CHAPTER 4 - FOUNDATIONS

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4.1 SCOPE

Monitoring of the construction of foundations for road related structures is concerned not only with the verification of compliance with the design requirements, but also with the construction methods, permanent and temporary works and safety measures necessary to achieve adequate and economical foundations.

In this chapter guidance is provided about relevant design aspects and the issues which commonly arise during the construction of foundations for conventional spread footings. These foundations are usually located at depths not more than about 5 m below ground but in certain instances can be considerably deeper. The construction of piled foundations and caissons is dealt with in Chapter 5.

Sometimes it is economical to carry out soil compaction, replacement or other soil improvement procedures in order to found on weak soils at shallow depth. These specialised procedures are also briefly discussed in this chapter.

4.2 FUNCTION

The primary function of foundations is to provide adequate support to the structures which they carry. This implies sufficient load bearing capacity to safely resist the effects of the various combinations of permanent and transient loads transmitted to the founding strata, without excessive deformation, which could otherwise compromise the integrity of the structure or impair its use. The safe or allowable bearing pressure is therefore a function of the ultimate load bearing capacity of the ground at the founding level and the load-settlement characteristics of the underlying layers.

In the case of rock foundations the allowable bearing pressure is determined from rock mechanics principles, with due regard to the degree of weathering, the inclination of the rock strata, the presence of shear planes, fissures and clay gouges in the bedding planes, among other factors. On intact rock foundations, bearing capacity may be less critical than other criteria, such as safety against overturning of earth retaining components for example.

The interaction between the structure and the ground when founding on compressible soils is an important consideration regarding the articulation of the structure, usually to a greater degree than when founding on rock. The deformation of soils under load can vary greatly depending on the type, depth and characteristics of the soil, which are determined from in situ or laboratory tests. When it is uneconomical or unsafe to found at shallow depth due to the estimated magnitude of the deformation, it becomes necessary to resort to soil improvement or support on piles or caissons.

The safety of the foundations of river bridges and drainage culverts is also subject to the potential effects of scour. Resistance to undermining by scour is dependent on the nature of the support strata, the depth to founding and the protective measures, among other factors, which are beyond the scope of this chapter.

4.3 DESIGN AND CONSTRUCTION FACTORS

The factors which relate to the foundations and which influence the design of structures and subsequently become the concern of the contractor and those monitoring the construction of foundations, can be summarised as follows:
4.3.1 Founding Material

(a) Soil or rock.
(b) Degree of compressibility, expansiveness, porosity etc.

4.3.2 Depth of Founding

(a) Shallow: usually not more than about 3 m.
(b) Intermediate: usually between about 3 m and 6 m.
(c) Deep: usually greater than 6 m.

4.3.3 Location of Founding

(a) Land environments, which are further subdivided into those which are:
   • remote from existing constructions, or
   • adjacent or near to existing services (roads, railway lines, pipelines etc) or structures
     (buildings, bridges to be widened etc.).
(b) Water environments, in which the structure is required to be founded below water level, or in
    waterlogged or unstable ground.

4.3.4 Method of Construction

(a) Access to and drainage of the excavations.
(b) Open unsupported excavations.
(c) Excavations which require lateral support.
(d) Underpinning of existing structures.
(e) The method of excavation and removal of spoil.

The circumstances which render it unsafe or uneconomical to construct conventional spread footings
and preferable to resort to piled foundations or caissons can vary greatly from site to site and are likely
to be influenced by the rate of progress needed to meet tight programmes, especially in water
environments subject to flooding.

4.4 GEOTECHNICAL INVESTIGATION

It is of the utmost importance to obtain adequate and reliable
knowledge of the sub-surface conditions from well-planned
geotechnical investigations. The information provided by such
investigations is required initially for design purposes and later as a
guide during the tender and construction stages.

REQUIREMENT
It is essential that the monitoring staff are in
possession and aware of the contents of the
geotechnical report.

At the design stage, information about the founding conditions is one of the main determinants in the
selection of the structural form of bridges, the span lengths and the configuration of the components of
these structures. At the tender stage the foundation and other site data are needed for the purposes of
planning and pricing the permanent works and any temporary works required for safety during
excavations. This information is carried through to the construction stage for implementation and the
guidance of those monitoring the work.
4.5 SOURCES AND AVOIDANCE OF RISK

Foundation work is usually that part of the construction of structures which is the most uncertain and prone to risk. The sources of risk include factors which affect the safety of the work during construction and the utility of the structure on completion, such as the following:

(a) Inadequate or inaccurate data obtained from the geotechnical investigations.
(b) Inadequate or variable conditions encountered at the anticipated founding levels.
(c) The difficulties of access and drainage and the potential for inundation in water environments.
(d) The potential for the collapse of excavation sides, especially in the presence of groundwater and when excavations are adjacent to existing roads, railway lines or structures.
(e) Inadequate lateral support of excavations, which can lead to settlement damage of adjacent services or structures.

Unreliable foundation data can result in possible delays and additional costs in rectification, potential claims for delay and in extreme cases to foundation failure.

Notwithstanding extensive foundation investigations it needs to be remembered that geological conditions can be highly variable even over short distances. Founding conditions should therefore always be treated as uncertain prior to excavation.

Uniformity in foundations is necessary to avoid the risk of differential settlement and distortion of the structure. When founding conditions at the anticipated levels differ significantly from those anticipated, advice should always be sought from the engineer on the steps to be followed. A provisional sum for Additional foundation investigation should be included in the Bill of Quantities to cater for this contingency (such as COLTO Item 61.01, for example).

