



**START Thinking and KEEP Thinking**

A CEDA Information Paper

# SOIL INVESTIGATION



*“You pay for soil investigation,  
whether you have one or not!”*

G. S. Littlejohn, author of *Ground: Reducing the Risk*.  
Thomas Telford (1994)

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## Citation

CEDA (2021). Soil Investigation. An Information Paper. [Online]. Available at:  
<http://www.dredging.org/media/ceda/org/documents/resources/cedaonline/2021-04-SI.pdf>

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# SOIL INVESTIGATION

This paper has been prepared by the Focus Group on Soil Investigation (FGSI), part of the Dredging Management Commission (DMC), the Central Dredging Association (CEDA).

## 1 Preface

FGSI was established by the DMC to produce a paper that would follow on from, and complement, CEDA's *Checklist for Successful Dredging Management* (CEDA, 2017). The Checklist was produced by a group of industry experts with various backgrounds and experience working on dredging and offshore projects. It discusses a number of topics and subtopics that may lead to problems/issues in the different stages of a dredging project. The first edition of the Checklist is available to download from the CEDA website ([www.dredging.org](http://www.dredging.org)) and is free for CEDA members.

## 2 Introduction

Inappropriate or insufficient soil investigation is widely acknowledged as one of the most important factors leading to cost increase, time overruns, claims and ultimately disputes between the owner and contractor, on dredging and maritime projects.

The topic of soil investigation is addressed, in CEDA's *Checklist for Successful Dredging Management*, as part of the preliminary studies that should be performed at the early project stage. This would be the case with, for example, bathymetric surveys, UXO detection surveys, and measurement

campaigns on hydrodynamic conditions and environmental states. The output of these studies serves to inform all parties involved in a project (the owner, contractor and other stakeholders) about local physical conditions, and helps define the design rules and employer's requirements to apply to that particular project. In the case of major dredging or reclamation works, it is often the most important study as it can significantly reduce, or limit, some of the main project risks and uncertainties.

START Thinking and KEEP Thinking		Feasibility	Preliminary Studies	Permitting	Basis of Design	Conceptual Design	Basic Design	Detailed Design	Procurement	Execution	Project Closing	Operations	Maintenance	Owner	Contractor	Other Stakeholders	Explanation	
Topics	Subtopics	Stage											Parties involved	Explanation				
PRELIMINARY STUDIES	General			X										X	X	X	Owner must be clear about the status of the provided information: reliability, validity, completeness. Attention must be paid to the quality and integrity of the company responsible for the preliminary study/investigation. Sufficient time should be allocated for execution of possible preliminary studies. In order to deliver relevant results in time, be sure to take into account, in project planning, that	
Soil investigation (SI)		X	X	X	X	X	X	X							X	X	X	Many stages are often required in carrying out differing levels of SI, which should be determined by the project requirements. Owners must not be afraid to invest in a qualitative SI but must make sure to collect the right soil information for the project. Early Contractor involvement during preliminary SIs (e.g. witnessing, assessment of scope of tests (in situ and in laboratory)) can be very useful. Sometimes it is wise to do SI in different stages: first exploring to assess the risks, then further detailing when deemed necessary: desk top, few boreholes or CPTs, further investigation.
	Navigational	X	X	X	X	X	X	X	X					X	X	X	Knowledge, that has the into, the data can be more easily provided as every vessel is equipped with such devices. For safety and/or operational considerations assessments are to be performed on different levels: desktop (expert/experienced judgement), fast track simulations, real time simulations. Owner to assess the relevance/necessity at each stage of the project. The national maritime authorities must be involved early in the process. They will be the major decision-making and approving authority regarding navigational safety measures to be implemented during execution of the project.	

Figure 2-1: Extract from CEDA's Checklist for Successful Dredging Management: Preliminary Studies section.

This information paper focusses on these soil investigations. However, it does not provide instructions on how to perform a proper soil investigation as plenty of good literature already exists on the subject. The emphasis of this paper is on common issues and points of contention, that often arise between the different contracting and investing parties on a project, and how the related disputes can be avoided as much as possible.

To illustrate the points made in the paper, there are some good and bad, real-life examples interspersed throughout the text. All examples of the issues surrounding soil investigation, and the lessons that were learned, have been kindly provided by CEDA members.

### 3 Justification

Dredging and reclamation works are major operations which are often complex and expensive. They may account for a substantial proportion of the cost of maritime projects. Effective planning and execution of dredging works requires knowledge about the soil to be dredged and the environmental conditions in which the dredging equipment will operate. The high mobilisation and operational/capital costs of equipment mean that inaccurate or false assessments of the soil and environmental parameters, and the potential consequent selection of unsuitable equipment and methods, or misguided estimations of production, may lead to substantial financial losses on the project. As a result, appropriate soil investigations are fundamental to the success of dredging operations from a technical, environmental and economic point of view. It is therefore in the interests of both the owner and the contractor to obtain a thorough understanding of the soil conditions, at the site, in order to ensure the smooth and efficient progress of the works and to assist in avoiding claims and disputes.

