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Observations from opening of a novel geotextile tube connection in field test site

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ABSTRACT

A novel connection configuration for geotextile tubes was proposed, involving the insertion of an auxiliary tube between two main tubes, to ensure proper alignment and leveling when connecting them in a series, thus consolidating individual tubes into a unified structure while maintaining a consistent horizontal level. The novel connection was implemented at a test bed site in the Saemangeum reclaimed area, South Korea, to test exposure to the marine environment including sea waves, sun light exposure and reclamation process. This study presents the observations made upon opening the connection tube after 8 years. The observation shows that the connected geotextile tubes using the proposed auxiliary tube are suitable for use in long-term reclamation projects.

1. Introduction

Geotextile tubes are sustainable, large, permeable fabric containers filled with slurry materials, commonly employed in civil infrastructure projects (Alvarez et al., 2007; Chu et al., 2012; Corbella and Stretch, 2012; Howard et al., 2018; Kelln et al., 2007; Kim et al., 2018; Lee and Douglas, 2012; Restall et al., 2002; Rowe et al., 1984; Saathoff et al., 2007; Shin and Oh, 2007; Yang et al., 2019; Yee et al., 2007, 2012). The common practice of connecting geotextile tubes in series with a 2–3m lap, as shown in Fig. 1, often results in gaps and uneven vertical profiles, leading to potential subsidence. This can cause long-term subsidence (Mao et al., 2022) and a non-continuous longitudinal profile at the connection points. The specific topic of geotextile tube connection has not been discussed in literature (Kim et al., 2024).

To address the connection issue, Kim et al. (2024) introduced a novel construction method for joining geotextile tubes in series, aiming to create an even vertical profile and prevent subsidence. The proposed method combines multiple geotextile tubes into a single, continuous structure, and was successfully employed in a field test site. After 8 years, the geotextile tube at the connection sections was opened, and the observations are presented in this technical note. The unique contribution of this technical note is the examination of the connection sections of the tubes, which provides new insights into its performance over an extended period. These observations can be beneficial for the engineering community, providing insights into the effectiveness of the proposed connection and aiding in the decision regarding the optimal length of the connection tube.

2. Background

2.1. Overview of connection configuration

The proposed connection configuration by the Kim et al. (2024) is presented in Fig. 2. Initially, the tubes are aligned and positioned together, followed by connecting the primary tubes through primary-primary connections. The auxiliary tube is then connected to the primary tube via the primary-auxiliary tube connection section, as shown in Fig. 2. The filling sequence involves first filling the primary tubes and subsequently filling the auxiliary tube, as illustrated in Fig. 2. For detailed information on the connections, refer to Kim et al. (2024).

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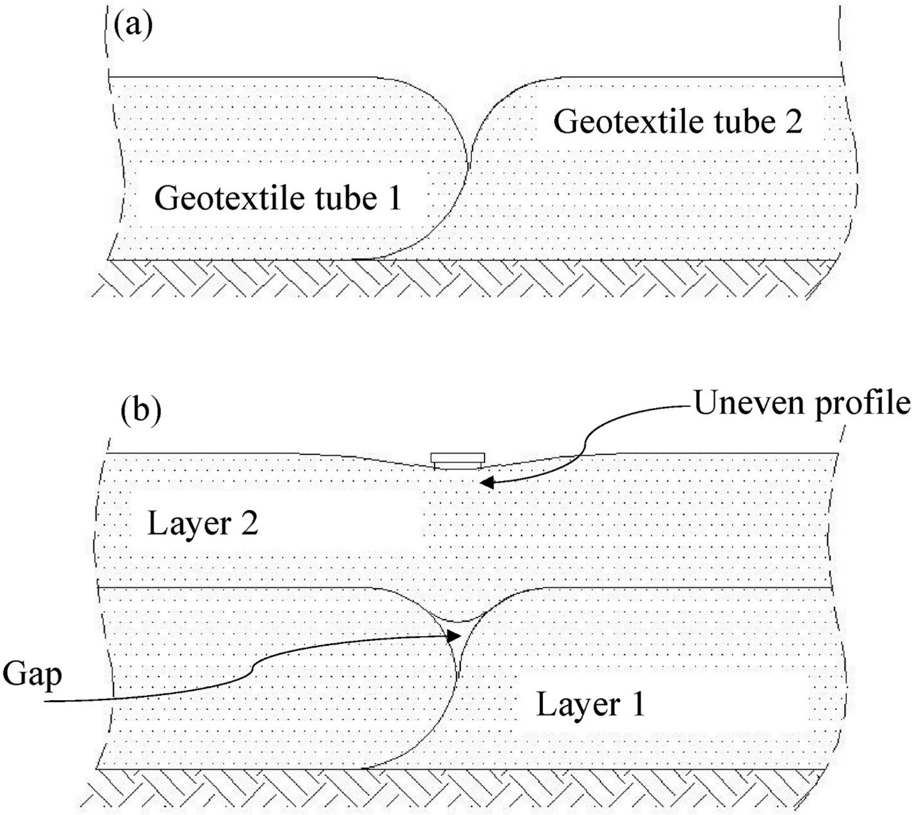

