Drainage of Excess Irrigation Water at El-Rabwa City, Giza Governorate, Egypt.

Waleed A. Ogila[1], Ali H. Al-batal[2], Noha A. Rabie[3]

Abstract- In arid and semi-arid regions, drainage of excess irrigation water is the next logical step towards improving water management in golf areas and reducing the environmental impacts of subsurface drainage flow. The urbanization and land development in Egypt started more than three decades ago. The construction activities extended from the narrow district in the Nile Valley and Delta toward the vast desert fringes. Desert soil is a problematic soil that may include expansive and collapsible soils, sandstone and limestone in one site. Groundwater related problems in such sites are due to the fact that the presence of water might not be taken into consideration during design and construction phases. El-Rabwa City is located in Giza Governorate at about 25km west of Cairo City. The goal of this paper is to undertake a study of the drainage of irrigation water considering both the topographic features of the ground and the subsurface layers that include impermeable clay layer with variable elevations. In addition, the study aims to investigate possible influence of the excess water on the foundations of the residential units. Hair fractures of some residential units were observed in the area. Excess of irrigation water was thought to be one of the most reasons of the observed fractures. A total of over 300 boreholes, supplemented by additional investigation boreholes, were reviewed. The geotechnical data of the boreholes were used to develop geological model for the site. The geological model of the site revealed the presence of top permeable layers (sand or fractured rock) underlain by impermeable clay layer. The surface topography, together with the permeability of the subsurface layers, determines the division of the excess irrigation water to runoff and infiltration water. The collected geotechnical data was used to study the topography of the subsurface clay layer that plays major role in determining the flow pattern of the excess water portion that permeate or infiltrate to the subsurface. The identification of both the topography and the geological models of the subsurface is a key factor in selection or the design of the alternative drainage systems for the excess irrigation water that are presented in the paper.

Index Terms- Excess irrigation water, drainage water, geological model, infiltration, Golf's areas, arid areas.

1 INTRODUCTION

Water demand for sports and other leisure purposes is growing rapidly in many countries. The most visible examples of this are on golf courses, which need large volumes of irrigation water to maintain optimum turf playing surfaces. The irrigation in arid and semi-arid environments inevitably leads to water table rise and often to problems of water-logging, the best solution to dealing with the water-logging, is to control the water table by means of artificial drainage.

The urbanization and land development in Egypt started more than three decades ago. The construction activities extended from the narrow district in the Nile Valley and Delta toward the vast desert fringes. Desert soil is a problematic soil that may include expansive and collapsible soils, sandstone and limestone in one site. Groundwater related problems in such sites are due to the fact that the presence of water might not be taken into consideration during design and construction phases. Therefore, post-construction groundwater control in such sites may introduce challenges to geotechnical engineers (1).

- [1] *Lecturer of Engineering Geology, Geology Dep., Faculty of Science, Ain Shams University, Cairo, Egypt (Corresponding Author). E-mail:walid_ogala@sci.asu.edu.eg walid_metwali@sci.asu.edu.eg*
- [2] *M.Sc in Construction Engineering, Minstry of public works and highways, Sana'a, Yemen. E-mail:ali.h.albatal@gmail.com*
- [3] *M.Sc in Geotechnical Engineering, Hamza Associates, Cairo, Egypt.*

Virtually every green areas or golf course has experienced some type of drainage problem on its property. The first step is to identify the nature (or cause) of a drainage problem by examining topography and subsoil conditions. Once identified, you can select the appropriate type of drainage system solution to effectively remedy your drainage problem. Although there are many types of drainage problems, but the most commonly problems found on golf courses and sports fields are impermeable soils, depression areas, high water table, and side hill seepage.

To prevent such problems, an efficient management for the excess irrigation water is required. The efficient management of water resources is a key element in accomplishing a proper environmental integration of golf courses. Water resource management on golf courses must be planned and implemented considering at least water resource conservation, reclaimed water use, irrigation efficiency, adapted non-invasive grasses, and lake management. The key points for good golf course management start with careful planning which, in relation with water, must include:

1- The identification of the water source(s) that will be used for watering all course facilities;
2- The building of the playing areas according to water availability and the resource to be used (i.e., reclaimed water);
3- The establishment of cultural practices (management) specifically designed to use reclaimed water (i.e., fertilization, pest management, soil maintenance, grass cutting ...).

