Development and Implementation of Ashghal Guidelines for the Evaluation and Repair of Sinkholes

Jamal Essa M Al-Ansari
Roads Operation & Maintenance Department, Public Works Authority (Ashghal), Doha, Qatar
alansari@ashghal.gov.qa

Khaled E Hassan
Stantec UK Limited, Qatar Branch, Doha, Qatar
khassan@ashghal.gov.qa

Kempaiah Kantha Kumar
Roads Operation & Maintenance Department, Public Works Authority (Ashghal), Doha, Qatar
kkumar@ashghal.gov.qa

Khaled N Helali
Stantec UK Limited, Qatar Branch, Doha, Qatar
khilali@ashghal.gov.qa

Abstract

Sinkholes are a common and recurring problem with potential safety risks to road users and authorities. A sinkhole is a void in the ground caused by natural and/or manmade activities, and mainly associated with carbonate rocks and underground water movement. It occurs suddenly and manifests as a hole in the ground, with the potential to cause significant problems of road closure and interruption to road users and construction activities. With the vast infrastructure, development over the last two decades and the majority of soil formation of Qatar exposes limestone and dolomites, the number of reported sinkholes has increased dramatically. This paper presents the development and implementation of new guidelines for the evaluation and repair of sinkholes for the Roads Operation and Maintenance Department (ROMD) at the Public Works Authority (Ashghal). It reviews the methodology adopted for the classification of sinkholes, application of Ground Penetrating Radar (GPR) technique for the early detection of subsurface voids and sinkholes before they become major problems. It also covers the approach adopted by ROMD and its Framework Partners for the repair of sinkholes. A case study is presented on the implementation of the new guidelines for the effective evaluation and repair of sinkholes, with performance monitoring in service. Successful implementation of the new guidelines contributes to enhanced management of road network in Qatar by maximizing asset performance and minimizing accidents and service disruption.

Keywords: Carbonate rock; Grout; Foamed concrete; Sinkhole geometry; Repair strategy

1 Introduction

With the rapid development of Qatar's infrastructure, there is an increasing concern about subsurface voids and sinkholes that pose health and safety hazards to road users and operators. Geologically, Qatar lies on a bed of sedimentary rock mostly made up of tertiary limestone and dolomite with interbedded clay, shale, gypsum and marl (Cavelier et al., 1970). These dominantly carbonate strata are highly variable, with strong bands interbedded with much weaker materials and dissolution cavities infilled with uncemented material. The strata have been subject to extensive dissolution and formation of cavities and sinkholes due to underground water movement (Leblanc, 2008). Sub-surface voids/sinkholes result from the simultaneous or sequential activity of subsurface dissolution and downward movement of the overlying material by internal erosion and/or gravity.

Sinkholes appear suddenly as a hole in the ground or pavement, even though they occur over a long time of bedrock erosion. Natural sinkholes are generally formed over thousands of years, whereas manmade activities can greatly accelerate their occurrence. For example, construction activities tend to increase overburden loads or lowering groundwater level, causing existing voids at deeper depths to collapse. In addition, breakage of water and sewer pipelines results in washing out the fine particles of soil and void formation (Iqbal, 2019). Many shallow depressions of 9736 are reported in Qatar over the last three decades, with the average intensity of 1 per km^2 (Sadiq & Nasir, 2002).

This paper summarises the guidelines developed by the Roads Operation and Maintenance Department (ROMD) at the Public Works Authority (Ashghal) for the evaluation and repair of sinkholes (Ashghal, 2020). The guidelines provide a quick and simple way for the classification of sinkholes, based on underground investigation using ground-penetrating radar (GPR), and effective procedures for repair, considering conventional construction materials and equipment currently in use in Qatar. A case study on the evaluation and repair of a sinkhole is presented along with performance monitoring approximately 20 months in service.

