Journal of Civil Engineering Research 2016, 6(2): 32-39
DOI: 10.5923/j.jce.20160602.02

# Methods for Groundwater Lowering and Construction of Drainage System under Buildings in Ulaanbaatar City

**Dalai Dashjamts**

School of Civil Engineering and Architecture, Mongolian University of Science and Technology, Mongolia

**Abstract** The territory of Ulaanbaatar city belongs to the Khentii mountain range, and located in the Valley of Tuul River that stretches out from east to west merging with small rivers like Selbe, Ulyastai and Tolgoit. Our investigation shows that the groundwater has undesirable effects on buildings. This paper describes the detailed hydrogeological study of Ulaanbaatar city to ensure the stability of construction foundations. Furthermore, it presents methodologies for lowering groundwater and designing drainage system depending on hydrogeological condition. Finally the paper reports the results of implementation of these methodologies in engineering construction projects.

**Keywords** Lowering groundwater, Drainage system, Soil, Foundation, Construction projects

## 1. Background: Hydrogeological Condition of Base Soil in Ulaanbaatar City

### 1.1. Geological Structure

The central and northern parts of Ulaanbaatar city are located within fractured zone of sloped from north to south, in the Selbe River valley. The slopes of mountainous edges on both sides of Selbe River valley are characterized by low Carbon sedimentary rock out crops underlying by the Upper and Modern Quaternary aged dilivium, dilivium-proluvium deposition of overburden soil in thin layer. The Neogene (N) deposition spreads from the center of the city to the west and north-west. The Upper and Modern Quaternary aged ($apQ_{II-III}$) overburden soil formation exists in 20-30m deep along the river valley.

The groundwater spreads throughout the northern part of the Ulaanbaatar city to Nogoon Nuur and Zuun Ail, from downstream of Belkhi River to the Selbe River valley creating wet areas, swamps and puddles. The groundwater in base soil is sustained by seasonal precipitation accumulated in gravely layer underlying the clayey and silty clayey soil formations. Soil water containing sediment is mostly dominated by silty sand and clayey sand formation.In accordiance with the geological origin, the area soil around the Selbe River is predominated by alluvium proluvium deposit and meanwhile the area around the Tuul River's terrain has alluvium deposit of water-bearing layers.

* Corresponding author:
ddashjamts@must.edu.mn (Dalai Dashjamts)
Published online at http://journal.sapub.org/jce


The underground water regime of Ulaanbaatar city is influenced by climate condition, surface water differential, geological condition of soil and rock, ground surface geomorphological characteristics, building and construction facilities and other factors which are environmental and human engineering activities.

Due to environmental and human engineering activities, seasonal precipitation and surface water seeps into the ground causing negative effect on the construction foundation or sub-basement of the building.

### 1.2. Hydrogeological Stratigraphic Features

The water-bearing soil layer exists in the center and nothern parts of Ulaanbaatar city. However, the most construction difficulties are experienced in the area of Selbe River downstream.

Referring to the stratigraphy, the groundwater has hydraulic connection existing in bedrock formation, which is enriched by the upper, and lower water-bearing layers. Lithological features are dominated by poorly graded gravel with clay and silt soils, which have low permeability and less water yield.

Stratigraphy in the central and northern parts of Ulaanbaatar city can be classified as following:

1. Water bearing layer of the Modern Quaternary alluvium proluvium depositions (al $-pQ_{2-3}$ )
2. Water bearing layer of the Modern Quaternary diluvium proluvium depositions (dl-p $Q_{2-3}$ )
3. The Neogene water bearing layer ($N_{2-3}$ )
4. The Paleozoic artesian aquifer in weathered fracture zone ($PZ_{2-3}$)

Among the hydro-geological stratigraphy the alluvial-proluvial underground water-bearing layer (al-pQ2-3) is the most abundant, and other layers and zones are widespread throughout Ulaanbaatar city. The fractured zones of Paleozoic artesian aquifer are widely distributed under the overburden soil formation.

### 1.3. Results of Groundwater Regime Investigation

The water bearing layer exists relatively close to ground surface. For example, in YII and XI district the groundwater level found up to 2m depth below the ground surface, in VI district it varies between 1.51-1.70m. In 2012, it was recorded that basement floors of buildings at central and northern part of the city are flooded. Therefore, the investigation was performed by drilling of boreholes near flooded buildings. The groundwater found in boreholes had the same levels with water found in basement, which proves that the flood was resulted from groundwater.

