GROUNDWATER PROBLEMS CAUSED BY EXCAVATION OF BUILDING BASEMENT FROM THE VIEWPOINT OF NATURE CONSERVATION

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ABSTRACT : Groundwater problems discussed here are as follows : 1) Influence of excavation of building basement (-9 to -17 m) recorded by automatic table register, especially bad influence on Zelkova trees planted along the road side as symbol tree of Sendai City. 2) Payment of damage for wells influenced by lowering of groundwater table originated by excavation. 3) Future groundwater problems and protection standing on nature conservation.

RESUME : Les problèmes discutés ici, concernant l'eau phréatique, sont les suivants: 1) Impact de l'excavation de fondement des bâtiments (-9 à -17 m) enregistré par "enregistreur automatique de niveau" et en particulier impact néfaste sur les Transcaucasias (Zelkova) plantées le long des avenues comme symbole de la ville de Sendai. 2) Dédommagement pour dégâts causés aux puits par abaissement du niveau d'eau phréatique. 3) Problèmes de l'avenir concernant l'eau phréatique, et mesures protectrices destinées à préserver la nature.

RESUMEN : Se discuten los siguientes problemas, relativos al agua subterránea : 1) Influencia nefasta de las excavaciones para cimientos de construcciones (-9 a -17 m), controladas por registrador automático de nivel, especialmente sobre las Transcaucasia (Zelkova) plantadas a lo largo de las avenidas, como árbol símbolo de la ciudad de Sendai. 2) Indemnizaciones por los daños ocasionados a los pozos, por descenso del nivel del agua subterránea a consecuencia de las excavaciones. 3) Problemas futuros, referentes al agua subterránea, y medidas destinadas a la protección de la naturaleza.

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Introduction

The topic in this paper deals with the groundwater problems associated with the excavation in the course of advanced urban development.

Urban groundwater is influenced not only by the pumping during the excavation work, but also by the pumping from the seepage water pit even after the completion of the underground structure. Representative examples for such problems are well drought and land subsidence in the vicinity of the construction site.

Among such problems, what is often neglected is the effect on the trees planted along boulevards in the process of heavy urban development. The author would like to introduce this problem based upon the results recorded by automatic water table register. Furthermore, it is also discussed here as to what kind of counter-measures be taken in order to prevent such adverse effect due to lowering of the groundwater table.

Cause of the problem and some background

Automatic water table register which will be frequently mentioned here was placed in the center of a busy downtown area of Sendai which is the largest city in the Tohoku Region with population of 620 000 (Figs. 1 and 2). This central area of the city has the concentration of buildings with more than 10 stories above and 2 - 3 stories below the ground level.

Although Sendai City had completely lost its long renowned beauty and changed from what was called a tree-clad town after the destruction during the war, thanks to the enthusiasm of the citizens of Sendai, grand view of Zelkova trees along the boulevards was reconstructed in downtown area where buildings are heavily concentrated making green columns of giant trees of 50 years of age.

Since Zelkova tree is named Tree of the City, citizens have strong affection toward these trees and it is one of the main background reasons for these people to seriously tackle with the problem of groundwater. Many of them have begun concerned about the fact that, along with the modernization of the city, ground surface is covered more and more by concrete or asphalt, almost totally cutting the percolation of rain water off, making groundwater necessary for Zelkova more scarce.

On the other hand, there has been much frequent construction of underground structure and galleries for the municipal water supply works and for the installation and control of telecommunication cables. Not only during the construction, but even after its completion, pumping is constantly conducted from the seepage water pit in order to maintain the underground structure.

Besides these adverse condition of modernization, it has become of recent trend that there are some years with precipitation of less than 1 000 mm (annual average of 1 245 mm). Furthermore, between April and July when plants should grow most vigorously, there are sometimes nearly two months consecutively with monthly precipitation of less than 30 mm (Figs. 6 and 7). If groundwater is pumped during this period with poor seasonal distribution, it is quite clear that normal growth of Zelkova tree becomes inhibited. Especially, in the future when trees eventually reach near the age of 100 years with a meter in diameter and 20 m in height, the amount of evapo-transpiration draft will considerably increase.

In view of these facts, it is evident that the groundwater balance for Zelkova would only turn out to be negative. If not corrected, it seems that it would become no longer a hypothesis to have a situation where the green would eventually disappear and the area becoming complete desert region.

Plant conservation department of Sendai municipal office, carefully paying attention to such future probability, decided to conduct an artificial groundwater recharge for the purpose of conservation, when a giant Zelkova tree of 150 years of age was left (1.5 m in diameter and 18 m in height) in the green belt of National Road Route 4 after recent extension works. Based upon such future perspective, the plant conservation department undertook the measures in order to improve the infiltration of groundwater in downtown area which will be discussed more in detail later in this paper.

Plant called Zelkova tree

Zelkova tree (*Zelkova serrata* Makino = *Planera japonica* Miq., *Ulmus Keaki* Sieb.) is a tall tree (broad leaved deciduous arborescence) which belongs to the genus of Ulmaceae and widely distributed in the main island of Japan.

Since the bright green of its sprout in early spring and sober yellow of its colored leaves in autumn are in good harmony with the aesthetic taste of Japanese people, this tree is the subject of popular affection and is found in the gardens and estates of Japanese people. Lumber of huge Zelkova trees of nature growth has sometimes very finely figured grains of annual rings. An expensive chest of drawers is made of such trees and varnished with Japanese lacquer (Urushi). Antique furniture lovers treasure it.

