Modern Civil Engineering (ISSN 2470-4180)
August 2024, Volume 4, No. 2, pp. 80-88
Doi:10.15341/mce(2470-4180)/03-04.04.2024/002
Academic Star Publishing Company, 2024
www.academicstar.us

Evaluation and Repair of Sinkholes in Qatar*

Jamal E M Al-Ansari[1], and Khaled E. Hassan[2]

1. Road Operation & Maintenance Department, Public Works Authority – Ashghal, Doha, Qatar

2. Gannett Fleming, Doha, Qatar

Abstract: Many sinkholes were reported in Qatar over recent years and during the rapid infrastructure development. A sinkhole is a void in the ground caused by natural and/or manmade activities and is mainly associated with carbonate rocks and underground water movement. It occurs suddenly under pavement 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. This paper presents new guidelines for the evaluation and repair of sinkholes, which were developed and implemented by the Roads Operation and Maintenance Department (ROMD) at the Public Works Authority (Ashghal) in Qatar. 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, and the approach adopted for the repair of sinkholes. A case study is presented on repaired sinkhole, and the performance of repair area compared to adjacent pavement after 30 months 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.

Key words: 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 [1]. 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 [2]. 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 drainage pipelines results in washing out the fine particles of soil and void formation [3]. Many shallow depressions of 9736 are reported in Qatar over the last three decades, with the average intensity of 1 per km^2 [4].

This paper summarises the guidelines developed by the Roads Operation and Maintenance Department

* The paper has been published in *Ashghal Guidelines for the Evaluation and Repair of Sinkholes: Proceedings of the International Conference on Civil Infrastructure and Construction (CIC)*, Qatar University Press, pp. 539-546, doi: https://doi.org/10.29117/cic.2023.0072.

Corresponding author: Khaled E. Hassan, Ph.D. in Civil Engineering, research area/interests: pavement and construction materials. E-mail: khassan@ashghal.gov.qa.

(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. A case study on the evaluation and repair of a sinkhole is presented along with performance monitoring after 30 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 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 and detecting changes in subsurface properties.

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

3. Sinkhole Repair Methodology

Fig. 2 summarises the methodology developed by ROMD for the evaluation and repair of sinkholes. The most important factors in the evaluation process are the causes of sinkhole and geometrical dimensions. Identifying and fixing the cause(s) of sinkholes are essential to avoid recurrence. The location of a sinkhole within a local road, highway structure or building may influence the repair method to be followed.

4. Evaluation of Sub-Surface Voids/Sinkholes

4.1 Causes of Sinkholes

Water is the main triggering mechanism for sinkhole formation and development in carbonate rocks. 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,