2 Detecting and Evaluation of Sub-Surface Voids/Sinkholes

Various techniques have been used for the detection of ground subsidence including GPR, electrical resistivity tomography, acoustic sensing, ultrasonic sensing, and seismic sensing. The GPR is a subsurface imaging method that provides high-resolution information to a depth of up to 30 m. Low frequency waves are generally used for deep ground investigation whereas high frequency waves are used for near surface. Ashghal is utilising a piece of advanced GPR equipment with a step frequency between 10 MHz and 10 GHz that enables high resolution scans up to four metres beneath the road surface. Fig. 1 shows the Ashghal GPR equipment, which operates by sending electromagnetic radar waves into the pavement structure to detect changes in subsurface properties.

Fig. 1: 3D-GPR equipment utilised by Ashghal for Sinkhole investigations

3 Sinkhole Repair Methodology

The methodology for sinkhole repair is dependent on appropriate evaluation of sinkhole causes and dimensions that need to be considered before repair. Fig. 2 illustrates the methodology of sinkhole evaluation and repair. The most important factors in the evaluation process are the causes of sinkhole and geometrical dimensions. The location of a sinkhole adjacent to a highway structure or building may influence the repair method to be followed.

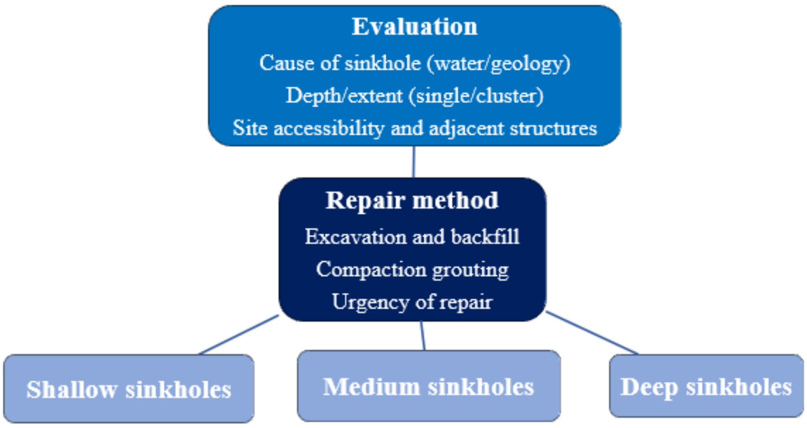

Fig. 2: Sinkhole Repair Methodology

4 Evaluation of Sub-Surfcae Voids/Sinkholes

4.1 Causes of Sinkholes

Water is the main triggering mechanism for sinkhole formation and development. Natural sinkholes are generally formed due to extensive dissolution of carbonate rocks due to changes in water/sea level and rainfalls. Manmade sinkholes are mainly associated with construction activities such as deep excavation of soil, dewatering, improper compaction, or breakage of pipelines. Increased construction activities and water movement result in increased soil erosion and weakening of the pavement structure. When the overburden loads exceed the load-bearing capacity of the foundation, the upper pavement surface eventually falls through and collapses as shown in Fig. 1. If water is found in a sinkhole, the source shall be identified. Water leaks caused by broken utility pipes should be immediately reported to the appropriate authority, who will undertake the remedial measures to stop the leak or discharge before repairing the sinkhole and reinstating the pavement layers.

4.2 Depth of Sinkhole

Sinkholes are generally circular in plan with a funnel shape, where the wide end opens at the surface and the narrow end is at the bottom. The depth of a sinkhole refers to the depth from the pavement surface (Finished Road Level, FRL) to the bottom of the sinkhole, as shown in Fig. 3. For repair purposes, sinkholes are classified into shallow, medium and deep as given below:

- Shallow sinkholes – up to 1.5m depth from the Finished Road Level (FRL)
- Medium sinkholes – greater than 1.5m and less than 5m depth from the FRL
- Deep sinkholes – greater than 5m depth from the FRL

Shallow and medium sinkholes are generally reached at their bases using regular excavation equipment, whereas deep sinkholes require drilling to reach their bases. In addition to the evaluation of a sinkhole depth, the length and width as shown in Fig. 3 are also required for appropriate repair.

