Geotechnical Engineering: The Driving Force for Korea's Economic Development and Prosperity

Ilhan Chang, Byungmin Kim, Junyoung Ko
Young Geotechnical Engineers (YGE) Forum Committee, Korean Geotechnical Society (KGS)

Eun-Chul Shin
Vice President (Asia), International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE)

Moonkyung Chung
President, Korean Geotechnical Society (KGS)

ABSTRACT: In the last 70 years, the Republic of Korea is the only country that has progressed from being the world's poorest to becoming a developed country. Geotechnical engineering is widely regarded as having played a pivotal role in Korea's modern development. This report summarizes major achievements in geotechnical engineering in Korea from the 1950s to the present. The Korean Geotechnical Society (KGS) hopes that the major projects and accomplishments summarized in the report will be used as data to look back on the footsteps of geotechnical engineering practices led and contributed by KGS and forecast the future prospects of geotechnical engineering in Korea.

1 REPUBLIC OF KOREA'S DEVELOPMENT TRAJECTORY (1950-2020)

Since the onset of rice farming in the 3rd century, geotechnical Engineering in Korea began with the development of irrigation facilities for agriculture (Jang 2010; Kang 2006). As such, since a long time, civil engineering technology is based on agricultural technology related to life and death and its scope has been expanded to include the development of national territory (roads, ports, dams, etc.) with the development of technology and civilization (Figs. 1 and 2).

Fig 1. Suwon *Chukmanje* Reservoir (Constructed in 1799).

Fig 2. Jecheon *Uirimji* Reservoir. (Constructed in 3rd century BC)

As part of the modernization movement of Korea in the late 19th century, relatively advanced Western civil engineering technology was introduced, many modern facilities were built by applying these civil engineering technologies, and Western civil engineering/science and technology was accepted actively (Fedman 2012).

During the period of Japanese colonial rule (1910–1945), various railroads were built, modernized dams and hydroelectric power plants were built along with river renovation, and the foundation for major port facilities was laid. However, due to the Korean War (1950–1953), more than 80%

of Korea's major social infrastructure was destroyed (Fig. 3), and then the need for rebuilding post-war cities and social capital facilities became the nation's biggest agenda, which increased the social importance of geotechnical engineering (Lee 2001; Shin 2001). The post-war restoration focused on road civil engineering projects and promoted projects such as port civil engineering, surveying, mapping, and the opening of water service piping based on necessity (Kim 2017; Lie 1997).

In 1961, the Ministry of Construction was newly established to lead the planning and promotion of domestic civil engineering and construction projects. It put spurs to waterworks, resource development, and river development projects for economic development, and later on due to efficiency-oriented national policy in accordance with economic development, it promoted civil engineering projects in the direction of regional development and regional functional characterization, which led to the construction of large civil engineering facilities (Kendall 2001; Kim and Park 2003).

Fig 3. Gwanghwamun area in Seoul destroyed during the Korean War (1952).

Fig 4. Railroad tourist map from the mid-1930s. (Korea Express Road Corporation)

In the 1980s, the characteristic of civil engineering projects changed from national land development to civil engineering projects centered on national land utilization and major projects, and it directly affected the convenience of people's lives as in housing complex construction, diversification of public transportation, and maintenance and pavement of local roads in addition to expressways. With the founding of Korean Geotechnical Society (KGS) in 1984, the participation of experts in national land development became active (Korean Geotechnical Society 2019).

As mentioned above, Korea's civil engineering and construction continued to develop mainly for agricultural and military purposes, and nowadays it has developed side by side with everything around our lives including transportation, convenience, and living as well as agricultural and military purposes. Through this, Korea today has made remarkable technological advances in all aspects of civil engineering, including construction planning, design, construction, and management, and the outcomes have been evident (Korean Geotechnical Society 2019).

2 GEOTECHNICAL ENGINEERING MILESTONES IN THE REPUBLIC OF KOREA

Korean civil engineering project capability has steadily advanced and is still in progress. The Korean Geotechnical Society selected considerable milestones in the field of geotechnical engineering and Korea's economic development over the past 70 years and summarized them as follows.

2.1 *Gyeongbu Expressway*

The Gyeongbu Expressway is the most important and longest (428 km) highway in Korea that connects Seoul and Busan, commonly referred to as the aorta of the country, and is a symbol representing the Miracle of Han River. It is a very meaningful structure in that it is the oldest highway in Korea and also the first highway built in Korea. It has the longest length and the heaviest traffic in Korea, but traffic there has recently been decreasing due to its connection with many highways. On July 7, 1970, the Daejeon-Daegu section was finally completed, and the Gyeongbu Expressway opened (Fig. 5). Currently, various new cities have been developed around the Gyeongbu Expressway in the metropolitan area, which is considered the center of the Korean economy (Choi 2012).

