CHAPTER 239

Plane Design of "SPAC"; Countermeasure against Seabed Scour due to Submerged Discharge and Large Waves

Takao Shimizu[1], Masaaki Ikeno[1], Hisayoshi Ujiie[2] and Kazuaki Yamauchi[3]

Abstract

Discussion is carried out on stability of submerged outlet structures of thermal power plants sited on sandy ocean beaches. The authors conceived the new scouring protection "SPAC" constructed by riprapping of the seabed just in front of the outlet. In this study, the authors investigated the plane design of the SPAC by means of 1/25 scale physical model. First of all, properties of seabed scour due to submerged discharge and monochromatic or multi-directional waves were examined. Secondly, the spreading process of the SPAC was investigated , and the necessary width of the SPAC was evaluated based on width of discharged current, and on the drift of discharged current effected by longshore current due to oblique incidence of waves. Finally, the physical model was verified by comparison with field data.

Introduction

In front of an outlet of a power plant sited on a sandy open beach, seabed scour due to submerged discharge and large waves causes instability of coastal structures

[1]Research Engineer, Central Research Institute of Electric Power Industry, Japan Society of Civil Engineers, 1646 Abiko, Abiko City, Japan 270-11

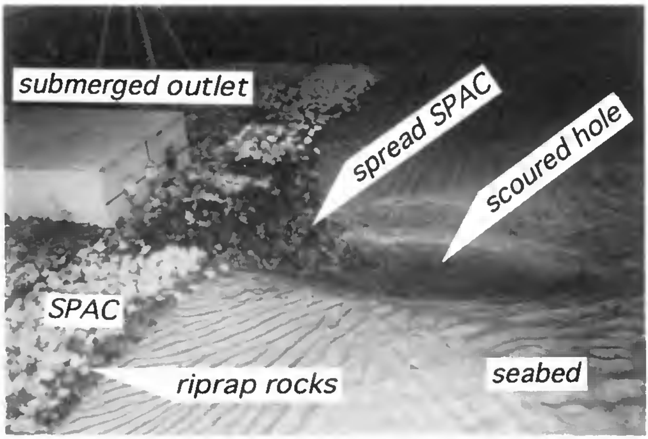
[2]Manager, Tohoku Electric Co., Ltd., Japan Society of Civil Engineers, 7-2-1 Nakayama, Aobaku, Sendai City, Japan 981

[3]Research Engineer, Tohoku Electric Co., Ltd., Japan Society of Civil Engineers, 7-2-1 Nakayama, Aobaku, Sendai City, Japan 981

such as discharge outlets.

Shimizu et al.(1991) proposed a new countermeasure called "SPAC"(Spreading Armor Coat). The SPAC is constructed by replacing seabed sand in front of an outlet with riprap rocks. During the seabed scouring due to current and waves, riprap rocks spread on the slope of the scoured hole forming an armor coat as shown in Poto 1. The SPAC thus protects the base of the outlet structure.

The process of cross sectional design of the SPAC shown in Fig.1 is as follows,(Shimizu et al.,1993).



Photograph 1. SPAC; Spreading Armor Coat

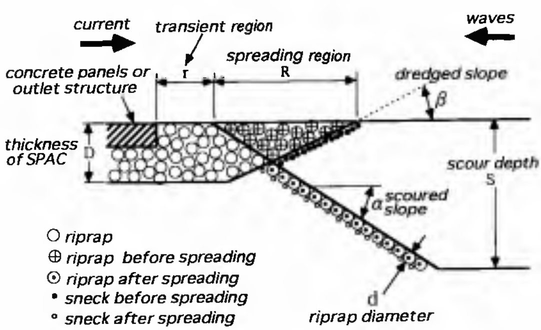


Figure 1. Cross Section of SPAC

1) Riprap diameter d is determined by the following equation,(Hasegawa,1993) that gives riprap weight W that is stable against waves.

$$W=\gamma_r U_b^6 g^{-3} F_{rc}^{-6}(s_r-1)^{-3} \tag{1}$$

where γ_r and s_r are respectively weight per unit volume and specific gravity of riprap rocks, U_b is bottom velocity, g is gravity accelaration. The value of the experimental constant F_{rc} is equal to 1.42.

2) Scour depth S is evaluated by the numerical simulation model,(Ushijima et al.,1992), not by a physical model experiment including scale effect.

