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Hydraulic Conductivity of New H-H Joint Steel Pipe Sheet Piles for Construction of Coastal waste disposal sites

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Abstract: *H-joint in steel pipe sheet piles is developed by welding H-steel section onto two steel pipe piles, it is completely waterproof, however, it would still have to alternate in series with problematic traditional joints; a joint referred to as H-H joint is proposed to alternate in series with the H-joint. H-H joint is formed from two H-steel sections of different sizes which interlock to form a joint. At interlocked state, the joint is not waterproof. The authors propose to seal this joint by coating the interlocking surfaces with a water-swelling paint with a view to applying H-jointed SPSP with H-H joints as cutoff barriers in coastal waste disposal landfills. Hydraulic conductivity tests are conducted on the H-H joint to evaluate its applicability and to determine a suitable thickness of water-swelling paint coating for sealing the H-H joints. Hydraulic conductivity of 10-8 cm/s is proposed for design of H-H joints sealed with the paint coat.*

Keywords: *Hydraulic conductivity, water-swelling paint, H-steel, H-H joint, steel pipe sheet piles*

I. Introduction

Due to strict environmental requirements and difficulties in land expropriation, in coastal cities and small area countries like Japan, Singapore, Korea etc, for inland landfill construction, coastal waste disposal landfills are increasingly being adopted and require large scale reclamations in ports and harbors near urban areas. In design of vertical cutoff barriers, conservation of port and harbor area as well as quality of waste material is considered. The cutoff must have both mechanical strength and low hydraulic conductivity in order to curb leakage of leachate from contained waste material to the open sea.

Coastal waste disposal facilities are in three designs: (a) rubble mound seawall, (b) caisson wall, and (c) double wall cutoff steel pipe sheet piles (SPSP), as shown in Figure 1. The rubble mound is mainly for stable (non-toxic) waste material but can suffer loss of riprap which leads to erosion of the toe by wave action and requires a large area since it must slope gently for stability purposes. Caisson type is for toxic waste materials; however, caisson has a shallow penetration depth. SPSP has good penetration depth, cheap and easy to construct as a cutoff barrier in coastal waste disposal landfills, but at the current state, there is a high risk of leakage of the leachate from contained waste through traditional SPSP joints.

Traditional joints in SPSP include L-T, P-P, and P-T joints as shown in Figure 2; among their shortcomings are as follows: (1) The joints must be grouted with mortar for sealing and increasing strength of the joint.

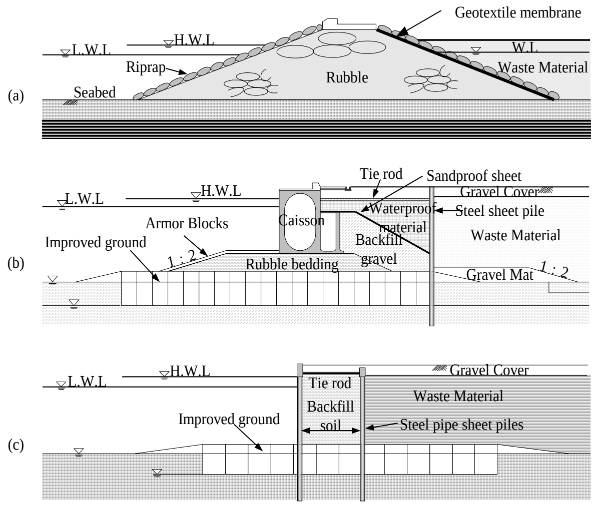


Figure 1.Types of cutoff walls for coastal waste landfills commonly used in Japan

