FEATURE

Site Investigation Practice PART 1

By Ir. Shaik Abdul Wahed, Director, Perunding GEA (M) Sdn Bhd

Every civil engineering structure needs the ground, to build on, to build with or to build into. There is no civil engineering structure that can exist without the ground being a part of it. This simply means that when we are dealing with any civil engineering project, the ground plays an important role. The ground is also one component of any civil engineering project we know the least about. This is because the ground we work with is not man made, no matter how much information we try to obtain, the information will never provide a complete picture of the ground below. Therefore, when dealing with ground, we have to intelligently make most of what "little" information we do obtain; and make the best use of this information by modifying its usage in conjunction with other known factors like geology of the site area, existing condition of site and surrounds, our engineering judgment and our experience.

To understand this, please consider. Any structure we put on the ground is man made. We can control and design every item that goes into this structure. We can design components that go into this structure like, for example, the concrete to meet strength we require and its behavior in service. We ensure the behavior of our structure by extensive quality control requiring verifications and testings during the construction. In short, we can control our structure to the last nail or the wall plug and have our structure built exactly as we want.

This is not true for the ground below. The ground below, the sub-soils, on which this structure will stand are not man made. We know very little about them and we can certainly cannot design or control the sub-soil behaviour. The sub-soil behaviour has been set by virtue of its having been through millions of years of geological processes and beyond the control of engineers or geologists.

What we can do is to understand the ground behaviour/ properties that affect us and design our ground related structural components (including ground itself) to comply with the ground behaviour. It is the ground below which will dictate the safety and the economies of our structure. The economics will determine how tall, how big, how safe the final structure is going to be and not the other way round. In short, the safety and economics of every civil engineering structure is dictated by the properties of ground below, the sub-soils, on which this structure will stand.

These properties of sub-soil are obtained via processes we refer to by various names, e.g. Ground Investigation, Geotechnical Investigation, Soil Investigation and so on. In this paper we will refer to it as Site Investigation or simply SI. How this sub-soil information is obtained determines the reliability of the information. Reliability of the information of these properties of sub-soils has large influence on cost and safety of the project.

What is a Site Investigation

Site investigation is the process by which we obtain relevant properties of soils underlying the site. The important thing to realize is that it is an INVESTIGATION. Like any investigation, be it Medical, Criminal or Geotechnical, it involves iterative processes. This means one cannot always be right the first time we carry an investigation or be 100% right when our investigation is completed.

"Site investigation is the process by which we obtain relevant properties of soils underlying the site... Like any investigation, ... it involves iterative processes. This means one cannot always be right the first time we carry an investigation or be 100% right when our investigation is completed."

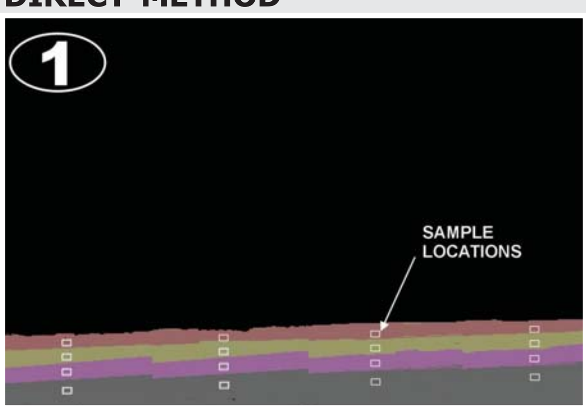
Any form of an investigation starts with some pre-information cumulating into some assumptions which are then verified by further steps, like in SI, sampling and testing, remote or direct using any of the number of methods available. Where the first assumptions are verified, well and good. Where the first assumptions are not satisfactorily verified, first assumptions are re-examined with what information is available and more tests/samples are carried out and so on. Amount of funds spent and continuous site problems that may occur during construction and ultimately the safety of the structure, depends upon the information obtained from the process of the SI.

DIRECT AND INDIRECT TESTS

Importance of SI can be easily seen if one compares the process of SI with a medical examiner trying to assess the nature of a patient's ailment. We use this analogy, as we will see later, both the medical assessment and the ground assessment, the SI involves indirect checks/samplings or tests. Putting this more crudely, it is not possible for medical examiner to open up the patient for direct examination of what may be ailing him (her). If the medical examiner indeed carries out direct examination he is very likely to find the exact problems affecting the patient but in the process of such examination, the patient would probably be dead (which is usually not permitted) or the patient will now face entirely new ailments as the result of the such direct examination.

