ASSESMENT of ESTIMATION MODELS for SCOUR AROUND PIPELINES under IRREGULAR WAVES

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This study focuses on scour around submarine pipelines exposed to normal-incidence irregular waves over a live bed in shoaling region. The Artificial Neural Network (ANN) method was applied. The models of this study were compared to those of Kızıloz et al. (2013) who used multiple regression analysis method. Two wave characteristic pairs $H_s - T_m$ and $H_{rms} - T_p$ identify the sea state of irregular wave train as the representative wave parameter pairs of parametric model for scour process. Because these pairs result the same scour depth as regular waves do. The best ANN models for regular and irregular waves were obtained with H_{s0}–T_{m0}–d–D or H_{s0}–L_{m0}–d–D input parameters considering deep water wave parameters and H_s–T_m–d–D or H_s–L_m–T_m–D input parameters considering local wave parameters. The mean wave period, T_m, and the significant wave height, H_s, representing the irregular waves are more compatible with the wave period and wave height of regular waves, respectively.

Keywords: pipelines; scour; modelling; Artificial Neural Network

INTRODUCTION

Pipelines are used for transporting liquids and gases such as fuel oil, natural gas, biofuels, water, waste water, slurry water, chemically stable substances. Pipelines on sandy seabeds in the coastal zone are exposed to waves under shoaling conditions. The interaction between pipelines, erodible bed and water flow causes scour around the submarine pipelines and the scour may influence their stability. The local scour around these structures may cause spanning hence damages to the pipelines.

The assessment of scour below pipelines is essential in design of marine pipelines and for the protection against scour. The process of scour around pipelines laid on mobile beds is complicated due to the physical processes arising from the triple action of waves/currents, beds and pipelines.

The scour develops in three stages: The onset of scour is related to the seepage flow in the sand beneath the pipeline, which is driven by the pressure difference between the upstream and downstream sides of the pipe. Piping occurs when this flow exceeds a critical limit, ejecting sediment and water downstream of the pipeline. The onset of scour is followed by the stage called tunnel erosion. During this stage, a substantial amount of water is diverted to the gap, leading to very large velocities in the gap and presumably resulting in very large shear stress on the bed just below the pipeline. The large increase in the bed shear stress below the pipe results in a tremendous increase in the sediment transport. This stage is followed by lee –wake erosion (Sumer and Fredsøe, 2002).

Flow around pipelines in a steady current and under waves has been investigated extensively in the past few decades. Some of these studies are; Chao and Hennesy (1972), Kjeldsen et al. (1973), Bijker and Leeuweistein (1984), İbrahim and Nalluri (1986), Mao (1986), Sumer and Fredsøe (1990), Sumer and Fredsøe, (1996), Klomp et al. (1996), Cevik and Yuksel (1999), Mousaviet et al. (2009), Yasa (2011) and Kızıloz et al. (2013). Numerical methods and other computing tools have been developed to simulate scour around submarine pipelines by Liang and Cheng (2005a), Liang and Cheng (2005b).

EXPERIMENTAL STUDY AND DISCUSSION

In this study, scour around submarine pipelines over a live bed in shoaling region exposed to normal-incidence irregular waves were studied both experimentally and by using the ANN method.

The data used in this study was obtained from an experimental study. It was evaluated together with the regular wave data of Cevik and Yuksel's (1999) study. The tests were carried out in a 1 m deep, 1 m wide and 20 m long wave flume at the Hydraulic and Coastal-Harbor Engineering Laboratory of Yildiz Technical University. The experiments were conducted under irregular wave conditions. The beach was modeled with a 1/10 steel ramp with 25 cm sand on top. Rigid model pipes with diameters D=32.3, 49, 77 and 114 mm were made of steel and placed 35 cm on horizontal seabed and 31 cm and 23cm on 1/10 sloping bed. The pipelines were exposed to normal incidence waves. 96 random wave tests were carried out during experimental study. The incident wave spectrum used in the experiments was Bretschneider spectrum model. Both deep water and local wave parameters were employed during evaluations. The test parameters for regular and irregular waves used during evaluations are shown in Fig. 1. and Fig. 2., respectively. The test parameter ranges of this study and those of Cevik and Yuksel's (1999) study are shown in Table 1.

