

Monitoring Program for Cement Grouting of Underground Karst Cavities

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ABSTRACT: A total of eight ground-surface subsidence was detected in a residential suburb. The subsurface failure cases in the suburb were investigated in detail after their development. Results of the investigations indicated that the geological profile in this suburb consists of overburden soil which is underlain by limestone bedrock. It was concluded that raveling of the overburden soil into the underlying Karst cavities was the main cause of ground-surface subsidence development. Filling the Karst cavities with cementitious grout was chosen as a treatment measure for the cavity problems. Before and during the grout works for filling the Karst cavities, continuous monitoring of elevations in some selected points at critical locations were considered as essential tool to detect any slight movement or change that may be evaluated and considered a warning for larger movements or cavity and ground-surface subsidence formations. The continuous monitoring program was based on two major elements; dilapidation survey of selected high risk locations, ground surface movement and the measurement of water levels for determining water fluctuations. Dilapidation was achieved through topographical site surveys including houses, utilities and general surveys along with a set of pictures illustrating important features. Station points were set all over the site and their elevations were checked regularly. Regular periodic evaluation of elevations, water-table levels and crack-meter readings were used as tools to evaluate the impact of the grouting works. Status of existing structures was checked regularly using crack-meters along with water-table levels through available piezometers. This paper contains description of the conducted dilapidation and topographical survey. Results of the monitoring program of the grouting works and their impact on the ground-surface subsidence is also presented in this paper.

Keywords: Subsidence; Grouting; Survey; Soil; Topographical

1. INTRODUCTION

A number of ground surface subsidence in the form of sinkholes of various sizes had been occurring in a residential suburb in State of Kuwait [1]. The first sinkhole of April 1989 (SH-1) was immediately backfilled with gravel, sand, and concrete. The occurrence of the second and third sinkholes during the same months led to the decision to evacuate more than 130 surrounding houses [2]. Extensive investigation studies had been conducted in this affected residential suburb in order to understand the causes of those sinkholes and recommend appropriate treatment methods [2]-[4]. The studies that included topographic and geophysical surveys, geological, and geotechnical investigations revealed the existence of underground Karst cavities within the Limestone bedrock underlying the overburden soil caused the sinkholes.

The studies also reported that the geological profile of this residential suburb consists of 35 to 40 m thick overburden soil comprising dense to very dense predominantly quartz sand, overlying the Karst limestone bedrock. The cause of the sinkholes had been attributed to the dissolution of the limestone bedrock and subsequent raveling of the overburden soil cover into the underlying Karst cavities.

Accordingly, treatment methods were recommended to minimize the recurrence of the sinkholes composing of filling the underground cavities by injecting cement grout at depths varying between 32 to 60 m in a pilot area and by eliminating the possibilities of collapse of the upper level

Karst cavities within the limestone bedrock [5].

The pilot area located in Sector A1 of the residential area classified as the evacuated area (Fig. 1), was divided into six treatment zones, TA1 to TA6, for sequential injection of grout according to these zones. In general terms, the grouting program work required performing dilapidation survey, drilling exploratory holes with in situ testing and sampling by designing a grout mix and developing quality assessment program, filling in deep limestone cavities using cement-based mortar, permeation grouting of remaining deep voids and fractured rocks using cement-based grout, drilling control holes at the end of grouting and overburden treatment.

Reference [6] shows the types of ground deformation measurements often used in tunneling for insuring safety and construction quality management. It also shows the monitoring methods and the types of devices in establishing early warning systems against incipient ground collapse or damage to structures at ground surface. ...

In this paper, the monitoring program used for the implementation of the treatment methods of underground cavities and fractured rocks is described. The continuous monitoring program focused on the impact of the treatment drilling and grouting works on the existing super-structures on the site, ground surface movement and fluctuation of underground water-table levels. The results are presented and discussed and conclusions are illustrated.

2. IMPLEMENTED GROUTING METHODS

The main purpose of the grouting treatment implementation is to reduce the risk of sinkhole recurrence by minimizing

the possibilities of collapse in the upper level cavities within the limestone bedrock. The scope is filling up of the uppermost cavities in the rock formation with stable cement mortar grout pumped from the ground surface. The work was carried out in the selected pilot that has a total surface area of around 62,000 m² [7].



Fig. 1. The six treatment zones, TA1-TA6, in the pilot area.

