Large Hydro-Geo Flume and its Use for Coastal Engineering Research

by

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ABSTRACT

A large wave flume named the Large Hydro-Geo Flume was completed in March 2000, being 184 m long, 3.5 m wide, and 12 m deep with a 4-m-deep sandbed. Installed in the flume are a piston-type wave-maker generating 3.5m waves, a current generator producing a 2m/s current, and a seepage flow generator to liquefy the sandbed.

Large-scale experiments can be conducted at a model scale of 1/5 to 1/1 without major problems due to scale effects. The wave flume is expected to contribute to promoting performance design of maritime structures via large-scale experiments that will elucidate failure processes such as deformation of structures, breakage of members, and scouring or liquefaction of the foundation.

The wave flume should also contribute to reveal the mechanism of sea-seabed interactions.

KEY WORDS: Large Scale Experiment
Wave Flume
Performance Design
Sea-seabed interaction

1. INTRODUCTION

Hydraulic model experiments are frequently used to effectively elucidate phenomena related to the des-ign of maritime structures. In conducting such ex-periments, however, scale effects must be consid-ered, especially for sandbed-associated experiments or others in which impulsive wave forces or wave splash effects are to be evaluated.

The most effective solution is to conduct experiments with a scale large enough to neglect scale effect problems.

At the Port and Airport Research Institute (PARI), construction of a large wave flume named the “Large Hydro-Geo Flume” (LHGF) began in 1995 and was completed in March 2000. The flume is 184 m long, 3.5 m wide, and 12 m deep with a sandbed 67 m long and 4 m deep (Fig. 1). The LHGF can generate regular and random waves heights up to 3.5 m (wave period 6–8 s) and a current with a flow rate up to 20 m3/s.Also installed is a seepage flow generator that can liquefy the sandbed, and large observation windows at the side of the flume allowing observation of phenomena occurring in the water and sandbed. Large-scale experiments with a model scale from 1/5 to 1/1 can be conducted without major scale effect problems.

The main objectives of the LHGF are discussed in Section 2, after which LHGF characteristics are described in Section 3 and some typical experiments in Section 4.

2. MAIN OBJECTIVES

2.1 Objectives and experiments

The LHGF was constructed as a prototype experi-ment facility incorporating a large sandbed. Various types of wave and current experiments can be con-ducted in the flume (Fig. 2).

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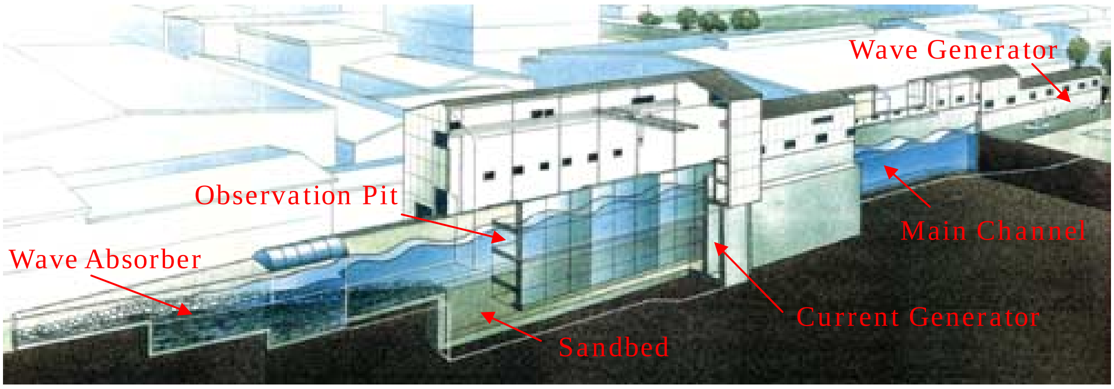

Figure 1. Perspective of the Large Hydro-Geo Flume.

The main objectives of LHGF are follows:
1)Promote performance design of maritime structures.
2) Solve complex coastal engineering problems.
3) Develop new type structures and technology.