Identification of the specific hazards and risks of foundation construction and formulation of the means to counteract these are critical initial steps in the avoidance of risk on any project. This must be followed by the diligent application and monitoring of the contractor's health and safety plan, as discussed in the following sections.
4.6 MONITORING OF FOUNDATION WORK

The function and duties of the various personnel appointed to administer and monitor construction contracts are outlined in Chapter 2. However, during foundation work additional vigilance is required because of the difficulties and hazards often arising during this stage of construction.

It also needs to be borne in mind that the start dates of subsequent elements of the work are dependent on timely progress with foundation construction and therefore require prompt response by the monitoring staff to the contractor's requests for inspections, answers to queries, instructions regarding unforeseen conditions, approvals and so on.

In this chapter reference is made to the contractor's competent person (CCP), appointed to design, inspect and verify the adequacy of temporary works, such as lateral support, required during the excavation and substructure work. In terms of the Engineering Profession Act (No. 46 of 2000) the CCP is required to be registered and competent in relation to the services to be rendered.

The monitoring staff should therefore:

- ascertain that the contractor has acted upon any concerns they may have recorded about the design and installation of the temporary works;
- ensure that the CCP has inspected and signed off the temporary works, and
- regularly thereafter inspect the temporary works until and during removal.

Any signs of distress in the temporary works, such as undue deflection or the settlement or cracking of the ground behind lateral support for example, must immediately be reported to the contractor and the engineer as these are indications of incipient failure.

Monitoring staff who require more detailed information and guidance about all aspects of foundation engineering relevant to their duties are encouraged to study the references listed at the end of this chapter.

4.7 CONTRACT DOCUMENTS AND CONTRACTOR'S SUBMISSIONS

4.7.1 Contract Documents

Prior to the commencement of construction the monitoring staff will be furnished with the contract documents, which comprise: general conditions of contract, specifications, project document, drawings and relevant reports.

With regard to the foundations, they are expected to thoroughly familiarise themselves with the drawings, geotechnical reports, hydrological reports when applicable, and any special foundation construction requirements, in order to understand the requirements of the design and guard against anticipated difficulties and hazards.
4.7.2 Contractor's Submissions

At an early stage after the award, the contractor will be required to submit the following information and construction proposals:

(a) Construction programme.
(b) Health and safety plan.
(c) Environmental management plan.
(d) Temporary works drawings for lateral support (including calculations if required).
(e) Method statements, including diagrams if necessary, for access and drainage works such as: temporary river or stream diversions, causeways, islands, cofferdams and dewatering arrangements.

The monitoring staff are required to critically review these submissions with regard to the feasible sequencing of the work, practicality, safety, environmental constraints and inadvertent omissions. The contractor must be advised of any perceived shortcomings in these submissions and instructed to make adjustments if necessary.

It is important to carefully appraise the contractor's proposals for the removal of temporary lateral supports as the most hazardous conditions often arise during this stage of foundation work, which is usually undertaken simultaneously with backfilling operations.

The monitoring staff are empowered to instruct the contractor to update the abovementioned submissions if progress is delayed or circumstances change materially from those envisaged at the outset.

4.7.3 Health and Safety Plan

The formulation, implementation and monitoring of the contractor's Health and Safety Plan, as outlined in Section 2.10 of Chapter 2, has particular relevance to foundations because of the hazards and risks inherent in this stage of bridge construction.

Whilst monitoring staff are required to verify the contractor's compliance with all facets of the safety plan, they are encouraged to approach their task in a co-operative spirit, in which pro-active mitigation of risk is advocated rather than re-active fault finding.

**WARNING**
The collapse of unsupported trenches or excavations is probably the leading cause of construction deaths. Those that treat excavations without due care do so at their peril!

The monitoring staff are advised to familiarise themselves with the responsibilities of each of the parties, as set out in the Construction Regulations, and are required to ensure the contractor's compliance with all facets of the approved health and safety plan. In the event of transgressions of sufficient severity, such as to cause an imminent threat to the health and safety of persons, the engineer is empowered to stop the work.
4.7.4 Environmental Management Plan

Foundation construction in environmentally sensitive areas such as rivers, dams, lagoons and wetlands is invariably subject to strict controls, whereas such work in less sensitive environments may require the application of 'good housekeeping' only.

As noted in Section 2.11 of Chapter 2, the Environmental Management Plan is likely to require special measures for foundation work involving stream diversions and for the construction and subsequent removal of access causeways and artificial islands. Likewise the location of excavation stockpiles will need to be strictly controlled to avoid environmental transgressions, when excavations are near to defined floodlines.
4.8 CONSTRUCTION

Issues likely to arise and points to watch during foundation construction are described in the following sub-sections in relation to the usual sequence of the work.

4.8.1 Setting Out

4.8.1.1 Accuracy

Setting out, as more fully described in Chapter 3, is a critical initial step required prior to the commencement of foundation excavations, to ensure the correct positioning and alignment of the substructure footings relative to the road staked line and in relation to each other.

It needs to be remembered that the geometry of the entire structure is dependent on the accuracy of setting out, which must be carried out in terms of and to the accuracy stipulated in the specifications.

4.8.1.2 Independent checks

Whereas the contractor is solely responsible for the setting out of the works, it is recommended that in the following cases the engineer should arrange for independent survey checks of the contractor's setting out, over and above any less rigorous checks carried out by the monitoring staff.

(a) Bridges which have complex plan geometry.
(b) Strut frame and arched structures which have inclined substructure elements and foundations, and for which the springing points are critical both in plan and elevation.
(c) Bridges which require the construction of causeways and artificial islands in order to gain access to the position of the foundations.