It is important to appreciate that the soil investigation techniques to be used in the marine environment differ significantly from those applicable on land. The constraints of working (often in difficult conditions), the cost of the specialised techniques and equipment required, and the often large areas which need to be investigated for dredging projects, explain why soil investigations for dredging works are often inadequate.

There is a direct link between the cutting of costs

#### CASE STUDIES: BAD EXAMPLE



##### Case 1: Capital dredging project with various soil layers overlying irregularly shaped bedrock.

A limited number of boreholes was drilled and no rock was encountered above dredge level. However, during execution of the works, various rock pinnacles were found, in between the boreholes, above dredge level. As a result, a cutter suction dredger, which was originally not deemed to be necessary by the contractor, needed to be mobilised after all. This led to increased project costs.

**Lesson:** This could have been avoided by carrying out a reflection/refraction seismic survey at the pre-tender stage.



*‘...and we can save 700 lira by not taking soil tests.’*

**Figure 3-1: Appropriate soil investigations are fundamental to the success of dredging operations.**  
Illustration from Craig and Jones (1985).

for soil investigation and unexpected rises in project costs (MBIE, 2014; and MacDonald and Soil Mechanics Ltd, 1994). This is illustrated by the following graph (Figure 3-2), taken from a study for the UK Highways Agency (now Highways England), from 1994, where a comparison was carried out between the cost of soil investigations and the related construction costs.

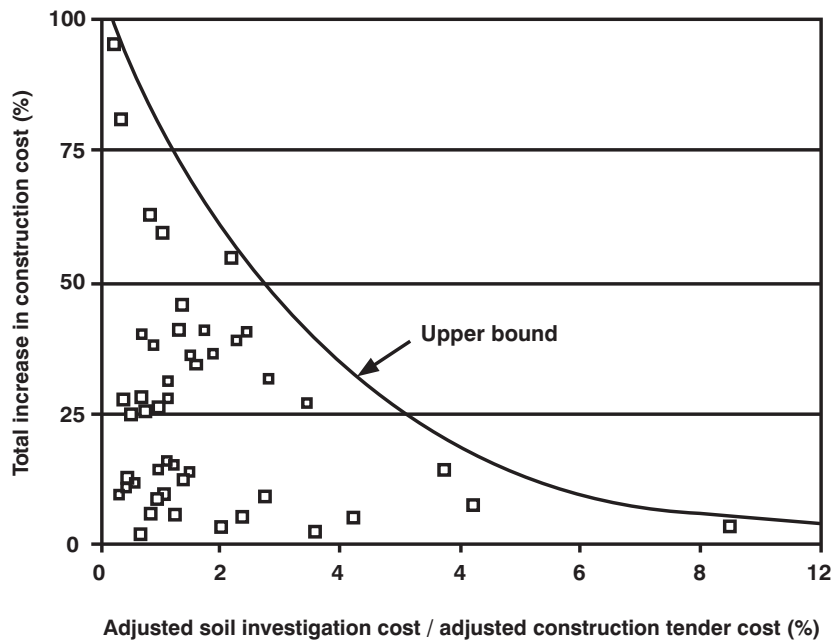


Figure 3-2: Total increase in construction cost, related to adjusted geotechnical investigation cost/construction tender cost (MBIE, 2016 (adjusted from MacDonald and Soil Mechanics, 1994)).

The graph shows that for low values (approximately 1%) of soil investigation cost / tender cost (adjusted values), the total increase in construction cost may vary between 2% and 98% with an average value of 15-25%. When the soil investigation budget is slightly increased (adjusted soil investigation cost / construction tender cost values between 2% and 4%), the total decrease in the construction cost typically ranges between 2% and 25% with an average value of 5-10%. This means that an increase of 1-2% on the construction tender cost, for

additional soil investigation, results in a significant drop of approximately 25% to 50% (absolute values) in the increase of the total construction cost.

In conclusion, it can be stated that the more the project owner is willing to invest (either directly or through the contractor) into an appropriate soil investigation, the lower the risk that unexpected soil conditions will lead to increased construction costs. Or, to quote Professor Littlejohn (1994) “You pay for a soil investigation, whether you have one or not”.

**CASE STUDIES: GOOD EXAMPLE**



**Case 1: Major submerged tunnel project.**

Amongst many other challenges, that were typical for this type of project, were the heterogeneous soil profile and the extreme depths. The owner understood this from the beginning, based on previous experiences with a similar crossing. As a result of that experience, the owner invested in extensive soil investigation, from the start, to reduce the project risks. He understood that the investment was only a fraction of the total and the financial exposure could be large if unexpected soil was encountered. A more detailed paper describing the soil investigation on this project can be found in the appendix on page 14 of this paper.

**4 Issues**

A number of CEDA member companies, representing all three main entities involved with specifying, designing and using the results from soil investigations (i.e. owner, consultant and contractor), were asked to review issues surrounding soil investigation, from an overall project view<sup>1</sup>. This consultation revealed the following main issues highlighted in the context of this paper.

