오만 소하르 담수용 SEA WATER INTAKE SYSTEM의 흡수조 시험

Sump Model Test on Sea Water Intake System for OMAN Sohar Power and Desalination Project

- 2005년 유체기계공업학회 유체기계 학술 대회 -

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연구 배경 및 목적

연구 배경

- 수리모형시험을 통한 펌프 운전상태의 예측 및 영향파악
- 펌프의 연속적이며 안정적인 운전실현을 위한 대책 수립
- 펌프의 부품 파손으로 인한 시간적, 경제적 손실을 사전에 방지

연구 목적

- 볼텍스로 인한 소음, 진동발생에 대한 원인 규명
- 볼텍스의 관찰(표면와류, 공기흡입와류, 수중와류)을 통한 펌프의 운전 상태 파악 및 방지 방안 수립
- 펌프장 흡입수조의 형상, 치수 설계 및 검정(HI Standard) 적합성 확인

Physical Model Scale

Previous Literature & Study

- Hecker, G.E.(1981)
  - ▶ Concluded Froudian scaling gives reliable good results on proto & model
- Anwar H.O(1978), Knauss, Jost(1978), ANSI/HI(1998)
  - ▶ Suggested 방 ortex formation is independent of Radial Reynolds No."
- The range of Webner no. is 50 ~ 75 that the vortex formation was unaffected as per experimental study by HR Wallingford

$$R_d = \frac{Q}{vS} > 20{,}000 \sim 30{,}000$$; Radial Reynold No.

$$W_e = \frac{4Q}{\pi D^2}\left[\frac{\rho S}{\sigma}\right]^{1/2}$$,Weber no.

Selection of Model Scale

- Acquire dynamic similarity between prototype and model
- Reproduce correctly vortex and swirl action at the pump suction
- Impossible to satisfy simultaneously the scaling laws as follows
  - ▶ E = Euler number ; Inertial force to pressure force
  - ▶ F = Froude number ; Inertial force to gravitational force
  - ▶ R = Reynolds number ; Inertial force to viscous force
  - ▶ W = Weber number ; Inertial force to surface force

❑ Selection of Model Scale (continued)

◑ Calculation of model scale using Radial Reynolds No. and Webner No.

▸ Prototype information of sump

Q[m³/hr]	S[m]	D[m]	Remark
16,000	4	1.2	ρ: 1028kg/m³, ν: 1.17E-6m²/s, σ: 0.073N/m

▸ Radial Reynolds no;9.5 x 10^5, Webner no.:930 for prototype

▸ λ= 13 (Radial Reynolds Number limit to 20, 000)

▸ λ= 19 (Weber Number limit to 50)

▸ λ= 10 ; Experimental model scale by HECO

◑ Froudian Similarity between the model and prototype (HI/JSME)

$$F_r = \frac{V_m}{\sqrt{gL_m}} \approx \frac{V_p}{\sqrt{gL_p}} \qquad V_m = V_p \left(\frac{Lm}{Lp}\right)^n \text{ or } Q_m = Q_p \left(\frac{Lm}{Lp}\right)^{n+2}$$

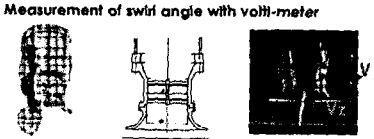
▸ n = 0.5 ; Same Froude
▸ n = 0.2 ; Medium Velocity
▸ n = 0.0 ; Equal Velocity

❑ Test Criteria

◑ Scale ratios related with model test investigation

Parameter	HI Froude No.	JSME 004 - 1984 Equal Velocity
Geometry (λ)	1:10	1:10
Velocity (v)	$1 : 10^{0.5} = 1:3.16$	$1:10^{0} = 1 : 1$
Flow Rate (Q)	$1 : 10^{2.5} = 1:316$	$1:10^{2.0} = 1: 100$
Time (t)	$1 : 10^{0.5} = 1:3.16$	1:10
Swirl angle	5°	5°