Since Zelkova is a tall tree which favors furtile land and running groundwater, it is planted to symbolyze water god by the well in ar old estate of traditional families, serving as a simple and naive indicator of the presence of groundwater. Therefore, where an old well is, one usually finds a giant Zelkova tree nearby standing loftily with its height of more than 20 m and diameter of 1 m, and a small shrine for water god at its foot. In some places, Japanese cedars (Cryptomeria japonica D. Don) are planted in stead of Zelkova, which likewise favor running groundwater.

Environment indicated by fossil Zelkova

Fig. 3 shows three leaves of Zelkova, amongst which "A" indicates a leaf from a Zelkova tree growing at a site where automatic table register is placed. This particular one was taken from leaves defoliated at the end of August which is about two months ahead of normal defoliation.

This abnormal defoliated leaf is an evidence of weakened growth of the tree, and it may be attributable to the water supply deficiency. As seen in the figure, there are blackened parts and dots which can be interpreted as signs of desease due to weakened tree growth and air pollution.

"B" is taken from leaves defoliated in a normal defoliation period in November which means that they are the ones from better environment with sufficient water. Leaf surface shows clear sign of autumnal tints.

"C" is a fossil leaf of Zelkova taken from Miocene Nenoshiroishi plant bed near Sendai area (Okutsu, 1955). When this fossil leaf is compared with recent leaves of "A" and "B", they are almost the same in terms of the characteristics of serration and the number of secondary, suggesting that they have survived through 10 million years without changing the leaf shape at all.

On the other hand, in view of the environment of sedimentation, it is reserved in the varved tuffaceous shale which shows lake deposit. Therefore it can be considered that Zelkova trees from which these fossil leaves were taken grew on a slope along a valley with abundant groundwater near large lakes.

Thus, Zelkova trees have come through 10 million years maintaining the nature of favoring furtile area with abundant groundwater. This very fact is considered to be the source of its strong viability.

Site of automatic water table register and its geological condition

As above described, an automatic water table register has been installed at the site as shown in Figs. 1 and 2 to find out the cause of the weakening of Zelkova trees.

Since this site is close to the Sendai railway station, around where many modern buildings are being constructed, it is not favorable surroundings for Zelkova trees to grow, although the need of conservation is strongly felt.

Since 1970, the author has had the opinion that the cause of the weakening of Zelkova trees must depend on the water deficiency which comes from the lowering of groundwater table. To prove this assumption, the writer has emphasized the need of installation of the register.

Fortunately, in 1972, Sendai South Rotary Club adopted this idea into their social welfare project, and the register was installed at the site shown in Figs. 1 and 2. This register recorded the abnormal lowering of groundwater table by the excavation of building basement from 1972 to 1974. And it is still working to record the fluctuation of groundwater table.

The flat plane, where the above referred business center is located, correlates the middle terrace plane, and the subsurface geology of the area consists of the following 5 layers (Figs. 4 and 5).

Age:	Order of soil layers:	Thickness:
Alluvium	(1) Surface soil (organic clay)	0.5
	(2) Sandy loam	1.5
Diluvium	(3) River terrace gravel	4.8
Tertiary (Pliocene)	(4) Weathered bed (clay)	1.4
	(5) Bed rock (tuffaceous sandstone)	10.0

(1) and (2) are distributed within 2 m under the surface, which form the foundation bed of one or two story wooden houses. Surface soil (1) composed of organic clay or peat (Okutsu, 1972), sometimes makes soft ground of 1 - 2 m thickness. When a wooden house which is based directly on such soft ground often leans owing to the land subsidence caused by the excavation of building basement or pumping up of groundwater for air conditioning. This fact often leads to the law dispute of indemnity.

(2) is the root swelling zone of laterals or rootlets of tall trees such as Zelkova (Fig. 4).

(3) is the river terrace deposits left by the Hirose River running through Sendai area. The deposits are characterized by terrace gravel (Okutsu, 1967). The upper part of these deposits are mainly composed of loam with gravel, lower part consists of sand and gravel, and forms the storage of shallow groundwater (un-confined), which is used as aquifer for dug wells. The basements of three - five storied apartment houses are based on this gravel bed. The rootlets and hair roots of Zelkova trees reach the upper part of terrace gravel. So, the root swelling zone is deeply fastened into loam with gravel to get supply of fringing water.

This root extension shows the mechanism of resist the drought (Fig. 4). But when abnormal lowering continues for several months during vigorous growth season, it is clear that the growth of Zelkova trees faces the crisis.

(4) is the clay derived from weathering of bed rock (tuffaceous sandstone), which distributes on the contact plane between terrace gravel and bedrock. This clay has usually 0.5 - 1 m thickness, and shows weak bearing power (S.P.T., N value = 10). Accordingly, where clay is thicker than 1.5 m, it is necessary to change the design of excavation depth of building basement.

(5) is the bedrock of this area. Geological age is Pliocene (Neogene Tertiary), and mainly consists of tuffaceous sandstone ∿ tuffaceous mudstone (Tatsunokuchi formation of Sendai area). As this formation is characterized by fossil shells and fossil plants such as Zelkova tree, at the time of excavation, a tremendous amount of fossil shells are being found. Sometimes shark teeth and fossil skeletons of whales or dorphines are also discovered. Under the Tatsunokuchi formation, Kameoka formation is laid which is characterized by lignite seam.

