MANUAL

SITE PREPARATION AND EARTHWORKS

DEP 34.11.00.11-Gen.

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DESIGN AND ENGINEERING PRACTICE

USED BY

COMPANIES OF THE ROYAL DUTCH/SHELL GROUP

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1. INTRODUCTION

1.1 GENERAL

This manual is a revision of DEP 64.11.10.31-Gen. entitled `Site preparation' dated March 1972 which was cancelled with DEP circular 27/82.

It is intended for use in oil refineries, chemical plants, gas plants, and, where applicable, in exploration, production and new ventures.

Unless otherwise authorized by SIPM, the distribution of this manual is confined to companies belonging to or managed by the Royal Dutch/Shell Group, and to contractors nominated by them.

All publications referred to in this manual are listed in Section 7; the relevant standard drawings in Section 8.

Where cross references are made, the number of the section or sub-section referred to is shown in brackets.

1.2 SCOPE

This manual contains minimum requirements and guidance on the design, planning, materials and construction for:

- site preparation
- earthworks
- tank bunds and tank pads and
- shore protection.

1.3 MINIMUM REQUIREMENTS

The minimum technical requirements as laid down in this manual shall be applied to the design, materials selected, planning and execution of site preparation, earthworks, tank bund construction and shore and scour protection works.

Supplementary to these requirements, work shall be carried out in accordance with recognized and accepted theories, methods, codes of practice, standards and good engineering practice.

As a rule the requirements of this manual shall be adhered to.

However, national and/or local regulations may exist in which some of the requirements are more stringent.

The contractor shall determine by careful scrutiny which of the requirements are more stringent and which combination of requirements will be acceptable as regards safety, economic and legal aspects.

In all cases the contractor shall inform the principal of any deviation from the requirements of this manual which is considered to be necessary, in order to comply with national and/or local regulations. The principal may then negotiate with the authorities concerned with the object of obtaining agreement to follow this manual as closely as possible.

1.4 DEFINITIONS

1.4.1 General definitions

For the purpose of this manual, the following definitions shall hold:

Shall and **Should** - the word `shall' is to be understood as mandatory and the word `should' as strongly recommended to comply with the requirements of this manual.

The **Principal** is the party which initiates the project and ultimately pays for its design and construction. The Principal will generally specify the technical requirements. The Principal may also include an agent or consultant, authorized to act for the Principal.

The **Contractor** is the party which carries out all or part of the design, engineering, procurement, construction and commissioning for the project. The Principal may sometimes undertake all or part of the duties of the Contractor.

1.4.2 Definitions of materials

In this manual, the following definitions of materials are adopted for site preparation and earthworks:

- **Suitable materials** shall comprise all that which is acceptable in a natural or processed state in terms of its intended use and shall be specified for each application.
- **Unsuitable material** shall mean other than suitable material and shall amongst others include:

a) material from swamps, marshes and bogs

b) peat, logs, stumps and perishable materials

c) material susceptible to spontaneous combustion

d) material in a frozen condition (if otherwise suitable shall be classified as suitable when unfrozen)

e) materials with undefined properties

f) materials having a moisture content greater than the maximum permitted for such materials

g) building rubble and domestic and industrial wastes (unless otherwise approved by the principal)

h) soils and rock susceptible to deterioration/change of their properties (unless otherwise approved by the principal).

Rock shall mean those geological strata or deposits and any hard material requiring the use of blasting or approved pneumatic tools for its removal.

Rockfill shall consist of hard durable inert material of size and shape suitable for placement and compaction.

Soils shall mean all suitable non-cemented granular and cohesive soils.

Silt shall mean non-clayey soils with individual particle size less than 0.06 mm.

Cemented soils shall mean soils in which the grains or aggregates adhere firmly, bound together by a material which acts as a cementing agent, e.g. lime, silica, aluminium hydrates, etc.

2. GENERAL

2.1 EXISTING SERVICES AND FACILITIES

The nature and location of all existing aboveground and underground services, and facilities shall be ascertained on site and adjacent areas, where necessary by hand excavation, before commencing site investigations, site preparation works and earthworks.
Every precaution shall be taken including the provision of all necessary temporary supporting, bridging shoring and safety barriers to protect these services and facilities from damage or interference during the execution of the works. The stability of existing above and underground services and the measures considered to be necessary should be proven by calculations based on realistic assumptions and/or available data.