◑ Measurement of swirl angle with volti-meter



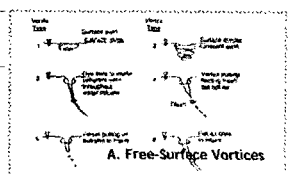
$$\theta = \tan^{-1}\frac{V_\theta}{V_z} \text{ ; swirl angle}$$

▸ V_θ;Tangential velocity vector
▸ Vz;Axial mean velocity vector

❑ Test Criteria

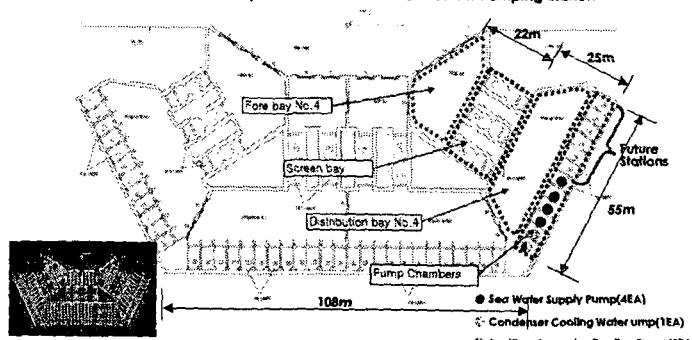
◑ Acceptance Criteria as per HI

Classification of Vortex	Acceptable Criteria
(1) Free Surface Vortices	
▫ Surface Swirl(Class A-1)	●
▫ Surface Dimple(Class A-2)	●
▫ Dye Core to Intake(Class A-3)	×
(2) Sub Surface Vortices	
▫ Swirl (Class B-1)	●
▫ Dye core(Class B-2)	×
▫ Air Core or Bubbles	×
● Acceptable, × Not Acceptable	



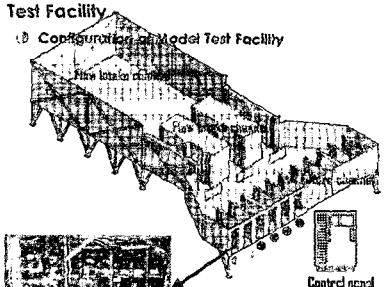
❑ Configuration Test Facility

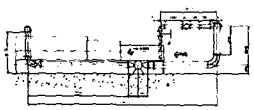
◑ General schematic layout of Onshore Intake Area for Pumping Station

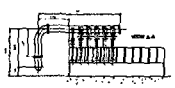


❑ Test Facility

◑ Configuration of Model Test Facility





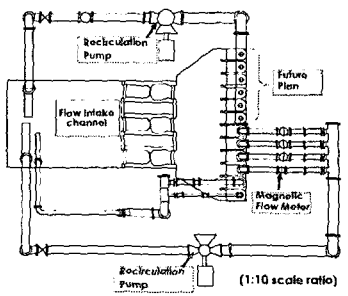


- ⊙ SWSPump(4EA)
- CCWP(1EA)
- ◐ ASCP(1EA)

Pump suction

❑ Test Facility

◑ Configuration of Model Test Facility (continued)



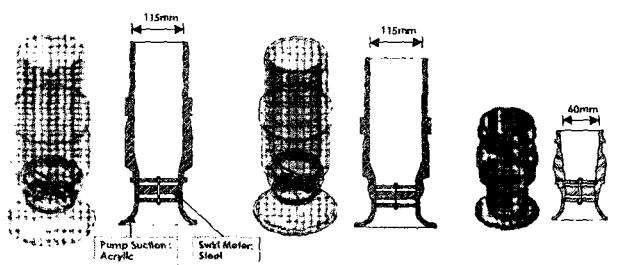
(1:10 scale ratio)