Fig. 1. Current state of practice of placing geotextile tubes a) adjacent tubes, b) stacked geotextile tubes.

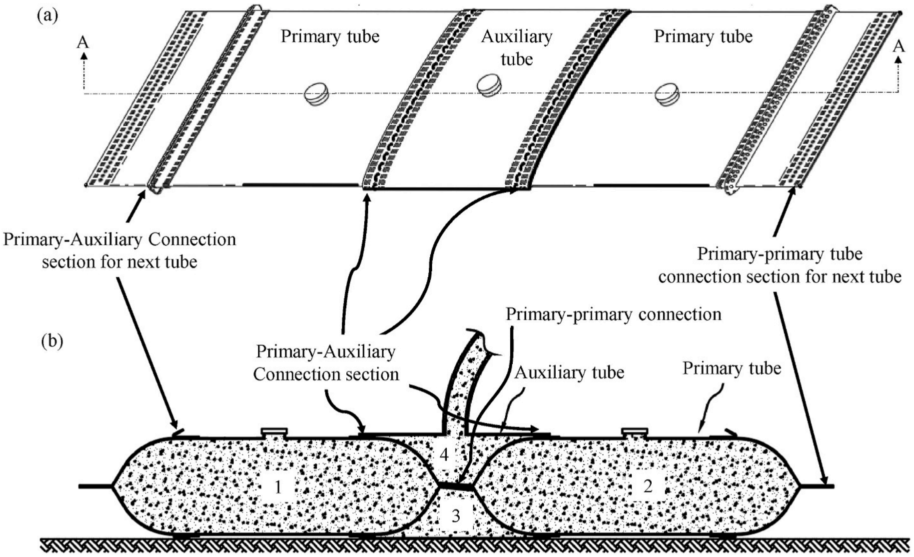

Fig. 2. a) Proposed novel connection assembly plan, b) sectional elevation AA and filling sequence.

2.2. *Materials*

The dredged soil was placed into a test tube with 15.9% natural water content, specific gravity of 2.687, non-plastic behavior and 25% passing through the No. 200 sieve classified silty sand (*SM*) as per *USCS*. The geotextile woven tube, made of polyester with an apparent opening size of 315 μm and permeability of 8.5×10^{-5} m/s was used for the test tube. Tensile strengths were 176.1 kN/m (14.3% elongation) in the wrap direction and 168.6 kN/m (13.7% elongation) in the weft direction (see Table 1). The standard nylon zip cable ties used at the primary-auxiliary tube connection have a tensile strength of 491 *N*.

2.3. *Construction at test site*

The test tube was constructed in the marine environment of the Saemangeum reclaimed area, South Korea, to observe its performance during filling and over an extended period. Two main geotextile tubes, each having a theoretical diameter of 3 *m* and extending 25 *m* in length, were joined together using a 12 *m* auxiliary tube (connection), thereby achieving a combined test site length of 50 *m*.

Table 1
Specifications of the Geotextile tube (Kim et al., 2024).

