Damage pattern scope prediction for well point dewatering on building foundations

Ahmed M D¹, Khudair B H¹, and Shiekha A A²
¹ Civil department, Engineering College, University of Baghdad, Baghdad, Iraq.
² Engineering College, University of Baghdad, Baghdad, Iraq.

Abstract. In the well point construction process, it is necessary to control underground water effectively. The expected damage pattern scope within the influence radius of the depression cone of the well point can be determined according to noticeable ground and building settlement, as well as reference to the soil property changes due to the dewatering process with the aid of the formation mechanisms of underground water, based on underground water flow theory. This paper examines the Damage Pattern Scope expectation (DPS) and discusses some underground water conditions and practical key points by means of examining a laboratory pilot-scale model with light well point water lowering of different soil strata thickness, thus analysing the impact on the surrounding environment due to water lowering. The results showed that the water content and the void ratio of soil subjected to dewatering were reduced and that soil density and cohesion thus increases.

Keywords: Dewatering, Well point extraction, Settlement of nearby buildings, Experimental model.

1. Introduction

Land subsidence occurs in many areas, particularly in densely populated cities throughout the world [1]. As a result of higher population intensity, the tendency to construct high building has increased, and excavation close to existing buildings is popular in urban areas; most constructions in an area are thus nearby to each other, with the closest distance often occurring between new high buildings and the oldest existing buildings. The nearby old buildings' state is also generally more dangerous as a result of their shallow foundation levels and structural weakness [2].

Urban construction and the improvement of city facilities in territories with high water tables require for adoption of dewatering processes prior to construction, with a specific end goal of maintaining the stability of the adjacent buildings, streets, and city pipelines, as well as the stability of the foundation ditch sides themselves. It is thus important to select a proper dewatering outline for setting up ditch and underground water control techniques [3].

Underground water represents a major damage risk for the general security of foundation ditches. Where underground water is not controlled accurately, it can prompt the crumpling of the ditch slant, water bursting from ditch base, difficulty in shaping a generally dry environment in a foundation ditch, and making foundation construction procedures infeasible [4].

The extraction of underground water accelerates consolidation of the surrounding soil, however [5], making the buildings and structures within the surroundings of the extraction well area develop cracks in some parts, as shown in figure (1). This may lead to the breakage of underground pipes in severe cases. This paper thus aims to examine the Damage Pattern Scope expectation (DPS) by means of a laboratory pilot-scale model.
The seeping water from silty sand or sand layers usually contains large amounts of silt or/and powdered sand, and these can influence construction processes and the surrounding environment. The regular soil surface drop of a relatively large area around a ditch case usually happens when the level of confined water is reduced by 1–2 times the depth of the level of confined water [6].

The objectives of this research are to analyse the effects of dewatering on soil properties and to examine the effective scope on nearby buildings.

2. **Groundwater drawdown process**

An extraction well is a hydraulic construction which is created to allow water extraction from an aquifer, as shown in figure (2).

1. The volume of pumped water per unit of time is the Well Yield (Q).
2. The groundwater level before pumping commences is the Static Water Level {SWL}, here denoted by (H).
3. Water level during pumping is the Pumping Water Level {PWL}, denoted by (h_w).
4. The difference between SWL and PWL is called the Drawdown \( S = H - h_w \).
5. The mathematical formula type used for the confined aquifer equation (1) and the unconfined aquifer equation (2) are obtained from the Dupuit-Forchheimer equation [7]:

\[
S = H - h_w = Q \ln(R_/r_w)(2\pi KB)^{-1} \\
H^2 - h_w^2 = Q \ln(R_/r_w)(\pi K)^{-1}
\]

(1) \hspace{1cm} (2)
When an inclined high permeability soil layer is confined by an overlying soil layer with low permeability an artesian condition will exist; the water pressure in the artesian soil layer will not be directed by the local phreatic surface, but rather respond to a higher phreatic surface level at a distant site where the layer is unconfined; thus, the confined or unconfined nature depends on soil strata arrangements [8].

The well point distribution depends on the construction’s planar size and digging depth, and the water lowering curve after stabilisation should be less than the digging depth at each point by at least 0.5 m. The closed circle distributed well points’ inner region curve hydraulic slope can be computed using 1/10, while the outer region curve’s hydraulic slope depends on geotechnical conditions, and must thus be determined by testing or recent experience [9].