Equipment	Specification	Maker	Remark
Magnetic Flow Meter(A)	Nominal Diameter : 250 A Accuracy : ± 0.5%	Bailey Fischer & Porter	GERMANY
Magnetic Flow Meter(B)	Nominal Diameter : 150A Accuracy : ± 0.3%	HEINRICHS	GERMANY
Magnetic Flow Meter(C)	Nominal Diameter : 150A Accuracy : ± 0.3%	ABB	SWEDEN
Magnetic Flow Meter(D)	Nominal Diameter : 80A Accuracy : ± 0.3%	YOKOGAWA	JAPAN
Propeller Vortimeter	Impeller;4 flat blade Fluid : Water	HYOSUNG-EBARA	KOREA

Measuring equipment

❑ Test Facility

◑ Pump Suction and Swirl Meter



⊃ Sea Water Supply Pump ⊃ Condenser Cooling Pump ⊃ Aux. Seawater Pump

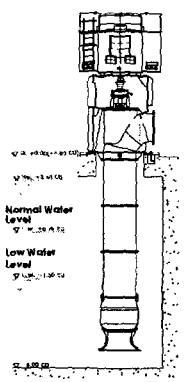
❑ Original Initial Test

◑ Case 1. Low Water Level (-1.5CD, 450mm)

- ■ case 1.1 Maximum flow rate (17,600 m³/hr)
  - ▶ Equal velocity as per JSME
  - ▶ Froude no. similarity as per HI
- ■ case 1.2 Rated flow rate (16,000 m³/hr)
  - ▶ Equal velocity
  - ▶ Froude no. similarity

◐ Case 2. Normal Water Level (+0.75CD, 695mm)

- ■ case 2.1 Maximum flow rate (17,600 m³/hr)
  - ▶ Equal velocity as per JSME
  - ▶ Froude no. similarity as per HI
- ■ case 2.2 Rated flow rate (16,000 m³/hr)
  - ▶ Equal velocity
  - ▶ Froude no. similarity



⊃ Sea Water Supply Pump

❑ Original Initial Test

◑ Case 1.1 Low Water Level (-1.5CD, 450mm), Maximum flow rate

Test case	Pump Operation	Similarity	Water Level(mm)		Flow Rate(㎥/Hr)		Remark (Capacity)
			Prototype	Model	Prototype	Model	
01-M-V-1	A1-A2-A3	Equal velocity	L.W.L (-1.5CD)	L.W.L (450)	17,600	176	
01-M-V-2	A1-A2-A4	"	L.W.L (-1.5CD)	L.W.L (450)	17,600	176	
01-M-V-3	A1-A3-A4	"	L.W.L (-1.5CD)	L.W.L (450)	17,600	176	
01-M-V-4	A2-A3-A4	"	L.W.L (-1.5CD)	L.W.L (450)	17,600	176	Maximum
01-M-F-1	A1-A2-A3	Froude no.	L.W.L (-1.5CD)	L.W.L (450)	17,600	56	Flow Rate
01-M-F-2	A1-A2-A4	"	L.W.L (-1.5CD)	L.W.L (450)	17,600	56	
01-M-F-3	A1-A3-A4	"	L.W.L (-1.5CD)	L.W.L (450)	17,600	56	
01-M-F-4	A2-A3-A4	"	L.W.L (-1.5CD)	L.W.L (450)	17,600	56	

◑ Case 1.2 Low Water Level (-1.5CD, 450mm), Rated flow rate

Test case	Pump Operation	Similarity	Water Level(mm)		Flow Rate(㎥/Hr)		Remark (Capacity)
			Prototype	Model	Prototype	Model	
01-R-V-1	A1-A2-A3	Equal velocity	L.W.L (-1.5CD)	L.W.L (450)	16,000	160	
01-R-V-2	A1-A2-A4	"	L.W.L (-1.5CD)	L.W.L (450)	16,000	160	
01-R-V-3	A1-A3-A4	"	L.W.L (-1.5CD)	L.W.L (450)	16,000	160	
01-R-V-4	A2-A3-A4	"	L.W.L (-1.5CD)	L.W.L (450)	16,000	160	Rated
01-R-F-1	A1-A2-A3	Froude no.	L.W.L (-1.5CD)	L.W.L (450)	16,000	51	Flow Rate
01-R-F-2	A1 A2 A4	"	L.W.L (-1.5CD)	L.W.L (450)	16,000	51	
01-R-F-3	A1-A3-A4	"	L.W.L (-1.5CD)	L.W.L (450)	16,000	51	
01-R-F-4	A2-A3-A4	"	L.W.L (-1.5CD)	L.W.L (450)	16,000	51	