Characteristics	Value
Composition	Polyester
Manufacture	Woven
Apparent opening size (AOS)	315 μm
Permeability	8.5×10^{-5} m/s
Wrap direction tensile strength	176.1 kN/m
Wrap direction elongation	14.3%
Weft direction tensile strength	168.6 kN/m
Weft direction elongation	13.7%

The assembly of connected geotextile tubes was transported to the test site, and the following steps were taken for their construction: Since the test site was located in water, an access road and platform were first prepared. Site surveys were then conducted to measure the elevation of the proposed construction bed. Afterward, a layer of geosynthetics was placed on the bed. The connected geotextile tube assembly was positioned on top of this geosynthetics layer. Steel rods were placed in order to retain the geotextile tubes in place during the filling. Saemangeum silty sand, a reclaimed soil, was dredged using an excavator and fed into the hopper (see Fig. 3a and b). Refer to Kim et al. (2024) for further details.

Fig. 3 illustrates the various construction stages, with Fig. 3c specifically showing the primary-auxiliary tube connection secured with nylon ties in the holes. Concerns regarding the effectiveness of the connection section include its performance during filling, long-term stability, and ensuring the auxiliary tube's length is sufficient to prevent loss of filling material. As shown, the connection section performed well during filling, neither opening of tube or the nylon ties was observed. However, in this technical note, the tube is opened to examine the soil deposition profile within the connection length. This observation provides further insight into the optimal length required for the connection tube.

Fig. 3. Construction stages of test tube, a, b) filling of primary tube, c) view of the primary-auxiliary tube connection during auxiliary of tube filling and d) view after completion of filling/construction (Construction December 2015).

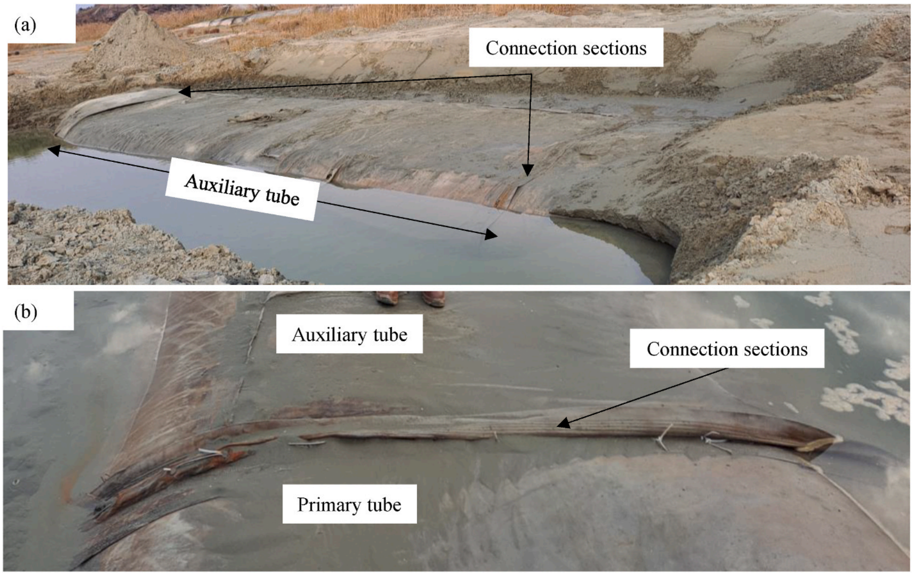

Fig. 4. a) View of connection section, after excavating reclaimed soil and b) connection section primary-auxiliary tube.

