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TIME DEVELOPMENT OF LOCAL SCOUR DEPTH BELOW PIPELINES EXPOSED TO WAVES

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AIM OF THE STUDY

The aim of this study is to find an empirical formula to predict the time development of local scour below a pipeline laid on an erodible bed. This paper is a part of ongoing research projects investigating the scour below submerged pipelines due to regular waves. These projects cover the range of the following topics; equilibrium scour depth, time-dependent scour depth, time scale of scour process, scour development along the pipe, and scour protection. This poster contains only the second phase of the research mentioned above. A specific empirical relationship for computing the "Temporal Variation of Scour Depth" (Figure 1) was derived from the experimental data.

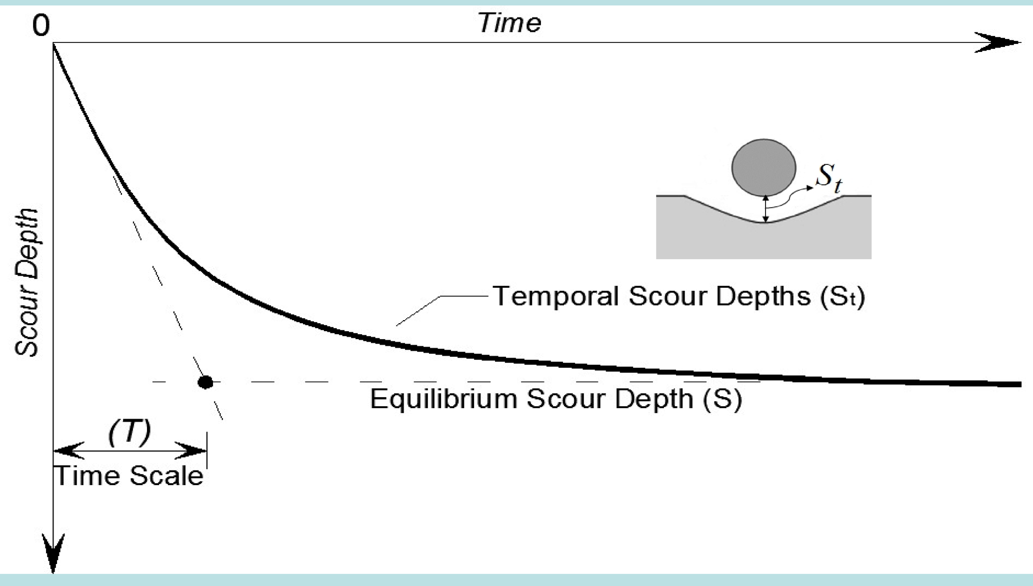

Figure 1. The variation of the scour depth with time

MATHEMATICAL BACKGROUND

The book by Sumer and Fredsøe (2002) is the most significant literature, which covers all research in this field, until its publication date. In their book, they stated that the time variation of scour depth can be represented by the following formula

$$S_t = S\left(1 - e^{-t/T}\right) \tag{1}$$

in which S_t is the time dependent scour depth, S is the equilibrium scour depth, t denotes time, and T is the "time scale" of the scour process. Sumer and Fredsøe also indicated that Keulegan-Carpenter number (KC) and Shields parameter (ϑ) are the most important governing parameters for dimensionless analysis of the time-development of local scour under the wave conditions.

$$KC = \frac{U_m T_w}{D}\ , \quad \theta = \frac{U_{fm}^{\ 2}}{g\,(s-1)\,d_{50}} \qquad (2), (3)$$

where, U_m is the maximum value of the velocity of the orbital motion of water particles at the pipe axis, T_w wave period, D pipe diameter, U_{fm} the maximum value of bed shear velocity, g acceleration due to gravity, s specific gravity of sediment grains, and d_{50} grain sizes. In the present study, an empirical relation between time dependent scour depth and KC - ϑ pair was investigated based on the experimental data.

EXPERIMENTAL SET-UP AND PROCEDURE

The experimental test program was conducted in a wave channel 33 m long, 3.6 m wide and 1.2 m deep (Figure 2). The wave channel has a plunger type wave generator at one end, and a sloping wave absorber at the other end to eliminate reflection waves. Adjustment of input wave parameters was maintained with the aid of an electronic pitch control unit. The horizontal water particle velocity in the pipe axis, time-dependent scour depths, T_w, H and U_m values were determined through an Ultrasonic Velocity Profiler (UVP) device and an Ultra Lab System (ULS), their transducers and associated software (Figure 3).