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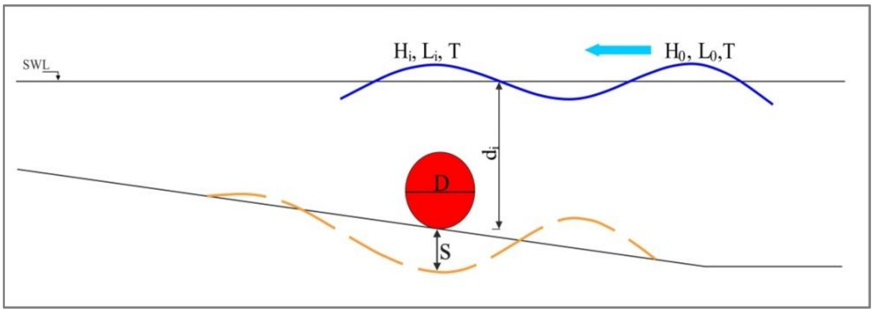


Figure 1. Schematic description of test parameters for regular waves.

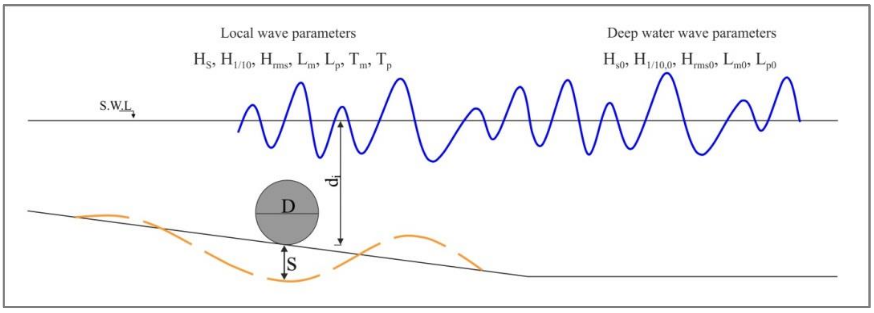


Figure 2. Schematic description of test parameters for irregular waves.

Table 1. Test parameters ranges.

Condition	Parameters		Range involved
Regular wave attack (Cevik and Yuksel, 1999)	H	Wave height	6.7–16.5 cm
	T	Wave period	0.9–2.64 s
	L	Wave length	120–497 cm
	S	Scour depth	0.40–3.85 cm
Irregular wave attack (Kızılöz et al., 2013)	H_s	Significant wave height	4.71–11.43cm
	T_p	Peak period	1.14–2.67 s
	L_p	Wave length (depending on T_p)	151–498. cm
	S	Scour depth	0.15–2.10 cm
	d	Water depth	23–35 cm
	D	Pipe diameter	3.23–11.40 cm

Relative Scour Depth in Regular and Irregular Wave Attack

Cevik and Yuksel (1999) stated an expression using their test results for the equilibrium scour depth of horizontal submarine pipelines in shoaling region for both sloping region (1/5 and 1/10) and horizontal bed exposed to regular waves.

$$\frac{S}{D} = 0.042 U_{RP}^{0.41} \tag{1}$$

where U_{RP} is the modified Ursell parameter which was obtained by the Ursell parameter (U_R) and the relative wave height (H/D):

$$U_{RP} = \left(\frac{HL^2}{d^3}\right)\left(\frac{H}{D}\right)^2 = \frac{H^3L^2}{d^3D^2} \tag{2}$$

Kızıloz et al. (2013) carried out a similar study to that of Cevik and Yuksel's (1999) except wave types. In Kızıloz et al. (2013)' study, irregular waves were used instead of regular waves. They developed models using multiple regression analysis to predict the scour depth under pipelines under the influence of irregular wave attack.

Irregular wave storms can be expressed by many representative wave parameters. The representative wave parameter pairs (H–T) of the irregular wave field considered in their study were (H_s –T_m), (H_s –T_p), ($H_{1/10}$ –T_m), ($H_{1/10}$ –T_p), (H_{rms} –T_m), (H_{rms} –T_p). They developed six different equations for all these pairs. All of the models predicted the dimensionless scour depth with a high degree of correlation as seen in Table 2. These models gave the same result for the scour depth below pipelines exposed to irregular waves. The general form of the scour depth equations is shown below:

$$\frac{S}{D} = aU^{b}_{RP} \qquad (3)$$

Table 2. Coefficients (a) and powers (b) of the modified Ursell parameters for different representative wave characteristic pairs (Kızıloz et al., 2013).