❑ Original Initial Test (Continued)

◑ Case 2.1 Normal Water Level (+0.95CD, 695mm), Maximum flow rate

Test case	Pump Operation	Velocity	Water Level(mm)		Flow Rate(㎥/Hr)		Remark (Capacity)
			Prototype	Model	Prototype	Model	
02-M-V-1	A1-A2-A3	V	N.W.L (+0.95CD)	N.W.L (695)	17,600	176	
02-M-V-2	A1-A2-A4	V	N.W.L (+0.95CD)	N.W.L (695)	17,600	176	
02-M-V-3	A1-A3-A4	V	N.W.L (+0.95CD)	N.W.L (695)	17,600	176	
02-M-V-4	A2-A3-A4	V	N.W.L (+0.95CD)	N.W.L (695)	17,600	176	Maximum
02-M-F-1	A1-A2-A3	F	N.W.L (+0.95CD)	N.W.L (695)	17,600	56	Flow Rate
02-M-F-2	A1-A2-A4	F	N.W.L (+0.95CD)	N.W.L (695)	17,600	56	
02-M-F-3	A1-A3-A4	F	N.W.L (+0.95CD)	N.W.L (695)	17,600	56	
02-M-F-4	A2-A3-A4	F	N.W.L (+0.95CD)	N.W.L (695)	17,600	56	

◑ Case 2.2 Normal Water Level (+0.95CD, 695mm), Rated flow rate

Test case	Pump Operation	Velocity	Water Level(mm)		Flow Rate(㎥/Hr)		Remark (Capacity)
			Prototype	Model	Prototype	Model	
02-R-V-1	A1-A2-A3	V	N.W.L (+0.95CD)	N.W.L (695)	16,000	160	
02-R-V-2	A1-A2-A4	V	N.W.L (+0.95CD)	N.W.L (695)	16,000	160	
02-R-V-3	A1-A3-A4	V	N.W.L (+0.95CD)	N.W.L (695)	16,000	160	
02-R-V-4	A2-A3-A4	V	N.W.L (+0.95CD)	N.W.L (695)	16,000	160	Rated
02-R-F-1	A1-A2-A3	F	N.W.L (+0.95CD)	N.W.L (695)	16,000	51	Flow Rate
02 R F 2	A1 A2 A4	F	N.W.L (+0.95CD)	N.W.L (695)	16,000	51	
02-R-F-3	A1-A3-A4	F	N.W.L (+0.95CD)	N.W.L (695)	16,000	51	
02-R-F-4	A2-A3-A4	F	N.W.L (+0.95CD)	N.W.L (695)	16,000	51	

