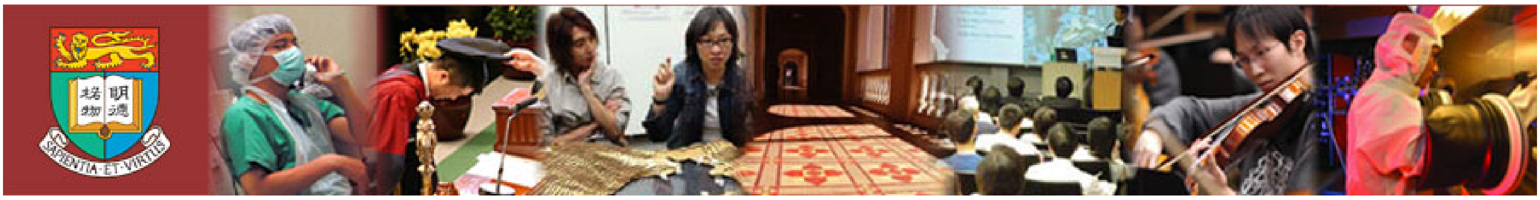

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Grouted Jetted Precast Reinforced Concrete Piling Technology for No Dredge Seawall and Land Reclamation in Hong Kong

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ABSTRACT

Seawall and reclaiming land in Hong Kong have to be robust, cost-effective and environmental-friendly. To achieve this goal, this paper introduces an innovative technology of originality for design and construction of continuous and impermeable seawall and land reclamation environmental-friendly and cost-effectively. It is called the grouted jetted precast reinforced concrete piling (GJPRCP) technology. It is briefly introduced at first. Applications are given for illustration afterward. The idea of GJPRCP based no dredge seawall and reclamation is presented and discussed with illustration of conceptual design and construction steps. It can form continuous and impermeable and robust reinforced concrete structural seawall. The seawall can be used as a continuous impermeable cofferdam and a diaphragm during the construction stage. Brief examination and discussion of both the practice of conventional dredge seawall and reclamation and the adoption of no dredge seawall and reclamation in Hong Kong can show that because of their high structural rigidity, the GJPRCP based no dredge seawall and reclamation can be acceptable, feasible and applicable in Hong Kong.

1 INTRODUCTION

Hong Kong is a small territory of about 1104 km2 land area and 1651 km2 sea area. Because of population growth, it has an ever-increasing demand for land to cope with development. Cutting into hillside and reclaiming the sea have been the two dominant methods in forming new lands for development. However, there is a limited land reclamation practice in Hong Kong over last 15 years. Therefore, the theme of this 36th Annual Seminar of the HKIE Geotechnical Division is “Reclamation: Challenge and Beyond”. It is to capture and showcase the achievement that we have made in reclamation projects in recent years. It also provides a platform to share new knowledge and techniques that will enable engineers to meet the demand and tackle the challenges in the near future and beyond.

For land reclamation over the sea, a stable and robust seawall is an essential and necessary structure to protect a reclaimed land from erosion against wave and current actions(CEO 2002a, 2002b, 2004). The seawall can be a deep seated reinforced concrete retaining structure to confine and protect the soil fill of reclaimed land. Furthermore, the seawall and reclamation should be cost-effective and environmental-friendly. Hence, this paper aims to introduce an innovative technology of originality for design and construction of continuous and impermeable seawall and land reclamation environmental-friendly and cost-effectively. This technology is the so-called grouted jetted precast reinforced concrete piling (GJPRCP). Details can be found in the two papers by Xu et al. (2004, 2006). Other related materials and history can be found in the cited references (McVay, et al. 2014; Shestopal, et al. 1959; Tsinker 1988; Hameed et al. 2000). It is expected that this technology can be accepted and adopted by our geotechnical engineering community in Hong Kong.

The paper is outlined as follows. The GJPRCP technology is briefly introduced at first. Some application cases are given afterward. Thirdly, an idea for GJPRCP based no dredge seawall and reclamation is discussed. Its conceptual design and construction steps are described accordingly. Basically, the GJPRCP technology can form continuous and impermeable and robust reinforced concrete structural seawall. It can be used as a continuous impermeable cofferdam and a diaphragm during the construction stage. The function of a cofferdam is for treating and improving in-situ soft marine mud ground within the reclaimed seabed before filling soils for reclaiming land. The function of a diaphragm wall is to retain the compacted fill soils and protect the sea wave and current actions.

2 GJPRCP TECHNOLOGY

2.1 Set up

The GJPRCP technology is shown in Figure 1. It consists of a floating platform with a crane to lift the pile and two pump systems. The pile sinks vertically into water and soil at the chosen position by its own weight and the pressurized water jetting. One of the two pump systems is for jetting the water and the other is for grouting.

The pipe of various cross-sections has a steel pipe passing its center from head to toe vertically (Figure 2). This central pipe can be either temporary or permanent. It is connected to a horizontal nozzle pipe at the pile toe. The toe pipe has many small nozzles of 3 mm diameter and regular pattern. As a result, the soil beneath the pile toe can be liquefied and vertically cut. The disturbed gap between the sheet pile and the undisturbed soil is relatively small, typically 10 to 20 mm wide. The central pipe can be connected to a plastic hose for transferring its pressurized water from the water pump to the toe nozzle pipe. The pressurized water can be vertically jetted into the soil via the nozzles.

A steel I-beam and a steel tube are casted along one of the two connecting side surfaces, respectively (Figures 2 and 4). The tube has a narrow opening slightly wider than the I-beam web but much narrower than the I-beam flange. The tube inner width is larger than the I-beam flange. The tube inner length is longer than the half of the I-beam height. Each of the two side surfaces has two semi-circular hole channels around the I-beam or the tube (Figure 4). The I-beam, tube and the semi-circular hole channels are ended at some meters above the pile toe, as shown in Figure 2(e).

2.2 Sinking pile by jetting

The quiet process of sinking the precast pile by water jetting is shown in Figure 5. The crane erects the pile vertically and let its seating on the seabed surface. Then the pressurized water flow is pumped into the plastic hose-central pipe-nozzle pipeline and released via the nozzles into the soil. The pumping pressure is about 1.5 to 2.0 MPa. The total water discharge rate is about 50 to 80 liters per second. The soil immediately beneath the pile toe is loosened and liquefied by jetting. The pile sinks into the liquefied soil by its own weight until the design depth. Once the first pile is installed, a similar process is used to install the second pile. The installation of two connected precast reinforced concrete piles is also shown in Figure 5. The I-beam of the second pile is inserted into the tube of the first pile. This process is repeated with all subsequent piles.