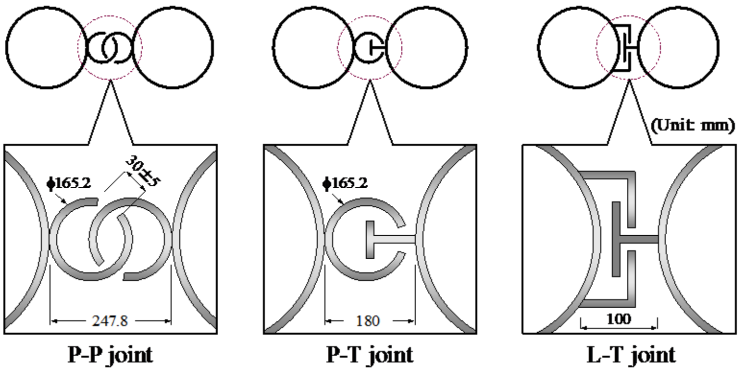
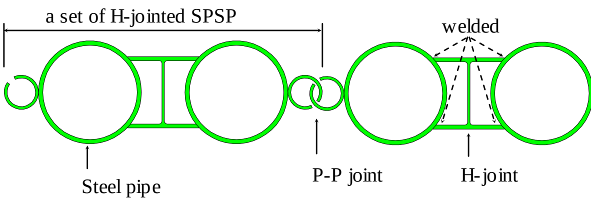


Figure 2. Types and sizes of traditional joints in SPSP



(a) H-joint alternating with P-P joint

(b) Photograph of H-jointed SPSP

Figure 3. H-joint steel pipe sheet piles

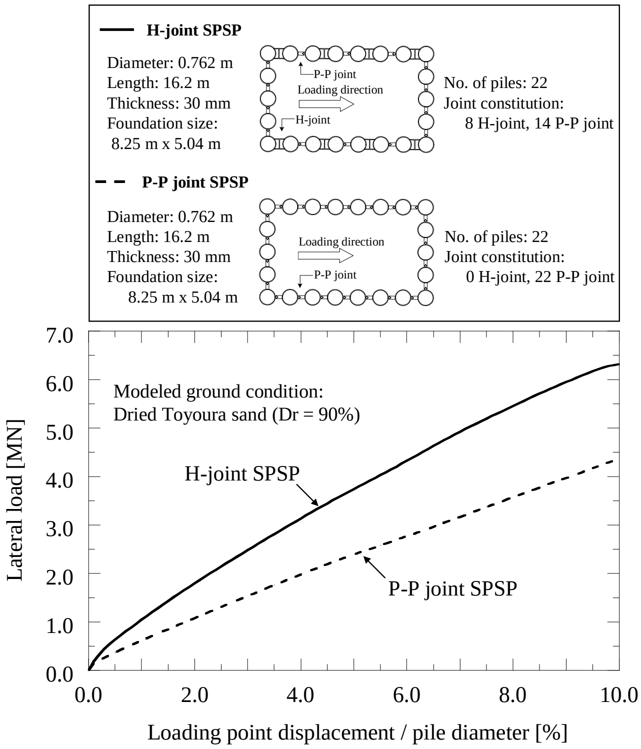


Figure 4. Lateral resistance property of H-joint and P-P joint SPSPs

The grouting process causes pollution leading to environmental degradation. (2) In the current practice, mortar is pumped into the joints after installation of SPSP is complete; in this construction procedure, it is difficult to control the quality of grouting, hence, existence of uncertainty with regard to effectiveness of such treatment. (3) Further, since the joints are submerged in a water body, injected mortar is packed to prevent segregation and the eventual dilution by the surrounding water body; this procedure increases the hydraulic conductivity of the grouted joints. (4) Excessive displacements and inclinations cause crushing of the traditional joints, especially, towards the tip of the piles making it near impossible to seal. (5) SPSP with traditional joints have low bending rigidity owing to vertical shear movements that occur at the joints under lateral load. (6) Only one pile is installed at a time leading to unnecessary long construction periods and high operation costs.