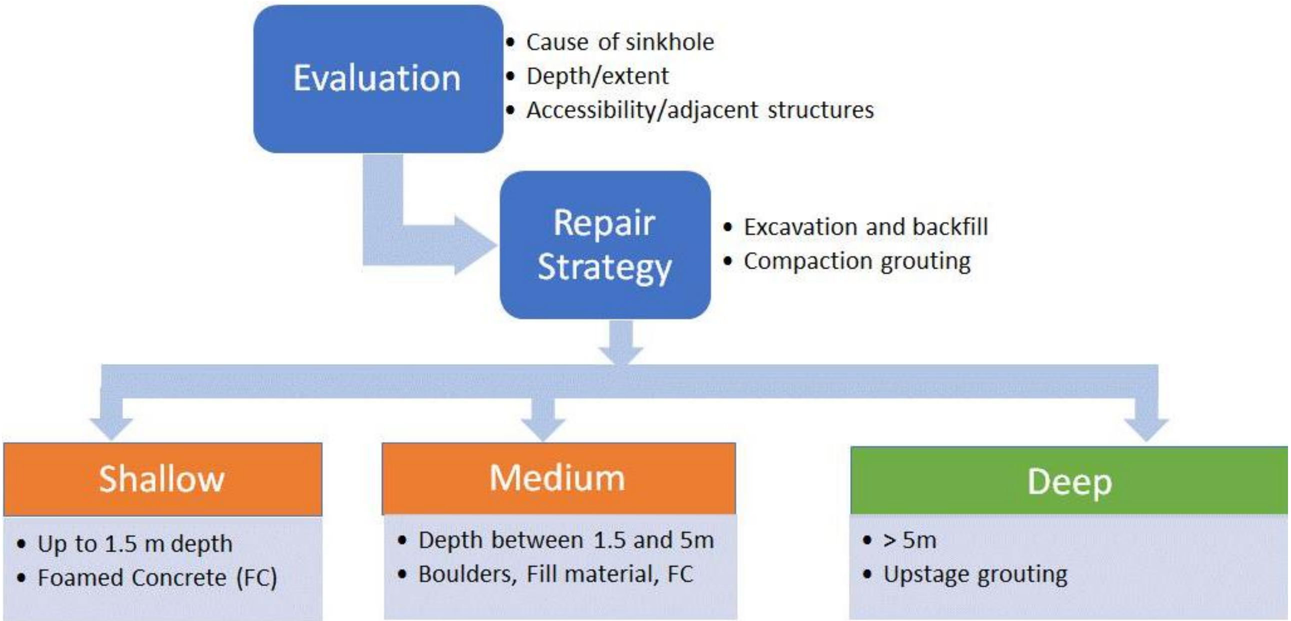

Fig. 2 Sinkhole repair methodology.

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. 3. If water is found in a sinkhole, the source shall be identified and repaired before any remedial works. Water leaks caused by damaged or broken utility pipes should be immediately repaired to stop the leak and washing of unbound materials 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, the ROMD manual classifies sinkholes into shallow, medium and deep as given below:

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

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.

5. Repair Methods

Two techniques are considered in the Ashghal guidelines [5] 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, drainage, 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.

