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트랜치내의 해저 관로 항력 변화 고찰

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Study of Drag Force of Subsea Pipeline in Trench

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KEY WORDS: P.I.V(Particle Image Velocimeter) 입자 영상 속도계, Subsea Pipeline 해저 관로, Stability 안정성, Trench 트랜치, Reduction Coefficient 감쇄 계수

ABSTRACT : *해저관로가 노출되어 있을 경우 파도와 조류 등에 의한 외적 하중으로부터 안정적이어야 한다. 트랜치 구간 내의 해저관로에 작용하는 유체 입자의 속도와 가속도는 해저면과 비교하여 볼 때 현저히 감소하므로 감쇄 계수를 사용하여 트랜치 구간 내에 설치되는 해저관로의 안정성을 해석한다. 그러나, 다양한 트랜치 구간의 깊이와 기울기에 대한 감쇄 계수에 대해 많은 자료가 부족하여 실제 설계에는 한정된 계수들이 이용된다. 본 논문에서는 다양한 깊이와 기울기를 가진 트랜치 구간의 실험 모형을 제작하여 회류 수조에서 P.I.V(입자 영상 속도계) 기법을 이용하여 여러 속도에 대하여 실험을 수행하였다. 다양한 트랜치 구간 내의 실린더 주변의 유동 특성과 유체 입자의 수평 속도를 측정하여 항력 감쇄 계수를 산출해 냈으며 실제 해양 공사에서 적용 가능한 안정성 해석 기준을 제시하였다.*

1. INTRODUCTION

Offshore industry has long recognized the importance of subsea pipelines as a vital link for the transmission of materials between onshore and offshore facilities. Although these subsea pipelines are costly in the installation, maintenance, etc. comparing to the onshore pipelines, they remain the most feasible and therefore the most economical method for transporting materials continuously. (Knoll and Herbich, 1980)

Many experiments have been conducted both in the ocean and in laboratory wave and current channels. Test results have frequently shown rather extreme scatter leaving the designer in the unfortunate position of possible grossly over-designing the structure or using coefficients which are less than the range of reported values. (Garrison, 1980).

There have been numbers of studies conducted to develop the criteria to predict the hydrodynamic loads imposed by external waves and currents. But not many for the pipelines in trench section. Quite number of pipelines in many regions are required to be placed in trench for protection from anchoring or fishing activities. However clear guidelines are not available to confirm the stability of pipeline in trench. Also the reduction of hydrodynamic loads of pipelines in trench is not provided except some specific conditions.

In this research the relationship between the trench depth and hydrodynamic force is investigate. Also the effects of various slopes on the hydrodynamic coefficients are observed. The models for 18 cases with various trench section slopes and depths are made and four various currents speeds are generated in a circulating water channel. But in this paper, only 9 cases for single pipeline are introduced. The PIV system measures the velocities around the cylinder models. And the reduction coefficients for drag over various experimental cases are obtained. The drag forces can be calculated by the modified method by Morrison et. al, 1950. The reduction coefficients proposed in the paper for various cases changed with trench slopes and depths can be applied to estimate the stability of pipelines in trench sections

2. APPLIED THEORIES

Pipelines in open trench is subjected to external loads such as wave and current (Sumer, 1997).

The hydrodynamic forces in trench can be estimated with reduction coefficients which vary with trench depth

(H) and slope. The relating equations are as described below:

$$F_D^* = F_D \times RF_D \quad (1)$$

$$F_L^* = F_L \times RF_L \quad (2)$$

$$F_M^* = F_M \times RF_M \quad (3)$$

where,

F_D^* : Drag Force in Open Trench (KN/m)

F_L^* : Lift Force in Open Trench (KN/m)

F_M^* : Inertia Force in Open Trench (KN/m)

F_D : Drag Force on Sea Bottom (KN/m)

F_L : Lift Force on Sea Bottom (KN/m)

F_M : Inertia Force on Sea Bottom (KN/m)