Compared to the investigation data from 1985, the groundwater level in 2012 has risen, but the annual groundwater level fluctuation has decreased. Figure 1 shows rise in measured groundwater level and decrease in seasonal fluctuation from 1973 to 2003.

For instance, periodical measurement of groundwater level performed since 1980’s in the areas of Sukhbaatar square, Parliament Building and Bank of Mongolia, which are located in the center of the city, showed that the groundwater level was increased up to 1.0-1.5m. It was estimated that groundwater levels has been rising by 2-3sm annually. The reason behind the water level rise, in addition to ground water seepage, is intensive development of construction and road pavement which limits evaporation and results in accumulation of soil moisture.

Based on observation and investigation, the combined drainage system can be located in east of Nogoon Nuur, Zuun Ail, VI-district apartments but the partial vertical drainage system can be planned in Parliament Building, Mongolian State University and Baga Toiruu areas.

## 2. Design and Methodology for Lowering Groundwater Level around Foundation

In recent years lowering groundwater level has become the main problem for construction work in geotechnical conditions of Ulaanbaatar city. When selecting the method to lower water level, it is important to determine the position of water bearing layer. Equally important is to avoid the suffusion phenomenon, when fine soil particles are seep away with ground water. Suffusion occurs in grave, course gravel, and sandy soil which have less cohesion. Velocity and coefficient of permeability for mechanical suffusion phenomenon depend on the irregularity coefficient of soil structure.

After determining the irregularity coefficient of soil by graph of research for soil structure ($U=d_{60}/d_{10}$) and hydraulic gradient by calculation ($I=V/K_f$ formula), safety gradient for mechanical suffusion shall be defined ($V$ –velocity of groundwater seepage, $K_f$ –coefficient of permeability). Hydraulic gradient of soil, $I_f$ should be equal or less than value which is shown in Table 1 ($I_\phi \leq I$).

Dewatering method is determined depending on the value of hydraulic gradient.

1. Open method. To drain groundwater from foundation excavation, a well of 1x1 m size is dug at the bottom of the excavation to collect water. Then collected water is drained by pump.
2. Deep method. If footing is located measurably below the level of groundwater, water is decreased in fine soil by artificial deep method.

The lowering of groundwater involves installation of water draining equipment, collection of the water flow, and then removal of water. Dewatering should be conducted gradually with groundwater level being steadily 0.5 m below the footing of construction (Figure 2).

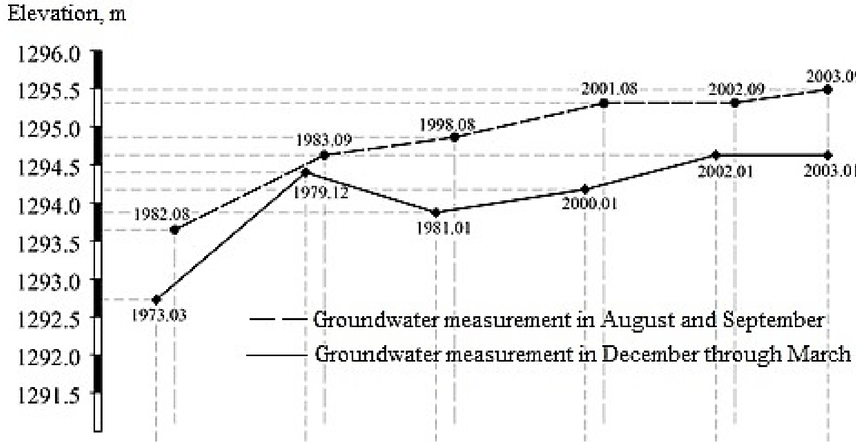


**Figure 1.** The rise and fluctuation of groundwater level

**Table 1.** Hydraulic gradient of soil

| $U=d_{60}/d_{10}$ | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 |
|---|---|---|---|---|---|---|---|---|
| $J$ | 0.75 | 0.5 | 0.4 | 0.3 | 0.27 | 0.25 | 0.25 | 0.25 |

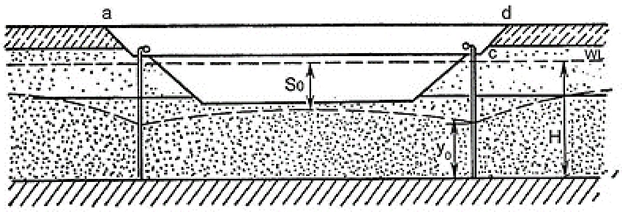


**Figure 2.** Scheme for lowering groundwater level

If required, multiple water draining equipment can be installed in rings or lines surrounding foundation excavation. Prior to inserting the wellpoint, a perforated tube to draw underground water, powerful water stream is applied to loosen the soil. Drainage equipment is used for sandy and gravel soil with groundwater permeability coefficient, $K_f$=0.1-40 m/day.