As the coarse sandstone of both formations forms good aquifer of deep groundwater (confined groundwater), a lot of deep wells (depth 150 - 250 m) penetrate to both formations (Okutsu, 1968, 1971), and these wells pump up 500 - 700 cubic meter of water per day (Fig. 5). The natural level in this area is less than -60 m under the surface, and pumping level less than -120 m, because of the high density of deep wells. There are some examples of submersible pump set in -200 m.

The lowering of the groundwater level as above cited decreases the confined goundwater reservoir. Furthermore, it squeezes the shallow groundwater from the un-confined groundwater reservoir in the gravel bed. The reader will understand how serious influence the underground works give to the groundwater situation.

The land subsidence (Okutsu, 1972) has already occurred owing to the excess withdrawal of groundwater in the Sendai coastal industrial area. Therefore Sendai municipal office has inacted groundwater control law for industrial use.

In addition to industrial supplies the utilization of groundwater for air conditioning in urban area on the terrace gravel has increased. So Sendai municipal office is going to conduct the analytical survey of groundwater to prevent the land subsidence.

The influence of excavation of building basement recorded by automatic water table register

In July 1972, automatic water table register was installed in the site shown in Fig. 2. The groundwater table at the time was about -4 m. In June 1973, the excavation for construction of the building with 9 stories above and 3 stories below the ground level started ("Y" building in Fig. 2). Since the register was set at 15 m from the building it clearly recorded the fluctuation of groundwater table (Fig. 6).

By this graph the drawdown of groundwater table was recognized at each stage: the excavation of gravel bed (-7 m), and of bedrock (-17 m). Comparing the stages before and after excavation, it is noticed that the amount of maximum drawdown was 1.3 m at the deepest excavation. The drawdown of 1 m kept continuing until the backfilling started. When the constructor started backfilling, groundwater table gradually rose up and it finally recovered the original level at the completion of backfilling.

Ten months after the completion of "Y" building, excavation of another building basement ("S" building in Fig. 2) began at the opposite side of the register location. The shortest distance from the register was 70 m. The register recorded the fluctuation of the same tendency (Fig. 7).

Underground environmental change which accompanies the urban development

Comparing the two graphs of the register which recorded the underground excavations of the two buildings it is clear that the influence of underground development is becoming serious. In the case of excavation of "Y" building, the groundwater of 400 - 500 litre per minute sprang out from gravel bed and bedrock. However, in case of "S" building, built 10 months after the other, in spite of the same hydrogeological condition the groundwater scarcely sprang out. This may be because of the difficulty of infiltration of rain water through the pavement surrounding "Y" building area, and also by pumping up of the seepage water pit constructed under "Y" building basement. The groundwater amount pumped up from the seepage water pit is about 2 cu. m per day (gross volume of "Y" building besement 68 250 cu. m).

The influence to shallow dug wells in the vicinity of excavation site

In the overcrowded area where the register is located, there are no old style shallow dug wells because this area has changed to business center. However, in other less crowded areas there remain a number of shallow dug wells which are still on use. Excavation of building basements surrounding these wells are also giving unfavorable influence on them.

Figs. 9 and 10 show the example of the influences. The depth of excavation of this example was -9 m from the surface, interference radius reached 70 m, and caused trouble to the inhabitants and the well drought (well depth 4 - 7 m).

Since such trouble occurs frequently, the necessity of prospecting of interference radius by the reasonable boring survey and simulation on electronic computer is strongly felt. Several examples show the interference radius is about 70 m by simulation. The data during excavation showed almost the same result. Shallow dug wells (depth 4 - 7 m) within radius 70 m - 100 m were affected by pumping of excavation. The dispute for compensation of this case was settled by laying the city water pipe.

Countermeasure for the protection

The abnormal going down of groundwater table which reaches radius 70 - 100 m gave bad influence to Zelkova trees. In order to prevent such bad influence and to increase infiltration capacity of rain water, following installations were designed:

(a) Plant conservation department of Sendai municipal office buried infiltration pipe (diameter 150 mm, length 2 m, depth 50 cm) connecting catch basin of drainage system and infiltration basin which was newly designed (Fig. 11). Accordingly rain water flows into the catch basin and infiltrates freely into sandy loam of root swelling zone. The distribution of these basins is shown in Fig. 13. It is designed to supply water to every Zelkova tree planted in a row.

(b) Another countermeasure: Installation of the infiltration pits on the paved sidewalk where the row of Zelkova trees stands (Fig. 12). These pits are most effective to increase infiltration capacity compared with the ordinary paving plate which covers the ground completely. As shown in Fig. 13, porous concrete pipe (diameter 150 mm, vertical length 600 mm) is buried which easily infiltrates rain water into the sandy loam after filtration by filled gravel. Besides, paving plates surrounding the infiltration pits were replaced by porous concrete plate for the rain water to infiltrate into surface soil. Porous concrete plate, however, has the following weak points:

a) To decrease its porous capacity by filling of sand, mud and dust.

b) Its weak registivity to heavy load.

These artificial recharge methods were just completed last August (1977). Remarkable effect is being expected for the sake of the trees. As a matter of fact, the groundwater table has a tendency to rise gradually as proved by the record of the register (Fig. 8). Today it is urgently needed to prevent the lowering of groundwater table by artificial recharge. From the nature conservation point of view recharging system above described is not only useful for Zelkova trees but also effective for the rising of shallow groundwater table.