Sinkholes can vary in size and depth and could be isolated or connected to other voids to form a cluster of sinkholes. The presence of a sinkhole throat indicates connected voids or cavities, which need to be sealed before repair, as discussed later in this paper. Evaluating the size and extent of sinkholes are essential for selecting the appropriate repair method.

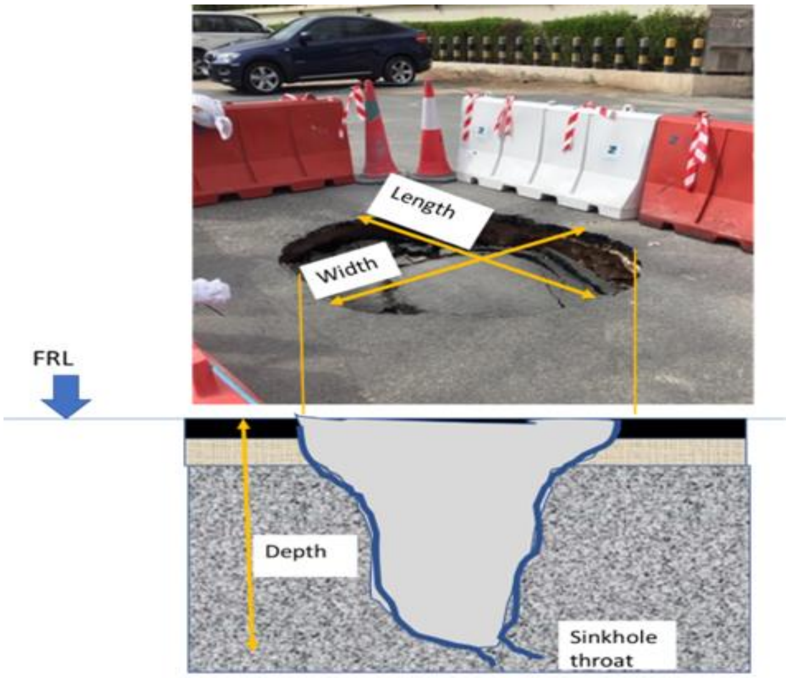

Fig. 3: Measurement of sinkhole dimensions

4.3 Adjacent Structures

The position of existing infrastructure in relation to the sinkhole location shall be identified together with any damaged of subsurface utility services. The foundation of a building or a structure could be greatly affected by the adjacent sinkhole. Utility pipelines and ducts that cannot be shut down or rerouted need to be considered during the repair process.

5 Repair Methods

Two techniques are considered in the Ashghal guidelines (Ashghal, 2020) for the repair of sinkholes to include excavation and backfill and compaction grouting. The excavation and backfill method is used for the repair of shallow- and medium-depth sinkholes, whereas the compaction grouting is used for the repair of deep sinkholes. The repair work needs to be carried out in coordination with the relevant authorities to ensure nearby utilities of water, sewer, telephone lines or cables are identified to prevent interference and damage during repair.

5.1 Excavation and Backfill

The method is used for shallow and medium depth sinkholes, and includes excavation, backfill and reinstatement of pavement layers as illustrated in Fig. 4. Excavation shall be carried out in a manner that removes loose and erodible materials and avoids undue damage to existing pavement and utilities. The surface dimensions of excavation should be at least 1.0 m away from the surface dimensions of the sinkhole until a firm excavated material is found. The excavation walls should be vertical, even and free from fractured materials.

In case of a sinkhole throat is detected during excavation, it should be plugged with rocks, stones, or concrete blocks of at least 1.5 times the maximum width of the throat. All service utilities under the road shall be surrounded in accordance with the service provider's standards and specified in the Code of Practice and Specification for Road Openings in the Highway (Ashghal, 2014).

