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A Case Study of Measuring Residual Groundwater Level on Reclaimed and Dredging Clay Layer

준설점토 지반상 잔류 지하수위의 계측 사례 연구

Yang, Tae-Seon[1]　　양 태 선

요 지

준설점토지역에서 적용되는 지하수위는 설계 기준에 따라 현장의 계측치와 동일하다고 가정하여 진행되었으나 실제로 잔류수위의 차이가 계측을 통하여 확인되고 있다. 본 논문에서는 광양항의 컨테이너부두 및 배후부지에 대한 지반개량공사의 계측관리중 지하수위에 관한 측정 사례를 살펴보고, 항만공사의 지반개량 설계 및 공사시 적용되는 지하수위 및 개량 후, 시공후 9년이 지난 시설물 사용 과정에서 측정된 잔류수위를 중심으로 컨테이너부두 및 부지 개발의 설계 및 시공, 사용시의 적용할 수 있는 지반개량지역의 잔류 지하수위(R.GWL) 적용의 합리성에 대하여 검토하였다.

Abstract

Grounwater level applied on dredged and reclaimed clay layer was assumed to be the same value under design criterion as field test one, but actually differences are found through the monitoring test. In this study, a case study of measuring residual groundwater level is performed in ground improvement construction of Gwangyang container terminal and hinterland. With priority given to residual groundwater level measured during construction and management period of 9 years, it is investigated that residual groundwater level (R. GWL) could be applied reasonably to the design, construction, and use stages of the container harbor and land development.

Keywords : Container terminal, Groundwater level, Residual water level, Reclaimed land, Soil improvement

1. Introduction

A large area is required to construct the harbor land and container terminal which are constructed in reclaimed land using the dredged materials, and these structure are constructed on ground improvement conditions.

After completion of Phase I, Phase II-1 and hinterland development projects which were started in 1993 and located in the eastern area of Gwang Yang Port, groundwater tables, which have been monitored in those projects since 1997, are studied in this paper (KGS, 2005).

About 9 years after the projects completion, the monitored groundwater levels are approximately similar to Mean Sea Level (D.L.(+)1.911 m) near quay wall but are higher than the Highest High Water Level

1 Member, Assistant Prof., Envir. & Civil Engrg., Kimpo College (sj98@kimpo.ac.kr)

(D.L.(+)3.822 m) in the reclaimed area respectively.

Based on the studies, the groundwater levels in the reclaimed area are governed by reclamation level, consolidation settlement and residual excess pore water pressure and the more monitoring results of ground water levels can provide the reliable ground water level when designers design the harbor structures.

This study was undertaken in order to investigate the behavior characteristics of groundwater level through the field tests. The tests were conducted for a groundwater level monitoring, under ground improvement conditions.

The monitoring results were compared with behaviors of groundwater level using the stand pipe type and large diameter type affected by design and pratice assumptions of groundwater level locations.

2. Ground Improvement Construction Status of Gwangyang Port

The geographical location of Gwangyang Bay takes a role of natural breakwater structures between Yeosu and Namhae Peninsula. Constant expansion of Gwangyang Port facilities resulted in 33 berths of container terminal and 82 berths of ports which will bring growth as a port that manages 9330 thousand TEU containers and 180 million tons of general cargo. 55 berths of general ports, now operating, general ports to be built (1 berth under construction, 27 berths to be built until 2011) are going to be connected to container terminal to bring custom made logistic service to customers. According to Gwangyang container terminal, development plan of governments and container terminal authorities in 2001. Comprises 3 phases constructing 33 berths until 2011.

Phase III-1, 4 berths (50 thousand DWT x 4),Phase III-2, 3 berths until 2005 now has constructing.

2.1 Dredging Status of Eastern Parts of Gwangyang Port

Gwangyang Development Project is progressed when dredging work after revetment construction was done (DL(+)6.0) including 500 thousand pyeong of eastern parts of Gwangyang port from March 1, 1993, before container terminal Phase I was constructed. After 1st dredging, outer revetment elevation was done until DL(+)8.7 and extra dredging was performed.

Representative reclamation elevation is DL(+)5.4 of Phase I of eastern part, DL(+)7.4 of Phase II-1, DL(+)6.0 (1 Block) - DL(+)10.2 (7 Block) of related area of Phase I, Phase II-1 construction (Korea Container Terminal Authority, 1994, 1996, 1997, 1999).

2.2 Monitoring Management

A comprehensive instrumentation program is applied to acquire results from sensitive monitoring. However, only one result is available at this moment: the groundwater level meter.

