New Technology of Precise Geophysical Exploration for Geotechnical Engineering

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Abstract: It make traditional geophysical exploration method to adapt new requirement such as resolution of meter-level, error of depth $\leq 5\%$ and marking border of target and geological interface that a lot of construction of geotechnical projects and preventing geological disaster projects. Due to hard research of scientific workers for twenty years, several methods and technology can meet the requirement and some methods would get breakthrough and some also get some progress. About 10 methods will be introduced in this paper such as Landsonar, Differential electric sounding (DES), C-1 and so on, meanwhile, development direction of some methods will be introduced such as geological radar.

Keywords: precise exploration, Landsonar, Differential electric sounding, geological radar, underwater acoustic exploration, resistivity imaging, Methods between two boreholes

0 Summary
In 21 century, a lot of construction of geotechnical engineering in China such as subway, high speed railway, tunnel, bridge and other huge buildings are going on, but traditional geophysical exploration method cannot meet the new requirement of those new construction. For example, result of geophysics exploration is not precise enough for construction of subway which also cannot just rely on drilling data; there may be a accident when one karst cave with only 1m diameter is met in location of pier in construction; it is a very difficult problems exploring and locating single middle or small karst caves in karst developed area which is about 30\% of land area of China. All the requirement push geophysics exploration method go ahead and resolution of 1m even 0.5m, maximum error of location of 5\% and interpreting the horizontal orientation and boundary of geological structure were the new target. The methods below some of which are already reach the target and some of which are have big progress will be introduced. It already is the world leading level shallow exploration technology of China in early 1990s, and can play a important role in preliminary survey and design stage but have a long way to go in location survey, construction design and construction stage.

In recent 20 years, it meets a lot of problems in most of foundation construction and raises higher claim to exploration technology, but traditional method and technology cannot keep pace with construction. Traditional geophysical exploration result cannot meet requirement of subway construction and only drilling exploration is not enough; it is a important dangerous the karst caves or soil caves of 1m diameter, which can lead to cave-in accident during piles construction; it is about 30\% of land area the karst area, and it is a problem to survey single middle and small karst caves with geophysical exploration methods in whole world; landslide is usual geological disaster of which sliding surface is also a problem to explorer. More foundation construction raise higher requirement to geophysical exploration such as more
precise, meter even decimeter-level resolution, depth error<5% and marking border of target and geological interface. And most projects are in busy city, so it is the problem must be solved underground current, electromagnetic and vibration interference, which need many geophysical exploration methods to get breakthrough and to make precise complex geophysical exploration come true. It not only need to research the method itself and also to research the requirement of engineering construction and lead the development way. All the requirement push geophysics exploration method go ahead and several methods and technology already can meet the requirement and some methods would get breakthrough in 3-5years and some also get some progress.

1 Successful methods

1.1 Introduce

1.1.1 Landsonar

(1) Landsonar, the abbreviation of Elastic reflection wave recording of continuous profiling with very short source-geophone distance and very wide band frequency, is one of geophysical exploration technology of independent research and development by Chinese scientific and technical worker.

Feature: ①An near zero-offset(0.5-1m) and single-channel was introduced; ②New idea and technology of hammer-source with which it can excite wave of 10-15000Hz, and with unique geophone and instrument, it can receive reflected wave of 10-4000Hz, any frequency aren't attenuated.

Advantage: ①It can avoid the interference of direct wave, surface wave, refracted wave and converted wave and have clear reflection of karst caves; ②The topographic effect was very limited and can work in small space; ③The received wave was bordering normal line incident and reflection to the reflecting surfaces, ④The power of reflected wave of near zero source-geophone method is stronger, so it can get reflected wave information of 400m deep and easy to distinct the events of karst caves and avoid converted wave.⑤It is convenience to get effective frequency information by frequency filtering from wide frequency band wave. It is easy to avoid the vibration interference of vehicles, walkers, and machine by abandoning frequency below 500Hz, and surveying the filling(soil, air, water, sand or sand and water) of karst caves by using high frequency reflected wave.⑥It can get high resolution with high frequency and high resolution instrument, even can get the clear reflected wave events of fault surface.

1.1.2 Differential electric sounding

The differential electric sounding (DES) is one of the resistivity methods and a good coordinated method. It adopts the acquisition configuration of the fixed AB electrodes and the MN of moving equidistantly electrodes perpendicular to AB. Its resolution and precision is one electrodes distance. This method get high resolution and precision and will be very slightly affected by the topographic fluctuation between A and B. The resultant resistivity curves are very similar to electric logging curves and easy to interpret. it can distinguish the geophysical property of filing in karst caves with difference of relative apparent resistivity of filing.
1.1.3 C-1 resistivity instrument

The instrument of DES C-1 (developed by He Jishan, Zhong Shihang, Bao Guangshu in 1980s) supply power to electrodes A B with alternating current of some frequency, can avoid the interference of stray electricity and can work when earth resistance of electrodes MN reach even 700kΩ, so the electrodes can work in busy city area and on the concrete pavement.
1.2 Instance

It have completed more than 160 projects of geophysical exploration the combination of those three method and technology since 20 years ago.