3) Length R of the spreading region of SPAC is given by the following equations assuming that SPAC spreads as a single layer armor coat.

if $S \leqq 0.5\delta\lambda^{-1}D^2d^{-1}+D$,

$$R=(\lambda^2d^2+2\delta\lambda Sd)^{0.5}-\lambda d \tag{2}$$

if $S > 0.5\delta\lambda^{-1}D^2d^{-1}+D$,

$$R=0.5\delta D+\lambda dD^{-1}(S-D) \tag{3}$$

where D is the thickness of the SPAC, $\delta=\cot\alpha+\cot\beta$, $\lambda=\mathrm{cosec}\,\alpha$, α is the angle of repose of the scoured slope, β is the dredged slope angle. The value of α was equal to 20 degree according to the experimental results.

4) Snecks should be inserted under the front edge of the SPAC in order to prevent sands from being sucked out through the void of riprap rocks after spreading. For the size of sneck, 1/3 of riprap diameter is recomended. For the amount of snecks, 15% of the riprap rocks of the spreading region is recomended.

In 1992, a SPAC works was carried out at Noshiro Power Station (Tohoku Electric Power Co.) facing the Japan Sea. In this study, the plane design of the SPAC is investigated to rationalize this countermeasure, by means of a 1/25 scale physical model simulating the sea condition in front of Noshiro Power Station.

SCHEME OF PLANE DESIGN

The process of plane design of the SPAC shown in Fig.2 is as follows.

1) Width B_f of scour is evaluated from the width of

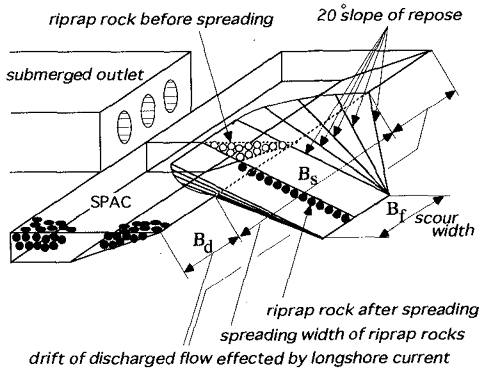


Figure 2. Definition Sketch for Plane Design Parameters of SPAC

the discharged current at the front edge of the SPAC.

2) Width B_s of the spreading region of the SPAC is evaluated from B_f.

3) Drift B_d of discharged current is evaluated from the velocity of longshore current due to oblique wave incidence.

4) The required width B of the SPAC is evaluated from B_s and B_d.

PHYSICAL MODEL EXPERIMENTS

In the multi-directional wave basin shown in Fig.3, we made seabed model with a 0.3m water depth, a sea-wall model covered with model armor units, a submerged outlet model consisting of three assembled pipes, and a discharge channel model.

Experimental cases and conditions are shown in Table 1. In the cases A1,A2 and A3, we compared the process of seabed scour due to submerged discharge alone, discharged flow plus multi-directional waves, and discharged flow plus the highest one-tenth monochromatic waves. In the cases B1 and B2, we colored and numbered some of the riprap rocks in both cases, short SPAC($R+r$ is small) and long SPAC($R+r$ is large), and tracked the spreading process of the rocks. The riprap diameter was 3cm. In the cases C1 and C2, we investigated the drift of the discharged flow effected by the longshore current due to oblique wave incidence. Finally, in the cases D1 and D2, an attempt was made to verify this experimental result by field data.