Injection method from the ground surface is used with low pressures for proper filling of the underground cavities (Fig. 2). The treatment is not intended to densify the rock or to improve its strength, but to fill up the existed voids and cavities and to prevent migration of sand from the overburden layer into the limestone bedrock. By closing cavities and voids in the limestone layer and preventing soil raveling, the thick overburden of dense sand will assure sufficient ground support for all structures above ground. The cavity filling grout, consisting of cement, sand, additives and water, is considered economical and efficient. The cavity filling grouting is replaced by permeation grouting in locations where no open cavities are observed but the uppermost layers of the rock prove to be highly pervious due to open fissures or the presence of frequent small Karst features. Permeation grout consists of cement water mix and additives without aggregates injected into the rock mass under pressures using packers. The applied treatment program is extensively used in the pilot area.

3. METHODOLOGY

The purpose of the monitoring program used herein is to monitor the potential impacts of drilling and grouting works for the implemented treatment methods on the existing structures and ground surface condition.

The monitoring program focused on the sinkholes and their behavior during and after the period of treatment implementation works to detect impacts resulted from the treatment campaign. The following subsections describe the methods used for monitoring the treatment effects in the area under study.

3.1 Dilapidation Survey

Dilapidation survey is a detailed record of land and buildings at a specific point in time. The survey started before implementing the treatment methods by describing the condition of the existing structures, identifying any defects, and a schedule of pictures for existed defects.

Large numbers of photos were taken including general views of the area, description and close up photos of some parts of the structures and utilities (Fig. 3). Detailed identification of location, date of photo taken, image number, and location on key map were also recorded for each photo.



Fig. 2. Delivery and pumping of cavity filling mortar.



Fig. 3. Dilapidation photo in area TA1.

3.2 Topographical Site Survey

At the beginning of the monitoring program, a site survey of the area under study was carried out. The output results of this part were drawings for locations of all existing buildings and facilities such as structures, fences, walls, roads, sidewalks, over and under-passes, gardens, open yards, trees, ditches, canals, culverts and wells, services and related structures (both above and below ground) such as water mains, sewers and electricity and telephone poles. They were considered as the "As-Built" drawings.

The topographical survey concentrated mostly on regular recording of elevations inside and around the treated areas. Elevation points were distributed on the ground surface forming a grid of less than 50 m spacing, in addition to points selected in each housing unit. The readings were evaluated and recorded using a total-station surveying instrument (Fig. 4). Any signs of undesired ground movement were detected and projected into maps and tables.



Fig. 4. Recording readings by total station survey.

3.3 Crack Propagation

Crack-meters of an accuracy of 0.001 mm were used to record movements of selected elements (Fig. 5). Crack meters were located on site mostly on structures, around sinkholes and other sensitive areas suspected with occurring movement. A number of crack-meters were set on columns, slabs, and on structural joints on ground and upper floors. One crack meter was set on the asphalt close to the progressing sinkhole SH-1. Each crack-meter was identified by a label with all necessary information on the location and the structure on which it is set.

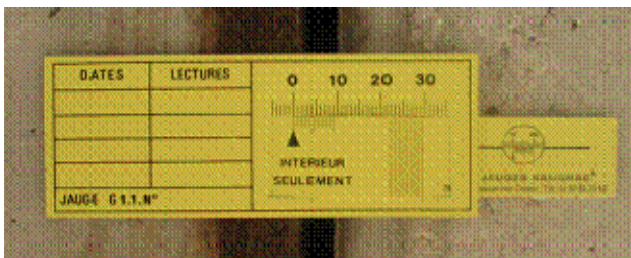


Fig. 5. A crack-meter sample used to monitor movements.

3.4 Water-Table Fluctuation

Evaluation and monitoring of groundwater and water-table levels is essential for detecting changes or risks, as the

water content affects the soil behavior and stability. Three piezometers were drilled and were used to evaluate water-table levels since 2002. These holes were unfortunately blocked during the heavy work on site. Three new holes were drilled and are currently being used to evaluate water-table levels and detect groundwater fluctuations. The locations of those new piezometers are shown in Fig. 6.

