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Mitigation of Sinkholes with Press-in Piles

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INTRODUCTION

A sinkhole is a depression or hole in the ground caused by some form of collapse of the surface layer. Certain areas in the world are highly prone to sudden and catastrophic sinkhole formations where the rock below the ground surface is limestone, carbonate rock, or rock of other types susceptible to dissolution by groundwater. For example, Florida, Texas, Alabama, Missouri, Kentucky, Tennessee, and Pennsylvania are known to have highest number of sinkholes in United States (Kuniansky et al., 2015). Depending on when and where they form, sinkholes can cause major damage to properties and threaten people's lives. They vary in size from 1 to 600m both in diameter and depth and also vary in forms from soil-lined bowls to bedrock-edged chasms. Sinkholes may form gradually or suddenly and are found worldwide (Wikipedia, https://en.wikipedia.org/wiki/Sinkhole). Fig. 1 shows six types of sinkholes based on the causes of their formation in limestone-dominant geological conditions illustrated by Waltham et al. (2005).

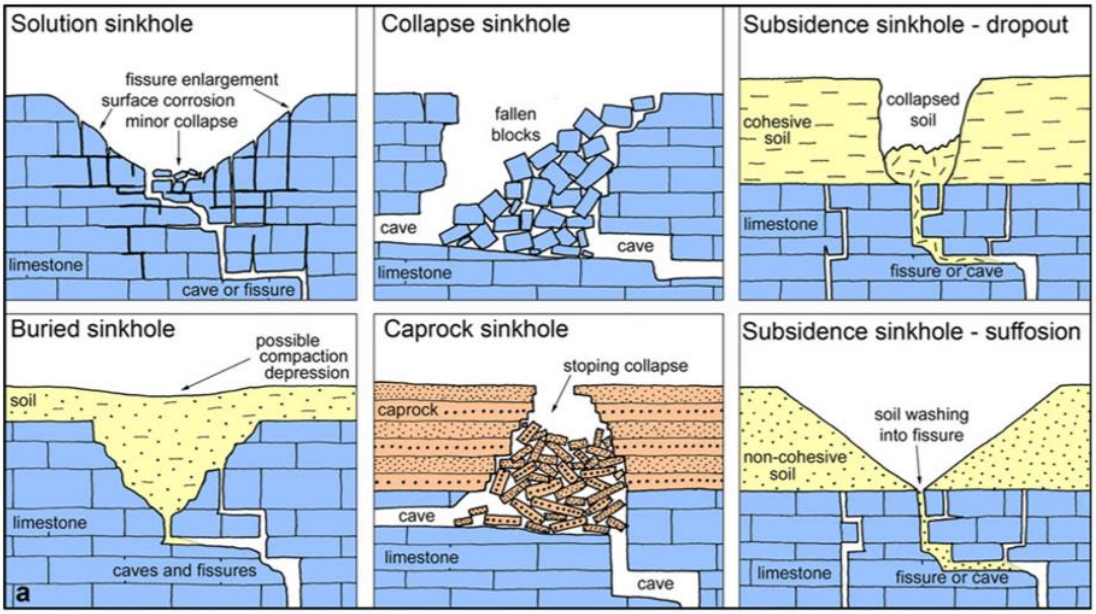

Fig. 1. Six Types of Sinkholes (Waltham et al., 2005)

MITIGATION METHODS

Although grouting is often used to stop sinkholes from further enlarging and/or deepening, it is difficult to predict effectiveness of the work due to the fissured and cavernous nature of the base rock. In addition, it may take a long time to complete grouting with its ever increasing cost. On the other hand, piles can provide a prompt and reliable solution. However, vibration associated with conventional pile driving methods may cause the already sensitive sinkhole to enlarge and put nearby structures more at risk. Among non-conventional piling methods, helical piles may be suited for underpinning existing structures while pressed-in piles are good for slope stabilization, even in the face of a threatening sinkhole; thanks to almost an undiscernible amount of vibration its installation only generates (White et al., 2002). The Press-in Piling Method utilizes a reaction force derived from a few previously installed piles to hydraulically press in the next pile without using vibratory or percussive force to install the pile. In addition, its auger attachment can drill through hard soil including gravel, cobbles, boulders, and soft rock such as limestone concurrently with pile installation (Takuma et al., 2017).