❑ Original Initial Test Results

◑ Case 1 Low Water Level (-1.5CD, 450mm), Maximum & Rated flow rate

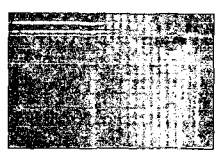
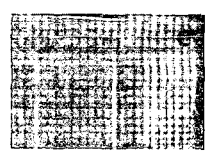
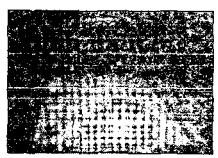
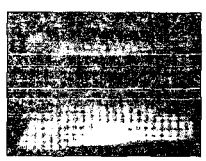
	Test Case	Type of Vortex Formation						Swirl Angle(θ)											
		SSP-A	SSP-B	SSP-C	SSP-D	CCWP	ASCP	SSP-A		SSP-B		SSP-C		SSP-D		CCWP		ASCP	
								CW	CCW	CW	CCW	CW	CCW	CW	CCW	CW	CCW	CW	CCW
Maximum Flow rate	01-M-V-1	◉	◉	◉	N/A	◉	n	-	-	-	-	-	-	-	-	-	-	-	-
	01-M-V-2	◉	◉	N/A	◉	◉	n	-	-	-	-	-	-	-	-	-	-	-	-
	01-M-V-3	◉	N/A	◉	◉	◉	n	-	-	-	-	-	-	-	-	-	-	-	-
	01-M-V-4	N/A	◉	◉	◉	◉	n	-	-	-	-	-	-	-	-	-	-	-	-
	01-M-F-1	^	n	n	N/A	◉	D	-	7.4	7.0	-	0.6	2.4	-	-	8.9	-	0.3	-
	01-M-F-2	^	^	N/A	◉, ^	◉	D	-	8.6	2.0	1.1	-	-	2.5	1.1	8.3	-	0.1	-
	01-M-F-3	◉, ^	N/A	◉	^	◉	D	-	9.6	-	-	8.3	-	1.3	1.9	8.4	-	0.2	-
	01-M-F-4	N/A	◉	◉	^	◉	D	-	0.0	10.5	-	7.6	-	1.3	1.9	7.6	-	0.2	-
Rated Flow rate	01-R-V-1	◉	◉	◉	N/A	◉	n	-	-	-	-	-	-	-	-	-	-	-	-
	01-R-V-2	◉	◉	N/A	◉	◉	n	-	-	-	-	-	-	-	-	-	-	-	-
	01-R-V-3	◉	N/A	◉	◉	◉	n	-	-	-	-	-	-	-	-	-	-	-	-
	01-R-V-4	N/A	◉	◉	◉	◉	n	-	-	-	-	-	-	-	-	-	-	-	-
	01-R-F-1	^	n	^	N/A	◉	^	-	7.3	7.4	-	0.8	2.9	-	-	8.6	-	0.4	-
	01-R-F-2	^	n	N/A	△	◉	△	-	9.6	2.6	2.7	-	-	2.9	-	8.6	-	0.3	-
	01-R-F-3	◉, ^	N/A	◉	^	◉	^	-	9.5	-	-	8.6	-	-	3.5	9.6	-	0.5	-
	01-R-F-4	N/A	◉	◉	△	◉	D	-	0.0	9.2	-	9.3	-	2.6	1.0	6.6	-	0.3	-

◉ : Submerged Vortex, ^ : Air-Entraining Vortex, D : Dimple & Surface Vortex, n : No Vortex, N/A : Not Applicable

CW : Clockwise, CCW : Counter Clockwise

❑ Original Initial Test Results

◑ Case 1 Low Water Level (-1.5CD, 450mm), Maximum flow rate

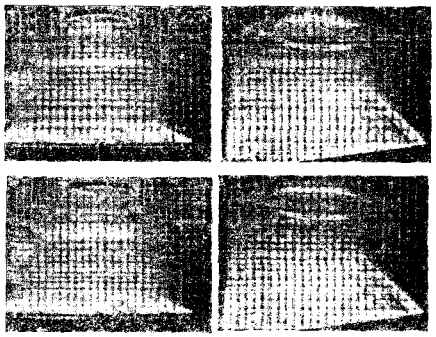





Principle of Similarity	Same Froude No.
Capacity of SSP	176m³/hr, Maximum flow capacity
Water Level	LWL, 450mm (-1.5CD)

- Submerged vortex and Dimple observed.
- SSP SEA operated
- CCWP, ASCP operated

❑ Original Initial Test Results

◑ Case 1 Low Water Level (-1.5CD, 450mm), Maximum flow rate

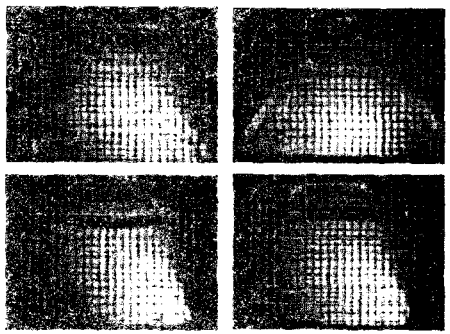


Principle of Similarity	Same Froude No.
Capacity of SSP	176m³/hr, Maximum flow capacity
Water Level	LWL, 450mm (-1.5CD)