Surcharge-settlement-water level-time history monitored

Table 1. Dredging status of Gwangyang port Phase I,II

Item	Base Excav.	1st (91)	2nd (91)	3rd (92)	4th (92)	5th (93)	6th (94)	7th (96)	8th (97)	9th (98)
Amount occurred (thousand m^3)	601	1,300	2,286	525	1,574	5,546	3,628	660	4,641	3,500
	601	1,901	4,187	4,712	6,286	11,832	15,460	16,120	20,761	24,261
Place reclaimed	Phase I, Related area, Roads in site Phase II−1, Related area, Roads in site Phase I, 4 berth ,Cotainer yard(future development area Phase II−1, Cotainer yard(future development)									

from the trial performance of embankment, is presented together with the predicted trend at design stages. Observed field data smoothly matche with the predicted final values. However, small discrepancies are shown during early stages. These discrepancies are basically attributed to different surcharge loading procedures. Therefore, it can be concluded from this comparison that predictions made in the design stage are reasonably good with acceptable tolerance even if water level does not match the one anticipated at the design stage followed by the surcharge scheme. It is notable that delays in surcharge loading will substantially slow down consolidation time and a little bit decrease water level (Choi,sung hak, 2004).

3. Measurement Results of the Phases I,II of Gwangyang Port

Development land of Gwangyang port (MSL (Mean Sea Level) : DL(+)1.911) is that Phase I and II-1 container harbor has been completed and used in front of eastern part, in the rear part classified as related area, roads in container harbor, and hinterland. Ground improvement of construction in related area and roads has been completed, or under construction in hinterland. Fig. 3 shows the eastern part and the locations of groundwater level meters, which stand pipe types were installed in container terminal and related area of Phase I, and large diameter types were also installed during construction of Phase II.

Grondwater level was measured by monitoring devices which were installed in quaywall area (Non-dredging) and CY (Container Yard) area of Phase I, and installed in related area of Phase I, II, which was completed in September, 2003. It is to examine applications of residual groundwater level in harbor construction when changes of water level during management were analysed after completion of construction.

Fig. 4 shows the cross section of groundwater level meter installation in area where ground improvement was completed. Quaywall area of Phase I, cross section of costruction, and installation location of groundwater level meter (how far from the quaywall) were shown in Fig. 4 (a). The cross section of ground improvement in related area of Phase I, II-1 and installation location of groundwater level meter were also shown in Fig. 4 (b) (Korea Container Terminal Authority,1994, 2002).