**4.1 Insufficient intensity of soil investigation**

It is common practice to allocate a certain proportion of a project budget to soil investigation. This frequently results in higher intensity of the soil investigation for

<sup>1</sup> i.e. disregarding specific roles, responsibilities or risk allocations, between contracting parties.

structures (such as quay walls, jetties, breakwaters etc.), which represent a very high level of capital investment per unit area compared with investigations for dredging works.

Dredging contractors are frequently faced with having to interpret, and in some cases extrapolate or even guess, soil conditions. They must then estimate costs on the basis of widely spaced, and often poor, data which do not adequately describe the soil to be dredged. Soils are heterogeneous materials and can vary rapidly over very short distances. Therefore, in geotechnical investigations, the observation of similar conditions at two adjacent investigation points does not automatically indicate that those same conditions will be encountered at all positions between those points. While geophysical investigations could easily be used to 'fill in' the gaps, these are often disregarded.

The less soil investigation performed, and the larger the surfaces to dredge, the higher the chance of overlooking some important differences in local soil conditions. This can lead to the mobilisation of unsuitable dredging equipment and significant underestimates of production rates, wear and tear and, ultimately, increased cost.

## 4.2 Poor quality soil investigation

The geologists, or geotechnical engineers, responsible for the design of the soil investigation scope, must ask themselves if the methods they propose to use are appropriate for the expected conditions. They must also be prepared to be reactive and to change the methodology to suit the different soil conditions encountered during the investigation. However, even when the most appropriate specifications have been put forward, to allow a proper soil investigation, its actual execution can still go wrong.

Appropriate equipment is a must, of course, but, as lots of decisions still need to be taken ad hoc on site, it is of utmost importance that well-trained, and experienced, specialists are involved in the planning and execution of the soil investigation.

It is often a challenge to procure the appropriate equipment, and experienced specialists, in restricted time windows – especially on remote sites where dredging will take place. The selection of inappropriate equipment and investigation methods, along with inexperienced personnel supervising and carrying out the soil investigation, can have dramatic consequences as they can lead to poor-quality results and/or misinterpretation of the delivered results.

## 4.3 Non-relevant soil investigations

Usually, a soil investigation is important for the following reasons:

- To evaluate the dredgeability of the soil. This is required to determine the type of dredging equipment, that is best suited for the job, and to estimate its wear and tear and productivity.



Figure 4-1 and 4-2: Good quality soil investigation cannot be performed with this type of equipment

**CASE STUDIES: BAD EXAMPLE**



**Case 2: Land reclamation project.**

Owner nominated the contractor to take grab samples in the future borrow area. Particle size analyses were completed and identified suitable sand. During the execution of the works, it was discovered that there was only a thin layer of suitable sand overlying cohesive soils, which made the borrow area unsuitable.

**Lesson: This could have been avoided, or mitigated, by completing a combination of a reflection seismic survey and vibro-coring.**

- To evaluate the re-use potential of the dredged material.
- To establish the foundation conditions for structures associated with the project, such as offshore structures, breakwaters, jetties, artificial islands and new land infrastructure.

In all three cases, different processes/parameters play a role in the use and application of the soil investigation results and therefore each should be assessed in an appropriate manner.

Although the basic objectives of the soil investigations may be similar, namely identifying and characterising (in civil engineering terms) the various geological units present at the site, different approaches of investigation might be necessary, resulting in differing data sets. Those responsible, for the design and execution of this type of marine work, may not always fully appreciate that different types of engineering data might be required for specific applications.

That is why, even in cases where the intensity of investigation appears to be sufficient, it can frequently be the case that the nature of the data obtained is only relevant to foundation designs but not to dredging. While there is a large degree of overlap, in the type of data required for both activities, the particular needs of the dredging project can often be overlooked.

**4.4 Unrealistic timing**

Not only is the need for a proper soil investigation often under-estimated, the actual time required to organise and execute it is also often under-estimated. Additionally, budgets have to be made available in time to finance the soil investigation. This can be a challenge

for the owner as immediate return on this investment is hard to demonstrate to financing institutions.

This failure to provide sufficient time may lead to soil investigation results not being available in time to be effectively utilised by the interested parties. This is inconvenient not only for the contractor, but also for the consultant or engineer, responsible for the design, or the permitting authorities, which may need it, for example, to assess the possible beneficial re-use of dredged material.

For the contractor, having reliable and relevant soil information in time is absolutely necessary to be able to provide a well-prepared tender. The better the quality, and appropriateness, of the provided results, the more accurately the contractor can determine the most efficient dredging methodology, and corresponding price, to the benefit of the project. Therefore, this soil information should be made available preferably before tendering in traditional contract types.