Any discrepancies between the initial setting out and the subsequent checks must be resolved before the commencement of excavations.

Photo 4.4: What to do now?

4.8.1.3 Foundation excavations

If the accuracy of foundation excavations is not indicated in the specifications, it must be inferred that the excavations should be set out to the same accuracy as specified for footings, when these are permitted to be concreted against ground.
When the engineer requires the side faces of the footings to be formed, the amount of side space beyond the perimeter of the footings allowed for measurement purposes is usually stated in the specifications (for example: 0.5 m in COLTO Sub Clause 6105 (c)). Any additional excavation arising from battering the sides of the excavations is to the contractor's account. In these instances the setting out and extent of the excavations at the ground surface are not the concern of the monitoring staff unless safety or environmental constraints are likely to be compromised.

### 4.8.1.4 Verification of setting out

As the initial setting out will have been carried out at the ground surface it is important that this should be rechecked at the founding level, which may be several metres below ground.

### 4.8.2 Access and Drainage

#### 4.8.2.1 Access

Access (as described in COLTO Sub Clause 6104 (b) for example) relates to the construction and subsequent removal of embankments, cofferdams and drainage facilities in locations where it would otherwise be impractical or unsafe to transport and operate plant and equipment needed for the excavations, or for the installation of piles or caissons.

In the case of running water it will usually be necessary to line the sides of embankments required for causeways or artificial islands with rock or other protective measures, in order to reduce the risk of erosion and thereby preserve the integrity and strength of the embankment. The choice of the level at the top of such embankments and the amount of freeboard above seasonal water levels is the contractor's risk alone. These levels will usually be sufficient to prevent inundation by minor floods, determined from information about previous floods if available, the size of the catchment and the duration of the work susceptible to flooding.

In the interests of safety in river environments, the contractor and the monitoring staff should regularly check weather forecasts, weather reports and water levels in order to effect timely evacuation and the removal of plant and equipment to minimise the risk of impending floods.

#### 4.8.2.2 Drainage

The adequacy of the drainage measures adopted during construction can significantly influence the safety of the excavation work and can adversely affect the bearing capacity of the founding and underlying strata if not soundly planned and implemented.

Drainage of excavations (as contemplated in COLTO Sub Clause 6104 (c) for example) includes the following measures, which may suffice individually or may need to be implemented in combination depending on the rate of ingress of water, in order to keep the foundations dry or to control the ponding of water to a degree which can be managed during the construction of the permanent work.

- **(a)** Exclusion of surface water from the excavations by the construction of berms and/or open drains.
- **(b)** Gravity drainage of open unsupported excavations, where topography permits drainage from a sump in one corner on the downhill side of the excavation.
- **(c)** Pumping from a sump formed outside the footprint of the permanent works. This is usually the most economical means of dewatering excavations.
(d) Additional exclusion measures such as the double lining of cofferdams or lowering the groundwater level, using sumps, wells or well points outside the excavations. These and other specialised drainage measures are described in the references.

If at any stage during the excavations the inflow of groundwater is perceived to render the work dangerous, the monitoring staff must bring the matter to the contractor's immediate attention, or instruct the evacuation of the excavation in the event of emergency. At the stage of inspecting the ground at the anticipated founding level, ponded or running water should always be removed by the installation of additional pumps if necessary, as verification of the adequacy of the foundations and subsequent concreting of the permanent works could otherwise be compromised.

4.8.3 Open Unsupported Excavations

This form of excavation is often the quickest, most economical and accessible for a foundation at shallow or intermediate depth in relatively stable soil, when space is not a problem. The main design consideration is that of the stability of the excavation side slopes, the safety of which must be verified in writing by the CCP in order to comply with the requirements of the OH&S Act Construction Regulations.

Unlike cofferdams, open unsupported excavations offer flexibility in the means of carrying out the excavations, including blasting when required, and of the removal of spoil. Likewise, backfilling operations can usually be carried out easily and safely, in contrast to excavations with lateral support in which props can be a hindrance and the subsequent removal of the support is often hazardous.
4.8.4 Ground Anchors

4.8.4.1 Types and applications

Ground anchors employed in the construction of foundations are subject to the provisions of the specifications and usually comprise two main types, viz:

(a) Post stressed tendons comprising threaded bars or strand, with alternative anchor configurations and differing arrangements for stressing, re-stressing or de-stressing.

(b) Soil nails comprising unstressed or lightly tensioned high yield stress bars, which are usually fully grouted and act together with a reinforced shotcrete membrane, which retains the material between anchors.

Both types of anchors can be used for temporary or permanent work. However, only post stressed anchors are employed to resist high forces imposed by retained soils and water pressures, or to impose high forces required to stabilise rock strata with inclined shear zones, for example. Untensioned soil nails are designed to give stability to excavated soil faces and are usually concealed behind precast concrete or similar facings when required for permanent, visible locations.

The range of applications, alternative types, technical requirements, design, installation and testing of ground anchors are described in detail in the references.

4.8.4.2 Duties of the various parties

In the case of ground anchors required as part of temporary lateral support work, the design will be undertaken by the CCP, but in the case of permanent rock anchors the design is the responsibility of the designer of the main structure, both of whom are referred to as the design engineer as follows.

The design engineer will determine the requirements of the ground anchor system as well as the responsibility of the contractor in terms of the performance of the anchor parts, the materials used, the transfer of the anchor force into the ground and the testing arrangements.