RF_D : Reduction Coefficient on Drag Force

RF_L : Reduction Coefficient on Lift Force

RF_M : Reduction Coefficient on Inertia Force

The reduction coefficients are dependent on velocity reduction factor and Reynolds number. The velocity reduction factor can be obtained from measurement of velocity on seabed and in trench. The velocity reduction factor can be obtained from (4):

$$\beta = \frac{u_e^*}{u_e} \quad (4)$$

where,

β : Reduction Factor on Velocity $(0 \le \beta \le 1)$

u_e : Effective Velocity of Flow on Sea Bottom (m/s)

u_e^* : Effective Velocity of Flow in Open Trench (m/s)

As per the velocity reduction factor, the hydrodynamic forces and reduction coefficients in trench can be written as follows:

$$RF_D = \frac{F_D^*}{F_D} = \frac{C_D^*}{C_D}\beta^2 \quad (5)$$

$$RF_L = \frac{F_L^*}{F_L} = \frac{C_L^*}{C_L}\beta^2 \quad (6)$$

$$RF_M = \frac{F_M^*}{F_M} = \frac{\rho_w C_M^* (\frac{\pi D^2}{4}) \frac{du^*}{dt}}{\rho_w C_M (\frac{\pi D^2}{4}) \frac{du}{dt}} \quad (7)$$

where,

C_D^* : Coefficient of Drag Force in Open Trench

C_M^* : Coefficient of Inertia Force in Open Trench

C_L^* : Coefficient of Lift Force in Open Trench

C_D : Coefficient of Drag Force on Sea Bottom

C_L : Coefficient of Lift Force on Sea Bottom

C_M : Coefficient of Inertia Force on Sea Bottom

ρ_w : Density of Sea Water (Kg/m^3)

D : Outside Diameter of Pipe (m)

u : Hor. Velocity of Wave & Current (m/s)

$\frac{du}{dt}$: Hor. Acceleration of Wave (m/s^2)

The schematic diagram of pipeline in trench is as shown in Fig. 1.

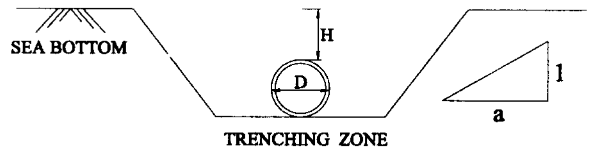

Fig. 1 Schematic Diagram of Pipe in Trench

The cover depth (H) is the gap between seabed and the top of the pipeline. In equation (8), H stands for the trench cover depth over the pipe and n of 1, 2, 3,... is used.

$$H = n \times D \quad (8)$$

The slope of trench section can be expressed as (9).

$$Slope = f(a) \quad (9)$$

3. EXPERIMENTAL SET-UP

The experimental set up is shown in Fig. 2~3. The frame for trench section is made out of bronze and the seabed and trench wall of acryl plates.

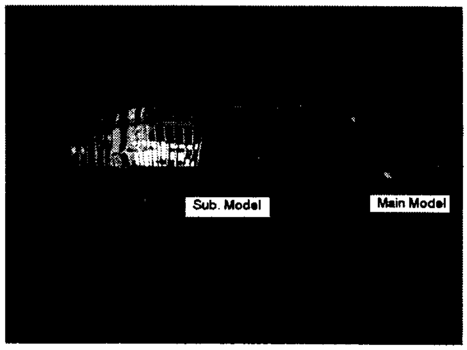

Fig. 2 Front View of Experimental Set-up

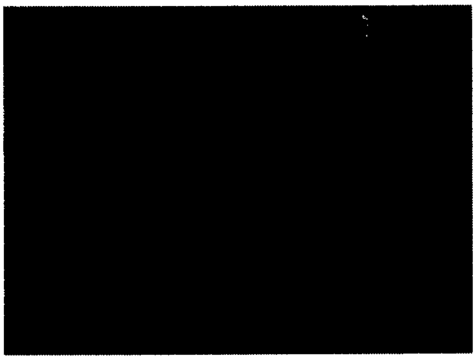

Fig. 3 Front View of Pipe in Trench

The experiment arrangement is as shown in Fig. 4.