Sometimes the information cannot be provided prior to the tendering period, or it is not appropriate, or sufficient, and the contractors have to organise their own soil investigation to fulfil their tendering requirements. This is not desirable, especially with Design & Build or Engineering, Procurement and Construction (EPC) contracts, as design activities might already have started and any new soil information, which becomes available late in the process, could lead to re-work, inefficiencies and potential claims to the owner.

**CASE STUDIES: GOOD EXAMPLE**



**Case 2: Offshore wind projects.**

These projects are constructed in offshore marine environments and the construction is often completed over large areas. In order to get the trust of financing institutions, and insurance companies, and to demonstrate the projects' financial robustness, assurance is often needed that the projects, in early stage, are properly prepared and engineered. Essential to the preparation and engineering, is the design basis which will necessarily include a detailed site assessment and soil investigation. Therefore, in general, the offshore wind developers are investing significant amounts in the quantitative and qualitative characterisation of the site. Usually a variety of methods and expertise are applied at a very early stage to guarantee these assessments.

## 5 DMC Recommendations

The following recommendations are based on the DMC review of the key issues identified in the preceding sections, namely the importance of:

- sufficient intensity of soil investigation;
- good quality soil investigation;
- relevant soil investigation; and
- realistic timing.

The recommendations generalise and address these issues in combination. They outline an exemplary set of processes that can be considered by contracting parties, when developing their own soil investigation procedures and practices, whether for general or specific projects.

### 5.1 Project phases

In situations where there are limited funds and/or time, data collection may have to be prioritised. In which case, a soil investigation may be completed in phases, as and when required, by first assessing the risks and then further detailing when deemed necessary. In other words, to work efficiently, it is often advisable to execute different levels of soil investigation in different project phases accordingly. There should be careful consideration of the phases, the soil investigation requirements and the resources available.

The required quality and quantity of data differs for each project phase. Usually each successive step in the design process requires a higher level of detail. However, even at an early stage of the project, adequate data should be made available to assess the project's feasibility and to commence the conceptual design.

A desktop study is a cost-effective and logical first step of a soil investigation carried out in an early stage of a project. In such a study, existing sources are examined, such as previously published geotechnical/geophysical investigation reports, computerised databanks of local universities and research institutes, and records of previous dredging projects. This may provide a first indication of the characteristics of the local geology to be expected and allow an initial assessment of the risks that are associated with it. It is advisable to further develop this initial geological/geotechnical risk assessment and to update it whenever new soil information becomes available, through extra soil investigation or other sources. As far

#### CASE STUDIES: BAD EXAMPLE



##### Case 3: Rock dredging project.

The soil investigation contractor reported a low Rock Quality Designation (RQD) value of the recovered rock, which is interpreted as highly fractured in situ. During execution of the works, the rock actually presented as being massive. The incorrectly identified low RQD was the result of improper drilling and misinterpretation of natural fractures and drilling induced fractures.

**Lesson: Drilling should always be done, and be properly supervised, by competent contractors. Owner should consider inviting the dredging contractor's representatives to witness the drilling.**

as possible, the desk study should be completed, and reported, before the specification and commencement of new investigation and conceptual design.

The next step in the design process is to make an inventory of the required data for the design process. Based on the data gathered during the desk study, a soil investigation campaign (field investigations) can be developed to provide the additional required information.

It is often advisable to perform the soil investigation in several stages, depending on the project and contract type.

Depending on the type of contract, and the party responsible for performing the detailed design, the following phase of more detailed soil investigation can be planned and organised by either the owner, the consultant or the contractor. However, it remains important that sufficient time is allocated for this continued process (see section 5.2). For a cost-effective design process, all soil properties and other data should be available before progressing to the detailed design stage.

A disadvantage of splitting the soil investigation into different campaigns, or stages, is the time required and the increase in initial costs due to extra mobilisations, and demobilisations, of the required investigation equipment. Counter to this, savings can be made as the second, more detailed campaign can be



organised much more efficiently if properly planned and implemented.

In the first phase of the soil investigation, multibeam investigations can be combined with geophysical investigation techniques, allowing coverage of large areas at a relatively low cost. Results and interpretations are quickly available when combined with the results from the initial desktop study. In a second phase, a more specialised set of equipment for geotechnical sampling (e.g. CPT and vibro-coring) can be mobilised to confirm, clarify or contradict, these preliminary results. These further investigations can also focus on unclear areas, or specific areas where adverse soil conditions are suspected. With this approach, the results of the complete soil investigation will be much more relevant to the different parties involved, thereby reducing the risk of unexpected soil conditions for the project.

## 5.2 Typical timeframes for good quality soil investigations

It is critical that the results of the soil investigation are made available in sufficient time to be effectively appraised and utilised by the different parties involved. Therefore, owners, who are on many projects responsible for organising the soil investigation, should be aware that this is a time-consuming process and that preparations should be started early to avoid compromising the overall project planning.

### CASE STUDIES: GOOD EXAMPLE



#### Case 3: Canal maintenance project.

A thorough soil investigation was completed. It revealed an abundance of UXOs and was properly and sufficiently characterised. Based on the information taken from the investigations, the contractor devised a purpose-specific suction head and UXO handling tool to prevent accidents. This worked well and the project was safely and successfully delivered.

