WATERWAY DREDGING WORKS IN CHINA-GEOLOGICAL EXPLORATION METHODS AND TECHNICAL REQUIREMENTS OF INVESTIGATION

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ABSTRACT

Simple geological exploration, geophysical exploration, drilling and geotechnical sampling methods as well as the technical requirements of investigation for waterway dredging works in China are briefly described in this paper. Simple geological methods include punch exploration and simple auger sampler exploration.

Geophysical methods cover the following: (1) electrical surveying (including the resistivity method, multi-electrode resistivity imaging, and imaging system of EH4 electrical conductivity); (2) seismic surveying (including mainly compression wave reflection methods) and (3) acoustic surveying (subbottom profiler exploration). Drilling is the main means of geological exploration for dredging works and involves the following: (1) drilling methods including mechanical rotary drilling and percussive-rotary drilling commonly used in the geological exploration of dredging works; (2) drilling operations, including open hole, overburden layer drilling , bedrock drilling , and slurry drilling; (3) drilling on water including drill site type , drilling barge location and drilling in pebble beds and (4) rock and soil sampling including the blowing-in method , pressing-in method and rotary method.

Technical requirements of investigation are described and include: (1) the requirements that the geologic investigation work for dredging works should satisfy; (2) the requirements that the layout of exploration lines and points should meet and (3) the requirements that one should meet while undertaking sub bottom profiler exploration.

Keywords China; waterway dredging works; geological exploration methods; technical requirements of investigation

INTRODUCTION

For the sake of improving the working quality and technical level of design and construction for dredging works and being adaptable to the needs of development and project management in dredging technology, the waterway dredging industry in China has always paid attention to geotechnical investigation for the dredging work. The process of investigation will depend on the purpose of the project, the property and scale of the project as well as the complexity of site, geological and operational conditions and economic factors. Differing exploration methods have been adopted in order to develop relevant technical requirements and make positive contributions to promote advances in geological exploration technology for waterway dredging works and to normalize the management for geotechnical investigation work associated with waterway dredging works.

EXPLORATION METHODS

In the design and construction of waterway dredging works, if one wants to know about the state of a shallow layer in a riverbed, simple geological exploration methods can be generally adopted. However, if one wants to find out the state of the deeper layers it is necessary to use geophysical exploration and drilling methods.

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Simple Geological Exploration

Punch Eexploration

Punch exploration is also called zone penetration exploration. A drill steel is driven downward into the soil to determine the thickness of unconsolidated overburden or the buried depth of bedrock. Generally, punch exploration can be used to ascertain the thickness of overlying sediment layers at the top surface of bedrock or boulders and can reach to a depth of about 10m. However, this method cannot be used to take samples of the material.

Simple AugerSampler Exploration

Simple auger sampler exploration is a method commonly used in geological exploration. It has the advantage of using only a light tool, with a small volume, convenient operation, drilling is relatively quick and is not labor intense. Its disadvantages are that with this method, undisturbed soil samples cannot be taken and there are difficulties when used in dense or solid formations.

Simple drilling tools commonly used for this method include the small twisted auger and the Luoyang shovel. The small twisted auger has a drilling structure that includes a twisted bit and drill rod and rotary drilling exploration is carried out by artificially applying pressure. This method is applicable when dealing with clayey soil and sandy loam soil formations and can take disturbed soil samples. Drilling depth is generally from 6 to 10 m. The Luoyang shovel makes use of shovel's gravity (see Figure 1) in order to cut into the soil. It drills a round hole with a small diameter to a greater depth and can take disturbed soil samples.

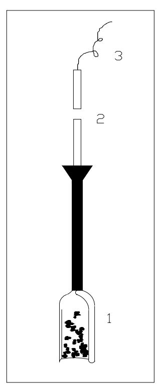

Figure 1. Luoyang shovel (1-shovel head, 2-wood pole, 3-rope).

