Research method of comprehensive geophysical exploration for urban covered karst

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Abstract. During engineering investigation of covered karst in cities via conventional drilling and geophysical exploration techniques, detection accuracy is highly affected by environmental conditions. In this paper, a karst investigation on an important municipal project in Wuhan is taken as example and the clue to study geophysical exploration of municipal covered karst is proposed: engineering investigation - choose of proper geophysical exploration method - geophysical exploration - drilling confirmation. In this clue, previous geotechnical investigation data should be fully used and based on the geological conditions, petro physical parameters and investigation purpose, comparison experiment was carried out among many geophysical exploration methods and then effective geophysical exploration method was selected to reduce unnecessary work load. Moreover, drilling holes were randomly chosen for verification. It proves that the result of karst study done by geophysical exploration method from experiment comparison is relatively in accordance with the actual karst development situation. The result can provide accurate and reliable basis for engineering designs.

1. Introduction
Covered karst is the type of karst that carbonate directly covered with quaternary loose sediment. It is widely spread in China, especially in many medium or large size cities along middle and lower Yangtze River[1]. In recent years, with the development of urbanization in China, the scale of cities is increasing yearly, infrastructural facilities are gradually constructed from ground to underground, incidence of geological hazards like karst collapse and goaf ground subsidence is growing [2]. Karst landforms are widely distributed all over the world (Figure 1). The main karst areas are: the central plateau in France, the Ural Mountain in Russia, the southern part of the Australian continent, Kentucky and Indiana in the United States, Cuba, Jamaica and Northern Vietnam and so on[3].

Monographic karst investigation can provide basic technical data for engineering construction, geological hazard control, and underground resource development and so on. Conventional geotechnical engineering investigation in cities often has bad working conditions as there are many instructions, traffic intersections, various electronic facilities and underground pipes, which may affect layout and construction of prospecting holes to some extent and also considerably influence on geophysical exploration methods as well as exploration accuracy. Common drilling and geophysical exploration methods are difficult to provide accurate results from municipal covered karst study.

Wuhan is of typically covered karst distribution. Underlying carbonate distributes in urban area and karst ground collapse occurred many times [4,5]. At present, many experts and scholars have conducted research on karst problems in Wuhan. These research results are mainly focused on cave detection, karst development law studies, karst control and prediction studies [6-8].
Based on a karst investigation on a lifeline municipal project in Wuhan, the way to study geophysical exploration of municipal covered karst is proposed.

![Distribution of carbonate or carbonate dominated strata. Carbonate outcrops that are small or whose form and outcrop is uncertain. Carbonate outcrop pattern generalised in mountain ranges.](image)

**Figure 1. Major outcrops of the carbonate rocks in the world**

### 2. Field geotechnical engineering situation and geophysical characteristics

#### 2.1. Field geotechnical engineering situation

The shallow karst in Wuhan area is covered or buried karst, and the surface karst phenomena is relatively rare. The development of karst in Wuhan area is mainly controlled by the tectonic position and stratigraphic lithology\[^7,8\]. This lifeline project is located at south bank of Yangtze River (see Figure 2). Quaternary loose sediment of 10~30m thickness distributes on the upper site while silurian-triassic strata on the lower with main lithology of limestone and mudstone. Among them, limestone calcite in carboniferous Huang-Long formation (C\(_2\)h), permianxi-xia formation (P\(_1\)q) and triassic da-ye formation (T\(_1\)d) present highest content so that their relatively strong dissolution ability result in the main karst patterns of solution fracture and cave. Many layers of underground water exist in project site and groundwater unit is complicated.

#### 2.2. geophysical characteristics

The main research object in area is underlying carbonate. In genera situation, high strength and hard integrated rock body is of high elastic wave velocity and electrical resistivity with low absorption of electromagnetic wave. When rock body is destroyed by fracture, small fault, fracture zone, shear zone, weak interlayer, thin layer and karst, its geophysical characteristics will accordingly change by different affecting content and the main geophysical response is: elastic wave velocity and electrical resistivity decreases with absorption of electromagnetic wave increases. This rules are the most primary and basic geological and geophysical features of the study area.
The difference of structure, composition and combination forms between geologic media (rock or soil) and bad rock body (karst or soil cave) determines the difference between various geologic objects, including elastic wave parameters, electrical resistivity, electromagnetic wave parameters and density parameters while among them, elastic wave and electrical resistivity are the most important differences. These geophysical differences provide geophysical premise for the application of geophysical exploration techniques.

Figure 2. Study area and distribution of carbonate belts in Wuhan[7-8]
3. Choose of geophysical exploration method

3.1. The necessity of choose of geophysical exploration methods
Through previous geotechnical investigation [9], karst development regularity in study area was determined for macro issues and geophysical exploration is the main way for karst geological investigation so that it is necessary and feasible to carry out lots of comprehensive geophysical exploration work. Obviously, not every geophysical exploration method is suitable for this study. Furthermore, considering urban working conditions, economy and working period, it is not allowed to use many comprehensive geophysical exploration methods in study area.

The appropriate way is: according to the geological conditions, petrophysical parameters and investigation purpose, typical experiment section is chosen to carry out comprehensive geophysical exploration and then optimal selection is done among many prospecting methods.