Based on several interviews with geotechnical experts, and their feedback, the DMC has established an indicative table with typical duration ranges of the different stages of a good quality soil investigation. These timeframes are for guidance only and will of course vary depending on numerous factors determined by the project and the parties involved. Depending on factors such as the extent of the area to investigate, complexity and type of tests required, accessibility of the site, and procurement framework, a specific soil investigation can take a greater or lesser period but, in general, an overall allowance of between five and eight months could be considered as a reasonable starting point.

Table 1 : Indicative timeframes for execution of a soil investigation.

	# weeks
Preparations (e.g. analysis of existing information, concept, drawing up specifications)	4 - 6
Tendering for soil investigation contractors	2
Execution of the soil investigation:	4 - 8
Desk study (e.g. database consultation, historical survey)	
Geophysical (e.g. refraction/reflection seismic)	
Geotechnical (e.g. SPT, CPT, vibro-cores, boreholes, coring)	
Laboratory testing	2-8
Interpretation of results	6
<b>TOTAL</b>	<b>20-30</b>

## CASE STUDIES: BAD EXAMPLE



### Case 4: Maintenance dredging project.

When commencing a maintenance project, the data used for tendering was no longer valid. Both bathymetry and the quality of the sediments had changed. The data had to be updated and consequently new permits were needed. This resulted in significant delays.

**Lesson: This could have been avoided by updating the data in time.**

In the event that the soil investigation is executed in phases, the timeframe may vary further as different parties would likely be responsible for carrying out those different phases of work (see section 5.1).

### 5.3 Suitability of data

It is important to define clearly, in advance, which output is expected from the soil investigation. The type of data which is most useful will differ depending on:

- type of the investigated area (borrow area, dredge area or reclamation area);
- soil type – different parameters are required for cohesive soils, non-cohesive soils, or rock; and
- design issues which have to be investigated, such as volume calculations, slope stability, consolidation, settlement, abrasion, possible dredging methods (excavation/transportation/disposal), expected productivity and wear and tear of applied equipment, liquefaction risk, debris, soil contamination and gas inclusions.

In Figure 5-1, the DMC provides a flowchart which points to the most relevant existing information, standards and guidelines, on the appropriate soil investigation for their specific project. It should be viewed in combination with the reference list given in section 6 (numbers in square brackets refer to corresponding list numbers).

The flowchart was developed for four main groups that were identified as classifying the most common dredging projects:

- dredging for minerals/aggregates;
- maintenance dredging;
- capital dredging; and
- beach nourishments/filling/land reclamation.

Note that, environmental remedial dredging works could be considered a separate category or a special type of maintenance dredging. Environmental remedial dredging involves the removal of polluted contaminated sediments from rivers, harbour basins, etc.. As such, environmental aspects must be taken into account during all phases of the execution of environmental dredging works, however, these are not considered in Figure 5-1.

Also, Figure 5-1 does not include dredging for offshore installations such as windfarms, cables, pipelines, trenches, etc.. Guidance for long-term stability, and operational monitoring, can be found in DNVG-RP-C212 (2019) and DNV (2015).

### 5.4 Ensuring quality of the soil investigation

It is essential to employ qualified companies with a good track record in soil investigation performance. When tendering for a soil investigation contractor, the procuring party should take the following into account:

- Start preparations in sufficient time. Preparations involve a desktop study identifying, amongst other items, possible risks and potential difficulties (see Table 1). Prepare a reliable, good-quality set of specifications and share all available information with the relevant parties. This will allow the soil investigation contractor to mobilise the most appropriate specialised equipment.
- Include a prequalification stage, where selection of soil investigation contractors, with proven track records, can be made.
- If preparation time is limited, work with well-known contractors with whom your company or organisation has good past experience, or call on world-renowned contractors.
- Insist that your own representatives, or your consultant, witnesses the execution of the soil investigation.