El-Rabwa City is located in Giza Governorate at about 25km west of Cairo City. It is located between longitudes

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30°58' 32.13" and 30° 59' 59.1" east, and latitudes 30° 03' 19.18" and 30° 04' 37.47" north (Fig., 1).

The goal of this paper is to undertake a study of the drainage of irrigation water considering both the topographic features of the ground and the subsurface layers that include impermeable clay layer with variable elevations. In addition, the study aims to investigate possible influence of the excess water on the foundations of the residential units of the extension of a luxurious compound, whereas hair fractures of some residential units were observed in the area (Fig., 2).

The study presented in this paper consists of following phases:

1- Study the stratigraphic section of El-Rabwa Extension area,
2- Development and description of the topographic model of the area,
3- Collection of all existing available geotechnical data at the area,
4- All the geotechnical data was used to build a geological model for the site taking into considerations the variation in elevations of the ground surface and the impermeable clay layer,
5- Review of sources of excess water in the area and the flow pattern of the drainage water taking into consideration both the topography and the geological model of the area,
6- Assessment of any geotechnical problems for the site and the foundations of the villas that might be born from excess irrigation water, and
7- Provision of potential solutions.

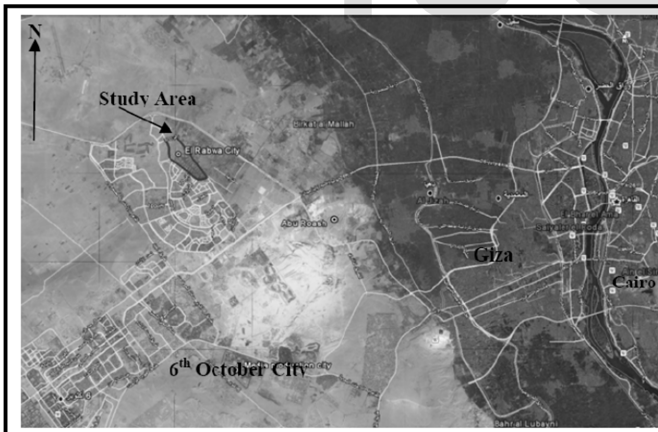

Fig. 1. Location map of El-Rabwa City.

2 Geology of the Area

The exposed rocks in the studied area are divided into two main units which are Gebel Qatrani Formation and Gebel Khashab Formation. Gebel Qatrani Formation recorded in El-Rabwa Extension and all boreholes that drilled in the area. This formation includes sedimentary rocks and volcanic rocks (basaltic flows). The sedimentary rocks of this formation consist of varicolored sand, clay, shale, ferruginous sandstone and greywacke sandstone. The sandstone is typically interbedded with marine shales and associated with submarine lava flow which generally associated with faults (basalt). Gebel Khashab Formation consists of varicolored, medium to coarse grained sand, interbedded with several thin bands of rounded gravel with silicified tree trunks.

Fig. 2. Hair fractures at external wall of residential units at El-Rabwa Extension area.

3 Topography of the Area

Topographically, El-Rabwa Extension is ranging in elevation from 120.0m above sea level at the northeastern and eastern parts to 190.0m above sea level at the northern, northwestern and southwestern parts (see Fig., 3). The high areas are capped by basaltic flow, and the drainage inside the area is internal and dry filled with sand.

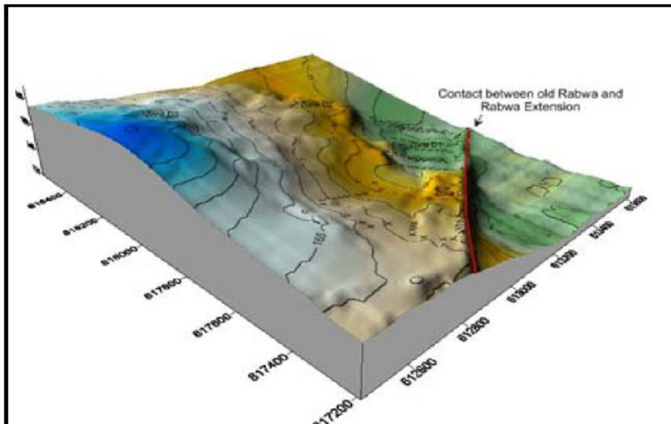

Fig. 3. 3D surface map of the area.