2.3 Grouting for connecting and stabilizing piles

As shown in Figure 6(a), the two adjacent piles are initially connected with the I-beam inside the tube. The gap space between the two adjacent piles is filled with liquefied mud, which has to be cleaned before grouting. Each of the two cylindrical holes are firstly sealed completely with a grout-filled cylindrical plastic bag of the hole length. Once the liquid grout in the two plastic bags is hardened, the mud water within the tube can be washed and cleaned. A steel pipe with a toe nozzle is inserted into the rectangular tube until its toe and used for pumping clean water to flush the mud out of the tube and gap within the two grouted bags. As shown in Figure 6(b), liquid grout is then pumped into the tube toe via a steel pipe. The liquid grout gradually fills up the tube and the gap from bottom to top. The grouting is stopped when the liquid grout begins to flow out of the tube head. To enhance pile strength, the toe nozzle pipe, the central pipe and the contact zone between the pile toe and the soil beneath should be grouted. Clean water can be used to wash and clean the pipes. Fresh grout is then pumped into the toe pipe to fill these spaces. The central steel pipe, if it is a temporary pipe, may be retrieved for cost saving before cleaning and grouting. If it is a permanent pile, the pipe can be used as a reinforcement for the pile and seawall. Lastly, the soils of 10 to 20 mm close to the pile walls can be disturbed and loosened. They can be strengthened with grouting (Figure 6(c)).

The above GJPRCP method can be summarized as following steps. Reinforced concrete piles shall be designed and pre-casted. Water jetting is used to drive the pile into the soil platform. The connection zone between two piles and the surrounding disturbed soils should be grouted. The internal pipes should be grouted and pile caps should be casted in-situ.

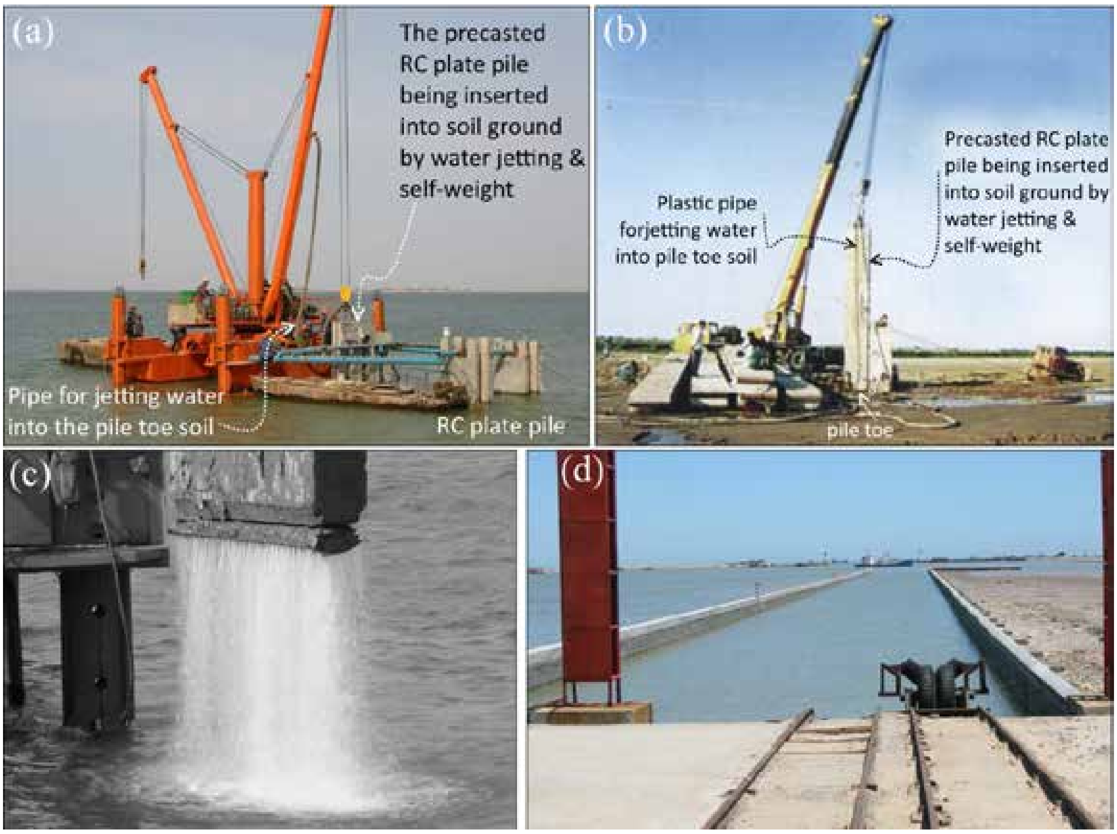

Figure 1: The grouted jetted reinforced concrete piling technology and results

(a) Piling on floating platform; (b) Piling on soft soil ground; (c) Vertical jetting of pressurized water from small nozzles at pile toe; (d) Seawall by GJPRCP

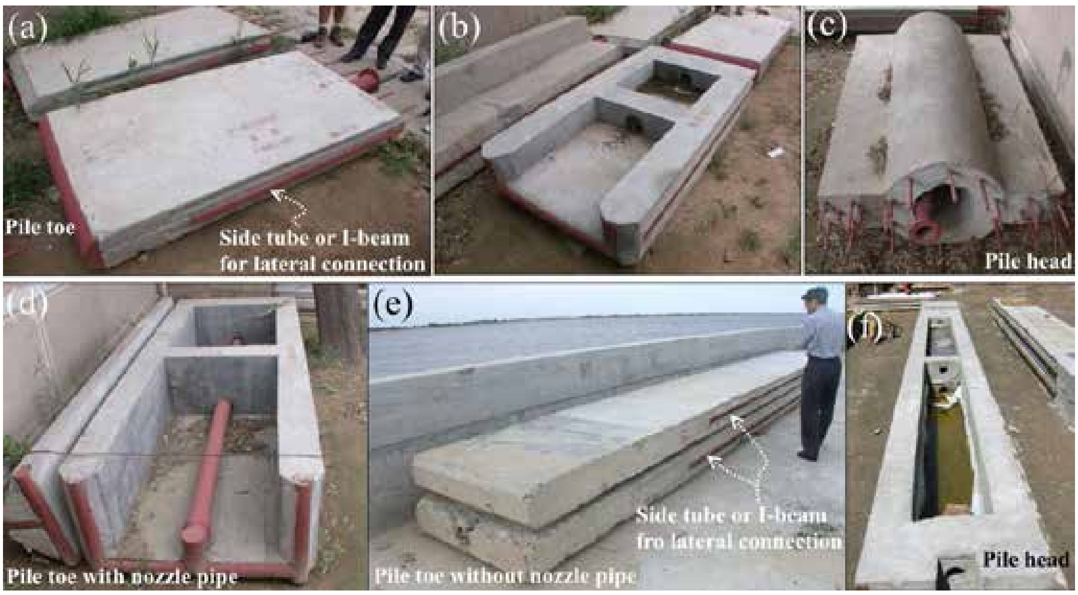

Figure 2: Various and flexible design of precast reinforced concrete piles for jetting and grouting installation

