WHY DO SITE INVESTIGATIONS MATTER?
Site investigations are no longer a guessing game. With modern techniques and computer-based site investigations they are an integral part of any marine construction project. Especially because the risks of encountering “unforeseen” material persist and are not only inconvenient, but also time-consuming and invariably costly. Accurate preparation will help define the design of the project, the type of equipment needed and will limit, as much as possible, conflicts arising unforeseen conditions. This is a feasible goal. A well-designed site investigation informs all parties – the contractor, the client and the stakeholders – and reduces risks and uncertainties. Site investigations are the first step toward a successful project.

WHEN IS A SITE INVESTIGATION NECESSARY?
Always. One of the most frequent causes of delay and additional unexpected, unbudgeted costs is an inadequate site investigation. In some dredging and maritime construction projects, primarily maintenance operations, information may already be available. Some large contractors have databases with the results of previous investigations. In those cases a desk study examining existing data may suffice. For most capital dredging projects, however, thorough inspection of the entire area is crucial. The most recent data is important because conditions change and earlier investigations may not wholly represent the present situation. For land reclamation projects, site investigations should include both the site of the dredging project, as well as the site of the borrow pit where fill is being extracted.

WHEN SHOULD A SITE INVESTIGATION TAKE PLACE?
Prior to tendering. Since the costs of the dredging operation are directly related to the materials and conditions encountered on site, the more comprehensive the data collected, the better the contractor can plan the work. Substantial data collection at a site prior to tendering also helps manage risks for the client and the contractor. The basic questions a site investigation should answer are:
- What types of soils and material are present?
- Are these materials dredgeable?
- What type of equipment and plant will be needed?
- What will the wear and tear on plant be?
- Is the stipulated budget feasible for the work to be carried out?

WHAT CONSTITUTES A THOROUGH SITE INVESTIGATION?
Although a comprehensive site investigation is the ideal, this may not always be financially possible. Site investigations are not inexpensive. Given limited funds, data collection may have to be prioritised and a site investigation may be done in phases as needed. When possible however data collection of three aspects of ground examination are recommended:
- geological and geotechnical evaluations;
- bathymetric surveys; and
- environmental assessments.

WHAT ARE GEOTECHNICAL AND GEOLOGICAL EVALUATIONS?
Geotechnical and geological investigations help determine the type, quantities and locations of material to be dredged. Since the volumes to be dredged are used to calculate the costs of the dredging, the highest accuracy is of great importance. Geotechnical and geological investigations are also essential in analysing the physical and mechanical properties to determine if the (sub)seabed comprises cohesive and non-cohesive soils or rock including the grain size of gravel, sand, silt or clay and the strength and structure of rock. A detailed identification of the subsoil may be achieved by multiple boreholes with several undisturbed samples at each location. Tests and analyses are then performed on these samples to determine: particle size distribution, soil consistency/water content, organic content, settlement and consolidation characteristics, shear strength characteristics, plasticity,
in-situ density, mineralogy, particle specific gravity, permeability and so on. These data can then be supplemented with field tests such as cone penetration testing (CPT). This information determines what type of plant is needed. It may also determine if material is suitable for reuse as well as whether contaminated materials will require special treatment or disposal arrangements.

HOW IS GEOLOGICAL DATA GATHERED?
Field investigations are the primary source of data. Some information can be gathered from desk studies of existing sources such as previously published geological surveys, computerised databanks, universities and research institutes, and records of previous dredging projects. Even satellite imagery and aerial photography can provide some pertinent geophysical information during planning stages. But field investigations are the most direct method of investigation and these indirect methods are only to be used in conjunction with more direct investigative means at the site.

WHAT IS A BATHYMETRIC SURVEY?
Bathymetric surveys establish the water depths and level of the sea/riverbeds including tidal levels at a number of points. This will result in the creation of “isobaths curves” or depth contours, cross sections and/or digitised grids of the investigated site. Echo sounders are the most commonly used method for assessing water depths, and today’s state-of-the-art ultrasonic echo sounders can be used in waters up to 5,000 metres deep. They usually work at sound frequencies which can reflect low-density fluid muds as well as the more solid layers below them.