On this point of view, Zelkova tree may be called an indicator of groundwater conservation. On the other hand, at the excavation, it is necessary to find better methods to prevent lowering of groundwater. For example: (a) cement covering and grouting to prevent the gushing out of groundwater from gravel bed. (b) cut shallow aquifer by sheet pile, and recharging pump-upped groundwater around the excavation site observing the quality of water. (c) practice of underwater excavation, etc.

Conclusion

The protection of trees on boulevard is becoming important accompanied by highly developing density of the city. One of the reasons is the lowering of groundwater table during the excavation of building basement (Figs. 6 and 7). Irrigation to the root is somewhat useful, but construction of infiltration pipe and infiltration basin is more effective (Fig. 8).

Acknowledgements

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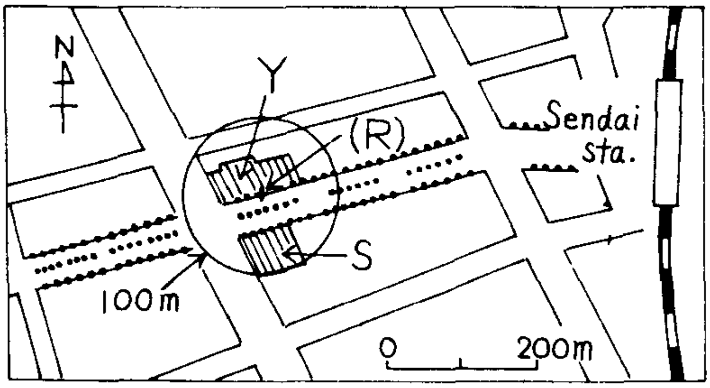


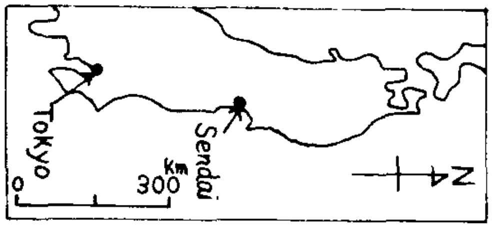


Fig. 1 shows: Excavation sites ("Y" and "S"), boulevard of Zelkova trees (dotted line), and site of automatic water table register (R).

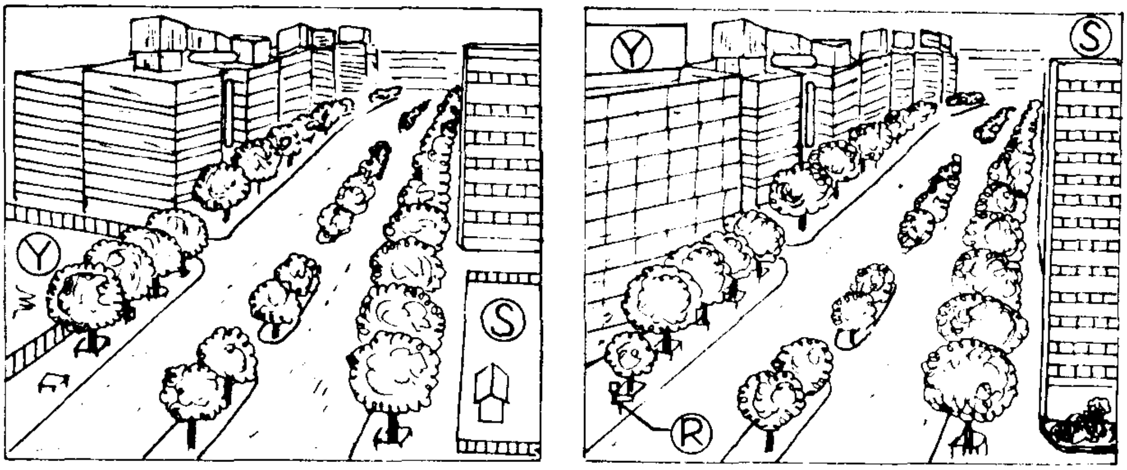
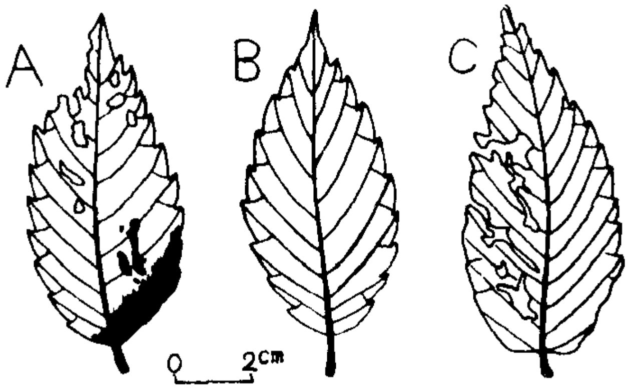