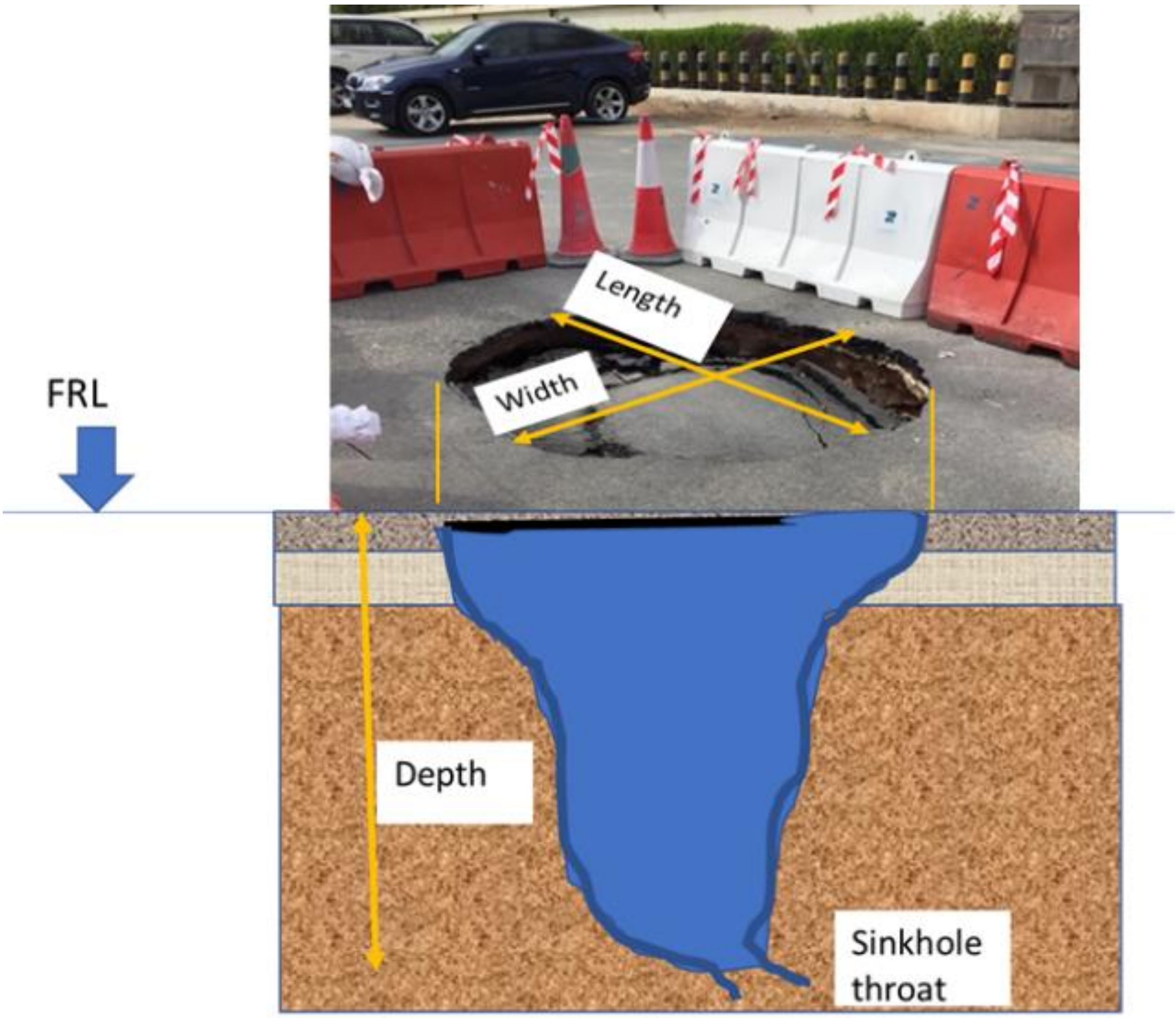

Fig. 3 Measurement of sinkhole dimensions.