2.2 Performance design

Performance design is a new design method that can elucidate stability performance of a maritime structure (Takahashi and Shimosako, 2001) such that advanced designs are realized. In applying such performance design, it is essential to estimate deformation (damage level), particularly that due to extreme waves higher than the design wave height.

As no major scale effects are present in large-scale experiments conducted in the LHGF, deformation can be quantitatively investigated, especially sandbed deformation or breakage of structural members.

Performance design is an advanced design method compared to conventional design practice, one allowing for the development and actual construction of more efficient, economical maritime structures.

2.3 Interaction of wave, foundation, and structure

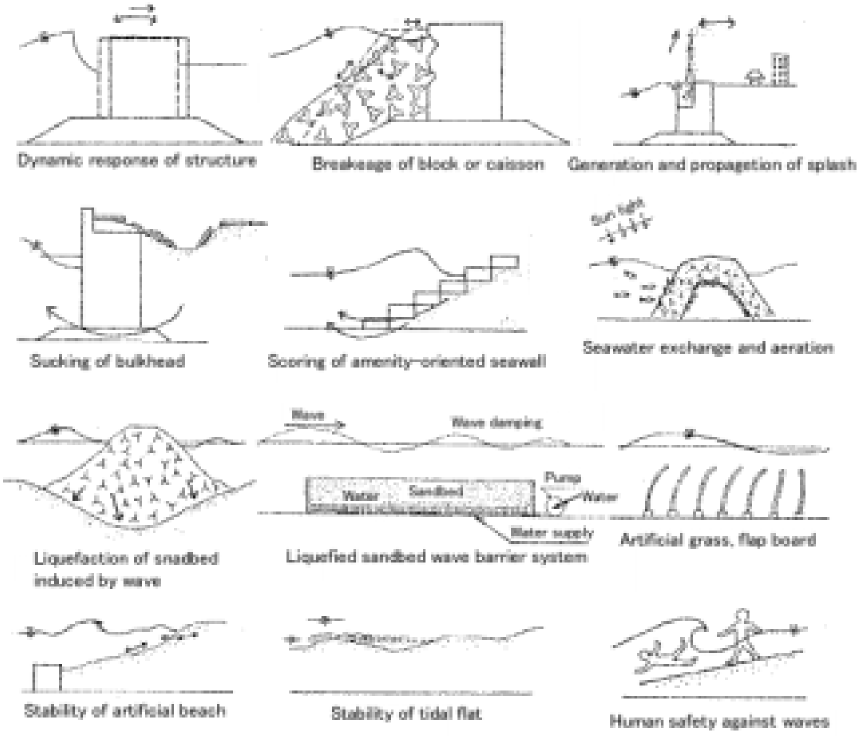

Figure 2. Research topics in the LHGF.

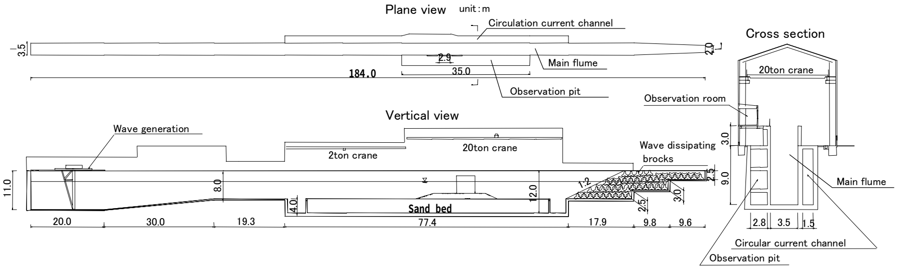

Figure 3. Dimensions of the LHGF.