The Gyeongbu Expressway plan experienced difficulties from the outset. Until the early 1960s, it was thought that highways were not needed immediately, and requests were mainly about high-speed railroads. However, from the late 1960s, the demand for road expansion began to increase with the increase in the supply of automobiles and the remarkable advance of the national economy. In addition, there were many problems with the technological capability of Korea at the time. No company has ever designed and constructed a largescale expressway exceeding 400 km, and at the time of bidding, the construction budget was calculated in a wide variety. At the time, Hyundai Engineering & Construction, which had experience in overseas construction, participated in construction. The biggest challenge during the construction was Dangjae Tunnel, and the ground where the tunnel was constructed was a sedimentary layer consisting of sheering rock. It collapsed during blasting and casualties also occurred frequently. With the scheduled completion date just around the corner, Hyundai Engineering & Construction applied high rapid cement, which had not been applied at the time, and reinforced the tunnel with enhanced strength by placing concrete before the tunnel shield collapsed. In doing so, the construction sped up and it became complete two days before the scheduled opening date of July 7, 1970 (Park 2010; Yoo et al. 2021).

Recently, a project to place the expressway under the ground from Yangjae to Hwaseong, the busiest section of the Gyeongbu Expressway, has been promoted (Fig. 6). The Ministry of Land and Transportation has finalized its mid- to long-term investment plan by 2025, and a total of 3 trillion and 205.2 billion won is scheduled to be invested. As such, Gyeongbu Expressway is under constant development at the national and local government levels. Namely, a safer highway network is being built with the application of new construction methods.

Fig 5. Gyeongbu Expressway completion photo. (1970)

Fig 6. Gyeongbu Expressway Seoul Yangjae IC to Gyeonggi-do Hwaseong Section Underground Expansion Concept Map. (2022)

2.2 *Seoul Metropolitan Subway*

The urban tram, which had been operated until 1968, was completely suspended and demolished due to the steady growth of road traffic and Yang Taek-sik, who was appointed as the mayor of Seoul in April 1970, began to promote the construction of Seoul Metropolitan Subway to disperse the road traffic supersaturated because of short public transportation after the demolition. The metropolitan subway is a collection and system of commuting urban railroads and suburban commuting metropolitan railroads operating in the metropolitan area, centering on the capital city Seoul. The metropolitan subway first began operation on August 15, 1974, when the section of Seoul Station to Cheongnyangni Station of Seoul Subway Line 1 was opened (Fig. 7), and the Subway Line began to operate after directly connected with the railroads of Gyeongbu Line and Gyeongwon Line (with the total length of 81.8 km) (Jin and Kim 2017). Subsequently, as more Seoul subway lines were newly built and the transportation demand in the suburbs of Seoul increased, those were reorganized into the metropolitan electric railways by including the metropolitan Gyeongin Line, the Chungang Line, the Gyeongwon Line, the Suin Line, and the Janghang Line. After that, the metropolitan Bundang Line, Ansan Line, and Ilsan Line were newly built for commuting purposes. Currently, routes have been rapidly expanded to Cheonan, Asan, and Chuncheon, and routes that are not intended to enter Seoul Metropolitan City are also being additionally built. (Fig. 8 and Table 1; As of December 2021, 1,200 km) (Song and Kim 2018)

The subway in the metropolitan area was constructed by applying many different construction methods. For constructing a subway, they apply the open cut method or the tunnel method. Generally in the construction of Korean subways they most often applied the earth retaining (earth retaining type) open cut method of driving in as many earth retaining H-piles as necessary for excavation and then building excavation structures, Recently, tunnel methods often have been applied often, and when constructing subways in the metropolitan area, NATM (New Australian Tunneling) method, Shield Tunnel Boring Machine method, CAM method, and TRCM (Tubular Roof Construction Method) were used (Lee et al. 2018; Shin et al. 2006; Shin et al. 2006).

The recent subway construction in the Seoul metropolitan area requires doing with existing subways or structures present, so it is very limited to apply the open cut method that affects the surrounding area. Accordingly, companies that construct subways in the Seoul metropolitan area make many different attempts to carry out construction, and Ssangyong Engineering & Construction's Seoul Subway Line 9 Express Terminal Station is one of them. In about 200m section of their 1.78 km section of Line 9, the Gangnam Express Terminal Marriott Hotel, and largescale apartment complexes concentrated on the ground, and existing shopping malls over 30 years old and a largescale underground station to be built with three routes, Line 3, Line 7 and Line 9 that need transferring under the ground were challenges to the construction. In particular, the Express Terminal Station (station No. 923) of Line 9 had to be built only 15 cm vertically apart from the existing Subway Line 3 station, and there were also risks of weak ground and groundwater inflow (Lee and Shin 2013; Song et al. 2004). However, as a result of persistent research, they constructed a largescale tunnel-type station without affecting the surrounding facilities under unfavorable circumstances by applying the TRCM method of forming an underground tunnel-shaped structure across the street and applying a fusion method of filling the pipe with reinforced concrete for building a support base and excavating the lower ground.

In addition, the Ministry of Land, Infrastructure and Transport is conducting the Great Train eXpress (GTX) project, a railroad network that connects major hubs outside the metropolitan area in 30 minutes to ease the growing traffic difficulties and improve transportation welfare for long-distance commuters (Tebay 2017). Currently, because the underground state of downtown has progressed a lot, this project is being conceptualized as a great-depth express railroad (Kim et al. 2011). GTX has been planned with three routes (A, B, and C) of 240.4 km length, and the project budget has been set at 15 trillion and 524.4 billion won. Route A is 39.5 km from Samsung to Dongtan, 39.5 km from Paju to Samsung, Route B is 80.1 km from Songdo to Maseok, and Route C is 74.8 km from Deokjeong to Suwon. Route A is currently under excavation and roadbed construction and is being promoted for opening in 2023. Route B is under feasibility study and basic plan, and the facility project basic plan for Route C has been announced. They are attracting a lot of attention from geotechnical engineers for tunneling by excavating at a great depth without affecting existing subways or structures (Kho and Choi 2011).