Geophysical Exploration

Task and Function of Geophysical Exploration

When making geological investigations for waterway dredging work in order to ascertain the characteristics of rock and soil, the thickness of overburden, the undulation and buried depth of bedrock plane, the attitude and magnitude of tectonic features as well as the hydro geological conditions in these**,** makes it is often necessary for this type of exploration to be carried out in conjunction with appropriate drilling methods.

Method and Technology of Geophysical Exploration

Geophysical methods include electrical surveying, seismic surveying, acoustic surveying, precision magnetic surveying, electrical borehole logging and gravity surveying. Geophysical exploration has non-unique interpretations of results due to the fact that it is frequently affected by various disturbed factors such as topography, geographical objects and surroundings. The geophysical exploration method selected and adopted should be made in light of the scale and properties of a project, physical characteristics, distribution and reserve of rock and soil. The amount of work is also determined comprehensively in combination with the requirements for design and construction.

(1)Electrical surveying

(a) Electrical surveying mainly adopts the resistivity method, which can be further divided into electric sounding and electric profiling methods according to the different devices and electrode distance.

Electric sounding methods are mainly used to explore the change in electrical properties of a rock formation and lithology in a vertical direction and to solve some depth-dependent geological problems, e.g. underground water table in bedrock, formation layers, and the buried depth of a weathered layer. Electric profiling methods are used to explore the change in electric properties of a rock formation and lithology in a horizontal direction and solve some geological problems relating to its plane position, e.g. the contact interface position of faults and rock layers.

(b) Multi-electrode resistivity imaging is an efficient new type of electric exploration method. It combines the electric profiling method with the electric sounding method and can acquire a higher level of efficiency and accuracy. When testing, a Wenner four-pole device is adopted for high density electrical surveying in order to explore the fracture behavior of the earth electricity around a borehole. Multi-electrode resistivity imaging method gathers a vast quantity of information, more than hundred times that from the common resistivity method. It is characterized by high exploration accuracy, fast speed and a high degree of automation. It is mainly used to explore geological structures, investigate faults, ascertain the spatial distribution of the karst position and underground goaf (mine waste) etc. It can also monitor landslides, find the ground water levels as well as analyzing the formation.

(c) The imaging system of EH4 electric conductivity is the extension and development of electric exploration. Since it has a specific working frequency and is equipped with a self-contained high-frequency signal transmitter, the system can easily explore the information on underground resistivity within the range of several meters to kilometers underground. Since testing instruments for the imaging system of EH4 electric conductivity have a high sensitivity and can remove various outside disturbances, it can quickly complete a single point test task.

(2) Seismic surveying

Seismic surveying uses the principle that the elastic wave excited by an artificial source travels underground. It explores the rock properties and geological structure, enables one to know about the relief condition of bedrock surface, integrity of the bedrock and the division between the weathered zone and the position of a shattered fault zone. Also, it can explore a dense fissure zone and veins in the rock, and takes advantage of the penetrated wave to measure the profile of the wave velocity thereby classifying the engineering geology of the rock masses and estimating their dynamic, physical and mechanical parameters. Methods of exciting the elastic waves usually include systems using striking or explosions. Seismic surveying can be further divided into reflection and refraction methods according to the propagation mode of the electric wave.

As for waterway dredging works, the compression wave reflection method is usually adopted. Namely the multi-stacked technique using a number of common-reflection points and with stacked ranges numbering from 4 to 6. When it is used, the receiving cable is hung at the tail of a working vessel and lowered to a given depth underwater It keeps a certain distance from the cable receiver in order to test the continuous travel of the vessel, excite and record on a time elapsed basis. Through field tests, parameters are usually adopted which are as follows: 1000ms for record length, 25Hz to 250Hz for the filter range, 1.5m to 2m for cable's underwater depth, 1m/s for sampling rate, 12m for off-range distance and 10s for excitation interval.