Regarding interactions between waves, foundation, and structure, e.g., sandbed liquefaction by waves, scouring and through wash are critical, complex phenomena associated with the design of maritime structures. Since the LHGF has a large sandbed, the-se phenomena can be investigated using large-scale experiments. In addition, shoreline change problems, such as cross-shore sediment transport, or soil mechanics problems such as collapse of the rubble mound or foundation, can be studied.

3 DESCRIPTION OF THE LHGF

3.1 Wave flume

Figure 3 shows the dimensions of the LHGF, which is covered with a protective roof and includes an observation pit (35 m long and 2.8 m wide) and circulation channel for current generator arranged parallel to the main flume. The roof height of the observation area (40 m long and 15 m wide) is 15 m from ground level, being sufficiently high such that no wave splash will reach. An observation room (30 m long and 3 m wide) is present in the area. The semi-underground type flume has its top elevation 3m above ground level with a typical water depth of 5 m, i.e., the water level is equal to the ground level which is 3 m below the top of the flume.

Flume dimensions were selected based on using a model scale from 1/5 to 1/1, although the width and length were restricted due to a limited amount of open space. For example, if the water depth h = 15 m and wave height H = 10.5 m at the field with a model scale of 1/3, then h and H correspond to 5 and 3.5 m, respectively. The width of the flume corresponds to 10.5 m in prototype. Experiments

Figure 4. Measurement stage.

Figure 5. Array of water supply pipes at the bottom of the LHGF.

are normally conducted using fresh water, however, seawater experiments for less than a week can be performed as the corrosion protection had been implemented.

The structural design of the flume considered the following loads:

1) Earth pressure from the outside (flume with no water).
2) Hydrostatic pressure (flume filled with water).
3) Impulsive pressure by waves.
4) Soil pressure produced by structure model.

Regarding structural design, wall strength and deformation are both important, and the displacement at the top of the flume must be sufficiently small to install the wave generator and measurement stage.

Tetrapods (1 ton/unit) are installed as a wave absorber at the end of the flume inclined at 1:2 (Fig. 3). These blocks are also used in experiments as wave dissipating blocks of a breakwater.

Figure 4 shows the moving measurement stage installed at the top of the flume. It can be used to fix a model or measurement equipment, and it has a lift that can be lowered to the bottom of the flume.

Large observation windows made of acrylic plate are installed at the center of the observation pit, being 2.45 m wide, 1.05–2.70 m high, and 8–20 cm thick. A 20-ton crane is also installed in the observation area.

3.2 Sandbed and seepage flow generator

The sandbed basin is filled with 1500 tons of Cape Flattery sand produced in Australia with a mean

Figure 6. Resultant formation of sandbed.

Figure 7. Formed flat sandbed surface.

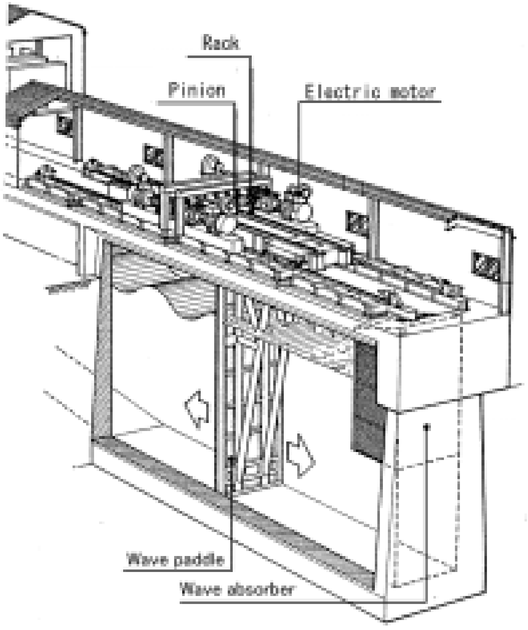

Figure 8. Wave generator in the LHGF.

