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Soil improvement methods of Incheon and Astana International Airports

Amelioration du sol a l' methode Aeroport International de Incheon et de Astana

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ABSTRACT
Many large-scale land reclamation works are being performed along the south coast and the west coast in Korean Peninsula and left coast of Ishim River in Astana (Kazakhstan). A great amount soils are hydraulically filled by the dredging ship and various soil improvement techniques such as sand compaction piles on land and sea, plastic board drains, packed drains, horizontal and vertical vacuum consolidations, dynamic compaction, deep mixing method, progressive trenching method are being used for stabilization of soft ground. This paper describes soil improvement methods of the Incheon and Astana International Airports in Korea and Kazakhstan. The selection of soil improvement method is depended on geological formation of soil, soil characteristics, cost, availability of backfill material, and experience in the past.

RÉSUMÉ
Plusieurs travaux de reclamation de terre de grande echelle sont en train d'etre accomplis au long de la cote du sud et de l'ouest de la peninsule coreenne. Une grande quantite de terre est remplie au moyen des drageurs et differents techniques d'amelioration de sol, tels que des pieux de sable compact sur terre et sur mer, des conduits d'ecoulement en planches plastiques, des e'gouts emballes, des consolidations horizontales et verticales en vide, une compaction dynamique, une methode de melange profond et une methode de retranchement progressif sont utilises pour la stabilisation du sol mou. Ce papier decrit quelques unes de ces etudes en dossier en Coree, en Kasakhstan. La selection de methode d'amelioration du sol est dependente de la formation geologique du sol, des caracteristiques du sol, du prix, de la disposition du materiau de remplissage et des experiences du passe.

1 INTRODUCTION

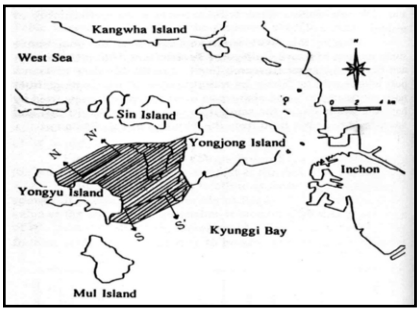
Most of land reclamation projects from the sea have been extensively implemented in the south and west coastal lines because its depths of sea water is relatively shallower than that of the east coastal line. These reclaimed lands are mostly used for port and harbor facilities, industrial complex, airport, storage tanks, and residential area (Shin et al., 1993). The characteristics of man-made land are consisted of soft clay, silty clay or silty sand, and hence low bearing capacity. Various soil improvement techniques can be applied for stabilization of this kind of soil to increase its shear strength and reduce the possible excessive settlement (Shin et al.,1992). This paper presents the soil improvement case history of the Incheon International Airport which is located in the bay of Incheon.

The construction site of the Incheon International Airport (IIA) was visualized in the area where the depth of seawater is relatively shallow and site location is an air traffic and environmental problems free. The site shown in Fig. 1 was chosen from the survey of 11 tentative sites around a 100 km radius of Seoul.

The construction site of the International Astana Airport find at left coast of Ishim River.

2 NATURAL SITE CONDITION

The IIA site is located on an estuary of the Han River. The foundation materials found at this site were excessively soft and wet, and will not be able to support airport loads without remedial measures or soil improvements. There are also several small hills at the site that will require removal to achieve the required flatness and expanse. Of the over 5000 hectares of the airport site more than 80% or 4,743 hectares were covered with an average 5 m thick soft soil layer. The maximum depth of soft soil was about 11.5 m. These soft soils contained silts and excessive moisture, which are not recommended for the foundation materials.