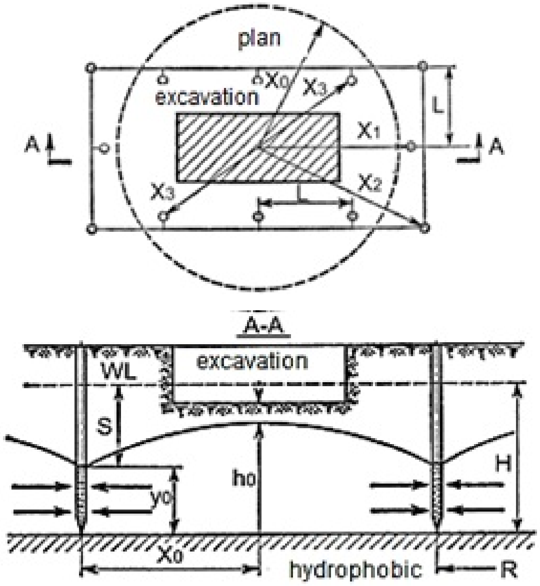


**Figure 3.** Design scheme of equipment for lowering groundwater

Distance between equipment for draining is 0.6 to 3.0 m. At once, 20 to 60 equipment are connected to the pump depending on its capacity. By one circle, groundwater level can be lowered by 4 to 5m. When wellpoint pit is drilled into imperious barrier (hydrophobic soil layer), it is called fully penetrating well (Figure 3). When well point is not touching hydrophobic soil, it is called as partially penetrating well.

Complete inserted pit is made based on following calculation (Pravdivets, 1998).

1. Depth of the pit, (H) is taken depending on section of engineering –geology, mainly on thickness of water seeping layer.
2. Drainage radius is determined by I.P. usatkin's formula.

$$R = r + 2 \cdot S \cdot \sqrt{K_f \cdot H}; \quad (1)$$

r-radius of equipment,

S–required size of lowering ground water level.

3. The distance between the center and all pits expressed as radius $X_0$ is defined as follows.

a. If pits drilled in rings $X_0=r$

b. For rectangular area of B: A=1:10 dimension:

$$x_0 = \sqrt{\frac{F}{\pi}}; \quad (2)$$

c. For pits installed in lines B: A=1:10

$$x_0 = \sqrt{x_1 \cdot x_2 \cdot x_3 \cdot \ldots x_n}; \quad (3)$$

Also expression, $x_0=P/2\cdot\pi$ may be used with $P$ as perimeter of equipment.

4. Total amount of water accumulated in the pits or required capacity of the equipment are defined as following formula.

$$Q = \frac{1{,}36(2H - S)S k_f}{\lg R - Lg x_o} \quad (4)$$

Here: $q$- amount of water absorbing in one pit, $H$–thickness of ground water surface, $S$–required amount of lowering ground water level.

For soils with low permeability ($K_f \leq 0{,}1$m/day) electro osmosis system of dewatering is recommended, which applies wellpoints along with electrical line.

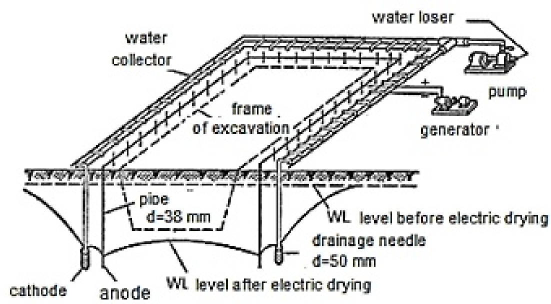


**Figure 4.** Scheme for lowering groundwater level by electro osmosis

The line of wellpoints is located at 1.5 to 2.0 m distance from the edge of excavation. Steel bar electrodes are installed not far (1.5 to 2 m) from well points with alternating cathodes and anodes. Electrical potential gradient causes positively charged ions and water around the soil particles to migrate to cathodes connected wellpoints (30 to 60 Wt). Then water accumulated in collector pipe is pumped. Energy of 5 to 40 kWT is spent per 1 $m^3$ of soil to be dewatered.