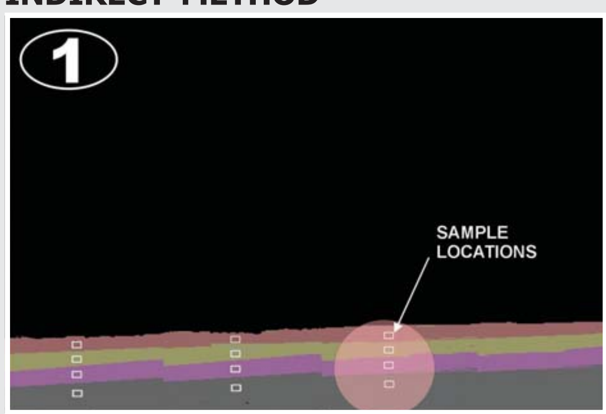
Similarly, we can carry out direct tests on the grounds of the site that we are interested in by digging extra huge holes/ pits, and carrying out numerous insitu tests or taking numerous extremely good samples for testing in laboratories. If we indeed carry out such direct testing, we are likely to get a very good picture of the sub-soils below but in the process may end up with altering the ground below to the extent that the nice picture we have obtained no longer represents the now altered ground below. Such testing is not practical. Direct sampling or testing is not very practical for depths greater than three metres as this method is not only very expensive but can be ridiculous when taken to the extreme as the following figures explain:

DIRECT METHOD



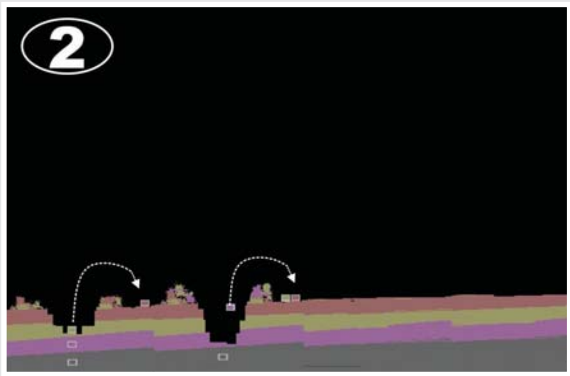
Let us say this is the site whose ground information we need to obtain. Let us also say using our desk study, we have identified where we want to take samples or want tests to be carried outstudy, we have identified where we want to take samples or want tests to be carried out

INDIRECT METHOD

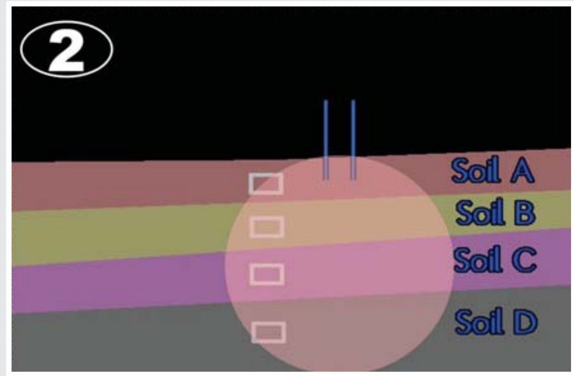


Let us say this is the site whose ground information we need to obtain. Let us also say using our desk study, we have identified where we want to take samples or want tests to be carried out.

DIRECT METHOD | **INDIRECT METHOD**

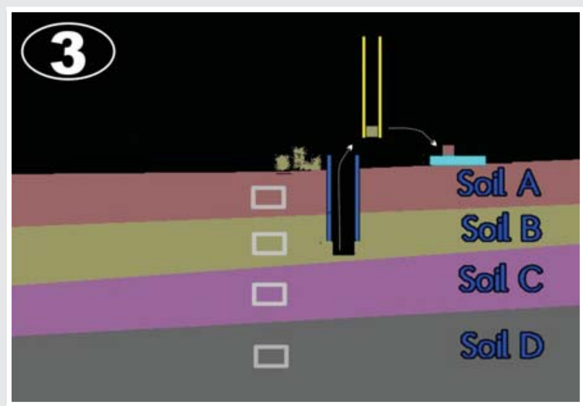


To get the best samples or tests we dig down to locations identified and say take the sample, and dig down to next location and do the same. Im2



So as not to destroy character of large volume of sub-soil, we drill a small hole to the position where we want to take sample, insert sampling mechanism, and cut out a sample or carry out a test. We are not physically at sample location and may not be able to see exactly how we are taking the sample. The only assurance we have of getting a good sample is we are following proper procedures and using correct equipment.