3.2. Choose of geophysical exploration method
Optimal selection of geophysical exploration methods in study area is carried out among many methods like high density resistivity method, ultrahigh density resistivity method, transient electromagnetic method, elastic wave CT and electromagnetic wave CT method and the conclusion is as following:

a) For resolution of karst determination, in-hole method is better than ground method as in-hole method can detect study area in multi-angles with higher resolution and less underground interference factors.

b) Elastic wave CT has the best result for in-hole karst investigation and then comes electromagnetic wave CT method while ultrahigh density resistivity method also has good result. In field, elastic wave CT can use electric spark and explosive source but electric spark needs to be coupled with water; electromagnetic wave CT can be used in holes with or without water; in ultrahigh density resistivity method, current electrode also needs to be coupled with water. Considering field working conditions, in the hole section of water with high water level, elastic wave CT should be applied as elastic wave can effectively pass through the drilling profile; while in the hole section of no water with low level water, electromagnetic wave CT should be adapted.

4. The implementation of geophysical inspecting

4.1. The affecting factors of geophysical inspecting implementation
It should be noticed that the urban geophysical environment is different from filed environment so that this karst investigation is also different from that of high velocity and resistivity background. The main disadvantages are:

a) the limitations of urban environment and various strong interferences;

b) Low velocity and resistivity and difficult to get signals from rock and soil interface.

In order to reduce various strong interferences of urban environment, field work should avoid from peak time of activity and data collection may be done on night working time. As limited by urban environment, only electric spark source can be used in elastic wave CT method but electric wave energy is limited and elastic wave signal stimulated by electric spark is difficult to effectively pass through the drilling profile due to the significant difference of media on interface of rock and soil. Because of the strong absorption of electromagnetic wave by overburden layer, upper bedrock as well as some kinds of rock bodies (e.g. high contents of soil), electromagnetic wave CT may not able to receive complete effective signals. These incomplete data has significant impact on CT imaging effect.

4.2. The work layout of geophysical inspecting implementation
Based on previous conclusion of investigation result and comparison of geophysical exploration methods, the work layout of geophysical exploration in this karst study take these principles:

a) Based on geological conditions revealed by previous geotechnical investigation (feasible study investigation and preliminary investigation), the karst study area is primarily determined;
b) According to the project features (this project is urban underground tunnel project), all the drilling holes must be arranged more than 3m away from tunnel structure line;

c) It should be carried out at the same time with detailed geotechnical investigation or a little later in order to fully use geotechnical investigation drilling holes;

d) Geophysical exploration methods proposed by preliminary prospecting comparison should be selected in preference, that is in-hole elastic wave CT or electromagnetic CT.

According to previous principles, schematic diagram of geophysical exploration work layout in karst study is shown in Figure 3. Firstly, based on preliminary investigation data (CK01 in Figure 3), the karst development area (underlying limestone) was primarily determined and drilling holes for karst study were arranged outside the tunnel project (K01, K02 in Figure 3); Elastic wave CT or electromagnetic CT were tested in holes using karst study drilling holes and detailed investigation drilling holes (XK01 in Figure 3); Considering the long distance between K01 and XK01 which may result in bad testing data, another testing hole K03 was set between two holes and two lines. If there was a karst cave revealed by preliminary investigation drilling holes, then one more drilling hole would be added to the side of that hole in order to infill exploration. After the geophysical exploration work finished, CT profiles were randomly chosen for setting verification drilling holes. In comparison to common way that monographic karst study is carried out after all geophysical exploration work finished, the workload of this monographic karst study is 20%-50% less than those of common methods so that it can effectively save investment with guaranteed good investigation accuracy.

![Figure 3. Schematic diagram of geophysical exploration work layout in karst study](image)

During the implement process, all data were analyzed on time and method and exploration layout were modified according to practical situation.

5. Drilling verification

After the explanation of geophysical exploration data, based on karst cave with revealed drilling holes, compliance verification and calibration were carried out on geophysical anomaly, profiles with geophysical anomaly were randomly chosen and drills were arranged for verification.
Figure 4. Drilling verification profile by electromagnetic wave CT

As shown in Figure 4, electromagnetic CT was carried out in drilling boreholes K01 and K02. In this profile, the upper part of electromagnetic CT absorb diagram is relatively strong while the lower part is relatively weak. Considerably complete boundary is on the height of 5 - 7m and anomaly exists on two places M1, M2 (karst caves with revealed drilling holes). Anomaly M1 is located from left 3m to right 15m of K01 with distributing height 6 - 17m. Verification drilling borehole YK1 was arranged and a karst cave was found at the height of 13.0 - 13.5m.

Drilling holes were arranged for verification based on random chosen CT profiles, which effectively prove the accuracy of this karst study.

6. Conclusion

During the study on geophysical exploration of municipal covered karst with the clue of engineering investigation - choose of proper geophysical exploration method - geophysical exploration - drilling confirmation, previous geotechnical investigation data can be fully used and based on geological conditions, physical conditions and target geotechnical problems, effective geophysical exploration method is chosen and confirmed by certain amount of drilling, the result can provide accurate and reliable basis for engineering designs.

The experiments in this monographic karst study are not common in other engineering investigations and the achievement data are accurate. The workload of this study is 20%-50% less than that of common methods so that it can effectively save investment with guaranteed good investigation accuracy.

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