# 3. Methods Used for Lowering Ground Water in Ulaanbaatar City

## 3.1. "Golomt Town" Residential Complex with Drainage System Moving underground Water to Underneath Layers

"Golomt town" was planned as 5 buildings, each 15 stories, with total area of 22,100 $m^2$ (Figure 5). It also includes 2 stories of underground parking with 7500 $m^2$ area for 240 cars. It is located in Sukhbaatar district at south- east area of Ulaanbaatar city.


**Figure 5.** View of Golomt Town today

Two layers of aquifers are found at 4.5 m and 7.5 m depth respectively. Therefore, starting from 4.5 m depth, clay soil layer of 3m thickness was drilled until high permeability coarse gravel and sandy loam soil was reached. Then, permanent vertical draining pit of 4mx4m was excavated and perforated steel pipe of 0.6 m diameter was installed to drain groundwater to coarse gravel and sandy loam soil of high permeability under clay soil. As a result foundation bed at 9.5 m depth was kept away from groundwater. This method can be called as *transferring groundwater to underneath layers*.

The upper surface of the construction site contains soil of technogenic origin found at 1.4 to 1.8 m depth in the pits. Gravel soil filled with large-debris clay and detritus soil filled with gravel and sandy loam which is alluvium-poluvium moraine and quarter's years spread widely under the technogenic soil (Figure 6). Detritus soil and gravely clay of 0.3 to 1.0 m and clay containing gravel of 1.5 to 2.1 m, detritus filled with sand of 0.5 to 1.0 m thickness exist between above soils. Fragments of soil appear to be smoothed and mainly consist of sediment and mafic rock.

Five pits with 4.0 to 15.0 m depth were drilled at the building site, and groundwater existence was found at 1.5 m depth from two pits. Ground water in the boreholes pits of BH-3, BH-4 and BH-5 bored for ground surface became apparent and existed from 7.0 m depth. Ditch water formed due to seepage through the west wall of the trench. This occurred due to leakage from nearby passing Selbe river. The stream of groundwater is directed from north-east to south-west, water discharge is 5.0 l/sec, natural discharge is 1.67 l/sec and coefficient of permeability is 67 m/sec. Foundation soil is detritus filled with sandy loam which has a buff color, from hard to half hard consistency. Ground water became apparent and existed from second layer at 7.1m to 9.0m deep. Average annual fluctuation of groundwater is 1m to 1.5 m, with surface water became apparent from 4.5 m depth at the north part of the site. The area was subjected to mid category of engineering-geology according to groundwater and swell capability of clay soil. Specified depth of seasonal freezing was 3.4 m. The clay soil was defined as normal bearing capacity base soil which is relatively dense, with medium shrink potential and without swelling.

The project of "Golomt Town" was started in 2001 and several measures have been taken in order to lower surface water level and protect foundation. These measures include following.

1. Surface water as well as groundwater in clay soil layer at 7 to 10m depth was drained into underneath soil layers by installing pile-screw with 8 m length and 800 mm in diameter.
2. Hydro- insulation material of two layers was applied in vertical and horizontal directions of foundation wall and footing. In addition, in order to prevent the heat loss brick protected insulation material and bitumen were applied on basement walls.
3. Metal plates were inserted along total perimeter of monolithic foundation wall for all blocks at maximum level of seasonal fluctuation for groundwater.

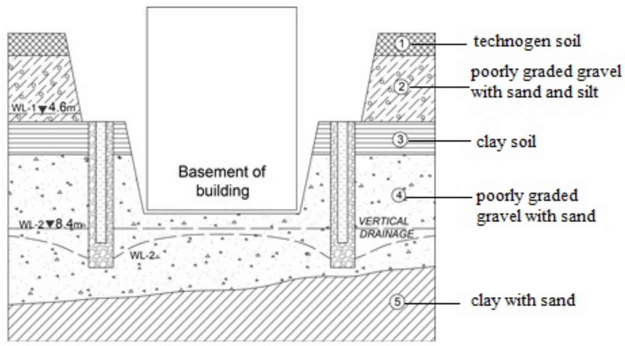


**Figure 6.** Engineering geological cross section of Golomt Town site

### 3.2. "Embassy Tower" Hotel and Service Complex with Insulation against Groundwater

Embassy tower is 15 stories building with 2 stories of underground construction (Figure 7).