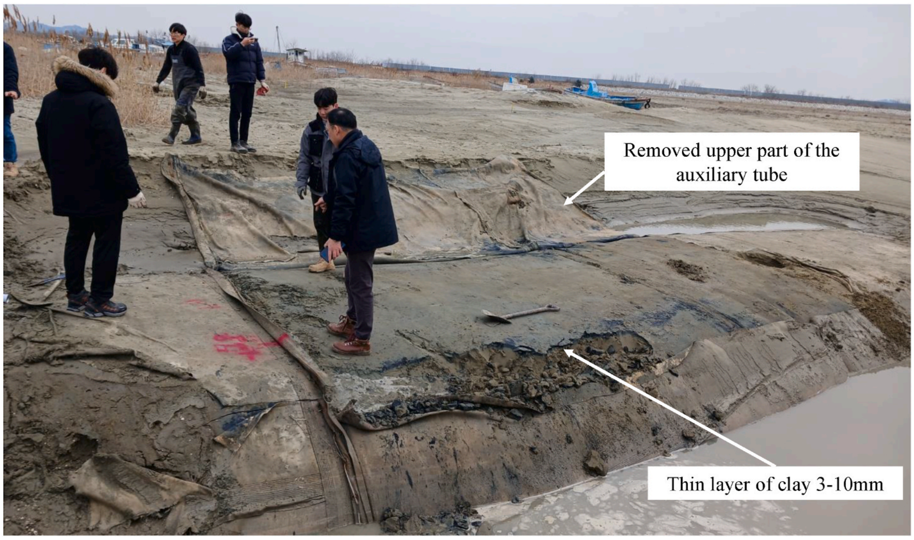

Fig. 5. Removing the upper part of the auxiliary tube from connection sections.

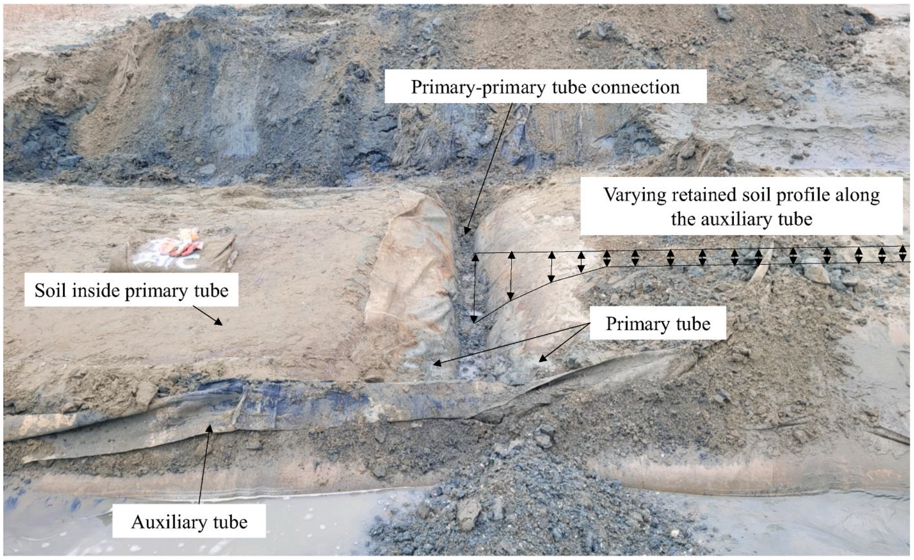

Fig. 6. Removal of the retained soil from the connection section.

3. Tube opening observations at the test site

The test connection tube, situated on reclaimed land, endured various weather conditions and water wave actions up to 2017, during which time the connection section remained intact. The wave height experienced by the geotextile tube ranges approximately from 0.1 to 0.3

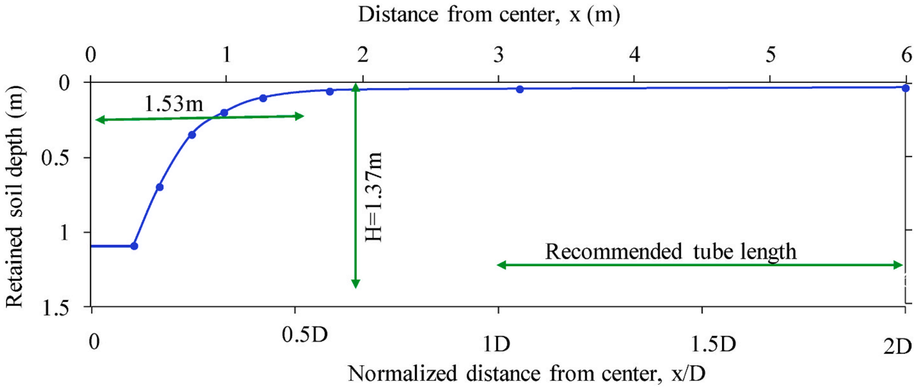

Fig. 7. Measured retained soil profile in the connection section.