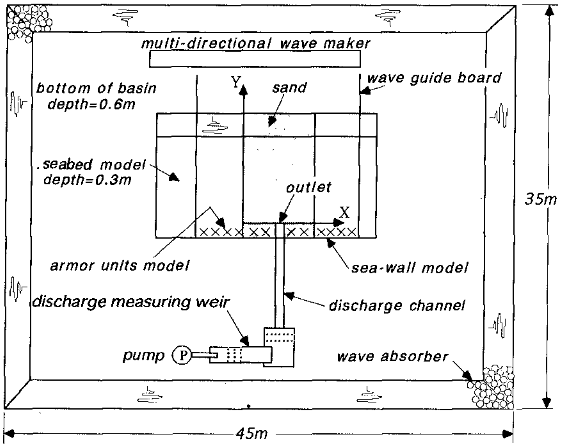


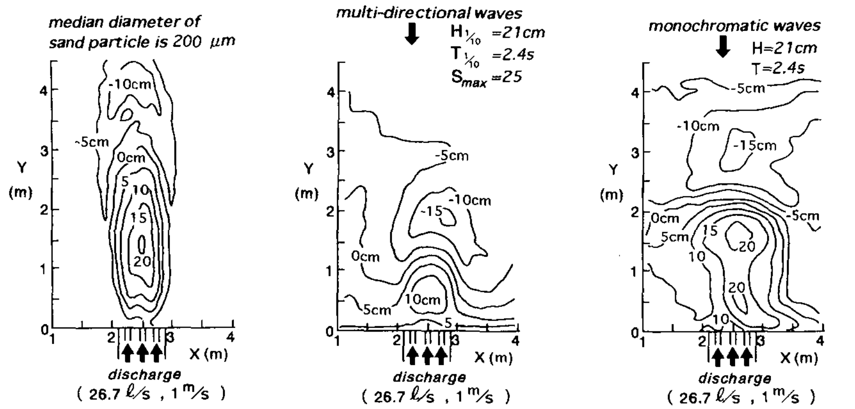
Figure 3. Arrangement of Physical Model Experiment

Table 1. Experimental Cases and Conditions

Case	Seabed	Discharge	Waves
A1	flat sand bed grain size is 0.2mm	3 pipes ϕ =10.7cm velocity is 1m/s	no wave
A2	ditto	ditto	multi-directional waves H1/3=16.5cm H1/10=21cm T1/3=2.4s
A3	ditto	ditto	monochromatic waves H=21cm T=2.4s
B1	flat sand bed protected by SPAC R+r=60cm	ditto	ditto
B2	ditto except R+r=150cm	ditto	ditto
C1	1/50 slope solid bed	ditto	oblique incident monochromatic waves H=22.1cm T=2s offshore wave angle is 30°
C2	ditto	ditto	ditto except H=28.4cm
D1	model of Noshiro P.S.	ditto except single pipe	multi-directional waves H1/3=16cm T1/3=2s
D2	ditto	ditto	ditto except no wave in first 80hr.

PROPERTY OF SCOUR DUE TO CURRENT AND WAVES

Fig.4 shows the seabed scour due to submerged discharge and waves in the cases A1, A2 and A3. The scoured hole due to discharge alone is longer along the line of discharged flow, and the maximum scour depth appears farther from the outlet than in other cases. The scoured hole due to discharged flow plus multi-directional waves is shallower, but the maximum depth appears nearer to the outlet. The scoured hole due to discharged flow plus monochromatic waves is the deepest and this condition is the most severe with regard to the stability of the outlet structure. We therefore adopted the last condition to the design of the SPAC.



a) Scour due to discharge (Case-A1 after 16hr.)

b) Scour due to discharge and multi-directional waves (Case-A2 after 16hr.)

c) Scour due to discharge and monochromatic waves (Case-A3 after 16hr.)

Figure 4. Seabed Scour due to Submerged Discharge and Waves

SPREADING WIDTH OF "SPAC"

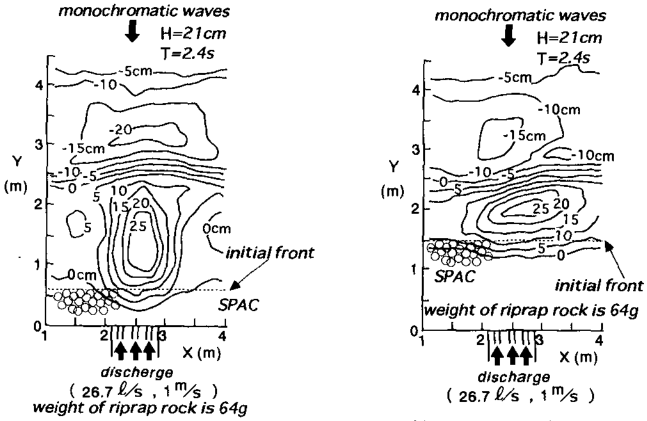
Fig.5 shows the seabed scour in front of the SPAC in the cases B1 and B2. The foot of the outlet structure was successfully protected in both cases.

Fig.6 shows the spread profile of the SPAC in the cases B1 and B2. The spread profiles are well predicted by the previously mentioned equations (2) and (3), except that the predicted lengths of the spreading region of the SPAC are slightly longer than the experimental results.

