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Geosynthetics in Sustainable Transportation Infrastructure Construction

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Abstract. Geosynthetics engineering has made phenomenal advances during the last decade in areas of manufacturing as well as practical applications. As a result, geosynthetics have become essential and regular construction materials that facilitate construction, ensure better short- and long-term performance and reduce the long-term maintenance cost in routine civil engineering works. Geosynthetics are also being recognized as fundamentals to sustainable infrastructure development as they reduce the carbon footprint contributed by infrastructure development by minimizing the use of natural resources. The creative use of geosynthetics in geo-engineering practice is expected to continuously expand as innovative materials and products are becoming available. In this paper, the issues related to global warming and sustainable benefits of geosynthetics are first discussed. Recent geosynthetics applications in transportation infrastructure development are introduced with research findings. Finally, the pathway forward regarding geosynthetics technology within the framework of sustainable infrastructure development is discussed.

1 Introduction

Since the first geosynthetic conference in Paris, 1977, geosynthetics have emerged as essential engineering materials in a wide range of civil engineering applications, e.g., transportation, geotechnical, geoenvironmental, and hydraulics [1]. Due to their cost-effectiveness, ease of installation, and well established mechanical and hydraulic properties, geosynthetics are now playing important roles in the field of geo-engineering. As indicated in the 9th Bucahanan Lecture paper by Holtz [2], major developments in civil engineering have only been possible with the parallel developments in the technology of construction materials. A good example of a parallel development in geo-engineering between the material and the geotechnical application may perhaps be the soil reinforcement technology which has a direct analogy with reinforced concrete. Thanks to the concerted efforts by the geosynthetic community in the past years, geosynthetics have become essential and regular construction materials that facilitate construction, ensure better short- and long-term performance and reduce the long-term maintenance cost in routine civil engineering works.

Despite the increased popularity of the use of the term "sustainability", the possibility that human societies will achieve environmental sustainability has been, and continues to be,

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questioned in light of environmental degradation, climate change, overconsumption, population growth and societies' pursuit of unlimited economic growth in a closed system. Being committed to sustainability will reduce the carbon footprint and the amount of toxins released into the environment, making our life safe. Climate change is already affecting people, ecosystems, and livelihoods all around the world. Tuvalu's foreign minister made an alarming speech to the United Nations climate conference in Glasgow (COP26) standing in knee-deep seawater to show how his low-lying Pacific Island nation is on the front line of climate change, drawing attention to Tuvalu's struggle against rising sea levels (Fig. 1). The fact that the construction industry is one of the largest users of global resources and contributors of pollution and GHG emission places a significant responsibility on the construction industry.

Fig. 1. Photos; (a) Tuvalu foreign minister giving a speech at COP26; (b) Tuvalu shoreline (Tuvalu Foreign Ministry | via Reuters).

In this paper, the global warming issues in relation to sustainable benefits of geosynthetics are discussed. Relevant case history of geosynthetic solutions for transportation infrastructure development are first presented. Recent advances in geosynthetics applications on transportation/geotechnical infrastructure systems are then introduced with emphasis on fundamentals and global challenges. Finally, the pathway forward regarding geosynthetics technology within the framework of sustainable infrastructure development is discussed.

2 Global warming – implications to construction industry

According to the Intergovernmental Panel on Climate Change (IPCC), human activities are estimated to have caused approximately 1.0℃ of global warming above pre-industrial levels, with a likely range of 0.8℃ to 1.2℃. Global warming is likely to reach 1.5℃ between 2030 and 2052 if it continues to increase at the current rate [3]. Limiting warming to 1.5℃ is possible within the laws of chemistry and physics but would require unprecedented transitions in all aspects of society. Consequences of global warming include an increase in global temperature, rising sea levels, changing precipitation, and expansion of deserts [4]. Fig. 2 illustrates human experience of present-day warming. As seen, nearly five billion people are experiencing 1.0℃ or more warming relative to pre-industrial in most strongly warming season.