[Instance 1] Surveying of the planning stage of Jinan subway and feature of spring area

Surveying area located in busy district with strong interference in Jinan. It is required surveying depth and thickness of the Quaternary period layers (gravelly soil, sandy clay), the limestone layer, the dolostone layer, the diorite and the gabbro between depth of 2-150m inside the 20km² area, and it was determined for classifying karst less developed area, karst developed area, karst more developed area and karst most developed area were marked according to number of karst caves and analysing the relationship between karst and famous springs. It was expressed by geological section that qualitative and quantitative data base on crossed 18 surveying lines of Landsonar which is coincident with 21 drilling data.

[Instance 2] Surveying karst cave in Guangzhou New Baiyun International Airport

Airport is in area of karst developed and there is busy for Grouting filling. It is done surveying several karst caves and filling detailedly with Landsonar and DES methods under the interference. It can be seen in Fig.3, Fig.4 that karst cave is very complex from exploration data which was be verified by three drilling data.
Fig. 5 Landsonar time section and geological section of JCR4 line
(A,B,C,D,E,F,G -- karst cave or cave in soil  H - bedrock surface)

[Instance 3] The karst exploration in land collapse zone in ZeLin, EZhou, Hubei
Two land collapse (T1, T2), one of which is next to Wujiu railway and the other is in bottom of one multi-story residential building, are disappeared. About two methods and C-1 were used to survey karst caves, soil caves, bedrock surface and main faults. It was predicted that 800 karst caves and 167 soil caves of which projection diameter is bigger than 1m in 0-60m deep. It was used to express the spatial position of result data that 60 geological section and 6 plane graphs include 0-20m, 20-30m, 30-40m, 40-50m and 50-60m deep except data list. Result was verified by static sounding in 7 points.
Fig. 6 One Landsonar time section

Fig. 7 One geological section of surveying line III

[Instance 5] Surveying Karst caves under tunnel bottom on 14 tunnels in Gui-Guang high-speed railway
There are many parts pass through limestone or dolostone zone in Gui-Guang high-speed railway and phenomenon of floor heave appeared at the debugging stage. Author’s company surveyed 14 tunnel among 179km railway and total extended meter was 23km. The main purpose was to locate the karst caves which diameter are bigger than 1m and 13m depth under tunnel foundation bed bottom. The total karst caves predicted diameter bigger than 1m were 4491 between 0-13m depth, and there were 402 karst caves of which diameter bigger than 2m and 20 karst caves of which diameter bigger than 3m. On the basis of predicted result, all the tunnels was classified to three levels(A, B, C) and in the same tunnel different parts were marked base on the amount of caves. And it was used to Excel express the predicted result that geological section, plane graphs and 3D spatial distributions. There were 8 boreholes used to test and verify the data of geophysical prospecting and 7 boreholes among them accorded well.

Fig.8 3D spatial distributions of karst caves

[Instance 5] Surveying sliding surface of Donghekou landslide
Donghekou landslide comprise rock, silt and sand, 1.5km long, formed during Wenchuan big earthquake. It were used to surveying the sliding surface the complex of Landsonar and DES, which cooperate with Chengdu University of Technology. landsonar data surveying several possible sliding surface and DES data surveying low resistance layer which means high water content which is a feature of sliding surface in according location.

[Instance 6] Surveying cause of water inflow and mud leakage in Lingjiao Tunnel
The Lingjiao tunnel of Cengxi-Shuiwen highway in Guangxi is forming by two parallel tunnels. There gushed out forty thousands cubic metres of mud on working face at YK18+215 in right tunnel, which made a collapse pit 1000-2000 square metres) appear on mountaintop at FK18+200 150m in the front of working face of left tunnel. In order to found the cause of water inflow and mud leakage, researched the solution and cavities after mud leakage, Landsonar had been used forward working face of tunnel and to survey on ground, and DES method had been used to assist Landsonar. There were more than ten middle and small faults of which spacing only 3-5m between 110-160m in front of working face from geological data of left tunnel, that was corresponding with the ground exploration data at K18+215+170. It was predicted a new undiscovered fault zone. Also several cavities were indicated, the width of the biggest cavities reached 5-6m and height reached nearly 20m, which was saw after excavation.