When one is doing seismic surveying, the geological profile is interpreted according to the seismic time cross-section obtained with on-site testing in combination with the regional geology and existing borehole data in an integrated manner. Since geophysical exploration has non-unique interpretations, an integrated geophysical method should be used if necessary so as to verify the testing results compared to each other in order to make the interpretation of the geological profile more accurate and reliable.

(3) Acoustic surveying

Acoustic surveying is also called sub bottom profiler exploration. It is a method used to specifically explore the topographical features of river bottoms and the distribution pattern of underwater formations.

Acoustic surveying is mainly used to solve a loose formation in which there are no cobbles and gravels or sparsely-distributed cobbles and gravels underwater.

Instrument and equipment used for acoustic surveying is operated on a motor-driven vessel. The motor-driven vessel used has generally a load capacity of 10t to 20t with small machinery noise. When acoustic surveying is carried out in a river channel or reservoir, cross-section piles should be installed symmetrically on both banks. When exploring, the motor-driven vessel travels in a straight line in a fixed direction. A point is measured at intervals of 50m, and the spacing between lines ranges from 200m to 300m. The vessel location can be located by a GPS positioning system or any other method. When water level fluctuates greatly (difference in elevation is more than 0.3m), the water level should be measured if necessary, and a "variation curve of the water surface elevation with time" at that day should be plotted.

Drilling

Drilling is one of main means of geological exploration for waterway dredging works, it can identify and describe the soil layer, take the samples from rock and soil, carry out a standard penetration test or velocity of rock and soil testing etc.

Selection and Installation of Drilling Rig

A rig should be selected in light of the drilling depth, borehole size, angle of dip, geological conditions, drilling methods etc. Drilling can be divided into percussive drilling, rotary drilling, percussive-rotary drilling and vibra-drilling on the basis of methods where rocks need to be crushed while drilling. Mechanical rotary drilling and percussive-rotary drilling are commonly used in geological exploration for dredging works.

(1) Rotary drilling

Rotary drilling means that a rotary motion of a drilling tool is utilized to make the cutting edge or abrasive material of the drill bit, cut or abrade the rock. This method can be further divided into bottom full-face drilling and the bottom ring drilling (core drilling). Core drilling is extensively used in engineering geological exploration, which can take undisturbed soil samples and relatively complete core samples. There are a variety of drill bits and abrasive material available in mechanical rotary drilling which can be adapted to various formations with differing degrees of hardness. Core drilling is further divided into tungsten-carbide and diamond drilling according to the drilling ability of the equipment required for the various rocks. The mechanical rotary drilling device is shown in Figure 2.

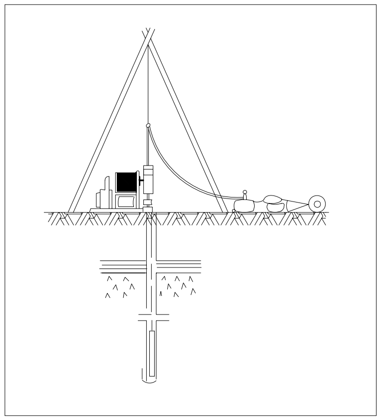

Figure 2. Mechanical rotary drilling device.

(2) Percussive-rotary drilling

Percussive-rotary drilling is also called integrated drilling with the drilling performed under percussion and rotary actions. It has a high drilling efficiency, is applicable to different ground formations, and can take core samples, making it widely used in geological exploration for engineering works. At present the drilling methods applied includes pneumatically-actuated and hydro dynamically operated ones. Percussive-rotary drilling with reverse circulation continuous sampling (or continuous sampling drilling with double-wall drill pipe and DTH hammer) has shown great promise in its application for exploring any rock formation.

Drilling Operation

(1) Opening hole

As for the opening hole of overburden layer, the method where the casing with a thick wall is driven into the layer is generally adopted; while it is driven, its angle and direction should be adjusted at any time. If the opening hole in bedrock is conducted underwater, it is also necessary to drive the casing with a thick wall to a given depth.