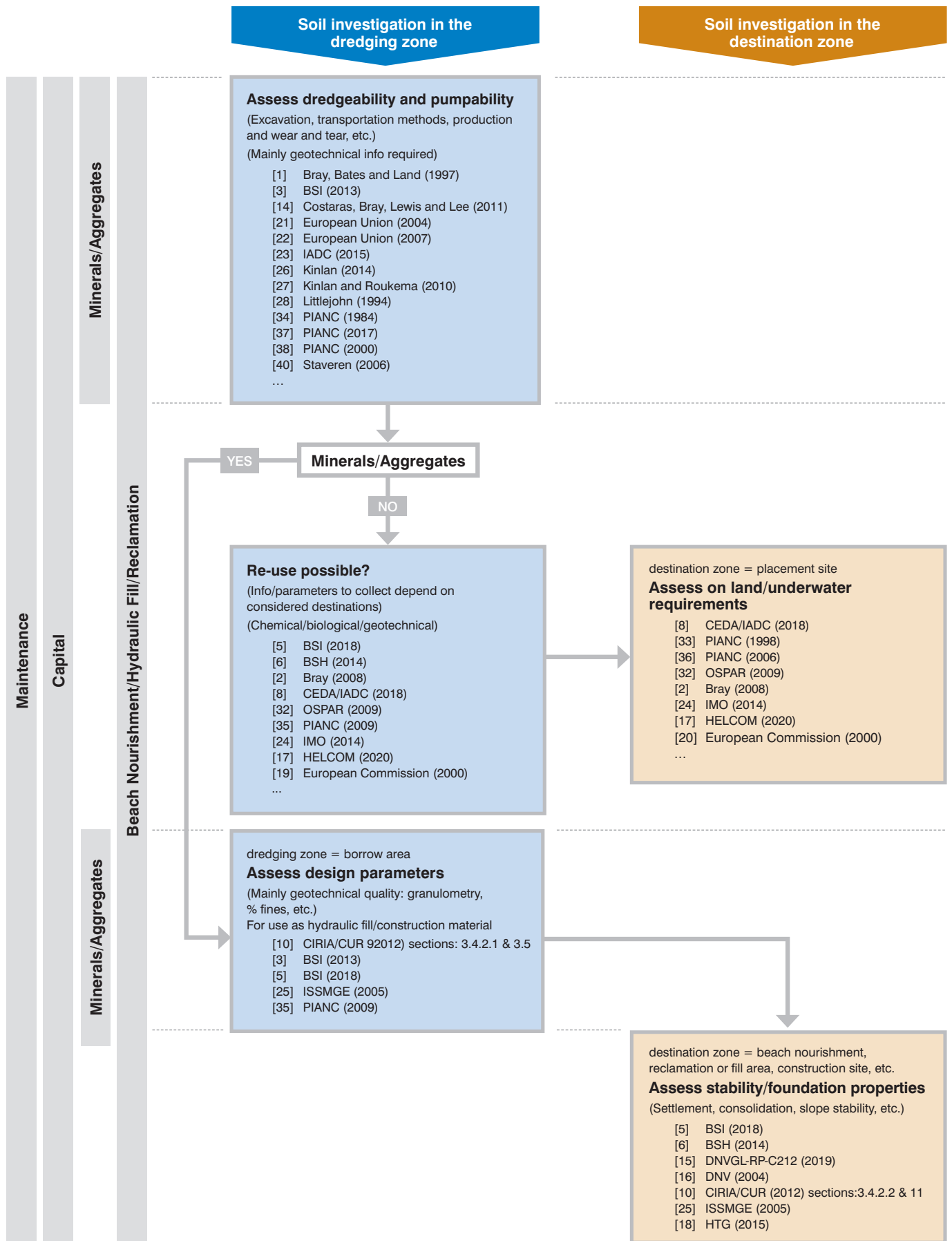


Figure 5-1 : Flowchart of recommended literature for specific soil investigations that might be required at the different stages of a project. This list is not exhaustive.

- Demand not only high-quality execution of the soil investigation (both on the site as well as in the laboratory), but also high-quality reporting from the soil investigation contractor. Once the soil investigation is completed, a report needs to be prepared containing all gathered data (*in-situ* and laboratory results) and the subsequent interpretation. It is important to include all factual data to allow the parties involved in the project to make their own interpretation. Often a party may not have been involved in the soil investigation and must rely solely on the reports. Therefore, ultimately, the total value of the soil investigation is represented by the quality of this final report.
- Early contractor involvement (ECI) is a method of construction contracting that allows a contractor to become involved, and potentially start work, before the design has been completed. An ECI during preliminary soil investigations (i.e. preparation of scope, witnessing, and assessment of scope of tests (*in situ* and in laboratory)) can be very useful. In fact, as a construction contractor needs to be certain that the data collection has been prepared by a competent soil investigation contractor, in accordance with accepted international standards, the owner might consider inviting potential bidders to witness the execution of the soil investigation. Contractors could then conceivably give the owner insight into what information they find necessary and can discover in time if any essential data is missing. The witnessing is useful as a visual inspection of sampling, and inspection of the soil investigation techniques used and possible laboratory testing, will provide a significant amount of extra information and enable the contractors to make a better interpretation at a later stage. It also gives the contractors a responsibility in accepting the soil investigation as correct and sufficient.

The earlier the consultants and contractor are involved, in the preparation and execution of the soil investigation, the more guarantees the owner has that later disputes and delays can be avoided.

## 5.5 Geotechnical risk assessment

It is advisable to complete a proper geotechnical risk assessment. Geotechnical risks can have a significant impact upon the ultimate works and, therefore, adequate analysis and management should be applied. While still rather limited, the amount of literature about geotechnical risk management is growing. For example, for generic geotechnical risk management methodologies, reference is made to Clayton (2001) and Van Staveren (2006).

Without doubt, geotechnical engineering is a key success factor for most construction projects. Currently, geotechnical risk management is gaining increasing attention, in these projects, and the methods and processes continue to be developed and refined.