With the backdrop of these numerous problems in SPSP with traditional joints, Kamon [2] assessed leachate migration paths in double wall SPSP applied as cutoff material in coastal waste disposal landfills. They proposed that a hydraulic conductivity of 10^{-8} cm/s is required of SPSP to effectively prevent leakage of leachate. To maintain this hydraulic conductivity over the whole SPSP wall, waterproof treatment of SPSP joints must be done to achieve hydraulic conductivity of the order 10^{-7} cm/s [2]. It is difficult to meet the required low hydraulic conductivity value using the traditional joints filled with mortar, Kimura [3] have therefore developed H-joint SPSP and proposed H-H joints to alternate in series with the H-joints.

In this paper, H-joint and H-H joint is described, evaluation of the hydraulic conductivity of H-jointed SPSP with H-H joints is done through experiments using full size joints. Water-swelling hydraulic sealant is used to seal the H-H joints, effectiveness of the sealant is demonstrated.

II. Developed H-Joint

Kimura [3] in an innovative contribution developed a new H-joint from a simple idea in which two steel pipe piles are connected by H-steel section welded on them as shown in Figure 3. The H-steel section is what is referred to as the H-joint and will still have to alternate in series with the traditional joints pending development of another suitable joint. The connected piles are easily driven simultaneously by any of the existing pile driving methods. Among advantages of H-joint piles are as follows:

(1) H-joint SPSP have high bending rigidity because H-steel section is welded rigidly and continuously against two steel pipes. Kimura [3] have shown by centrifugal modeling on rectangular H-joint SPSP foundations that H-joint SPSP exhibits higher lateral capacity than the SPSP with traditional joint connections (Figure 4).
(2) Precision of construction is high, with an accuracy of ±3 mm in the horizontal direction; this is because one side of H-joint pile has flat-like shape that minimizes inclination of the pile during driving [4].
(3) H-joint is completely water-proof because of the continuous welding, and can prevent backfill sand behind a seashore protection retaining wall from being washed away by water undercurrents.
(4) Use of the H-joint is environmentally friendly since it reduces the number of grouted joints.
(5) Two connected piles are driven simultaneously thus reducing the number of driven piles, shortened construction period and reduction in operation costs [4].
(6) Any foundation shape can be constructed.
(7) The H-joint increases strength per unit length which means smaller foundation dimensions can be designed hence less amount of steel material is required.

Clearly, the H-joint satisfies permeability and bearing capacity requirements. The only point of contention is the fact that it will still alternate with the problematic traditional joints. The authors are proposing H-H joint, described below, to alleviate this condition.

III. Proposed H-H Joint

H-joint is found to remediate problems of the traditional joints, however, at the current state it will still alternate in series with the problematic traditional joints. In order to do away with the use of traditional joints, another joint referred to as H-H joint is proposed; it is designed to alternate in series with the H-joint. H-H joint is formed from two H-steel sections of different sizes; sizes of their web heights and flange width are such that the two H-steel sections fit into one another as shown in Figure 5. H-steel coupling is welded on either side of H-jointed SPSP. The first H-joint pile with its couplings is installed; a second pile is driven adjacent to the first one such that their H-steel couplings interlocking to form H-H joint as shown in Figure 5. At the interlocked state, the joint is not completely waterproof. The authors, therefore, propose to seal this joint by coating the interlocking surfaces with a water-swelling paint whose properties are described in section 4.2. In this study two H steel sections of H250 x 250 x 9 x 14 mm and H200 x 200 x 8 x 12 mm formed the test H-H joint.

A. Advantages of H-H Joint

(1) It has high vertical and horizontal construction accuracy; unlike in the case of traditional joints which are prone to failing/crushing owing to low construction accuracy, the possibility of H-H joints failing is not expected due to high installation accuracy.

(2) They increase the mechanical stability of SPSP structures as has been proven of the H-joint SPSP through centrifugal model tests [3].

In evaluation of hydraulic conductivity of cutoff walls, the surface area over-which water is likely to leak through

is important in the correct interpretation of hydraulic conductivity. In SPSP, this surface area is defined as the horizontal distance (B) of the cutoff SPSP wall by the pile length (L) in contact with contained water; the flow distance being the thickness (T) of the wall, as illustrated in Figure 6. Hydraulic conductivity will describe the rate of flow of contained water through the cutoff wall to the outside.