In response, the contractor is required to submit details of the proprietary anchor system proposed together with a method statement for approval by the design engineer.

4.8.4.3 Construction and monitoring

Normally the installation of ground anchors and the de-stressing of temporary anchors is undertaken by a specialist geotechnical contractor. In view of the importance and technical complexities of this element of foundation work it is essential that the work should be entrusted only to companies with the requisite skills and experience.

The duties of the monitoring staff relate particularly to the construction of permanent ground anchors to ensure that:

(a) The materials comply with the specified requirements, with particular regard to materials strengths, extension properties and corrosion protection.

(b) Drilling is undertaken in compliance with the required geometry.

(c) Anchors are assembled and protected as specified and installed (homing) as soon as practical after drilling.

(d) Grouting is completed as soon as practical.
The stressing and testing of prestressed ground anchors, including proving tests, when relevant, is required to be carried out in compliance with the approved method statement and is the most important aspect of this type of ground anchor construction, which requires diligent overview and record keeping by the monitoring staff.

When the acceptance tests prove the adequacy of a ground anchor this must be signed off by the contractor and the monitoring staff, following which the anchor head must be coated, sealed or concreted in the box out as specified.

### 4.8.5 Lateral Support and Underpinning

#### 4.8.5.1 Cofferdams

The function of a cofferdam is to provide safe working space down to the founding level when lateral support of the surrounding ground is required, and from which water is excluded sufficiently to provide access for workmen, plant etc, removal of spoil and the execution of the permanent work.

A cofferdam is usually a circular or rectangular enclosure which is driven into the ground prior to the commencement of excavation, to a safe depth in relation to the anticipated founding level, in order to provide lateral support and limit the ingress of ground water to a degree which can be controlled without excessive pumping. Cofferdams and caissons fall into the same class of structures, the main difference being that a cofferdam is generally a temporary structure, part or all of which is removed after construction, whereas a caisson is primarily a permanent structure, or one which is subsequently incorporated into the permanent work.

Cofferdams may be used down to depths of about 15 m below water level, depending on the nature of the surrounding soil. These structures offer the advantage of access for the purpose of inspection and verification of the quality of the foundations. However, the installation and removal of cofferdams can be slow and expensive and is often avoided in favour of construction using caissons or piles. Cofferdams are normally constructed using one of the alternative embedded wall systems listed in the following sub-section.

**WARNING**

In the event of the failure of a ground anchor to meet the acceptance criteria, the matter must be promptly referred to the design engineer for a decision on the steps to be followed.
4.8.5.2 Lateral support systems

The factors which influence the selection of a lateral support system are those listed in sub-sections 4.3.1 to 4.3.3 and additionally include:

(a) The magnitude of the ground movement which can be tolerated by adjacent services and structures, when applicable, during and after construction.

(b) The availability of the skills, plant and materials needed for this specialist aspect of foundation work.

Lateral support systems fall into two main classes, viz:

(a) **Embedded walls**, which act either as vertical cantilevers to support the excavated faces, or which are successively braced or tied back by ground anchors at greater depths as the excavation proceeds.

(b) **Reinforced soils**, which comprise soil nails (high yield stress bars, fully bonded by grout in the retained soil) inserted into the ground behind the excavated face as the work progresses in stages, acting together with mesh reinforced shotcrete covering of the face. Other forms of reinforced soils, described in the references, are not normally applicable to the support of excavations required for road related structures.

The forms of embedded walls most likely to be used to support the excavation of bridge foundations are: steel trench sheets, steel sheet piles, precast concrete piles and steel soldiers with timber lagging.

Steel trench sheeting is manufactured in South Africa and is suitable as a means of support for shallow excavations, not normally exceeding a depth of about 4 m. Trench sheeting is an economical support system for narrow excavations often required for foundations between or adjacent to existing roads or railway lines. As this system can usually be installed and removed quickly, it is particularly convenient when railway occupations limit the frequency and duration of foundation work permitted near too busy export and commuter lines.

Steel sheet piling, braced by props or tied back by ground anchors, is the most common form of lateral support for intermediate and deep excavations, especially when it is necessary to exclude groundwater. Sheet piles have the facility to interlock and essentially form a watertight wall or enclosure. However, steel sheet piles are imported, expensive and sometimes difficult to procure, which can delay the start of construction. Precast concrete piles and steel soldiers with timber lagging are an alternative to steel sheet piles but do not exclude groundwater to the same degree.

In the case of bridge widening and doubling, it is often necessary to remove parts of existing road embankments and to support the remaining cut faces in order to provide safe working space for the construction of new foundations. Lateral support comprising soil nails with mesh reinforced shotcrete facings is particularly advantageous in these circumstances, as these can be installed very quickly at vertical increments of about 1,5 m as the excavations proceed. However, this system is not suitable in most instances below the water table or in the presence of soft clays or boulders.
The references provide detailed information about the range of applications, advantages, disadvantages and comparative costs for the alternative lateral support systems available, as well as guidance about the design and installation of these systems.

### 4.8.5.3 Underpinning

The need for underpinning of existing structures can arise in several circumstances associated with roadworks, such as:

(a) The widening or doubling of existing bridges, which require new foundations adjacent to the existing foundations.

(b) The introduction of new traffic lanes in built up areas, where cuttings extend close to road reserve boundaries and affect adjacent buildings.

(c) Foundations of bridges or culverts which have been undermined by scour or piping of granular founding strata. In the case of culverts it will be necessary to compare the cost of the remedial work with that of replacement of the culvert in its entirety, before embarking on reinstatement of the support.

