# Application of Full Equation in Kinematic Shock on Emergency Core Cooling System

Seung-Chan Lee*, Duk-Joo Yoon and Sang-Jun Ha
Korea Hydro Nuclear Power Electricity Co., KHNP Central Research Institute, Reactor Safety Laboratory,
Yuseong-daero 1312-gil, Yuseong, Daejeon 305-343 Korea.
**Corresponding author: eitotheflash@khnp.co.kr*

## 1. Introduction

Generic Letter 2008-01shows that the void packet inner of pipes in front of ECCS(Emergency Core Cooling System) pumps is very important effect element in analyzing head loss. The purpose of this paper is to develop the solution of the kinematic shock equation. In this work, the simplified equation of Perdu test study is changed into Full equation by our development study of calculating a kinematic shock. The development result of the solution of full equation is applied and compared with current simplified equation [1,2,3]. Finally, the full equation method is used for calculating the criteria of void packet in Westinghouse type NPP in preliminary sample study. In this work's theoretical base is on the study of Seung-Chan Lee et al in KHNP in 2012[1].

## 2. Methodology

Some fundamental forms are introduced to illustrate the phenomena of kinematic shock.

### *2.1. Void Packet Behavior*

The movement of the void packet of ECCS pipes is illustrated from Newton Mechanics.
If the void packet is big, the air is similar to a falling object. Also, it have the kinetic energy equivalent to potential energy of hight H.
Here, the void packets experience the falling motion of gravity. Therefore, the falling velocity of void packet in ECCS pipe is followed below;

$$\frac{1}{2}mv^2 = mgH \tag{1}$$

Where m is mass of falling void packet, v is velocity, g is gravity acceleration, H is vertical length of falling void packet.
From Equation (1), the velocity of falling void packet is introduced as following;

$$V = \sqrt{2gH} \tag{2}$$

The damage possibility of pumps located in front of the SI pump is specified by the depth of void package.
Using equation (1) and (2), a vertical separated flow frame enables the water to accelerate such that

$$U(H) = U_0 + \sqrt{2gH} \tag{3}$$

The volumetric flow remains constant, hence

$$A_w(H) = \frac{Q_0}{U(H)} = \frac{A_0 U_0}{U(H)} \tag{4}$$

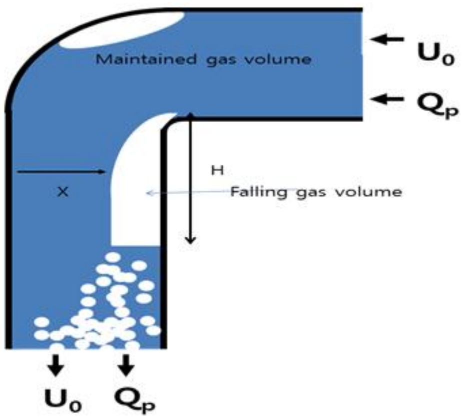
Where $A_w(H)$ is the vertical cross section of water fall H or the vertical cross section of falling gas volume height H.

Here, assume the water thickness x would be approximated as a linear function such that the flow area could be represented as below;

$$A_w(H) = \frac{\pi}{4} D x(H) \tag{5}$$

From equation (4) and (5), as the water accelerates, the thickness change is below;

$$x(H) = \frac{4Q_0}{\pi D U} = \frac{4Q_0}{\pi D (U_0 + \sqrt{2gH})} \tag{6}$$




### *2.2. Kinematic Shock of Simplified Equation*

Through the equation (1) ~ the equation(6), it is founded that the water volume is bounded by the bottom of the high point pipe and the location where the water jet plunges into the water filled down-comer where the jet entrains air from the gas volume.
The pattern is below;

$$V_w = \int_0^H \frac{\pi}{4} D x(H) dH = \int_0^H \frac{Q_0}{U_0 + \sqrt{2gH}} dH \tag{7}$$

Here, in order to simplify, letting the term of liquid motion ($U_0$) zero. Or Assume that $U_0$ is smaller than $\sqrt{2gH}$. Then, this equation is written as;

$$V_w = \int_0^H \frac{Q_0}{\sqrt{2gH}} dH = Q_0 \sqrt{\frac{2H}{g}} \tag{8}$$

From equation (7) and (8), the gas volume is calculated as like equation (9) and modified as like equation (10).