Whilst calm seas improve the reliability of sounding data, some movement of the survey vessel is unavoidable. This is a difficult and time-consuming process and the skill needed to achieve reliable results should not be underestimated. Automated systems have greatly expedited the collection of sounding data but not eliminated the need for double-checking by manual measurements. Bathymetric surveys will also identify any operational or access restraints. More detailed surveys, for instance, by side-scan or magnetometer, can be used to identify obstructions such as underwater pipelines or debris.

WHAT ARE ENVIRONMENTAL ASSESSMENTS?
In the last few decades, environmental impact assessments (EIAs) have become a regular part of site investigations. Environmental assessments will determine:
- the presence of contaminants at the site or surroundings in the borrow and/or reclamation areas;
- the existence of flora and fauna which may be impacted by dredging;
- the potential effects of the extraction of fill material on the environment.

Environmental assessments provide meteorological, hydraulic, and sediment transport information. The data may include wave action and current velocity, the degree of sedimentation, siltation and erosion, and the effects of wind, waves and weather. Nowadays the flora and fauna of a region such as seagrass or corals or marine fauna are carefully studied and the repercussions of disturbing these by maritime construction are evaluated. As a result of this awareness, extensive research has been done to mitigate these impacts and in most dredging projects these new techniques have become part of the project design.

WHAT TOOLS ARE USED FOR SITE INVESTIGATIONS?
Site investigations begin with a desk study of available data and can provide an indication of the characteristics of the local geological characteristics to be expected. This will be followed by investigations that involve direct, physical searches – samplings – or indirect methods such as geophysical means and remote sensing. In nearshore projects research may be done from a fixed platform. For some
Each of these tools has advantages and disadvantages which should be carefully considered. Clearly the laboratory must meet high standards to ensure accurate and reliable test results. In some cases, for a particularly complex situation, a trial dredging area may be advisable.

**ARE THERE SPECIFIC SITE INVESTIGATION TECHNIQUES FOR ROCK?**
Rock, a rather general term for hard material, can present serious obstacles: First of all, if the contractor is not aware that rock is present and secondly, when the type of rock is not clearly identified. Dredging rock requires specific data and often rock will need to be blasted. To prepare a good blasting design, the characteristics of the material to be blasted must be known in order to choose the correct explosives. The most important characteristics of the rock influencing the blasting result include tensile and compressive strength, density and seismic velocity.

**HOW MANY SAMPLES SHOULD BE COLLECTED?**
Enough samples should be collected to ensure that the site to be dredged is adequately covered and that the samples accurately reflect the composition of the ground. Since factors vary quite significantly, no standard plan can be offered. Therefore the collection of field samples should be carefully planned including mapping, statistical designs, types of gear and techniques to be used, and the estimated scheduling and costs. The more samples taken, the higher the costs will be, but, on the other hand, the client should feel confident with the degree of information acquired.

**WHAT ARE OTHER ASPECTS OF A SITE INVESTIGATION?**
Broader “above water” types of investigation should also be mentioned. Knowledge of the frequency of marine traffic, obstructions such as debris, the location of outfalls, navigational markers or buoys, regulations specific to the