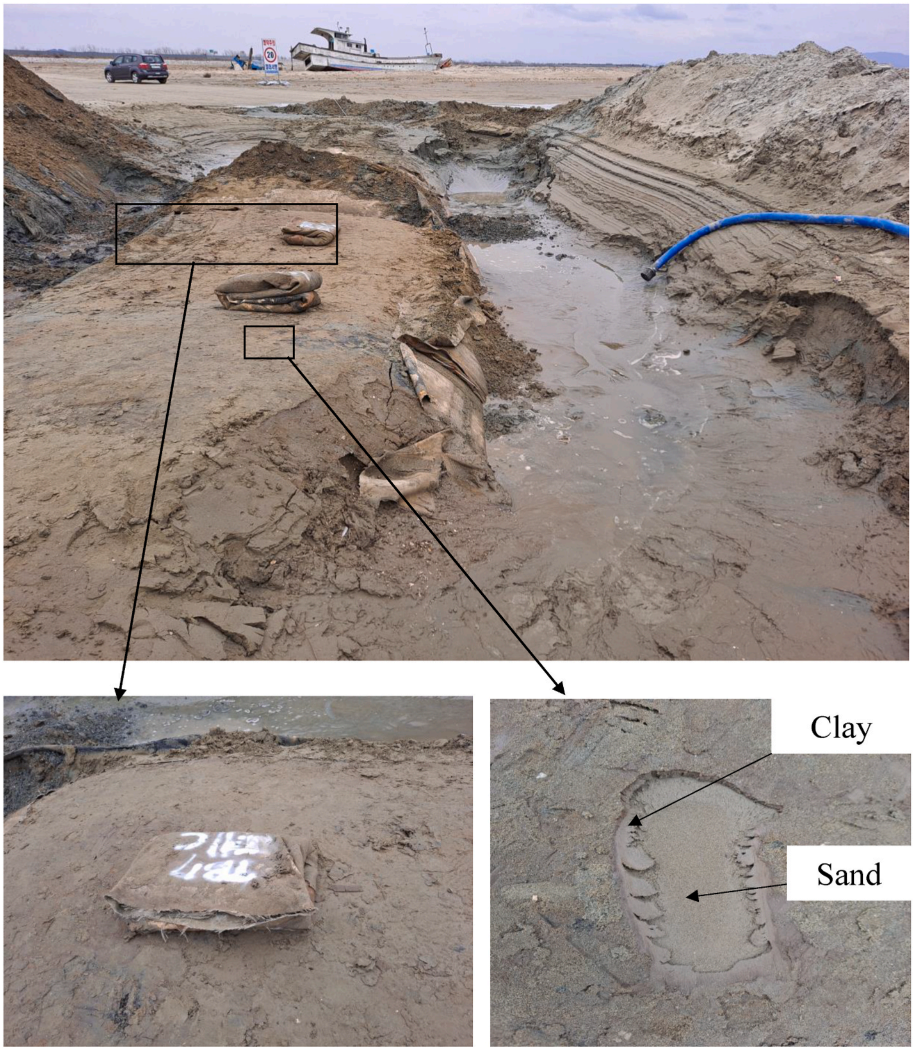

Fig. 8. Formation of filter cake around the geotextile tube in the primary tube.

m. After 2017, the reclamation process began, and the tube was buried under reclaimed soil. In 2023, the tube was excavated (Fig. 4), marking the end of an 8-year period of both exposure and burial. The observed connection section is shown in Fig. 4b. It is worth noting that the tubes height was roughly 30–50% of their theoretical diameter (D).The measured base width and height of the tubes were $B = 7.48\ m$ and $H = 1.37\ m \approx 0.5\ D$, respectively, indicating no significant settlements at the connection section. Notably, both auxiliary-primary tube connection sections remained resilient, with no damage or loosening of the nylon ties.

The auxiliary tube from the connection section was removed, as shown in Fig. 5. At the interface between the woven geotextile and the filled soil, a thin clay layer of 3–10 mm, followed by silty clay known as filter cake, was observed (Fig. 5). During the slurry filling of the dredged soil, soil particles settled in the tube according to Stokes' law, with silty sand settling earlier than clay particles. The formation of the filter cake indicates that the material inside stabilized at the end of dewatering/consolidation and remained in a similar state long-term, preventing any loss of retained soil.