3 APPLICATIONS

The GJPRCP technology has been applied to many projects in Mainland China. They include seawall, breakwater, bridges, piers, port-bank, river embankment, reservoir embankment, division dike, baffle dike, conduit, underground water tanks, and small islands, as shown in Figure 1(d), Figures, 7 8 and 9. Figure 1(d) shows the GJPRCP seawall in Tianjian Port. It is 9.5 m long and 4.5 m buried in soil.

In particular, Figure 7(a) shows a GJPRCP breakwater built in July 1998 at a coastal site in northern China on the shore of the Bohai Sea. Its aim was to determine whether this breakwater could resist heavy seabed erosion. It was located 30 m outside the main embankment. Figure 7(b) shows its design details. A T-shaped pile was also used for supporting. Each pile was 1.2 m wide, 0.3 m thick and 16.0 m long. A pile cap was constructed using cast-in-place method. It is still standing there. The wastewater treatment tanks in Figure 8(c) was constructed in 2000. Each tank was 3.5 m deep, 15 m wide and 56 m long. The tank-wall has been impermeable and functioning well for many years.

Other applications GJPRCP technology can be found in a research project report recently made by McVay et al. (2014) in USA (see also Figure 3(c)).

Figure 3: Flexible design of head and toe of precast reinforced concrete piles for jetting and grouting installation

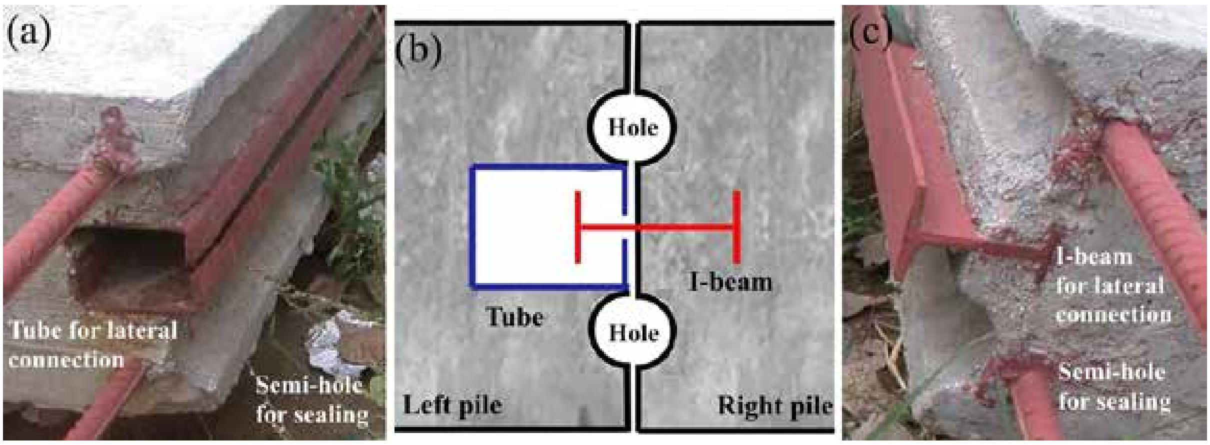

Figure 4: Steel tube or I-beam and two semi-circular hole on one side surface of pile for connection with grout in-situ

(a) Female side wall with steel tube and two semi-holes; (b) Connection arrangement of a male side wall with a female side wall; (c) Male side wall with I-beam and two semi-holes