(a) Location of IIA site

(b) Aerial view of IIA

Fig. 1 Construction site of Incheon International Airport

Table 1 Soil properties of soft marine clay

Soil parameter	Quantity
Water content (%)	25 ~ 40
Liquid limit (%)	30 ~ 50
Plastic limit (%)	10 ~ 23
Void ratio	0.7 ~ 1.1
Undrained strength (kN/m^2)	11 ~ 55
Specific gravity	2.67 ~ 2.71
No. 200 passing (%)	72 ~ 99
OCR	1.1 ~ 1.3

Because the IIA site is located on an estuary where the average thickness of soft soil material is about 5 meters, tremendous amount of fill materials are required. For the first stage of the soil improvement alone, more than 65million cubic meters of fill were needed. These fill material requirement was met by dredging 52 million cubic meters of sand from the nearby sea bed, with the remaining 13 million cubic meters of fill materials taken from surrounding hills, which had to be removed because they will obstruct aircraft movements.

Several methods of soil improvement were utilized for the runway, taxiway, and aircraft parking aprons. Areas subjected to aircraft landing, parking and movement were designed to support aircraft with take off weights in excess of 492 tons.

While the soil supporting underground utility areas was improved to support future large aircraft weighing more than 600 tons, or the super jumbo jets which can carry 600 passengers. Thus, ensuring the safe movement of the current supersonic 747-400 aircraft with a weight of 396 tons.

Ground investigation work was performed at the IIA site as early as 1994 or during the preliminary planning stage. Where more than 2,300 locations were selected for soil boring or Standard Penetration Test. The average spacing between boring holes was only 72 meters, which is considerably more conservative than the current construction industry standard of 100-200 m spacing, thereby indicating the seriousness of the soil studies conducted for the IIA site. A three dimensional model of the results of the Standard Penetration Tests for the whole site was prepared to reveal the topography and soil classification throughout the IIA foundation zone. This will also enable an immediate inspection and retrieval of soil data for any location within the project. The typical soil properties of soft marine clay are tabulated in Table 1.

3 SELECTION OF THE BEST METHOD FOR IMPROVING SOIL CONDITION

The field pilot tests were conducted for 20 months period from the beginning of April 1994 to determine the best soil improvement method with considering various large international airports such as the Kansai Airport in Japan, Hong Kong's new Chep Lap Kok Airport, Singapore's Changi Airport, and local projects located over reclaimed lands.

The field pilot tests within the reclaimed area was performed on the area of 84 m by 360 m. This area is also situated within the planned airport runway. The field pilot test was conducted with various soil improvement methods such as sand compaction pile (D = 0.7 m, S = 2.5 m), sand drain (D = 0.5 m, S = 2.0 m), packed drain (D = 0.12 m, S = 2.4 m), and plastic board drains (S = 1.0 m) to select the most suitable soil improvement method. The pilot test site was subjected to loads 1.5 times the maximum anticipated load. The field test results of various soil improvement methods are plotted in Fig. 2.

The settlement levels of improved ground under preloading are given about the same ranges as 34～38 cm. In the first beginning of the soil improvement work, 30% overall work, sand drain with spacing of 2.0 m was applied because backfill sand was readily available at that time.

However, the field pilot test results indicated that plastic board drain method gives a similar settlement level while obtaining of a good quality sand for SD or SCP was not easy and expensive. These similar values of settlement for various soil improvement methods are somewhat influenced due to the predominant of sand seams in the soil layers. Finally, plastic board drain was selected and used the rest of the site (Fig. 3). About 95 % of consolidation settlement was achieved in 6 months after installation of PBD with the preloading height of 5 m. The permissible residual settlement levels of various areas were es timated for the period of 30 years. This is the most important matter to operate the airport safely and economically. Some of these results are tabulated in Table 2.

The settlement gauges are placed in the various facilities to measure the future prospective settlement. The settlement gauge at the bottom of runway was recorded as 4.9 ~ 5.5 mm settlement so far since December 2000. It is clear that the secondary con solidation settlement of clayey soil is not occurred.