Fig 7. The opening ceremony of the Seoul Subway Line 1. (August 15, 1974)

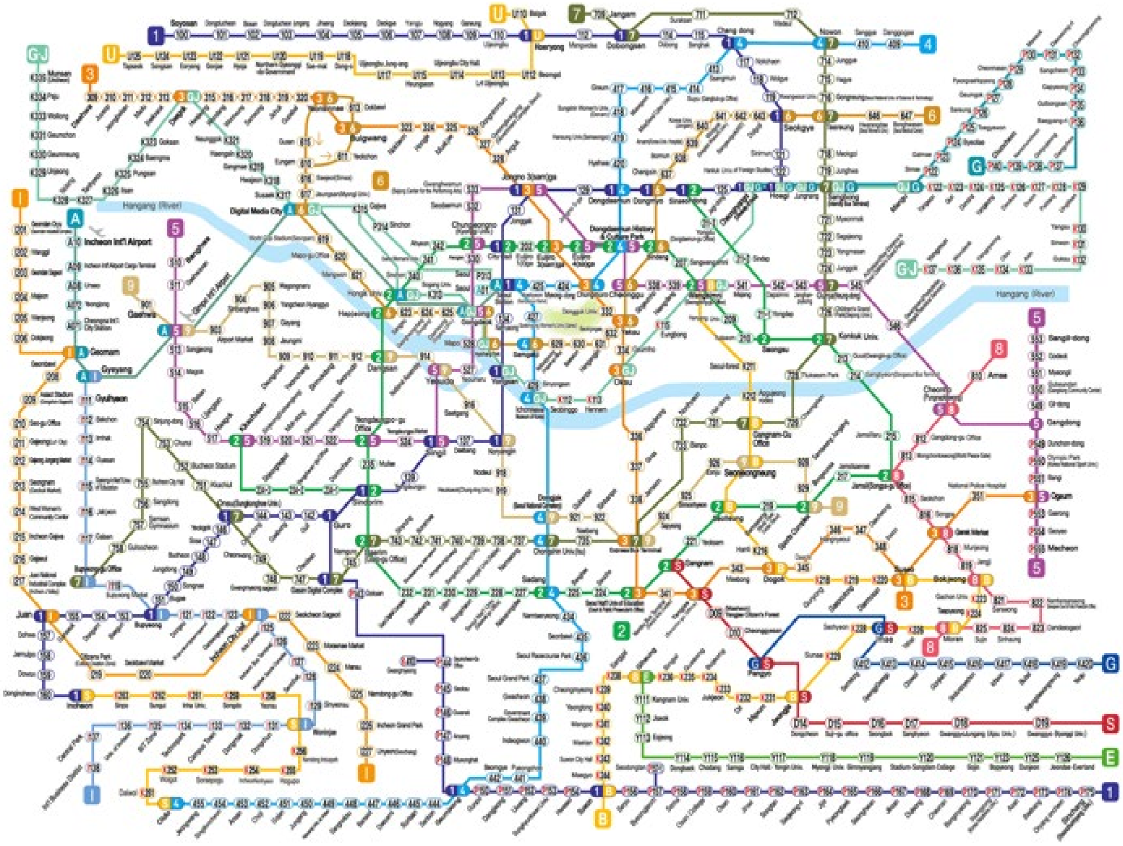

Fig 8. The current metropolitan area subway route map in Seoul (2021).

Table 1. Metropolitan subway in operation. (Status in 2021)

Route	Starting point	Main transit terminal(s)	Number of stations	Total length (km)	First opening date
Line 1	Soyosan Station	Incheon Station, Seodongtan Station, Gwangmyeong Station, Sinchang Station	99	200.7	1947.8.15
Line 2	City Hall Station		51	60.2	1980.10.31
	Seongsu Station	Sinseoldong Station			
	Sindorim Station	Kachisan Station			
Line 3	Deahwa Station	Ogeum Station	44	57.4	1985.7.12
Line 4	Danggogae Station	Oido Station	48	71.5	1985.4.20
Line 5	Banghwa Station	Hanam Geomdansan Station Macheon Station	56	60.0	1995.11.15
Line 6	Eungam Station	Shinnae Station	39	36.4	2000.8. 7
Line 7	Jangam Station	Seoknam Station	53	61.3	1996.10.11
Line 8	Amsa Station	Moran Station	18	17.7	1996.11.23
Line 9	Gaehwa Station	Central Veterans Hospital Station	18	40.6	2009.7.24
Gyeonggang Line	Pangyo Station	Yeoju Station	11	56.0	2016.9.24
Gyeonggi Central Line	Dorasan Station	Jipyeong Station, Seoul Station	57	137.8	2014.12.27
Gyeongchun Line	Cheongnyangni Station, Kwangwoon University Station	Chuncheon Station	25	90.2	2010.12.21
Airport Railroad	Seoul Station	Incheon Airport Terminal 2 Station	14	63.8	2007.3.23
West Sea Line	Sosa Station	Onesi Station	12	22.0	2018.6.16
Suin Bundang Line	Cheongnyangni Station	Incheon Station	63	106.9	2020.9.12
Shinbundang Line	Gangnam Station	Gwanggyo Station	16	33.7	2011.10.28
Gimpo Urban Railway	Yangchon Station	Gimpo Airport Station	10	23.7	2019.9.28
Yongin Everline	Giheung Station	Jeondae Everland Station	15	18.1	2013.4.26
UI - Shinseol-Line	Bukhansan-Ui Station	Sinseoldong Station	13	11.4	2017.9.2
Uijeongbu light rail	Balgok Station	Tapseok Station	16	11.4	2012.7.1
Incheon line 1	Gyeyang Station	Songdo Moonlight Festival Station	30	30.3	1999.10.6
Incheon line 2	Geomdan Oryu Station	Unyeon Station	27	29.1	2016.7.30
Incheon Airport Maglev Railway	Incheon Engineering Terminal 1 Station	Yongyu Station	6	6.1	2016.2.3