3. Geotechnical impact of drawdown process

When water pumping begins, after the well pipes have been laid out, the water level in the well will decrease, and the water in the surrounding water-containing layer will continuously flow toward the filter pipe; after some time, a cone shaped curved water surface will form around the well point. This surface will settle gradually, a process that usually takes a few days. Increase in effective stress thus occurs when groundwater is lowered in compressible soils and leads to consolidation settlement [10]. A drop in the groundwater level at any site will increase the effective stress within the soil deposits due to the reduction in buoyancy forces, and excessive stress will be accompanied by strain (Hooke’s Law). The integration of strain over the affected volume of material shows that the soil settlement and the settlement amount depend on the soil stiffness and stress history [11].

Groundwater extraction can generate land subsidence by causing the compaction of susceptible aquifer systems [12] unless appropriate control measurements and precautions are conducted to eliminate this enviro-geologic hazard [13]. The variation of vertical stress at the base of an excavation increases soil heaving underneath the excavation as well as the lateral movement of the soil. Furthermore, variation of the water table, grouting, and high traffic loads may also increase total soil movement [14]. Variation of the groundwater table also influences nearby buildings [15]. Real-life structures are not normally built and then tested to failure due to prohibitively high costs; full-scale testing of structures to failure is deemed uneconomical and undesirable [16].

4. Laboratory model setup

A laboratory pilot-scale model was thus made to replicate the process of water extraction by means of examining a well made from different soil layer thicknesses. Water was extracted in different quantities and foundations laid at different distances from the well in order to record the settlement induced by dewatering. In this study, transparent tubes were also installed to represent observation wells, allowing the
level of water to be monitored during groundwater dewatering; see Fig. (3) and plate (1). Modelling the groundwater flow system in this way provides insight about water head distribution in the aquifer systems [11].

The model was constructed in a glass box which consisted of glass plates of 10 mm thickness as shown in Plate (1). The inside dimensions of the model were 1 m x 1 m x 0.5 m length, width, and depth, respectively. The inside consisted of two parts, the first of which was a quarter circle where the soil layers were placed and the second part of which contained water used to supply the soil layer with a constant water table. Two curved aluminium plates of 1.57 m length and 0.5 m width, with holes of 5 mm diameter and fibres between them, were used to divide the box space and allow water to pass throughout the parts of the glass box model.

The water table level was controlled inside the model box by means of adjusting the air ball, which was connected with a crow bar and a control nut, to fix the water level by closing the inflow of water to the box model. Two layers of silty clay layer over a silty sand layer were laid inside the box to be tested; each one had a thickness of 15 cm.

5. Results and discussion

Figure (3) demonstrates the laboratory pilot-scale model used as exploratory work to portray the foundation reactions to a dewatering framework. Three foundation models were set over an alternate separation from the well with a specific end goal to determine the extent of dewatering impact on adjacent building foundations. The drawdown of the groundwater level at each point was recorded with time, as shown in figure (4) and figure (5); this indicated a time about one hour to reach maximum drawdown, reaching a steady state for soil layer thickness 30 cm and discharge amount 40 mL/min.

The calculated settlement was normalised with respect to depth of soil layer under the foundation; the radius of cone of depression was normalised with respect to the distance of each foundation from the extraction well. Foundation model settlement was tested under three different flow rates, obtained after examining the capacity of the experimental model to achieve maximum extracted water without reaching a dryness state.
Table (1) displays the final results obtained from the experimental work with two layers of soil in which a silty sand soil was overlain by a silty clay layer.

Table 1. Results obtained from experimental work of two layers of soil.

| Discharge Q out (mL/min) | Water head h (cm) | R (cm) | R/r | Water head hp (cm) | Final settlement S (mm) |
|-------------------------|-------------------|-------|-----|--------------------|------------------------|
| 40                      | 15                | 28    | 3.57 | 19                 | 0.17                   |
|                         | 54                | 1.85  | 21.5 | 0.10               |
|                         | 80                | 1.25  | 24.2 | 0.03               |
| 48                      | 7                 | 28    | 3.57 | 15.6               | 0.24                   |
|                         | 54                | 1.85  | 18.6 | 0.18               |
|                         | 80                | 1.25  | 23.4 | 0.05               |
| 60                      | 2                 | 28    | 3.57 | 14.3               | 0.27                   |
|                         | 54                | 1.85  | 17.8 | 0.20               |
|                         | 80                | 1.25  | 22.3 | 0.08               |