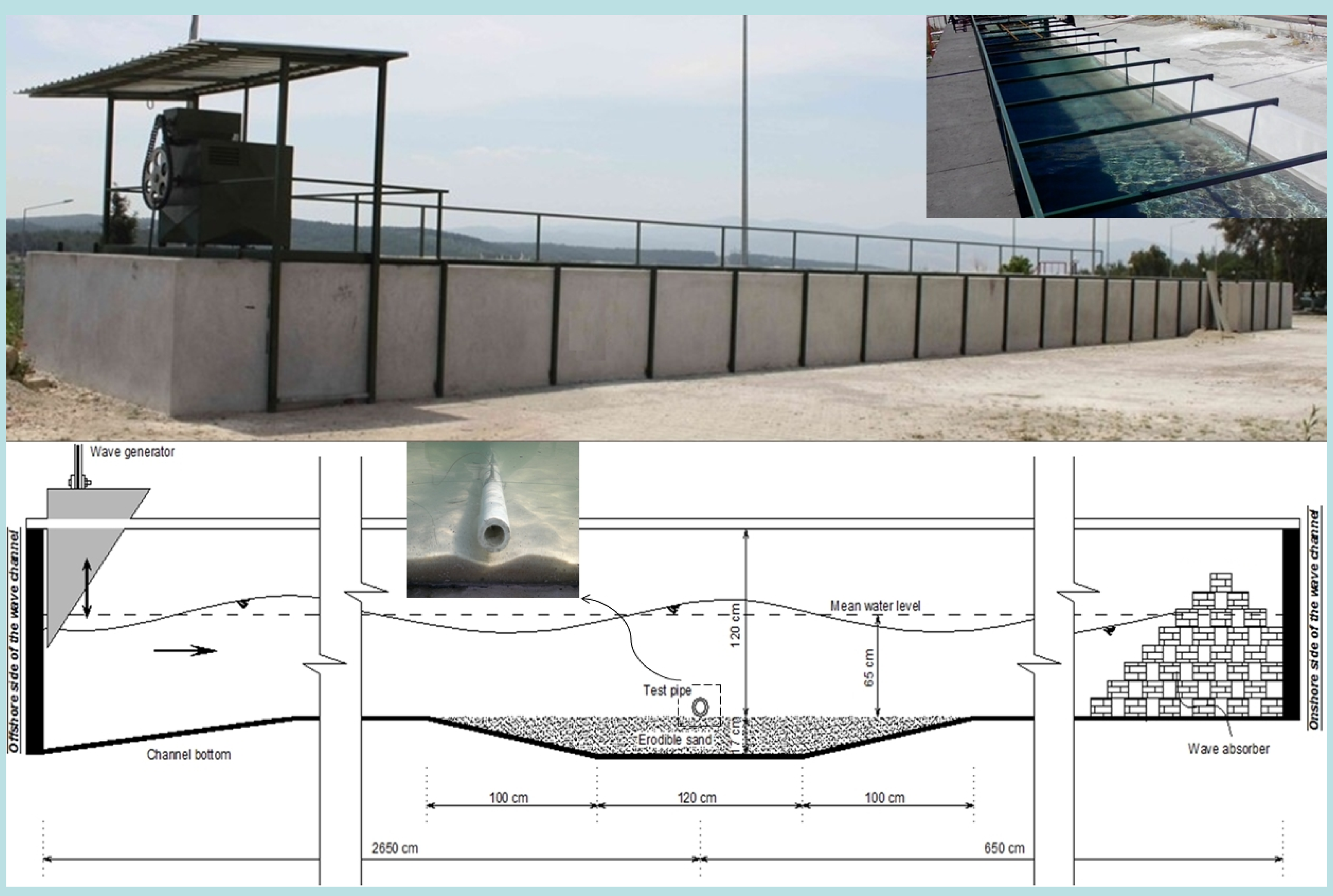

Figure 2. Pictures and schematic description of the experimental set-up

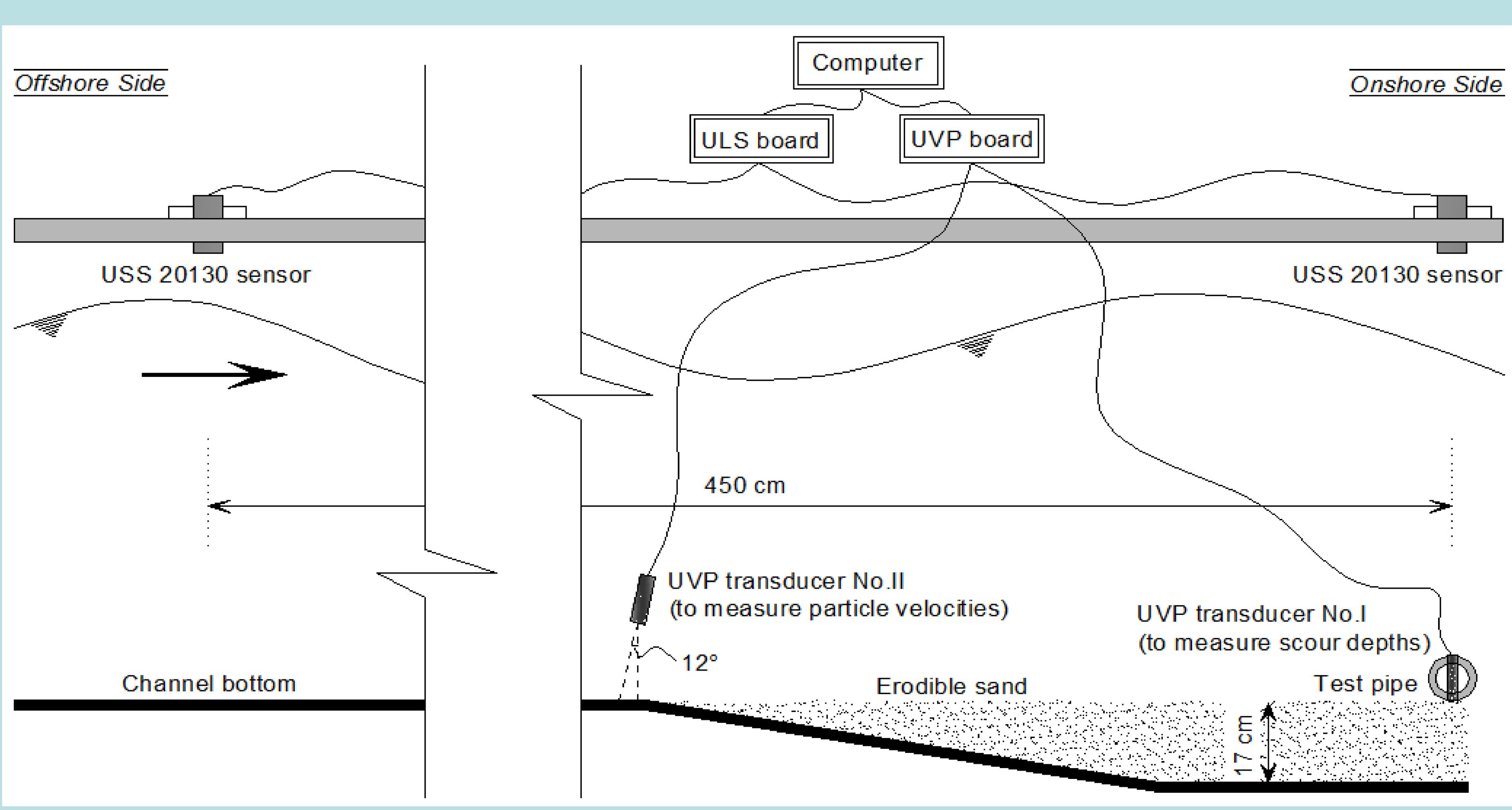

Figure 3. Position of the ultrasonic devices used in the present study

In the study, the experiments were carried out with three different grain sizes of bed materials, three different diameters of pipes and four different types of regular waves. The characteristic parameters of the experimental variables and some of the calculated data are shown in Table 1.