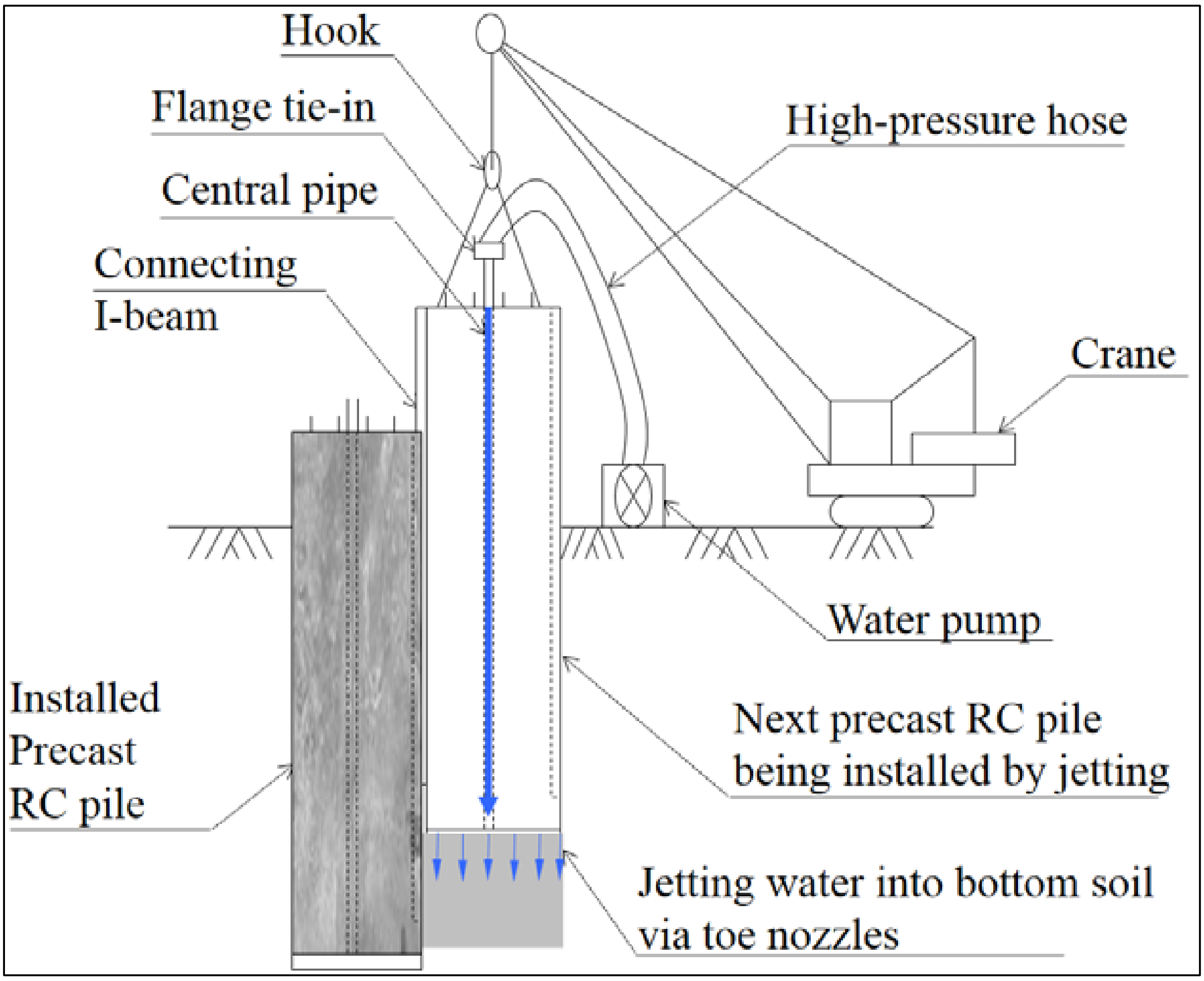

Figure 5: Installation of two connected rectangular precast reinforced concrete piles with jetting of pressurized water from pile head into the toe nozzles via the central pipe

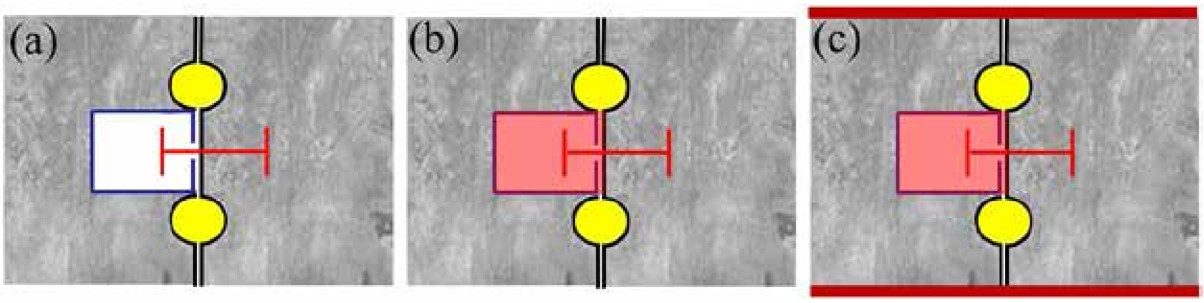

Figure 6: Lateral connection of a male side wall with I-beam and a female side wall with tube by in-situ grouting

(a) In-situ grouting the two circular holes within the male and female side walls with plastic bag; (b) In-situ grouting the gap within the tube; (c) In-situ grouting the longitudinal side wall with adjacent soil

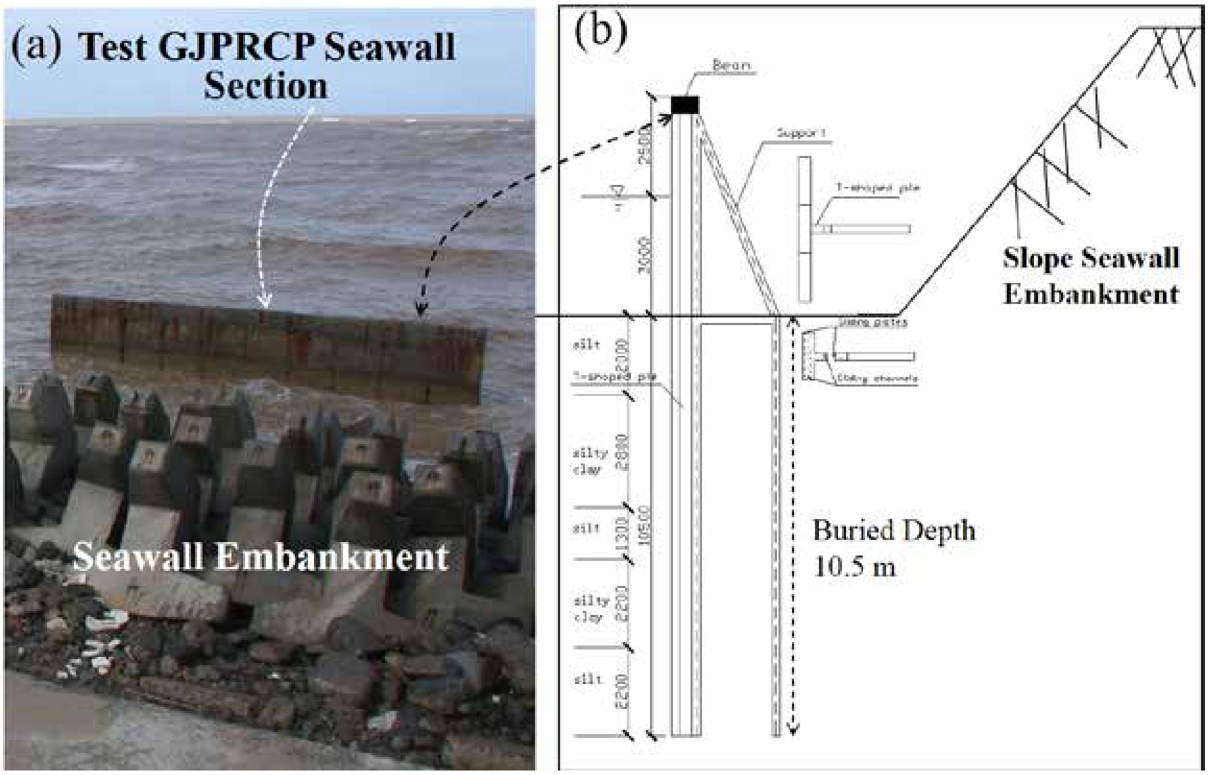

Figure 7: Design details of a test section of a grout jetted precast reinforced concrete pile seawall in front of a main seawall embankment

(a) Photograph showing the seawall condition in 2003; (b) Cross-section details of the seawall