Similarly we take all the samples we have identified

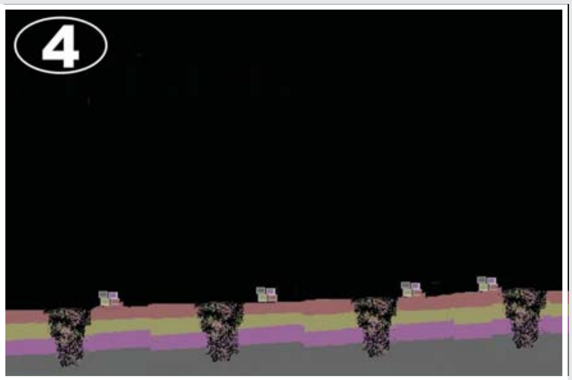


Similarly, using correct equipment and following proper procedures plus our field experience, we obtain the rest of the samples. We have to be very careful as only one sample can be obtained at a location, we are working remotely from above and cannot see what is going on at sampling position and only thing that guides us is our experience together with good equipment and procedures.

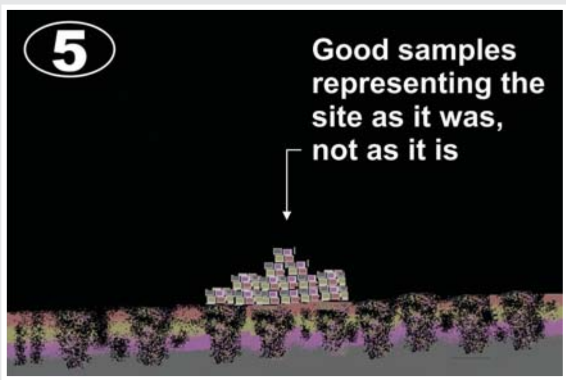
Extending this analogy, before doctor carries out any form of testing on the patient, he has to have some idea of what ails the patient. A doctor can assess likely causes affecting his patient by examining patient's medical history, age, sex weight and even occupation (in geotechnology, carry out similar assessments in the form of DESKSTUDY). This is then followed by direct examination like measuring temperature, weight, heartbeats, prodding and poking at various suspected areas of the body (comparable to the site visit). By this stage the doctor would have reasonable idea of what could be the problem. He would then ask for some tests to confirm his first assessment. He could be right and the results will confirm his assessment and he would then arrange for treatment which would very likely cure the patient.

On the other hand, if the tests he specified do not confirm his first assessment, he would have to re-examine the results

DIRECT METHOD

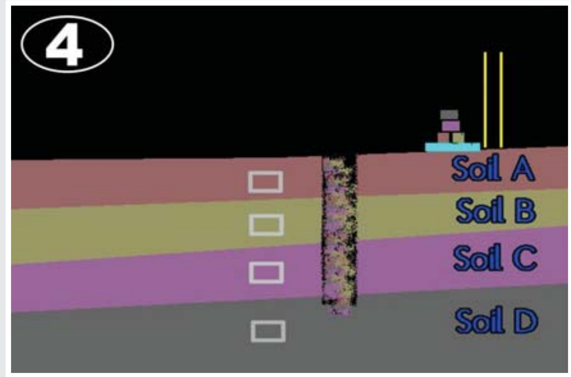


Having taken the samples we now fill the huge hole we created in the ground, under the assumption that more samples we get better will be our assessment of the site, we can repeat the same procedure all over the site...

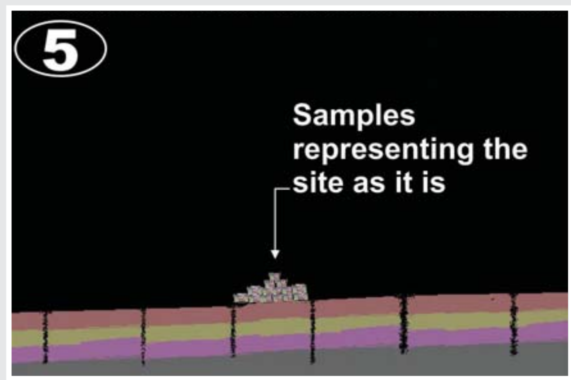


We now end up with good samples which are useless as all our digging and filling have very badly altered our site. Now our samples do not represent our site any more. We may have to repeat all this from beginning or look at different method of getting information we need.