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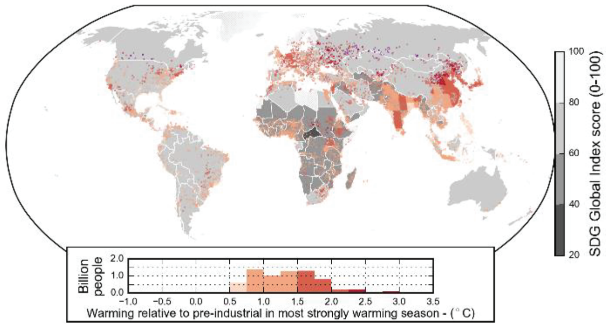

Fig. 2. Human experience of present-day warming [2].

In 2015 the United Nations (UN) recognised the need to establish a trajectory for sustainable development and set goals to achieve by 2030, namely the Sustainable Development Goals (SDGs), also known as the Global Goals. These include specific action plans to end poverty and protect the planet by 2030. A total of 17 SDGs is integrated as shown in Fig. 3 so that an action in one area will affect outcomes in others, considering social, economic, and environmental sustainability.

According to Gourbran [6], 17% of the SDG targets are directly dependent and 27% of the targets are indirectly dependent on construction and real estate activities. More importantly, some of them are clearly supported by geosynthetics at least in environmental and economic aspects.

Fig. 3. The 17 UN Sustainable Development Goals.

2.1 Sustainability in construction industry

The issue of sustainability has also become one of important agenda in the construction industry these days considering that the construction industry is one of the largest users of global resources and contributors of pollution and greenhouse gas (GHG) emissions as discussed earlier.

No doubt that construction has played a vital role in our societies from the beginning of human civilization and will continue to be a key player in sustainable infrastructure development. As members of the construction industry, we must fully recognize the industry's role in collaborating with a diverse set of professionals to act towards the common goals of building a better, healthy, and sustainable world for future generations.

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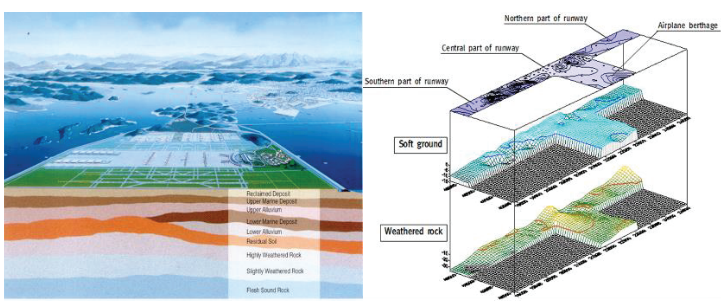
3 Geosynthetics solutions in transportation applications

Geosynthetics are not only sustainable solutions but also technically sound solutions, especially for transportation applications. In this chapter, examples of geosynthetics solutions are introduced together with case histories and on-going research results.

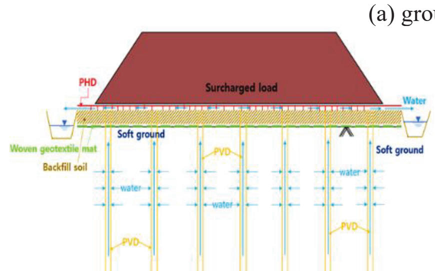
3.1 Geosynthetics in airport construction

Construction of Incheon International Airport, which is the main gate to Korea, began in 1992 on the reclaimed land between two islands. This project was initially scheduled for 1997 but delayed due to the economic crisis. The airport was officially opened on 21 March 2001 after successful excution of the project. Below is the summary of the work reported by Shin [7].

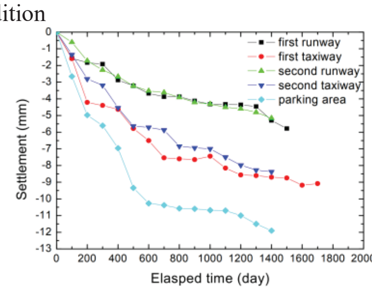
Because of the nature of the project, ground improvement was the key to the successful execution of the project considering the 10 to 15 thick, soft marine clay at the site, having undrained shear strength of 11-55 kPa with OCR of 1.1 to 1.3. The preloading method together with vertical drains (PVD) was adopted as the primary ground improvement method. More than 50 km of PVDs together with 65 million cubic meters embankment fill materials for surcharge were used to accelerate the consolidation of the marine clay deposit. Thanks to the successful execution of the observational method, the measured residual settlements at various locations after opening to service were less than 20 mm as shown in Fig. 4.