Table 1. The summary of the experimental data and calculated data

Experiment Number	D	d_{50}	T_w	H	U_m	a	U_{fm}	KC	Re_d	θ	θ_{cr}	Scour Regime	S
	(mm)	(mm)	(s)	(cm)	(cm/s)	(cm)	(cm/s)	---	---	---	---	---	(mm)
1	63	0.55	2.7	30	47.7	21.2	3.92	20.4	19.76	0.145	0.035	Live-bed	47.1
2	63	1.85	2.7	30	47.7	21.2	3.92	20.4	77.36	0.058	0.047	Live-bed	25.0
3	63	3.75	2.7	30	47.7	21.2	3.92	20.4	171.3	0.034	0.047	Clear-water	23.3
4	63	0.55	3.1	24	38.7	20.4	3.34	19.0	16.12	0.096	0.034	Live-bed	26.6
5	63	1.85	3.1	24	38.7	20.4	3.34	19.0	63.08	0.039	0.047	Clear-water	16.1
6	63	3.75	3.1	24	38.7	20.4	3.34	19.0	139.7	0.023	0.047	Clear-water	13.6
7	63	0.55	3.6	16	29.0	16.4	2.70	16.6	12.41	0.057	0.033	Live-bed	24.6
8	63	1.85	3.6	16	29.0	16.4	2.70	16.6	48.56	0.023	0.045	Clear-water	20.2
9	63	3.75	3.6	16	29.0	16.4	2.70	16.6	107.5	0.014	0.047	Clear-water	13.2
10	63	0.55	4.3	13	25.9	16.6	2.54	17.7	11.06	0.045	0.032	Live-bed	24.3
11	63	1.85	4.3	13	25.9	16.6	2.54	17.7	43.30	0.018	0.045	Clear-water	15.1
12	63	3.75	4.3	13	25.9	16.6	2.54	17.7	95.89	0.011	0.047	Clear-water	16.4
13	90	0.55	2.7	30	47.7	21.2	3.92	14.3	19.76	0.145	0.035	Live-bed	20.7
14	90	1.85	2.7	30	47.7	21.2	3.92	14.3	77.36	0.058	0.047	Live-bed	12.5
15	90	3.75	2.7	30	47.7	21.2	3.92	14.3	171.3	0.034	0.047	Clear-water	13.0
16	90	3.75	3.1	24	38.7	20.4	3.34	13.3	139.7	0.023	0.047	Clear-water	20.0
17	90	3.75	3.6	16	29.0	16.4	2.70	11.6	107.5	0.014	0.047	Clear-water	8.8
18	90	0.55	4.3	13	25.9	16.6	2.54	12.4	11.06	0.045	0.032	Live-bed	15.0
19	90	1.85	4.3	13	25.9	16.6	2.54	12.4	43.30	0.018	0.045	Clear-water	20.0
20	110	0.55	2.7	30	47.7	21.2	3.92	11.7	19.76	0.145	0.035	Live-bed	19.1
21	110	1.85	2.7	30	47.7	21.2	3.92	11.7	77.36	0.058	0.047	Live-bed	19.1
22	110	3.75	2.7	30	47.7	21.2	3.92	11.7	171.3	0.034	0.047	Clear-water	16.9
23	110	0.55	3.1	24	38.7	20.4	3.34	10.9	16.12	0.096	0.034	Live-bed	19.0
24	110	1.85	3.1	24	38.7	20.4	3.34	10.9	63.08	0.039	0.047	Clear-water	15.4
25	110	3.75	3.1	24	38.7	20.4	3.34	10.9	139.7	0.023	0.047	Clear-water	18.1
26	110	1.85	3.6	16	29.0	16.4	2.70	9.5	48.56	0.023	0.045	Clear-water	9.6

a = The amplitude of horizontal component of orbital motion of water particles, Re_d = Grain Reynolds number, ϑ_{cr} = The critical value of Shields parameter

RESULTS

A review of the experimental data has shown that the time development of scour depths underneath the test pipe area is coming into sight with two phases (developing and equilibrium stages), similar to the previous studies. S_t/D non-dimensional time dependent scour depth for the live-bed scour regime can be represented by least-square fit;

$$\frac{S_t}{D} = 0.0012\,KC^{2.3}\,\theta^{1/3}\left(1 - e^{-0.005\,t_s}\right) \tag{4}$$

where t_s denotes the non-dimensional time variable as it is described below,

$$t_s = \frac{\sqrt{g\,(s-1)\,d_{50}}}{D}\,t \tag{5}$$

Some actual measurements and calculated values from Eq.(4) are plotted in Figure 4.