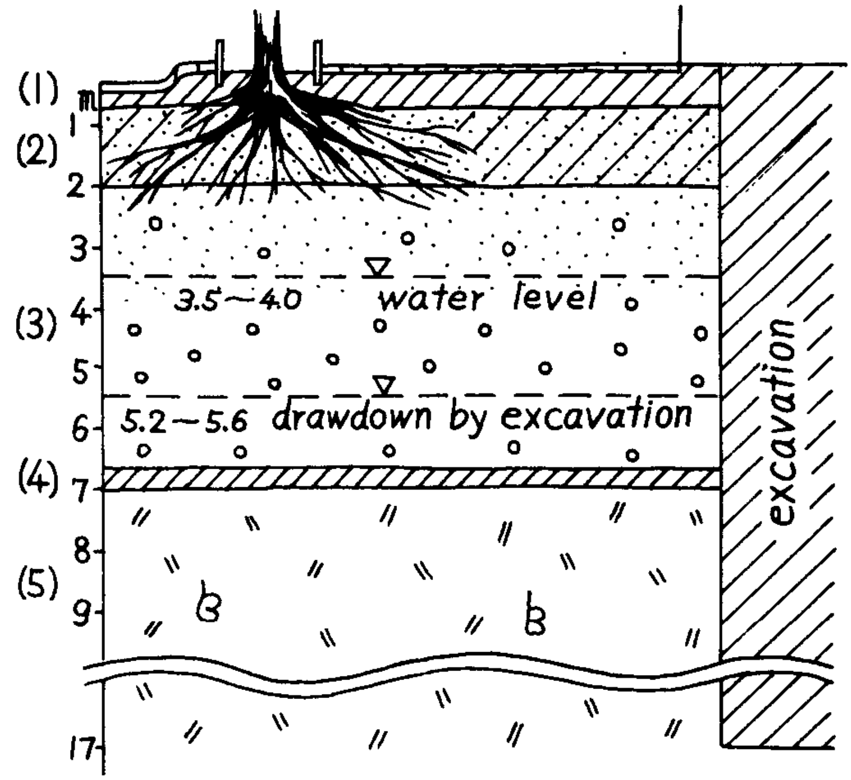
Fig. 2. Change of environments by urban renewal.

Left = 1972
Right = 1977



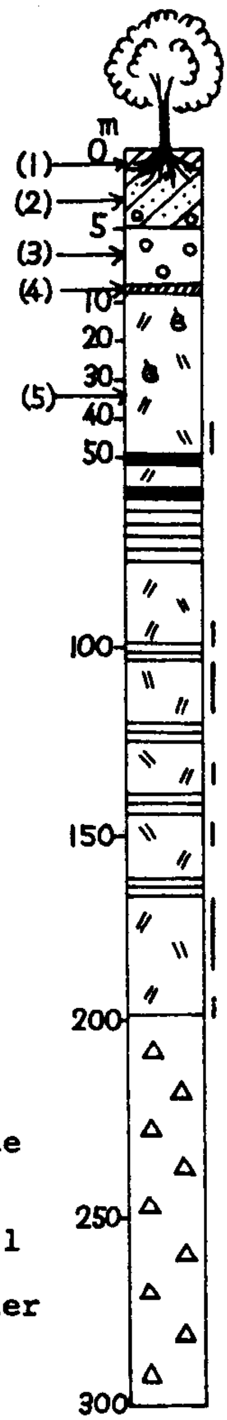
A = Abnormal defoliated leaf.
B = Normal defoliated leaf.
C = Fossil leaf.

Fig. 3. Recent and fossil leaves of Zelkova trees.



(1)(2) = Surface soil and sandy loam.
(3) = Terrace gravel.
(4) = Weathered zone.
(5) = Bed rock (tuffaceous sandstone)

Fig. 4. Ideal diagramic section of root swelling zone and change of groundwater table by excavation by building basement ("Y" building).



Legend

- Surface soil
- Sandy loam
- Loam with gravel
- Gravel
- Tuff
- Mudstone
- Agglomerate
- Lignite
- Fossil shell
- Strainer

A = Non-confined groundwater.
B = Confined groundwater.
(1) - (5) = The same as Fig. 4.

Fig. 5. Columnar section of hydrogeology in the environs of the register.

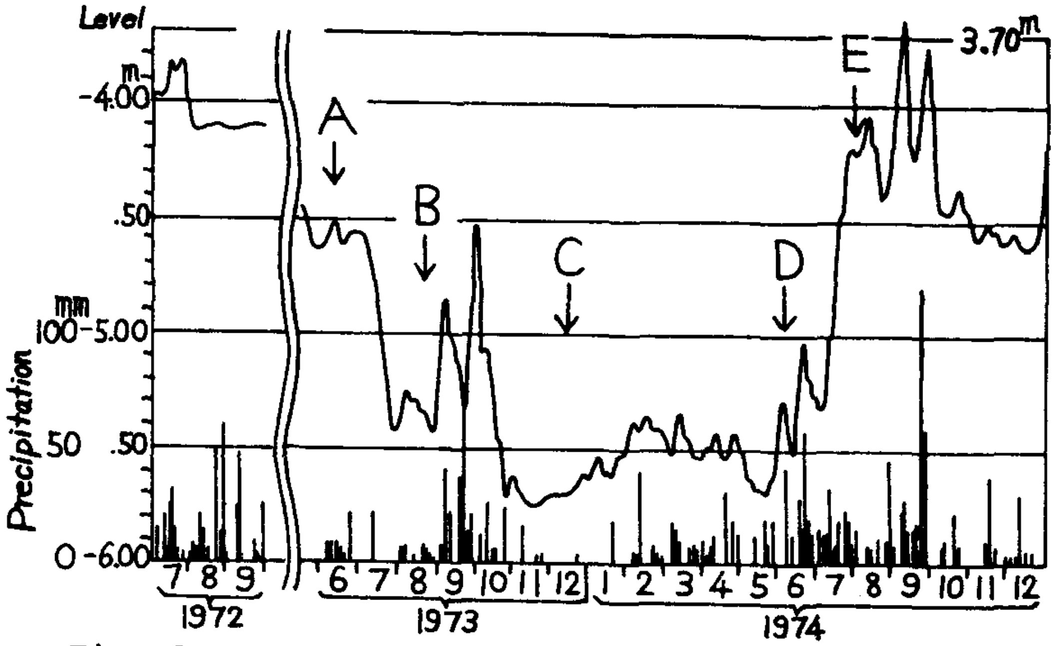


Fig. 6. Relationship of fluctuation of groundwater table and excavation of building basement ("Y" bldg).