4 Geotechnical Data

A total of over 300 boreholes were reviewed. The subsurface of the area consists of following four main soil types:

Clay layer: this layer appears in different places and depths in the site. This layer is hard, sandy lean clay at some parts and fat clay at other parts. It is brown to grey in color.

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Basalt Layer: this layer covers high areas in of the extension of the site; it is fragmented, weathered, and grayish black in color.

Sand Layer: brown poorly graded, dense to very dense, clayey, silty, gravelly, cemented friable, this layer is inter-bedded with clay layer.

Sandstone layer: brown medium weak to medium hard, ferruginous, weathered, fragmented, with fractural planes filled with iron oxides.

Figure (4) shows the approximate distribution of the subsurface foundation bed of the study area.

The geotechnical data of the boreholes were used to develop geological model for the site. Eleven geological cross-sections were constructed to display the subsurface formations in the area. The sections are labeled (1) to (11) and their locations and orientations are shown on Figure (5). The geological model of the site revealed the presence of top permeable layers (sand or fragmented rock) underlain by impermeable clay layer. Figure (6) presented examples of the geological cross sections.

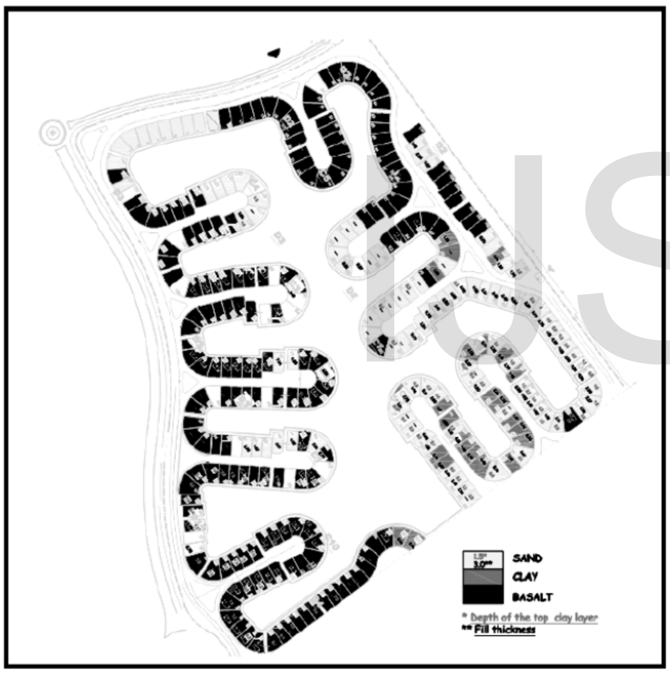

Fig. 4. Foundation beds of the study area.

5 WATER SOURCES AND FLOW PATTERN

The sources of water to the subsurface of the area include the following sources:

1- Irrigation water of the following green areas (Fig., 7):
   a) Gardens of individual villas
   b) Green areas between the villas
   c) Golf area
2- Surface infiltration of excess water that might be born due to leakage of surface utilities including pipe networks and/or manholes.

Part of the irrigation water is expected to flow over the ground surface. The surface flow vector map of surface runoff water shows that the main flow direction on the earth surface is directed from north, northwestern and southwestern parts of the area of the site to northeastern and southeastern parts (see Fig., 8a). The other portion of the irrigation water, together with other sources of water, is expected to infiltrate through the surface sandy soil or the fragmented rock.

The infiltrated water is then expected to be retained by the impermeable clay layer. The presence and the topographic features of the surface of the clay layer are considered a key factor controlling the flow of the excess water in the subsurface. The flow vector map shows that the main infiltrated water flow direction on the clay layer is directed from north, northwestern and southwestern parts of the site to northeastern and southeastern parts (see Fig., 8b). It is interesting to note that, the surface portion of the water is expected to flow toward the lowest area indicated on the four sided shape indicated on Figure (8a). Once it reaches there, the water is expected to theoretically flow through the surface permeable layer and be retained by the lower low permeability clay layer. While the infiltrated water is expected to flow on the surface of the subsurface clay layer and is expected to be destined at the four sided shape area indicated on Figure (8b). The two indicated areas coincide at the same area that is hatched on the layout of the villas in the site in Figure (8c).