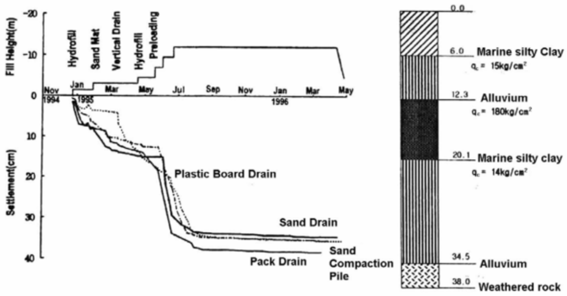


Fig. 2 Comparison of settlement for different types of vertical drain

Table 2 Permissible long term and controlled settlement

Area	Settlement (cm)	
	Long term	Controlled
Runway	7.5	2.5
Taxiway	10.0	5.0
Apron	10.0	5.0
Road	15.0	10.0

Fig. 3 Installation of plastic board drain

4 SOIL IMPROVEMENT

4.1 *Removal of excess water from soil and compaction of silty clay layer: Combined sand drain, plastic board drains and preloading method*

The state-of-the-art technique utilized for soft soil improvement at the IIA site consisted of placing vertical sand piles with 500 mm diameters at regular intervals throughout the entire thickness of the underlying soil. After the installation of the sand drains, the underlying soil was preloaded with by placing a 5m high layer of sand over the reclaimed area. The equivalent weight of this layer of sand is equal to 1.5 times the weight of the design aircraft and pavement. This procedure is known in the geotechnical industry as pre-loading. This accelerated the dissipation of pore pressures on the subsurface materials by removing excess water from the soil. To further enhance the removal of excess water from the soft soil layer, plastic board drains were driven into the soft ground.

The 5 m high sand as a pre-loading material compacts the lower soft soil materials forcing the excess water upwards through the sand drains or plastic board drains into the 50 cm thick sand mat on the ground surface layer. The water is then drained away from the reclaimed area.

4.2 *Compaction work over reclaimed area*

After the initial compaction of the soft subsurface material by pre-loading, additional compaction of the reclaimed area was conducted to further reduce the amount of anticipated settlement and increase the load bearing capacity of foundation material.

In order to determine the most efficient and effective method of additional compaction of the reclaimed area, 4 types of compaction methods were tested. They are roller compaction, dynamic compaction, hydraulic hammer compaction and the mammoth vibro-tapping compaction method.

The tests were conducted over an area measuring 220 m by 110 m and designed to eliminate interference between each test method. For this pilot testing alone, more than 88 different testing equipments such as underground pressure cells, screw type settlement bars, and various types of probes were utilized. Total two thousand field measurements were performed including undrained shear strength of clay, N-values, cone resistance, settlement measurement at the ground surface and also in the layers of soils, pore water pressure, inclinations of slope, field density of compacted material by means of 7 different field testing methods. Laboratory tests were also conducted for the six hundred soil specimens which were obtained from the field.

The heavy hydraulic hammer compaction method was adopted in the area where the height of the hydraulic fill was 2.0 to 6.1 m. The diameter of rammer in this compaction equipment is 1.5 m and its weights are 10 metric ton for runway and taxiway area and a 7 metric ton for the rest of the area. The number of blows per one spot was 20 blows with the drop height of 1.5 m. The spacing of tamping was 2.1 m and the pore water pressure was measured during the tamping period. The hydraulic hammering was induced an extra 40~50 cm settlement due to an additional compaction of the foundation materials.

After the hydraulic hammer compaction was performed, the amount of additional soil settlement was found to be 40 cm. The strength of the underlying soil was then measured using Cone Penetration Test (CPT) and SPT. The measured result from the CPT tests indicated soil shear strength of 20 Mpa, which means that the improved soil at the IIA can sufficiently support the load of new large aircraft. In comparison soil strengths found at Changi airport is only 15 Mpa, which is comparable only normal road construction criteria.

The Standard Penetration Test results shown in Fig. 4 indicated the depth of the soil improved is about 5 m and the degree of soil improvement is a little more than 2 times.