**Figure 7.** View of Embassy Tower

The site is located on territory of 1st khoroo of Sukhbaatar district. Groundwater found at 3 m depth and water saturated sandy loam soil continues up to 20 m deep. Following steps have been taken against groundwater in two stories basement with deep foundation.

1. Excavation of deep foundation pit.
2. Bracing of foundation pit to provide resistance to earth pressure
3. Lowering groundwater below foundation level.
4. Insulation of foundation and basement walls from groundwater.

3.2.1. Lowering Ground Water Level

The level of groundwater level under the site of "Embassy tower" is high and water accumulated in basement floor. The measures against groundwater were taken based on investigation data from Batsaikhan, 2007. Permeability coefficient was determined using data of hydro geological pits. In this case, water discharge and thickness of water layer and drop of the ground water level for the four pits, were averaged. Furthermore, relationship of groundwater level fed by precipitation water during summer time was taken into calculation. Amount of groundwater is determined as accumulated natural resources and feeder of natural resources. Total length of the building area is 53 m and width 33 m when calculating amount of ground water near the building area as width of cross section.

Amount of ground water through strip for 100 meter of width near the site is Q = 13460 $m^3$/day or 155.7 l/sec. When draining for 10 pits, ground water is drained 15.5 l/sec or 55.8 $m^3$/h for one pit. The pits is positioned 3 by 3 in series along two side, 2 by 2 in parallel at north and south side. Distance between pits is designed 15 to 20 meter. Since there wasn't any drainage canal nearby, water was transferred to Selbe River at 1500 m distance. By doing this the ground water can be lowered from 5m to 11m (Figure 8-11).

When calculating the depth of lowering ground depth of the foundation is 11 m, thickness of concrete bed is 2.0 m. Ground water feeds by rain water during summer and increases by 1.5 m than the level in April, May and June. So ground- water level descent for the design was taken by 9.5 m. Total descent of the level was 12.5 m depending on the level which was from ground surface to given level.

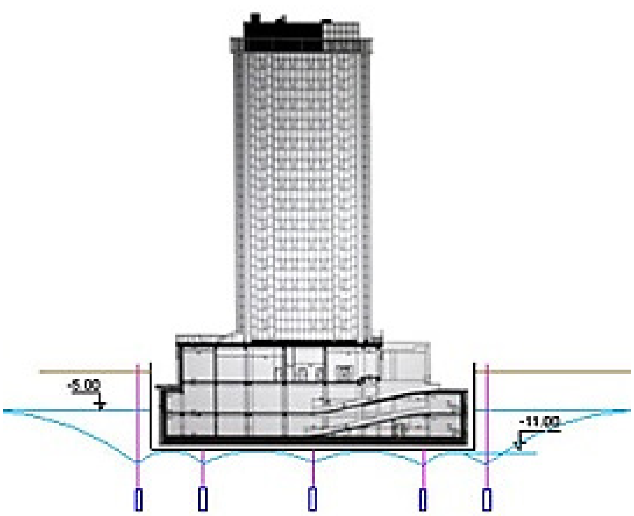


**Figure 8.** Cross section of Embassy Tower

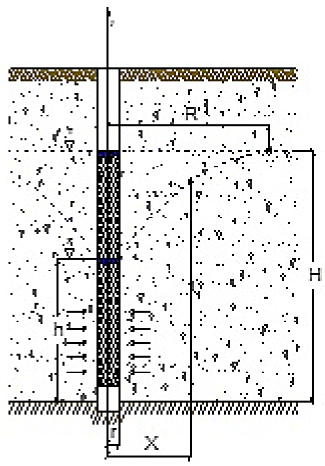


**Figure 9.** Design scheme for the pit

**Figure 10.** Construction site before after dewatering

**Figure 11.** Construction site after dewatering

Based on the feature of external border for watering layer with a high capacity of losing moraine, Q = 13460 $m^3$/day or 155.7 l/sec water discharge, design level descent of ground water without tide was calculated as equation of hydro dynamic method.

