Thesis for the Degree of Master of Engineering

# Free Surface Vortex Control for Pump Sump with a Curtain Wall and Energy Dissipating Structures

**by**

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# 커튼월 및 EDS 설치에 따른 펌프 흡입구 주위의 자유표면 보텍스 제어

**by**

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**In the Department of Mechatronics Engineering,**

**The Graduate School,**

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# 커튼월 및 EDS 설치에 따른 펌프 흡입구 주위의 자유표면 보텍스 제어

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## 요지서

화력 및 원자력 발전소에서는 시스템 냉각용으로 펌프를 이용하여 펌프장의 물을 순환시킨다. 펌프를 이용하여 물을 흡입하는 과정에서 경우에 따라 흡입정 주위에는 보텍스 (Vortex)나 스월(Swirl)이 발생한다. 흡입정 주위에 보텍스와 스월이 발생하면 펌프 흡입구로 물 뿐만 아니라 공기도 함께 흡입되면 흡입배관 내부에 강한 와류가 발생한다. 배관 내부로 유입된 와류는 소음 및 진동을 유발시키고, 심할 경우 펌프 임펠러 및 회전축의 손상을 야기하기도 한다. 이러한 보텍스 및 스월의 발생 원인으로는 펌프의 흡입 유량, 흡입정의 수위 및 흡입 수조의 적절하지 못한 구조 등이 있다.

흡입정 주위에 발생하는 보텍스의 종류는 자유표면 보텍스 (Free Surface Vortex)와 수중 보텍스 (Submerged Vortex)가 있다. 자유표면 보텍스는 커튼월 (Curtain Wall), 수중 볼텍스는 AVD

(Anti Vortex Device) 를 설치하여 제어하는 것이 일반적이다. 자세한 규격은 Hydraulic Institute Standard (HIS) 에서 기술하고 있다.

본 연구는 펌프 흡입구 주변 유동장에 대하여 다상유동 모델을 적용하여 수치해석적 방법으로 해석하였다. 추가적으로 EDS (Energy Dissipating Structure) 를 설치하여, 커튼월과 EDS의 자유표면 보텍스 제어 효과와 흡입구 내부 유동을 분석하여 가시적으로 나타내었다. EDS를 추가적으로 설치한 경우 균일한 유동이 형성되면서 자유표면 보텍스가 소멸되는 것을 확인할 수 있었다.

# Free Surface Vortex Control for Pump Sump with a Curtain Wall and Energy Dissipating Structures

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## ABSTRACT

Nuclear power plants or steam power plants need water to remove heat. During water pumping process vortex or swirl can occur which can cause strong turbulence in the pump inlet as well as the air intake. Vibration and noise can also occur which at times can damage the pump. The occurrence of vortices in pump sumps and their effects are the most common and difficult problem to encounter. The free surface vortex appears on the water surface level. In order to minimize the effect of vortex and to ensure the safety of the system, a curtain wall and Energy Dissipating Structures has to be installed to prevent a free surface vortex according to the Hydraulics Institute Standards (HIS).

In this study, free surface vortex creation in pump sump was analyzed for a multiphase flow model using numerical analysis. Both L-Type model and Line model have been discussed. In the line model, a curtain wall installation totally controlled vortex. In the L-Type model, a curtain wall installation was not enough to control the vortex. Hence, EDS (Energy Dissipating Structure) was additionally to made uniform flow. The simulation will investigate preventive measures against the above adverse flow conditions in order to provide acceptable flow conditions for the pump sump.

# Nomenclature

| | |
|---|---|
| $C$ | Distance between the inlet bell and floor [mm] |
| $D$ | Inlet bell diameter [mm] |
| $H$ | Minimum water lever [mm] |
| $S$ | Minimum submergence depth [mm] |
| $g$ | gravitational acceleration [$m/s^2$ ] |
| $Q$ | Flow rate [$m^3/min$] |
| $F$ | Froude number [-] |
| $V_Z$ | Mean axial velocity [m/s] |
| $V_\theta$ | Angle axial velocity [m/s] |
| $n$ | Number of revolution per minute [rpm] |
| $u$ | Flow velocity component in x direction [m/s] |
| $v$ | Flow velocity component in y direction [m/s] |
| $w$ | Flow velocity component in z direction [m/s] |

# Glossary

**AVD:** Anti-Vortex Device.

**CFD:** Computational Fluid Dynamics.

**EDS:** Energy Dissipating Structures.

**SST:** Shear Stress Transport.

**Intake:** The structure or piping system used to conduct fluid to the pump suction.

**Swirl:** Rotation of fluid around its mean, axial flow direction.

**Swirl Angle:** The angle formed by the axial and tangential components of a velocity vector.

**Swirl Meter:** A device with four flat vane of zero pitch used to determine the extent of rotation in otherwise axial flow.

**Vortex:** A well-defined swirling flow core from either the free surface or from a solid boundary to the pump inlet.

**Vortex, free surface:** A vortex that terminates at the free surface of a flow field.

**Vortex, Subsurface:** A vortex that terminates on the floor or sidewalls of an intake.

# 1. Introduction

## 1.1. Background of the study

In order to have a safe, reliable and sustainable water intake system for a plant, the flow patterns in such an intake system should be verified. A region within a fluid where the flow spins about an imaginary axis is generally termed as vortex. Vortex and swirl occurs due to the water level in the tank, the rate at which the fluid is taken in at its mouth (due to its spinning motion). Nuclear power plants or steam power plants need water to take heat. During water pumping process vortex or swirl can occur, which can cause strong turbulence in the pump inlet as well as the air intake. Vibration and noise can also occur which at times can damage the pump. The occurrence of vortices in pump sumps and their effects are the most common and difficult problem to encounter. Fig 1 shows that there are mainly two types of vortices, namely the free surface vortex and the submerged vortex. Appears on the water surface level and the submerged vortex occurs at the bottom and wall of the tank. In order to minimize the effect of vortex and to ensure the safety of the system, Fig 2 shows that a curtain wall has to be installed to prevent a free surface vortex. Fig 3 shows that an Anti-Vortex Device (AVD) has to be installed in order to avoid a submerged vortex according to the Hydraulics Institute Standards (HIS) [1].

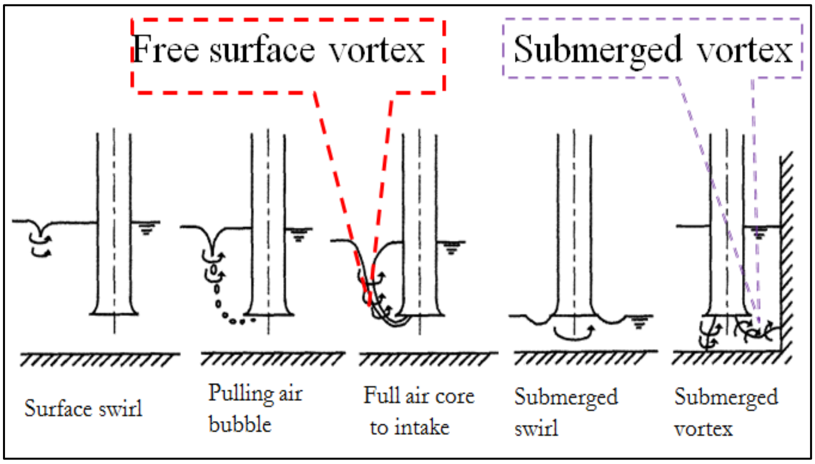



Fig. 1 Types of vortex

Fig. 2 Curtain Wall

Fig. 3 AVD

It is necessary to implement new measures in addition to the HI standards recommendation to ensure the safety of the pipe as well as to find new extensions to the HI standards itself.

Previous studies were conducted on this topic in a broader sense. Constantinescu et al. analyzed the flow in accordance with the level of underwater behavior of free surface vortex through CFD [2]. Bayeul-Laine et al. analyzed, by CFD, the flow around mouth of multi-phase pump suction with dimensionless number and turbulence model [3]. Wicklein et al. studied about the effect of curtain wall and AVD installation in general [4]. Shyam et al. made a comparison of CFD analysis and experiment to analyze the presence or absence of the installation of a curtain wall on the model of the pumping station [5]. However, they didn`t carry out the study to resolve transient phenomena and also the installation of a curtain wall and energy dissipating structures was made in a general sense.

In this study, instead for a two phase flow model of both water and air is introduced into the pump inlet. Also the behavior of the volume ratio of water and air, by means of both quality and quantity, is checked. In addition, we focus on 6 cases for the curtain wall and EDS (Energy dissipating structures) installation from the center of the intake pipe and from the minimum liquid level to find the optimal curtain wall and EDS installation condition in the flow characteristics inside the pipe.