In the first two cases, the need for underpinning can be caused by the following:

(a) The reduction or removal of lateral support to the material under existing foundations.

(b) A change in the water table which affects the strength or the compressibility of the soil under existing foundations that may lead to unacceptable settlements.

(c) The possibility of settlements of structures due to underground excavations or vibration caused by blasting, pile driving etc.

The procedures currently available for underpinning are many and varied and are briefly outlined in the references. When the need for underpinning has been foreseen at the design stage, the proposed method of underpinning should be fully outlined in the drawings and project specifications. When the need for underpinning becomes apparent only during the foundation work, the procedure to be followed must be defined or approved by the engineer.
4.8.5.4 Construction monitoring and verification of adequacy

Foundation work involving the construction and subsequent removal of lateral support systems and the work within the associated excavations falls into the category of high risk because of the significant lateral forces imposed on those systems by the retained soil and the potential for bottom surface "blow out". Underpinning the foundations of existing adjacent buildings or bridges is an equally risky operation.
Monitoring staff are required to pay special attention to the requirements of the applicable method statements and drawings to avoid any short cuts on the part of the contractor during the work associated with lateral support and underpinning. When underpinning is required it is essential that a detailed inspection and record of the state of the existing structure is made, including photographs, and that these are confirmed in writing by the contractor, monitoring staff and the affected property owner, when applicable. A similar inspection and record should follow completion of the underpinning and adjacent foundation work in order to avoid spurious claims or to substantiate claims.

4.8.6 Excavation

Prior to and during the process of excavation the monitoring staff, in co-operation with the contractor must establish, take note of, act, measure and agree on the following, as applicable:

(a) That the accuracy of the foundation setting out has been checked and confirmed.
(b) The surface levels of the undisturbed ground at the top of each excavation.
(c) Whether or not working space is required to be provided around the perimeter of the footings.
(d) The lateral support and drainage measures to be implemented during the work, including the inspection and signing off by the CCP.
(e) The protective barriers to be installed around the perimeter of excavations at surface level.
(f) The proposed method of excavation and the protective measures required by the engineer to be implemented when blasting is permitted.
(g) The engineer’s requirements for backfilling of overbreak i.e. mass concrete or concrete of the same class as the footing.
(h) The quantities of the materials excavated in the relevant depth ranges and the classification thereof i.e. soft or hard (including the size and density of boulders when applicable).

The monitoring staff are advised to compare the nature of the soil or rock strata encountered at succeeding depths with the borehole data, in order to judge whether conditions at the anticipated founding levels are likely to match the design requirements. The engineer should be advised of any significant discrepancies.

A record must be kept and agreed with the contractor of any alteration to the method of excavation required by the engineer and of any additional hand work required when the excavations have been completed.

WARNING

In the event of unforeseen conditions arising during the course of excavation, which are perceived to be potentially dangerous or which could give rise to extra cost, the monitoring staff should promptly advise the contractor and consult the engineer on the steps to be followed.
4.8.7  Founding

4.8.7.1  Verification of adequacy

When the excavation reaches a level at or near to the anticipated founding level shown on the drawings which is perceived to be suitable for founding in terms of the safe bearing pressure, the bottom of the excavation shall be cut and trimmed to a uniform surface and inspected by the engineer to confirm its adequacy. Following the engineer's confirmation of the suitability of the material for founding, the bottom surface levels should be agreed with the contractor and concrete screed or foundation fill, as required by the engineer, placed as soon as practical.

If the material at the anticipated founding level is deemed to be unsuitable by the engineer, this process should be repeated to the depth limit indicated by the engineer, below which the engineer will again advise on the steps to be followed. When the founding conditions differ materially from those anticipated it may be necessary to carry out additional foundation investigations and in extreme cases to redesign the affected part of the structure. At no stage should site monitoring staff undertake this redesign themselves.

4.8.7.2  Additional measures

Prior to the placing of concrete screed or foundation fill the following additional measures should be implemented as shown on the drawings or as instructed by the engineer:

(a) Grouting of rock fissures.
(b) Installation of foundation dowels.
(c) Installation of foundation lining.

4.8.7.3  Foundations for box culverts

The foundation investigations for box culverts often requires careful planning to avoid difficulties which can arise when the alignment of these structures depart from the natural water courses at intervals because of the tortuosity of the streams. This can result in significant variations in the strength and compressibility of the founding materials along the length of a culvert. In coastal areas culverts are often founded on loose sands and soft clays which extend to significant depths.

In these circumstances it is usually necessary to remove weak soils or unstable ground to the depth of several metres and to install engineered rock fills. This measure will usually reduce the potential for settlement and embankment stretch to a degree which can be accommodated by the careful design and construction of the culvert joints. In order to avoid the ponding of water it is also advisable to pre-camber such culverts, but not to the extent of creating reverse gradients in case the anticipated settlements do not occur.

When foundation difficulties become fully evident only when the excavations for box culverts are in progress, it may be necessary to resort to one of the Alternative Precautionary Measures illustrated in the Appendix 4D.
4.8.8 Backfill

Backfill to foundation excavations is an important final step in foundation work which must be strictly carried out as described in the specifications. In the case of bridge abutments, underpasses and box culverts the ultimate rideability of the road is highly dependent on the achievement of the necessary compaction densities in the backfill.

This is an item which is sometimes casually treated and which is deserving of constant vigilant attention on the part of the monitoring staff, who must ensure that backfill is frequently tested and removed and replaced when found to be non-compliant with the specified requirements.

In circumstances where any amount of settlement is highly undesirable, adding cement to the backfill material (dry soilcrete) may be justified.