The retained soil in the connection section was removed to measure the profile, as shown in Fig. 6. The primary-primary tube connection section is located at the center of the auxiliary tube, as indicated in the figure. It can be observed that the deposited soil profile varies in a concave shape from the center towards the primary-auxiliary connection section. The measured profile, plotted in Fig. 6, shows that the maximum soil deposition occurs at the center and becomes constant at $1.53\ m$ ($\sim 0.5\ D$) from the center (where $D = 3\ m$ is the theoretical diameter of the tube), also this distance is close to the height of the tube ($H = 1.37\ m \approx 0.5\ D$). In the current test tube, the length of the auxiliary tube was $2D$ from the center (total $4\ D$). Therefore, it can be inferred that an optimal auxiliary tube length for effective connection is between $1D$ and $2D$ from the center (see Fig. 7).

Furthermore, the primary tube was also removed as shown in Figs. 6 and 8. The phenomenon of filter cake formation was more pronounced in the primary tube, as shown in Fig. 8, demonstrating that the dredged soil filling was stabilized at the end of the dewatering/consolidation process, forming a compact structure.

To observe the formation of the filter cake at the bottom of the geotextile tube, an excavation was performed as shown in Fig. 9. However, the presence of water made it difficult to measure the thickness of the filter cake. It is believed that, due to the permeable ground beneath the geotextile tube, dewatering occurred downward after filling, leading sedimentation settling resulting in formation of a similar filter cake at the bottom. However, the thickness of the bottom filter cake would be less than that of the filter cake at the top and sides.

The primary tubes' ends were closed using two rows of six stitches, with 30 mm diameter holes placed between these rows to facilitate the connection between the primary-primary tubes (see Fig. 5, Kim et al. (2024)). Nylon ties and steel wire were then used in these holes to secure the primary-primary connection. This method ensured that the

Fig. 9. View of excavated bottom of primary tube.

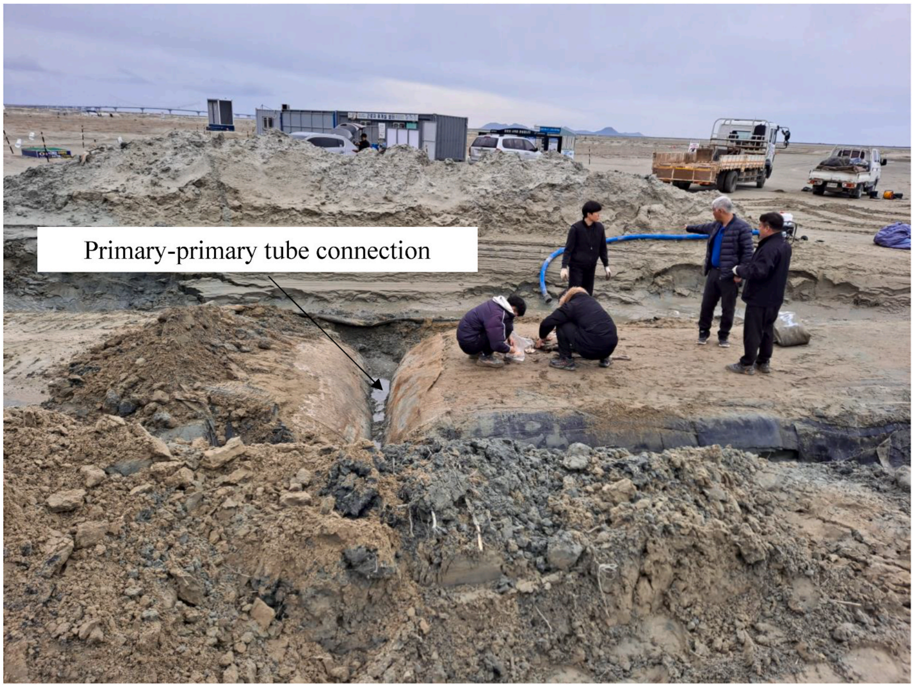

Fig. 10. View of primary-primary tube connection.

connection remained intact, it was evident on removing the surrounding soil in the auxiliary tube as observed in the intact nylon ties and steel wire (see Fig. 10). The construction of the primary-primary connection, particularly its role in retaining the soil within the primary tube, is evident in Fig. 9. The concave shape of the tube or the retained soil in the primary tubes underscores the importance of this connection in maintaining the structural integrity of the soil within the auxiliary tube. This retention of soil contributed to the overall stability of the primary-primary and primary-auxiliary connection. It can be inferred that stability of primary-primary connection results in concave profile of tubes, leading to improved soil retention within auxiliary tube and enhanced load distribution and structural performance.