Figure 8: Application cases of GJPRCP technology

(a) Bridge piles; (b) Pier piles; (c) Walls of waste water treatment tanks; (d) Port on river; (e) Control lock for water discharge

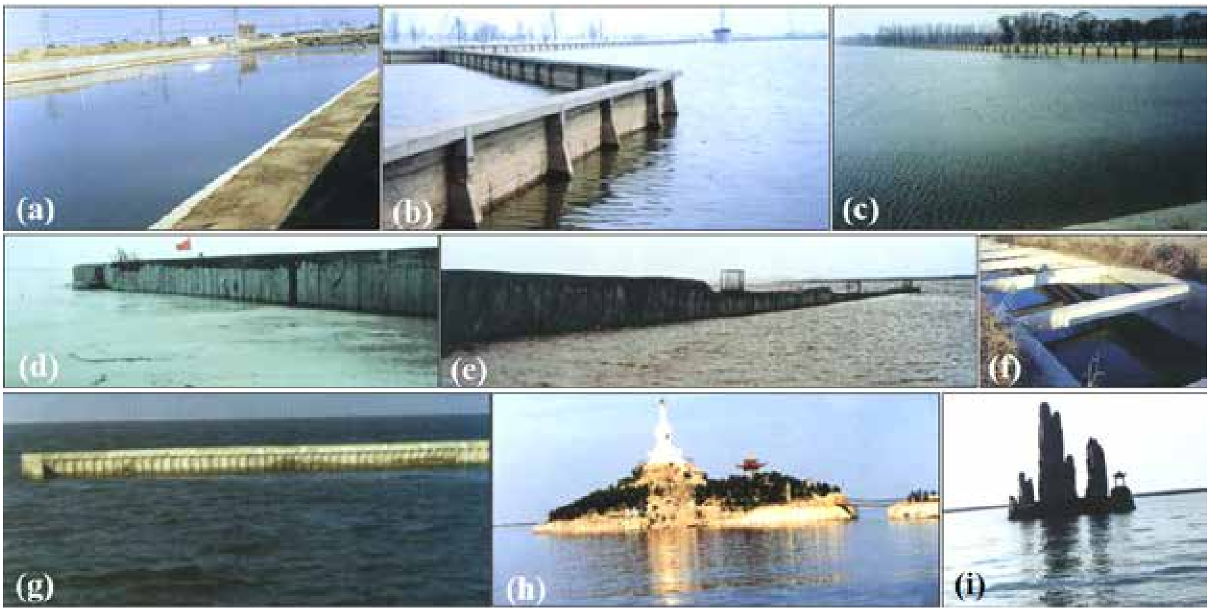

Figure 9: Further application cases of GJPRCP technology

(a) River embankment; (b) Division dike in river; (c) Reservoir-wall; (d) Baffle dike; (e) Baffle dike; (f) water supply conduit; (g) Breakwater; (h) Island-wall; (i) Caisson-mount on lake

4 GJPRCP-BASED NO DREDGE SEAWALL AND RECLAMATION

4.1 General

The seawater depth in Hong Kong is about 5 to 10 m. Its typical seabed soil and rock conditions are a top layer of soft marine deposit of 10 to 30 m thick, overlying alluvium, residual soil, completely decomposed rock and bedrock (Lumb and Holt 1968; GEO 1988). The marine deposit is too soft to support any structures (Li et al. 2005a, 2005b; Yue et al. 1994a, 1994b). The many successful applications of the GJPRCP technology have demonstrated that the design and construction and installation of the precast reinforce concrete piles are flexible, effective, efficient and economic. The piles are structurally and continuously jointed and connected. They can form a continuous, impermeable and rigid seawall and can function as a cofferdam with underground diaphragm wall during construction and a permanent RC structured rigid seawall retaining the fill materials for the reclaimed land. A conceptual idea for the design and construction process of such no dredge seawall and reclamation is shown in Figures 10 to 14 on the basis of the general guide by GEO (1984, 1994). They can be briefed as follows.

4.2 Structural design and stability checking

At first, conventional ground investigation and laboratory testing have to be carried out along the seawall alignment to define the seawater depth, the thickness and physical and mechanical properties of the marine mud deposit, the alluvia, residual soils, CDG or CDV, and/or bedrocks. Next, the precast RC seawall structure and stability have to be calculated and designed according to the three geotechnical cross-section models in Figure 14. The first model is to check the stability and structure of the JGPRCP seawall when it is used as the cofferdam during pumping and expelling seawater out of the sealed space within the seawall. The second model is to check the stability and structure of the JGPRCP seawall when it is used as a cofferdam during treatment of soft marine mud with the cofferdam. The third model is to check the stability and structure of the JGPRCP seawall when it is used as the permanent seawall during soil filling of the cofferdam space up to the designed ground level of +2.5 mPD and after completion of the land reclamation works. Accordingly, the reinforcements and concrete properties and cross-section dimensions and lengths of the piles can be determined. The size and length of the I-beam and tube can be determined so that an impermeable seawall can be formed. It is noted that the seawall can be formed with either single layer of the connected piles (Figure 12) or double layers of the connected piles (Figure 13). The double layered pile seawall can be used as a temporary paved road for ground vehicle transportation.

4.3 Construction steps

The construction process of the GJPRCP based no dredge seawall and reclamation is shown in Figures 10 to 13. Controlling rectangular pile groups (caissons) can be installed at first for working platforms and for stability at critical and isolated locations along the seawall in the sea. The seawall piles are installed for continuous and impermeable connection between each of the two pile groups. Then the seawater is pumped out of the cofferdam formed by the seawall. Subsequently, the soft marine mud within the cofferdam is improved via conventional vacuum preloading with wick drains (Li et al. 2005a, 2005b). Some backfill sand can be added afterward and gradually for increasing the mud consolidation process. The backfilling can be carried out with compaction for reducing the fill voids and increase its strength and deformation moduli. It will be completed until the designed ground level is reached. During these construction processes, the seawall movements and ground settlements should be monitored and measured. Additional piles can be added to the seawall system if necessary. The actual founding level of each pile toe depth can be determined via pre-probing of a steel pipe with a toe nozzle. This steel pipe can be sunk into the soil ground via jetting of pressured water stream, similar to the pile jetting.