The principal shall be notified in writing should any previously unrecorded services or other objects be discovered during investigations. A description, dimensions, levels related to reference datum and other relevant details of such services shall be accurately recorded and supplied to the principal.

A certificate or permit shall be obtained from the principal or the responsible body, confirming that services have been cut off and made safe and specifying any services or other facilities adjacent to the work including related safety aspects and measures which must be maintained during the execution of the work.

In the event that services such as drains or natural drainage of a certain area require to be cut during the execution of the works these shall be made good to the satisfaction of the principal, and where applicable a temporary or permanent rerouting shall be provided.

In the event that services or facilities are accidentally cut or damaged, these shall be made good as directed by the principal.

2.2 SITE LEVELS

When selecting site levels (e.g. high point of paving), the following considerations shall be taken into account:

- Surface water run off should be able to take place under gravity via the plant drainage systems to public water, in accordance with DEP 34.14.20.31-Gen.
- Site lay-out/plot plan and related safety aspects should be adhered to.
- Cut and fill should be economically planned such that cut and fill balancing is optimized including allowances for earthen structures and general fill, bulking, wastage and unsuitable materials.
- Danger of flooding should not exist (highest sea level, river level, etc.) or alternatively the area should be adequately protected.

Prior to the commencement of work a limited number of permanent monuments shall be strategically placed on site and accurately related to the plant and/or national grid system for time and level.

Prior to the commencement of work the original site surface levels shall be surveyed and recorded on an appropriate drawing.

2.3 SITE INVESTIGATIONS

Prior to the commencement of site preparation and earthworks a site investigation shall be carried out. This investigation should include but not be limited to soils, topographical, hydrological and geohydrological surveys (and under certain conditions engineering geological surveys).

The design, materials, planning and execution of site preparation and earthworks shall be based on the results of a recently completed full scale or confirmatory site investigation. See also DEP 34.11.00.10-Gen.