## 1.2. Purpose

The purpose is that adverse hydraulic conditions which can affect pump performance will be examined through simulation. Such as: free-surface and sub-surface vortex conditions, swirl approaching the pump impeller, flow separation energy at the pump used EDS, and a non-uniform axial velocity distribution at the suction. The simulation will investigate preventive measures against the above adverse flow conditions in order to provide acceptable flow conditions for the pump sump.

# 2. Principle & Experiment

## 2.1. Principle of physical model similitude

In general, following three principles of similarities are considered. The geometry model ratio, 1:20, shall be applied for the model geometry similarity. The Froude number, representing the inertial to gravitational forces, for a proper reproduction of the flow in the model, it is required to apply equal Froude numbers in both the model and the prototype. Modeling based on Froude number means an equal ratio between the inertia and gravity forces in both the model and the prototype. Pump intakes can be defined.

The geometrical model scale of the model is $N_1$ = 20.00, which is based on the test facility used, the availability of Perspex pipes and the maximum submergence of the model, while keeping the model scale factor sufficiently large to prevent scale effects. For Froude scaling, the relevant scales.

**Table 1** Relationship between real and experiment of models

| Parameter | Same Froude number | 1.5 Times Froude No | Equal velocity |
|---|---|---|---|
| Length | 1 : 20 | 1 : 20 | 1 : 20 |
| Velocity | $1 : 20^{0.5} = 1 : 4.47$ | $1 : 0.666*20^{0.5} = 1 : 2.98$ | $1 : 20^{0}=1:1$ |
| Flow rate | $1 : 20^{2.5} = 1 : 1788.85$ | $1 : 0.666*20^{2.5} = 1 : 1191$ | $1 : 20^{2}=1:400$ |
| Time | $1 : {}^{0.5}= 1 : 4.47$ | $1 : 0.666*20^{0.5} = 1 : 2.98$ | 1 : 20 |

## 2.2. Minimum water level determination

The basic design: Adequate depth of flow to limit velocities in the pump bays and reduce the potential for formulation of surface vortices. When the pump bay becomes wide, in conjunction with the depth, the maximum pump approach velocities are limited to 0.5m/s [1]. Free surface vortex is more likely to occur when the water level is below minimum in the pumping station. The minimum water level is determined by the Froude number.

$$\mathbf{F_D = V/ (g\ D)^{0.5}}$$

$F_D$ = Froude number (dimensionless)

V = Velocity at suction inlet (Flow/Area, based on D)

D = Outside diameter of bell or pipe inlet

g = gravitational acceleration

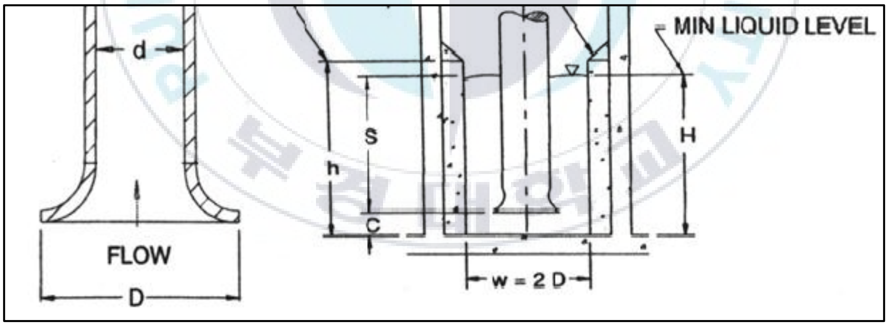



Fig 2.1. Minimum water level H: ※ HIS(Hydraulic Institute Standard)

H = S+C

S = D (1+2.3$F_D$)

S = Minimum pump inlet bell submergence

C = 0.3D to 0.5D (Distance between the inlet ball and floor)

## 2.3. Experimental setup

The experimental setup consists of a pump intake model, experimental process:

1. Pump automate pumping
2. Water intake
3. The circulatory system is water flow from Reserve tank get water to Bay and get through intake pipe transport.

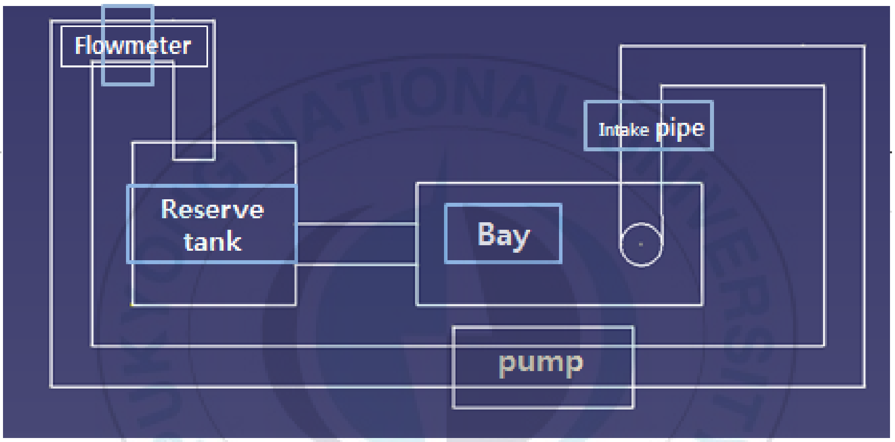
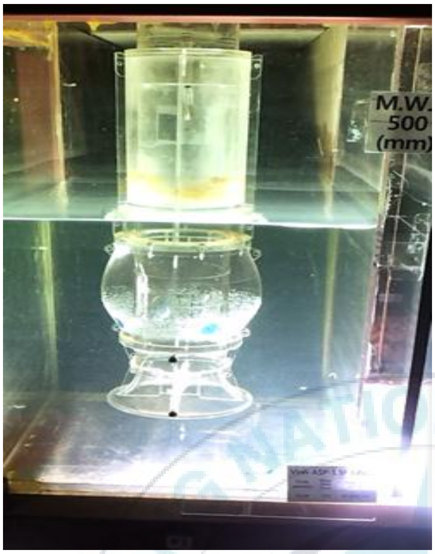



Fig. 2.2. Circulation system of pump sump

(a) Bay

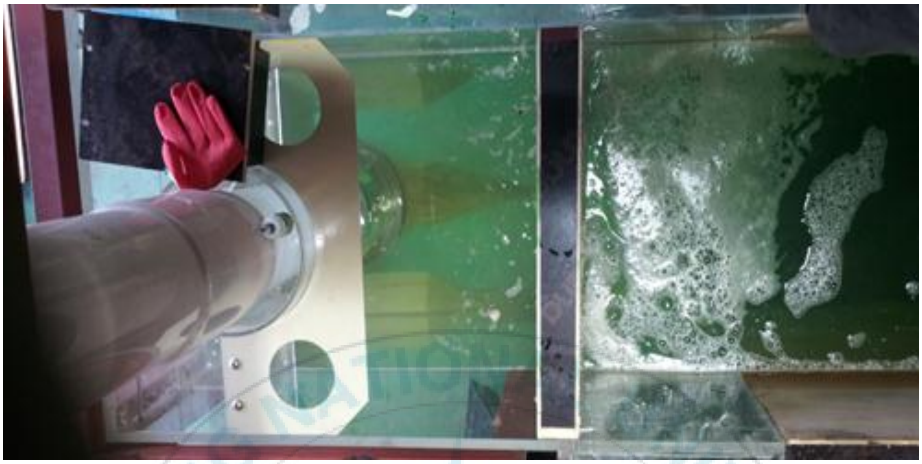



(b) Intake pipe

(c) Reserve tank

(d) Pump


(e) Flowmeter



(f) Curtain wall top-view

(g) No Curtain wall (h) Installation of curtain wall

Fig 2.3 Experiment photographs (a ~ h)

**Table 2.** Specifications of flowmeter

| | |
|---|---|
| Flowmeter | Electro-Magnetic Flow Meter |
| Nominal Diameter | 150A |
| Maker | Korea Flowmeter Co. |
| Model No | KTM-900 |
| Range of current | From 0.3m/s to 10m/s |
| Accuracy | F.S±0.5% |
| Fluid | Water |
| Range of temperature | -10 ~ +60℃ |

The free surface vortex to evaluate the strength of vortices at pump intakes systematically, the vortex strength scale varying from a surface swirl or dimple to an air core vortex, shown in Figure (f), (g), (h) shall be used. Vortex types are identified in the model by visual observations with the help of dye and artificial debris, and identification of a coherent dye core to the pump bell or pump suction flange is important. Vortices are usually unsteady in strength and intermittent in occurrence. Hence, an indication of the persistence of varying vortex strengths shell be obtained through observations made at short intervals in the model for at least 10 minutes, so that a vortex type versus frequency evaluation can be made and accurate average and maximum vortex types may be determined. Such detailed vortex observations are needed only if coherent dye core (or stronger) vortices exist for any test. Photographic or video documentation of vortices is recommended.