- Submerged vortex and Dimple observed.
- SSP 3EA operated
- CCWP, ASCP operated

❑ Original Initial Test Results

◑ Case 1 Low Water Level (-1.5CD, 450mm), Maximum flow rate

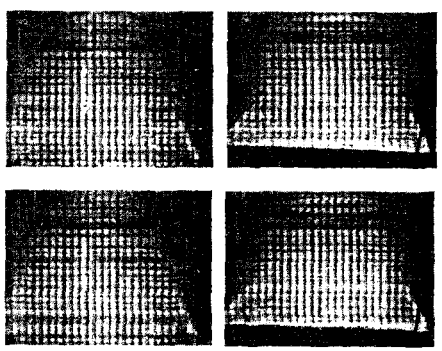


Principle of Similarity	Equal Velocity
Capacity of SSP	176m³/hr, Maximum flow capacity
Water Level	LWL, 450mm (-1.5CD)

- Submerged vortex and Dimple observed.
- SSP 3EA operated
- CCWP, ASCP operated

❑ Original Initial Test Results

◑ Case 1 Low Water Level (-1.5CD, 450mm), Rated flow rate

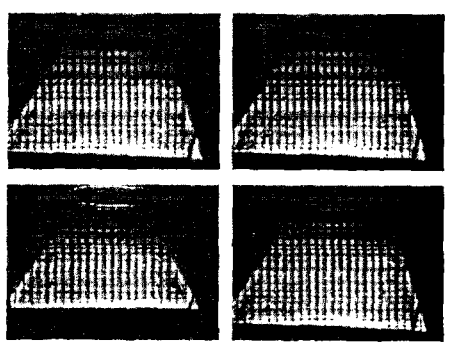


Principle of Similarity	Equal Velocity
Capacity of SSP	160m³/hr, Maximum flow capacity
Water Level	LWL, 450mm (-1.5CD)

- Submerged vortex and Dimple observed.
- SSP 3EA operated
- CCWP, ASCP operated

❑ Original Initial Test Results

◑ Case 1 Low Water Level (-1.5CD, 450mm), Rated flow rate

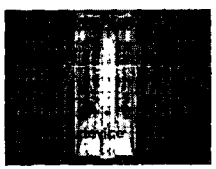


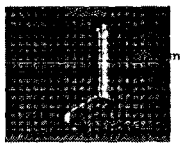
Principle of Similarity	Same Froude
Capacity of SSP	160m³/hr, Maximum flow capacity
Water Level	LWL, 450mm (-1.5CD)

- Submerged vortex and Dimple observed.
- SSP 3EA operated
- CCWP, ASCP operated

❑ Modified Remedial Test

◑ Anti-Vortex Device and Curtain Wall

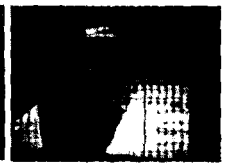
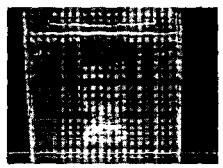
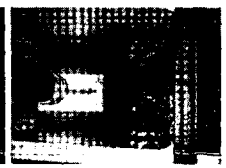




Water Level	Flow Rate [m³/hr]	Anti-Vortex Device		Similarity	Remark
		L-Splitter	Wall Curtain		
-1.5CD	17,600/56	●	×	Same Froude No.	Distribution Baffle
-0.72CD	17,600/56	●	×	Same Froude No.	Distribution Baffle

❑ Modified Remedial Test Results

◑ Case 1 Low Water Level (-1.5CD, 450mm), Rated flow rate

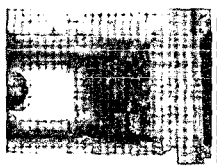
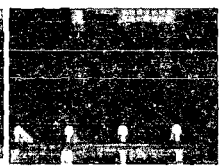
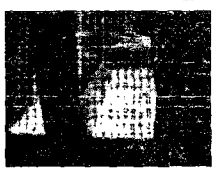