2.3 *Seamangeum reclamation project*

The Saemangeum reclamation project is a national project that constructs the 'global masterpiece Saemangeum', having a clean ecological environment, that will grow as a North East Asian economic center while integrating the economy, industry and tourism by building the world's longest (33.9km) seawall connecting Buan-gun and Gunsan-si, Jeollabuk-do to create 291 km^2 of reclaimed land and 118km^2 of freshwater lake and developing 3.3km^2 of Gogunsan Islands and 4.9km^2 of new port outside the seawall (Fig. 9). The Saemangeum seawall, listed in the Guinness Book of World Records as the world's longest seawall, began to be constructed in November 1991 and was completed in about 18 years and 5 months. The stop gate construction was completed in 2006, the seawall road construction was completed in 2010, and the reclamation work and land construction were completed in 2020 (Koh et al. 2010).

In order to minimize damage from tsunamis and waves, the Saemangeum seawall was constructed as a gently sloped riprap embankment that protects the outside and forms a cross section using sea sand inside using a sea sand fillup method. As fillup material they used sea sand dredged to save the construction cost. So, they avoided environmental damage caused by using the soil from the land. The total amount of soil and stone used in the construction of the seawall is 122,939 ㎥, including 41,616 ㎥ of riprap and 81,323 ㎥ of sea sand, which is an amount that can be stacked on 418km of Gyeongbu Expressway at a height of 13m (Cho 2007).

The final closing work was a difficult construction unprecedented in the world's reclamation history with a maximum flow rate of 7.08 m/sec (range of tide 6.95 m), but by applying gradually narrowing method using net bags for riprap they developed on their own, for the first time in reclamation history, they built two net bags filled with 3 tons of riprap (6 tons total) and put in the sea for withstanding fast flow. The state-of-the-art equipment was used to measure the flow velocity and tide velocity by depth of water, and by investigating and modeling topographic changes, they could complete the final closing successfully, thereby retaining world-class deep-sea reclamation technology (Lie et al. 2008).

With the completion of the Saemangeum seawall (Fig. 10), the drainage in 12,000 ha of flood-prone area behind the Dongjingang and Mangyeonggang basins was improved, and the travel distance between Gunsan and Buan was shortened by as much as 66 km. In addition, with the opening of the seawall and by using the 33km sea route connecting Buan and Gunsan, it secured a space for life where we can fully enjoy the beauty and mystery of nature in the Byeonsan Peninsula and the Gogunsan Islands, and the magnificent seawall created by humans. The internal development of Saemangeum as the "Economic Center of Northeast Asia," Mecca of complex cultural tourism and a growth engine that will lead Korea in the future is expected to be promoted through low-carbon green growth in a clean ecological environment (Beigel and Christou 2010).

Fig 9. Aerial view of the Saemangeum basin in 2019.

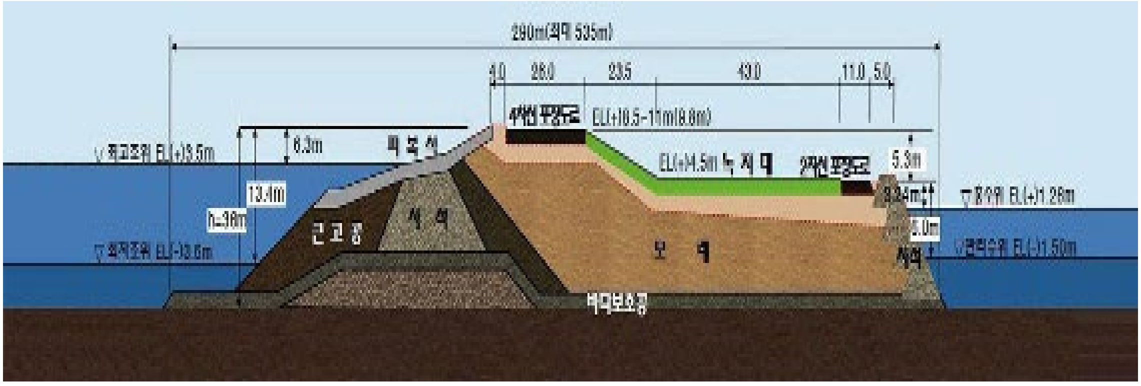

Fig 10. Cross-section of the Saemangeum seawall.