4.8.9 Measurement and payment

**BEWARE**

Measurement for payment is an important duty of the monitoring staff and is required to be undertaken in good time for the preparation of payment certificates. Measurement of each billed foundation item should be promptly carried out on completion, before covering up, and thereafter agreed and signed off with the contractor. Any disagreement on either the quantity measurements or about interpretation should be referred to the engineer for a decision.

4.8.9.1 Standard and special items

The standard measurement and payment items for conventional foundations and ground anchors are described in the specifications. Project specific elements of the work, such as underpinning, which are required as part of the permanent work and which fall outside the scope of the standard items are described in the project specifications, together with the applicable units of measurement and a description of the work deemed to be included in the tender prices.
4.8.9.2 Tender and measured quantities

Because of the variability of founding conditions, the billed quantities included in the tender documents are often merely indicative. It is recommended that the monitoring staff should always be furnished at the outset with a copy of the original quantity calculations, for comparison with the measured quantities as the work proceeds. This information will assist the monitoring staff to assess and report to the engineer, when required, on overexpenditure or underexpenditure against the tender amounts and the reasons for the differences.

It is essential that measurement files should be systematic, comprehensive and kept up to date for both interim and signed off measurements for completed work items. These files are subject to periodic audit by the employer and provide important reference information in the event of disputes or claims.

4.8.9.3 Application of specific items

For the purpose of comment about the measurement and payment items for foundation work, the COLTO Standard Specifications for Road and Bridge Works for State Road Authorities is used as an example. Monitoring staff should note that the measurement and payment items for foundation work may differ in other standard specifications.

Excavation (COLTO Item 61.02)

It is noteworthy that the tendered rates for the various classes and depths of excavation are deemed to be all-inclusive with respect to the method of excavation, disposal of the spoil and protective measures etc. in completing the excavation.

With regard to the volume of excavation measured, no distinction is made between open excavations with unsupported sloping sides and those with vertical sides and designed lateral support, for example.

However, a distinction is made about the volume of excavation measured, which is dependent on whether:

(a) Placing of the footing concrete against the earth faces is permitted by the engineer, or
whether:

(b) Formwork is required to be provided to the sides of the footing.

In the first case the volumes of excavation measured are required to be based on the net plan area of the footing, multiplied by the applicable depths. In the second case the plan area is extended by a width of 0.5 m around the entire perimeter of the footing, to provide for working space.

The designer's intention regarding these options is clearly indicated by the inclusion of formwork to the sides of the footings in the bill of quantities. However, this can be altered by the engineer during construction, if circumstances permit and economy can be achieved.

Clearly it will be necessary to allow for working space in the case of excavations which require designed lateral support down to the founding level, such as a cofferdam.
Overbreak in excavation in hard material (COLTO Item 61.07)

When footing concrete is permitted to be cast against hard material the contractor is required to be compensated by extra payment under this item for overbreak. It must be noted that the unit of measurement for the excavation of overbreak and for the concrete fill is the square metre of the surface area of the vertical outer faces of the base, irrespective of the width or volume of the overbreak.

This payment method imposes a contractual risk insofar as careful work is required to limit the amount of overbreak. However, this element of foundation measurement is prone to claims for extra payment, which may be justified when the nature of the hard material encountered at the footing level is substantially different from that which could reasonably be anticipated from the borehole or other relevant tender data.

When working space is permitted around the perimeter of a footing, overbreak is not measurable and payable for the excavations, irrespective of the nature of the material excavated.

Access and drainage (COLTO Item 61.03)

(a) Access is usually only required in water environments and is also an all-inclusive pay item, from which only excavation is excluded and paid separately in terms of COLTO Item 61.02.

(b) Drainage where no access has been provided is usually applicable in land environments.

Special Items : Lateral support and underpinning

Lateral support which is designed as part of temporary work required for the safety of excavation is deemed to be included in the rates tendered for COLTO Item 61.02 and is not separately measured.
In certain instances it may be preferable to separately identify the need for lateral support, in circumstances which should not be left to the discretion of the contractor, or in which the need for lateral support could escape the attention of the contractor at the tender stage. These circumstances are likely to include excavations for bridge widening or doubling, where new work is adjacent to existing substructure components or where new foundations require limited excavations into the sides of existing embankments.

When the need for underpinning is known at the design stage the required method should be reflected on the drawings and appropriate measurement items included in the bill of quantities. When the need for underpinning becomes evident only at the construction stage, the design and measurement items will be the subject of a Variation Order issued by the engineer.

**Requirement**

When, for any reason, the lateral support of a foundation is deemed to be mandatory, this should preferably be separately identified and measured in the Bill of Quantities.

**Ground Anchors (COLTO Items 75.01 to 75.08)**

When ground anchors form part of the contractor's temporary works for the safety of excavations, these are also deemed to be included in the rates tendered for COLTO Item 61.02 and are not separately measured. Ground anchors required as part of the permanent foundation work will be measured separately for payment in terms of COLTO Items 75.01 to 75.08 inclusive.

### 4.9 SOIL IMPROVEMENT

#### 4.9.1 Purpose and Application

The purpose of soil improvement is to increase the load bearing capacity of loose or compressible soils to a sufficient degree to permit the founding of structures at comparatively shallow depth, in circumstances which would otherwise require the installation of piled foundations or caissons. The available methods are applicable to the foundations of small to medium span bridges and sign gantries, which impose comparatively light loads and are tolerant of a small degree of settlement or angular distortion. Soil improvement can also be used to reduce the settlement of embankments behind bridge abutments and thereby to diminish the down drag forces imposed on abutment piles, when the natural ground in these locations is compressible.