## 2.4. Measurement of Swirl Angle

Pump performance is susceptible to the swirling flow around pump. The stronger the swirling flow, the greater the effect on pump performance will be. Moreover stronger swirling flow is likely to generate vortex. In the model test, whether swirl angle indicated by the swirl meter rotation, must be less than 5 degree for reference (1) HI Standard Pump Intake Design – 9.8-2012.

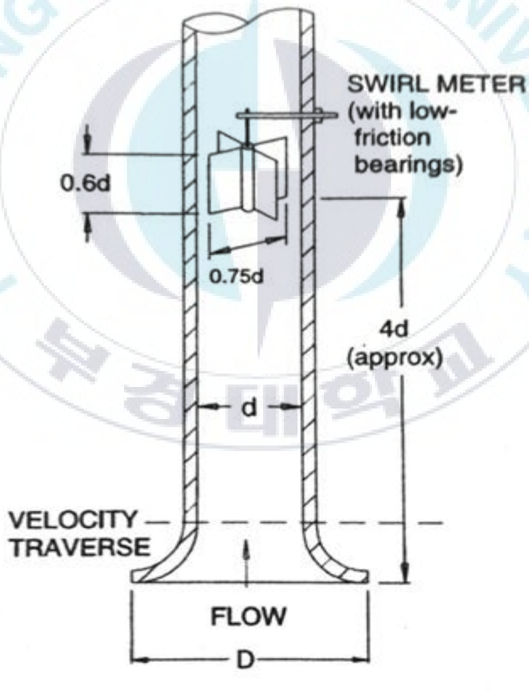



Fig. 2.4 Installation of swirl meter

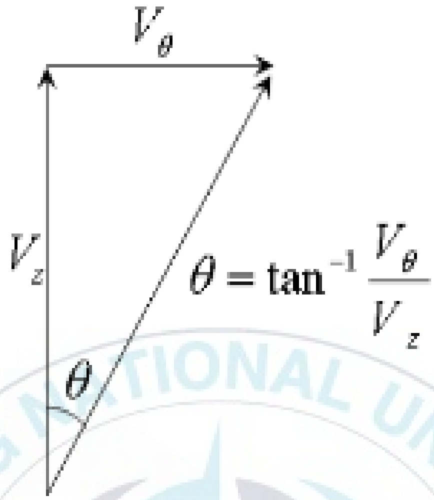



Fig. 2.5. Angle of velocity

Swirl angle is calculated according to the following equations.

$$V_\theta = \frac{0.75d\pi n}{60}\left(\frac{m}{s}\right)$$

$$V_z = \frac{q}{0.25\pi d^2}\left(\frac{m}{s}\right)$$

$V_\theta$= distance traveled by point on the edge of a swirl meter blade per second.

$V_z$= mean axial velocity.

Where:

n: Number of revolution per minute [rpm]

d: Diameter of throat [m]

q: flow rate [$m^3$/s]

### 2.5. Measurement Velocity at Bell Mouth

Velocity measurement at bell throat by Pitot tube is implemented by HI method. Typical Pitot tube configuration and installation are shown in Fig 2.6. Eight measuring points are recorded in Fig 2.7. Pressure sensor and data recorder are used for automatic measurements.

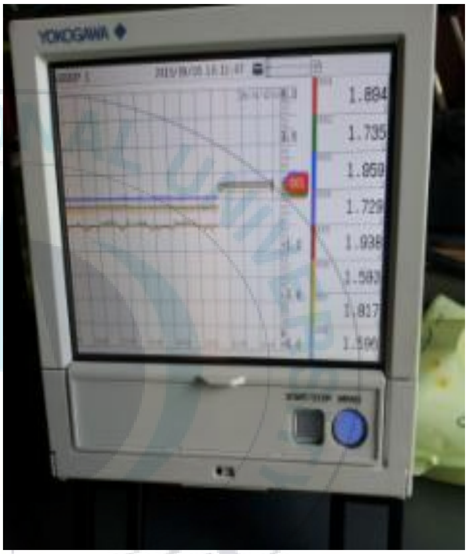



Fig 2.6. Pitot tube configuration Fig 2.7. Recorder

Fig 2.8. Pressure sensor

The following materials will be included in the test reported for sump.

(1)Experiment procedure: intake or piping design, model description, scaling and scaling and similitude criteria, instrumentation description, etc.

(2) Experiment results: tabulated data, conclusions, etc.

(3) Photographs: both initial and final model designs, relevant flow conditions identified with dye or other tracers, etc.

(3) Video recording: all hydraulic model tests including typical flow problems observed during the test shall be recorded and submitted.

(4) Recommended modifications: dimensioned drawings of recommended modifications.

## 2.6. Energy Dissipating Structures Standard

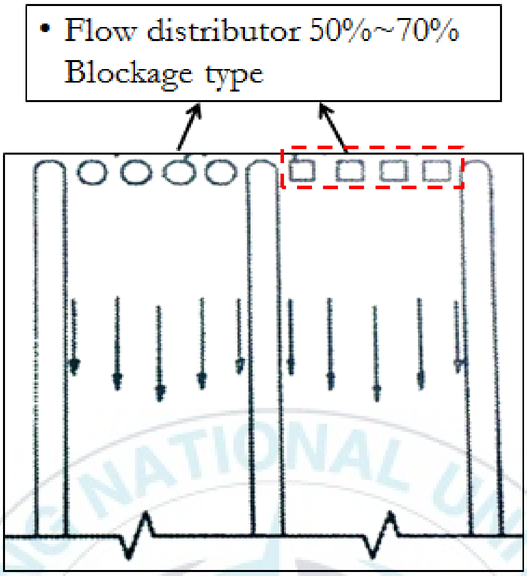



Fig 2.9. EDS types

This is a schematic diagram of the HI standard flow conditions at intake structure with one parallel wall, one perpendicular wall to the direction of final approach. The HI standard flow distributor ranges from 50~70 %. In Fig 2.9, the two types EDS plates per bay help turn the flow. Although distinct flow separation eddies occur at each pier, eddies are smaller than the single flow separation that would occur along one bay wall. A large amount of smaller columns or structural members may be placed at the bay entrance, and these are effective in both turning and creating more uniform by inducing a head loss across the column array [1].

# 3. CFD Analysis

## 3.1. The design of bay for intake pipe

**The model design**

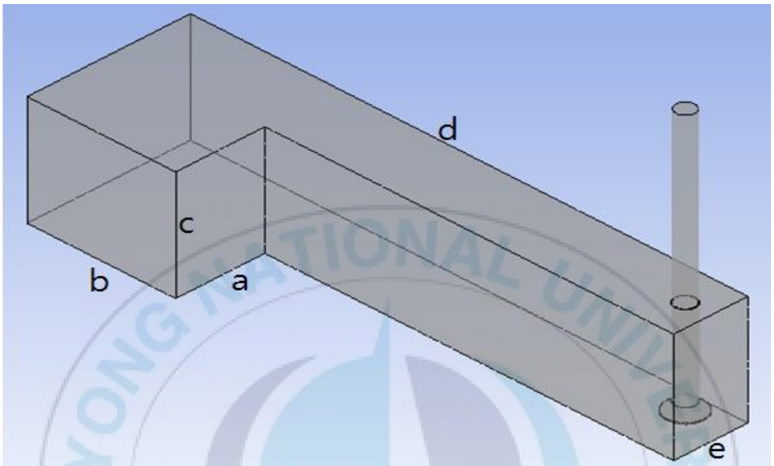



Fig 3.1 No curtain wall

**Table 3** Dimensions of the L-shaped channel Unit (mm)

| Symbol | a | b | c | d | e |
|---|---|---|---|---|---|
| Length | 834 | 500 | 700 | 3128 | 417 |

The material is organized by the general type of hydraulic problem in an upstream to downstream direction, because proper upstream flow conditions minimize downstream remedial changes. The inlet width is equal to 2e distance.