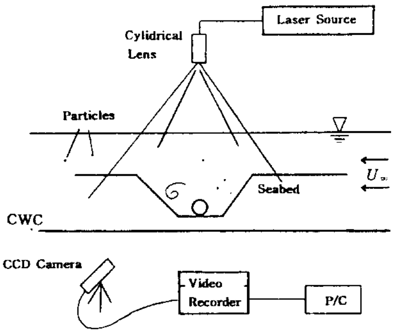

Fig. 4 Experiment Arrangement

Having various trench cover depths and slopes, 18 models are made. And four different, from 0.2 m/s to 0.5 m/s with 0.1 m/s interval, current velocities are generated. Two pipeline types, single and bundled, are simulated. However, in this paper, only single pipeline is introduced. Table 1 shows the test conditions of pipe size, velocities, etc. Table 2 indicates the experimental cases.

Table 1 Test Conditions

O.D of Model Pipe	32 mm	
Ratio Breadth-to-O.D	About 30	
Laser Source	1 W	
Particle Tracer	150 ~ 200 μm	
Velocity	m/s	Re
	0.2	7.16×10^3
	0.3	1.07×10^4
	0.4	1.43×10^4
	0.5	1.79×10^4

Table 2 Experimental Cases

PIPE	Depth (H)	Slope (1 : a)	CASE
Single Pipe Type	1 D	1 : 1	Case 1
		1 : 3	Case 2
		1 : 5	Case 3
	2 D	1 : 1	Case 4
		1 : 3	Case 5
		1 : 5	Case 6
	3 D	1 : 1	Case 7
		1 : 3	Case 8
		1 : 5	Case 9

The experimental set up and PIV system were validated with a test run with 0.2 m/s on the flat plate with a good agreement with the other available data.

To minimize side wall effect, the model was installed 15 cm apart from the wall and the width of model was 90 cm which made the width/diameter ratio of nearly 30. Having the measuring spot at the center of the model, any effect created from side wall was eliminated. The model was set up above 30 cm from the tank bottom to avoid the viscosity effect. To obtain a steady flow there was a 1.2 m straight plate attached in front of trench model. The end of straight plate was curve to avoid vortex at the edge. There was 5 minutes gab between each flow velocity change to stabilize the fluid. Also the model was securely fastened by two support piles downstream from vibration.

4. RESULT ANALYSIS

The reduction factors are represented as the ratio between seabed and trench section.

Variable Depths

The velocity and drag reduction factors for various cover depths are shown in Fig. 5 to 6. They indicate that as the cover depth increases the reduction factor decreases. Among three different trench slopes, 1:1, 1:3 and 1:5, when slope is 1:1 the reduction factors are significantly decreased. For the same slope, as the velocity increases the reduction factor decreases.

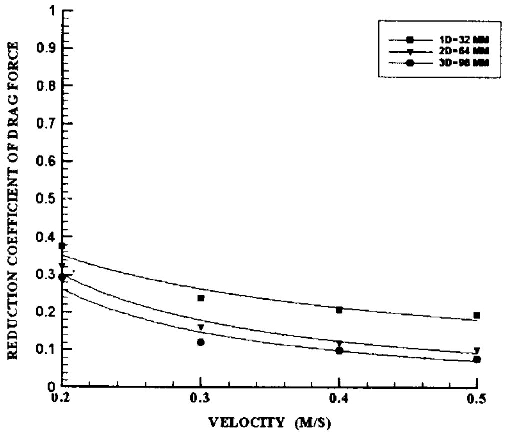

Fig. 5 Drag Reduction Coefficient vs. Cover Depth (Slope 1 : 1)