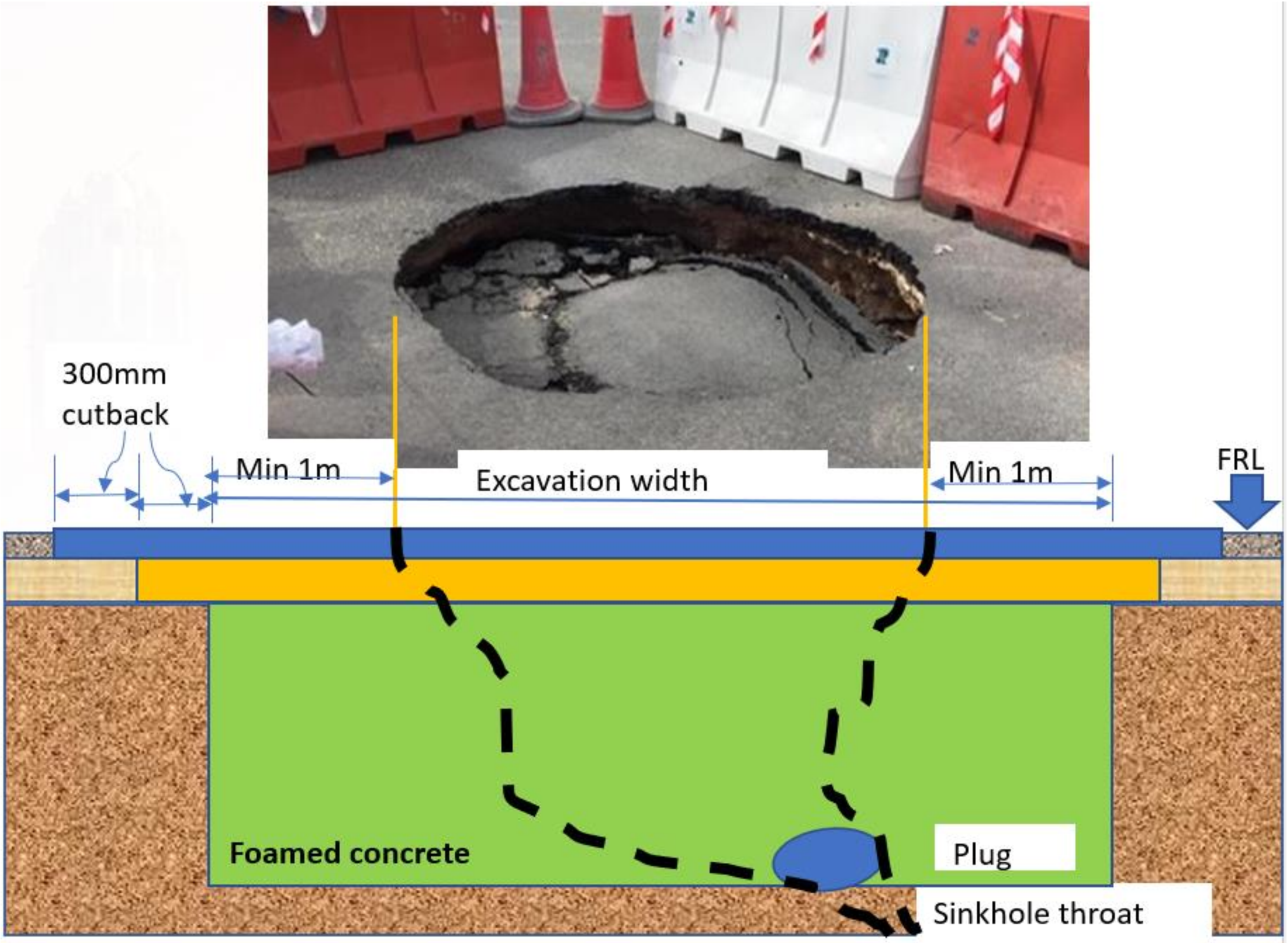

Fig. 4 Schematic diagram of the excavation and backfill repair method.

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 [6].

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 [7]. 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 [6].

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.

Fig. 5 Different stages of sinkhole evaluation and repair — Case Study 1.

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 [8], 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. 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 100 sites investigated over the last three years. Investigations revealed only shallow and medium sinkholes, caused mainly due to leakage of water or sewers.

A case study is presented on the evaluation and repair of a sinkhole, which was reported at a residential area. The GPR investigation was initially performed, and the analysis indicated inconsistent layers of up to 0.8 m below the pavement surface, i.e., a shallow-depth sinkhole. The GPR investigation also indicated a wider area of the sinkhole than what the hole appeared at the surface. Fig. 5 shows the reported sinkhole in March 2021 with the surface hole detected near a manhole cover, together with the full area of sinkhole under the pavement surface. The cavity was due to the washing of poorly compacted materials around a manhole cover for the Surface Ground Water (SGW) pipeline, which was fixed before carrying out the pavement repair.

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 of unbound subbase materials and asphalt 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 January 2024, 30 months after repair. The pavement layers were intact with no evidence of surface or subsurface defects. The 3D-GPR results indicated consistent pavement layers around the manhole covers for the patched area. Cores were also taken from the repaired area, patch on top of foam concrete, and from the adjacent control pavement. Dynamic cone penetrometer (DCP) testing was conducted in the core locations, as per ASTM D6951 [9], and the results are shown in Fig. 6. The results indicate the foam concrete provides stronger foundation support, almost double the CBR value of the pavement foundation with the natural subgrade material.