$$V_g = A_0 H - V_w \tag{9}$$

$$H = \frac{(V_g + V_w)}{A_0} \tag{10}$$

If equation (8) is inserted into equation(10), equation(10) is rewritten as;

$$H = \frac{\left(V_g + Q_0 \sqrt{\frac{2H}{g}}\right)}{A_0} \tag{11}$$

Letting $H_1 = \sqrt{H}$ , equation (11) is modified into secondary equation (12) and the solution is written (13).

$$H_1^2 - U_0\sqrt{\frac{2}{g}}H_1 - \frac{V_g}{A_0} = 0 \qquad (12)$$

$$H_1 = \frac{1}{2}\left[U_0\sqrt{\frac{2}{g}} + \left(\frac{2U_0^2}{g} + \frac{4V_g}{A_0}\right)^{1/2}\right] \qquad (13)$$

Here, equation (13) is simplified form.

### *2.3. Development of Full equation for Kinematic Shock*

In section 2.1, the current term U is neglected under assuming it is very small. But the term should be considered, if it is enough to affect to the falling water.
Integrating Equation (7), it is converted to equation (14)

$$V_w = \int_0^H \frac{Q_0}{U+\sqrt{2gH}}dH = Q_0\sqrt{\frac{2H}{g}} + \frac{Q_0U}{g}(\log(\sqrt{2gH}+U) \qquad (14)$$

Using equation (9) and (10), equation(14) is written as;

$$H = \frac{\left(V_g + Q_0\sqrt{\frac{2H}{g}} + \frac{Q_0U}{g}(\log(\sqrt{2gH}+U)\right)}{A_0} \qquad (15)$$

From equation (15), letting $H_1 = \sqrt{H}$ ,

$$H_1^2 - U_0\sqrt{\frac{2}{g}}H_1 - \frac{V_g}{A_0} + \frac{Q_0}{A_0}\left(\frac{U\log(\sqrt{2g}H_1+U)}{g}\right) = 0 \qquad (16)$$

Here, fourth term of equation (16) is written as Taylor's expansion;

$$\frac{Q_0}{A_0}\left(\frac{U\log(\sqrt{2g}H_1+U)}{g}\right) = \frac{\log(UQ_0A_0)}{gA_0} + \frac{\sqrt{2g}Q_0H_1}{gA_0} - \frac{Q_0H_1^2}{UA_0} + \frac{2\sqrt{2g}Q_0H_1^3}{3U^2A_0} - \frac{gQ_0H_1^4}{U^3A_0} + \cdots \ (17)$$

Taylor's expansion is considered up to the second term. Then equation (16) is converted into equation (18) and (19).

$$H_1^2 - U_0\sqrt{\frac{2}{g}}H_1 - \frac{V_g}{A_0} + \left(\frac{\log(UQ_0A_0)}{gA_0} + \frac{\sqrt{2g}Q_0H_1}{gA_0} - \frac{Q_0H_1^2}{UA_0}\right) = 0 \qquad (18)$$

$$H_1 = \frac{1}{2}\left[\left(U_0 - \sqrt{U_0}\right)\sqrt{\frac{2}{g}} + \left(Q_0 - \sqrt{Q_0}\right)\sqrt{\frac{2}{g}} + \left(\frac{4Q_0U_0}{g} + \frac{4V_g}{A_0}\right)^{1/2}\right] \qquad (19)$$

### *2.4. Approximation of Full Equation*

In the previous section, the solution of full equation was introduced. Equation (18) can be changed as equation (20).

$$H_1^2 - U_0\sqrt{\frac{2}{g}}H_1 - \frac{V_g}{A_0} + \left(\frac{\log(UQ_0A_0)}{gA_0}\right) = 0 \qquad (20)$$

The solution of equation (20) is expressed as following;

$$H_1 = \frac{1}{2}\left[\left(U_0 - \sqrt{U_0}\right)\sqrt{\frac{2}{g}} + \left(\frac{4Q_0U_0^2}{g} + \frac{4V_g}{A_0}\right)^{1/2}\right] \qquad (21)$$

### *2.5. Movement Effect of Void Packet in Kinematic Shock*

The movement effect of void packet is estimated in this chapter. For the estimation, three elements are checked such as essential path ways, suction side levels, and minimum suction pressures. The elements are shown on Table 1, 2 and 3. These conditions are used void packet criteria in the location in front of pump locations.

