	
Break at CL1A	0.0	0.0	
Reactor trip (followed by RCP trip, MSIV close, and MFIV close)	23.7	35.4	PZR P<12.97MPa
Initiation of secondary system depressurization as AM	456.7	456.7	Requirement : 279K/h in RCS
Injection of Aux FW (Broken/Intact)	465.4 / 559.2	465.4 / 559.2	
The 1st excursion/maximum of cladding temperature	630.0 / 706.0	656.6 / 688.3	Quenched by loop seal clearing
Injection of ACC to CL1A and 2A	838.6	883.8	DC P<4.51MPa
The 2nd excursion/maximum of cladding temperature	722.0 / 910.0	793.7 / 903.3	Quenched by ACC injection
Termination of ACC	1398	1428.6	
Injection of LPI to CL1A / 2A	2354 / 2324	1881 / 1851	DC P<1.2MPa

($A_R=d_{oR}^2\ /l_{oR}^{1/2}$ =0.278), which yielded a break diameter of 5.4 mm. In actual simulation of the ATLAS counterpart test with MARS-KS code, it was increased to 6.05 mm to scale the break flow more accurately. The results presented that the break size design in the ATLAS test facility could successfully simulate the break flow behavior during the SBLOCA transient.

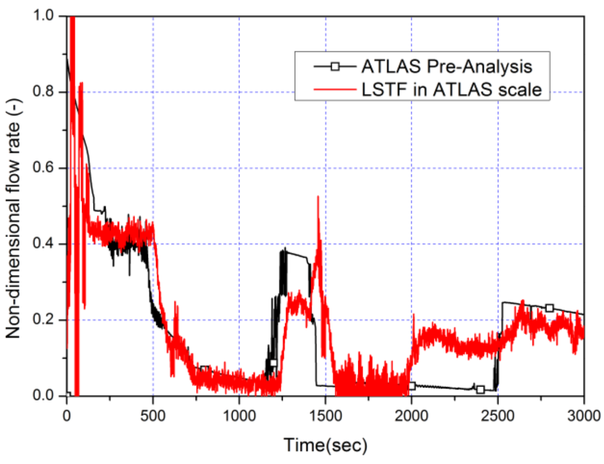

Fig. 2. Break flow in counterpart test of ATLAS

Maximum cladding temperature in the core was presented in Fig. 3. For both of the ATLAS counterpart test and the LSTF test, two peaks for the maximum cladding temperature were observed. The first peak was reduced after core quenching by a loop seal clearing phenomenon, while the quenching after the second peak is related to the accumulator injection. The figure revealed that the ATLAS counterpart test was able to preserve the transient behavior of the peak cladding temperature with the equivalent time scale. The amount of wall superheat at the peak in the ATLAS was larger than that of the LSTF. This was induced by a larger heat flux on the electrical heaters in the reactor core, which was an inevitable scaling distortion in a reduced-height test facility.

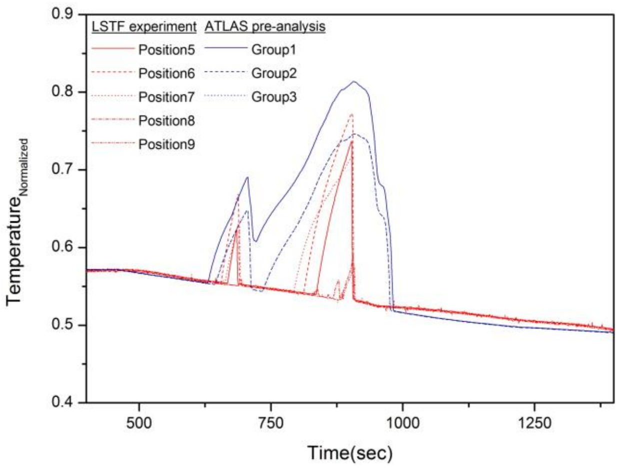

Fig. 3. Maximum cladding temperature in counterpart test of ATLAS

4. Conclusions

To validate the scaling methodology and the design parameter of the ATLAS test facility, the counterpart test condition was determined for the cold leg SBLOCA simulation. The initial and boundary conditions in SB-CL-32 test data of the LSTF were scaled down according to the scaling methodology, so that the test condition in the ATLAS was obtained. In prior to the experiment, MARS-KS code simulated the steady state and transient in the ATLAS test facility. The code calculation result proved that the counterpart test in the

ATLAS could preserve the transient behavior in the reactor coolant system during the SBLOCA. Major events such as the pressure plateau and excursion of the maximum cladding temperature showed a good agreement with the LSTF test data. In the further work, the experiment for the counterpart test will be performed and scaling effect in the ATLAS test data can be analyzed in detail by comparing the result to the LSTF test data.

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