### 3.2. Energy Dissipating Structure design

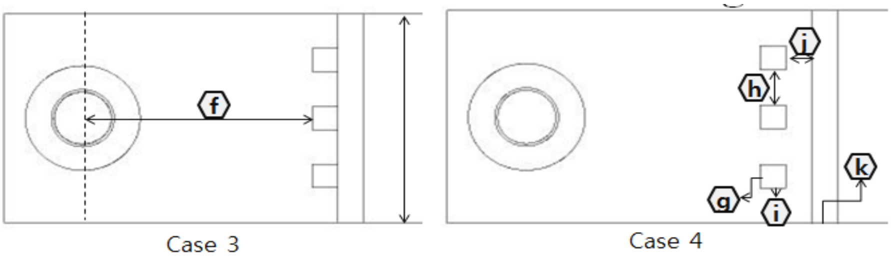



Fig 3.2. Case 3 and Case 4 curtain wall and EDS design

Figure 3.2. shows the EDS installation, where i is bar wide, g is bar length, h between the bars, f is distance between pipe intake and the center, which is 2D similarity HI standard for curtain wall.

**Table 4** Dimensions of the different modifications.

| EDS (Energy Dissipating Structure) | | | | | Curtain wall | |
|---|---|---|---|---|---|---|
| **Unit(mm)** | **f** | **g** | **h** | **i** | **j** | **k** |
| **Case 3** | 417 | 46.3 | 69.5 | 46.3 | 0 | 46.3 |
| **Case 4** | 417 | 46.3 | 69.5 | 46.3 | 46.3 | 46.3 |
| **Case 5** | 417 | 46.3 | 46.3 | 46.3 | 0 | 46.3 |
| **Case 6** | 417 | 46.3 | 46.3 | 46.3 | 46.3 | 46.3 |
| **Case 7** | 417 | 46.3 | 30.8 | 46.3 | 0 | 46.3 |
| **Case 8** | 417 | 46.3 | 30.8 | 46.3 | 46.3 | 46.3 |

### 3.3. Blockage rate calculations

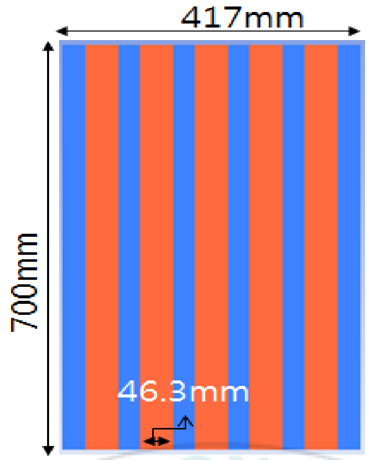



Fig 3.3. Case 7 and Case 8 EDS numbers

The HI standard blockage range is 50~70 %. And our calculations fall within that range which shows good agreement with the HI standard range. If sump system is used to make the uniform flow on the EDS, eddies will be smaller than can become the single flow separation eddy. Alternatively, a number of smaller square bars or structure members may be placed at the bay entrance, and these are effective in both turning and creating more uniform velocity by inducing a head loss across the square bars [1].

**Table 5** Flow distributor Unit(mm)

<table>
<tr><th>Model</th><th>EDS Area</th><th>The Total Area</th><th>Blockage Rate</th></tr>
<tr><td>Case3</td><td rowspan="2">46.3*700*3</td><td rowspan="6">700*417</td><td rowspan="2">33.3%</td></tr>
<tr><td>Case4</td></tr>
<tr><td>Case5</td><td rowspan="2">46.3*700*4</td><td rowspan="2">44.4%</td></tr>
<tr><td>Case6</td></tr>
<tr><td>Case7</td><td rowspan="2">46.3*700*5</td><td rowspan="2">55.5%</td></tr>
<tr><td>Case8</td></tr>
</table>

# 4. Numerical Analysis

## 4.1. Numerical model

The numerical model is described in constantinescu and patel (1998a). Extensive calculations with this model were made by constantinescu and patel (1998b) to study the flow features as the geometry of the intake bay and the flow parameters were varied. The model solves the Reynolds-averaged Navier-Stokes (RANS) equations in generalized curvilinear coordinates with the two-layer k-$\varepsilon$ turbulence closure of Chen and patel (1988). Steady-state solutions are found by iteration in pseudo time. In the momentum equations, the viscous and pressure terms are discretized with second -order upwind difference [2].

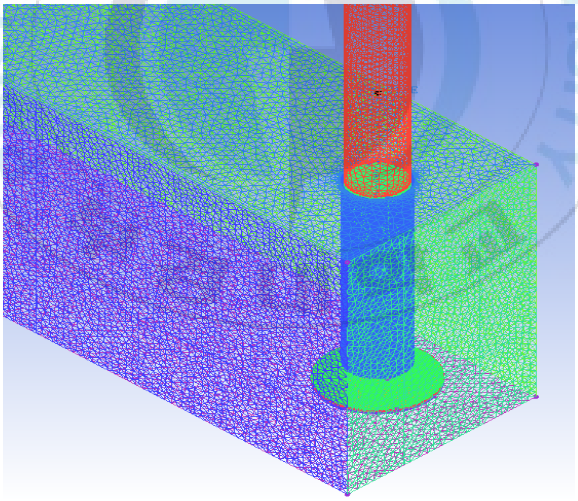


Fig 4.1. Grid system

This study the geometry specifications used model is based on the HIS recommendation to select the default width and height in the pumping station. The curtain wall has to be installed at a distance of the diameter for the intake pipe. ICEM-CFD 15.0 is used in the modeling. Fig 4.1. Showed the model approximately 1,200,000 Tetra and Prism grids were used for flow analysis. In the pump station with on curtain wall installed. To improve the reliability of the flow analysis, a denser lattice is formed especially near the intake pipe. showed the model in the pump station with on curtain wall installed. To improve the reliability of the flow analysis, formed especially near the intake pipe.

## 4.2. Boundary conditions

**Table 6** Conditions for model

| | |
|---|---|
| Flow model | SST turbulence model |
| State type | Unsteady-state |
| Analysis phase | Two-phase (water and air) |
| Inlet | Hydraulic pressure |
| Outlet | Mass Flow Rate 41.58 [kg/s] |
| Surface | Relative pressure 0 [pa] |

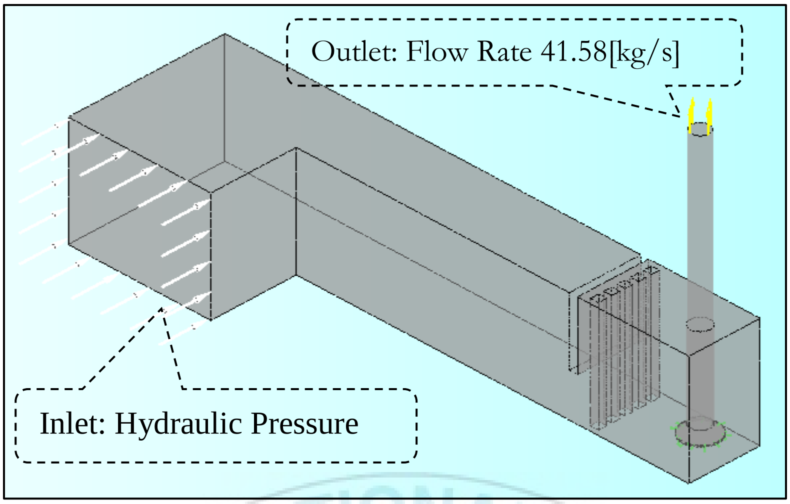



Fig 4.2. Curtain wall and EDS model

Figure 4.2.showed that inlet is water surface from the bottom to the intake pipe of the minimum liquid level, the boundary details relative pressure setup Hydraulic pressure. Outlet is in pipe top surface, use mass flow rate 41.58 kg/s. The unsteady state condition in water and air for two-phase flow model was applied to the SST (Shear Stress Transport) turbulence model based on the k-ω model. The surface boundary putted opening condition and the relative pressure 0(pa).

### 4.3. Basic Equations

Continuity equation

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} + \frac{\partial(\rho w)}{\partial z} = 0 \quad (4.1)$$

Momentum equation

$$\frac{\partial(\rho u)}{\partial t} + \frac{\partial(\rho uu)}{\partial x} + \frac{\partial(\rho uv)}{\partial y} + \frac{\partial(\rho uw)}{\partial z} = -\frac{\partial p}{\partial x} + \mu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right) + S_u$$

$$\frac{\partial(\rho v)}{\partial t} + \frac{\partial(\rho vu)}{\partial x} + \frac{\partial(\rho vv)}{\partial y} + \frac{\partial(\rho vw)}{\partial z} = -\frac{\partial p}{\partial y} + \mu\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2}\right) + S_v$$

$$\frac{\partial(\rho w)}{\partial t} + \frac{\partial(\rho wu)}{\partial x} + \frac{\partial(\rho wv)}{\partial y} + \frac{\partial(\rho ww)}{\partial z} = -\frac{\partial p}{\partial z} + \mu\left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2}\right) + S_w$$

(4.2)

### 4.4. SST (Shear Stress Transport)

Shear Stress Transport turbulence model is a widely used and robust two-equation eddy-viscosity turbulence model used in Computational Fluid Dynamics. The model combines the k-omega turbulence model and k-epsilon turbulence model such that the k-omega is uesd in the inner region of the boimdary layer and switches to the k-epsilon in the free shear flow.