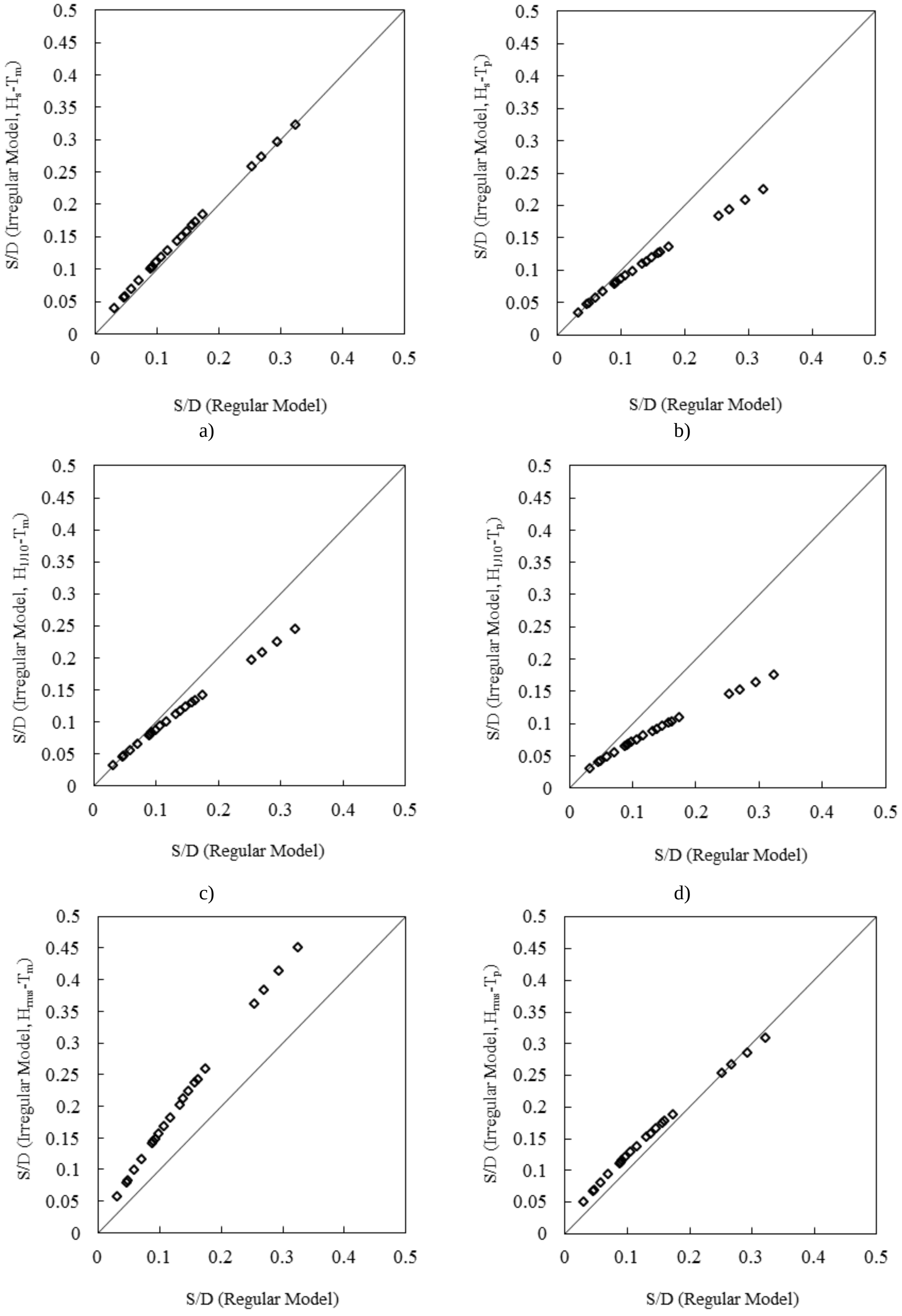
Model number	Model variables	aU_{RB}^{b}		R
		a	b	
1	H_{rms}, T_p, d, D	0.069	0.299	0.96
2	H_s, T_p, d, D	0.049	0.302	0.96
3	$H_{1/10}$, T_p, d, D	0.041	0.289	0.96
4	H_{rms}, T_m, d, D	0.083	0.336	0.95
5	H_s, T_m, d, D	0.058	0.341	0.95
6	$H_{1/10}$, T_m, d, D	0.047	0.327	0.95