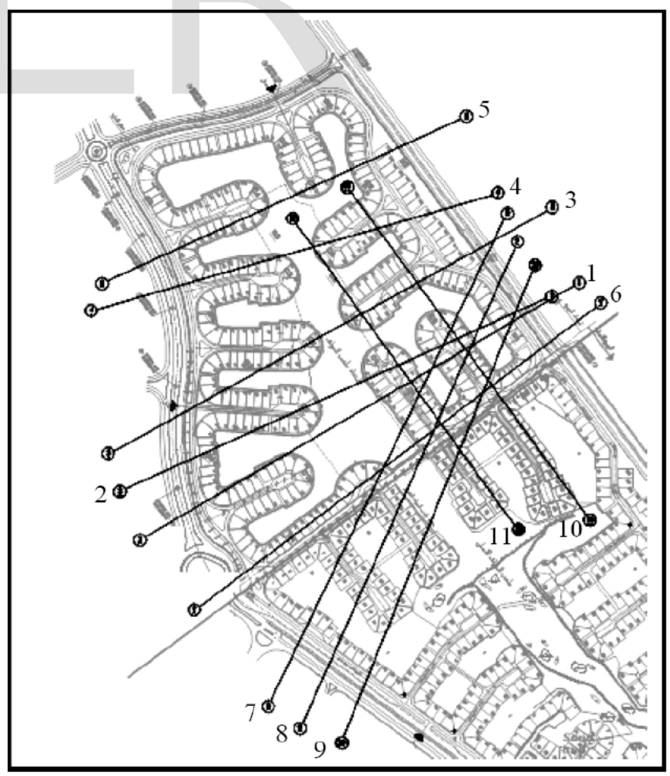

Fig. 5. Geological cross sections location layout.

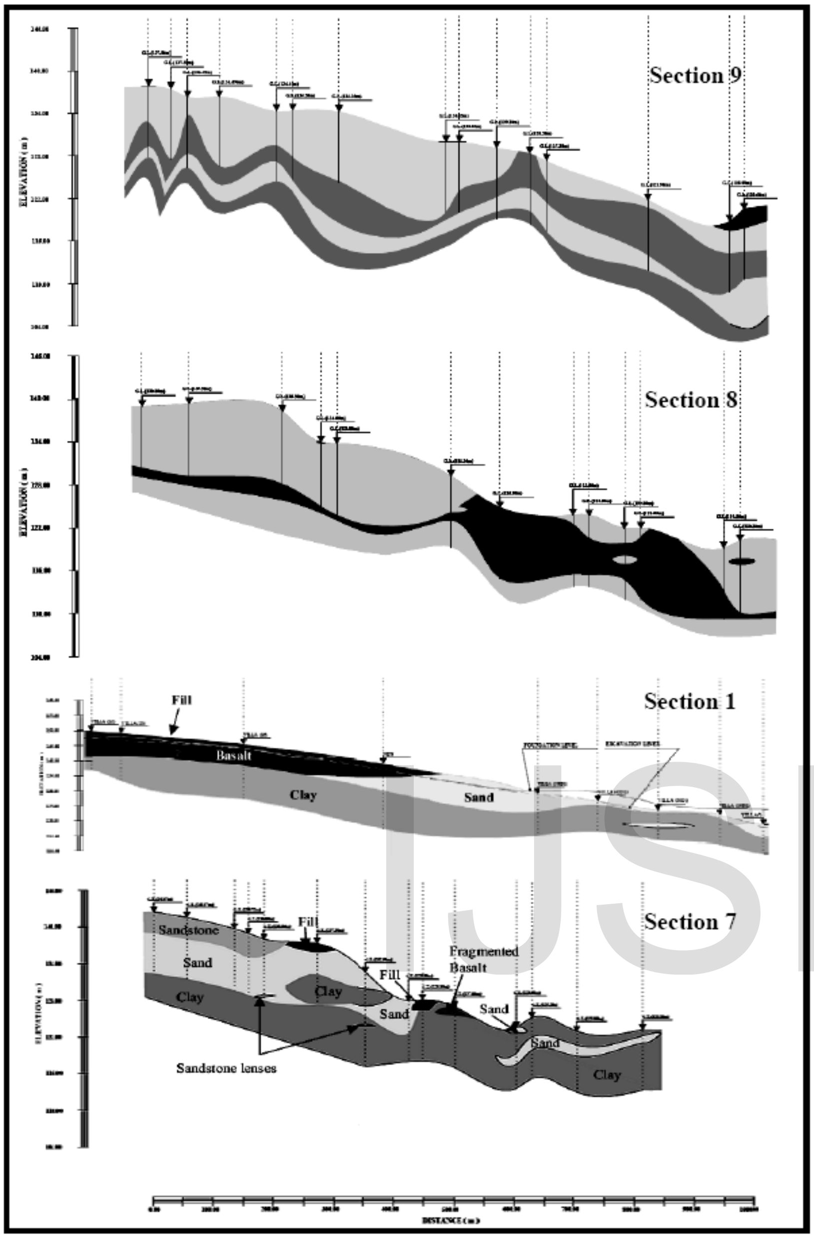

Fig. 6. Geological cross sections.