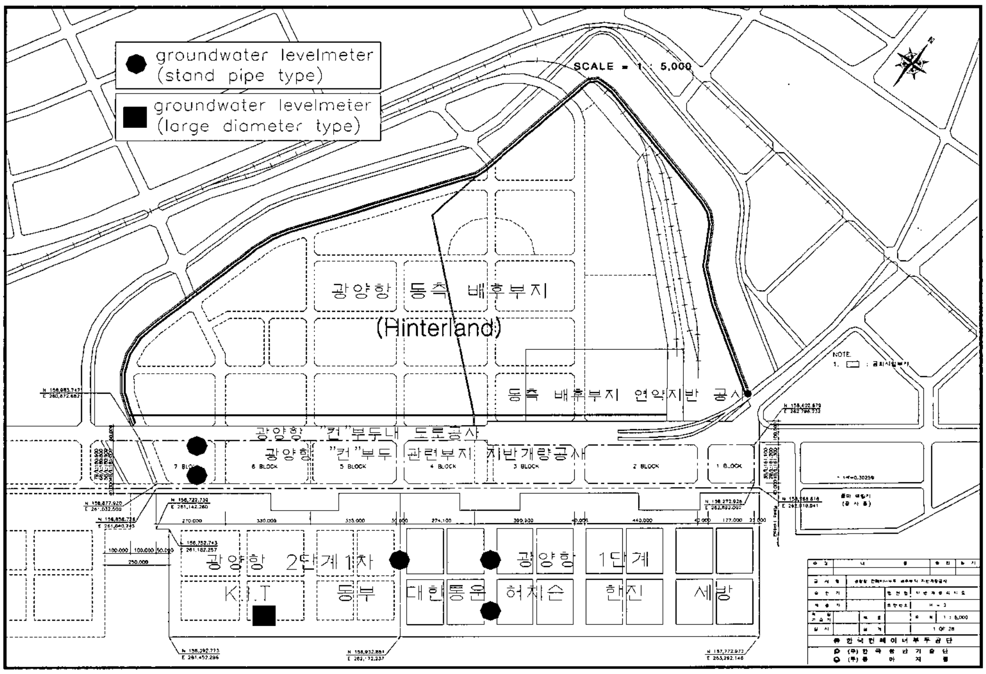
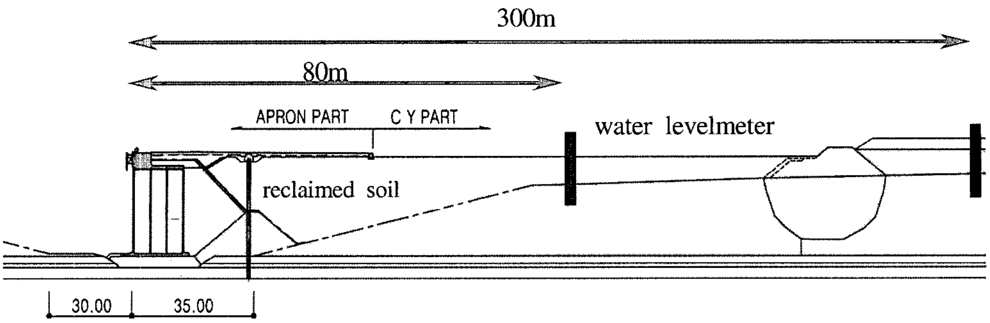
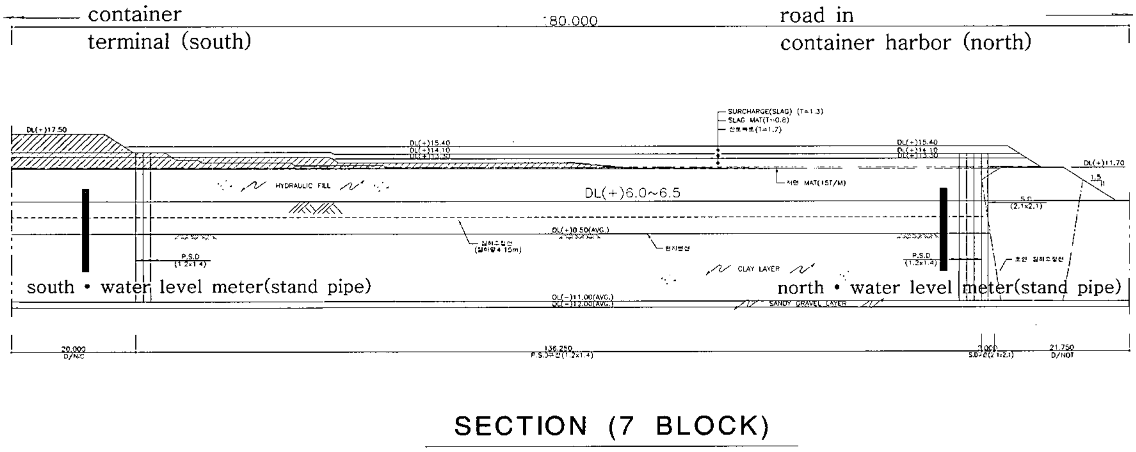


Fig. 3. Installation location of groundwater level meter in Phase-I and related area



(a) Groundwater level meter after Phase I constructed



(b) Water level meter in related area

Fig. 4. Cross section of installation location of groundwater level meter

3.1 Measurement Results of Groundwater Level Meter in the Phase I Container Harbor of Gwangyang Port (Korea Container Terminal Authority, 1994,1997)

3.1.1 Installation Background of Groundwater Level Meter

During monitoring the groundwater table under the construction of Phase II-1 after completion of the Phase I in 1997, November, measured value displays higher than the actual one owing to excess pore water pressure increased by embankments. In order to judge more accurate groundwater level, excess pore water pressure, existing water level meter of stand pipe type was changed to large diameter type with the approval of a superintendent. This water level meter was installed in quaywall 3 points (large diameter type), harbor 2 points (stand pipe type) on 1998, October.

3.1.2 Instrumentation Results

Fig. 5 shows the monitoring results in quaywall area of the Phase I from October, 1999 to March, 2005. The value is distributed among DL(+)2.3~2.8, owing to rainfall effects of seasonal changes on the water level values. When considering Mean Sea Level (MSL) DL(+)1.911, the water level values to the sea side act as dull slope in qyaywall area (Non-dredging) 80 m away from the front of caisson because of a low water level, a thin clay layer, and the low upper elevation (DL(+)o.o)

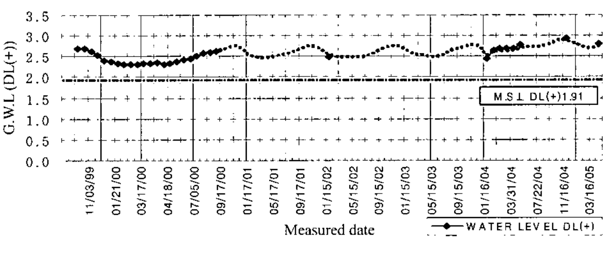


Fig. 5. Results of groundwater level monitoring (Phase I Quaywall area (Non-dredging))

in this area even after harbor completion.