(a) ground condition



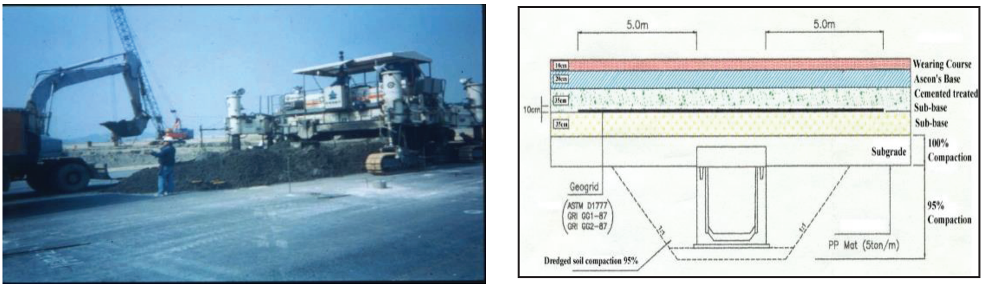
(a) typical cross section of PVD



(b) residual settlement after opening

Fig. 4. Incheon Int'l Airport construction in 1990s – PVD ground improvement [7].

Another interesting geosynthetic application was runway subbase stabilization using geogrids. As you can see in Fig. 5, a layer of geogrid was installed between the cement treated subbase and regular subbase to reduce the thickness of the subbase. In this project, a total of 9000 square meters of geogrid was used for all three runway subbase stabilization. This was the first case history of successful geogrid application in pavement in Korea.



(a) construction photo (b) subbase stabilization using geogrid

Fig. 5. Incheon Int'l Airport construction in 1990s – runway subbase stabilization [7].

This project indeed demonstrated that the geosynthetics are sound technical solutions. Without the geosynthetic solutions for the ground improvement as well as for the subbase stabilization, the project would not have been finished on time. This case history is a good old day's Korean experience (a success story) regarding the use of geosynthetics in transportation infrastructure development.

3.2 GRS bridge abutment

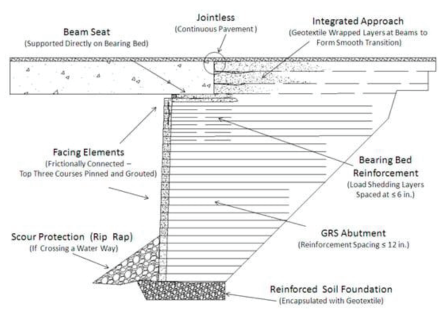


Fig. 6. Typical cross section view of GRS abutment [8].

Geosynthetic reinforced soil bridge abutment, known as GRS abutment, is becoming an economical and ease-of-construction alternative to some traditional bridge system in many countries. The bridge deck structure is constructed on top of reinforced soil structure and therefor is essentially a surcharge loaded GRS or mechanically stabilized earth (MSE) wall as shown in Fig. 6. When compared to traditional systems, the GRS abutment offers a number of technical and economic advantages, in addition to sustainable benefits, including its ability to alleviate the "bridge bump" caused by differential settlements between the bridge abutment and approach way, among others [8].

In the GRS bridge abutment system, the surcharge load is the combination of the superstructure weight and traffic loading which increases vertical stresses in the reinforced soil mass, thereby increasing the tensile forces in the reinforcement. The load carrying characteristics of the GRS structure is therefore of fundamental importance in implementing this technology.

Yoo and Kim [9] reported the result of a full scale load test on a GRS wall, which was conducted as part of a national research program focusing on the use of geosynthetics in transportation infrastructure construciton. The test wall was a 5 m high two-tier GRS wall. A gravity-type load was applied at the top of the wall using a precast concrete (PC) box frame, having dimensions of 2.4 m x 2.4 m in plan and 2.4 m in height, together with ready mixed concrete and a steel frame [Fig. 7(a)]. The load was applied in steps by controlling about of ready mixed concrete. A total of 348 kN of vertical load was applied on a concrete pad, placed immediately behind the facing with 0.2 m clearance, with the same footprint dimension of the PC box frame, exerting 62 kPa to the top surface of the reinforced zone. The vertical pressure level of 62 kPa can be considered to be a working stress (i.e., serviceability) condition that is the operational condition of most interest to designers.