A = Starting of excavation of gravel.
B = Starting of excavation of bedrock.
C = Completion of excavation of bedrock.
D = Starting of backfilling.
E = Completion of backfilling.

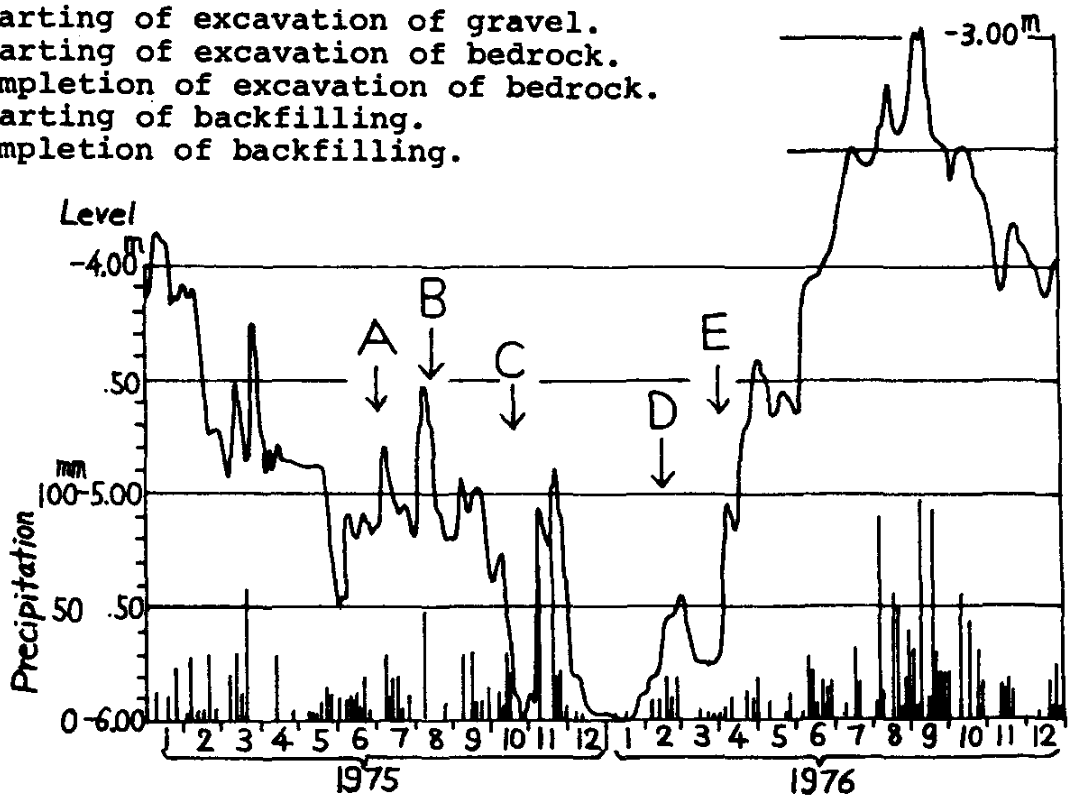
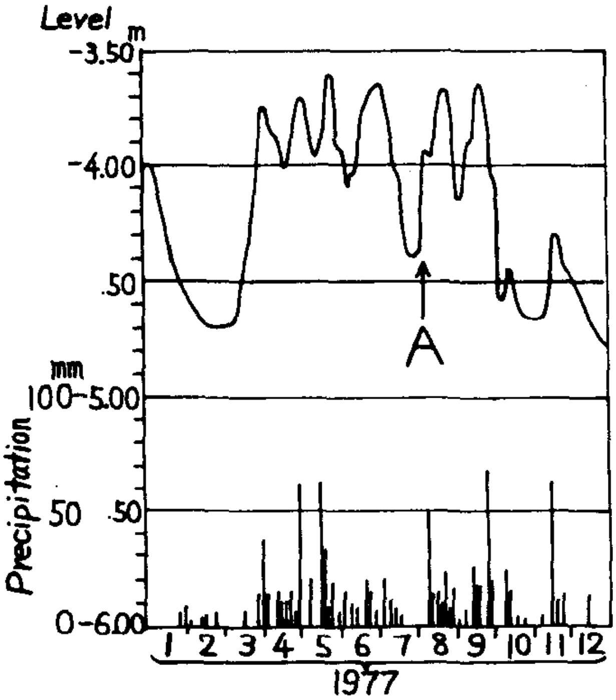
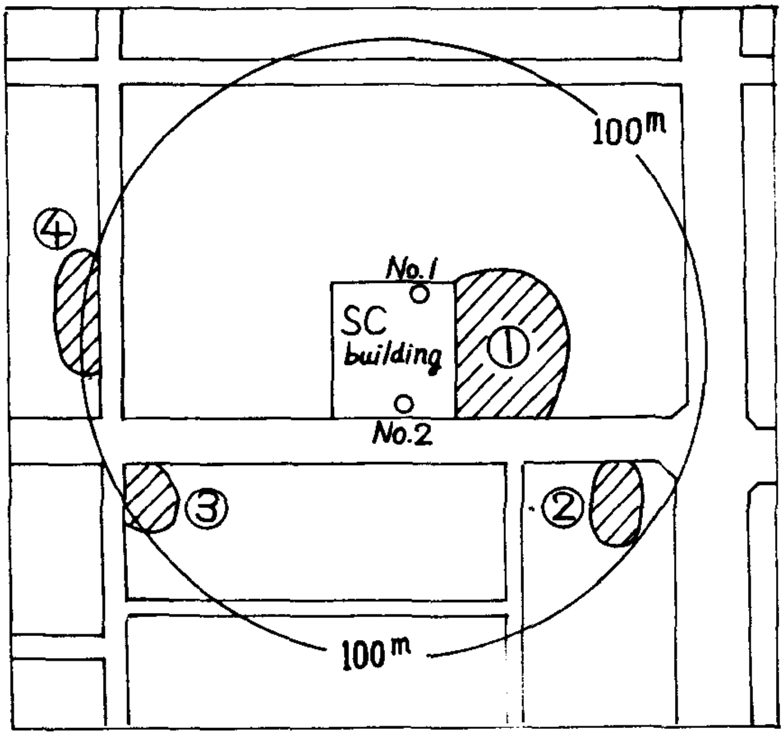