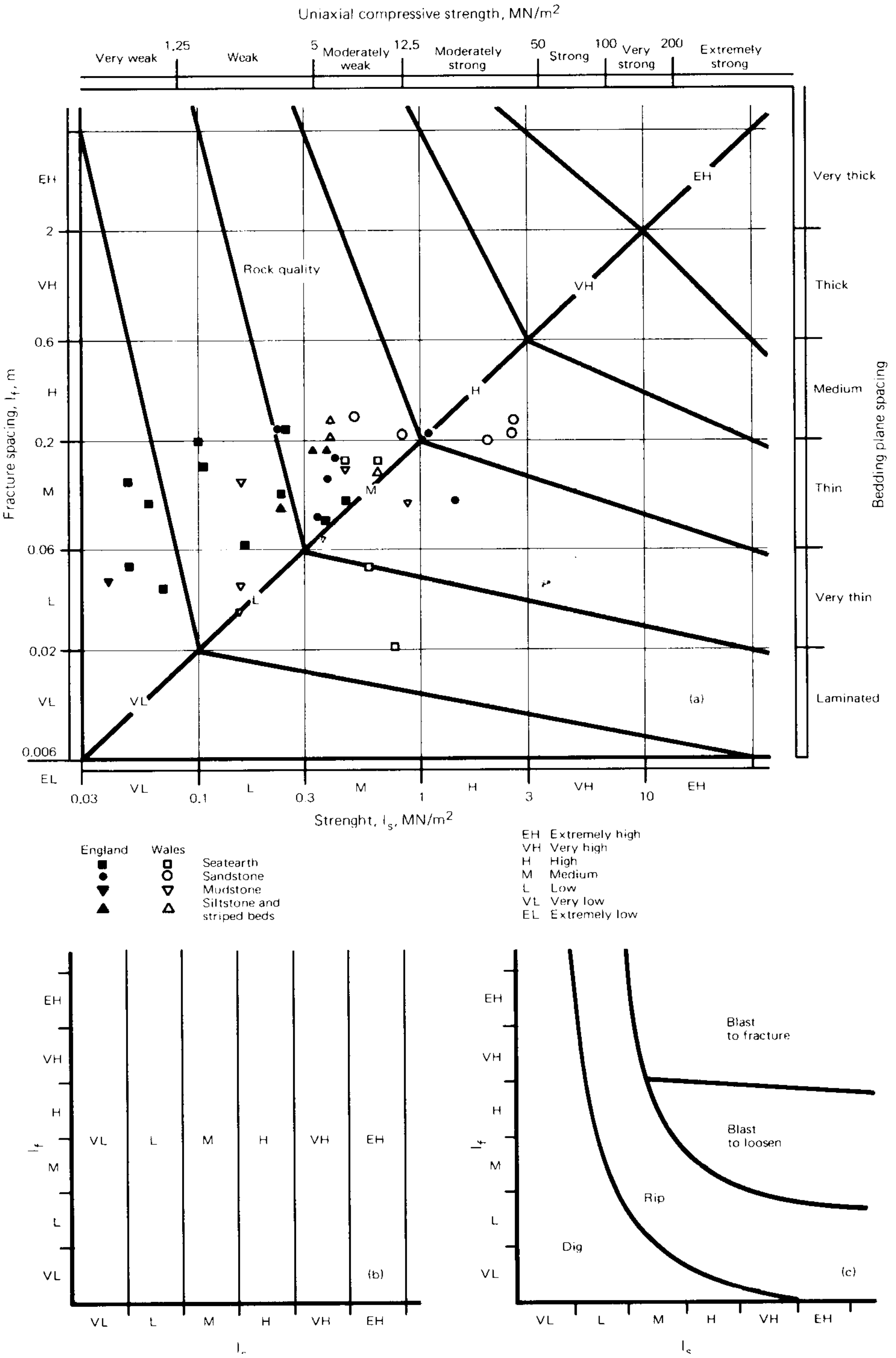
2.4 CLASSIFICATION OF SOILS AND ROCKS

2.4.1 Soil classification

Classification system	Particle size equivalent diameter, mm				British Standard sieve: 75 µm	212 µm	600 µm → ← mm: 2.36	5	10	19	37.5	63
		0.002		0.02				
International Society of Soil Science	Clay ←	Silt		Fine sand		Coarse sand		Gravel
United States Public Roads Administration	Clay (Colloids 0.001)	← 0,005 Silt		0,05	Fine sand	Coarse sand		Gravel
Massachusetts Institute of Technology	Clay ←	Fine silt	Medium silt	Coarse silt	Fine sand	Medium sand	Coarse sand	Gravel
British Standards Institution	Clay ←	Fine silt	Medium silt	Coarse silt	Fine sand	Medium sand	Coarse sand	Gravel
Particle size	0.002	0.006	0.02	0.06	0.2	0.6	2.0	60 →mm

The `Sandy' and `Clayey' character of finegrained soils (e.g. sandy clay, silty sand, clayey sand) shall be determined with the aid of Atterberg limits, e.g. plasticity index (PI) of clean sand is < 4. The durability of sand shall be shown by the determination of its calcium content, its chemical stability in general and the `hardness' of the particles.

2.4.2 Rock classification



Rock quality classification diagrams: (a), general purpose classification (the sub-division on the top and that on the right of the diagram refer to suggestions by The Geological Society of London); (b) and (c) alternative methods of sub-division (Ref.: Franklin Broch and Walton 1971).

Rock is a natural aggregate of mineral particles connected by `strong and permanent' cohesive forces. Igneous and metamorphic rocks, e.g. marble granite, etc., consist of interlocking crystals. Sedimentary rocks, e.g. sand stone, limestone, etc., consist of closely packed mineral grains, often bound together by a natural cement. Since the terms `strong and permanent' are subject to different interpretations, the boundary between rocks and cemented soils is necessarily arbitrary.

Aspects such as the degree of weathering, chemical stability, fracture spacing, bedding plane spacing, strength, structure/texture durability and hardness determine the engineering character of rocks.

2.5 SEISMIC ASPECTS

Design and execution of site preparation and earthworks shall be based on the seismic conditions and relevant consequences prevalent in the area under consideration.

Liquefaction potential shall be thoroughly investigated by means of laboratory and field tests. In situ checks should be carried out upon completion of the earthworks.