(2) Drilling in overburden layer

(a) Drilling in soft soil layers: when drilling in a clayey soil layer under soft plastic or flowing states, long auger drilling with a low angle can be used or pipe drilling with valve is adopted to shock the layer. Casings are followed-in while drilling so as to prevent the size of the hole from contracting. When mechanical rotary drilling is used, high-quality slurry should be used. If the hole seriously collapses, the hole-wall should be protected by putting in a casing. Before drilling, any grout at the bottom of the hole should be scoured out first so as to prevent too much grout building up in the hole.

(b) Drilling in loose sand layers: When drilling is carried out in loose water-bearing sand layers, the phenomenon of upwelling in the running sand should be prevented. As for the drilling method, the pipe drill shock system is generally adopted with the stroke length not too long, generally in range of 0.1m to 0.2m. In order to avoid the borehole problems from sand boiling the man-made injection method should be adopted in order to make the water level in borehole higher than the underground water level. If necessary, slurry should be used to increase the pressure against the boiling of sand. When percussive drilling with a pipe drill is conducted a casing is generally put in while drilling. For the sand layer needed when making the standard penetration test, strict precautions must be taken against the boiling of sand.

(c) Drilling in a formation with bulk crushed rocks: the crushed stone formation with a particle diameter of less than 20 cm can be broken into finger sized stones by using a straight or cross bit and then withdrawn using a pipe drill with valve. Once every blow the drilling tool should be turned left 15º to 30º to make sure the stone blocks are broken uniformly and the wall of the hole is kept a rounded shape. If larger stone blocks are encountered, mechanically-operated rotary drilling can be used or bore blasting adopted. If a loose and leaking formation is encountered and drilling is difficult a sufficient amount of clay balls can be plunged into the borehole. The percussive drilling can then be carried out to make the clay and stone blocks bond and finally sampled by the half-round drill or pipe drill. When the wall of the hole has collapsed due to scaling, it is necessary to put a casing in to strengthen the wall. When the percussive drilling is carried out using the core pipe, the blow count per meter of penetration depth should be recorded.

(3) Drilling in bedrock

(a) Drillability and classification of rock: Since various rocks have different physical and mechanical properties, they exert different effects on the drilling speed. During the process of actual drilling, the drilling speed of various rocks measured under a certain technical condition is known as the drillability of rock.

(b) Drilling: The drill bit and the size of the hole are adopted according to the characteristics of the formation to be drilled for the dredging works. When drilling is conducted using a small bore diamond or the core barrel the double tube-single swivel type is used, flushing liquor from a pump is used. This flows through and between the outer and inner tubes into the space between the drill bit at bottom and the rocks. This can reduce the scouring by the flushing liquor on the rock core. While drilling, the drilling rod is driven by increasing the rotation, increasingly driving the reamer of the outer tube and drill bit so as to drill in a rotary manner into the formation while the inner tube is kept immobile (it is in a motionless state owing to the friction of rock core, and only collects the rock core while drilling). The rock core in the core barrel is, therefore, generally no longer abraded which can protect the rock core.

Percussive-rotary drilling is performed under a combined action of the percussion and rotary motion which is suitable for various formations. Since it has a high drilling efficiency, this method has been extensively used in the exploration of bedrock formations.

(4) Slurry drilling

In drilling rock and soil layers, except for clayey soil layers that can maintain the stability of wall of the hole and the integral rock layer, hole-wall protection measures should be taken. Flushing liquor, commonly used as drilling slurry, can also be used to protect the hole-wall. In addition, it has functions such as carrying, suspending and removal of rock dust, cooling-down of the drill bit, lubricating of the drilling tool and sealing any leakage. Raw materials used for making slurry include clay soil and water.