Fig.7 shows the velocity distribution and half-value width of velocity ofdischarged current flowing against waves propagation in the early stage of Case A3. If the width of discharged current is represented by half-value width, it also represents almost 1/8-value width of sand transport rate distribution, because the sand transport rate is approximately proportional to the cube of the flow velocity. So, it was decided that half-value width B_f adequately represents the scour width.

Fig 8 shows the relationship between half-value width of discharged current velocity and offshore distance from the outlet in the case A3. The half-value width of discharged current is almost linearly proportional to the distance from the outlet.

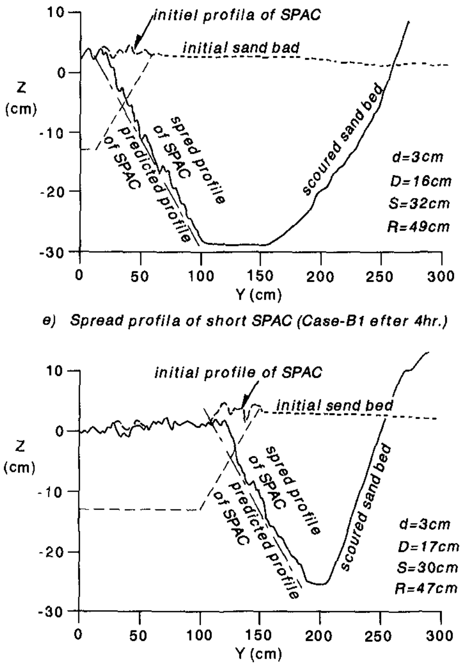
Fig.9 shows the spread pattern of the SPAC for cases B1 and B2. The open circle at the end of the pin shaped mark shows the final position of spreading rock, and the other end shows the initial position of the rock. The closed circle shows unspresd rock. The riprap rocks spreaded toward the center of the scoured hole, that is, the toe of the spreading SPAC. The spreading area of riprap rocks is perfectly covered by a spreading slope of half-value width B_f at the center part and a pair of fan shaped transient slopes at both ends. Width B_s of the spreading region of SPAC is the distance between both intersections of the fans and the initial front end of the SPAC.



a) Protection by short SPAC (Case-B1 after 4hr.)

b) Protection by long SPAC (Case-B2 after 8hr.)

Figure 5. Protection by the SPAC and Seabed Scours in front of the SPAC



e) Spread profila of short SPAC (Case-B1 efter 4hr.)

b) Spraad profile of long SPAC (Casa-B2 after 8hr.)

Figure 6. Spread Profile of SPAC

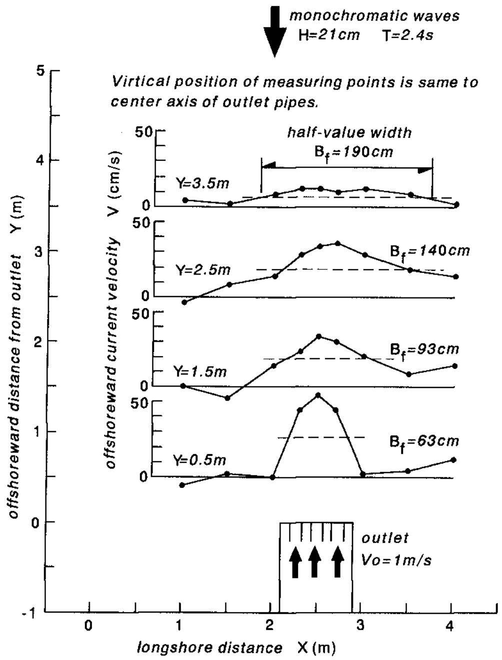


Figure 7. Velocity Distribution of Discharged Current Flowing against Wave Propagation