The representative wave parameters that characterize the irregular sea state causing the same scour depth as regular wave attack were determined. So, both the irregular wave and regular wave (Cevik and Yuksel, 1999) tests were assessed together. Here the key issue was how to choose wave parameters characterizing the sea state of irregular wave attack that causes the same scour depth as the regular waves do. Therefore, the relative scour depth (S/D) was computed from the relative scour depth equation for regular waves (Eq. 1) for the chosen parameters such as water depth (d), pipe diameter (D), wave period (T) and wave height (H). Similarly the relative scour depths (S/D) for these parameters were calculated by using the equations for irregular waves given in Table 2 one by one. Computed relative scour depths (S/D) by each different representative wave parameter pairs was plotted against the relative scour depths of regular waves (Fig. 3). Two wave characteristic pairs H_s –T_m (Fig. 3a) and H_{rms} –T_p (Fig. 3f) identify the sea state of irregular wave train as the representative wave parameter pairs for scour process.

$$\frac{S}{D} = 0.055\left(\frac{H_s^3 L_m^2}{d^3 D^2}\right)^{0.353} = 0.055U_{RP}^{0.353} \qquad (4)$$

$$\frac{S}{D} = 0.062\left(\frac{H_{rms}^3 L_p^2}{d^3 D^2}\right)^{0.328} = 0.062U_{RP}^{0.328} \qquad (5)$$

Figs. 4 and 5 show the variation of the relative scour depth with respect to the modified Ursell parameter for both regular and irregular wave data by H_s and T_p and H_{rms} T_p pairs, respectively.



a) b) c) d) e) f)

Figure 3. The regular wave model versus irregular wave model of different characteristic wave parameter pairs of irregular wave trains (H-T), Kızıloz et al. (2013).

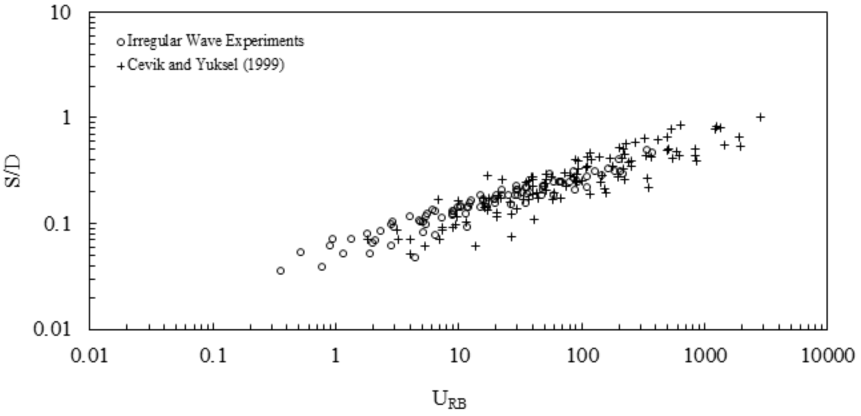


Figure 4. Relative scour depth versus modified Ursell parameter (H_s –T_m) (Kızıloz et al., 2013).

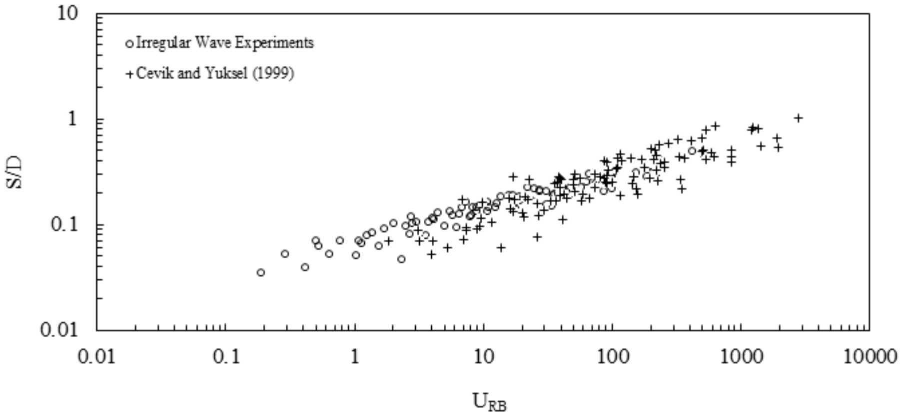


Figure 5. Relative scour depth versus modified Ursell parameter (H_{rms} –T_p) (Kızıloz et al., 2013).