When slurry is made, dosage of clay soil can be calculated in the light of the following expression

$$Q = V\rho_1 \frac{\rho_2 - \rho_3}{\rho_1 - \rho_3}$$

where Q——Clay soil mass required to make slurry (t) ; V——Slurry volume to be made (m^3); and.ρ_1, ρ_2 and ρ_3——Densities of clay soil, slurry to be made and water, respectively (t/m^3).

Calculation expression of water demand is

$$W = (V - \frac{Q}{\rho_1})\ \rho_3$$

For the sake of making the slurry achieve the performance required for drilling technology it is necessary to add the right amount of treatment chemicals into the slurry. The quantity to be added is generally determined through testing.

Drilling On-water

(1) Type of drill site

For a drill site that is on the water a floating drill rig is generally used, except where a hanging rope bridge can be used and where the riverbed is narrow and has rapid flow. The floating of a drill on water can involve the use of a barge, oil drum raft, bamboo or wooden rafts. However a barge is mainly used. Tonnage and size of the drilling barge should be determined according to the hydrologic regime drilling depth required, drilling equipment to be used etc.

When drilling is carried out in a river mouth or coastal area with deep water and high waves, a steel barge should be used with a tonnage generally from 150t to 200t, a length of about 38m and a width of about 8m. The layout of such a barge is shown in Figure3.

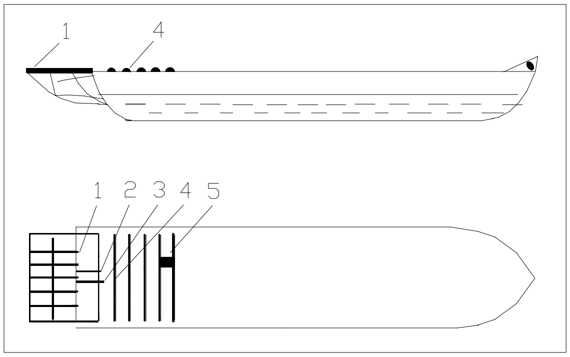

Figure 3. Layout of the drill site on steel barge (1-welded structure of angle steel and I-bar support, 2-hole site, 3-rig ,4-I-bar sill beam 5-water pump).

When drilling is performed in the water area of an inland river, bay or reservoir with a velocity of less than 3m/s, a wooden barge is usually used. Usually two barges are connected in parallel on which a drilling machine is installed. The tonnage of a single barge is in the range of 5t to 20t with a width of 3.5m and a length of about 20m.

(2) Location of drilling barge

After the arrangement of a drilling platform is finished the drilling barge is moved to the predetermined drilling site. Following confirmation of the drilling position, the main anchor and bow anchor are thrown on to the riverbed and then placed in position using a small craft. An anchor cable is then strung using a wire-rope hoist installed on the craft and the drilling barge is moved gradually towards the drilling position where stern anchors and side anchors are cast. The number of anchors used is determined according to the actual conditions. It is generally in range of 4 to 7 with the weight per anchor of 30kg to 50kg (for an inland river) or 50kg to 100kg (for coastal work) as shown in Figure 4.

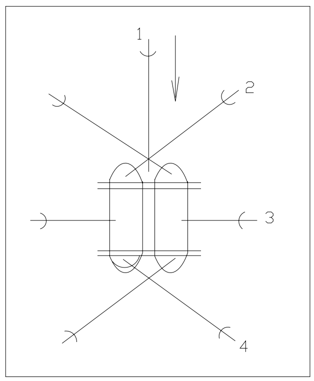

Figure 4. Sketch of anchoring in deep water with strong currents (1-Anchor, 2-Bow anchor, 3-Side anchor 4-Stern anchor).

(3) Drilling in pebble beds

Since the pebble layer on a riverbed has an ability to resist erosion and frequently forms a protective layer over the general bed configuration, it is an important to target geologic research for the analysis of fluvial processes.