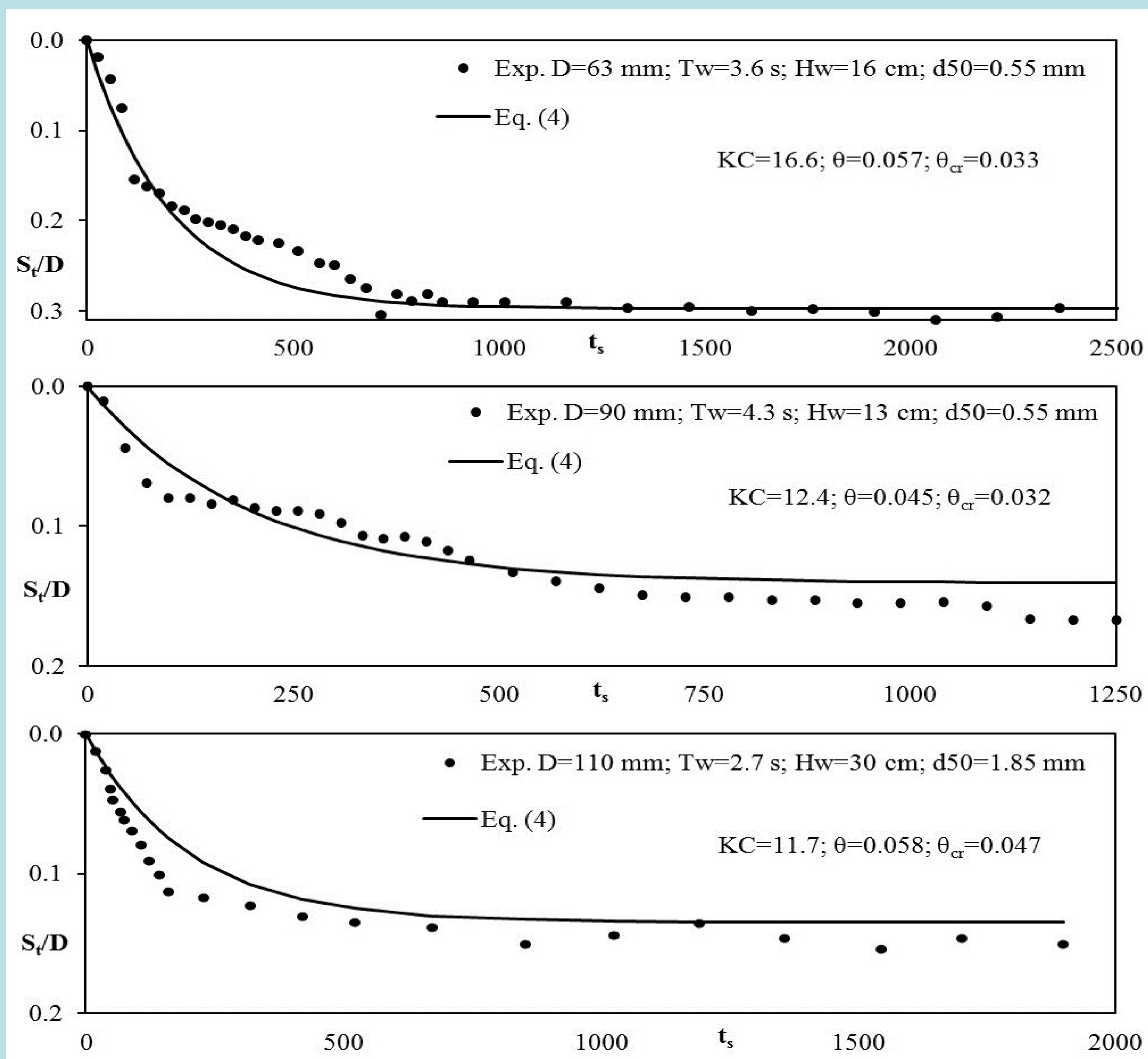

Figure 4. Time development of scour depths.

CONCLUSION

The experiments has revealed that scour process below a submerged pipe is dominated by both Keulegan-Carpenter number and Shields parameter. An empirical relationship, which includes these well-known dimensionless numbers, has been suggested to describe the temporal variation of scour depth below pipelines due to regular waves. Thus, the characteristics both of incident wave and bed material can be adapted easily to the computation of time dependent scour depths by way of these parameters. The proposed formula is valid only for the live-bed regime; but the selection of a wide range of the grain sizes of seabed materials can be considered as a contribution to the study of the scour below pipelines.

REFERENCES

Sumer, Fredsøe (2002): The mechanics of scour in the marine environment, World Scientific Pub., Singapore.

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