The SST two equation turbulence model was introduced in 1994 by F.R. Menter to deal with the strong freestream sensitivity of the k-omega turbulence model and improve the predictions of adverse pressure gradients. The formulation of the SST model is based on physical experiments and attempts to predict solutions to typical engineering problems. Over the last two decades the model has been altered to more accurately reflect certain flow conditions. The Reynold's Averaged Eddy-viscosity is a pseudo-force and not physically present in the system. The two variables calculated are usually interpreted so k is the turbulent kinetic energy and omega is the rate of dissipation of the eddies.

k equation

$$\frac{\partial(k)}{\partial t} + \mathrm{U}_i \frac{\partial k}{\partial x_i} = P_k - \beta * k\omega + \frac{\partial}{\partial x_i}[(v + \sigma_k v_\Gamma)\frac{\partial k}{\partial x_i}] \quad (4.3)$$

ω equation

$$\frac{\partial \omega}{\partial t} + \mathrm{U}_i \frac{\partial \omega}{\partial x_i} = \alpha S^2 - \beta\omega^2 + \frac{\partial}{\partial x_i}\left[(v + \sigma_\omega v_\Gamma)\frac{\partial \omega}{\partial x_i}\right] + 2（1 - \mathrm{F}_1）\sigma_{\omega^2}\frac{1}{\omega}\frac{\partial k}{\partial x_i}\frac{\partial \omega}{\partial x_i} \quad (4.4)$$

Turbulence viscosity coefficient $\nu_\Gamma$

$$\nu_\Gamma = \frac{\alpha_1 k}{\max(\alpha_1 \omega, SF_2)} \quad (4.5)$$

(4.3) ~ (4.5) equation variate to define $\mathrm{p}_k$, $F_1$, $F_2$,

$$P_k = \min(\tau_{ij}\frac{\partial U_i}{\partial x_j}, 10\beta * k\omega) \quad (4.6)$$

$$\mathrm{F}_1 = \tan h\{\{\min[\max\left(\frac{\sqrt{k}}{\beta * \omega y}, \frac{500v}{y^2\omega}\right), \frac{4\sigma_{\omega^2} k}{CD_{k\omega} y^2}]\}^4\} \quad (4.7)$$

$$\mathrm{F}_2 = \tan h\,\{\left[\max\left(\frac{2\sqrt{k}}{\beta * \omega y}, \frac{500v}{y^2\omega}\right)\right]^2\} \quad (4.8)$$

$$CD_{k\omega} = \max(2\rho\sigma_{\omega^2}\frac{1}{\omega}\frac{\partial k}{\partial x_i}\frac{\partial \omega}{\partial x_i}, 10^{-10}) \quad (4.9)$$

(4.3) and (4.4) equation coefficients $\alpha, \beta, \sigma_k, \sigma_\omega$ relationship to define the new coefficients $\alpha_3, \beta_3, \sigma_{k3}, \sigma_{\omega 3}$

$$\Phi_3 = F_1\Phi_1 + (1 - F_1)\Phi_2 \quad (4.10)$$

Similarity Initial value

$$\alpha_1 = \frac{5}{9}, \alpha_2 = 0.44, \beta_1 = \frac{3}{40}, \beta_2 = 0.0828, \sigma_{K1} = 0.85,$$

$$\sigma_{K2} = 0.5, \sigma_{\omega 1} = 0.5, \sigma_{\omega 2} = 0.856$$

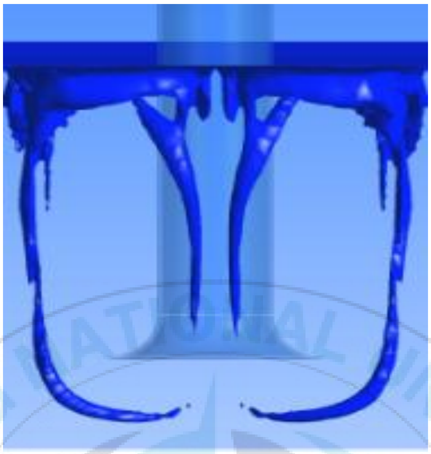
Coefficient is defined as $\beta^*$

$$\beta^* = \frac{9}{100} \quad (4.11)$$

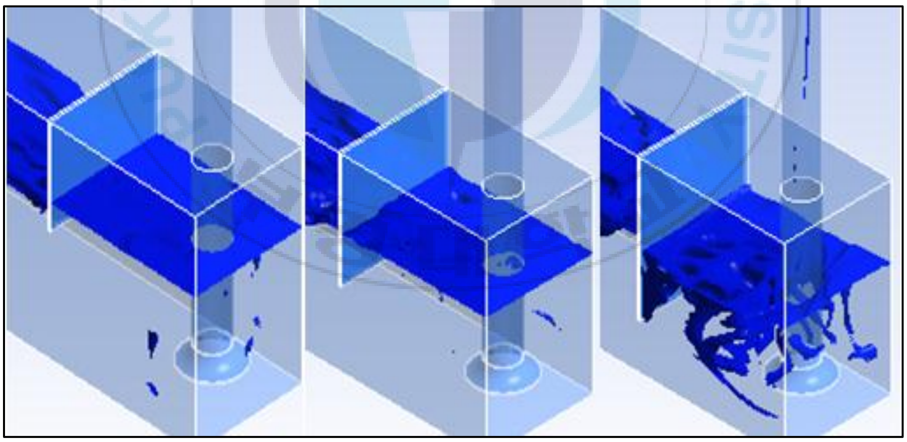
(4.4) and (4.5) S rate of change .

# 5. Results and discussions

## 5.1. Curtain wall installation depth effects



No curtain wall



0.5D 1D 1.5D

Fig 5.1. The air volume fraction of 1%

Figure 5.1. showed that the free surface velocity which was unstable at the free surface level due to no curtain wall. When the curtain wall

was installed 0.5D, 1D and 1.5D cases under free surface of water, the free surface vortexes changing situation, in case 0.5D and 1D situations the rotational component was generated in the free surface. In the 1.5D case, between the curtain wall and the suction pipe had more vortexes compare to 0.5D and 1D cases.

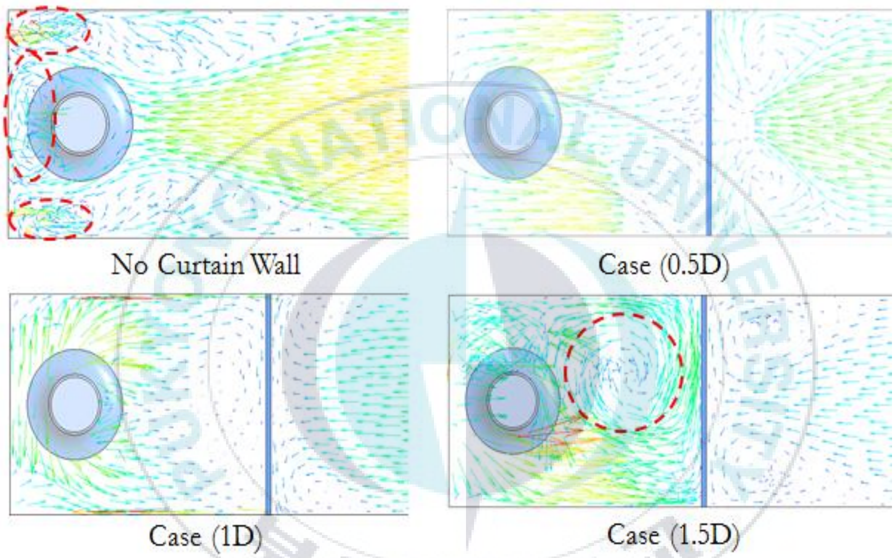



Fig 5.2 Free surface flow-Top view(line model)

Figure 5.2 showed that when the case no curtain wall the free surface vortex can occur symetrically from inlet center. when the curtain wall installed in 0.5D and 1D cases free surface vortexes were stable. But when the curtain wall installed at 1.5D case the free surface vortexes were bigger than the other cases and the flow was unstable near the inlet pipe.