3. SITE PREPARATION

3.1 GENERAL

Site preparation may consist of one or more of the following activities:

- demolition and site clearance (3.2)
- stripping of turf and top soil (3.3)
- treatment of existing ditches and water courses (3.4)
- treatment of underground cavities (3.5)
- treatment of subsoils (3.6)
- provision of site drainage (surface and subsurface) (3.8)
- earthworks (3.9)
- provision of temporary access and laydown areas (3.10) and (3.11)
- shore protection works (3.12).

3.2 DEMOLITION AND SITE CLEARANCE

Demolition works shall include but may not be limited to the demolition and removal of buildings, structures, culverts, roads, pavements, above and underground services and associated foundations.

Site clearance shall include but may not be limited to the taking down or grubbing up and immediate removal from site of surface obstructions and unsuitable materials, such as debris, rubble, gates, fences, shrubs, hedges, trees, stumps and roots.

The principal may direct to leave in place certain items such as fences, shrubs, trees, or other features required for incorporation in landscaping. The contractor shall, under such conditions, be responsible for the care and protection of such items during the course of the works.

Demolition and site clearance works shall be planned and executed in a manner such that the safety of personnel, the work and adjacent property is guaranteed and such that a minimum of inconvenience is caused.

All necessary temporary works such as safety barriers, fences, safety nets, coverings and screens shall be provided to protect personnel and adjacent property from injury or damage caused by demolition operations.

All necessary dead or raking shores to support existing work shall be provided during demolition and associated operations.

All materials arising from demolition and site clearance work except materials specified for re-use or as otherwise specified by the principal shall be removed from site as the work progresses, and shall be disposed of. Such materials should not be permitted to accumulate and the site shall be maintained in a safe and workmanlike condition at all times.

Materials required for re-use shall be stored in a safe location and protected from damage or deterioration as agreed with the principal.

Materials removed from site shall be disposed of in accordance with governing local and national laws and regulations.

3.3 STRIPPING OF TURF AND TOP SOIL

All areas to be excavated, filled or constructed upon, should be stripped entirely of turf and top soil to a suitable depth below ground level, as indicated by the site investigation and agreed with the principal.

Turf intended for re-use, as agreed with the principal, shall be taken up in strips of a constant breadth with an approved turfing tool.

Turf intended for re-use shall be removed to a location approved by the principal where it shall be neatly stacked and regularly watered and tended until required for relaying.

Top soil intended for re-use as agreed with the principal shall be stock-piled and/or spread at approved locations.

The remaining top soil and turf shall be disposed of at locations agreed by the principal. Disposal shall be carried out in accordance with national and local laws and regulations.

3.4 TREATMENT OF EXISTING DITCHES AND WATER COURSES

Existing drainage ditches and water courses shall be temporarily or permanently rerouted, where necessary, in order to prevent

- unacceptable rise or fall in ground water level in, and flooding of, the site
- unacceptable changes to the hydrological and geohydrological regimes of the adjacent areas.

The invert and sides of abandoned ditches and water courses shall be cleared of unsuitable deposits which shall be disposed of in a manner approved by the principal.

Filling and compaction of cleared ditches and water courses shall be carried out in accordance with (4.3) and (4.4).

Erosion protection where required for rerouted water courses shall be designed and constructed in accordance with (5.).

3.5 TREATMENT OF UNDERGROUND CAVITIES

Where naturally occurring cavities e.g. caverns, underground water courses or man-made cavities, e.g. mineworkings, wells, cesspools, basements are detected under or adjacent to the construction area, these shall be suitably treated in consultation with the principal.

The selected treatment shall take into account not only the effect on the geohydrology of the surrounding areas but also the requirements of the structures to be founded within the influence zone of the cavities.

3.6 TREATMENT OF SUBSOILS

In cases where a change in the permeability, an increase in strength/friction properties/density or a decrease in the liquefaction susceptability/compressibility of the subsoil (i.e. reduction in subsequent settlements) is required, consideration shall be given to the use of soils improvement methods, e.g.:

- shallow or surface compaction
- deep compaction (e.g. vibroflotation, dynamic compaction, stone columns)
- vertical and/or horizontal drainage
- injection of grouts or chemicals
- soils replacement
- preloading.