2.4 *Geoga Bridge (Gaduk Subsea Tunnel)*

The Geogadaegyo Bridge (Fig. 11) connects Gadeokdo Island in Busan and Geoje-si, and it played a role in shortening the travel distance between Busan and Geoje from 140 km to 60 km, reducing the travel time from 2 hours to 50 minutes. It has a bridge-tunnel complex road with a total length of 8.2 km, two cable-stayed bridges with a total length of 3.5 km, a 3.7 km submerged tunnel, and two land tunnels with a total length of 1 km. Korea's first submerged tunnel and 3-main-tower-continuous cable-stayed bridge providing an opportunity for Korean construction technology to leap (Janssen et al. 2006).

In particular, the Navy is stationed in Jinhae, near this area, so the Gadeokdo-Jungjukdo section corresponds to the naval operational area. Therefore, it was an important route for naval warships and submarines and for frequenting large ships, making it difficult to build a bridge there. In addition, as most parts of this section consist of sea clay layers with very weak ground support, they were constructed as submerged tunnels that do not require large ground support and can minimize ground subsidence due to the weight of the structure.

The tunnel has a number of new records. First, with a tunnel length of 3.7 km, it was recorded as the world's longest undersea submerged tunnel at the time of construction (currently the longest submerged tunnel is Gangjuao Bridge, 6.7 km). Next, its prefabricated tunnel block (hull) is 180m long, the world's longest hull, and it was constructed in the deepest water depth of 48 m among the undersea submerged tunnels used for roads (Fig. 12). In particular, because divers cannot enter in deep water sections, they relied solely on GPS to connect huge hull of 180 m in length and 45,000 tons in weight within the error tolerance of 2 cm in the sea (Jensen et al. 2006; Jeong and Kim 2012; Odgaard et al. 2006).

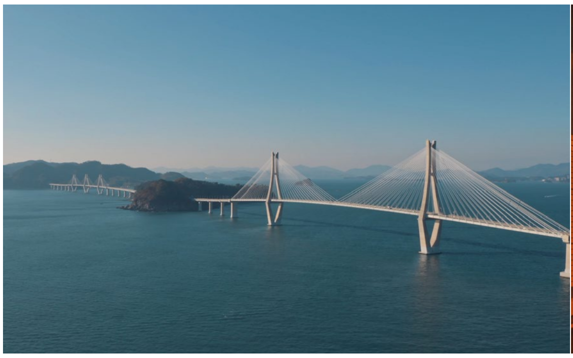

Fig 11. View of Geoga Bridge.

Fig 12. The world's deepest (48 m) submerged tunnel.

In addition, submerged tunnels are mostly constructed in the inland sea, and it is also the first submerged tunnel built in the open sea with strong winds and waves. Finally, in preparation against natural disasters such as earthquakes and tsunamis, it had the world's first double-joint hull connection method applied to construct a safe tunnel.

2.5 *Incheon Bridge*

The Incheon Bridge construction was led by the Korea Expressway Corporation and was completed in 2009 after its construction began in 2005 with the participation of many construction companies with the highest-level technology in Korea (Fig. 13) (Yang et al. 2012).

With a total length of 18.2 km, Incheon Bridge is the 6th longest bridge in the world. The distance between the towers of the cable-stayed bridge reaches 800 m, close to the entire length of any common bridge. It is the 5th longest cable-stayed bridge in the world. The tower is 238.5 m high, close to the height of Yeouido 62 Building. In order to build such towers, world-class technologies such as a construction method of placing large steel pipes with a diameter of 3m into a soft rock layer at 60m under the sea and placing concrete in the steel pipe having a rebar net inside and the world's largest RDC foundation pile construction technology were applied (Fig. 14). The steel pipe itself weighs 75 tons, and the rebar net weighs over 70 tons. In this way, Incheon Bridge was designed to withstand strong earthquakes of magnitude 7 and strong winds of 200 km/h, and to support up to 6,000 tons by a pile (Cho et al. 2009; Kim 2016; Samsung C&T 2017).

In December 2005, Construction News, a British construction magazine, selected Incheon Bridge as "one of ten wonders of the construction world." It has also won various awards in the United States, the United Kingdom, Japan, etc

Fig 13. View of Incheon Bridge.

Fig 14. Pylon pile clearance in 2009.

2.6 *Gyeongju Low-Intermediate and High-Level Repository Plans*

Gyeongju low-intermediate repository (Fig. 15), which has been in operation since 2015, is the first cave-type waste disposal site in Asia that can only dispose of low-intermediate waste with relatively low radioactivity concentration (World Nuclear News 2015).

At the low-intermediate repository in Gyeongju, low-intermediate radioactive waste is put and sealed in a drum, and then permanently stored in a concrete structure (silo) in a rock cave 80 to 130 m deep underground (fig. 16). It can permanently store up to 100,000 drums of waste and has a 1,415-m-long operating cave, a 1,950-m-long construction cave, a loading and unloading cave connecting the two, six silos as key facilities of the repository, and a vertical entrance (Kim et al. 2013; Park et al. 2021).