INDIRECT METHOD



Once we are finished with the hole, we fill it up properly. Note that we are changing or altering only a thin column of soil where our hole was. The soil around the hole is still intact.



We now end up with good samples which still represent almost whole of our site as most of the site is still unaltered. We can repeat this method at as many locations as we like and still have information that relates to our site. This method is referred to as Boring/Drilling in soils and there are number of variations to methods used.

Figure 1. (Direct Method & Indirect Method 1, 2, 3, 4, 5). Except for very shallow depths, all subsoil testing / sampling involves indirect method, or better put, are remotely carried out.

and the patient and based on available findings, ask for different tests or more detailed tests and repeat the process or seek further expert advice.

Now imagine, the doctor does not know the patient's history (no desk study), fails to make physical examination of the patient (no site visit), specifies tests to be carried out based on his so called "experience". The tests are then carried out by outside laboratories on competitive basis and very likely carried out by imported, unskilled experts simply to save money (as our present state of SI). Under these circumstances, the patient may live with overdosed and costly treatment if lucky. If not lucky and the real problem was unnoticed, he may die or become yet more sick due to aggravated real ailment. If due to aggravated conditions, and more tests are carried out on the same patient by the same testing crew, the patient's future becomes somewhat uncertain.

Geotechnical engineering and ground assessment are very close to the medical analogy used above. The difference is, our medical profession has very good control on how tests are carried out, our geotechnical/engineering profession has no such control, at least, in our country.

What is RELIABILITY

Reliable SI information can be defined as information in compliance with specifications and relevant codes of practice using suitable equipment and ancillaries by trained operators under competent supervision.

Why RELIABILITY of Site Investigation is important

We have at our disposal many different methods of obtaining ground related information. Every method, without exception, requires skill, knowledge, care and adherence to procedures (as laid out in Specifications, Codes of Practice(s), manufacturer's guidelines). When all these are adhered to, we meet with underlying principle that the information obtained is *reliable, representative* and can be used in design by the engineer with confidence. This we would refer to as a good practice.

In this article we will focus on the most common method of Site Investigation using Boring and Drilling and in-situ sampling and testing.

The term "Reliability" where SI is concerned means all information obtained is obtained in line with good practice. All information obtained and observations made on work site are honestly and factually reported. In short, we feel confident that the information thus obtained is one on which we can rely upon. Such confidence or the reliability of information controls the design confidence and in turn, the cost of the project and the project safety. Reliability becomes yet more important when we take into account that all our information is obtained indirectly and remotely from above the ground at the test location far below the ground.

To see why reliability of information is so important, consider a simple 10-storey structure having, say, 10,000 square metre foot print as presented in Figure 2. Assuming that the bedrock is about 30 metres below, we estimate that this structure will affect the ground below as shown in Figure 3. Volume below affected by our structure is about or probably more than 10,000 x 30 metres of soil volume or 300,000 cubic metres. For our project, we need to estimate/assess the volume of soils below that is going to support our structure.

For the structure considered, we are likely to put down between 5 to 10 boreholes. Being generous and careful, let us say using 10 boreholes which will provide us with about 200 samples (or/and tests).

The total volume of sub-soil below actually sampled/tested will be at or less than some 200 x 1 metre x (area sampler 75mm) =0.8839285 cu metres or about 1 cubic metre. Of the above volume, in most cases less than half of collected samples will actually be tested and used for the assessment of the properties of the ground below. This one cubic metre of tested soil represents some 300,000 cu metres of affected ground below or as engineers call it, the sub-soils. This, in terms of percentages means our total ground assessment will be based on (1/300,000)x100 % or 0.00033 % of total volume of the affected subs-oils below.