The H-jointed SPSP with H-H joint has a bigger B which is more effective in water exclusion than SPSP with traditional joints because the H-joint portion is welded thus treated as an impermeable surface as shown in Figures. 5 and 6. This means the ratio of perfect waterproofing area per unit distance B is much bigger in the H-jointed SPSP with H-H joints than for the traditional joints.

(1) The proposed water-swelling paint is coated over the interlocking surface of the H-H joint before construction, this process is accomplished in the factory where quality of coating is controlled to produce uniform coating and ensuring compliance with the required bonding strength between the paint and steel necessary to resist any damage during construction; the high construction accuracy achieved in H-jointed SPSP with H-H joints will almost guarantee no-damage state of the water-swelling paint. Waterproofing treatment of the traditional joints, on the other hand, is done after construction completion, this procedure does not guarantee complete impermeability since it is difficult to control the quality of mortar application. Also, because of its low construction accuracy, failure of the traditional joints occur because of excess inclination or horizontal displacement at the lower lengths of the SPSP which leaves mortar to be the only means of sealing such failed joints; this explains why most authorities are reluctant to extensively apply SPSP in toxic waste containment facilities.

(3) H-H joint can maintain a high hydraulic conductivity without mortar filling, the use of a water-swelling paint will suffice.
(4) With the use of a water-swelling paint to seal the H-H joint, the joint is waterproof and does not require use of mortar. If need be, at the discretion of the client, for mortar to be put at the H-H joints it will be environmentally safe since the swollen paint coat will have isolated the mortar application point.
(5) It is easy to apply the water-swelling paint over the interlocking surfaces of the H-H joint because the surfaces are flat plane unlike the traditional joints which have curves and corners that make it difficult to apply mortar.

IV. Permeability Test On Sealed H-H Joint

T The object is to evaluate the performance of H-H joint sealed by water-swelling paint sheet when exposed to 0.02 - 0.5 MPa water pressure in a coastal waste disposal facility; it is done by carrying out hydraulic conductivity tests. The thickness of the paint coat affects its swelling volume and the resulting swelling force; this determines waterproof strength of the paint at the H-H connection and therefore a suitable thickness of the paint coat that will produce required pressure resistance will be estimated.

A. Properties of the Water-Swelling Paint

The water-swelling paint swells when it comes in contact with water; it is a solid with fluidity blending of water-absorbing polymer, filling-agent, and fluxing material into synthetic-resin elastomer as a base material. Water extracted from dried coating film of the water-swelling paint has been tested and found to satisfy the standard of water-purity based on the food hygiene law, and to suit the reduction of environmental impacts. The water-swelling paint used in the experiment begins to swell after 1 to 2 hours after it comes in contact with water, and the volume will be increased to about 20 times of the original volume after 24 hours achieving a hydraulic conductivity of 1.42 x 10^{-9} cm/s. Figure 7 shows the swelling property of the water-swelling paint over 24 hours after immersion; the y-axis is obtained by dividing the weight of the swollen paint coat after immersion for time, t, by the weight of that paint coat before immersion.

B. Specimen Description

Table 1 shows the test cases; Case-1, Case-2 and Case-3 had a paint sheet of 1, 2, and 3 mm respectively. The H-H joint specimen was welded at the bottom and the sides of a 450 x 350 x 300 mm steel chamber shown in Figure 8 so that water paths were only at the H interlocking surfaces. Rubber packing placed over the top of the chamber is for ensuring watertight conditions in the chamber. The steel plate is bolted over the rubber covered chamber. The influent flow and collected effluent flow was measured by the calibrated water reservoir and by weight using a weighing machine shown in Figure 8, respectively.