Figure (6) shows a comparison of settlement for foundations subjected to the effects of nearby dewatering at various horizontal distances of 28, 54, and 80 cm and two types of soil layer setups with 30 cm soil layer thickness. The following features were observed in terms of foundation response according to well point system distance:

1. The horizontal distance of adjacent dewatering points noticeably affected the settlement of the foundations. Maximum settlement increased with decreasing horizontal distance between the well point and adjacent foundation. This finding may be attributed to the soil settlement induced by effective stress increments.

2. It is obvious that for all examined discharge quantities, the effect of dewatering is more pronounced as the horizontal distance of the well point system gets closer to the foundation. As the horizontal distance of the well becomes R/2 or greater, the effect of dewatering becomes insignificant. The extreme settlement area around the well is the highest and the decrease begins significantly at R/3, decreasing slightly after R/2.

3. The maximum drawdown near the well reveals that the maximum settlement accrues at the centre of the
well point.
4. The deformation of the silty sand layer may be attributed to an increase in soil density above the layer, while settlement of the silty clay layer is attributed to an increase in effective pressure and the dissipation of pore pressure.
5. The largest variations of the maximum settlement with horizontal distance occur at R/4 and R/2, but little effect is observed beyond those distances, and the drawdown time is the same at all points, which may lead to differential settlement.

Figure 6. Comparisons of settlement for foundations subjected to the effects of dewatering at various horizontal distances.

5.1. Radius of water lowering cone and relationship with damage pattern scope.
According to the experimental results, a relationship can be found between Damage Pattern Scope and the radius of the water lowering cone that allows estimation of well point water lowering method’s influence on the surrounding geotechnical environment and the resulting soil surface drop. This can be achieved based on equation (3) and equation (4):

\[
Rg = 0.4R \quad (3)
\]

\[
R = 3000S(K)^{1/2} \quad (4)
\]

As the soil body properties in this range were altered according to laboratory tests after dewatering, as presented in table 2, and the largest variation of the maximum settlement with horizontal distance occurs at R/4 and R/2, but little effect is observed beyond that distance and the drawdown time is the same at all points, differential settlement may occur. The influence range is strongly influenced by soil layers, and it is thus necessary to adopt a water pumping test to determine the influence radius of the water lowering method in advance of important construction projects.

Table 2. Soil properties before dewatering and after dewatering.

| Soil Properties | Density Kg/m³ | Water Content% | Void ratio | Cohesion kPa |
|-----------------|---------------|----------------|------------|--------------|
| Before          | 18.4          | 17.7           | 0.65       | 33           |
| After           | 19.5          | 19.4           | 0.46       | 46           |

5.2. Ground surface settlement expectation induced by water dewatering method
As long as no large amount of fine grains is carried away along with the underground water in the well
point water dewatering method, the drop in the surrounding soil surface can be computed using a layer summation method [2] as shown in equation (5):

\[
\delta = \sum_{i=1}^{n} \frac{c_i}{1+e_i} \Delta p_i \Delta h_i
\]  

During the dewatering or lowering process, the soil layers below the water lowering surface cannot form obvious consolidation drops; however, the soil layers between the water lowering surface and the original underground water surface will rapidly drop because of their increased self-weight stress and due to good water expulsion conditions; the soil surface drop due to water lowering is mainly due to this process.

6. Conclusion

Based on Skempton and Brogan [17], who considered that voids filled by fines do not transfer load and thus would be easily moved by water flow, where fines are eroded away by water flow from the reservoir side to the well side in the experimental model, this will lead to

- A change in hydraulic conductivity, and
- Alteration in void ratios

The effect of water extraction is quite clear at the first third of the horizontal distance from the well extraction centre point. This finding was noted for all examined flow rate amounts.

The effect of water extraction vanishes gradually as the horizontal distance increases beyond half of the radius of the depression cone for all flow rate amounts.

The water content decreases by about 8 to 12% in the location of the water depression cone.