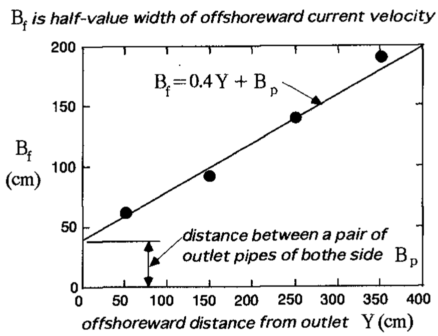
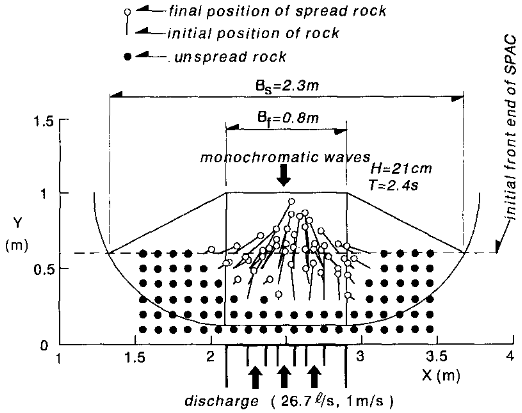
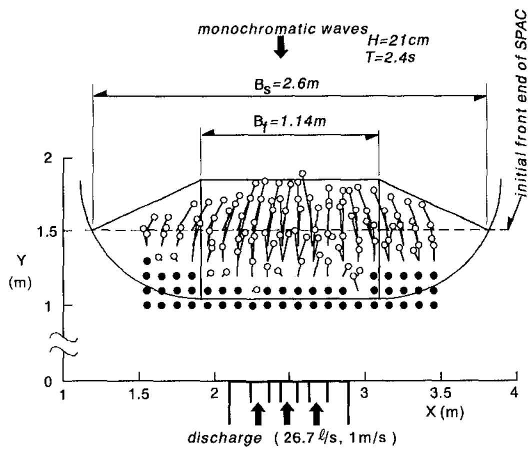


Figure 8. Half-value Width of Offshoreward Current Velocity



a) Spread pattern of short SPAC (Case-B1 after 4hr.)



b) Spread pattern of long SPAC (Case-B2 after 8hr.)

Figure 9. Spread Pattern of SPAC

DRIFT OF DISCHARGED CURRENT

Fig.10 shows cross-shore distribution of longshore current velocity due to obliquely incident waves for cases C1 and C2, without discharge from the outlet. U on the vertical axis shows longshore current velocity normalized by analytical velocity U_{b0} at the breaking point, neglecting horizontal eddy viscosity. Closed triangles indicate longshore current velocity in front of reclaimed land in the experiment. Y' on the horizontal axis shows offshore distance from virtual shoreline under the condition of no reclaimed land. Smooth curves show velocity distribution of longshore current along a uniform slope beach after Kraus and Sasaki(1979). Longshore current velocity just in front of the seawall of the reclaimed land is nearly equal to or less than the velocity of longshore current along the beach.

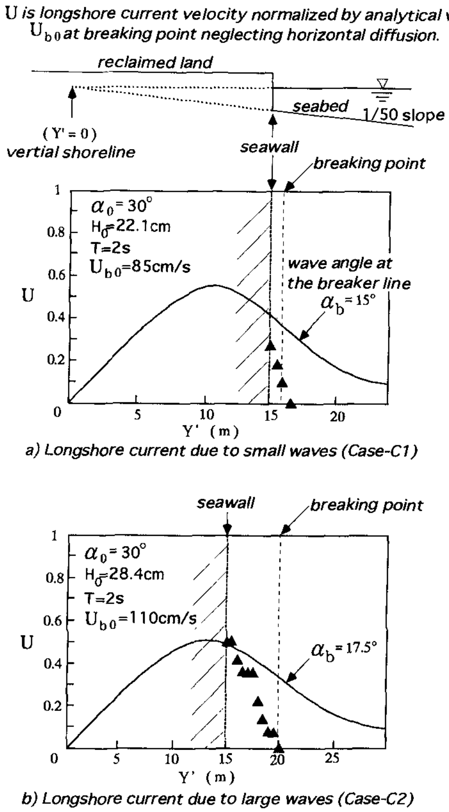


Figure 10. Longshore Current due to Oblique Incident Waves in front of Reclaimed Land

Fig.11 shows the drift of discharged current effected by longshore current for case C2. Vectors are flow velocity in the experiment. The curve from the outlet to the right is the trajectory of discharged current calculated by the following equation,(Katano et al.,1976).

$$(B_d / B_p) = 0.26 \, (u / V_0)^3 \, (Y / B_p)^4 \tag{4}$$

where B_d is the drift of discharged current, B_p is the width of the outlet, u is the longshore current velocity, V_0 is the discharged velocity, and Y is the offshore distance from the outlet. The drift of discharged flow was well traced by the above equation.