It is advisable to commence a study of the geotechnical risks at an early stage of the investigation process, list them in a risk matrix, and assess the mitigation measures in detail. Such risk analyses should be dynamic documents and should be updated with each subsequent phase, or stage, of soil investigation.

## 5.6 Relation with contract/project delivery method and risk allocation

While recognising the importance and impact of a good soil investigation, the question may be raised as to which party would be the best to take responsibility for its organisation and/or execution. As project particulars can be very different, from one case to another, there is no straightforward answer to this. Depending on the main project constraints, usually time, money and/or quality, the reply can be different. Furthermore, the responsibilities and liabilities of the owner, consultant and contractor, with regard to the interpretation and procurement of soil data, will depend strongly on the type of contract. Often, a FIDIC form of contract is adopted. In section 3.2 of the *Hydraulic Fill Manual* (CIRIA/CUR, 2012) an overview is given of the relevant clauses in the different FIDIC contracts. Other useful literature on the subject can be found in section 2 of the PIANC (2000) report on *Site Investigations for Dredging Works* and the paper from Kinlan and Roukema (2010) published in *Terra et Aqua*.

The owner is often best placed to investigate the potential site, given that usually they are most familiar with the specific area, and should have the time to organise a soil investigation at an early stage of project development. The contractor usually has limited time to tender and results of a soil investigation, organised by the contractor itself, frequently arrive too late for adequate pricing and risk analysis. Of course, this is usually due to the owner not allowing sufficient time, in the overall process, to enable a good quality and robust soil investigation.

Contractors generally have to base their pricing on the information provided by the owner, which can give rise to disputes if, afterwards, the investigation appears to be unrepresentative of the actual ground conditions. Therefore, owners must not be afraid to invest in a qualitative soil investigation while ensuring the collection of the right soil information for the project. The better quality and more extensive the soil information provided in a tender, the less risk for the project. Therefore, the contractor will be able to present an offer with the best solution, for that particular task, which is reflected in the price.

Owners must be aware that, in general, a contractor, in establishing their price, will be entitled to place reliance upon any soil investigation carried out prior to the signing of a contract. Although the contract terms should address this, owners are advised to ensure any

soil investigation, carried out on their behalf, is robust and accurate.

The limits, scope and extent, of any soil investigation carried out for the project, by the owner, may be guided by the form and type of contract/delivery method applied to the specific project. There exists a large range of possible contracting models, each of which provides a different allocation of risk between the owner and the contractor relating to, amongst others, the risk of changes to, or unforeseen, ground conditions. CEDA (2019) provides guidance and assistance in reviewing such issues in its paper *Effective Contract-Type Selection in the Dredging Industry*.

Increasingly, owners are implementing EPC type contracts, which frequently include dredging portions. These delivery models impart significant elements of risk, upon the contractor, which usually include ground condition variances. Of course, the owner 'pays' for this risk allocation in the lump-sum price. Commonly in such contracts, the owner may have carried out initial soil investigation but may seek to limit their ownership of it within the contract terms (i.e. the contractor accepts the initial owner-procured soil investigation as their own). Owners should take care, in such circumstances, as they may still be liable for negligence, in carrying out and collating such soil investigation, should it be shown subsequently to be incorrect.

## 6 Appendix

### CASE STUDIES: GOOD EXAMPLE



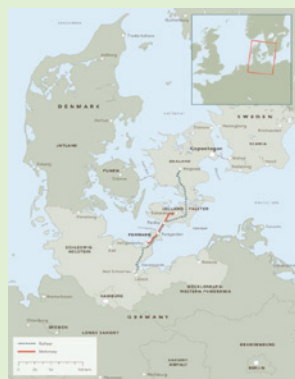
#### Case 1: Major submerged tunnel project: Fehmarnbelt project

##### Background

Femern A/S was tasked with the design and planning of a fixed link, across the Fehmarnbelt, between Denmark and Germany. As a subsidiary of the Danish, state-owned Sund & Bælt Holding A/S, Femern A/S has experience on the construction of fixed links across Storebælt and Øresund.

##### The project

The Fehmarnbelt is an 18.5 km wide strait, which links the Baltic to international waters (see Case Study Figure 1). The preferred solution for the crossing is an immersed tunnel (see Case Study Figure 2) which will be completed based on the principles of Design & Construct (i.e. detailed design and construction under the same contract).

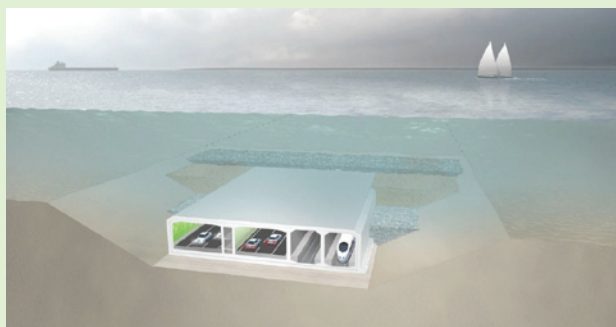


Case Study Figure 1: Project location

More than 50 million euros have been invested in ensuring a thorough understanding of the soil conditions as a basis for the project's success. Femern A/S has completed the geotechnical investigations for design and construction and Case Study Figure 3 shows the revealed soil conditions of the Fehmarnbelt.