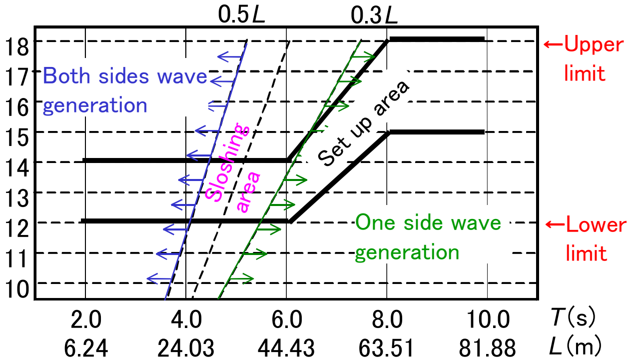

Figure 9. Relation between wave period and rear side distance of the paddle.

diameter of 0.2 mm. The sand is white which allows easily distinguishing the sandbed surface.

The seepage flow generator is used (i) for liquefied sandbed wave barrier system (LSWB) system prototype experiments (Sec. 4) and (ii) to form a homogeneous foundation for sandbed-associated experiments, consisting of a water supply pump, main piping for water supply, and 240 water supply pipes spaced 27.8 cm apart. These pipes have an inner diameter of 4 cm and have holes (dia., 0.4 cm) drilled along both sides at 4 cm intervals. They are covered with filter sheets intended to prevent clogging of holes. Figure 5 shows a photo of the array of water supply pipes installed at the bottom of sand-bed. The maximum flow rate of the supply pump is 6 m3/min at a pump pressure head of 8.5 m and rated power of 75 kW.

Figure 6 shows the resultant formation of a sandbed. Sand is placed in the flume at a fixed place, after which the seepage flow generator produces a 67-m-long homogeneous sandbed foundation. Figure 7 shows the flat sandbed surface seen from an observation window. In a test run of the wave generator, we observed liquefaction of the sandbed induced by waves (h = 5 m, H = 2.7 m, and T = 6 s); i.e., the sandbed moved back and forth about 50 cm at the surface, and after wave action, water flowed out of the sandbed due to wave-induced excess pore pressure. These phenomena are quite interesting and cannot be reproduced at a small test facility.

3.3 Wave generator

Installed at the end of the flume is a piston type wave generator (Fig. 8) driven by a rack and pinion drive system with four a.c. electric servomotors,

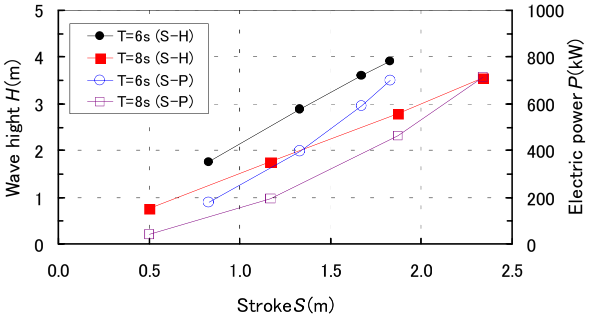

Figure 10. Relation between wave paddle stroke and generated wave height in front of the wave paddle or electric power consumption

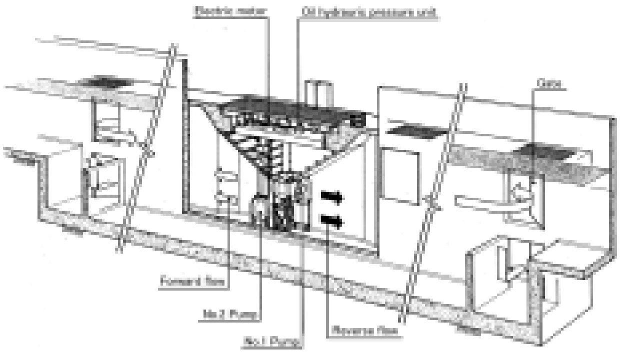

Figure 12. Current generator in the LHGF.

Figure 11. Generated waves.