Fig.9 Horizontal and vertical geological section of tunnel geological prediction
Fig. 10 The big cavities during tunnel excavation and surveying in Landsonar time section

[Instance 7] geological prediction of tunnel construction
Landsonar method, can surveying single karst caves diameter is bigger than 0.5m and get its size and spatial position, and surveying big, middle, small faults and get its strike, dip, dip angle and error is <5%, make precise tunnel geological prediction come true and already completed a lot of geological prediction of 100 tunnels

Fig. 11 3D show of faults of one tunnel geological prediction
Methods and technology would got breakthrough

2.1 Geological radar
It is called geological radar that the theory of radar is applied in surveying underground geological information, which can adapt to various site, can be applied in busy city because of strong anti-interference of electromagnetism and has high resolution, but cannot get geological information of deep enough, surveying 10m deep on soil surface and 20m deep on rock surface, for example. If big progress would make survey depth of geological radar reach 40m on any surface, it can use in more fields.

The common formula of wave velocity of geological radar is

\[ V = \frac{C_0}{\sqrt{\varepsilon}} \]  

(1)

Which is the formula of air radar and not exact for geological radar. The below is the exact formula of wave velocity of geological radar derived from wave equal of electromagnetic field

\[ V = \frac{\omega}{\beta} = \frac{1}{\sqrt{\frac{\mu \sigma}{\omega \varepsilon}}} \sqrt{\frac{2}{\mu \sigma}} \frac{\sigma + 1}{\sigma - 1} + 1 \]  

(2)

Conductivity of air nearly is zero, so wave velocity can simplify to compute with air radar formula, but conductivity of soil, sandstone, shale, concrete are not zero, wave velocity must be got by actual measurement, which is a problem except some concrete surface need to be broken through. Meanwhile, surveying underground water and multiple reflection also are problem of geological radar.

2.2 KS marine acoustic instrument
At present, there are two methods usually being used to surveying geological information of floor of river, lake or shallow sea: Sub-bottom profiler and Marine seismic reflection method.
Marine Seismic reflection method: It can survey rock layer but its survey line must is straight line, which will make route closed.
Sub-bottom profiler: It can survey silt layer, sand layer and can work along the survey line of curve or polyline.
KS marine acoustics prospecting instrument which absorbs advantages of above two methods can predict thickness and scale of silt layer, sand layer, cobble layer and riprap layer, and can predict broken area, karst caves, faults below water floor of 80 deep, can work along the survey line of curve or polyline. It only work in Changjiang and Huaihe need more progress to work on shallow sea.

2.3 Nature electromagnetic radiation sounding
It use the vertical component of induced current on conducting layer to surveying rock layer, when nature electromagnetic of perpendicular to the ground pass through stratum of different resistivity. It have a good effect in contrast to drilling data in test of 100m deep, 300m deep and 1500m deep. This method need more research and test.

3 methods using boreholes

3.1 Single borehole radar
The key problem of this method is confirm direction, which block it applied in more projects.

3.2 Resistivity imaging between two borehole
It is a kind of apparent resistivity equivalent imaging method used a lot of electrodes of two
boreholes to survey potential difference. It cannot be bigger than 15m the maximum distance between two boreholes. It can predict the scale of karst but predicting single karst caves is not reasonable. Prediction result of below section refer to the corresponding Landsonar data which reflects the importance of complex geophysical exploration. It is not enough only by data of two boreholes a complete imaging method, which need add additional ground survey line at least. So this method still have a long way to go: ①adding ground survey line ② increasing maximum distance between two boreholes to 40m.

3.3 Elastic wave imaging between two borehole
This method, have the same problem with resistivity imaging method, can predict karst developed area but cannot predict single karst caves of 0.5-3m diameter. It only have restraint of two direction, but don’t have ground direction and bottom direction, which make prediction result not exact. Progress way: ①Increasing elastic wave frequency to 2000-4000Hz ②Adding survey line of ground ③Increasing maximum distance between boreholes to 40m.

3. Radio wave penetration method between four borehole
This is a method of 1970s which have a good effect at predicting karst developed area, but its frequency is not high enough and its emitting-radio have leakage phenomenon and it only use in deeper borehole, which need to be research to adapt to shallow borehole about 30m deep.

4 Conclusion
(1) It make traditional geophysical exploration method to get more progress and step into precise geophysical exploration the requirement of a lot of construction of geotechnical projects and preventing geological disaster projects.
(2) These methods Landsonar, DES, C-1 instrument are successful methods which need to be applied in more projects.
These methods, geological radar, Nature electromagnetic radiation sounding, KS marine acoustic instrument need to be improved and get breakthrough.

It has a good prospect but imagine methods with boreholes still have a way to go.

Improving more methods into precise geophysical exploration stage and emphasizing complex geophysical exploration.

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