Fig. 7. Golf and green areas at El-Rabwa Extension area.

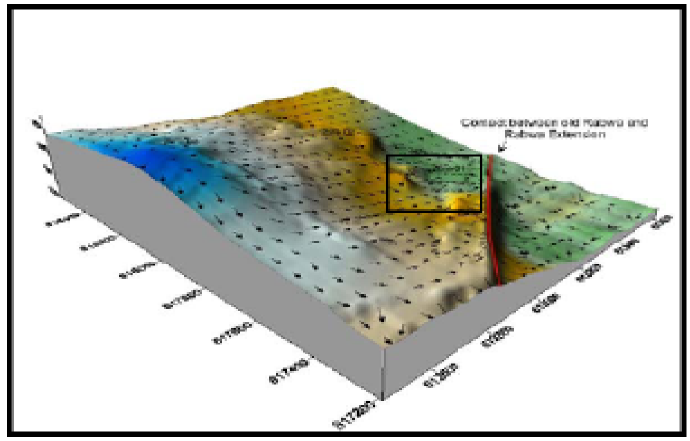

Fig. 8a. Destination of surface flow water.

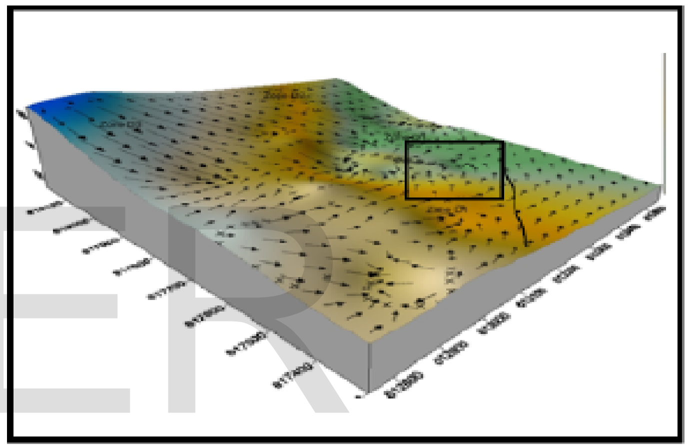

Fig. 8b. Destination of infiltrated water over surface of clay layer.

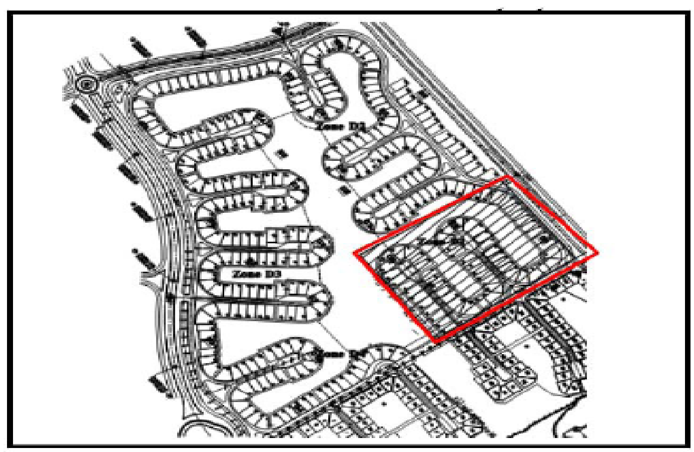

Fig. 8c. Marked destination area of surface and infiltrated water on top of clay layer under the layout of the villas in the site.

6 Potential Problems

The potential problems that shall be born due to presence of clay layer, subsurface water and water flow are discussed in this section. The main goal of the discussion is to exclude or include the problems that require solution(s). The potential problems include:

Global sliding potential: The possibility of development of perched water table above the subsurface clay layer may lead to softening of the clay layer and thus the potential of global slopes instability problem. However, the calculated overall slopes inclination of the clay layer for the cross sections presented in this study suggests that global overall instability may not be of major concern.