Comparing this with tests we carry out on concrete we will use for structure above founded on this ground, we see that with total volume of concrete used for our structure, including foundations, will be some 1,500 cubic metres. Total number of test cubes taken will be (1500/50)x2x6 = 360 tests cubes. If only 1 in 6 cubes are tested, this

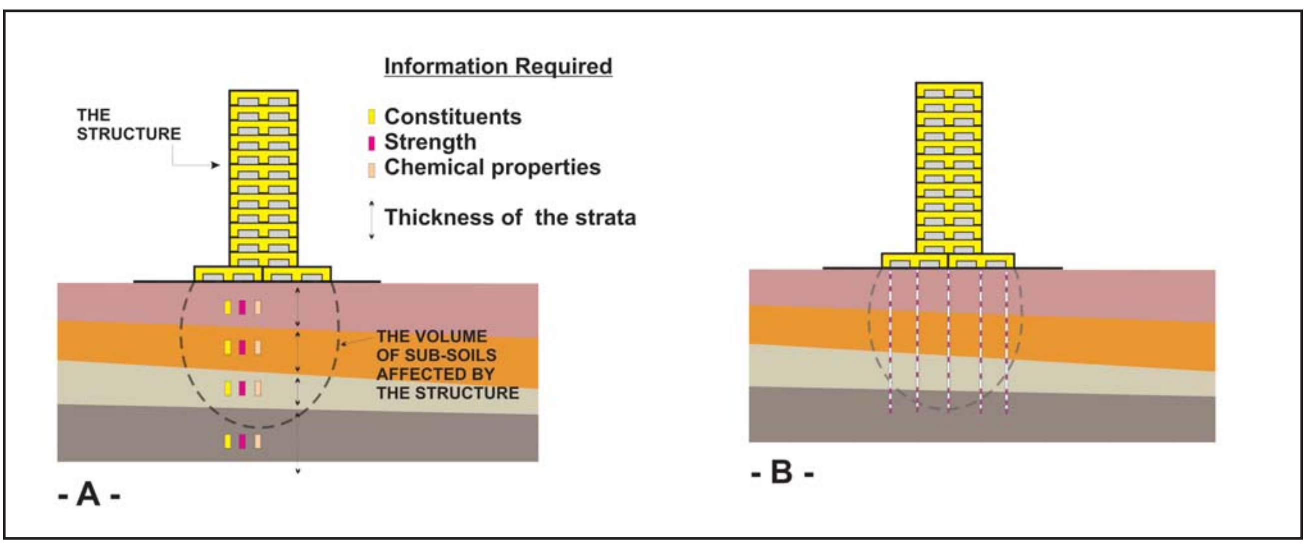


Figure 2

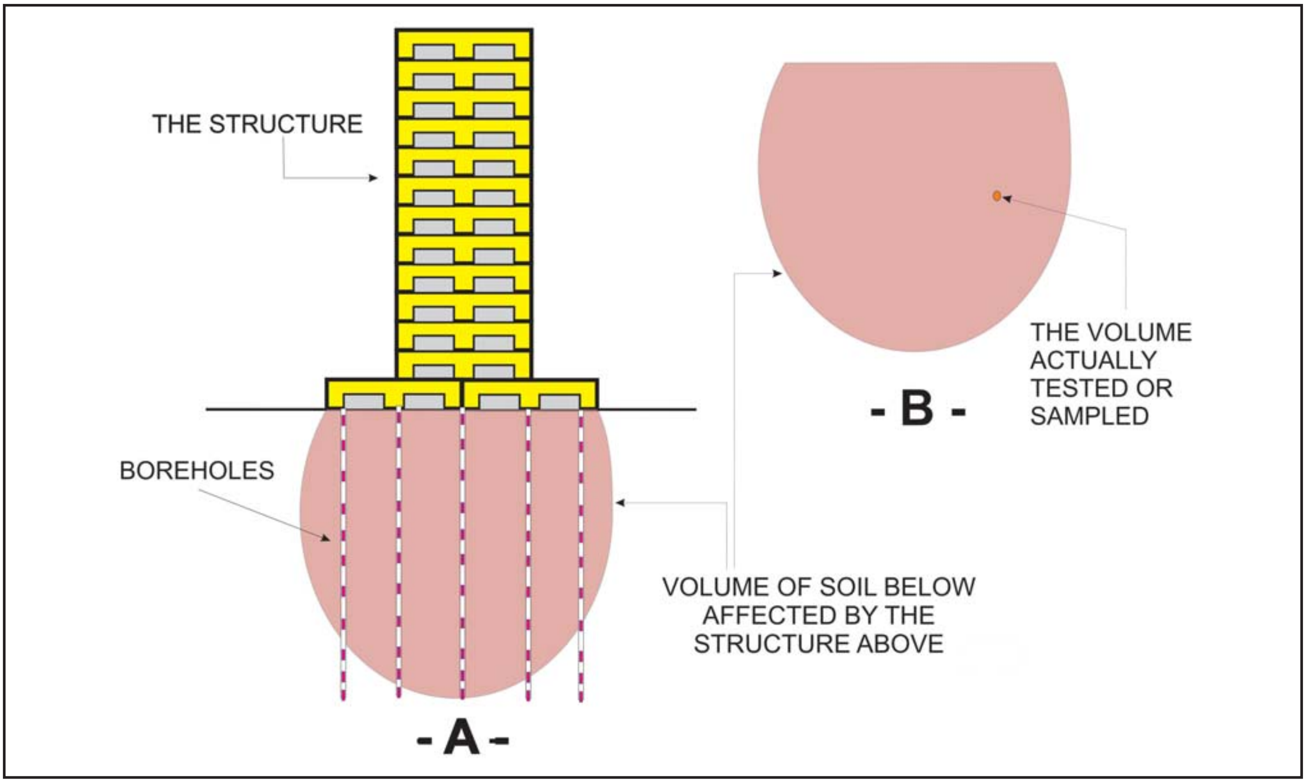


Figure 3

constitutes 0.0141 % of the total volume of concrete tested. What this means is that we carry out 40 times more tests on concrete than on sub-soils on which this concrete structure will stand.

In case of concrete, if one cube is bad, there are five in reserve; in case of sub-soils there are no reserves (we cannot take six samples at the same location below). As for representation, six concrete cubes represent 50 cu metres of concrete. In case of soils one sample represents 1500 cu metres of sub-soils.

Looking at this further, concrete is man made, we design and control closely the properties of the concrete that goes into our project. On the other hand, sub-soils below are not man made, they are very variable and we have no control over the properties of the sub-soils. *In short, we test the material we can control and design at much greater intensity (40 times more) than material over which we have no control, i.e. sub-soils properties of which we cannot control.*