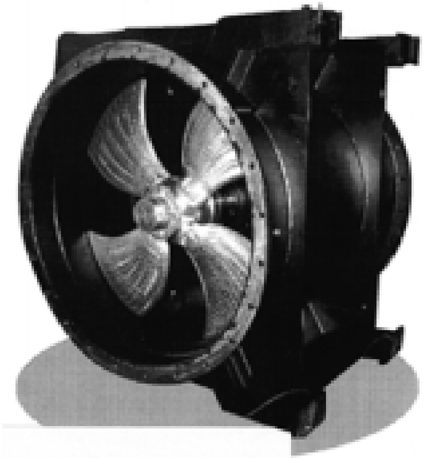

Figure 13. Variable propeller type pump.

each rated at 220 kW. A unique aspect of the generator is that both the front and rear of the wave paddle are filled with water such that waves are generated on both sides; hence twice as much as power is required. It is for this reason that relatively large-scale wave generators typically keep the rear side of the paddle dry. This is not necessary, however, since the wave making resistance for the rear side can be reduced by controlling the neutral position of wave paddle, i.e., when the distance between the paddle and end of the flume is small enough compared to the wavelength, the water surface at the rear side moves up and down only such that the wave making power for the rear side is nearly zero. When the wavelength is small (short wave period), waves are generated on both sides because the power requirement is not large. As shown in Fig. 8, a wave absorber for the rear side of the paddle is installed at the end of the flume.

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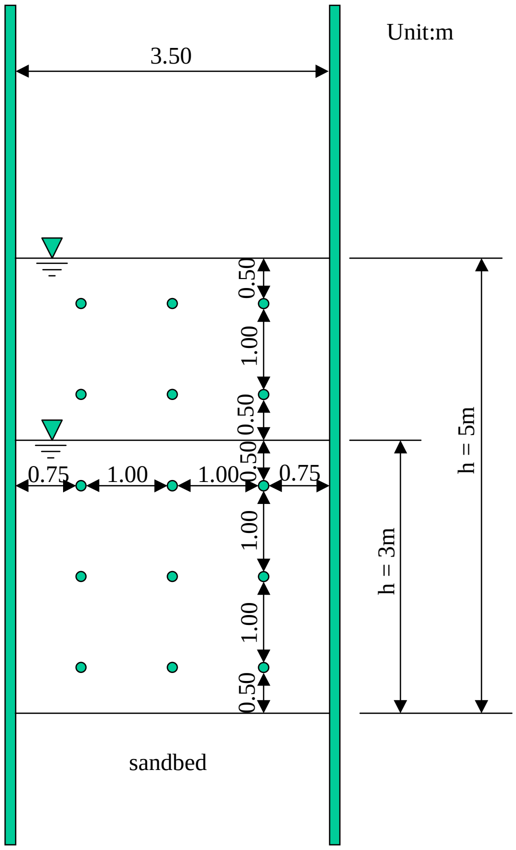

Figure 14. Point at which velocity was measured.

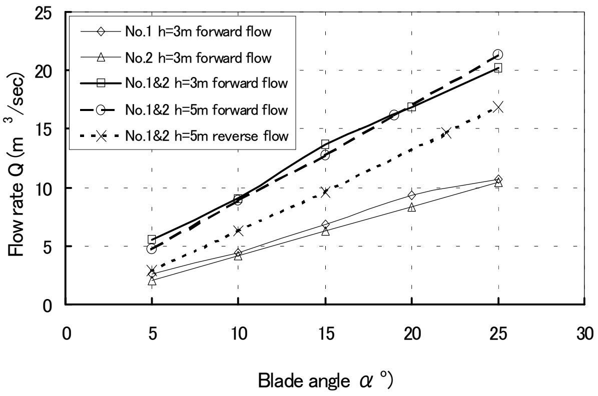

Figure 15. Relation between blade angle and flow rate calculated using measured velocity.