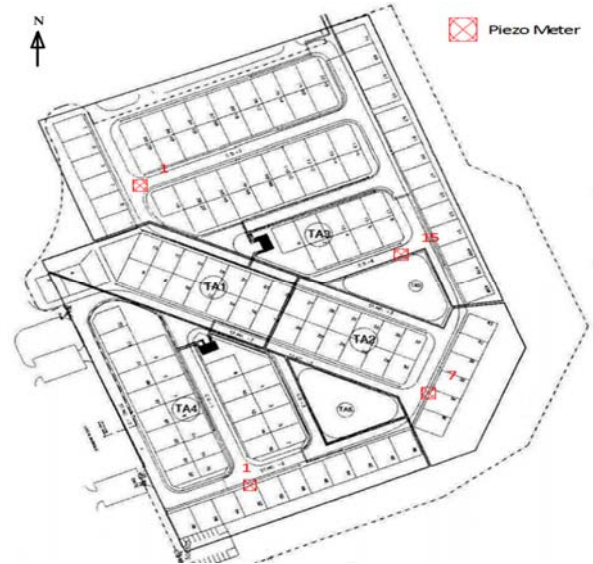


Fig. 6. Location of the piezometers.

3.5 Visual Inspection

A visual inspection was performed to document the common defects, whether they are due to demolishing, aging, construction etc. A sample picture of those defects is shown in Fig. 7. Those cases pictures reflect the general status and condition of the site and structures.



Fig. 7. Exposed corroded reinforcement and expelled concrete at the bottom of a ground floor column.

4 RESULTS AND DISCUSSION

In the monitoring program, effects of drilling and grouting on ground surface and existing structures were considered. The drilling is carried out with a drilling fluid, either water with polymer or air alone. The fluid has an ability to permeate more easily in the underground channel because it is light and not loaded with too much particles. Two types of grouting treatment were used which included mortar filling and permeation grouting.

Cavity filling with mortar was carried out as specified by the gravity process and, consequently, the pressure exerted during the process was not very high (~ 5 bars). Therefore, there was no change recorded in any elevation consecutive to the cavity filling.

A higher pressure of 30 bars was applied during the permeation grouting stage. No perceivable changes in the elevation of the surveyed points were recorded as a result of the permeation grouting. This indicates that there was sufficient room for the voids to redistribute in the ground without impacting the surface.

Dilapidation pictures show general views of the area, description and close up photos of some parts of the villas, utilities, etc. Detailed identification of location, date of photo taken, image number, and location on key map are presented as well on each photo.

For the topographical survey, appraisal of the readings recorded for elevation points by a total station was monitored through any sign of ground undesired movement. Safety of the housing units is the most important issue before and after treatment implementation, therefore; points are concentrated on the houses and around the old sinkhole locations. Fig. 8 shows the selected monitoring points and their elevations, and Fig. 9 shows sample records for selected points in zone TA3 which indicates no significant changes in the elevation of those points during the treatment implementation period.



Fig. 8. Coordinates and elevations of selected points.

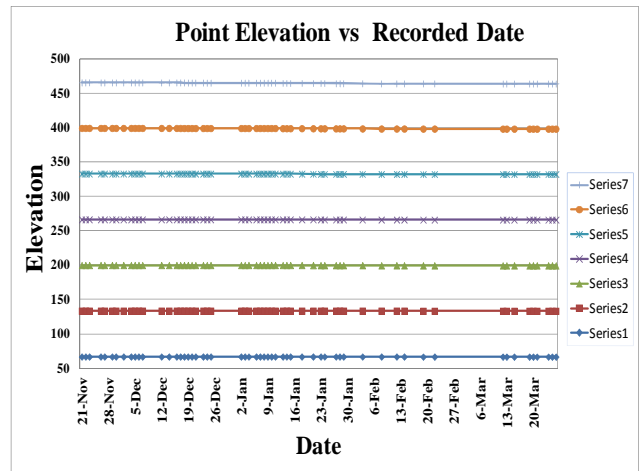


Fig. 9. Display of elevations for area TA3.

For crack propagation monitoring, a number of crack-meters were mounted at different locations and readings were taken periodically. Fig. 10 is a plan view of the treated area where the rectangular red marks and numbers show the locations of the mounted crack meters. Table 1 is a summary of the accumulated readings of a sample of crack-meters.