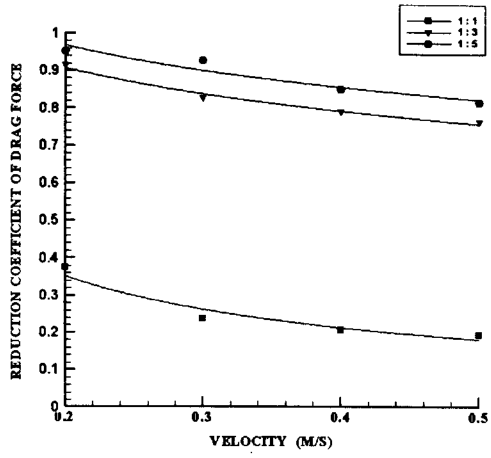

Fig. 7 Drag Reduction Coefficient vs. Trench Slope (Cover Depth 1D=32MM)

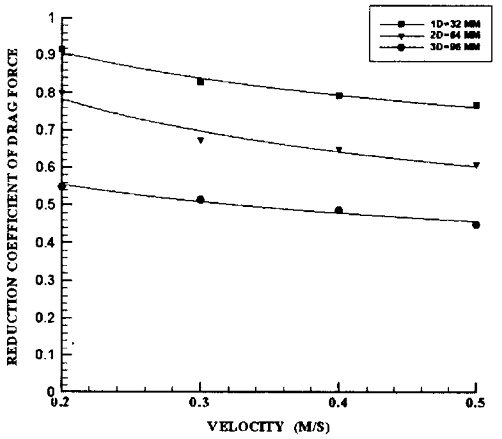

Fig. 6 Drag Reduction Coefficient vs. Cover Depth (Slope 1 : 3)

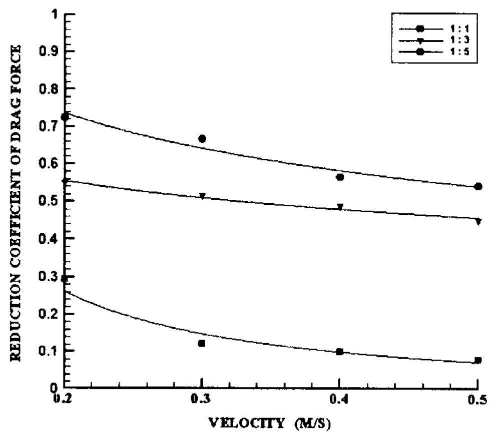

Fig. 8 Drag Reduction Coefficient vs. Trench Slope (Cover Depth 3D=96MM)

Variable Trench Slopes

Fig. 7 to 8 indicate that as the slope increases the reduction factor decrease. The results show that the reduction factors and coefficients for slopes of 1:3 and 1:5 are much larger than those for 1:1 slope. Also as the velocity is large the reduction factors become smaller. It seems that the slope influences more significantly to the reduction factors than the cover depth.

Flow Patterns of Open Trench

The current velocity around the pipeline in trench can be measured with PIV system. Fig. 9 illustrate the flow patterns for various slopes at cover depth of 2D and current velocity of 0.3 m/s for the slope of 1:1.

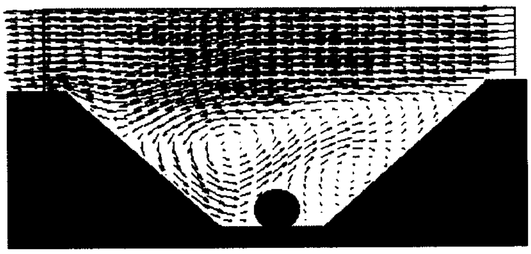

Fig. 9 Flow Patterns as Trench Slope of 1 : 1

5. CONCLUSION

The reduction factors for various trench slopes and cover depths at several current velocities are investigated with application of PIV system. From the physical modeling, it was observed that :

As the current velocity increases the reduction factor decreases.

Also as the cover depth increases the reduction factors becomes smaller but the cover depth is related to the pipe outer-diameter the outer diameter would contribute to the reduction factors as well. The trench slopes greatly influence on the reduction factors. The slope of 1:1 shows significant effect on the reduction coefficients.

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