Figure 9 shows the relation between wave period and rear side distance of the paddle. From the neutral position, the maximum stroke of the wave paddle is 4 m for both sides. Designed maximum wave height is about 3.5 m with a wave period from 6–8 s and water depth in front of the wave paddle of 7.6 m. Regarding control of the wave generator, ordinary position control or nonreflective generation methods are available. To absorb the long-period wave component of irregular waves, the non-reflective generation method will need to be modified in future. The length of the wave paddle drive area is 28 m, being sufficient to absorb such long-period waves.

Figure 10 shows the relation between wave paddle stroke and generated wave height in front of the wave paddle or electric power consumption (root mean square value) when the water depth in front of the wave paddle is 7.6 m. The measured maximum wave height for a wave period of 6 s is 3.9 m, which is almost 110% of the maximum design value. Note that even in this case only 700 kW is required, which is smaller than the rated value of 880 kW. Although not indicated, irregular wave tests were conducted in which the largest wave generated was 1.4 m in significant wave height with a wave period of 5.49 s.

Figure 11 shows actual wave action in the flume where waves braking at the slope of the flume had a breaking wave height reaching up to 4 m. With no structure installed in the flume, waves collided against wave dissipating blocks at the end of the flume causing large splash and vibration.

3.4 Current generator

The current generator consists of pumps, gates, and control equipment (Fig. 12). A sub channel (circular current channel) which is 76 m long, 1.5 m wide, and 8.5 m high is situated parallel to the main flume. Two variable propeller type pumps (Fig. 13) are installed at the center of the sub channel. The rotation speed of the propeller blade is fixed at 240 rpm, with the current direction and velocity being controlled by varying blade angle. The maximum flow rate of two pumps is approximately 20 m3/s.

There are five gates (2.5 m wide and 3.5 m high), with one being located at the center of the sub channel and two at either end of it. Gates are opened and closed by oil hydraulic pressure.

Performance tests of the current generator were conducted with h = 3 and 5 m to obtain the relation between velocity and blade angle. Figure 14 shows the point at which velocity was measured, while Fig. 15 shows the relation between blade angle and flow rate calculated using measured velocity. Since the velocity fluctuates periodically, flow rate was evaluated using mean velocity. Forward flow is the direction from the wave generator to wave dissipating blocks. With a blade angle of 25º, the forward flow rate using two pumps was slightly greater than 20 m3/s for h = 3 and 5 m, while maximum flow rate for reverse flow was approximately 17 m3/s. Maximum electric power was 430 kW.

Velocity fluctuations are significant at a relatively large flow rate. Since the gates are not located at the ends of the flume, there is flow outside the circular current, i.e., toward the wave generator or wave dissipating blocks. This flow includes part of the out-flow from the sub channel and some water which should flow into it, and seems to be responsible for inducing long-period oscillations in the flume. To reduce fluctuations, rectification plates for the cur-rent should be installed near the gates. Ten sheets of hard rubber mat with a specific gravity of 3.9 were placed on the sandbed and steel plates were set on top of them as weights to prevent scouring by rapid flow. Unfortunately, however, sand was sucked out from the gap between the mat and side wall of the flume at a velocity of about 1 m/s, thereby causing the mat near the gate to roll up and such that wide scouring of the sandbed occurred at nearly 2 m/s. To maintain the sandbed stable against such rapid flow, other countermeasures must be implemented in the future.

3.5 Measuring equipment

Six sets of capacitance-type wave gages and thirty pore pressure gages are in place, and a wave pressure gage, velocimeter, and displacement meter are used according to experiment needs. The output cables of these devices are connected to an amplifier and data acquisition PC installed in a rack placed be-side the flume. This PC is connected by LAN to a data analysis PC placed in the observation room, and the acquisition of experimental data can be con-trolled by the data analysis PC. Control units of the wave generator, current generator, and seepage flow generator are also installed in the observation room.

3.6 Water supply and drainage

The water used in the LHGF is stored in a 2800 m3 water tank used for the large experimental basin. To save water, the tank is also used to store water pumped out of the LHGF. Two pumps rated at 30 kW are installed: one for supply and the other for drainage. It takes about 6 hours to fill the flume 5 m deep, and 10 hours to drain it.