When lowering the ground water by 9.5 m, maximum water discharge per pit is 1396.8 $m^3$/day or 16.0 l/sec. So 1396.8 $m^3$/day of water discharge through 10 pits is drained. The maximum level descent in maximum loading pit for parallel pits is 12.4 m. When draining ground water with 15.5 l/sec water discharge, descent of ground water level per one pit is 9.6 meter as hydraulic method design.

Since lowering of ground water level was insufficient during designing the level descent of ground water in accordance with hydraulic method, linear equation of empiric formula was not possible to use, so analogy method was used. In this case, private water discharge of pit was taken into calculation. The effect radius was found as R = 50 m, natural resource amount of ground water around the area is 1209.8 $m^3$/day or 14 l/sec.

### 3.2.2. Bracing of Foundation Pit

The site has technogenic soil of 3.1m to 3.8 m thickness containing large debris clay and detritus soil with rock stones. Excavation of foundation pit with wall reaching 11.25 m height in such soil brings high probability of collapse. Therefore, bracing of foundation was required during excavation.

The foundation pit was excavated in four tiers each 3 m depth. Steel pipes spaced 1.5 m were drilled with $6^o$ slope at 13 m depth and secured with 5m length anchors at $45^o$ angle. Then wall was finished with wooden sheeting boards of 70 mm of thickness. Installing steel pipes with $6^o$ angle increased pressure resistance properties of the wall. In addition to supporting wall, steel pipes also have a role of vertical drainage system (Figure 12 and 13).

**Figure 12.** Water drainage system of Embassy tower: pipes for transferring water to central sewage system

**Figure 13.** Water drainage system of Embassy tower: vertical and horizontal pipes

Measures for foundation basement included: compacting and leveling the bottom of excavated foundation pit, preparing concrete bed, hydro-insulation with bitumen, application of waterproofing sheets (Uniflex), laying protecting concrete bed upon which raft foundation was constructed (Figure 14). In case of foundation walls, hydro-insulation included application of bitumen, and waterproofing sheets. Upon heat insulation foam the wall was bricked up and plastered (Figure 15). Double plastering was performed for section below the seasonal freezing depth. Finally, the site was backfilled and compacted.

**Figure 14.** Application of hydro-insulation on concrete bed

**Figure 15.** Foundation wall with applied hydro and heat insulation

### 3.3. "Castle of ZuunKhuree" Residential Complex with Permanent underground Drainage

"Castle of Zuun Khuree" was planned as 5 building blocks each 15 stories with total 500 apartments. In addition, it includes two stories underground parking for 200 cars (Figure 16). The site area is located in $4^{th}$ khoroo of Bayanzukh district of Ulaanbaatar city, on the mid-height mountain slope. Absolute elevation is 1297.80 to 1302.45 meter. The difference of the elevation is 4.65 meter. Rocky soil with cracks located under sharp sloping, formed mere due to accumulation of surface water leaked along the slope from above as well as groundwater seeping from below. Construction of permanent underground drainage system was considered as a solution, which included installation of water accumulating wells connected with collector, and draining this accumulated water through lift pump to city sewage system located at 1500 m far from the site.

The following soils or EGE (engineering geological elements) have been detected from drilled pits (Figure 17).

EGE-1: The technogenic soil contains gravel with sandy loam mixed with construction and household waste from 1.0 to 3.2 meter thickness.

EGE-2: Under the technogenic soil layer exist gravelly sandy loam of Upper and Middle Quaternary Alluvium age and continues from 1.5 to 5.0 m depth.

EGE-3: weathered sandy stone (bedrock) of Low Carbon age.

**Figure 16.** Zuun-Khuree complex

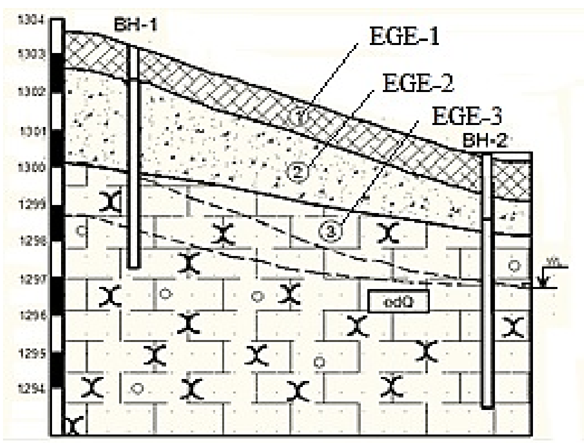


**Figure 17.** Engineering- geological cross section of the Zuun-Khuree site

Ground water occurs 2.5 to 3.5 m deep in pits at the site. The water accumulates in weathered cracks of sandy stone. Seven vertical well pits were drilled and connected with horizontal pipes for collecting water and drain it to central sewage system at 1.5 km far. The well W7 with lift pump for draining water was positioned at the corner of the site as shown in scheme (Figure 18).