A swirl meter is a device which measures both the predetermined time rotation speed and the magnitude of the interior of the intake pipe. A swirl meter was installed at a distance of 4 D from the mouth of the suction pipe in the numerical experiment.

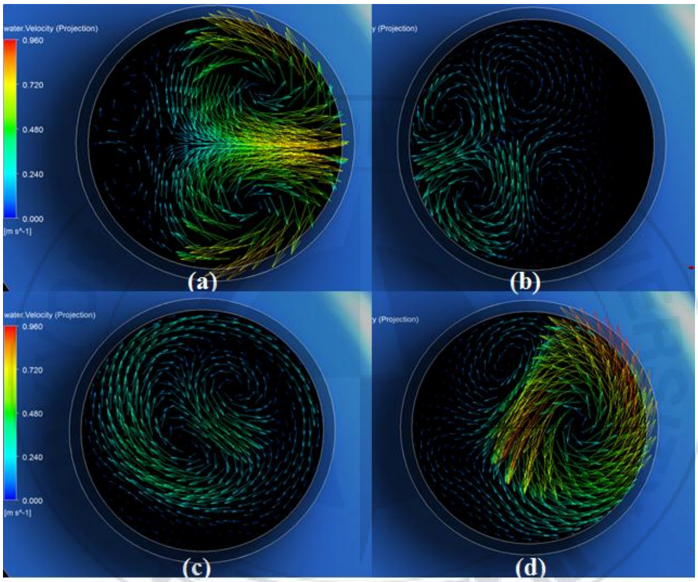



Fig 5.3 Velocity in pipe swirl meter.

Figure 5.3 showed that the velocity vectors of the flow at the installation position of the swirl meter. In the case (a) there was no curtain wall and case (d) curtain wall was installed 1.5D under the free surface of water. It was clear that, the internal flow of case (d) through the pipe much stronger, while the case (b) 0.5D and case (c) 1D were weaker becasuse of curtain wall installation.

In this study, the vortex phenomena that occur around the intake pipe had been studied using CFD. HI Standard conditions maintain for curtain wall installation near the inlet pipe for vortex control. Three different parameters of curtain wall was installed to check vortex control and an optimization for the parameters was obtained for the case of 1 D.

## 5.2. Comparison between no curtain wall and with curtain wall

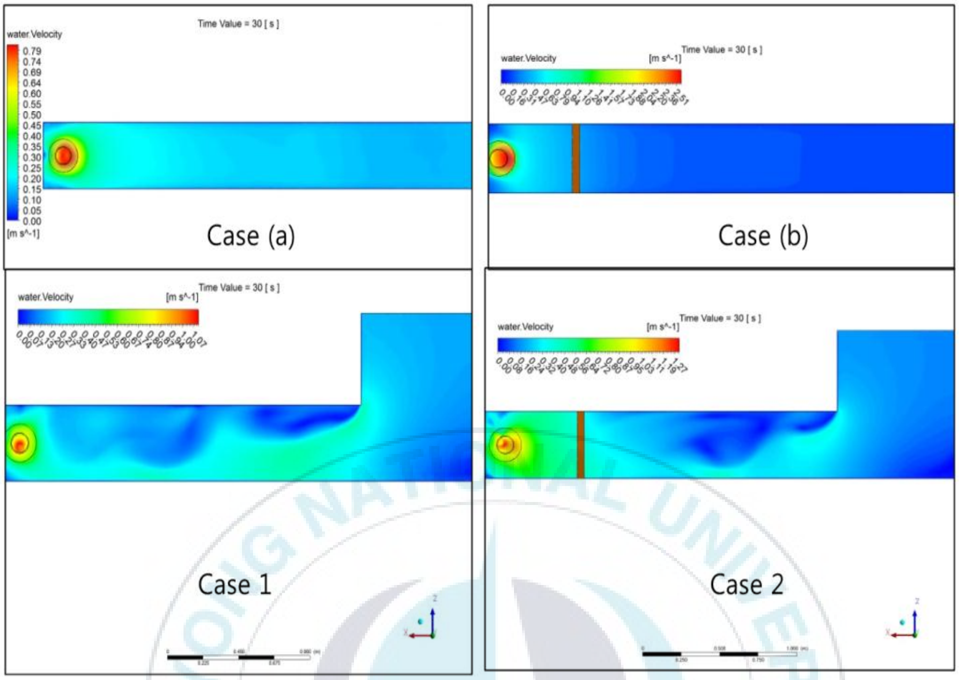



Fig 5.4 Comparing between  the line case and L-Type case.

Figure 5.4. Showed that case (a) and case (b) had same fluid domain except curtain wall at case (b). In case (a), there was no curtain wall so the vortex was high where as in case (b) a curtain wall was installed near the inlet pipe then vortex was controled compared to case (a). In order to bring vortex under more control, a different fluid domain was considered with curtain wall and EDS .

Case 1 and Case 2  had a different fluid domain when compared to Case (a) and Case (b). Case 1 had No curtain wall and hence there was more vortex. In case 2, a curtain wall was installed and hence the vortex was under control when compared to case 1.

Comparison between the line case and L- Type case.

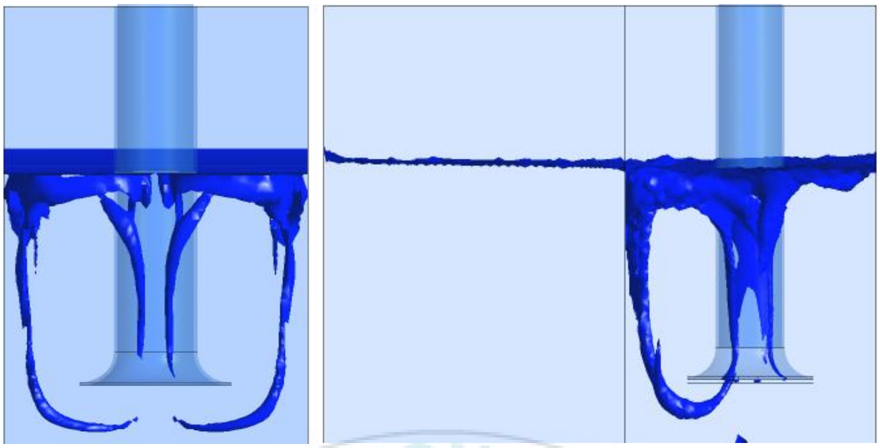


Fig 5.5.  Line model-Front and L-Type model-Front view

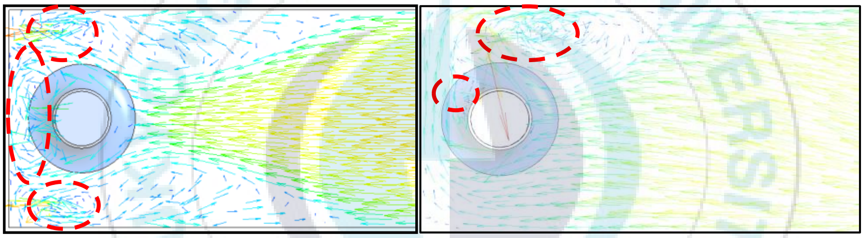
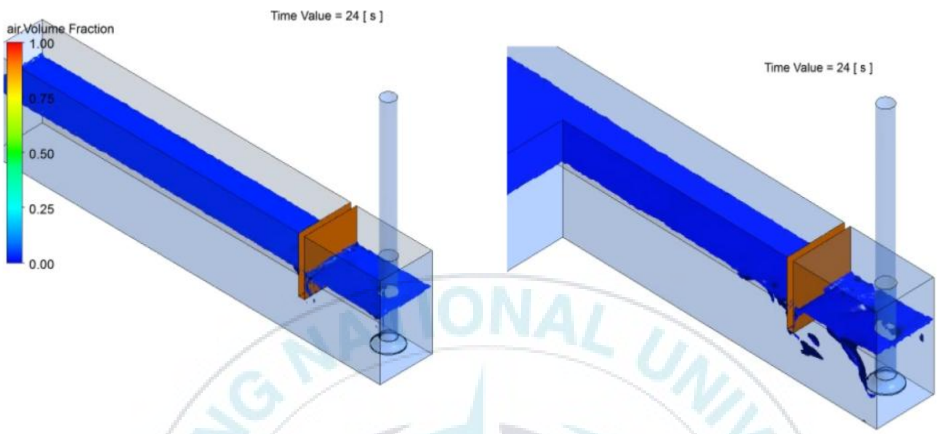


Fig 5.6. Line model-Front and L-Type model-Top view

The flow pattern between the line model and the L-Type model was compared, in the front view of the line model, the flow pattern was uniform and free surface vortex was symmetric, while in the top view on line model, the free surface vortex occurs at various piaces near the bell mouth of the intake pipe. In the front view of the L-Type model, the flow pattern was around one side of the pipe only and which was stronger than the line model, while top view in the L-Type model, the free surface vortex occurs in a few places, but strongly near the mouth of the intake pipe.