Clay swell potential: The index and swell potential properties of the clay layer as experienced in the general site of the area suggest that the clay layer may have significant swell potential upon wetting at some localities of the area. If the climate, wetting incidences, the closeness of the clay layer to the ground surface, and the thickness of the clay layer allow, the clay layer may undergo vertical movement due to swelling. Such movement may have adverse influence on the foundations of the villas in the site.

Sand collapse potential: The surface sand layer at some locations above and sometimes below the clay layer is silty and/or clayey in nature and thus may have significant collapse potential upon wetting that may cause problems to the foundations of some villas in the area.

Loss of cementation of material filling surface rock fractures: At some localities, surface fragmented rock layer exist. The fractures are filled with fine material that might be cemented. Flow of water from the ground surface in the downward direction, may result in loss of cementation of that material and/or migration through the cracks leading to possible voids and thus observed vertical movement.

Water accumulation over clay hollows: As has been concluded in the major study of ground water in old part of the site that water may accumulate on the impermeable layer in a local area where the clay layer is concaving upward like a spoon similar to what was observed at one of the investigated villas (1). The fact that the lowest level area indicated in Figure (8c) is relatively wide and flatter area as compared to the concaving feature under the villa in the previous study of the old part of the site. Thus water accumulation is possible but not expected in major quantities or depths.

Migration of finer material through courser soil matrix: As discussed earlier that water might flow parallel and on top of the clay layer. It is also known that on top of the clay layer there are materials such as silty sand or engineered fill with gravel and sand components. In both cases (silty sand and engineered fill), there is potential that the flow of water may carry the finer material and flow through coarser matrix leaving voids in the coarser component and thus ground surface settlement. It is believed that the occurrence of this phenomenon requires a critical hydraulic gradient. The critical hydraulic gradient Criteria for the selective transportation and washing out of fines from the coarser soil matrix have been published by (2). The critical hydraulic gradient is considered to be dependent on the coefficient of uniformity Cu, i.e. the risk for washing increases with the increase in Cu (3) according to the following values:

$$i_c = \begin{Bmatrix} 0.3 \; to \; 0.4 & for \;\; C_u < 10 \\ 0.2 \;\; for & 10 \le C_u \le 20 \\ 0.1 & for \;\; C_u > 20 \end{Bmatrix}$$

In their laboratory tests, (4) noted a significant decrease in the critical gradient when dealing with internally unstable material. (4) compared their values to those based on tests with horizontal flow direction presented by (5), who noted a gradient of 0.70 for stable material, and 0.16 to 0.17 for unstable materials. It should be noted that the hydraulic gradient of the infiltrated water flow is controlled by the slope of the under clay layer surface. The maximum slope angle of the clay layer surface is about 4o from horizontal. Such a slope corresponds to a slope causing flow with hydraulic gradient of about 0.07. Considering the above mentioned minimum critical hydraulic gradient for fines migration of 0.16, the resulting factor of safety for fines migration is in excess of about 2.0. Therefore, the occurrence of such a phenomenon is not expected.

7 Suggested solutions

The possible solution for the problem of drainage of excess water could be one or combination of the following solutions:

Shallow network of perforated pipes: A shallow network of perforated pipes may be designed and installed to collect the infiltrated water from under the irrigated area. The perforated pipes may be installed in trenches with a suitable gravel and filter media surrounding the pipes. The network may be connected to existing manholes system if its capacity and levels allow (see Fig., 9).

System of vertical gravel drains: A system of gravel vertical drains may be designed and installed to drain the accumulating water above the clay layer through the layer and get rid of the water in the sand layer below the clay layer. The drains should be filtered to prevent the migration of fines from the top sand layer (see Fig., 10). As water flow through the drains may cause wetting of the clay layer. If this system to be implemented, it is to be installed at a safe distance from the foundations of the villas in order to avoid any consequences of wetting the sand layer under the clay layer due to the possible nature of collapsibility of the under sand layer.

Deep network of perforated pipes: A network of perforated pipes may be designed and installed to drain the accumulating water and direct the water toward a manhole and be collected using a submersible pump. The perforated pipes may be installed in trenches directly on top of the clay layer with a suitable gravel and filter media surrounding the pipes. Another alternative is to connect the network to existing water manhole system if its capacity and levels allow (see Fig., 11).