Fig. 7. Relationship of fluctuation of the groundwater table and excavation of building basement ("S" bldg).



A = Start of recharge (August 1977)

Fig. 8. The fluctuation of groundwater table during no excavation after recharge of rain water by infiltration pipe and basin.



SC = Excavation site of SC building basement. Nos. 1 & 2 = Boring point. (1) - (4) = Order of influence.

Fig. 9. Distribution of droughty well by influence of excavation of building basement.

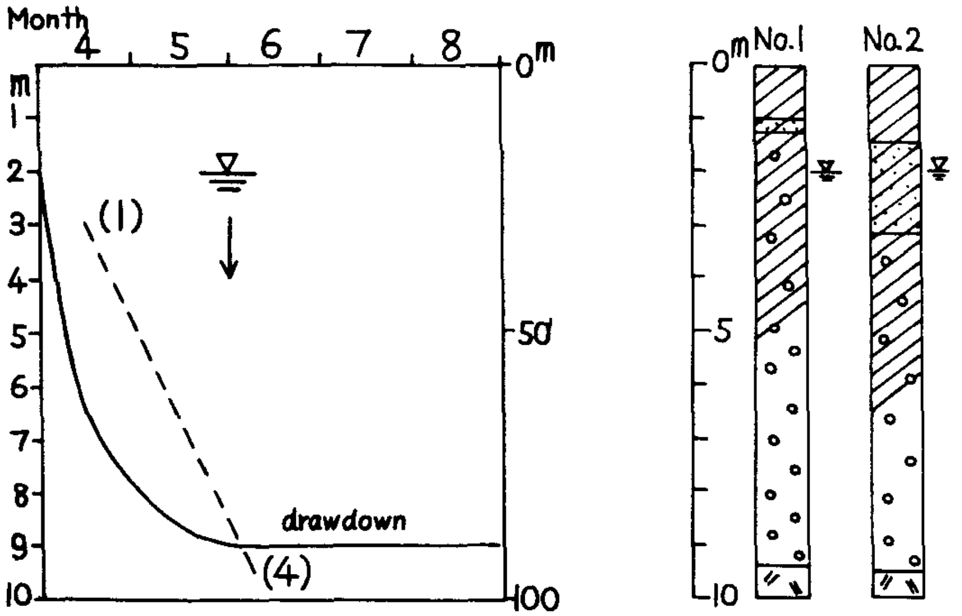


Fig. 10. Subsurface geology and relationship of progress of excavation and drawdown of ground-water table of well (symbol of soil and rock same as Fig. 5). (1)-(4)= Order of influence (Fig. 9).