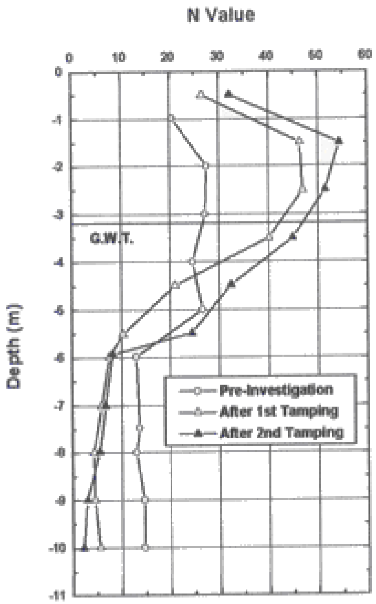


Fig. 4 Test results of SPT for heavy hydraulic hammer area

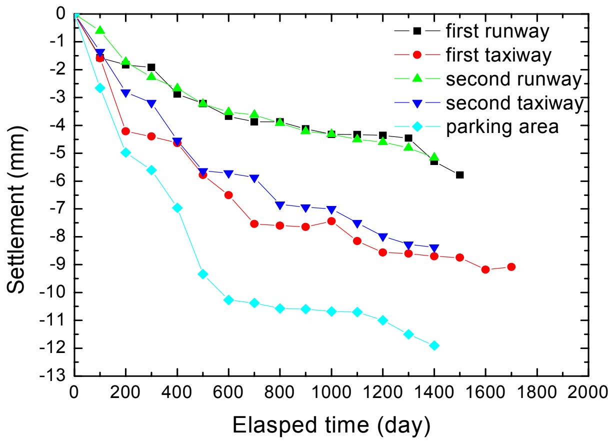


Fig. 5 Field measured settlement levels at various spots

4.3 *Result of field measured settlement*

Field settlement has been measured with times at various spots as shown in Fig. 5. The largest settlement occurred at the aircraft parking area due to the static load of aircraft. However, all the field settlement levels are far below the controlled limits which are described in Table 2. Runway settlement was much less than those of taxiway and parking areas. The field measured settlements for Runway No.1 and Runway No.2 are 5.77 mm and 5.16 mm, respectively. The first and second taxiway settlements are 9.08 mm and 8.37 mm. The field measured settlement for an Apron area is about 11.91 mm. From the field settlement results and permissible long term settlement, the paved areas for an airport operation is expected very stable condition in terms of settlement level.

5 RUNWAY GEOGRID REINFORCEMENT

The geogrid reinforcement technique was also applied the area where the runway is to cross over the underground box culvert. The backfill area adjacent to the box culvert is not easy to have a proper compaction by the compaction equipment. The magnitude of differential settlement was expected about 3 cm. The method of soil reinforcement was either 20 cm thick concrete slab or geogrid reinforcement. The feasibility study was conducted by Shin et al. (1999) and one layer of stiff biaxial geogrid was placed in between cement stabilized layer and sub-base layer. The length of geogrid reinforcement is 5 m from the end of box culvert for both sides. The extended length of geogrid was 2 m from the end of backfill soil in the box culvert to induce the interlocking forces and hence mobilizing the tensile forces of geogrid with sub-base material.

The cross section of geogrid reinforced asphalt pavement is shown in Fig. 6. Therefore, the construction damage to the geogrid could be occurred because the cement treated sub-base layer or lean concrete was spread by the finisher. The geogrid specimen was taken out from the field and tested it's tensile strength. It is turned out to be that the construction damage of the goegrid due to the field construction is very minor and negligible.