The design of such improvement shall be based on a thorough soils investigation and shall take into account the soil type (e.g. whether cohesive, granular, cemented) particle strength, particle size and shape analysis, silt content, in-situ density, mineralogical and chemical composition and primary as well as secondary permeability of the soil to be treated.

In general it should be noted that:

- Clay, clayey and silty layers cannot be effectively compacted by means of mechanical compaction. Preloading is the only effective method, although it may take a significant period of time to obtain the required degree of compaction/consolidation (i.e. a number of months or years).
- Deep compaction will not be effective at low stress levels (i.e. in the first 1.5 to 4.0 metres below ground level) and should always be followed up by a shallow surface compaction. The site may alternatively be `surcharged' during deep compaction.
- The secondary permeability (i.e. water flow through cracks and subsurface channels and cavities) is generally more critical and complicated than primary permeability (i.e. water flow through pores). Secondary permeability may exist/develop in cemented soils, dried out clays and especially in rocks.

3.7 FAULTS AND OTHER GEOLOGICAL DISTURBANCES

If faults and or other geological disturbances exist at the site the long-term behaviour hereof and the behaviour during earthquake, if applicable, shall be investigated by an expert in the field. A second opinion on such investigations is often considered desirable. The conclusions of this investigation shall be taken into consideration for the subsequent earthworks (and foundation and structural design).

3.8 PROVISION OF SITE DRAINAGE

Adequate drainage systems shall be provided to deal with ground water and surface water run off.

Permanent surface water run off drainage systems shall be designed in accordance with DEP 34.14.20.31-Gen.

Temporary surface water run off drains (e.g. ditches) and subsoil water drains (e.g. horizontal buried drains, vertical drains) shall be provided in order to prevent flooding and maintain access on site during construction until the permanent drainage systems are brought into operation.
The requirements of construction plant, work progress, building pits and meteorological conditions shall be taken into consideration.

Disturbance of the natural water drainage systems, both surface and subsurface, by construction activities in the area shall be taken into account and where necessary measures shall be taken to eliminate any detrimental effects.

Examples of disturbances:

- Excavation may lead to a lowering of ground water levels in the adjacent area which may cause foundation settlements and consequently damage to foundations and supported structures. Drying out of vegetation can also occur.
- General fill and embankments may lead to a general raising of the ground water level in the fill and surrounding areas with unacceptable consequences such as uplift of foundations and buried structures, corrosion and drainage problems. Drainage problems may become critical during extreme conditions.

3.9 EARTHWORKS

Earthworks forming part of site preparation works shall be designed and executed in accordance with (4.).

3.10 PROVISION OF TEMPORARY ACCESS

Suitable temporary roads should be laid to provide all-weather access for construction activities including site preparation.

The temporary access routes should preferably coincide with the planned permanent routes.

Temporary access shall be designed to suit climatic, traffic and subsoil conditions.

The effects of heavy traffic along temporary roads (e.g. propagation of dust clouds, damage to existing structures by vibrations, disturbance of surface and subsurface drainage) shall be taken into consideration and where necessary suitable precautions shall be taken.

Traffic routing schemes should be established, especially for large-scale works.

3.11 LAYDOWN AND STOCKPILE AREAS

Permanent laydown areas normally located inside battery or module limits for the laying down of bundles, trays, columns, flares and other structures during shutdown or maintenance of plants shall be designed and constructed in accordance with DEP 34.13.20.31-Gen.

Temporary laydown areas (included in the contractors areas) required for construction activities should be suitably levelled and provided with suitable access, temporary paving and surface drainage where required.

The area shall be drained such that stored materials remain dry and the area remains accessible (surface and possibly subsurface drainage may be required).

For stockpiling see (4.3.4).

3.12 SHORE PROTECTION, COASTAL DEFENCE AND RIVER WORKS

Shore, river embankment and scour protection works forming part of site preparation works shall be designed and executed in accordance with (5.).

4. EARTHWORKS

4.1 GENERAL

Site preparation for earthworks shall be designed, planned and executed in accordance with (3.).