Relative Scour Depth with Artificial Neural Network

The models were developed by using Feed Forward Back Propagation Artificial Neural Network technique. A three-layer feed forward back propagation network with the sigmoid transfer function in the hidden layer and a linear transfer function in the output layer were selected for all models in this study. The experimental data were used for training, validation and testing. All the data used to predict the scour depth under the pipeline for both regular and irregular waves were taken into account together for both a horizontal bottom and a 1/10 sloping bed. A total of 206 data were used; 55% of the total data was allocated for training (113 data), 35% for validation (72 data) and 10% for testing (21 data). Data were divided randomly, and the same training, validation and test data were used for each model run.

To construct the best model, different individual input variables and combinations of the input variables and the resulting output (scour depth, S) have been run to obtain the performance parameters such as maximum correlation coefficient R, the minimum root mean square error RMSE (calculated as the square root of MSE), the minimum scatter index SI, and the bias for all validation data sets in the ANN models.

ANN models with neurons in the input layer (wave height, H, wave period, T, wave length, L, water depth, and d pipe diameter, D) different numbers of neurons (from 1 to 5) in the hidden layer and one neuron (S) in the output layer were trained to obtain the best model.

Effects of each parameter and double, triple and quadruple combinations of them on the scour depth have been investigated. Many models were developed by the ANN method to obtain the best predicted model with maximum accuracy. Alternative models with different inputs and neuron numbers were evaluated by using training and error technique. The best models were obtained with four input variables. The prediction results agree well with measurements. At an irregular sea state, the model using deep water wave parameters consists of H_{x0}–T_{p0}–d–D, and local wave parameters consists of H_x–T_p–d–D, (here subscript "x" corresponds to s, 1/10 and rms). The scatter diagrams of models using deep water wave parameters and local wave parameters versus the measurements are shown in Fig. 6 and Fig. 7, respectively. All models obtained in this study have small error and high correlation coefficient and are not biased in the prediction of S/D.

Table 3. Performance of three and four-input variables ANN models.

Models	Input parameter Condition	Model No	Input Combinations	R	RMSE	SI (%)
Three -parameter	Deep water wave parameters	3.1	$H_{rms,0}-T_{m0}-d$	0.95	0.239	16.88
		3.2	$H_{s0}–T_{m0}-d$	0.93	0.247	17.47
		3.3	$H_{1/10,0}-T_{m0}-d$	0.92	0.270	19.11
		3.4	$H_{rms,0}-L_{m0}-d$	0.93	0.239	16.88
		3.5	$H_{s0}-L_{m0}-d$	0.92	0.265	18.71
		3.6	$H_{1/10,0}-L_{m0}-d$	0.91	0.279	19.75
	Local wave parameters	3.7	$H_{1/10}-T_m-d$	0.95	0.243	17.18
		3.8	H_s-T_m-d	0.94	0.245	17.32
		3.9	$H_{rms}-T_m-d$	0.93	0.259	18.31
		3.10	$H_{1/10}-L_m-d$	0.93	0.281	19.88
		3.11	H_s-L_m-d	0.92	0.266	18.84
		3.12	$H_{rms}-L_m-d$	0.90	0.290	20.50
		3.13	$H_{rms}-L_m-D$	0.90	0.293	20.74
		3.14	H_s-L_m-D	0.90	0.318	22.48
		3.15	$H_{1/10}-L_m-D$	0.86	0.319	22.59
Four -parameter	Deep water wave parameters	4.1	$H_{so}-T_m-d-D$	0.95	0.221	15.65
		4.2	$H_{rms,0}-T_m-d-D$	0.93	0.232	16.43
		4.3	$H_{1/10,0}-T_m-d-D$	0.92	0.266	18.84
		4.4	$H_{s0}-L_{m0}-T_m-D$	0.91	0.247	17.47
		4.5	$H_{1/10,0}-L_{m0}-T_m-D$	0.91	0.281	19.88
		4.6	$H_{rms,0}-L_{m0}-T_m-D$	0.90	0.283	20.00
		4.9	$H_{s0}-L_{m0}-d-D$	0.95	0.230	16.28
		4.10	$H_{rms,0}-L_{m0}-d-D$	0.92	0.259	18.31
		4.11	$H_{1/10,0}-L_{m0}-d-D$	0.89	0.293	20.74
	Local wave parameters	4.12	H_s-T_m-d-D	0.96	0.245	17.32
		4.13	$H_{1/10}-T_m-d-D$	0.95	0.243	17.18
		4.14	$H_{rms}-T_m-d-D$	0.93	0.245	17.32
		4.15	$H_{rms}-T_p-d-D$	0.91	0.268	18.98
		4.16	$H_s-L_m-T_m-D$	0.96	0.251	17.75
		4.17	$H_{rms}-L_m-T_m-D$	0.95	0.245	17.32
		4.18	$H_{1/10}-L_m-T_m-D$	0.93	0.251	17.75
		4.19	$H_{rms}-L_p-T_p-D$	0.94	0.255	18.03

Table 4. Limits of R and RMSE of all regular/irregular wave models.