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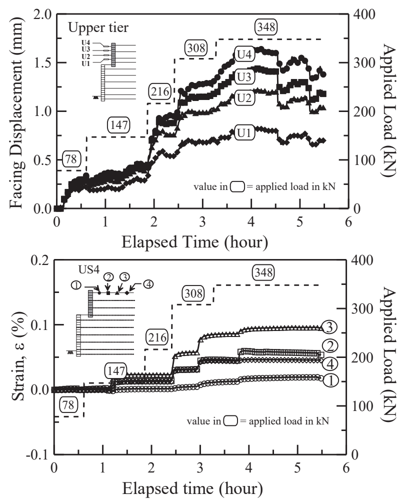
As shown in Fig. 7(b), the surcharge load of 348 kN, or 62 kPa, induced a maximum horizontal wall displacement less than 2 mm although no provision was made for the surcharge load during the wall design. In addition, the surcharge load included reinforcement strains were less than 0.1% in the top tier reinforcement with negligible reinforcement strains in the rest of the layers in the lower tier. The test results showed insignificant surcharge load-induced wall displacement and reinforcement strains, thus confirming that the surcharge load did not impose any threat to the internal stability of the test wall even though the wall was not designed for the surcharge load. An excellent load carrying capacity of the GRS wall was demonstrated in this study.

(a) test wall configuration



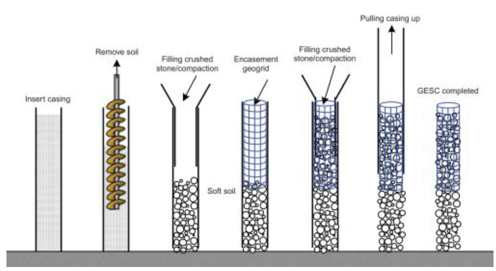
(b) test results

Fig. 7. Full-scale test wall configuration and results [9].

3.3 Geosynthetic encased stone column

The geosynthetic encased stone column (GESC) technique, shown in Fig. 8, has gained wide acceptance as a means of increasing the load carrying capacity of ordinary stone columns (OSC) installed in soft ground, where OSCs cannot be used because sufficient lateral pressure from the surrounding soil required to maintain the column integrity is not available.

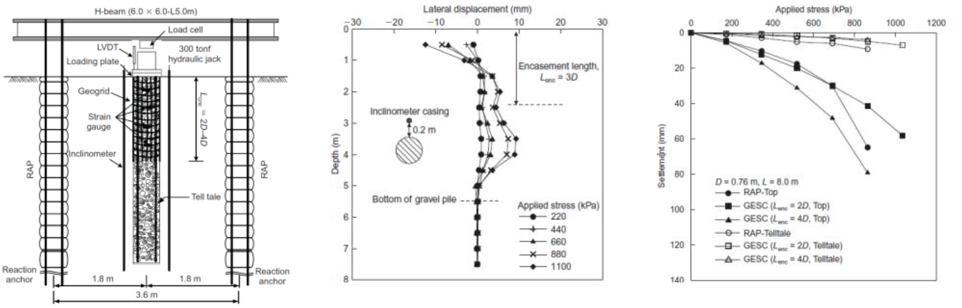
(a) schematic view



(b) GESC installation procedure [10]

Fig. 8. Geosynthetics encased stone column technique.

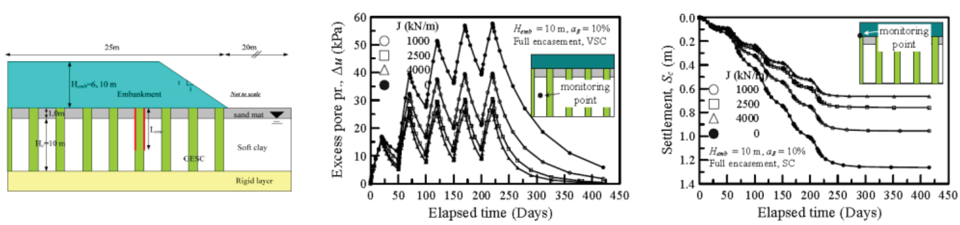
The load carrying capacity of a GESC has been well demonstrated in a number of studies, especially by Yoo and Lee [10]. As shown in Fig. 9, the load carrying capacity became doubled with only partial encasement by limiting lateral bulging of the stone column. The added confinement by the geogrid encasement was in essence reponsible for the improvment.