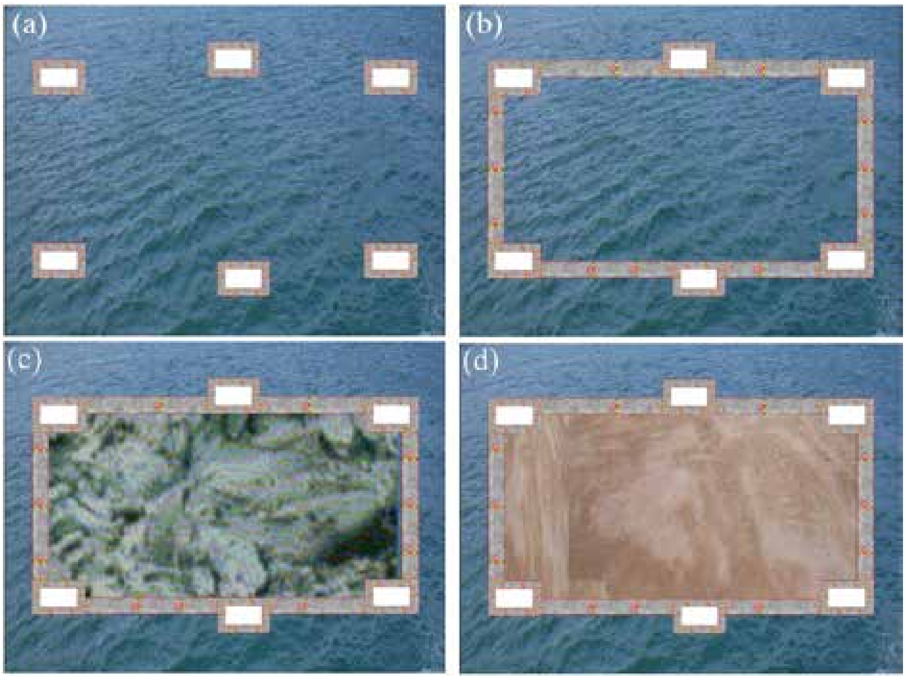

Figure 10: Plan view of a conceptual design and construction process of land reclamation of island on sea with GJPRCP technology

(a) Step A: Installation of six controlling rectangular pile groups; (b) Step B: Installation of wall piles for continuous and impermeable connection between each two pile groups; (c) Pumping water out of the connected pile wall cofferdam and improving the soft marine mud via vacuum preloading with wick drains; (d) Filling the empty space of the cofferdam with general fill or sand fills with compaction

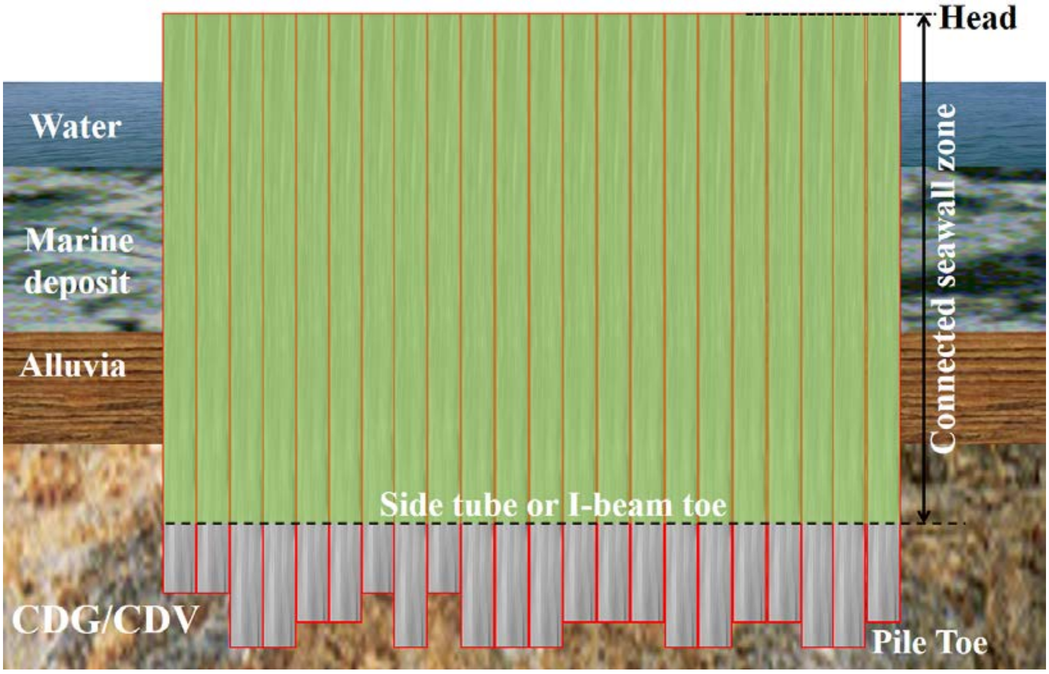

Figure 11: Longitudinal cross-section of the conceptual seawall with GJPRCP technology

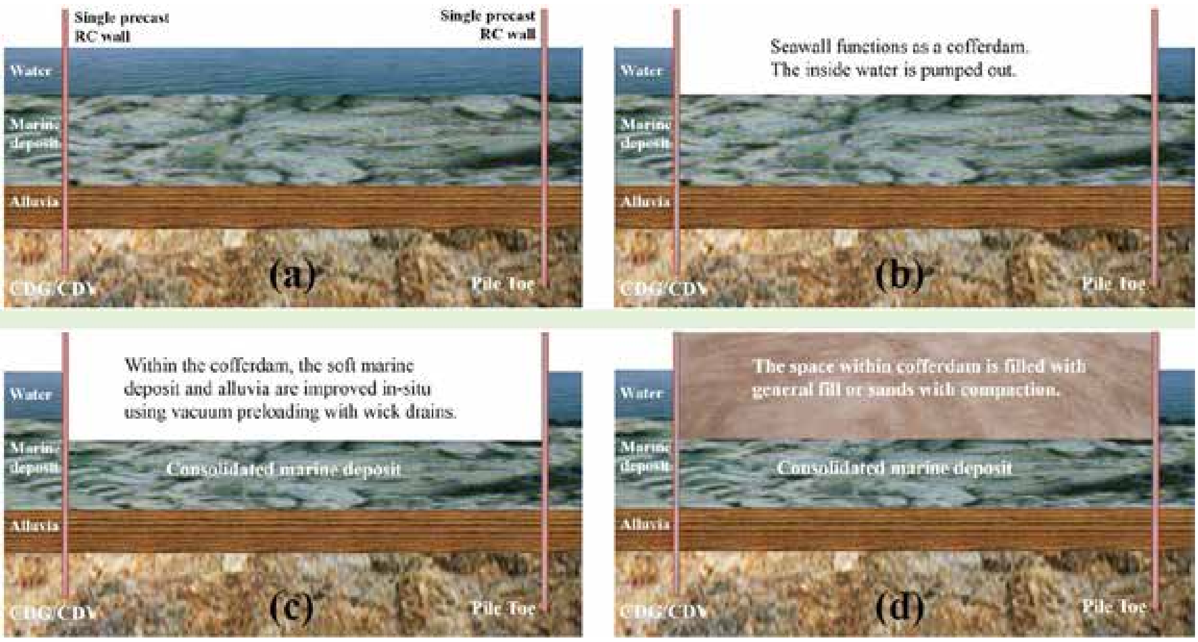

Figure 12: Lateral cross-sections of the conceptual seawall design and construction with single pile wall