C. Hydraulic Conductivity Test Procedure

The layout of the apparatus used in the test is shown in Figure 8 and the test was as follows:
1) For ease of using, the water-swelling paint sheets were used, they were glued over the H flanges at the interlocking interfaces by a high strength adhesive as shown in Figure 8.
2) Water was introduced into the three compartments in the chamber so that the largest surface area of the paint-sheets was wetted and balance of water pressure in the chamber.
The steel plate cover was bolted over the rubber packing onto the chamber before swelling process of the paint-sheet began, this procedure ensures that swelling is only in the horizontal and transverse directions. Excessive swelling in the vertical direction at the top of the chamber makes bolting of the sheet plate difficult and ineffective against air-tightening.
3) The sealed model was kept at immersed state for 24 hours at maintained temperature of 20°C to allow time for the paint sheet to react and swell to its optimum.
4) Water was put in the reservoir tank and into the effluent collecting cup.
5) The air compressor accessories are fixed in the pressure inlet on steel plate cover and the outflow tube fixed in place to terminate into the effluent collecting cup.

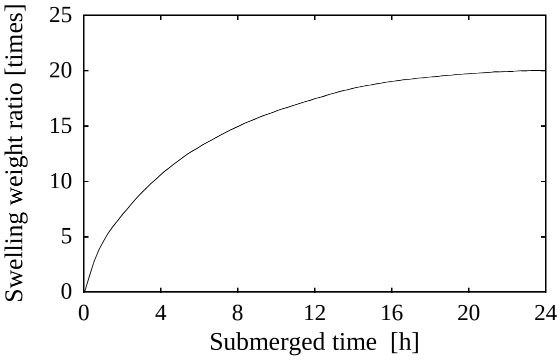
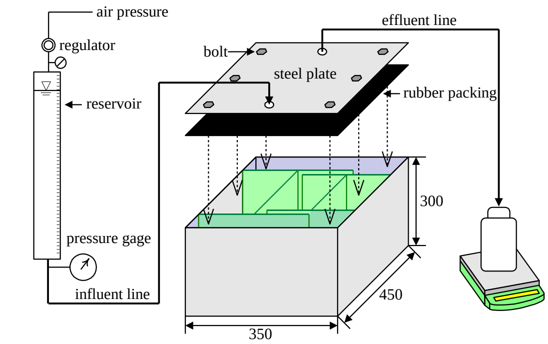
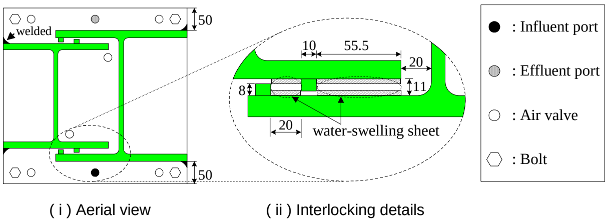


Figure 7. The swelling property of the water-swelling paint



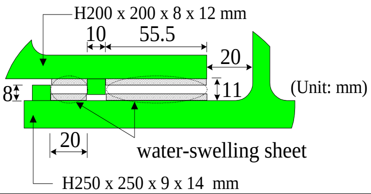
(a) Schematic diagram of hydraulic conductivity test set-up (Unit: mm)



(b) Schematic model aerial view and H-H joint interlocking details

Figure 8. Hydraulic conductivity test layout, model aerial view and details of H-H joint interlock

Table 1. Description of test cases

Test case	Case-1	Case-2	Case-3
Coating thickness	1 mm	2 mm	3 mm
H-steel and H-H joint interlock surface			

The following pressure amounts were applied: 0.02, 0.05, 0.1, 0.2, 0.3, 0.4, and 0.5 MPa. Each pressure level was maintained for 6 hours while monitoring and measuring the influent and effluent flow at intervals of 30 minutes to ensure stability, a total of 12 such measurements were made within the 6 hours. Stable condition is defined as that state in which the influent flow Q_{in} equals (approximately equal to) the effluent flow Q_{eff}. Leakage or presence of trapped air is detected when $Q_{in} > Q_{eff}$. [5].

6) At the end of Case-1 tests, the other cases were done following the same procedure.