Underwater drilling is mainly used to verify the elevation of any pebble bed and the composition and thickness of any overburden material likely to be eroded above the pebble bed. The drilling method can relate to the drilling method for a soft soil layer and loose sand layer in the above-mentioned overburden layer. If the soil quality condition of the overburden layer is clear the punch exploration method can also be used.

According to the different needs of the project or the object of the investigation there is sometimes a need to know about the thickness of any pebble bed, so it is necessary to drill through the pebble bed. The drilling method can be assessed by referring to the drilling method for bulk crushed stone formations.

Sampling of Rock and Soil

Methods of taking undisturbed samples during drilling include:

(1) Hammering methods

(a) Hammering method using the energy from a light hammer.

(b) This can be divided into the top and bottom hammering methods according to the position of the hammer.

(2) Pressing-in methods

(a) Slow pressing-in method: lever, lifting jack and hand-feed core drill of a drilling rig etc. are used to apply the pressure, and the process where the soil sampler is drilled into the soil layer is not continuous. Sampling by slow pressing-in method disturbs the soil samples to some degree.

(b) Quick pressing-in method: a soil sampler is pressed quickly and uniformly into the soil. This method disturbs the soil samples to a minimum extent. At present, there are generally two kinds of utilized methods.

i) Piston hydraulic tube method: a piston hydraulic tube slightly longer than the soil sampler is adopted to switch on a high-pressure and force the piston hydraulic tube to be pushed into the soil with a constant speed.

ii) Wire rope and pulley-block method: mechanical force is achieved through wire rope and pulley devices in order to push the soil sampler into the soil.

(3) Rotary method

This method means that a rotary soil sampler is used to take soil samples. When soil samples are to be taken, the inner tube is driven into the soil to take samples. Waste soil is penetrated in a rotary motion by the outer tube and generally taken out of the orifice using a flushing liquid through a mechanical drilling rig. Sampling by using this method can reduce the degree of disturbance by the soil sampler thereby improving the sampling quality.

TECHNICAL REQUIREMENTS OF INVESTIGATION

Some technical requirements for the geotechnical investigation, including the layout of exploration lines and points as well as the use of the sub bottom profiler, have been put forward in the codes of practice concerning waterway dredging works in China.

Requirements that the Geotechnical Investigation of Waterway Dredging Works Should Meet

(1) Before carrying out the design and construction of dredging works, geotechnical conditions of the site must be fully investigated, soil and rock test analysis must be done and an evaluation be made of dredging characteristics.

(2) The geotechnical investigation should be made within the planned dredged area, and the geotechnical data outside the area must not be used as the basis of the design and construction. When the geotechnical investigation for dredging is conducted in parallel with other projects at a port, the geotechnical investigations for dredging works should not only be in conformity with the provisions in the current sector standard *Code for Geologic Investigation in Port Engineering (JTJ240-97)*, but also the special requirements in the *Code for Dredging Engineering (JTJ 319-99)*.

(3) The scope of the investigation, technical specifications and methods to be employed should be determined in the light of project's purpose, property and scale of works, complexity of field geological conditions, operating conditions and economic factors. Before any investigation, the local geotechnical data should be collected from relevant authorities, and a reasonable investigation program should be developed on the basis of analyzing the geological structure in the field and the characteristics of the soil and rock.

(4) The type and the engineering characteristics for the specific distribution of rock and soil in the areas proposed for dredging works should be ascertained so as to be able to choose dredgers in the design stage, to determine construction methods, to arrange job time periods and to calculate costs. The investigation of rocks and soils for dredging purposes should accord with the provisions in the standard *Criteria for Classification of Rocks and Soils in Dredging (JTJ/T320-96)*.

For general dredging works the investigation of rocks and soils for dredging purposes should be completed at one time before the project design stage. However, for large-scale works with complex geological conditions, the job may be carried out in two stages, i.e. design investigation and then construction investigation.