In case of sub-soils, apart from not having direct control, we have just one sample representing a large volume of sub-soil compared to six concrete cubes (samples) representing much smaller volume. We do not have backup as in concrete or steel. We therefore have to get our testing or sampling right the first time. This requires not only the strict adherence to procedures but large amount of operator skill and competent supervision. Here adherence to procedures, operator skills and care play paramount role, and is a good practice. When good practice is followed, the test information can be considered reliable. Such information provides design confidence and lead not only to safe designs, but save considerable funds and avoid mid or post construction problems.

Reliability of SI information is dependent upon the following:

- Suitable Equipment And Ancillary
- Operator Competence,
- Procedure Adherence
- Competent Supervision
- Open Communication
- Intelligent Observations
- Ability To Vary Test Procedures
- Factual Reporting

When all the above are in place, we can say with confidence, our SI data is reliable and it can be used in design. The influence of the reliability of the SI information is represented in Figure 4. When data is reliable and the engineer knows it is reliable, ground related designs are bound to be economical and safe (Blue circle).

However when data is unreliable, the engineer is forced to apply all sorts of adjustments at each step during the design, increasing costs. All this is then doubled or tripled by applying a conservative factor of safety. All this does not guarantee project safety, but makes it expensive. It also cannot avoid costly mid and post construction problems or cost increases introduced by foundation contractor to cover himself against uncertainties.