The entrance to the disposal facility cave stands 30 m above sea level and is designed to be safe from earthquakes and tsunamis. The underground disposal facility is quintuple sealed with natural bedrock, shotcrete, waterproof sheet, concrete silo, concrete disposal container, etc. After closure, the inside is filled with crushed stone and concrete and sealed to prevent leakage of radioactive substances (Korea Radioactive Waste Agency 2018).

The Gyeongju low-intermediate repository was selected as an excellent case in May 2015 by the International Atomic Energy Agency and was selected as the world's best underground tunnel in 2015 by the World Tunneling and Underground Space Association in Switzerland in November, and its excellence has been recognized.

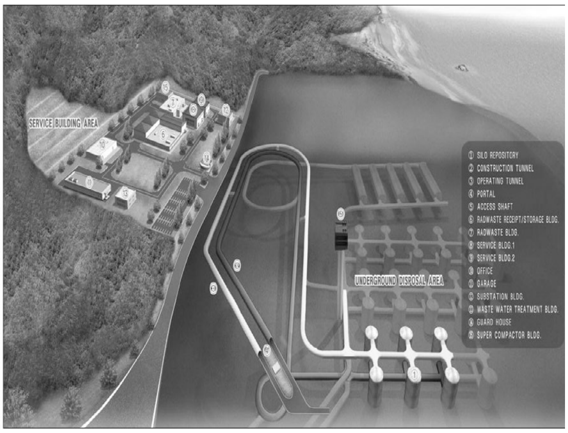

Fig 15. Disposal facility layout.

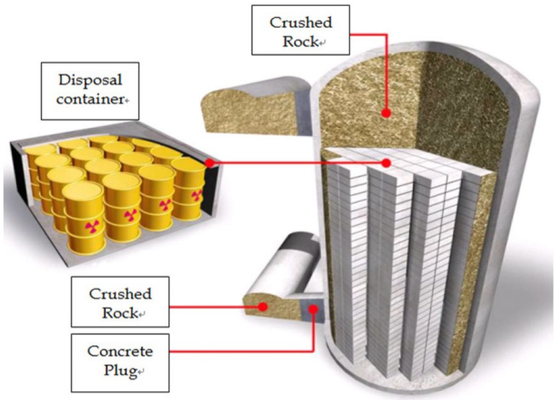

Fig 16. Silo concept diagram.

2.7 *Offshore Wind Power*

Countries around the world are developing a variety of new renewable energy to respond to the risk of global warming and energy depletion. Among them, offshore wind power is deemed to be an important energy resource in the future because it has greater expandability than land wind power. Wind power generation is expected to help solve global warming because there is no fuel consumption other than wind after installing power generation facilities, so there is little trash or waste generated, and greenhouse gases are not emitted. Offshore wind power generation is a competitive power generation method because the cost of power generation is lower than that of existing wind power generation and the noise problem is solved.

The offshore wind power development project in Southwest Sea began in November 2011, and a 60 MW offshore wind power demonstration complex was completed in January 2020, and development of a 400 MW pilot complex began to secure a track record by 2027, and a 2,000 MW spreading complex for developing a largescale complex after the completion of the pilot complex is planned (Fig. 17) (Kim et al. 2018; Shi et al. 2015).

Construction procedures, periods, and costs were reduced by applying suction foundation to the sea for installing offshore wind power turbines. When applying the suction foundation, air and water inside the pile are discharged, resulting in the pressure inside the pile lowered and the external pressure increased, and the entire pile is inserted and fixed (Ahn et al. 2017; Plodpradit et al. 2020). In addition, the larger the rotation part of the blade, the higher the wind energy utilization ratio. Through the development of carbon fiber blade technology, the blade was made to have higher strength and lighter weight, and the diameter of the rotor was increased up to 100 m (Kim et al. 2020; Tran et al. 2022).

Through the construction of an unmanned offshore substation, the voltage of electricity produced by wind power generators was increased so that power could be transmitted to the land. Remote monitoring and control systems were established for unmanned operation, and desalination facilities, pollution spill prevention facilities, emergency sea escape facilities, and dual automatic systems were established for operating at sea. The offshore monitoring system enabled fishing boats to navigate and do fishing operations in the offshore wind power complex (Fig. 18).

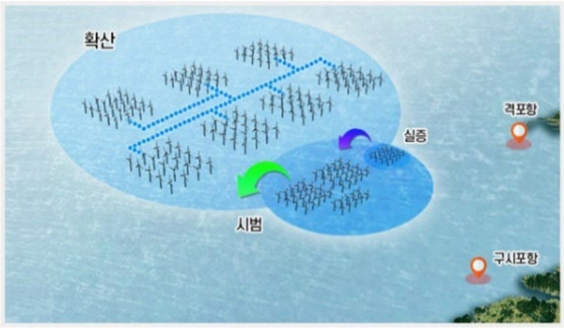

Fig 17. Overview of offshore wind power development project.

Fig 18. Seonamhae offshore wind farm complex. (2020)

2.8 *Lotte World Tower*

As the tallest building in Korea (the world's sixth tallest building in 2022) whose construction began in 2010 with a total 132 floors and a height of 555m and opened in April 2017, Lotte World Tower boasts of its magnificent dignity (Fig. 19). The building has about 13 million visitors a year (as of 2019), serving as a landmark in downtown Seoul, the capital of Korea (Besjak et al. 2009; von Klemperer 2018).