7. References

[1] Ruilin H 2009 Urban land subsidence in China Engineering geology for tomorrow’s cities. Geological Society, London, Engineering Geology Special Publication**,(on CD-ROM insert, Paper 786)

[2] Ramadan E, Ramadan M, Khashila M and Kenawi M 2013 Analysis of piles supporting excavation adjacent to existing buildings. In: Conference of Soil Mechanics and Geotechnical Engineering, pp 2835-8

[3] Huang F, Wang G, Wang C and Pan X 2013 Application analysis of large-diameter vacuum tube dewatering well-with a certain range of beijing subway project as an example Electronic Journal of Geotechnical Engineering 18 2281-96

[4] Ahmed M D, Al-OBAIDY B and Sheikhah A A 2016 Dewatering Effect on Virtual Settlement of Pile Foundation: case study in Bab AL-Mudham area, Baghdad-Iraq

[5] Qi T and Gao B 2011 Strata consolidation subsidence induced by metro tunneling in saturated soft clay strata Journal of Modern Transportation 19 35-41

[6] Lee C K, Fallou S N and Mei C C 1992 Subsidence due to Pumping from a Soil Stratum with a Soft Aquitard Philosophical Transactions: Physical Sciences and Engineering 339 193-230

[7] Powers J P 2007 Construction dewatering and groundwater control: new methods and applications: John Wiley & Sons)

[8] Knappett J 2012 Craig’s soil mechanics vol 8: Spon Press London, UK)

[9] Alonso C, Ferrer A and Soria V 2008 Finite element simulation of construction site dewatering. In: International Conference on Engineering and Mathematics ENMA 2008,

[10] Mokwa R L, Mokwa L P and Mokwa T P 2011 A case study on construction dewatering-induced settlement damage: Could This Have Been Avoided? Journal of Civil Engineering and Architecture 5
[11] Kaviyarasan R S H, Sasidhar P 2013 Assessment of Groundwater Flow for an Unconfined Coastal Aquifer International Journal of Innovative Research in Science 12-8
[12] Galloway D L and Burbey T J 2011 Regional land subsidence accompanying groundwater extraction Hydrogeology Journal 19 1459-86
[13] Balogun W O, Anifowose M, Shogo M and Salaudeen F 2011 Trends and mechanisms of land subsidence of a coastal plain in the delta of Yangtze River-China Researcher 3 76-81
[14] Kempfert H-G and Gebreselassie B 2006 Excavations and foundations in soft soils: Springer Science & Business Media)
[15] Poulos H G 2007 Ground movements–A hidden source of loading on deep foundations DFI Journal-The Journal of the Deep Foundations Institute 1 37-53
[16] Ong D, Leung C and Chow Y 2004 Pile behaviour behind a collapsed wall. In: Proc. International Conference on Structural and Foundation Failures, Singapore, pp 410-21
[17] Chang D S and Zhang L M 2013 Extended internal stability criteria for soils under seepage Soils and Foundations 53 569-83

Acknowledgements

Special gratitude and many thanks are given to the faculty and staff in the Department of Civil Engineering at the College of Engineering, University of Baghdad.

| Nomenclatures | Definition |
|---------------|------------|
| $\Delta h_i$  | Thickness of the $i^{th}$ soil layer (cm) |
| $\Delta p_i$  | Additional stress due to water lowering for the $i^{th}$ soil layer kPa |
| B             | Soil layer thickness (m) |
| $C_c$         | Compression coefficient of the $i^{th}$ soil layer kPa$^{-1}$ |
| $e_{oi}$      | Initial void ratio of the $i^{th}$ soil layer |
| $H$           | Thickness of water stratum (m) |
| $h_w$         | Initial underground water depth (m) |
| K             | Hydraulic conductivity(m/sec) |
| $n$           | Number of soil layers within the compression layer range |
| $Q$           | Output volume of the well point system (Well Yield) |
| $R$           | Influence radius according to Sichardt equation for single well pumping (m)[3]. |
| $R_0$         | Radius of influence(m) |
| $R_g$         | Geotechnical influence radius (Damage Pattern Scope).(m) |
| $r_w$         | Well radius(m) |
| $S$           | Total drawdown ($S = H - h_w$). |
| $\delta$      | The ultimate drop of the soil surface (cm) |