(a) test setup (b) lateral displacement (c) load vs. settlement

Fig. 9. Full-scale load test on OSC and GESC [10].

When installed to support embankment constructed on soft ground, GESCs are also known to improve the settlement charateristics of the embankemnt by accelerrating pore water pressure dissipation caused by the embankement loading as shown in Fig. 10. Greater benefit of geogrid encasement in terms of settlement redution can be achived by adopting higher stiffness geogrid as less embankment load is transferred to the original ground.



(a) GESC supported embankment (b) excess pore pressure dissipation (c) settlement development

Fig. 10. Settlement characteristics of GESC supported embankment [11].

When implementied for roads and railway tracks, GESCs are subjected to cyclic loads from moving trains or vehicles. The response of GESC system under cyclic loadings may vary with the loading characteristics including frequency, amplitude, and duration. To investigate the GESC response to cyclic loading, Yoo and Abbas [12] conducted a series of 1-g reduced scale model tests involving GESCs installed in soft clay by varying the principal parameters considering the cyclic loading characteristics including frequency and amplitude, and the encasement stiffness as you can see in Table 1.

Table 1. Test cases [12]

Series	s_u, (kPa)	Encasement	*Frequency, f (Hz)	No. of cycles, N	Amplitude, A_m (kPa)	Encasement length, L_{enc}/H
A			0.1, 0.5, 1.0		70	1.0
B	12	RG	0.5	10,800	40, 70, 100	1.0
C			0.5		70	0.0, 0.3, 0.5, 1.0

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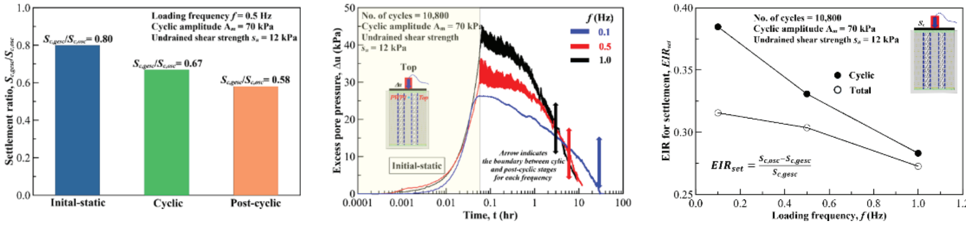

(a) settlement ratio (b) excess pore pr. (b) varitio of EIR

Fig. 11. Response characteristics of GESC supported embankment to cyclic loading [12].

Yoo and Abbas [12] reported, as shown in Fig. 11, among other things that the overall benefit of the encasement to the performance of stone column depends significantly on the cyclic loading characteristics. The geogrid encasement is also found to be more effective in improving the column performance in terms of settlement and post-cyclic capacity when subjected to lower frequency and/or smaller amplitude loading. Additionally observed ios that the degree of load transfer to the column also decreased as the loading frequency increased. A decreased stress concentration ratio from the static one was recommended when subjected to higher frequency and/or larger amplitude loading.

4 Conclusion

In this paper, the global warming issue in relation to sustainable benefits of geosynthetics are discussed together with recent advances in geosynthetics applications on transportation/geotechnical infrastructure systems.

Geosynthetics are increasingly used as regular construction materials in transportation infrastructure construction, e.g., road and railway track stabilization, pavement, bridge abutment, etc. This success is due mainly to 1) high cost-effectiveness; 2) high performance; and 3) ease of construction. Additioanlly, geosynthetics have proven to be sustainable solutions in various civil engineering projects as they tend to reduce significant amount of carbon footprint over conventional systems by allowing less use of natural resources. It is important to understand that geosynthetics are engineered materials that require proper engineering design consideration when implementing routine civil engineering works.

Climate change adaptation and mitigation by geosynthetics technology development can be crucial for future infrastructure development. Further development in geosynthetics technology in transportation applications will warrant safe, economic and sustainable infrastructure development in the coming days

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