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<th>Schematic chart of data required for a site investigation, adapted from Hydraulic Fill Manual.</th>
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<tr>
<td>Bathymetric or topographic survey</td>
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<td>Single beam survey</td>
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offshore research a platform may be towed to the site. Self-propelled survey vessels can cover wide areas far offshore. Some of site investigation techniques most commonly used are:
- **Geophysical and seismic methods**: includes sub-seabed profilers, parametric echo sounders, chirp systems and boomers which are useful for establishing the geology of a large area and can assist in establishing a borehole grid.
- **Side scan sonar**: detects objects on the subsurface, but not soil properties.
- **Rotary drilling**: used from a platform to get core samples from conglomerates and intact rocks in-situ.
- **Shell and auger boring**: usually used from a platform to get undisturbed samples from sandy subsoil.
- **Vibrocores**: an inexpensive means to get samples from sandy soils at relatively shallow, 3 to 5 metre range, by lowering the framework to the seabed.
- **Box corer**: used for investigations of the benthic micro- to macrofauna, geochemical processes, sampling of bottom water or sedimentology.
- **Jet probe**: a relatively easy, quick method to establish point readings for top of rock.
- **Cone Penetration Tests (CPTs)**: give a continuous reading of cone pressure and shear along the penetration length and indicates the type of soil in cohesive and sandy soils, but not usable with rocky seabeds.
- **Standard Penetration Tests (SPTs)**: indicate the relative density of granular deposits, such as sands and gravels, from which it is virtually impossible to obtain undisturbed samples. A simple and inexpensive method widely used in combination with sampling.
- **Van Veen sampling**: a low cost method of getting a sample from the top of the seabed.
- **Laboratory testing**: increases the value of the in-situ investigation and is an important tool for determining engineering values for classical soil mechanic parameters or special dredgeability factors.
particular harbour, as well as applicable national, international and local laws, and support and safety facilities such as air-sea rescue services, tugs, safe havens, and fuel and electricity supplies are also part of “investigating” the site.

Other pre-dredging investigations could include the evaluation of noise and air quality, the presence of cultural or archaeological objects of value, and the impact of dredging on area activities, for instance, recreation. The more knowledge the contractor, client and for that matter the public, have the better chances of a cost-effective operation with minimal risks.

WHO IS RESPONSIBLE FOR THE SITE INVESTIGATION?
Since the results of a site investigation directly influence the choice of plant, method of operation and contractual costs, the conclusion might be that the dredging contractor should bear the responsibility of the site investigation. In reality that is not typically the case. The client is best placed to investigate the potential site given that the client is most familiar with the specific area and has the time to hire an independent site investigator at an early stage of project development. The contractor usually has limited time to tender and can only summarily inspect the location before pricing the tender. Tenders are then based on this third-party information, which can give rise to disputes if the investigation is not representative of the actual ground conditions.

In fact, a tenderer needs to be certain that the data collection has been prepared by a competent soil investigation company in accordance with accepted international standards such as British Standards (BS), American Society for Testing and Materials (ASTM) or others. A client might consider inviting potential tenderers to witness the soil investigation campaign firsthand. Contractors could conceivably give the client insight into what information tenderers find necessary and a tenderer can discover if essential data is missing. According to the FIDIC contract, the risk of adverse ground conditions, that is, the proper cost of removing physical obstructions or conditions that are not reasonably foreseeable by an experienced contractor, lies with the client.

WHAT ARE THE ADVANTAGES TO A SITE INVESTIGATION?
Besides avoiding unforeseen conditions as much as possible, thorough knowledge of the project site will allow the contractor to propose and present a tender with specific state-of-the-art solutions tailored to the particular task. For instance, data about the presence of weak subsoils will allow the contractor to plan for strengthening the soil by suitable means – such as drainage, compaction, and/or mixing soil with additives. Awareness of the presence of contaminated sediments allows the parties to suggest special disposal remedies. Such innovative solutions and the budget for them should be included in a tender and not come as surprise after a project is underway.

WHO BENEFITS FROM A GOOD SITE INVESTIGATION?
All parties – the dredging contractor, the client and the stakeholders – should realise that in the long term their interests are linked and are best served by a reliable site investigation. Reasonable estimates from the contractor based on the best possible data, plus financial agreements between the contractor and the client for unforeseen situations, will ultimately lead to more harmonious working arrangements. Investing in an experienced site investigator whose qualifications have been verified by the appropriate governmental authorities can help mitigate potential conflict and unexpected revelations for both parties. The least expensive solution may look good at the start, but often is more costly at the end of the day.
FOR FURTHER READING AND INFORMATION


An acoustic instrument used for measuring currents and waves gathers essential geotechnical data.

A shallow seismic Boomer being towed on the water’s surface.

Box corer, a marine geological sampling tool for soft sediments.

Taking undisturbed soil sampling with a ship-mounted rotary drilling rig.