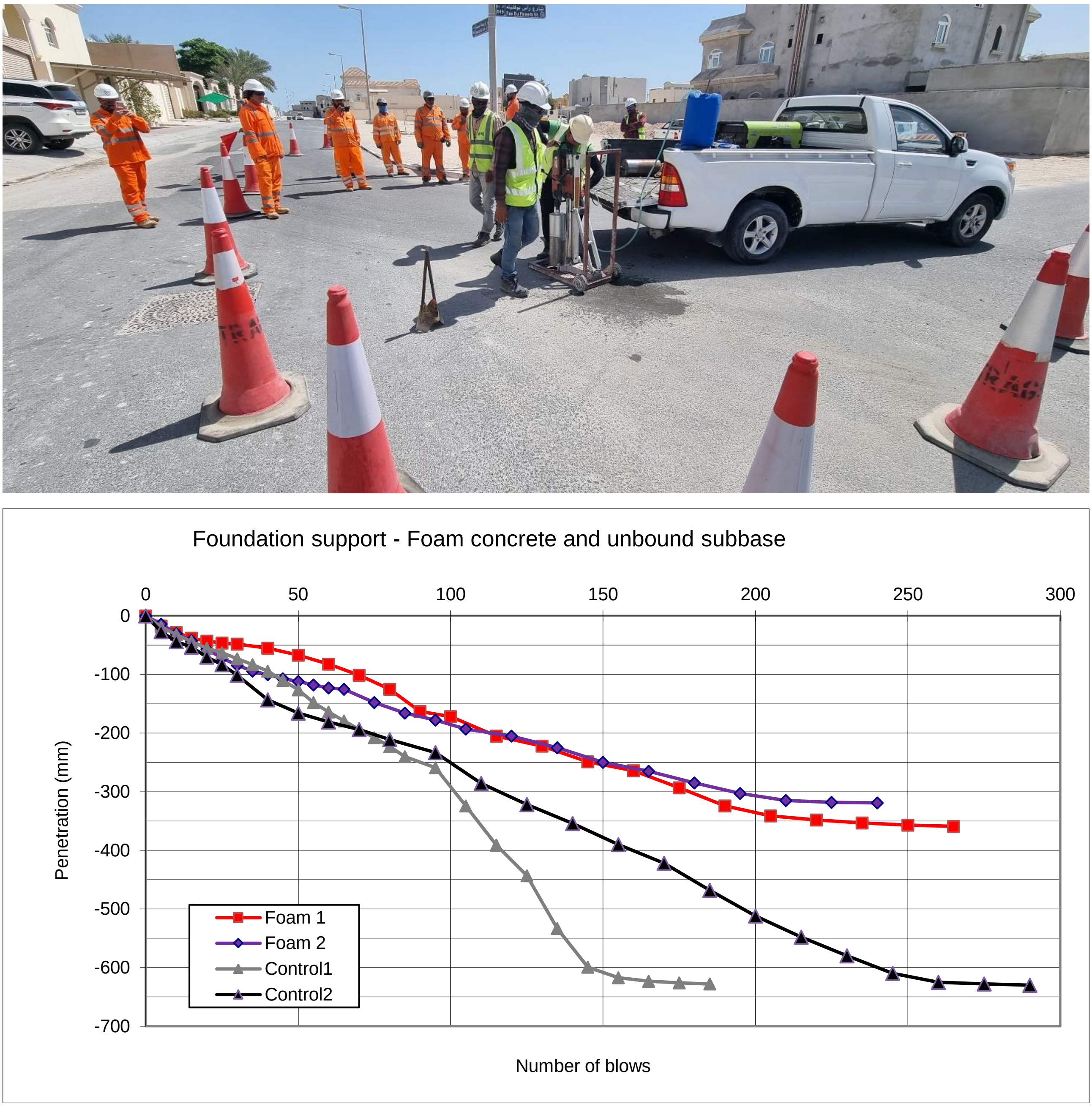

Fig. 6 Monitoring of the repaired site after 30 months in service.

ROMD worked with their Framework Partners on implementing the new guidelines for the evaluation and repair of sinkholes in several sites, and most of them are visually inspected periodically, and few selected for detailed investigation as per this case study. Excellent performance has been achieved to date from the monitoring sites, which is encouraging for wider implementation. Further work is currently conducted by Ashghal on the early detection of sinkholes before they reflect through the pavement surfaces. Efficient detection and repair of sinkholes contributes to enhanced road safety and more efficient operations and maintenance 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 3 years. Consideration shall be taken when implementing the repair procedures for deep sinkholes as no performance data is available to date.

7. Conclusion

This paper presents the new guidelines developed at Ashghal for the evaluation and repair of sinkholes. Identifying causes and assessing 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 is the recommended repair 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 30 months in service. The foam concrete provides strong foundation support to the reinstated pavement layers. Further monitoring is planned for the continuous improvement and enhancement of the safety and efficiency of the road network in Qatar.

References

[1] Cavelier, C., Sallatt, A., and 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, available online at: https://pascal-francis.inist.fr/vibad/index.php?action=getRecordDetail&idt=GEODEBRGM71110099.

[2] Leblanc, J. (2008). A fossil hunting guide to the tertiary formations of Qatar, doi: 10.13140/RG.2.1.3850.0966.

[3] Iqbal, M. A. (2019). Decades of engineering experiences with sinkholes, in: *8th International Conference on Case Histories in Geotechnical Engineering*, Philadelphia, Pennsylvania, pp. 65-78, doi: /10.1061/9780784482117.006.

[4] Sadiq, A. M., and Nasir, S. J. (2002). Middle Pleistocene Karst evolution in the State of Qatar, Arabian Gulf, *Journal of Cave & Karst Studies* 64 (2) 132-139.

[5] Ashghal (2020). Sinkhole repair guidelines: Roads Operation and Maintenance Department (ROMD) at the Public Work Authority (Ashghal), Doha, Qatar.

[6] 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.

[7] QCS (2014). Qatar construction specification, Ministry of Municipality, Doha, Qatar, available online at: https://www.mme.gov.qa/cui/view.dox?id=1441&contentI D=3815&siteID=2.

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

[9] ASTM D6951 (2018). Standard Test Method for Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications. ASTM International, Pennsylvania, USA.