Photo 1 shows ground water level meter which was installed on the pavement and controlled on the border between 3rd berth and 4th berth in.Phase I.

Fig. 6 shows the monitoring results of groundwater level meter 300 m away from the sea side in harbor area. The value is distributed among DL(+)4.1 ~ 5.1, owing to the water level values caused by rainfall effects of seasonal changes as in quaywall area. It can be seen that as in Fig. 7, locations of groundwater table in dredging and reclaimed area have close relations with the place where a drainage layer is remained.

It is shown that groundwater level was built up, through the monitoring results of groundwater level and clay elevation, in the sand mat layer and capillary saturated zone constructed for remaining consolidation drainage of dredged clay layer after ground improvement of Phase I. After construction completion, ground elevation status of dredged clay and sandmat layer through monitoring and construction results are shown in Table 6.

Photo 2 shows groundwater level meter controlled, Fig. 7 shows the cross section scheme of water level changes before and after ground improvement in order to compare the design and practice stage. Also, it is found that the section has been changed by the reclaimed elevation and

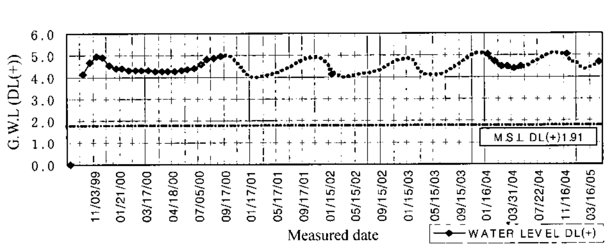


Fig. 6. Results of groundwater level montoring (Phase I CY area (Dredging))

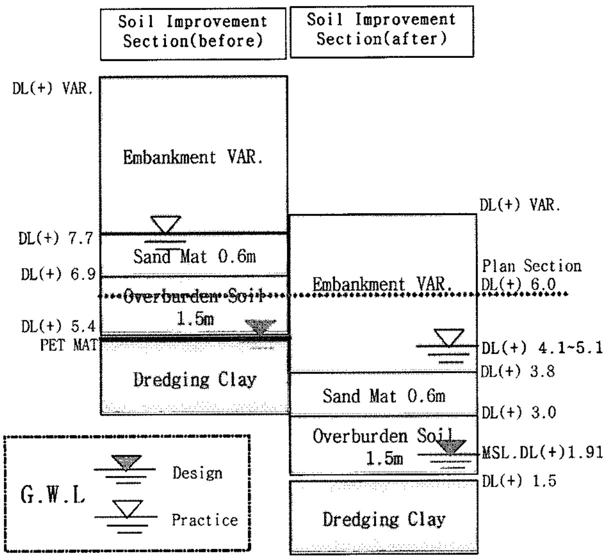


Fig. 7. Cross section scheme of water level changes befor and after ground improvement (Comparison between Design & Practice stage)

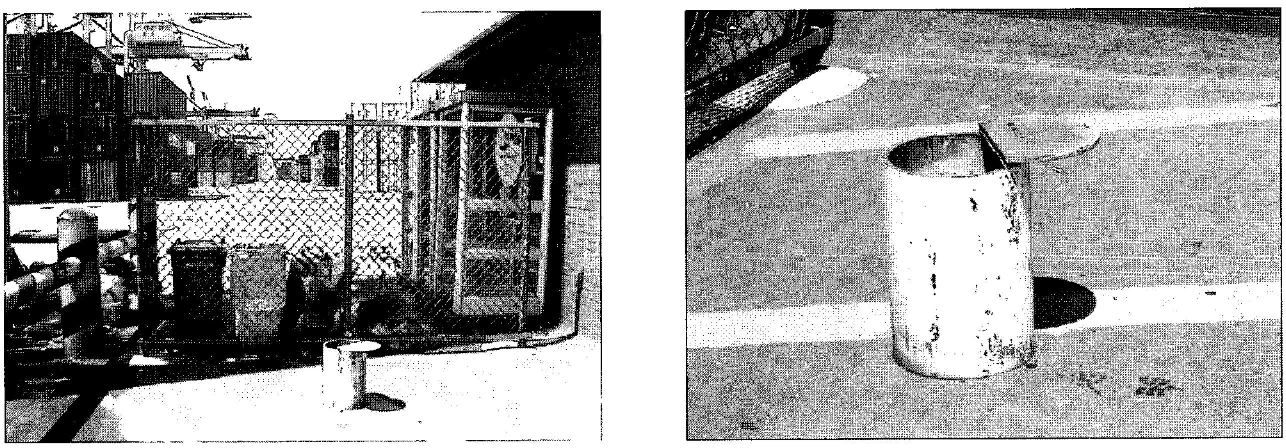


Photo 1. Groundwater level meter (Phase I Quaywall area (Non- dredging))