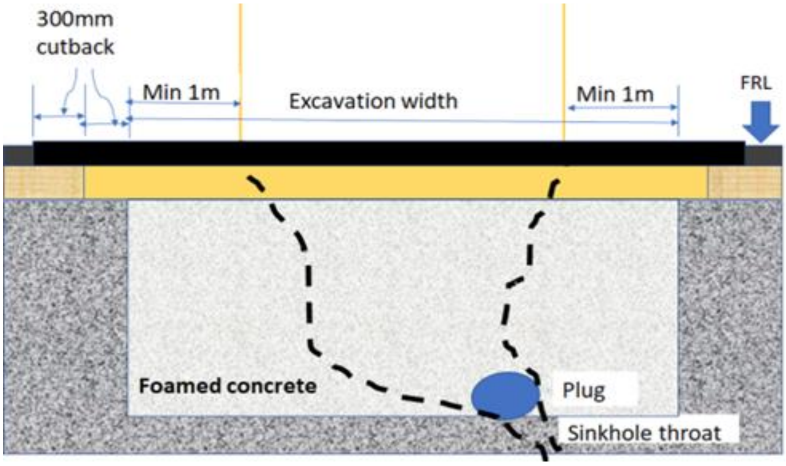

Fig. 4: Schematic diagram of the excavation and backfill repair method

A flowable fill of Foamed Concrete (C5) shall be used as the backfill material for the entire layer. The Foamed Concrete shall be flowable and self-levelling that complies with the requirements of the Qatar Construction Specification of Section 8: Part 2 (QCS, 2014). It may be placed by chutes, conveyors, or pumps in layers of up to 1.0 m single lift depth and should not be tamped or compacted on site. The placed concrete should be left to cure for at least 8 hours to attain adequate strength before reinstating the pavement layers. Reinstatement of the pavement layers shall be made to match existing pavement construction and in accordance with the Code of Practice and Specification for Road Openings in the Highway (Ashghal, 2014).

5.2 Compaction Grouting

Compaction grouting is generally considered for the repair of deep sinkholes that are adjacent to structures, with difficulties of excavating and accessing the bottom of sinkholes. It involves the injection of a low-slump mortar under a specific pressure, down a pre-drilled borehole, to fill voids or to densify subsurface soil. The thick mortar grout forms a series of bulbs in the soil and increases its density as shown in Fig. 5.

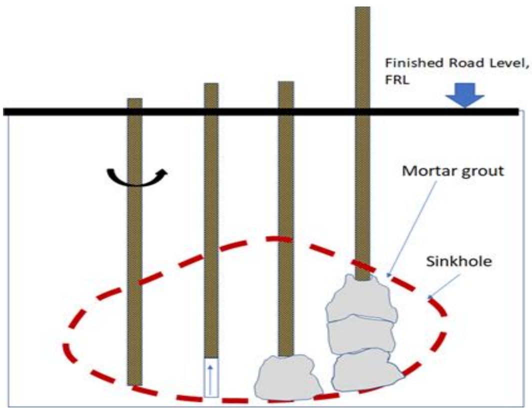

Fig. 5: Schematic diagram of the staged compaction grouting for deep sinkholes

Deep sinkholes cause depression and settlement of the pavement surface and are generally detected using underground investigation. Compaction grouting repair is usually planned as a series of primary and secondary boreholes. The primary points are drilled first and grouted followed by the secondary points, which are usually located midway between the primary points. Before drilling and grouting, the levels of the pavement surface and structures around the working area shall be recorded. The injection pressure shall be limited to a maximum of 5 bar, and vertical movement of the pavement surface and surrounding structures shall be limited to a maximum of 2.0 mm.