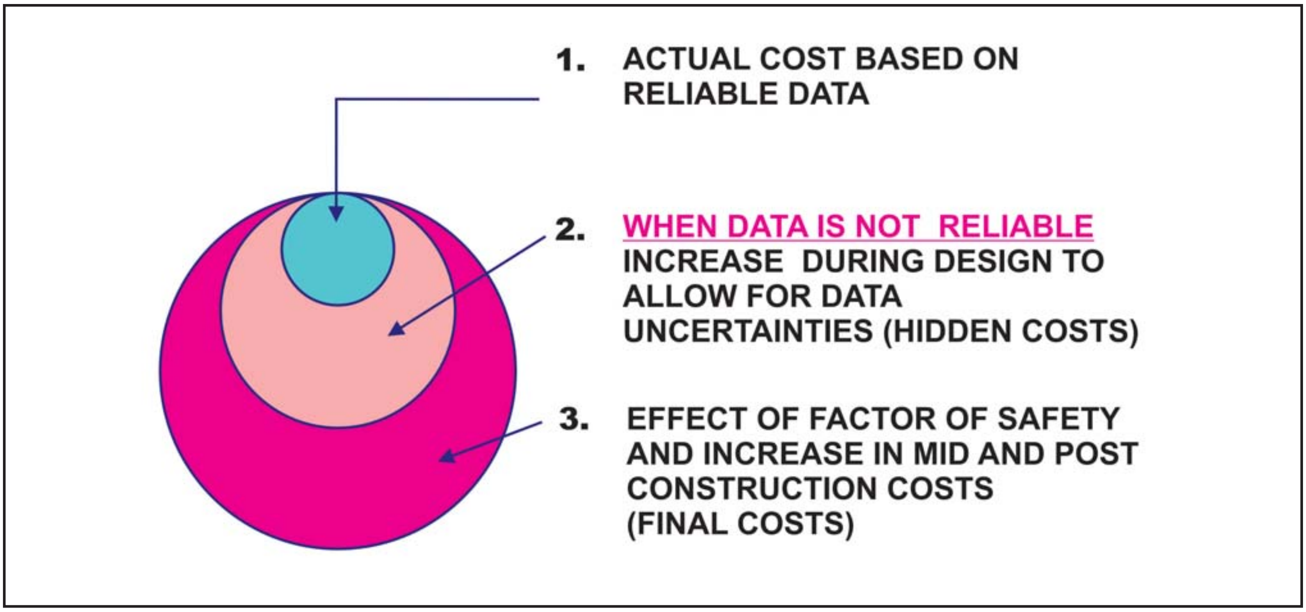


Figure 4

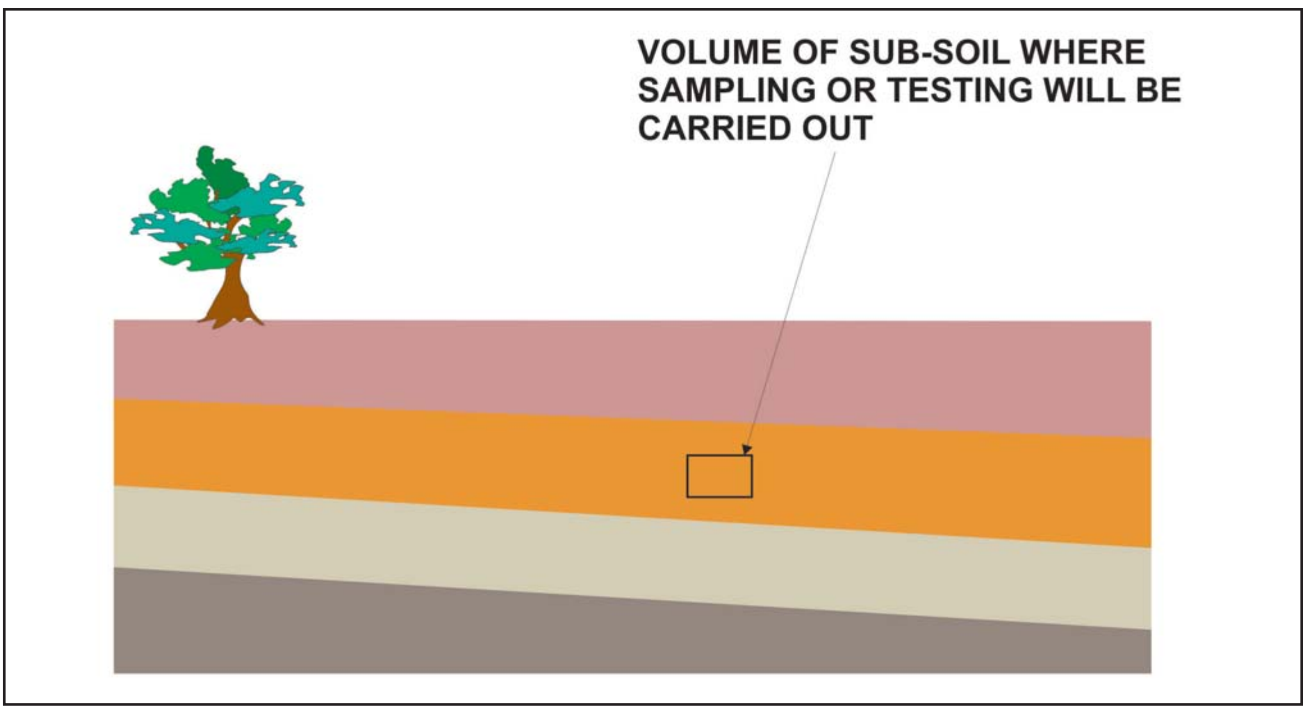
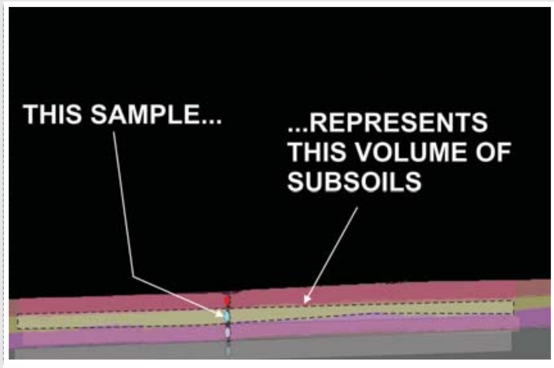
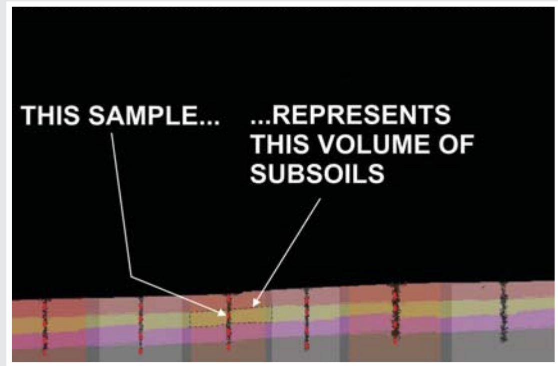