Table 6. Results of construction completion (Phase I)

Item	water level after completion (DL(+))	residual excess pore water pressure (t/m^2)	elevation on clay layer (DL(+))	thickness of banking (m)	Remarks
result	5.1	5	1.5	3.0	Average during construction

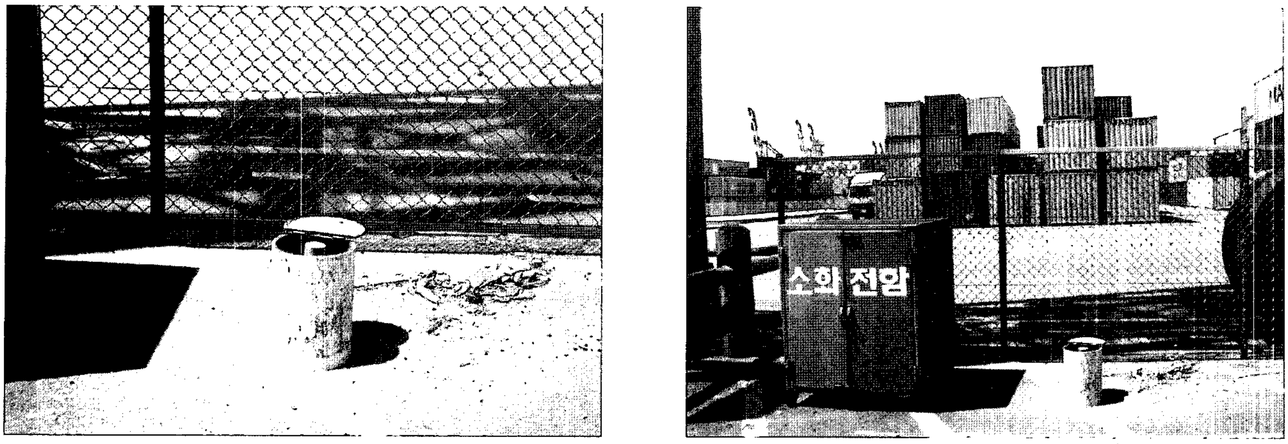


Photo 2. Groundwater level meter (Phase I CY area (dredging))

settlement. When it comes to locations of residual water level, sandmat layer is higher than MSL, because groundwater level rose.

In particular, a common point is found by changing trends of grondwater level for 9 years after completion of construction as shown in Fig. 5 and Fig. 6 so that water level values decreased from March, and increased continuously to be highest in September, but decreased again in winter session.

The design assumption that residual water level would approach to MSL finally at ground improvement stage while water level comes up to the upper part of dredged clay layer or upper part of sandmat at underconstruction stage, needs a long- term monitoring and more examination.

3.2 Measurement Results of Related Area in Gwangyang Port

3.2.1 Background of Groundwater Level Meter Installation

Related area of Gwangyang port is developed mainly by ground improvement from 1999 to 2003. To confirm groundwater level monitoring, 2 groundwater level meters (stand pipe type) were installed in locations of Fig. 3 (Korea Container Terminal Authority, 1994, 2002).

3.2.2 Results of Water Level Monitoring

Fig. 8 and Fig. 9 show measurement results of groundwater level (South, North) for 16 months from January 2004 to April 2005 installed in sector of 180 m length of related area as shown in Photos 3, 4. It is known that when 3 years have passed since completion of

Table 7. Water level after completion in related area

Item	water level after completion (DL(+))	residual excess pore water pressure (t/m^2)	elevation on clay layer (DL(+))	Remarks
result	5.5	1.5	4.1	Average during construction

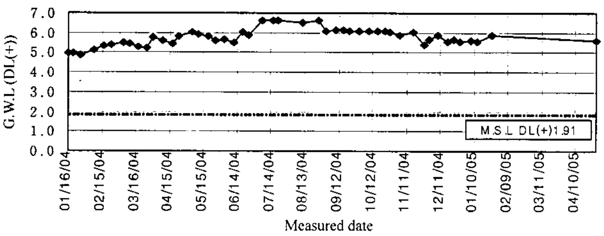


Fig. 8. Results of groundwater level montoring (Phase I related South area (Dredging))