Reinforced concrete well structures for standard sewage were used for draining. But a plastic pipe was applied for transferring pipes. Installation was performed with following technology.

1. To drain the water accumulating at the bottom of footing bed, plastic pipes (200 mm diameter) was positioned. The holes were drilled spaced every 10sm on top of the pipes to collect underground water. The pipes were wrapped with plastic mesh to provide durability in underground usage and covered with gravel soil. Then all this was compacted from above with sandy loam and clay soil.
2. Drainage canals were built in around the building and connected with the well located at 10 m distance from the building. Water collected in well was lift pumped to pipes connecting to central sewage system of city located at 1500 m far from the construction site.

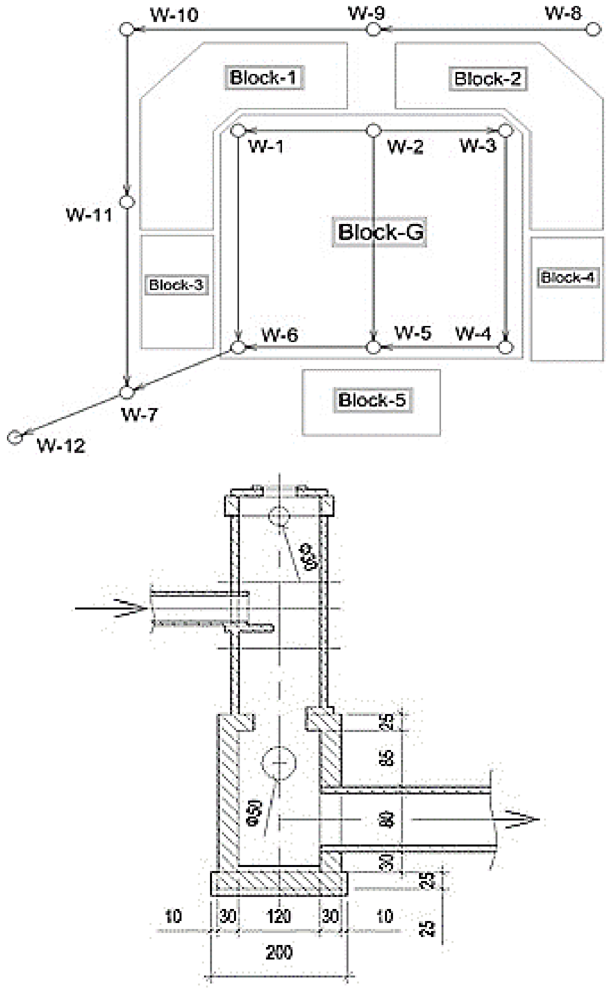


**Figure 18.** Foundation plan with drainage system (above) and cross section of W7 (below)

## 4. Conclusions

Investigation is confirmed that groundwater level has been raising at the central area of the city. Construction of new buildings requires appropriate drainage system design to protect from groundwater damage. When considering the problem of dewatering, geotechnical condition and specific features of the each site should be taken into consideration. Three construction projects described in this paper, are located within 4 km distance from each other. However, geotechnical and hydrogeological structures are not the same, consequently construction works require different approaches dealing with groundwater. For Golomt Town underground water from two aquifers was transferred to underneath layers and hydro-insulation techniques were applied. The site of Embassy Tower had a relatively thick layer of soil saturated with underground water. Therefore, temporary dewatering was conducted during the construction period and then hydro-insulation was performed. The third site of Zuun Khuree Castle was located on weathered sandy stones, which accumulated water from surface, as well as underground. Underground drainage system was installed and connected to central sewage system of the city.

## ACKNOWLEDGEMENTS

The author thanks the subjects whose participation made this paper possible. A. Ariunjargal and M. Sugar helped with translation; and D. Uranchimeg and J. Altantsetseg provided technical assistance with illustrations.

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