#### 4.9.2 Soil Improvement Systems

The soil improvement systems which are suitable for the foundations of road related structures include the following:

(a) **Vibratory or dynamic soil compaction methods** to densify the soil at and below the anticipated founding level in order to reduce settlement and thereby increase the bearing capacity.

(b) **Soil replacement methods**, which involve the formation of compacted stone columns at predetermined spacings within the ground, using various techniques to remove and replace the compressible soils and thereby increase the bearing capacity of the entire area treated.

(c) **Accelerated consolidation** of clay substrata by the introduction of band or other suitable drains at predetermined spacings in the ground to reduce the length of the flow path for dissipation of pore water, followed by the construction of an embankment to preload the ground and increase the pore water pressure and thereby induce consolidation at an accelerated rate.

(d) **Compacting grouting** is achieved by drilling at close spacing through thin but shallow hard layers, such as calcrete, and high pressure injection of fluid grout to densify the underlying compressible soil and thereby increase load bearing capacity to a greater depth.
4.9.3 Information Required

Prior to the adoption of a soil improvement system as a means to permit founding at shallow depth in compressible soils the following information is required:

(a) Detailed information about the characteristics, layer thicknesses and overall depth of the 'problem' soils.
(b) The loads and load combinations to be supported.
(c) The total and differential settlements which can be accommodated by the structure.
(d) Knowledge of the available soil improvement systems, with particular regard to: the equipment required; the typical bearing capacity which can be achieved; the depth of application; limitations concerning the nature of the soils; comparative advantages and indicative costs of the alternative systems.

The technical details of the alternative soil improvement systems available in South Africa are fully described in Reference 3, together with guidelines about the applicability, design and implementation of these systems.

4.9.4 Selection of a Soil Improvement System

The following are some of the factors which need to be considered in determining which soil improvement system is the most suitable for a particular site:

(a) The time available to achieve the necessary soil improvement.
(b) The allowable bearing pressure on the improved soil.
(c) The number and spacing of the treatment points required.
(d) The depth of treatment and the degree of improvement necessary to meet settlement limitations and bearing requirements.
(e) The presence and level of the water table.
(f) The presence of very soft layers which cannot be treated mechanically, and the potential effects of boulders or other obstructions.
(g) The ease or difficulty in achieving the required depth.
(h) The sensitivity of the environs, including existing services or structures, to vibration and noise.
(i) Problems associated with the use of large volumes of water used in the treatment process.
(j) The combined cost of the soil improvement and the footings, compared with other methods of founding in poor soils or of accommodating the effects of significant settlement.

4.9.5 Construction

When a soil improvement system is specified as part of the foundation work, the required method and results will be fully documented as part of the project specifications. This work should be undertaken by specialist subcontractors who have the necessary equipment, knowledge and experience to achieve the desired results. It is incumbent on the engineer to approve only reputable subcontractors with the appropriate credentials for this type of foundation work.

In the case of vibratory compaction it is recommended that the spacing of the compaction points be decided upon by carrying out test compaction patterns together with 'pre' and 'post' compaction soil
strength measurements. This method of soil improvement is normally ineffective near the ground surface because of the dissipation of the vibratory effort. The depth of soil to be recompacted by impact roller or other means must be confirmed by testing.

Figure 4.1: Sequence of operations to improve bearing capacity through vibratory compaction

The monitoring staff will be expected to ascertain that: the required depth and lateral extent are achieved and that the soil strength and other requirements of the particular improvement system are confirmed by adequate and appropriate testing. Soil improvement will be required to extend beyond the footprint of the footings by predetermined margins.

Photo 4.12: Typical dynamic compaction
(Note: this example is not related to bridge work)
Soil improvements by accelerated consolidation will require the input of monitoring staff well in advance of the commencement of the permanent structural work, firstly to oversee the installation of the drainage system and to confirm the compaction (density) of the preload embankment, and periodically thereafter to monitor the consolidation actually achieved.

The monitoring staff will be expected to keep detailed records of the extent of the soil improvement work, together with test results related to specific locations, for the purpose of re-analysis and additional soil improvement, if required, and for measurement and payment in terms of the contract.

4.10 CHECK LISTS

Check lists related to the foundations are included in the Appendices to this Chapter and are intended to serve as aide memoires to the monitoring staff and as convenient date related records for the signing off of completed work.

4.11 REFERENCES

1.) British Standards Institution; Code of Practice for FOUNDATIONS; CP8004, Latest edition.

2.) The South African Institution of Civil Engineers (Geotechnical Division); Lateral Support in Surface Excavations, Code of Practice; Latest edition.

INDEX TO APPENDICES

4A - FOUNDATION CHECK LIST

4B - GROUND ANCHOR AND UNDERPINNING CHECK LIST

4C - GROUND IMPROVEMENT CHECK LIST

4D - BOX CULVERT FOUNDATION PROBLEMS : PRECAUTIONARY MEASURES
# CONSTRUCTION MONITORING CHECKLIST

## PROJECT NO. / NAME:

## INSPECTOR’S NAME(S):

## STRUCTURE: ...........................................................  ELEMENT: ...........................................................