The amplitude recorded varies from 0 to 0.5 mm for the typical cracks and 0-3 mm for the dilatation joints. It may be said that these recorded data are expected and could be attributed exclusively to the thermal effect. The readings showing the more significant displacements are recorded along the dilatation joints at upper floor during the wintertime when thermal effect is measured. From the general survey, the crack meters have confirmed the fact that there was no impact recorded.

For the water-table level monitoring, the ground water and its effect on the soil is of real importance in evaluating the treatment method. The water-table level was targeted since few years before the treatment implementation. Table 2 lists sample reading for the water-table level for the new piezometers. In general, slight rise in the water-table level was observed during the treatment implementation campaign.

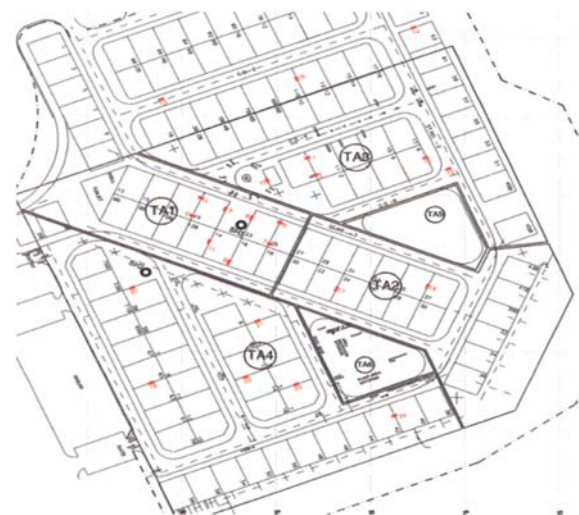


Fig. 10. Locations of crack meters.

Table 1. Summary of Crack-Meter Readings

No.	Min. (mm)	Max. (mm)	Difference (mm)	Location			Unit Adjacent
				Zone (TA)	Unit	Floor	
1	0.50	2.70	2.20	3	9	1st	11
2	-3.00	1.00	4.00	3	9	1st	11
3	1.50	1.50	0.00	1	19	GF	-
4	0.00	1.50	1.50	1	19	1st	17
5	2.00	2.00	0.00	1	23	1st	25
6	0.50	1.00	0.50	1	23	1st	-
7	0.00	0.00	0.00	3	Asphalt	-	-
8	0.00	0.00	0.00	3	A2	1st	-
9	0.50	0.50	0.00	3	8	1st	-
10	0.00	0.00	0.00	3	11B	1st	13
11	0.00	0.00	0.00	2	35	1st	36
12	0.00	0.00	0.00	4	63	GF	65
13	-0.50	-0.50	0.00	4	3B	1st	-
14	0.00	0.00	0.00	4	5	1st	7
15	-0.50	-0.50	0.00	1	40	1st	42

Table 2: Sample records for the water-table level

Date	Hole 7	Hole 11	Hole 18
	NetDepth of Water (m)	NetDepth of Water (m)	NetDepth of Water (m)
20/11/2006	27.89	29.91	30.48
17/12/2006	27.91	29.92	30.52
02/01/2007		29.89	30.51
03/02/2007		29.86	30.50
20/02/2007	27.77	29.79	30.51
21/02/2007	27.70	29.9	30.61
25/03/2007		29.84	30.60
14/4/2007	27.82	29.88	30.64
15/11/2007	27.86	29.91	30.64
31/1/2008	27.83	29.86	30.62

5 CONCLUSION

The outcomes of the pilot area under study depend mainly on the geological profile encountered, the type of works, and the porosity of the sand. The thickness of the overburden is of 30 meters which here is sufficient to allow redistribution of the porosity during grouting. The rock grouting took place with a rather limited pressure.

The monitoring and surveying campaign represented an important essential component of the treatment implementation process of underground cavities in the area under study. The area was intensively treated using two different types of rock treatments; cavity filling and permeation grouting.

Regular periodic evaluation of elevations, water-table levels and crack-meter readings were used as tools to evaluate the impact of the drilling and grouting works of the treatment implementation program. During the treatment implementation using low and high pressure grouting, no alarming signs or significant move or settlement was observed due to the grouting works. It signify that sufficient space for the voids were available to redistribute in underground level without impacting the surface.

Continuous monitoring was recommended to be achieved by regular evaluation of elevations in selected higher risk locations reporting any alarming changes, along with monitoring water-table levels through available piezometers in order to assure the safety of the area and its occupants.

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