The building weighs 750,000 tons, equivalent to 10 million adults weighing 75 kg. In order to support this heavy weight, the ground was dug up to a depth of about 38 m underground, and 108 piles with a diameter of 1 m and a length of 30 m were installed on the hard rock bed layer below it to reinforce the rock bed. On top of that, the world's largest concrete mat foundation of 72 m × 72 m with a thickness of 6.5 m, and a total concrete volume of 31,637 m^3 was built (Fig. 20). The area of the mat foundation is about 80% of the size of the soccer field, and the amount of concrete used to install the mat foundation was equivalent to that for building about 5,500 apartments of 1,150 ft^2 (Park and Oh 2018; Sze and Lam 2019).

In addition, not only has a thicker mat foundation been constructed compared to that of the world's tallest building Burj Khalifa, but it is also solid enough to have 2.5 times the amount of concrete used. In order to ensure structural integrity, they constructed by placing concrete at once without dividing it, after developing ultraheat generating concrete with a design strength of 50 MPa and extremely controlling hydration heat on their own and applied. In addition, they conducted a simulation in consideration of the conditions of concrete placing within a limited site while being a city center construction in downtown Seoul, and applying the results, they used about 5,300 truckloads of ready mixed concrete for about 30 hours to build the mat foundation (Kim and Lee 2016; Lee et al. 2014; Moon et al. 2008). This is the largest mat foundation in Korea and the second largest in the world.

Fig 19. Lotte World Tower view.

Fig 20. Ground reinforcement work and temporary cover installation in 2011.

2.9 *Boryeong Undersea Tunnel*

The Boryeong Undersea Tunnel is a part section of the road constructed between Boryeong and Taean on National Route 77 and is a tunnel having a total length of 6.927 km with a 5.209 km undersea section, which connects Daecheon Port in Sinheuk-dong with Wonsando Island, Ocheon-myeon, Boryeong-si, Chungcheongnam-do. It is the longest undersea tunnel in Korea, completed with domestic construction technology, and is the fifth longest undersea tunnel used as road in the world ((1) Tokyo Aqualine in Japan (9.5 km), (2) Bomnafjord in Norway (7.9 km), (3) Acresander in Norway (7.8 km), (4) Oslo fjord in Norway (7.2 km) and (5) Boryeong Undersea Tunnel in Korea (6.9 km)). Construction of this tunnel began in December 2010, and the total project cost KRW 488.1 billion, and it was completed after ca. 4,000 days (approximately 11 years) (Hyundai Engineering & Construction 2022).

It is located at a maximum 80 m below the sea level (25 m average depth, maximum 55 m from sea floor level), and the NATM method was applied for the first time in Korea when constructing the undersea section. In addition, in order to prevent seawater leakage, the optimized excavation method was applied through geological analysis using 3D computing to successfully penetrate the center of the tunnel. As a result of 3D geological analysis, they found many dangerous sections such as weak coal layers (stratum containing coal) and folds, so while continuously monitoring the sections needing caution, they installed special waterproof doors (1m thick) for evacuation in many places to secure stability (Bae 2017).

In addition, the intelligent multi grouting system was applied to effectively block seawater inflow into the tunnel during construction, which was improvement of existing grouting technologies such as optimal pressure, flow rate, and precise time control in consideration of the characteristics of each ground. In addition, in order to ensure the stability and durability of the tunnel, they increased the concrete lining thickness (from 30 cm to 40 cm) and strength (from 24–27 MPa to 40 MPa) compared to general land tunnels (Jee 2012; Kim et al. 2017).

Fig. 21. Penetration of the subsea tunnel excavation from both side (Boryeong tunnel, 2019).

Fig. 22. Schematic view of the Boryeong subsea tunnel.

3 CLOSING REMARKS – GEOTECHNICAL ENGINEERING AND KOREA'S ECONOMIC GROWTH

As such, civil engineering work in many fields was carried out in Korea with steady development of geotechnical engineering from the 1970s to the present in the year 2021. Accordingly, the economy of Korea has also developed significantly, which can be seen by checking the growth rate of gross domestic product (GDP) and gross national income per capita (PCI) over the past 50 years.

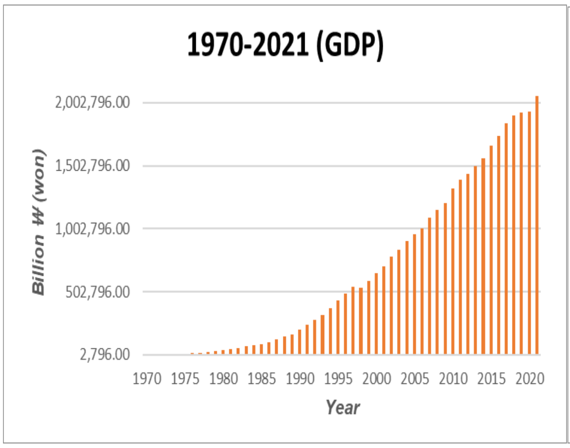

Fig. 23. 1970-2021 Korea GDP.