Original Model (Line Model) New Model (L-Type Model)

Fig 5.7. The two types model

This Figure 5.7. Showed that the free surface vortex control in the line and L-Type models. In the line model, free surface vortex was under control with the curtain wall installation. However, in the L-Type model with curtain wall installation, the free surface vortex can not under control of the expected levels.

## 5.3. Simulation for effects of curtain wall and EDS

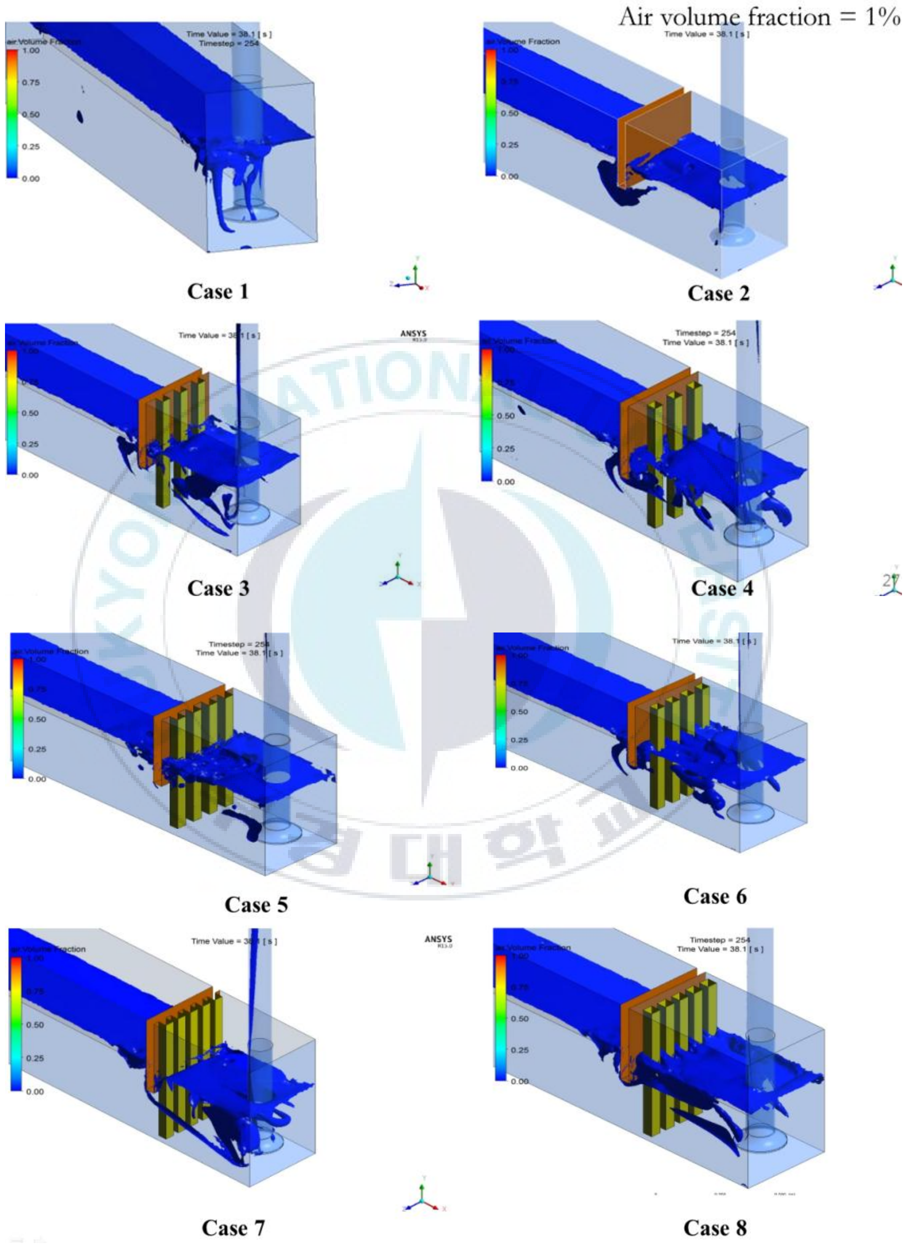
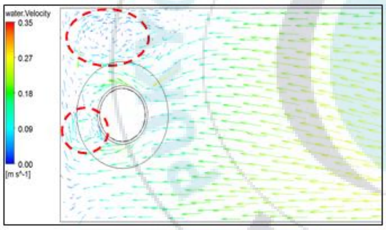


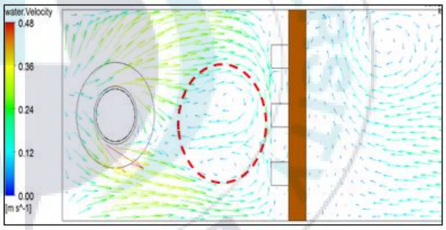

Fig 5.8. Simulation for cases 1~8

Figure 5.8. Showed that the air volume fraction of 1% with on curtain wall installed where the flow was unstable due to the presence of vortex. Two installation types of Energy Dissipating Structures, one was EDS and curtain wall stick together, the other was separated EDS and curtain wall. By observing figures, the stick together types case 3, 5, 7 the water flow velocity was puny get through EDS. The separate EDS and contain wall types for case 4, 6, 8 we can see the water velocity faster than case 3, 5, 7.

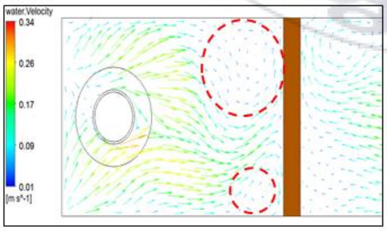
### 5.4. Flow at free surface.



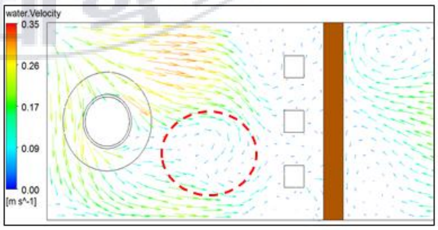

**case 1**




**case 3**




**case 2**




**case 4**

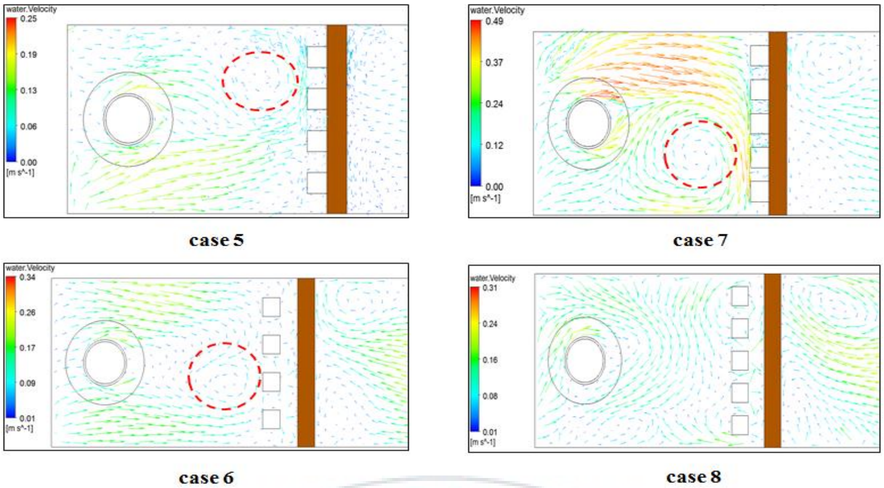
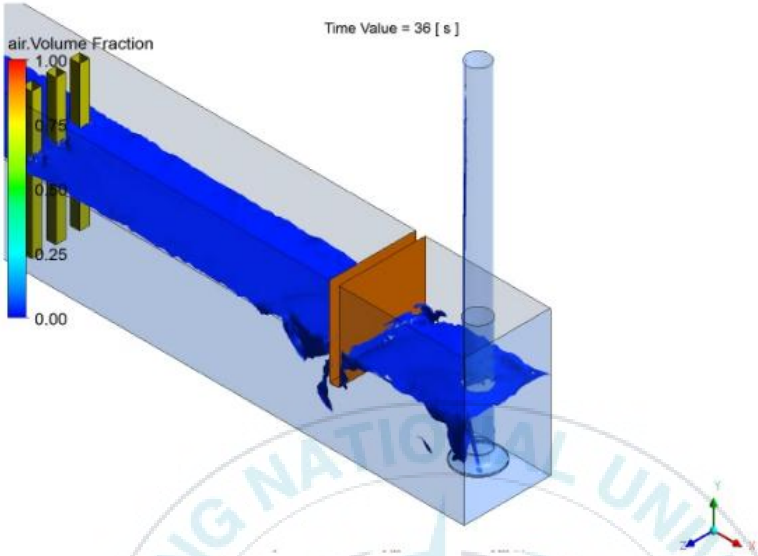