(a) Step 1: Installation of controlling rectangular pile groups and single connecting rectangular piles with in-situ grouting for impermeability; (b) Step 2: Pumping seawater out of the cofferdam formed with the vertical seawalls; (c) Step 3: Consolidating the soft marine mud within the cofferdam via vacuum preloading with wick drains; (d) Step 4: Filling the empty space within the cofferdam with general soils or sand fills and in-situ compaction

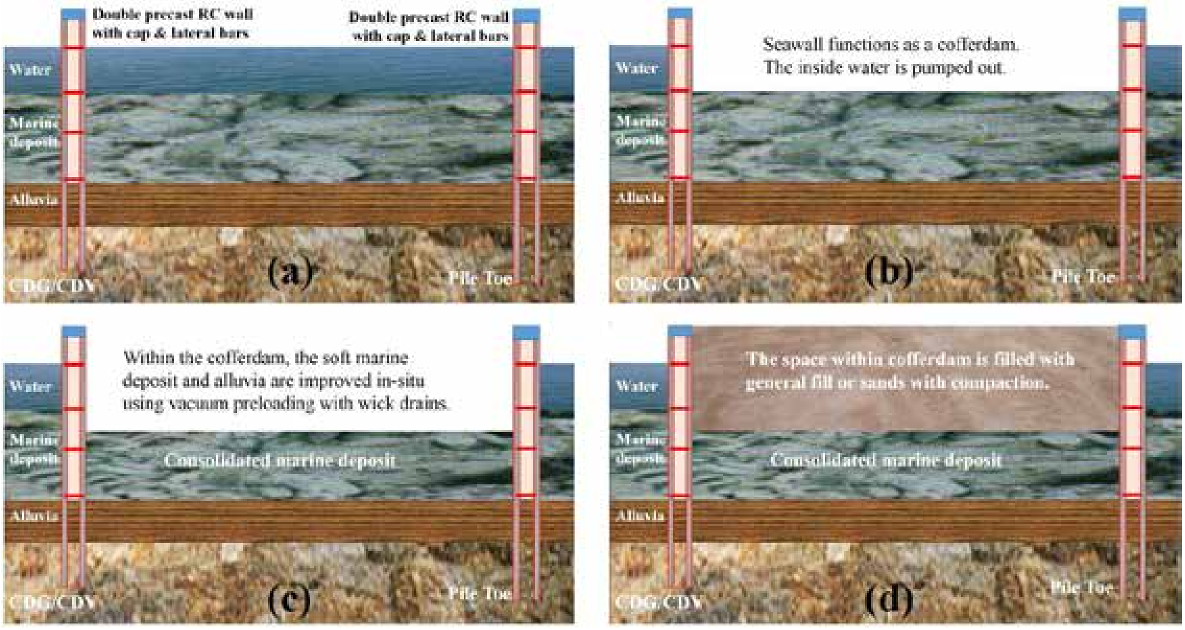

Figure 13: Lateral cross-sections of the conceptual seawall design and construction with connected double pile walls

(a) Step 1: Installation of controlling rectangular pile groups and two rows of connecting rectangular piles with in-situ grouting for impermeability; (b) Step 2: Pumping seawater out of the cofferdam formed with the vertical seawalls; (c) Step 3: Consolidating the soft marine mud within the cofferdam via vacuum preloading with wick drains; (d) Step 4: Filling the empty space within the cofferdam with general soils or sand fills and in-situ compaction

5 APPLICABILITY IN HONG KONG

5.1 Conventional dredge seawall and reclamation and concerns

The conventional reclamation practice is to dredge the thick soft marine deposit, build the seawalls and fill the enclosed space by sand (CEO 2002a, 2002b, 2004; Li et al. 2005a, 2005b). This conventional approach has many shortcomings in terms of adverse environmental effects, shortage of dumping site for dredged mud and large deformation and/or failure of conventional seawalls.

The seawalls can be vertical or sloping and include concrete blockwork seawalls, caisson seawalls, wave absorption vertical seawalls and rubble mound sloping seawalls. They also need to dredge the thick soft marine deposit and fill with sand and fractured rock aggregates. The concerns on environmental impacts have made extreme difficulty to be used again. These impacts are similar to reclaiming and include dredging and dumping of marine mud, impacts on water quality and ecology and marine traffic of large amount of backfilling materials.

5.2 The first and only no dredge seawall and reclamation and concerns

Therefore, no dredge reclamation for both seawall construction and reclaiming land have been accepted and adopted in recent years. The advantages of no dredge reclamation include significant reductions of dredging and dumping and suspended particles, as well as reductions of backfilling material and construction marine traffic by 50%. The first and only example is the HK$7 billion Hong Kong Boundary Facilities (HKBCF) reclamation. It is a key element of the Hong Kong Zhuhai Macau bridge (HZMB) infrastructure.