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**STATUS INCLUDES**

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CCP : Contractor’s Competent Person

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<td>• Remedial measures agreed/completed</td>
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### (Compaction and Replacement Methods)

#### 1. SELECTED SYSTEM

1.1 Method Statement
1.2 Diagram

#### 2. PRE-INSTALLATION TESTS

2.1 Trial test pattern depth and compaction tests
2.2 Confirmation of pattern/depth

#### 3. INSTALLATION AND RECORDS

(Attach record of each treatment point)

3.1 Treatment points: number and spacing
3.2 Depth of treatment
3.3 Measurement diagram and materials quantities

#### 4. ACCEPTANCE TESTS

4.1 Strength/settlement
4.2 Recompaction of problem areas and upper layers?

#### 5. MEASUREMENT AND PAYMENT

---

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Foundations
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<tr>
<th>PROBLEM</th>
<th>DESCRIPTION</th>
<th>DIAGRAM</th>
<th>ALTERNATIVE PRECAUTIONARY MEASURES</th>
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<tbody>
<tr>
<td>1. <strong>DIFFERENTIAL LONDS ONAL SETTLEMENT</strong>&lt;br&gt;This arises from variable embankment load on a culvert founded on compressible ground and results in opening and closing of joints, possible structural damage to the culvert barrel, deposition of slurry in the barrel sag and possible loss of waterway area.</td>
<td><img src="image" alt="Diagram of differential longitudinal settlement" /></td>
<td>1. Camber invert upwards (Check that a reverse gradient is not created if the predicted settlement does not occur.)&lt;br&gt;2. Increase joint width.&lt;br&gt;3. Reduce joint spacing when predicted settlement is severe.&lt;br&gt;4. Articulate barrel by providing joint through complete section and encircle joint with a suitable collar around outer perimeter.&lt;br&gt;5. Consider the removal of unsuitable founding material to some depth to be replaced by stronger granular backfill.</td>
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<td>2. <strong>TILTING OF BARREL END PANELS</strong>&lt;br&gt;Outward rotation of a culvert end panel may occur in very poor founding conditions due to the mass of the earings hanging from the end of the barrel, resulting in opening and closing of the end joint and possible structural damage.</td>
<td><img src="image" alt="Diagram of tilting of barrel end panels" /></td>
<td>1. Increase length of culvert end panel. Recommended minimum length is 6 m.&lt;br&gt;2. Reduce length of earings.&lt;br&gt;3. Continue barrel base slab beyond end of barrel to provide greater bearing area.&lt;br&gt;<strong>NOTE:</strong> Each solution is aimed at adjusting the centroid of the total vertical loads or the centroid of the bearing area so that they coincide.</td>
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<td>3. <strong>VARIABLE FOUNDATION CONDITIONS</strong>&lt;br&gt;Variable founding conditions, e.g. shallow depth to rock for portion of culvert length, may lead to severe structural damage and &quot;broken back&quot; type failure arising from severe differential settlement.</td>
<td><img src="image" alt="Diagram of variable foundation conditions" /></td>
<td>1. Introduce additional barrel joints on either side of foundation discontinuity, treat joints as for 1 under problem 1.&lt;br&gt;2. Camber invert upwards for portion of barrel on compressible ground&lt;br&gt;3. If a rock pinnacle approaches barrel invert for a short length, consider removal of rock and replacement with weaker backfill material.</td>
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<td>4. <strong>EMBANKMENT &amp; CULVERT STRETCH</strong>&lt;br&gt;This only occurs in conjunction with problem 1, although settlement may occur without stretch, depending on the shear strength of the insitu founding material. Stretch arises from the outward shear flow of the founding material and creep of the embankment and may result in tensile failure of the culvert bottom slab at the joints and ingress of fines from the fill.</td>
<td><img src="image" alt="Diagram of embankment &amp; culvert stretch" /></td>
<td>1. In general, provide a continuous base slab with tensile tie bars in the bottom slab equal in area to the distribution steel detailed in the barrel walls and slabs. Enclose the joint with suitable collars around the outer perimeter.&lt;br&gt;2. In very poor founding conditions treat the joints as for 1 under problem 1.</td>
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<td>5. <strong>BARREL SETTLEMENT RELATIVE TO INLET &amp; OUTLET SCOUR APRONS</strong>&lt;br&gt;Barrel settlement as described in problem 1, may result in the inlet and outlet scour aprons &quot;floating&quot; at a higher level than the culvert barrel. In these cases concrete aprons may become severely cracked and slabs, deposited at the downstream end of the barrel, resulting in a loss of waterway area.</td>
<td><img src="image" alt="Diagram of barrel settlement relative to inlet &amp; outlet scour aprons" /></td>
<td>1. In sandy founding conditions where settlements will be &quot;instantaneous&quot; (during construction) construct concrete apron slabs only after embankment fill over culvert is completed.&lt;br&gt;2. In clayey founding conditions where settlements may be &quot;long term&quot; depending on the rate of dissipation of pore water pressure, consider use of flexible aprons (e.g., gabions) laid later in the construction program and which could be realigned after settlement continues.</td>
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<td>6. <strong>BARREL SETTLEMENT RELATIVE TO WINGWALLS</strong>&lt;br&gt;Settlement of two-lever wingwalls may be associated with barrel and earing settlements, resulting in the jamming at the top or bottom of the joint between the two lever wingwalls and ear wingwalls as displayed by local shear cracking at the top or bottom corners of the walls.</td>
<td><img src="image" alt="Diagram of barrel settlement relative to wingwalls" /></td>
<td>1. Provide a sufficiently wide joint between the walls to prevent jamming and seal the base toe with geotextile or similar to prevent the ingress of fines from the embankment.&lt;br&gt;2. In particularly poor founding conditions consider replacing the two-lever wingwall with gabions or reinforced earth walls which are tolerant of settlement.</td>
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