Table 1. Path way for estimation of movement effect of void packet in front of Pumps in ECCS in Westinghouse type.

| ISO drawing | Path way | Location |
|---|---|---|
| KR34-SCPA | SUMP TO CS PUMP | KR4-CS1-LOCATION # |
| KR34-RCPA | RWST TO CS PUMP | KR4-CS3-LOCATION # |
| KR34-SRPA | SUMP TO RHR PUMP | KR4-RHR1-LOCATION # |
| KR34-RRPA | RWST TO RHR PUMP | KR4-RHR3-LOCATION # |
| KR34-LRPB | RCS HOT LEG TO RHR PUMP | KR4-RHR6-LOCATION # |
| KR34-RHPA | RWST TO CHG/HPSI PUMP | KR4-HPSI1-LOCATION # |
| KR34-RPHPA | RHR PUMP TO CHG/HPSI PUMP | KR4-HPSI3-LOCATION # |

Table 2. Condition of Maximum Level in Pump suction side

| Path way | Maximum level of suction sides |
|---|---|
| RHR from the RWST | 147.77 ft |
| RHR from the Sump | 147.77 ft |
| RHR from the RCS Hot leg | 147.77 ft |
| CHG/HPSI from RHR discharge | 107.9 ft |
| CHG/HPSI from the RWST | 107.9 ft |
| CS from the Sump | 147.77 ft |

Table 3. Condition of Minimum suction pressure in pumps

| Path way | Minimum suction pressure in pump location |
|---|---|
| RHR from the RWST | 24.19 psia |
| RHR from the Sump | 24.98 psia |
| RHR from the RCS Hot leg | 370.30 psia |
| CHG/HPSI from RHR discharge | 30.13 psia |
| CHG/HPSI from the RWST | 30.23 psia |
| CS from the Sump | 25.93 psia |

## 3. Result and Discussion

### *3.1. Comparison between Simplified and Full Equations*

The kinematic shock is very sensitive to the void packet velocity but is not by the void packet area. However, the kinematic shock is depend on the falling object dynamic. The sensitivity is shown in Figure 2, 3, and 4.

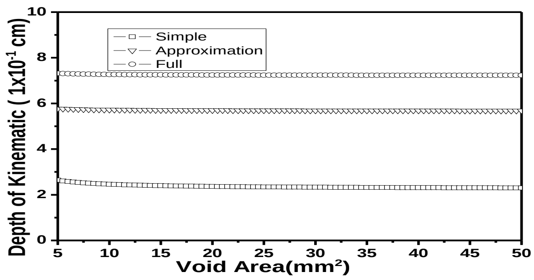



Fig. 2 Kinematic shock under void packet area

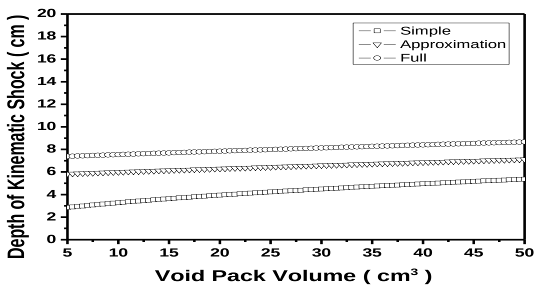



Fig. 3 Kinematic shock under void packet volume

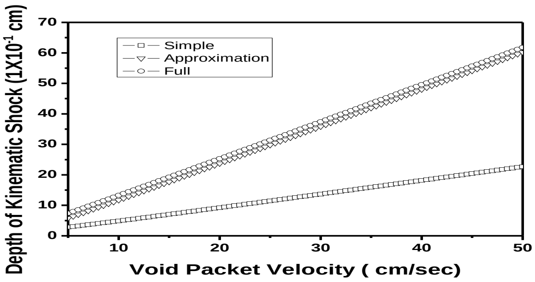



Fig. 4 Kinematic shock under void packet velocity

*3.2. Comparison between The modeling in This Work and Other Experimental Example.*

In order to verify this work, this result is compared with the Perdu Test experiment example.