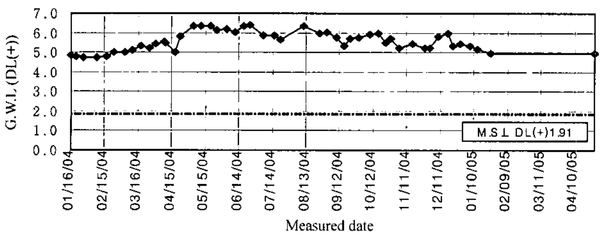


Fig. 9. Results of groundwater level montoring (Phase I related North area (Dredging))

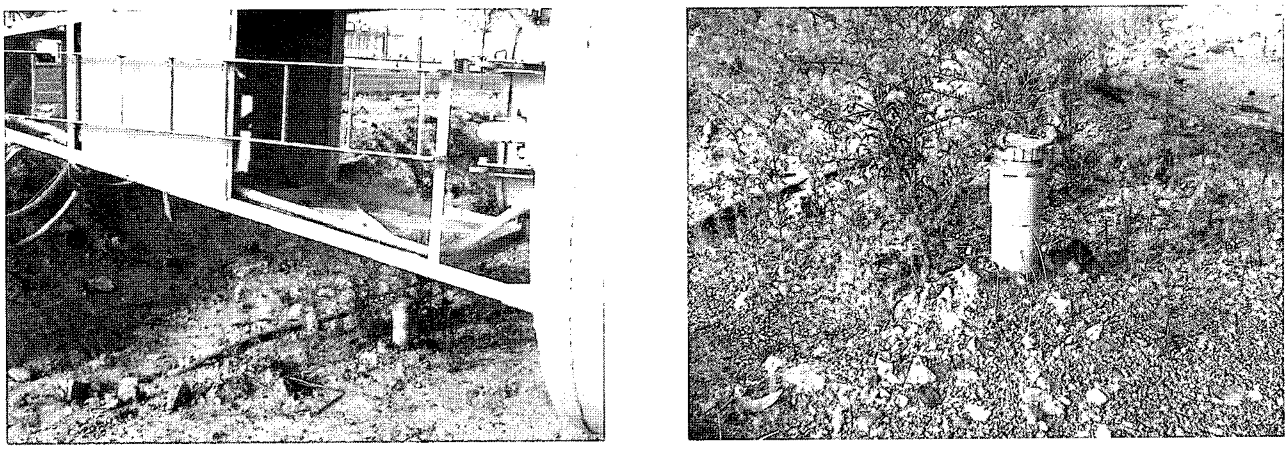


Photo 3. Groundwater level meter (Phase I, II related south area (dredging))

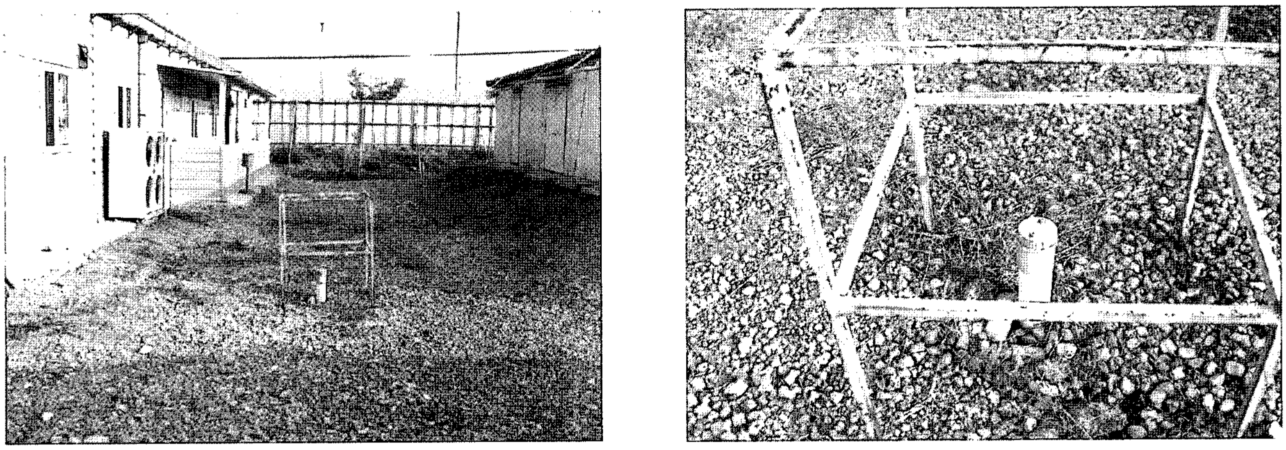


Photo 4. Groundwater level meter (Phase I, II related north area (dredging))

construction, water level did not sharply decline. Groundwater level is measured as DL(+)4.7~6.3 in the southern area, DL(+)4.8~6.0 in the northern area. It was a trend that water level values increased from April to September, but decreased in winter session.