The grout mixture shall be of stiff consistency, slump of 50±10 mm as per BS EN 12350-2 (BSI, 2019), and 28-day compressive strength between 10-15 MPa. Compaction grouting shall start with primary holes, in increments of 400-900 mm, under continuous pressure by the bottom-up injection method as shown in Fig. 5. Monitoring during grouting is essential for the grout consistency, injection rate, injection pressure and injected volume. The grouting data shall be used for the determination of grout quantity and compared with the pre-assessed sinkhole dimensions. A reliable relation should be obtained only if sufficient sinkhole and soil information are available. Controlling the grout consistency and injection method enables accurate verification of quantities injected during grouting. In addition to the grout volume verification, it is recommended to carry out underground investigation before and after grouting to clarify the percentage of voids filling.

6 Case Study

Implementation of the Ashghal guidelines for the evaluation and repair of sinkholes commenced in late 2020, with more than 50 sites investigated over the last two years. Investigations revealed only shallow and medium sinkholes, caused mainly due to leakage of water or sewers, and none of the investigated sites revealed deep sinkholes. A case study is presented on the evaluation and repair of a sinkhole, which was reported at a residential area. A GPR investigation was performed, and the analysis indicated inconsistent layers of up to 0.75m below the pavement surface, i.e., a shallow-depth sinkhole. The GPR investigation also indicated a wider length and width of the sinkhole than what the hole appeared at the surface. Fig. 6 shows the reported sinkhole in March 2021 with the surface hole detected near a manhole cover, together with the GPR report of the depth and extent of sinkhole.