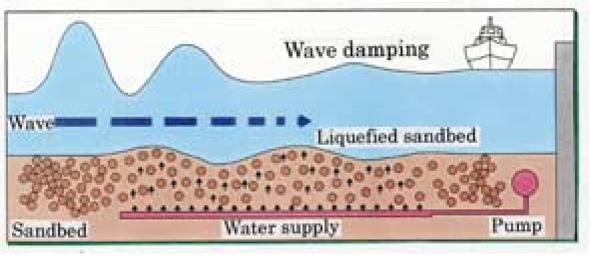

Figure 16. Schematic diagram of LSWB for a wave energy absorbing system.

4 MODEL EXPERIMENTS IN LHGF

4.1 Liquefied sandbed wave barrier (LSWB)

4.1.1 Concept of LSWB system

A liquefied sandbed wave barrier (LSWB) system consisting of horizontal pipes buried in the sandbed sandbed is currently under development at PHRI (Fig. 16). This system is designed to dissipate wave energy using damping by movement of liquefied sand. By pumping water through the pipes, the pore pressure in the sandbed is increased and “sand liquefaction ” occurs; an effect which significantly decreases the shear modulus of the sandbed such that large movement of the sand occurs due to wave action. This causes wave energy dissipation by friction among the sand particles during their wave-induced movement. To investigate the wave damping effect of the LSWB, hydraulic model experiments and fi-nite element method (FEM) calculations have been carried out. Results indicate that the wave-damping effect of the LSWB is significant, i.e., the wave transmission coefficient can be 0.2–0.4 through a LSWB with a liquefied sandbed length equal to one wavelength and a thickness equal to the water depth.

4.1.2 Experimental results

Prototype experiments of the LSWB system were conducted using the above-mentioned LHGF