Models	Limits of Correlation Coefficient (R)	Limits of RMSE
One-parameter	$0.63 \leq R \leq 0.86$	$0.310 \leq RMSE \leq 0.485$
Two-parameter	$0.85 \leq R \leq 0.92$	$0.268 \leq RMSE \leq 0.345$
Three-parameter	$0.86 \leq R \leq 0.95$	$0.239 \leq RMSE \leq 0.319$
Four-parameter	$0.89 \leq R \leq 0.96$	$0.221 \leq RMSE \leq 0.293$

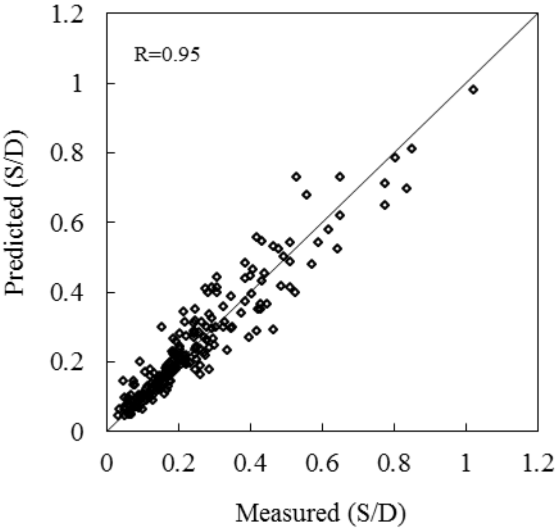


Figure 6. Scatter plot of measured and predicted (S/D) from Model 4.1 by using deep water wave characteristics.

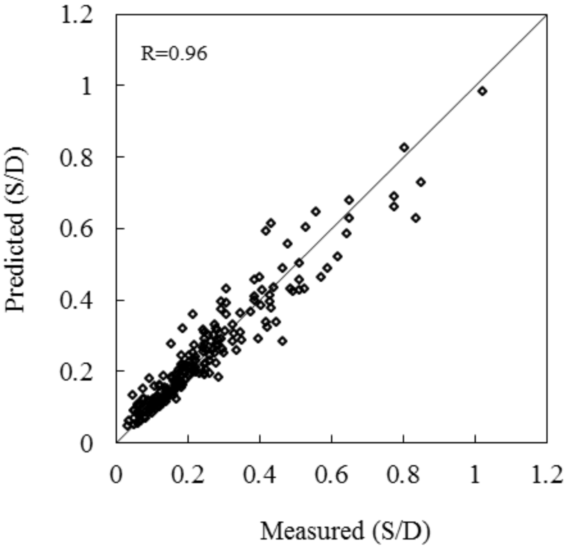


Figure 7. Scatter plot of measured and predicted (S/D) from Model 4.12 by using local wave characteristics.

CONCLUSIONS

Overall results for parametric models show that using T_m gives better results than T_p as an input parameter. All the characteristic wave height parameters yield the same accurate prediction of irregular sea state. Two wave characteristic pairs H_s $–T_m$ and H_{rms} $–T_p$ identify the sea state of irregular wave train as the representative wave parameter pairs for scour process. Because these pairs result the same scour depth as regular waves do.

The ANN model using deep water wave parameters consists of four input variables as $H_{x0}–T_{p0}–d–D$ and the model using local wave parameters consists of four input variables as $H_x–T_p–d–D$ for scour around submarine pipelines exposed to normal-incidence irregular sea state;

The best ANN models for regular and irregular waves were obtained with $H_{s0}–T_{m0}–d–D$ or $H_{s0}–L_{m0}–d–D$ input parameters considering deep water wave parameters and $H_s–T_m–d–D$ or $H_s–L_m–T_m–D$ input parameters considering local wave parameters. The mean wave period, T_m, and the significant wave height, H_s, representing the irregular waves are more compatible with the wave period and wave height of regular waves, respectively.

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