Figure 5



With only one borehole, each sample represents very large volumes of soils. Such representation does give some idea of sub-soils below, but not a good picture



With a number of boreholes put down at carefully selected locations, each sample now represents much smaller volume than the above case and the sub-soil picture obtained is a lot closer to actual. Each sample still represents a very large volume of sub-soil. To be able to do this requires local knowledge (geology) and experience.

Figure 6

REPRESENTATIVE SAMPLES/TESTS

Whatever the method used to test sub-soils, the prime requirement which must be met every time is that *the volume of sub soil to be tested or sampled must not be altered or changed before the test or sampling is carried out on that volume of the sub soil* (Figure 5). If this condition is not met, then we are actually testing or sampling in the sub-soil volume which is no longer the same as its surrounding soil. The sample or test here is no longer representative of sub-soil around it and therefore as good as useless. Where samples/tests are representative, they can be used to estimate the sub-soil characteristics with confidence. Representative samples by themselves cannot provide an acceptable picture of the sub-soils. The usable estimate of the sub-soils require not only reliable and representative sample/tests but selection of the number of tests and the locations where these samples/tests are taken. This requires both experience and local knowledge, because too many samples/tests obtained indiscriminately may cost more but do not provide good information. Figure 6 explains this.

Basics of SI

Site Investigation is unique compared to any other verification/proof or similar tests carried out for civil engineering projects. Site Investigation simply provides a report at the end of the day. It would be very difficult to verify correctness/reliability of this report after the work is finished. This report consists of faithfully reported findings at test location on project site. It does NOT provide information for the whole site. Nevertheless, this report forms the basis on which millions will be committed on a project and can make or break the project. Looking at how SI differs from any other civil engineering operations one will find that SI involves the ground and all grounds are variable from the engineering point of view. Because of this variability plus no direct accessibility to the test location, we are faced with a number of limitations if one compares sampling and testing of sub-soils with sampling and testing of man-made materials, from piles to the roof of an engineering structure.

All samples are taken and insitu tests are remotely carried out. We have to carry out this operation from ground surface to location some metres below the ground.

- Samples can only be tested once, once tested the sample is destroyed. Location at which sampling or testing is carried out is changed as the result of sampling or testing.
- Test results apply only to the location where the tests/samplings were carried out and this location is no longer the same as a result of testing/sampling.
- SI report provide FACTUAL reporting of all observation and findings but no interpretations
- SI report does not provide sub-soil information for the whole site, it only provides "key hole" view of sub-soils at the test locations. SI report by itself is insufficient for any site characterization.
- The site characterization of the whole site is made by geotechnical engineers and geologists using SI report as the basis, and in conjunction with their local knowledge, local geology and engineering judgment.