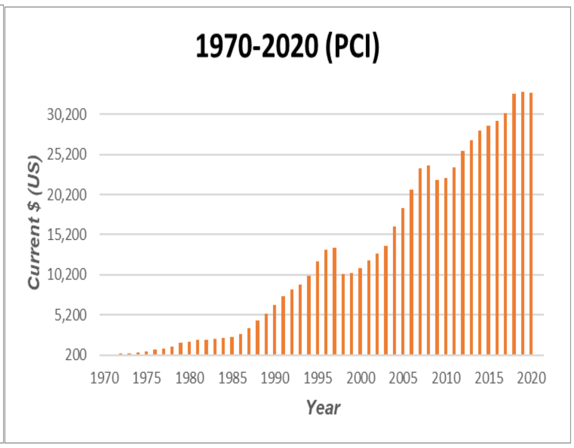

Fig. 24. 1970-2021 Korea PCI.

Korea's GDP was 2,796.6 billion KRW as of 1970, and it recorded 2,057,447.80 billion KRW in 2021 (Fig. 23). Since 1970, Korea has continued to develop steadily, showing an annual economic growth rate of up to 13.4%, and we can check out the average economic growth rate of more than 6% till 2021. In addition, looking at per capita income (PCI), the growth rate reached up to 32% in the 1970s and 1980s and increased by 10.774% on average through 2020 (Fig. 24).

Examining the trend of construction order from 1991 to 2020 shows that it has been on the decline since 1997, but it has shown a series of decreases and increases with time due to several social issues until recently. Among them, the civil engineering sector showed steady demand, increased orders for private power generation projects, transmission and distribution of power generation, railroads, ports, and airports in 2017 and 2018, recording 49.5 trillion KRW as of 2019 (Fig. 25).

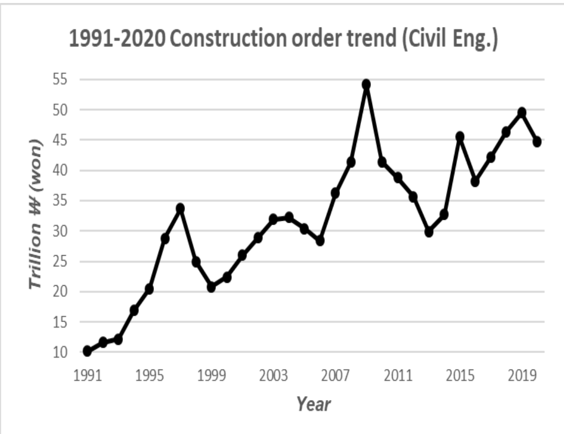

Fig. 25 1991-2020 Construction order trends (Domestic).

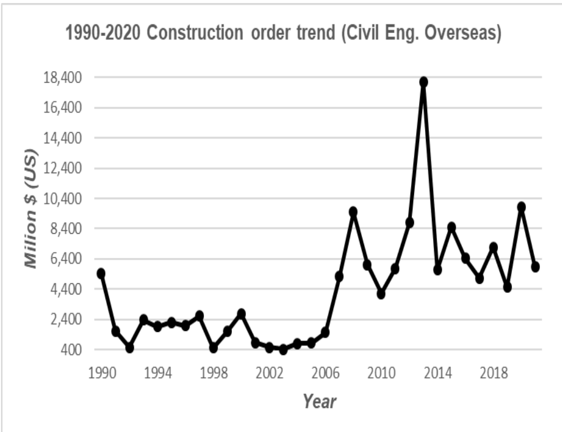

Fig. 26 1990-2021 Construction order trends (Overseas)

As domestic geotechnical engineering continued to develop, Korean companies got to win more construction contracts from overseas. Statistics on overseas construction orders, including all construction (civil engineering, architecture, plants, electricity/communication, services) from 1990 to 2021 show that it started at 6,770 million dollars in 1990 and greatly increased its scope and number to 30,616 million dollars in 2021 (Fig. 26). A peculiar aspect is that the proportion of overseas construction orders for civil engineering works shows consistent statistics for a long time, indicating that there has been a steady demand for civil engineering orders overseas, and that Korea's civil engineering technology is recognized to be at a high level.

As shown above, Korea is now recognized at home and abroad as a leader in geotechnical engineering and civil engineering and is showing the results that correspond to such. The domestic highway, whose construction started in 1968, was 67.0 km between Daejeon and Cheonan, and 4,766 km as of 2018, which is very densely organized compared to the land and the extension of the Seoul Metropolitan Subway, which opened in 1974 and steadily grew, is 1222.0 km as of 2020. Overseas, Korean companies, starting with the construction for the U.N. military in the early 1960s, developed while carrying out many overseas architecture and civil engineering projects such as the first section of Adam Link Road in Saudi Arabia and the E-ring Expressway project in Qatar.

So far, civil engineering construction planned and conducted from the 1970s to the present have been examined. It could be seen that civil engineering construction has been carried out in many fields, and that the applied technology has developed very widely, which has contributed to promoting people's lives, the economic development of the country, and the growth of domestic companies in promoting Korea’s ground engineering technology on a global scale.

Future civil engineering construction should ensure a wider range of development, such as improving the environment, residential environment, and supplementing existing technologies through the development and application of new eco-friendly and sustainable new materials/developed geotechnical engineering technologies that are currently attracting much attention, and the future is bright.

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