In Japan, the specified standard hydraulic conductivity of waterproofing structures in coastal waste disposal landfills is 10^{-6} cm/s; it is based on hydraulic conductivity of a 50 cm thick soil layer. Since the current standard do not expressly specify standards for SPSP as cutoff walls in waste disposal landfills, the measured hydraulic conductivity of the SPSP are thus converted to equivalent hydraulic conductivity for an homogenous soil layer whose dimensions are equal to those used to develop the Japanese hydraulic conductivity ($k \leq 10^{-6}$ cm/s) standard as shown in Figure 9. The equivalent hydraulic conductivity was calculated from Equation (1):

$$k_e = \frac{Q_{in} \cdot T}{B \cdot L \cdot \Delta h} \qquad (1)$$

where, Δh is the water head difference [cm], T is the converted flow distance [cm] (T = 50), B is the breadth of the flow area [cm], L is the length of flow area [cm], and Q_{in} is the influent flow at each time and for each swelling paint-sheet.

V. RESULTS AND DISCUSSIONS

Figure 10 shows measured hydraulic conductivity for H-jointed SPSP with H-H joint sealed with water-swelling paint sheets of thickness 1, 2, and 3 mm against water pressure; also shown are equivalent hydraulic conductivity for P-T joints sealed by mortar and rubber[6]. It is observed that k_e for H-H joints depends on water pressure; it increases with increasing water pressure, this may be because of the elastic nature of the water-swelling paint sheet. Paint sheets with thickness of 2 mm and above meet specified hydraulic conductivity of $k_e \leq 10^{-6}$ cm/s [1] for water exclusion structures up to water pressures of 0.5 MPa. On the other hand a 1 mm paint coat meets the standard k_e of $\leq 10^{-6}$ cm/s up to a water pressure of 0.4 MPa.

In coastal waste disposal landfills, maximum water level difference between the contained water and the outer sea level must not exceed 2 m [6]; this level is controlled during heavy rains, water tide variations, and high water waves. Reports, however, indicate that some landfills have been filled to 5 m way beyond the specified limit of 2 m water level difference. It is important therefore to evaluate k_e of H-jointed SPSP with H-H joints for application as a cutoff material in waste disposal landfills based on the 5 m (equivalent to 0.05 MPa water pressure) rather than the specified 2 m (equivalent to 0.02 MPa) water level difference.

From Figure 10, k_e for H-H joints coated with 1 and 2 mm paint sheets was very low in the order of 10^{-8} cm/s at a water pressure of 0.05 MPa; k_e for the 3 mm paint coated joint was too small and could not be measured, since there was not effluent flow collected in the 6 hour test duration, k_e can be said to be below 1 x 10^{-9} cm/s. The authors propose use of $k_e = 10^{-8}$ cm/s in design of H-H joints sealed with this water-swelling paint. When compared with findings of Oki [5], at 0.05 MPa the H-H joint has k_e of 2-order difference compared with the P-Ts joint sealed with mortar. The P-T joint sealed with mortar and rubber membrane is found to have $k_e = 10^{-8}$ cm/s like was the case with H-H joint, however, this value is based on laboratory findings in which application of mortar and the rubber membrane can easily be controlled; the case may not necessarily be true in actual construction practice because P-T joint treatment is done after construction and SPSP with this joint have low installation accuracy. Based on the advantages of the H-H joint SPSP mentioned in section 3.1 and backed by the measured low hydraulic conductivity values, the use of H-jointed SPSP with H-H joints sealed by water-swelling paint is highly recommended as a cutoff material in coastal waste disposal landfills, shoreline retaining walls, and in the construction of bridge pier SPSP foundation among other applications.

In this study the H-H interlock surfaces were sealed using water-swelling paint sheets, however, other methods of applying the water-swelling paint exist namely applying it in the form of paste. Unlike using a paint sheet which can easily peel off during construction, the pasted sealant bonds more strongly with the steel material than the sheet type hence recommended.