In the course of construction, if the rocks and soils actually dredged do not coincide with those noted in the design or show a great difference, a supplementary investigation should be carried out.

For an area with a small quantity of dredging work has been done before, where there is a certain amount of experience and there are relatively simple geological conditions, investigations can be simplified.

Requirements that Layout of Exploration Lines and Points Should Satisfy

(1) The layout of exploratory points, including boreholes, test pits and shafts, should be determined according to the requirements of the investigation stages, the topography, land features and complexity of the rock-soil layers in the area to be dredged.

(2) In the design stage of a project, the exploratory lines and points should be laid out on an up-to-date bathymetric map with their spacing determined with reference to the following Table 1.

Table 1. Spacing of exploratory lines and points.

Project area	Geological conditions	Description	Spacing for exploration lines (m) or line numbers	Spacing for exploration points (m)
Inland rivers	Complex	landform with big undulations, rock-soil property with a great variety and many geomorphic units	20-50	20-50
	General	landform with undulations, rock-soil property with some variety	50-100	50-100
	Simple	even landform, single rock-soil property, single land features	100-150	100-200
Coast	Complex	landform with big undulations, rock-soil property with a great variety and many geomorphic units	20-50m	20-50
	General	landform with undulations, rock-soil property with some variety	50-100	50-100
	Simple	even landform, single rock-soil property, single land feature	basin:200-500 waterway: 1-3 exploratory lines	200-500

Note: For any area with very complex geological conditions, exploration should be carried out intensively based on the project requirements.

(3) Boreholes in the area to be dredged should be drilled to a depth of 3m below the design dredge level and if a further dredging depth is taken into consideration, the depth of boreholes will be increased correspondingly.

Sub bottom Profiler Exploration Should Meet the Following Requirements

(1)Besides this code, the sub bottom profiler explorations should be in conformity with the standard *Criteria for Classification of Rocks and Soils in Dredging (JTJ/T320-96).*

(2) It is advisable that a sub bottom profiler with a high resolution ratio of1.5 to 12kHz sonic frequency is employed. It should be equipped with the software for bed material identification and sonic sub bottom recognition.

(3) For geotechnical interpretation, the sound impulse propagation speed can be taken as 1,600m/s to determine the buried depth of a boundary surface. In order to find out more objectively the buried boundary surface, it is necessary to utilize local borehole data in order to identify the buried depth of the boundary surface and the correct sound speed to be employed.

(4) If the soil conditions at the site are very complicated, the soil properties are too hard to identify and conventional investigation methods cannot ascertain actual geotechnical conditions, a trial dredge should be adopted. In order to evaluate the effect of the trial dredge and the performance of the equipment, the trial dredge conditions and parameters should be carefully monitored and recorded.

(5) The on-site and laboratory tests for rocks and soils to be dredged should be carried out based on the current standard *Criteria for Classification of Rocks and Soils in Dredging (JTJ/T320-96).*

SUMMARY

(1) In the design and construction of a waterway dredging works, in order to know about the status of shallow layer on a riverbed, simple geological methods can be adopted. In order to find out the status of the deeper layers, it is necessary to use geophysical exploration and drilling methods. For any specific project several methods are often employed to investigate the status of the rock-soil layers.

(2) In making geologic investigation for waterway dredging works, electrical surveying mainly adopts resistivity methods. Seismic surveying usually employs the compression wave reflection method with acoustic surveying mainly used for loose formations where there are no cobbles and gravels or only sparsely-distributed underwater cobbles and gravels,

(3) Drilling is one of main means of geological exploration for waterway dredging works and is widely used. It can identify and describe the rock-soil layers, take samples from rock and soil layers and carry out standard penetration or velocity rock-soil testing.

(4) In the codes concerning waterway dredging works in China, some technical requirements for geotechnical investigation, including the layout of exploration lines and points, as well as the use of a sub bottom profiler, have been put forward.

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