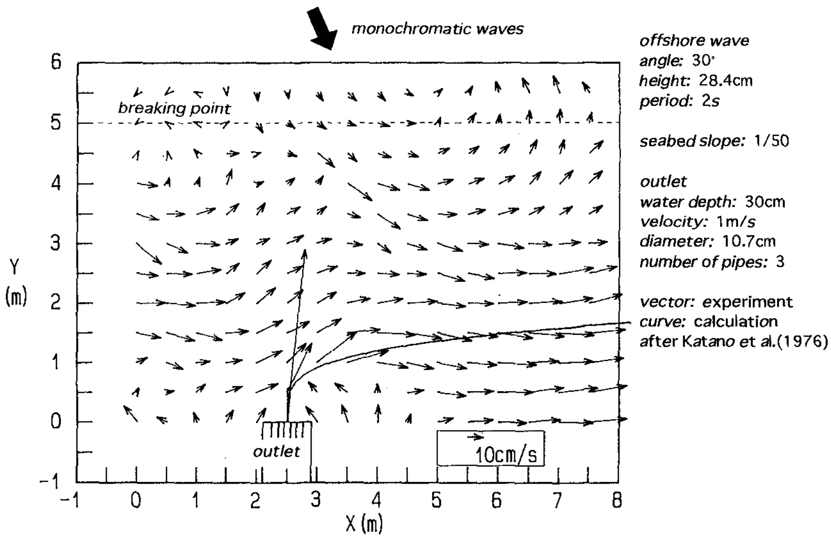


Figure 11. Drift of Discharged Flow Effected by Longshore Current

VERIFICATION by FIELD DATA

Fig.12 shows the field data of waves and warmed water discharge observed at Noshiro Power Station from July 1992 to May 1993. In this period, the unit No.1 of the power plant was under trial running. We adopted a 4m height and 10s period significant wave, and 27.8m^3/s discharge as the experimental condition for comparison with the field data.

Fig.13 shows the comparison between field scour and simulated scour on 1/25 scale model in the cases D1 and D2. Maximum scour depth 125cm in the field was well simulated as 5cm scour depth in each case of the 1/25 scale models. Scour width in the field was also well simulated in the case D1. The on-offshore length of the scoured hole in the model was smaller than for the field scour. A model scour occurs nearer the outlet structure than for the field scour.

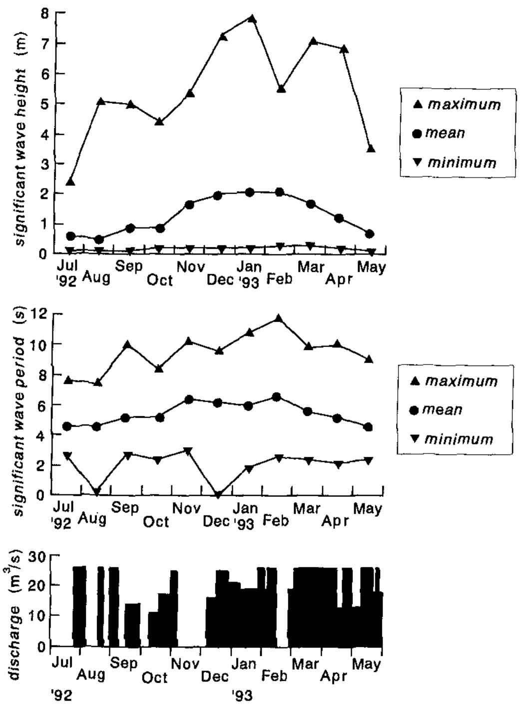


Figure 12. Field Data of Waves and Thermal Discharge Observed at Noshiro Power Station