ORLANDO APARTMENT SINKHOLE REMEDIATION PROJECT WITH PRESSED-IN PIPE PILES

A large sinkhole unexpectedly opened up in the middle of an apartment complex during the 2002 summer rainy season in Orlando, Florida in the U.S.A. It increased in size to a 47m x 37m ellipse with a cone shape section of a more than 18m depth, threatening a couple of nearby 2-story apartment buildings. The site access was quite limited with the sinkhole in the middle of the complex. The edge of the sinkhole was only 5m away from one of the buildings (See Fig. 2). Considering that it was at the height of the rainy season of the year, the project needed an expedient and reliable solution, but without disturbing the already vibration sensitive sinkhole and the foundation of the very close apartment buildings. After careful comparison of available remediation methods, constructing an earth retaining wall with pressed-in piles was chosen. Fifty-six 914mm diameter steel pipe piles with interlocks were pressed-in, successfully forming a 61m long solid and self-standing earth retaining wall in 13 days; thus saving the buildings. Fig. 3 shows the site's soil conditions with the depth location of the pipe pile wall. As can be seen, the soil there was generally soft with the SPT values less than 20 except for the weathered limestone layer at 18m below the ground level. See Fig. 4 for the cross section of the project showing the press-in piling machine with a small footprint fitted in the relatively tight zone between the edge of the sinkhole and the apartment building. Piles were hoisted over the apartment building to the piling machine on the other side of the building with a 300-ton capacity truck crane which had sufficient lifting capacity at as much as 39m reach.

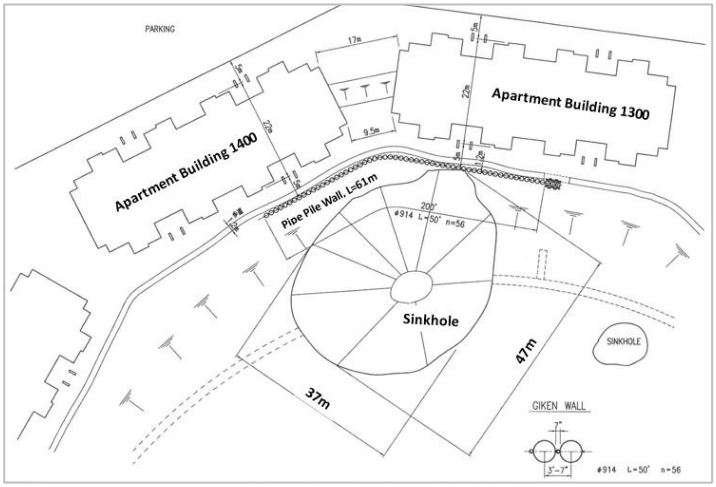

Fig. 2. Plan View of the Sinkhole, Apartment Buildings, and Pipe Pile

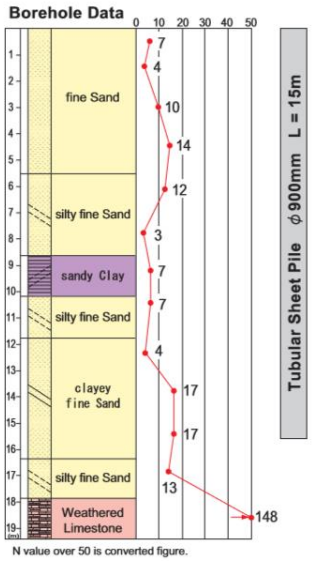

Fig. 3. Boring Data and Pile Location

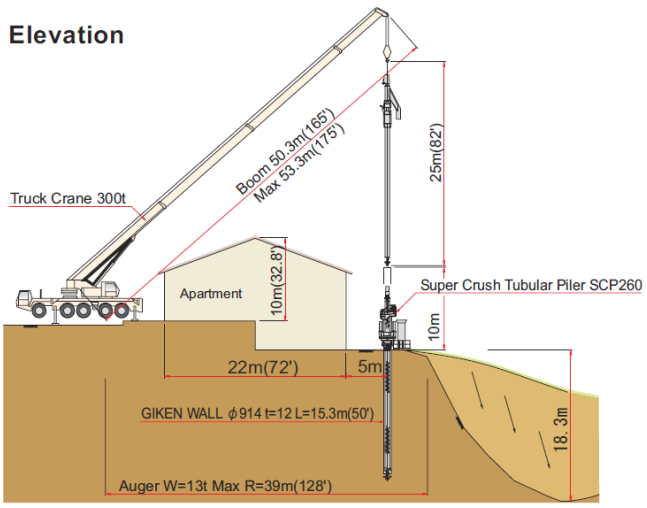

Fig. 4. Cross Section of Sinkhole Remediation Work

Fig. 5 shows pipe pile press-in installation work at the edge of the sinkhole. The gray color tarps were used for temporary slope protection against heavy rainfall. Fig. 6 shows the remediated and landscaped sinkhole with the saved apartment buildings in the background. The pressed-in pipe piles formed a rigid self-standing earth retaining wall without vibration, providing a prompt, safe, and environmentally friendly solution.