Principle of Similarity	Same Froude
Capacity of SSP	160m³/hr, Maximum flow capacity
Water Level	LWL, 450mm (-1.5CD)

- no vortex and dimple observed.
- SSP 3EA operated
- CCWP, ASCP operated

❑ Modified Remedial Test Results

◑ Case 1 Low Water Level (-1.5CD, 450mm), Rated flow rate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- CCWP, ASCP operated

❑ Modified Remedial Test

◑ Installation of Anti-Vortex Device and Curtain Wall

	Test Case	Type of Vortex Formation						Swirl Angle(θ)											
		SSP-A	SSP-B	SSP-C	SSP-D	CCWP	ASCP	SSP-A		SSP-B		SSP-C		SSP-D		CCWP		ASCP	
								CW	CCW	CW	CCW	CW	CCW	CW	CCW	CW	CCW	CW	CCW
Maximum Flow rate	01-M-V-1	n	n	n	n	n	n	-	-	-	-	-	-	-	-	-	-	-	-
	01-M-V-2	n	n	n	n	n	n	-	-	-	-	-	-	-	-	-	-	-	-
	01-M-V-3	n	n	n	n	n	n	-	-	-	-	-	-	-	-	-	-	-	-
	01-M-V-4	n	n	n	n	n	n	-	-	-	-	-	-	-	-	-	-	-	-
	01-M-F-1	n	n	n	n	n	n	4.4	1.2		1.7					2.4		-	-
	01-M-F-2	n	n	n	n	n	n	4.5	0.6	0.4						1.2		-	-
	01-M-F-3	n	n	n	n	n	n	4.6			1.9			1.7	2.1			-	-
	01-M-F-4	n	n	n	n	n	n	0.0	1.4		0.2			2.3	1.8			-	-
Rated Flow rate	01-R-V-1	n	n	n	n	n	n	-	-	-	-	-	-	-	-	-	-	-	-
	01-R-V-2	n	n	n	n	n	n	-	-	-	-	-	-	-	-	-	-	-	-
	01-R-V-3	n	n	n	n	n	n	-	-	-	-	-	-	-	-	-	-	-	-
	01-R-V-4	n	n	n	n	n	n	-	-	-	-	-	-	-	-	-	-	-	-
	01-R-F-1	n	n	n	n	n	n	4.3	1.0		0.8							-	-
	01-R-F-2	n	n	n	n	n	n	4.1	0.8	0.3				0.4		1.8		-	-
	01-R-F-3	n	n	n	n	n	n	4.4			2.2				0.4	2.0		-	-
	01-R-F-4	n	n	n	n	n	n	0.0	1.7		1.3				0.8	2.1		-	-

Conclusion

- A geometry model of the pumping station was constructed at a scale of 1:13 and tests were undertaken to investigate;
  - Flow conditions at the screen chambers
  - Approaching flow conditions to the pump chambers and suctions
  - Ensure that the entering flow to pump suctions was free from severe swirl
  - Ensure that the pump chambers were free from severe vortex action and no air was entrained at the pump suctions
  - Identify modifications of baffles and anti-vortex device to improve the pump operation performance
- The results of original model test are ;
  - Submerged vortex developed in the pump chamber was not within acceptable criteria
  - Air-entraining vortex in the pump chamber surface was not within acceptable criteria
  - Pre-swirl occurred at the pump suction was not within allowable swirl angle, 5°

Conclusion

- Modified remedial test results with anti-vortex device to eliminate submerged vortices with pre-swirl flow are ;
  - No submerged vortex was observed from the side and bottom wall
  - Pre-swirl angle at the inlet of pump suction was within acceptable limit

밟 odified remedial test demonstrated the 밟뱰 hape of splitter device was in effective of elimination of sub-vortex and swirl at the pump suction "

감사합니다!