Monitoring Program: A monitoring program is to be implemented to watch the water levels in the installed

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piezometers. A set of elevation reference points should be identified at the villas at and near the potential problem areas. The elevation reference points should be used to observe the vertical movements (if any) of the villas.

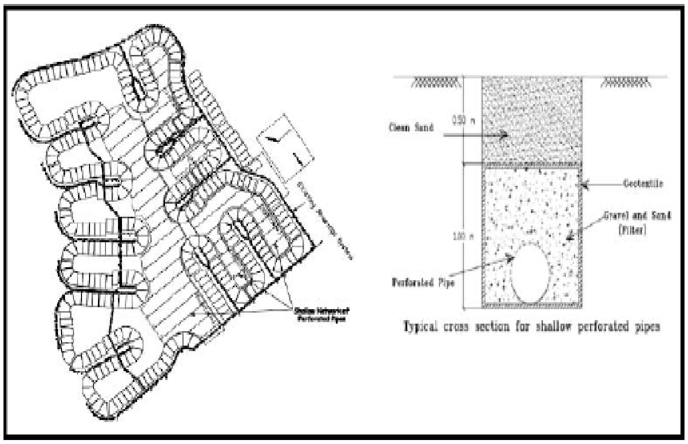

Fig. 9. Shallow network of perforated pipes.

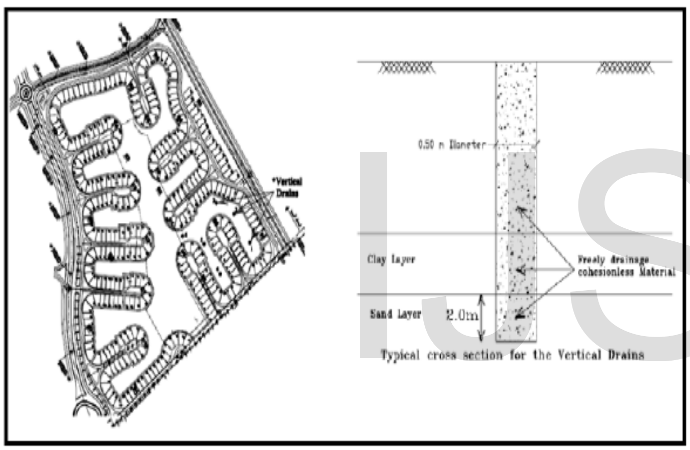

Fig. 10. Vertical gravel drains.

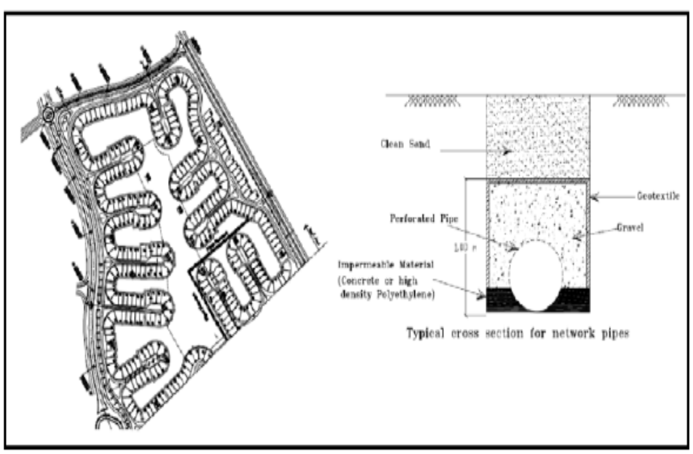

Fig. 11. Deep network of perforated pipes.

8 Conclusions

The development of luxurious compounds in arid desert areas requires the reclamation of huge green areas. Such process requires demands of large quantities of irrigation water. Bad management of drainage of excess irrigation water in such arid areas may cause major problems to the residential units constructed in such large projects. Especially that the presence of water, in a lot of cases, was not taken into consideration during design and construction phases. The problem becomes more complicated in the presence of problematic soils. The paper here demonstrates the potential problems that might be born due to miss management of excess irrigation water. The paper also shows that simple approach can be followed to efficiently manage the drainage of excess irrigation water based on full understanding of the mechanisms of flow pattern in the area utilizing macro level simple topographic and geological models of the area. Such understanding is a key factor in both identification of resulting potential problems and selection or the design of the potential solutions for the identified problems. At the end of the paper, potential solutions were presented for the possible expected problems.

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