Fig. 5. Pipe Pile Being Pressed in at the Edge of Sinkhole

Fig. 6. Remediated and Landscaped Sinkhole

MERIDIAN, MISSISSIPPI CAVE-IN REMEDIATION WITH PRESSED-IN SHEET PILES

12 cars were suddenly swallowed by a 120m-long and 10m-wide cave-in in one November evening in 2015 in Meridian, Mississippi in the U.S.A. The incident occurred in the parking lot of a newly opened family restaurant as shown in Fig. 7. Since the cave-in was on top of the alignment of a newly installed corrugated pipe storm drain, a man-made cause was suspected. Regardless, the restaurant building needed to be immediately protected since it was standing as close as 5m from the edge of the cave-in. Emergency sheet pile installation was planned. However, a conventional installation method with a vibratory hammer would have caused secondary damage due to its vibration-generating nature and proximity to the sensitive cave-in slope and the restaurant building. The press-in piling method was so selected to install 45 pairs of 13.7m long steel sheet piles. The project layout and the section view are as shown in Figs. 8 and 9.

Fig. 7. Cave-in that Swallowed 12 Cars

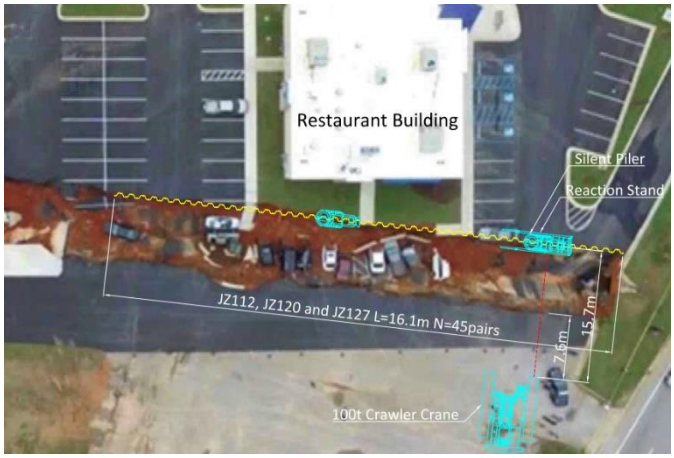

Fig. 8. Plan View of Project

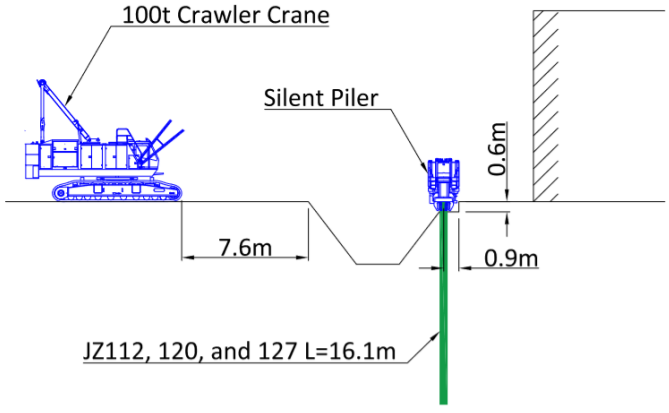

Fig. 9. Cross Section of Project

Fig. 10 shows the soil conditions and sheet pile depth location relative to the soil layers. The top 7 to 8 meters of soil was very soft with a much denser silty sand layer underneath with N values of 20 to 25 all the way down to the design tip elevation of 16m below the ground level. The ground water level was approximately at 5m below the GL near the bottom of the cave-in. The automobiles in the cave-in were removed prior to the remediation work. Due to the emergency nature of the project, sheet piles were continuously installed for 4 days and nights until completion of the 61m long earth retaining wall. See the night time installation in Fig. 11. As a result, further development of the cave-in was prevented and the brand new restaurant building was successfully protected.

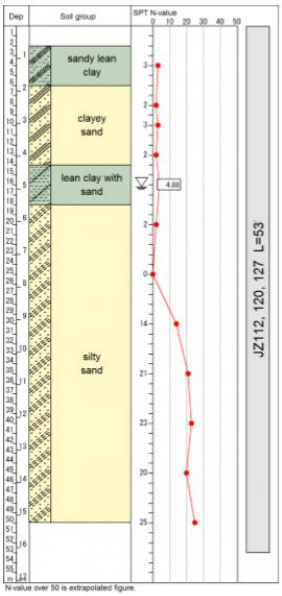

Fig. 10. Soil Conditions and Sheet Pile Location

Fig. 11. Sheet Pile Installation during Night Time

CONCLUSION

Naturally occurring sinkholes as well as man-made cave-ins often threaten existing structures and human lives. They need to be remediated promptly and safely. Pressed-in pile walls can provide solutions for these situations even where the site is physically tight and very close to sensitive structures and delicate sinkhole slopes.

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