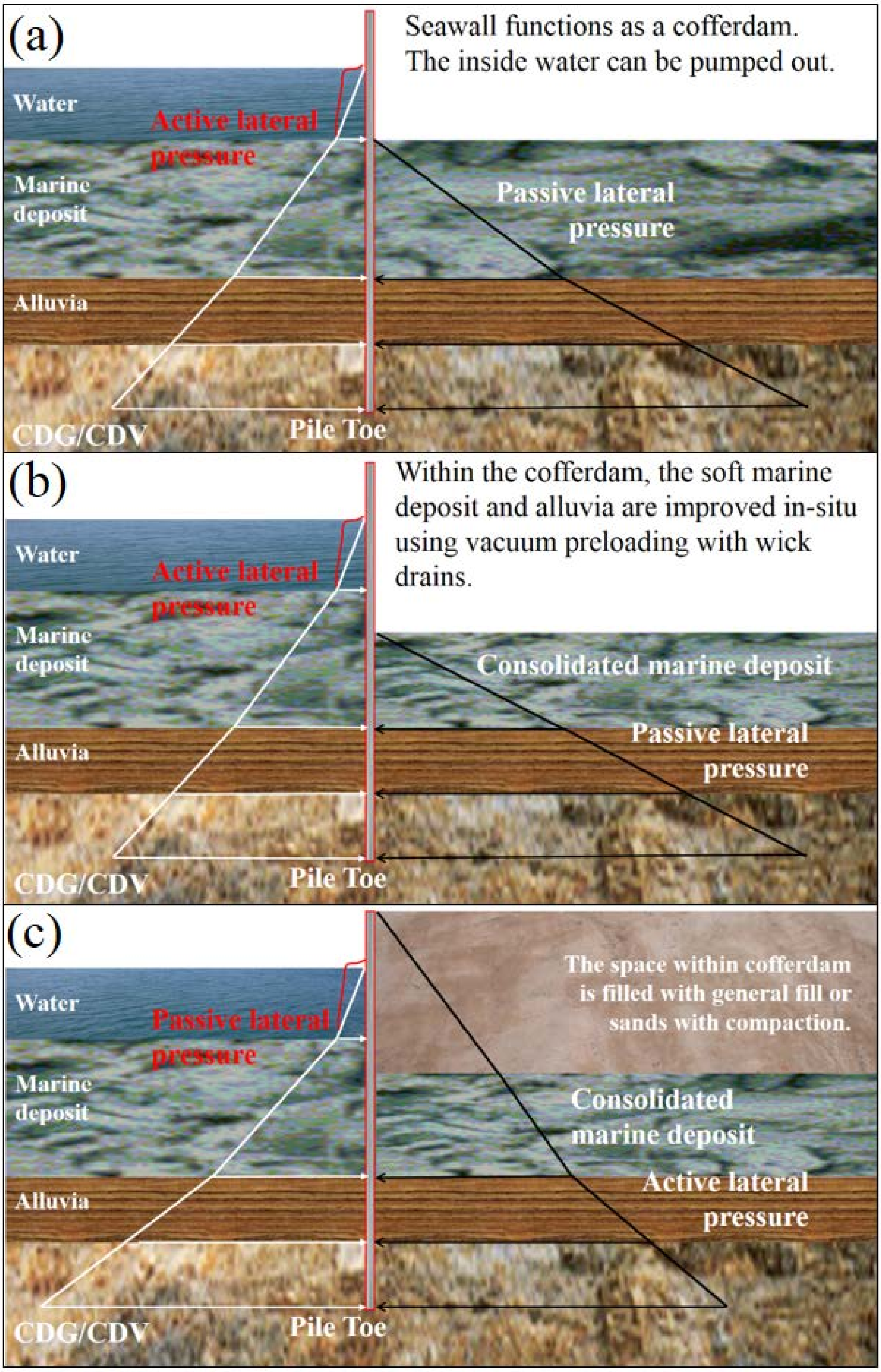

Figure 14: Geotechnical cross-section model for calculation and checking of displacement and stability of the vertical connected pipe walls

(a) Model for the cofferdam during pumping seawater out of the sealed space; (b) Model for cofferdam during treatment of soft marine mud with the cofferdam; (e) Model for the seawall during filling of the soil and after completion of the land reclamation works

The original completion date is the end of 2016, which has to be postponed to the end of 2017 or beyond (News, 2015). It may be due to many factors including the unexpected large deformation and movement of the no dredge seawall. The seawall comprises big steel circular caissons with a diameter of about 30 m. These were dropped into the sea 3 to 4 m apart and joined by a flexible steel wall. Each caisson weighs about 450 tons empty and as the mud is dug out from the middle it drives itself down until it reaches a hard stratum. Because of the huge weights and pressures and thick marine mud involved, the caissons can distort and sometimes tip and move. The sea wall is not expected to fail but it may not keep the correct shape. These unexpected issues have made another concern in local geotechnical community on the applicability of no dredge seawall and reclamation in Hong Kong.

5.3 Applicability

This project has demonstrated that no dredge seawall and reclamation are acceptable and suitable in Hong Kong. But, the large steel circular caisson seawall is too flexible to provide lateral constrains to the large lateral deformation of the soft soils under heavy weight loading of reclamation fills. So, excessive lateral-seaward displacement could occur in such steel caisson seawall. It has to be replaced by another no dredge seawall technology. The above GJPRCP technology can constructed RC seawall with high structural rigidity to retain the soft soils and to constrain their lateral deformation due to the fill weight. So, it can offer the method needed for design and construction of stable and rigid no dredge seawall. Subsequently, the no dredge land reclamation can be realized effectively and economically via the cost-effective and robust treatment of thick soft marine mud associated with the matured vacuum pre-loading with wick drains.

6 CONCLUSION

The GJPRCP technology has the following basic steps. (1) construction of precast reinforced concrete pile according to the site conditions; (2) Jetting of the pile into seabed using pressurized seawater; (3) grouting the I-beam and the tube for fixing the two connected piles and the thin soils on the side wall and the pile toe; (4) In-situ casting of the pile cap. Jetting for driving precast RC piles into soil ground has many advantages. It has no harm to the environment. It is robust and eliminates the quality uncertainty issues. It minimizes noise and vibration. It needs little grout for the thin soil at the pile-soil sides and toe. The tip grouting not only increases the tip resistance but also provides a proof test for adequate tip soil conditions according to design. Because it uses seawater to liquefy ground soils and RC pile own weight to sink itself into deep ground, it can use much less energy and become very cost-effective.

In particular, if boulders in alluvia and residual soils and/or corestones in the CDG or CDV soils are encountered, several methods can be used to overcome the obstacle. They include 1) to relocate the position of the pile nearby; 2) break the boulder or corestone with a hammer on the RC pile or steel bar; 3) supply highly pressurized water to break or shift the solid obstacle; 4) pre-probing such boulder or corestone with steel pipe jetting at the pile position; 5) using the corestones as the pile toe foundation and grout them together if they are very large and abundant.

The GJPRCP technology can offer the method needed for the design and construction of no dredge seawall and reclamation in Hong Kong. The seawall would be robust since it is formed by structurally connected precast RC piles. The settlement of the reclaimed land would be little since the thick marine mud deposit can be treated via matured vacuum pre-loading with wick drains and the fill soils can be compacted with high quality.

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