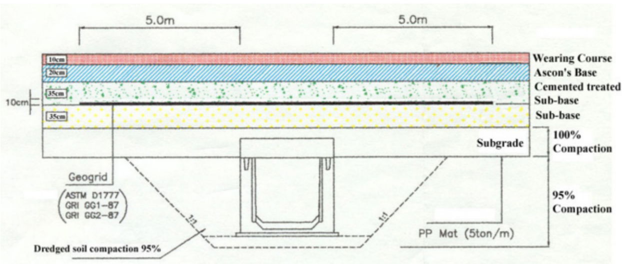


Fig. 6 Cross section of geogrid reinforced asphalt pavement

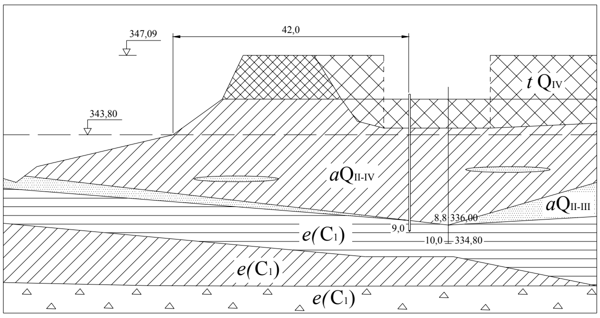


Fig. 7 Engineering and geological section

6 PHYSICAL AND MECHANICAL CHARACTERISTICS OF GROUNDS OF INTERNATIONAL AIRPORT AT ASTANA

The engineering and geological section of Ishim river quay is given in the Figure 7 and Table 3 (Zhusupbekov et al., 2004).

Given territory is a flat area of Ishim river bank, low natural level of which comparative with water level in the river is increased with fill-up soil tQ_{IV} with the depth 2,5…4,0 m. The overburden alluvial sediments are lying under deep layer: loam $aQ_{II\text{-}IV}$ and clay $aQ_{II\text{-}IV}$, strongly pressed. Underneath there are sands of average size $Q_{II\text{-}IV}$ and coarse sands and gravel $Q_{II\text{-}IV}$. Judging from sufficiently high value of deformation module, angle of internal friction and specific gravity, sands $Q_{II\text{-}IV}$ have density higher than average, and sands $Q_{II\text{-}III}$ have high density (Popov et al., 2003).

Under overburden sediments there are solid eluvial grounds of lower carbon: clay $e(C_1)$ and loams $e(C_1)$ including gruss and crushed stone. Both of these layers have similar and sufficiently high indices of mechanical properties, to which they have semi-solid and tightly plastic consistency (Zhusupbekov et al., 2003).

Clay of layers $aQ_{II\text{-}IV}$; $aQ_{II\text{-}III}$; $e(C_1)$ are characterized with new bedding, layer thinning and facies substitution are observed in geological sections (Zhusupbekov et al., 2004).

Table 3 Physical and mechanical characteristics of grounds

Designation of Characteristics	tQ_{IV}	$aQ_{II\text{-}IV}$	$aQ_{II\text{-}IV}$	$aQ_{II\text{-}IV}$	$aQ_{II\text{-}III}$	$e(C_1)$	$e(C_1)$	$e(C_1)$
Specific cohesion, kPa	5	16	49	2	1	31	31	-
Angle of internal friction, degree	30	16	20	38	40	33	33	-
Deformation module, MPa	10	6	7,5	21	36	15	15	-
Density of ground, g/cm^3	2	2,01	1,02	1,92	2,00	1,95	1,95	2,12
Poisson's ratio	0,35	0,35	0,42	0,30	0,27	0,42	0,35	-
Design resistance, kPa	-	-	-	-	-	-	-	450

7 CONCLUSION

1) With the limited land in the Korean Peninsular, the land reclamation projects have been extensively performed in the south and west coastal areas. Case histories of soil improvement works for the Incheon International Airport were presented in this paper. The selection of the most appropriate soil improvement for the given site is heavily depended on the geotechnical properties of soil, available filling material, construction equipment, soil stabilization period, location of site, and cost. By reviewing overall soil improvement case studies, PBD is the most popular deep soil improvement method for soft ground, mostly in the large-scale land reclamation works while the heavy hydraulic hammer method for the ground consisted of granular soil in the near ground surface. Geogrid reinforcement for the runway where box culvert is passed through in the underground was applied. Currently, the second stage of the construction with two runways for the IIA is in progress.
2) At 30 m distance of the load P1 from the river Ishim at Astana, depth of pile driving 8 m with support on gravel sands $aQ_{II\text{-}III}$ (above the river bottom) and 10 m of support on clay and loams $e(C_1)$ (under river bottom) the losses of "geosystem" balance "group structure-base" is not happening neither under rated loads nor under five-times over.
3) This investigations are important for designing and construction of international airports buildings on soft soil ground.

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