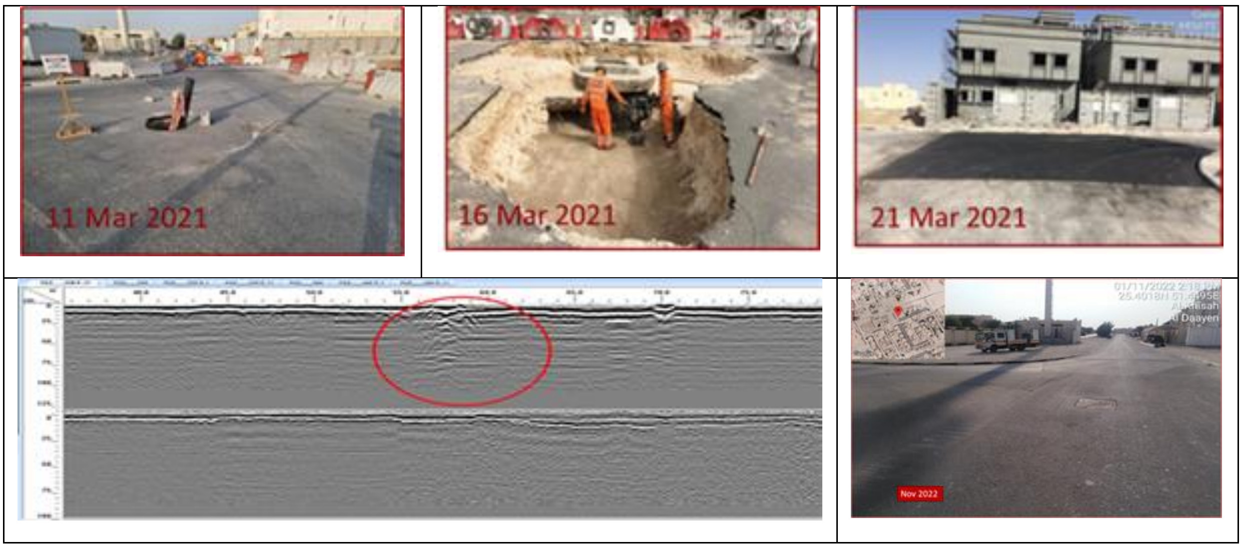

Fig. 6: Different stages of sinkhole evaluation and repair – Case Study 1

Excavation was conducted to remove all weak soil and erodible materials until a firm soil surface was reached. The bottom layer of the excavation was compacted to ensure a dense foundation support. A layer of Foamed Concrete (C5) was poured into the excavation hole and left to harden overnight before reinstating the pavement layers. The site was opened to traffic 24 hours after completion of repair and monitored periodically to assess performance under traffic and environmental loadings. No signs of depression or defects were observed up to the last monitoring date of November 2022, 20 months after repair. The pavement layers were intact with no evidence of surface or subsurface defects. ROMD worked with their Framework Partners on implementing the new guidelines for the evaluation and repair of sinkholes, and several sites are selected for performance monitoring. Excellent performance has been achieved to date from the monitoring sites, which is encouraging for wider implementation. Efficient detection and repair of sinkholes contributes to enhanced road safety and more efficient operations and maintenance of the road network in Qatar.

7 Conclusion

This paper presents the new guidelines developed at Ashghal for the evaluation and repair of sinkholes. Investigating the causes and assessing the dimensions of sinkholes are essential for appropriate repair. Underground investigation is recommended to assess the extent of sinkhole dimension below the pavement surface. The Ashghal guidelines classify sinkholes, based on depth from surface, into shallow, medium, and deep. Excavation and backfill repair is used for shallow and medium sinkholes, whereas deep sinkholes are repaired by compaction grouting.

The Ashghal guidelines for the evaluation and repair of sinkholes have been implemented in late 2020 at various locations. Performance monitoring after repair indicated excellent performance with no observed defects at pavement surface or subsurface. A case study is presented on the successful implementation of Ashghal guidelines for the repair of a shallow sinkhole with excellent performance for up to 20 months in service. Further monitoring is planned for the continuous improvement and enhancement of the safety and efficiency of the road network in Qatar.

The implementation of the new guidelines has been limited to shallow and medium-depth sinkholes, as no deep sinkholes have been identified by Ashghal over the last 2 years. Consideration shall be taken when implementing the repair procedures for deep sinkholes as no performance data is available to date.

References

Ashghal. (2014). Amendment to the Code of Practice and Specification for Road Opening in Highway. Roads Operation and Maintenance Department (ROMD) at the Public Work Authority (Ashghal), Doha, Qatar.

Ashghal. (2020). Sinkhole Repair Guidelines. Roads Operation and Maintenance Department (ROMD) at the Public Work Authority (Ashghal), Doha, Qatar.

BS EN 12350-2. (2019). Testing fresh concrete Slump test. British Standards Institution, London, UK.

Cavelier, C., Sallatt, A. & Heuze, Y. (1970). Geological Description of the Qatar Peninsula (explanation of the 1/100,000 geological maps of Qatar). Bureau de recherches geologiques et minieres, Department of Petroleum Affairs, Government of Qatar. https://pascal-francis.inist.fr/vibad/index.php?action=getRecordDetail&idt=GEODEBRGM71110099

Iqbal, M. A. (2019). Decades of Engineering Experiences with Sinkholes. 8th International Conference on Case Histories in Geotechnical Engineering, Philadelphia, Pennsylvania. Published by the American Society of Civil Engineers. ISBN: 9780784482117, pp. 65-78. DOI:/10.1061/9780784482117.006.

Leblanc, J. (2008). A Fossil Hunting Guide to the Tertiary Formations of Qatar. DOI:10.13140/RG.2.1.3850.0966.

QCS. (2014). Qatar Construction Specification. Ministry of Municipality, Doha, Qatar. https://www.mme.gov.qa/cui/view.dox?id=1441&contentID=3815&siteID=2.

Sadiq A. M. & Nasir S. J. (2002). Middle Pleistocene Karst Evolution in the State of Qatar, Arabian Gulf. *Journal of Cave & Karst Studies*, Vol. 64, No. 2, pp132-139.

Cite as: Al-Ansari J., Hassan K., Kumar K. & Helali K., "Ashghal Guidelines for the Evaluation and Repair of Sinkholes", *The 2nd International Conference on Civil Infrastructure and Construction (CIC 2023)*, Doha, Qatar, 5-8 February 2023, DOI: https://doi.org/10.29117/cic.2023.0072