Residual excess water pressure of dredged clay layer classified as CL, CH was not completely dissipated and more monitoring and analysis were needed continuously as time flows.

Photo 3, 4 show groundwater level meter of Phase I, II related south and north area.

3.3 Application Results of Large Diameter Groundwater Level Meter

When instumentation management of dredged reclaimed area is progressed for ground improvement of Gwangyang port Phase II-1 construction, value of water level meter (Stand Pipe Type) increases near ground surface in some spots. In order to decrease a capillary rise by excess pore water pressure, water level meter of corrugated steel pipe of large diameter (ϕ600 mm) was installed in Phase II-1 quaywall area (grond improvement sector) as well as in Phase I wharf.

Fig. 10 shows plan of installation location of large diameter water level meter ; table 8 shows results of groundwater level montoring.

From Fig. 10 and Table 8 we can compare the groundwater level meters and No.4, 6 (Large diameter,600 mm) installed in similar position from sea side. It can be seen tha the one (Stand Pipe, 50 mm) measured higher water level than the other (Large diameter, 600 mm). The effects of capillary rise by pore water pressure in lower part of pipe were not found in large diameter type, but

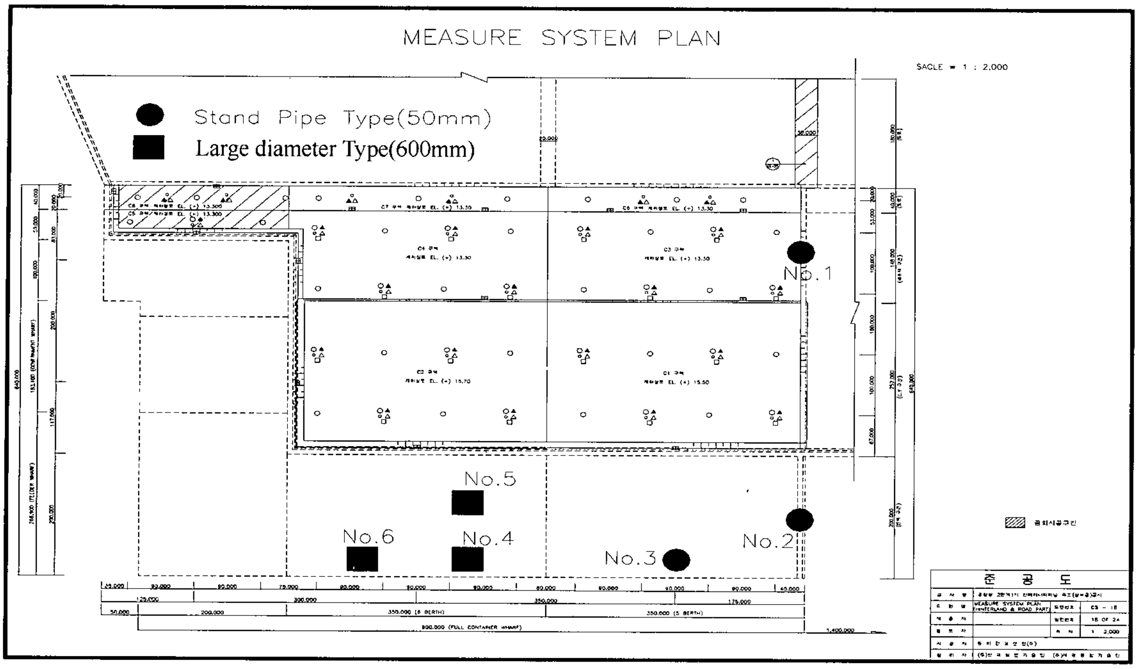


Fig. 10. Plan of installation location of large diameter water level meter (Phase I)

Table 8. Results of groundwater level montoring (Stand Pipe Type vs Large diameter Type)

Item	No.1	No.2	No.3	No.4	No.5	No.6
Results	4,703	2,778	2,765	2,125	1,757	1,772
	Stand Pipe (50 mm)	Stand Pipe (50 mm)	Stand Pipe (50 mm)	Large Dia. (600 mm)	Large Dia. (600 mm)	Large Dia. (600 mm)

the rise of water level by capillary was measured in No.3 (stand pipe type).