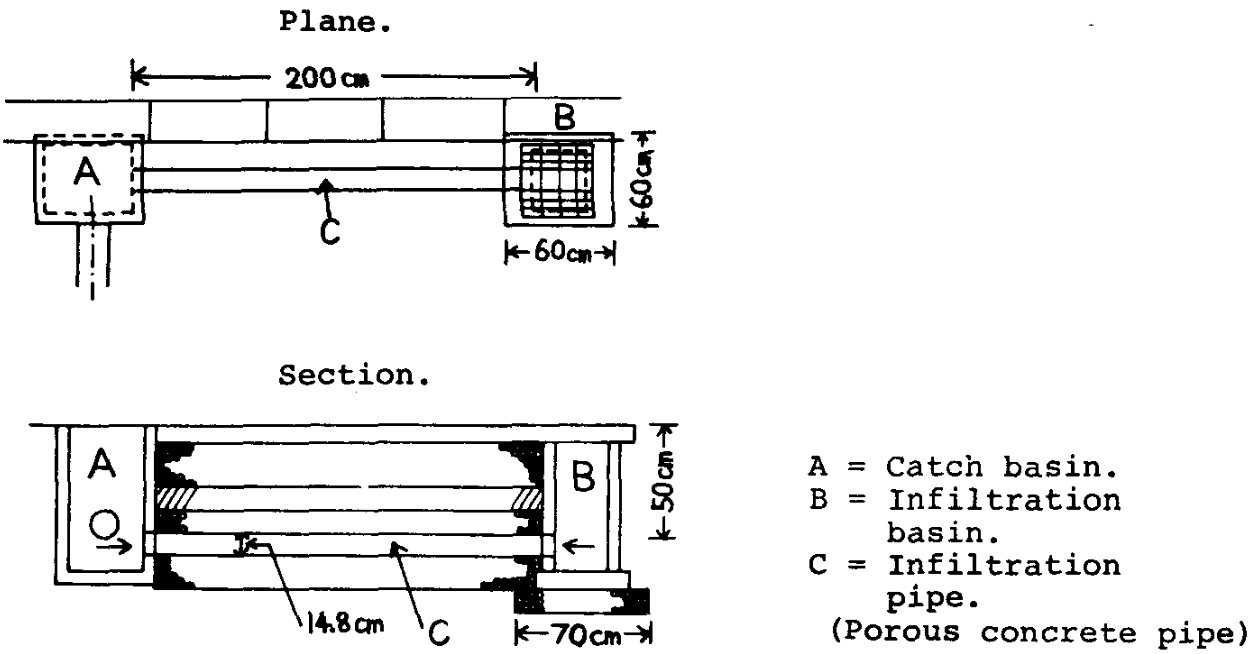
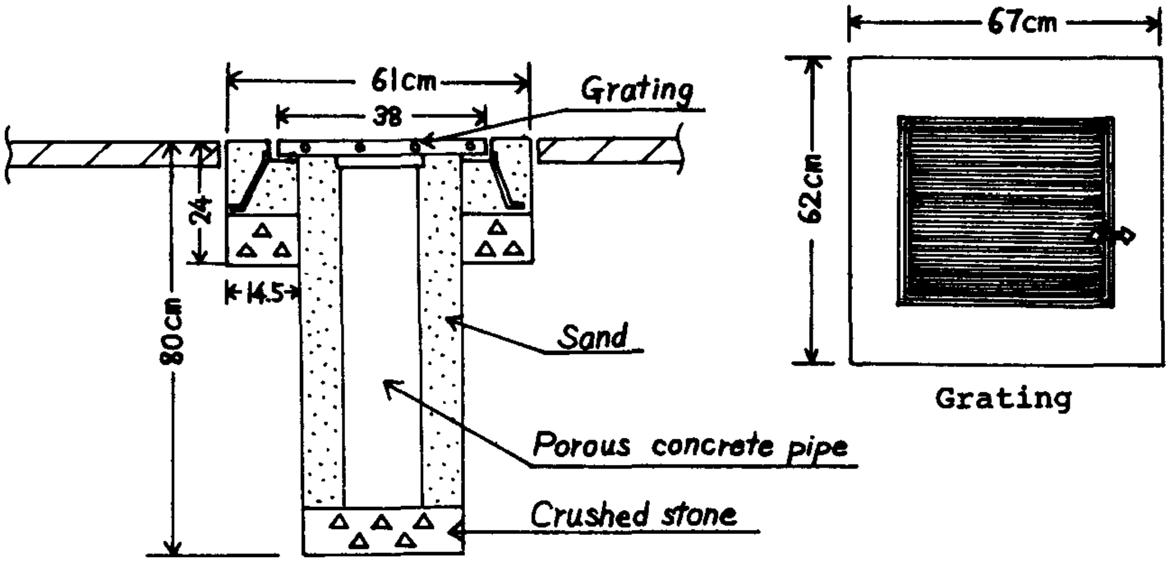
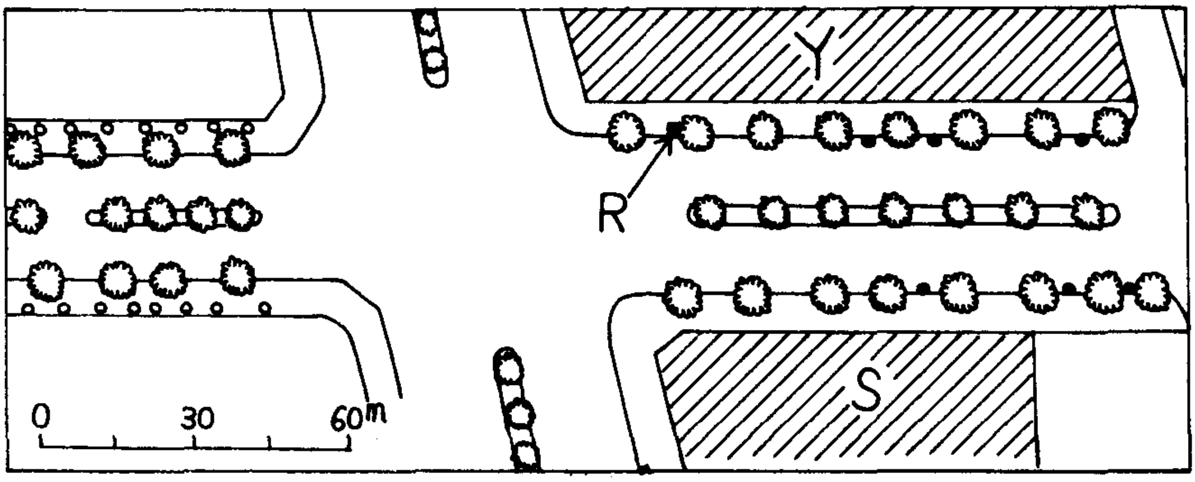


Fig. 11. Structure of infiltration pipe for Zelkova trees.



Left = Section.
Right = Plane.

Fig. 12. Structure of infiltration basin for Zelkova trees.



● Infiltration pipe.
o Infiltration basin.
O Zelkova trees.
R Register.

Fig. 13. Distribution of infiltration pipe and infiltration basin for Zelkova trees (Plain).