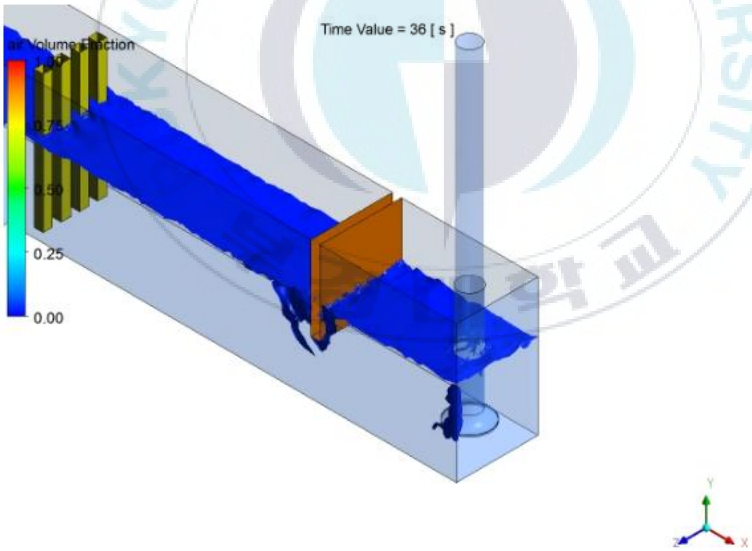

Fig 5.9. Case 1~ Case 8

Figure 5.4.1 the Case 1 with no curtain wall and EDS, observed result the high vortex can be seen near the bell mouth. Case 2 with only curtain wall, vortex can be seen around the curtain wall only. Case 3 with curtain wall and EDS joined, vortex can be seen near the installation. Case 4 with curtain wall and EDS separated, vortex can be seen in between the installation and bell mouth. In comparison to case 3, vortex was weak in case4. Case 5 and Case 7 in these two cases, curtain wall and EDS are joined together but EDS number was high in case 7. Case 6 and Case 8 in these two cases, curtain wall and EDS were separated from each other, but the EDS number was high in Case 8. Comparing case 5 and 7 with that of Case 6 and 8, it can be seen that the vortex appeared stronger in Case 5 and Case 7 and weaker in Case 6 and Case 8.

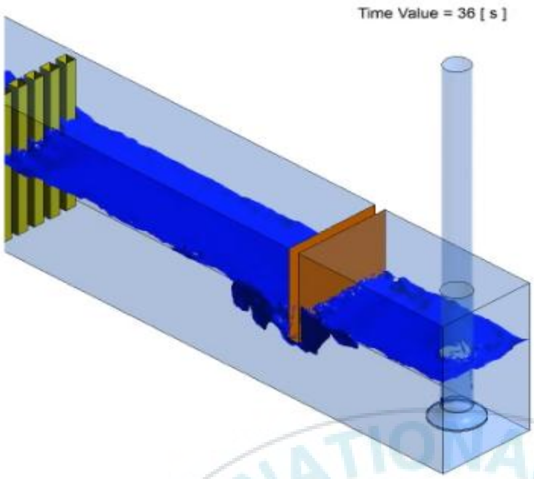
## 5.5. Simulation for different numbers of EDS.




**3 Square bars**




**4 Square bars**




**5 Square bars**

Fig 5.10 Effects of numbers of EDS

Figure 5.10 showed that the EDS installation near the elbow model, the EDS with 3 square bars, 4 squares bars and 5 square bars respectively. The EDS with three squares bars had the less uniform flow when compared to the EDS with four squares bars which was less uniform compared to the EDS with five squares bars.

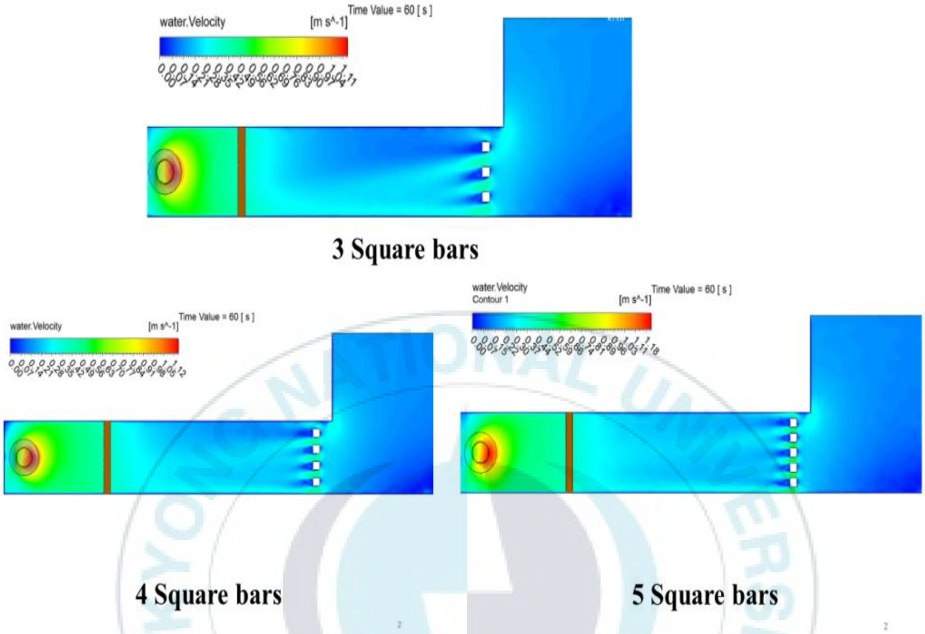



Fig 5.11 EDS 3, 4 and 5 Square bars near the elbow

Figure 5.11 showed that time value 60s when the EDS installations near the elbow, it can be seen that the water flow was more than uniform compared the EDS near the curtain wall case. In addition the EDS with three square bars had the uniform flow when compared to the EDS with four square bars which was more uniform compared to the EDS with five square bars.

# 6. Conclusions

In this study, free surface vortex creation in pump sump was analyzed for a multiphase flow model using CFD. Both L-Type model and Line model have been discussed. In the line model, a curtain wall installation totally controlled vortex. In the L-Type model, a curtain wall installation was not enough to control the vortex. Hence, EDS was additionally installed.

To control the effects of vortex, two methods of installations were considered.

1. First Method, eight different cases of curtain wall and EDS were installed in the channel. Case 1 was considered without a curtain wall or an EDS. Case 2 was considered with a curtain wall and no EDS. Case 3 was considered with a curtain wall and EDS (three numbers – attached). Case 4 was considered with a curtain wall and EDS (three numbers – separated). Case 5 was considered with a curtain wall and EDS (four numbers – attached). Case 6 was considered with a curtain wall and EDS (four numbers – separated). Case 7 was considered with a curtain wall and EDS (five numbers – attached). Case 8 was considered with a curtain wall and EDS (five numbers – separated). The HI Standard recommended flow distributor blockage rate was 50%-70%. The flow distributer blockage rate for Case 3 and Case 4 was 33.3%. Case 5 and Case 6 was 44.4%. Case 7 and Case 8 was 55.5%, Compared with Case 2, In Cases 3, 5 and 7 (curtain wall with attached EDS), the water velocity around the bell mouth region was evenly distributed and thus the flow was stable. When compared to Case 2 and Cases 3, 5 and 7, Cases 4, 6 and 8

(curtain wall with separated EDS), the water velocity around the bell mouth region was more evenly distributed. This was relatively excellent for Case 8 - where the flow regime was smoother around the bell mouth and the EDS region - than all the other cases.

2. Second Method, The flow at the straight section of the L-Type was uniform and stable whereas at the elbow section flow was not uniform and vortices occurred. In order to control the vortex around elbow, EDS was installed near the elbow of the L-Type model. Three cases of EDS were installed. The installation of five EDS numbers controlled the vortex and enabled a uniform flow near the elbow of the L-Type channel than the other two cases.

This showed that the curtain wall with separated EDS had more control of vortex than the cases with curtain wall with attached EDS.

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