Residual pore water pressure by piezometer is 1.1～2.9 t/m^2 in No.3, which is larger value than 0.4～2.6 t/m^2 in No.4～6. It is confirmed that groundwater level meter (stand pipe type) generally applied could measure the fixed quantity rise of water level by the effects of capillary rise by pore water pressure of lower part in ground improvement construction of dredged clay layers.

4. Discussion on Groundwater Level of Construction Sites in Gwangyang Port

Table 9 shows measured values of groundwater level in Gwangyang Phase I, Phase II-1 of construction site, which was located 200 m, 700 m respectively away from the sea side. Last residual groundwater level of construction sector, which is away more than 200 m from seashore, is unrelated with M.S.L. It can be seen that the water level was affected by residual excess pore water pressure after ground improvement, locations of sand mat, and ground level on the dredged clays (Korea Container Terminal Authority,1994 ,1996, 1997, 1999, 2002).

When harbor facilities were used after ground improvement on dredged caly sector, remaining water level did not mean sea level (MSL) and rised up to constant elevation which can drain by the effects of excess pore water pressure. It can be used to refer to remaining water level decision which is applied to design the improvement of soft ground in domestic harbor area.

Further study is needed on ground elevation over dredged clay layer remaining after ground improvement, locations of overburden soil and sand mat layer, capillary saturated zone, residual water table.

The fact that the anticipated value of ground water level by monitoring is over MSL is in close relation to the reclaimed elevation of dredging soil, and the cross section scheme of drainage layer to squeeze water. In the

Table 9. Groundwater level status of costruction sites neat Gwangyang port

Item	completion of ground improvement: residual excess pore water pressure (t/m^2)	completion of ground improvement: elevation on clay layer DL(+)	groundwater level: completion of ground improvement (banking removed) groundwater level (GWL DL(+))	groundwater level: Residual groundwater level (design)	Remarks
Container Terminal (Phase I)	0.10~2.61	1.5	5.1	1.91	M.S.L
Container Terminal (Phase II-1)	0.07~2.57	2.6	5.3	1.91	M.S.L
Container Terminal (Phase II-2)	0.51~3.81	3.5	6.1	1.91	M.S.L
Container Terminal Related Area (ground Improvement)	0.34~2.61	4.1	5.5	1.91	M.S.L
Container Terminal (roads)	0.65~2.30	4.0	7.2	1.91	M.S.L
Eastern CY (ground Improvement)	0.32~4.12	continued	8.9	3.9	M.S.L
water level reclamation (general harbor)	0.12~3.16	1.0	3.1	1.91	-

* Mean Sea Level in Gwangyang area : DL(+)1.91

future, extra management charges would be paid for steel corrosion of buildings, boxes, durability decline in the process of using facilities. So, it is reasonable that last residual water level may be applied to conservative value.

Based on the studies, the ground water tables in the reclaimed area are governed by reclamation level, consolidation settlement and remaining excess pore water pressure, and the more monitoring results of ground water levels can provide the reliable ground water table when designers plan the harbor structures.

5. Conclusions

Measurement results of water level under construction, operation in Gwangyang port are analysed as follows:

(1) In order to judge more accurate groundwater level, excess pore water pressure, the existing water level meter of stand pipe type was changed to large diameter type through the approval of a superintendent.

(2) 9 years have passed since completion of projects in 1997 which started in 1993 and are being operated now. Measurement results of groundwater level meter Phase I of Gwang Yang Port is distributed among DL(+) 2.3~2.8 in quaywall area (Non-dredging), DL(+)4.1~5.1 in CY area (Dredging). It is confirmed that as time passed, residual excess pore water pressure was not dissipated and water level did not decline.

(3) After ground improvement in 2002, measurement results of groundwater level meter Phase I, II-1 of Gwang Yang Port are distributed among DL(+) 4.7~6.3 in related area. It can be seen that residual water level did not decline in short time as was in harbor area of Phase I, II-1. Water level of costruction sites after completion of ground improvement near Gwangyang port (Referred to Table 9) is distributed among DL(+) 3.1~7.2. But the process of harbor and related area shows different level.

(4) To measure effective ground water level, using water level meter of large diameter type (600 mm) is reliable. The effects of capillary rise by pore water pressure in lower part of pipe were not found in large diameter type, but the rise of water level by capillary was measured in No.3 (stand pipe type).

(5) The ground water level is not converged to MSL even 9 years after completion of ground improvement, and even though operation load is applied after completion of target settlement, residual water level would not decline in short time.

(6) It can be seen that the effects of capillary rise pressure

in water level meter of large diameter type are smaller than the one in stand pipe type applied generally which is installed and managed in Phase II-1 of Gwang Yang Port.

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