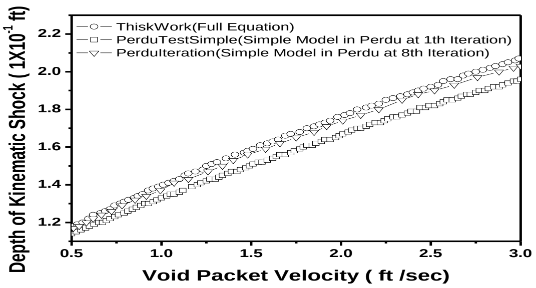



Fig. 5 Kinematic shock under the Perdu conditions

The verification of full equation is carried out by the comparison with Perdu Test example.
Generally, Perdu test simple model is calculated by many iterations of simple form developed by Perdu experimental lab. Figure 5 shows that the full equation of this work is in good agreement with the result of many iterations of Perdu simple model. The only one-step calculation of this work is completely matched with the multi-step calculation of Perdu Test.

*3.3. Criteria of Void Packet movement Effect by Full Equation.*

Using the full equation, a void packet movement effect is evaluated and the criteria is calculated. The results from full equation are shown in Table 4.
In Westinghouse type NPP, the criteria of void packet in ECCS is ranged from 0.3 ft$^3$ to 6.12ft$^3$.

Table 4. Criteria of Void Packt in in ECCS of Westinghouse type.

| Suction Path | Location | Allowable Pump Inlet Void Fraction | Vallowable.Post-Accidemt (ft$^3$) | Vallowable,Surveillance test (ft$^3$) | Allowable Gas Volume Fraction(%) |
|---|---|---|---|---|---|
| SUMP TO CS PUMP A | 1 | 5% | 6.20 | 1.55 | 12.83 |
| | 2 | | | | |
| SUMP TO CS PUMP B | 1 | 5% | 5.98 | 1.50 | 18.15 |
| | 2 | | | | |
| RWST TO CS PUMP A | 1 | 5% | 4.06 | 0.79 | 1.50 |
| | 2 | 5% | 4.06 | 0.92 | 3.40 |
| | 3 | 5% | 4.06 | 0.96 | 3.06 |
| | 4 | | | | |
| | 5 | | | | |
| | 6 | 5% | 1.44 | 0.30 | 14.39 |
| | 7 | | | | |
| | 8 | | | | |
| RWST TO CS PUMP B | 1 | 5% | 4.92 | 1.42 | 2.70 |
| | 2 | 5% | 4.06 | 0.92 | 3.40 |
| | 3 | 5% | 4.06 | 0.96 | 0.45 |
| | 4 | | | | |
| | 5 | | | | |
| | 6 | | | | |
| | 7 | 5% | 1.44 | 0.28 | 4.89 |
| | 8 | | | | |
| | 9 | | | | |
| SUMP TO RHR PUMP A | 1 | 5% | 6.12 | 1.12 | 3.77 |
| | 2 | | | | |
| SUMP TO RHR PUMP B | 1 | 5% | 6.12 | 1.12 | 3.77 |
| | 2 | | | | |

## 4. Conclusions

The new method of calculating the depth of the kinematic shock in U-type pipe in ECCS is introduced. The kinematic shock is strongly depended on the void packet velocity. In the part of verification, the difference between this work and Perdu experiment result is nothing in the condition of many iterations of Perdu simple model. In conclusion, this work's method is more efficient than Perdu simple model because of the use of only one-step calculation. In void packet criteria, using full equation, some results are calculated. The results are ranged from 0.3 ft$^3$ to 6.12ft$^3$ in Westinghouse type NPP

## REFERENCES

[1] Seung-Chan Lee et al. , KHNP, "Study of Kinematic Shock in Inverted U type Pipe of Emergency Core Cooling System", Transactions of the Korea Nuclear Society Autumn Meeting, Gyeongju, Korea, Oct 25-26, 2012.
[2] TSTF 10-05, Transmittal of TSTF-523, Revision 0. "Generic Letter 2008-01, Managing Gas Accumulation", June 29, 2010.
[3] Perdu Test Report, "Simplified Equation for Gas Transport To Pumps", January 21, 2010, NEI Workshop.