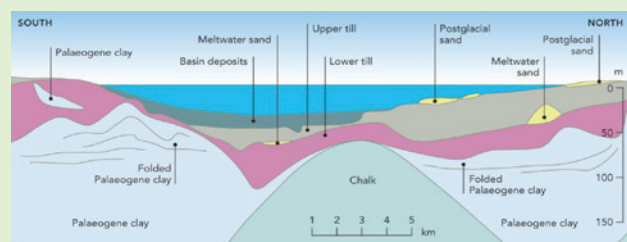
##### The outputs

The vast size of the project, and the complexity of the prevailing soil conditions, meant that the communication of geotechnical findings, to all shareholders, needed to be clear and unambiguous.



Case Study Figure 2: An immersed tunnel was the preferred solution for a fixed link

The geotechnical data reports, from the geotechnical investigations, clearly described the facts, the work carried out, and the results achieved. The reference conditions encompassed those geotechnical conditions which would have significant effects on the contractor's design and construction. Femern A/S produced these from their conclusions on the soil conditions, based on the investigations carried out and the design considerations made.



Case Study Figure 3: Geology of the Fehmarnbelt revealed by the geotechnical investigations

All geotechnical data reports and reference conditions, and the Geotechnical Information System and methodologies, were made available to the contractors to ensure a comprehensive, and unambiguous, understanding of the ground conditions.

The geotechnical reference conditions helped to ensure that geotechnical information was not misinterpreted, and the contractors used them as a basis when preparing bids. The contractor's geotechnical tasks, after award of the construction contracts, were limited to verification of the geotechnical basis according to the principles and methods specified in the contract. The contractor's verification investigations used the same methods as those applied by Femern A/S in the initial investigations for design and construction.

##### Conclusion

The top down approach from a geological understanding, and setting geotechnical data in context, was particularly beneficial for establishing the necessary geotechnical information for the project's success. In particular, Femern A/S communicated all geotechnical findings, to stakeholders, in an open and structured way, which helped to achieve a common understanding and appreciation of the soil condition.

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This list covers the most commonly used, and cited, guidelines and references. It is presented for information, and useful background, and is by no means an exhaustive list.

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## Abbreviations

<b>BSI</b>	British Standards Institution
<b>CEDA</b>	Central Dredging Association
<b>CIRIA</b>	Construction Industry Research and Information Association
<b>CPT</b>	Cone Penetration Test
<b>CUR-CROW</b>	Civieltechnisch Centrum Uitvoering Research en Regelgeving
<b>DMC</b>	(CEDA) Dredging Management Commission
<b>DNV GL</b>	An amalgamation of Det Norske Veritas (DNV) and Germanischer Lloyd (GL)
<b>ECI</b>	Early Contractor Involvement
<b>EPC</b>	Engineering, Procurement and Construction
<b>FGSI</b>	Focus Group Soil Investigations (within the DMC)
<b>FIDIC</b>	International Federation of Consulting Engineers
<b>HTG</b>	Hafentechnische Gesellschaft
<b>IADC</b>	International Association of Dredging Companies
<b>ISSMGE</b>	International Society for Soil Mechanics and Geotechnical Engineering
<b>MBIE</b>	Ministry of Business, Innovation & Employment
<b>PIANC</b>	World Association for Waterborne Transport Infrastructure
<b>RQD</b>	Rock Quality Designation
<b>SPT</b>	Standard Penetration Test
<b>TRL</b>	Transport Research Laboratory
<b>UXO</b>	Unexploded Ordnance

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We are grateful to our members who make a major contribution to our activities. In doing so they can be proud of the fact that they are also supporting the entire dredging community, and helping to bring together the many different parties involved, regardless of membership status. Without our members we would not be able to do such excellent work. We hope others will be encouraged to follow their example and join us in fulfilling our mission to spread knowledge, enhance mutual understanding and encourage best practice in the dredging profession.

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 Vuyk Engineering Rotterdam BV, *the Netherlands*  
 Vereniging van Waterbouwers, *the Netherlands*  
 Wärtsilä Nederland BV, *the Netherlands*  
 Wasa Dredging Oy Ltd., *Finland*  
 Witteveen+Bos

## Acknowledgement

This Information Paper is published by the Central Dredging Association (CEDA). CEDA is an independent, international forum for the exchange of knowledge, and experience, on all aspects of dredging, land reclamation and dredged sediment management. The Paper has been prepared by the Focus Group on Soil Investigation, working under the umbrella of the CEDA Dredging Management Commission.

\* The quote on the cover is from G. S. Littlejohn (1994).

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