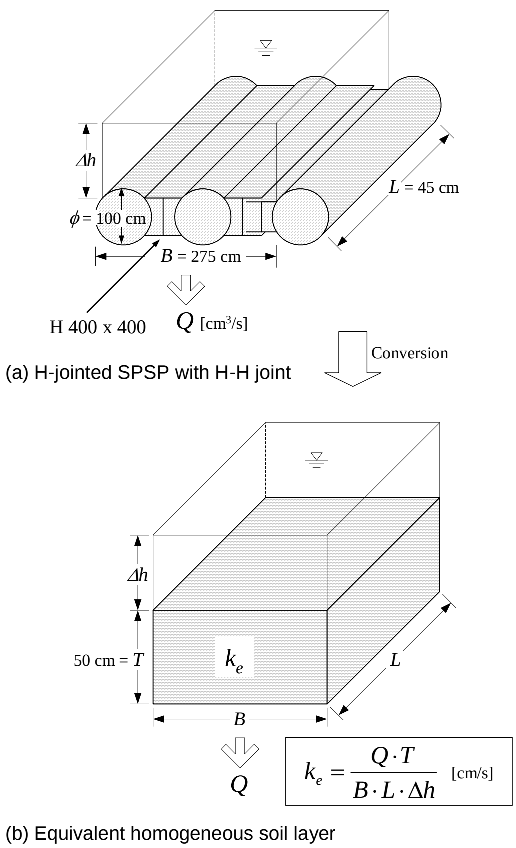


Figure 9. Conversion of the size of H-jointed SPSP with H-H joints into an equivalent homogeneous soil layer

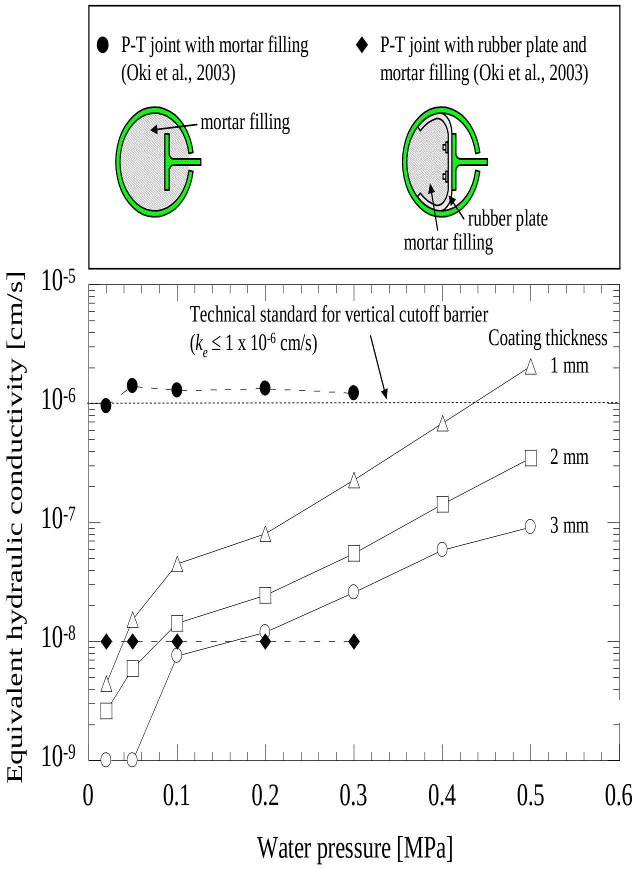


Figure 10. Equivalent hydraulic conductivity versus resisted water pressure

VI. Conclusions

The waterproof property of the H-H joint in SPSP is satisfactorily improved by coating it with the proposed water-swelling paint.

1) The hydraulic conductivity of the H-H joint treated with the paint coat depends on amount of applied water pressure.
2) The coating thickness of water-swelling paint controls water pressure resistance of treated H-H joints.
3) Hydraulic conductivity of 10^{-8} cm/s is proposed for use in design of H-H joints sealed with this water-swelling paint in applying as a cutoff barrier in coastal waste disposal landfills.

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