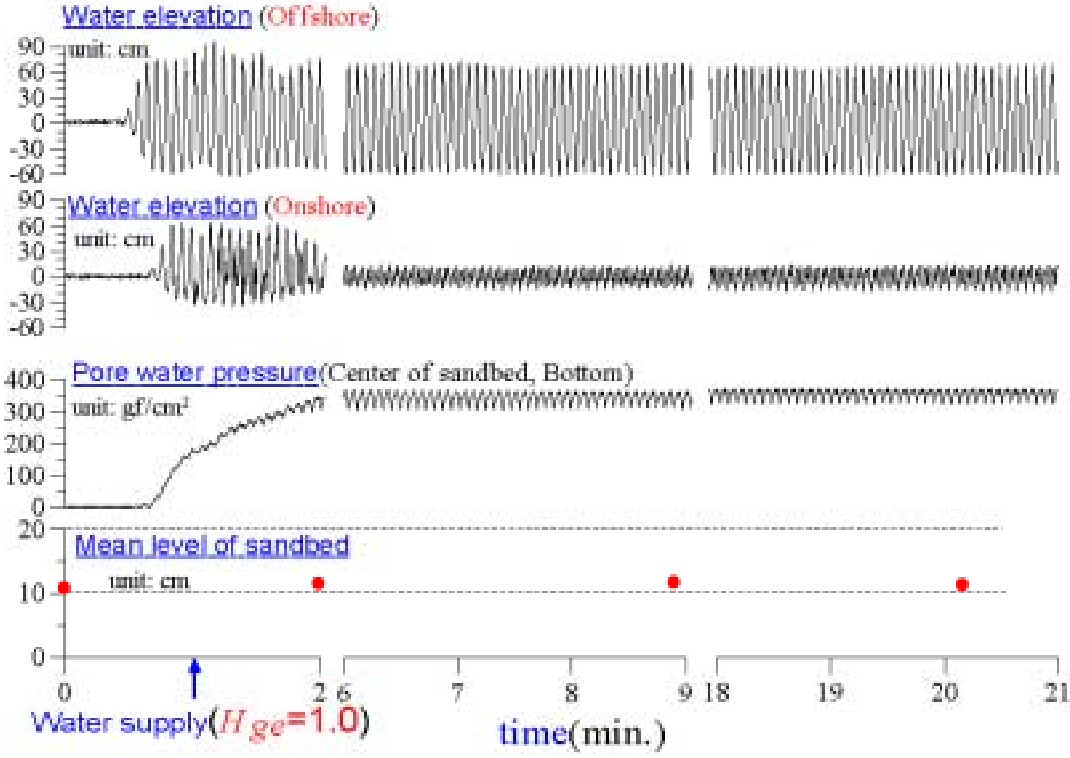

Figure 17. Typical data of prototype experiments for the regular waves with T = 4.5 s, H = 1.3 m, and h = 2.32.m

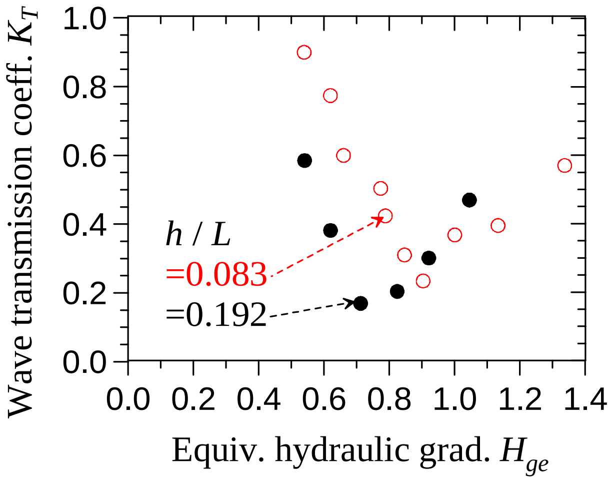

Figure 18. Experimental results on K_T values for regular waves with h/h_s = 0.625.

see-page flow generator. The 40-m-long, 3.75-m-deep sandbed was liquefied and waves with wave periods of 3, 4.5, and 6 s were generated in water depths of 2.32, 3.4, and 4.6 m. Wave attenuation, pore pres-sure, and the sandbed movement was measured (Kang et al., 2000).

Figure 17 shows typical results for prototype ex-periments using regular waves with T = 4.5 s, H = 1.3 m, and h = 2.32 m. Water flow rate correspond-ing to equivalent hydraulic gradient Hge =1.0 is sup-plied 1 min after wave generation, and transmitted waves are reduced in height to less than 20% that of incident waves. Despite using fine sand, there is no reduction in the wave damping effect due to wave-induced compaction observed in small model tests.

Both wave attenuation and oscillatory pore pressure are quite stable for a long time.

Figure 18 indicates the effect of Hge on KT for two kinds of regular waves (h/L = 0.083 and 0.192) with h/hs =0.625, where the minimum KT values are less than 0.2. Variations and minimum KT values agree fairly well with calculations (Kang et al., 1997). These results also confirm that influence of model scale on wave damping effect is negligible, thereby verifying previous results by Kang et al.

4.2 Other experiments

Experiments conducted thus far include a large-scale experiment studying the impulsive uplift force acting on a RC plate, a prototype test studying the friction coefficient between rubble mound and cais-son versus the static horizontal force, and experi-ments on the stability of wave dissipating blocks of a horizontally composite breakwater. Results will be published in the near future.

In addition, other kinds of experiments (Fig. 2) will be sequentially conducted.

5 CONCLUDING REMARKS

By the use of large-scale experiments, the Large Hydro-Geo Flume is expected to make major con-tributions in promoting performance design of mari-time structures including their failure processes: de-formation of the structures, breakage of members, and scouring and liquefaction of the foundation. Re-vealing the mechanism of sea-seabed interactions is also expected.

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