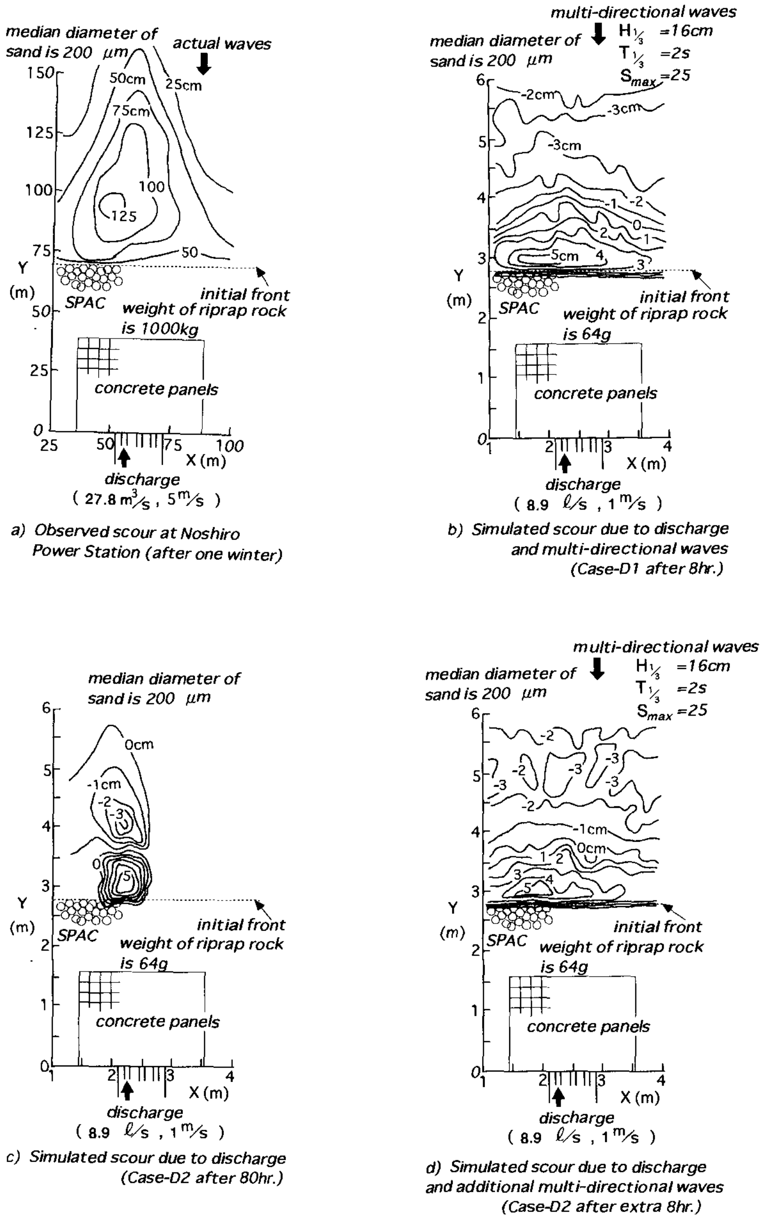


Figure 13. Comparison between Field Scour and Simulated Scours in 1/25 Scale Physical Model

CONCLUSIONS

(1) The SPAC design is sufficiently safe for the condition of discharged flow and highest one-tenth monochromatic waves.

(2) The width of the SPAC can be determined by both the spreading width of riprap rocks and the drift of discharged flow effected by a longshore current.

(3) The spreading width of the riprap rocks can be determined by assuming a scouring width as the half-value width of the discharged current velocity distribution, and by turning the 20 degree slope around toes at both ridges.

(4) The drift of the discharged flow effected by a longshore current is determined by using a formula based on a longshore current distribution caused by oblique incident waves, and by using a trajectory formula of jet injected into the current orthogonally.

(5) It was verified by the field data that the design method of the SPAC based on the physical model was within the safety margins required for the stability of the outlet structure.

REFERENCES

Hasegawa,H.(1993): Demonstration study of artificial beach formation technology using SEASUP concrete revetment with a gentle slope, *Report of Central Research Institute of Electric Power Industry*, No.U93033, p.66(in Japanese).

Kraus,N.C. and T.Sasaki(1979): Effects of wave angle and lateral mixing on the longshore current, *Coastal Engineering in Japan*, Vol.22, pp.59-74.

Shimizu,T., A.Sasaki and H.Ujiie (1991): The new countermeasure SPAC against seabed scour due to submerged discharge and large waves, *Proc. of Civil Eng. in the Ocean*, Vol.7, pp.301-306 (in Japanese).

Shimizu,T., M.Ikeno, H.Ujiie and A.Sasaki (1993): Using "SPAC" artificial armor coat to protect seabed against scour due to submerged discharge and large waves, *Proc. of XXV Cong. of Int. Asso. for Hydraulic Res.*, Vol.IV, pp.151-158.

Ushijima,S., T.Shimizu, A.Sasaki and Y.Takizawa (1992): Prediction method for local scour by warmed cooling-water jets, *Journal of Hydraulic Eng.*, Vol. 118, No.8 , pp. 1164-1183.