4. Engineering implications

The proposed novel connection configuration and the observations presented from an 8-year period represent a pioneering study. Its availability to the engineering community establishes a foundation for future advancements in the field. To the best of the authors' knowledge, this connection challenge has not been addressed in existing literature.

However, in engineering practice, an alternative might be filling the gap between primary tubes with sandbags. The proposed novel auxiliary tube connection offers several advantages over this method.

1. The auxiliary tube connection provides cohesive integration of individual geotextile tubes into a unified structure, ensuring consistent vertical profile levels. In contrast, sandbags function as separate structures, which can make it difficult to maintain a uniform vertical profile.
2. The proposed connection effectively blocks water passage to maintain a dry platform, whereas sandbags often leave gaps between the primary tubes, making it challenging to prevent water seepage.
3. The novel connection configuration is pre-assembled during manufacturing and is robust, facilitating easier installation in the field. In contrast, using sandbags complicates construction and integration with the primary tubes.

This specific case study did not involve loading the test tube with a top tube, it did experience loading from construction equipment during the burial period from 2017 to 2023. Additionally, the same configuration has been successfully implemented in practice. A three-layer stacked auxiliary tube system was used to construct a dry platform for bridge construction, as discussed in Section 3.3 of Kim et al. (2024). The construction of the test bed was carried out in shallow marine water along the coast of the reclaimed area. While it is believed that the novel configuration would perform similarly in deeper water, future studies are warranted to validate its applicability in such conditions. Furthermore, ongoing investigations include tensile strength testing and Scanning Electron Microscopy (SEM) analysis of samples from the primary and auxiliary tubes to evaluate the effects of the marine environment on the geotextile material. A comparative study of pre-construction and 8-year post-installation performance will be conducted, with results to be documented in a forthcoming manuscript.

5. Conclusions

The opening of the proposed connection tube configuration after 8 years reveals following observations.

1. The woven geotextile of the connection tube remained intact despite prolonged exposure to harsh marine environments, including weather, wave action, and the reclamation process.
2. Upon opening the tube, the removal of the auxiliary tube revealed a thin clay layer, known as filter cake, with a thickness ranging from 3 to 10 mm at the interface between the geotextile and the filled soil. This demonstrates that the material inside the tube has been stabilized and that water can pass through the tube without any loss of material.
3. The primary-primary tube connection, as well as the geotextile material of the primary tube buried inside retained soil in the connection tube, was found to be intact. Additionally, upon removal of the primary tube, a filter cake similar to that observed in the auxiliary tube was found around the interface of the geotextile and the filled soil.
4. The soil retention profile within the auxiliary tube indicated that the primary-auxiliary tube connection configuration effectively prevented soil loss. Additionally, the observations suggest that a connection tube length of 1–2 D from the center is optimal for the present case. Therefore, the use of the proposed connection tube is effective in maintaining an even vertical profile of the tube in the long term.

Data availability

Detailed drawings can be provided upon request to the corresponding author.

CRediT authorship contribution statement

Hyeong-Joo Kim: Project administration, Funding acquisition, Conceptualization. **Myoung-Soo Won:** Writing – review & editing, Supervision, Formal analysis, Conceptualization. **Shamsher Sadiq:** Writing – original draft, Visualization, Investigation, Formal analysis. **Tae-Woong Park:** Visualization, Supervision. **Hyeong-Soo Kim:** Visualization, Supervision, Investigation. **Young-Tak Ryu:** Writing – review & editing, Visualization. **Young-Chul Park:** Visualization, Investigation. **Ji-Hwi Gwak:** Visualization, Investigation. **Tae-Eon Kim:** Visualization, Investigation. **Jeong-Ho Choi:** Visualization, Investigation.

Data availability

No data was used for the research described in the article.

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