The effect of earthworks on neighbouring structures, services, etc., shall be analysed (for both short- and long-term effects) and detrimental effects shall be avoided or appropriate measures taken to safeguard the integrity of the item in question.

Similarly the effects of dewatering or disturbance of the existing geohydrological conditions as a result of earthworks on neighbouring structures, services, etc., shall be taken into account.

Examples are:

- change in horizontal earth pressure on foundations (especially piled foundations) may turn out to be unacceptable
- damage to foundations and structures as a result of differential settlements caused by lowering and raising of ground water level, placement of fill or other surcharge excavation and horizontal soil movement
- damage to foundations and structures by vibrations caused by earth moving equipment and heavy traffic.

The possible effect of earthquake on earthworks with respect to:

- liquefaction/excess pore water pressure build-up
- change in soil/rock properties
- change in loading situation

which shall be investigated and where necessary suitable measures taken.

Assumption with respect to magnitude of earthquake, earthquake coefficient, safety factors, etc., shall be made in agreement with the principal.

4.2 DESIGN OF CUTTINGS, EXCAVATIONS, EMBANKMENTS AND GENERAL FILL

The macro and micro stability of cuttings, excavation and embankment slopes and the related soil/rock deformations shall be analysed in accordance with DEP 34.11.00.12-Gen.

Design of cuttings, excavation and embankment slopes shall include erosion protection of slopes, and take into consideration aspects such as wind, rain, running surface water, seepage water, freezing and temperature effects.

Soil deformation with respect to settlements due to consolidation, compression of soil skeleton, movements required to develop shear resistance, the consequence of sliding and squeezing, etc., shall all be analysed in accordance with DEP 34.11.00.12-Gen.

Extreme hydrological and meteorological conditions shall be assumed in agreement with the principal for the design of earthworks. The impact of earthworks on ground water levels and the influence on drainage shall be analysed and where appropriate designed for.

Temporary conditions (i.e. short-term), e.g. extreme excess pore water pressure during filling, sliding of a soil mass, etc., shall be included in the design considerations. Vertical stability of excavations (uplift, piping, boiling, etc.) should be checked.

Possible change in soil and ground water properties due to earthworks, such as change in pH value and sulphate content, shall be investigated/studied.

4.3 EXCAVATION AND FILLING

4.3.1 General

Site preparation for earthworks shall be planned and executed in accordance with (3.).

Excavation and filling activities shall take into account the results of the stability and soil deformation analyses carried out in accordance with (4.2).

The planning of excavation and filling activities shall take into account the climatic conditions prevalent during the construction period. Drawings shall be prepared prior to commencing work showing locations of excavation, tipping and filling including quantities of each type or class of material to be moved to or from sections defined on the drawings.

Soil behaviour and soil properties (and possible changing hereof) during and after the execution of earthworks should be monitored if required and agreed with the principal.
Aspects such as settlements, horizontal movements, sliding, ground water levels, piezometric pore pressure and excess pore water pressure development, ground water composition should be monitored if required and agreed with the principal.

4.3.2 Excavation

Plant selection for excavation and earth movement shall take into account type of materials to be excavated, method of excavation, prevailing weather conditions and type of transport to be used.

Unsuitable material detected below stripped ground level or below foundation level in areas of cut should be excavated to firm ground. The resultant excavation shall be filled to the required levels with suitable materials which shall be deposited, spread and compacted in accordance with (4.3.5) and (4.4).

The excavation of an area of cut shall be so timed that the foundation level is not exposed to the deteriorating influence of the weather for longer than can be avoided.

Earth moving plant shall be routed such that minimum damage is caused to the natural subsoil structure of exposed formations.

The suitability of the subsoil below excavation level shall be proven by additional testing when it concerns excavation for foundation for concrete or steel structures, pipelines and storage tanks.

4.3.3 Excavation in rock

Where excavation in rock by mechanical or hand methods prove to be impractical or uneconomic, drilling and blasting should be considered.

Drilling and blasting shall be carried out only with the explicit written permission of the principal.

The contractor shall comply in all respects with the most stringent local and national laws, regulations and standards, the explosives manufacturer's recommendations and the direction of the principal relating to the storage, transportation, handling and use of explosives.

Blasting operations shall be carried out and supervised only by personnel qualified in and fully conversant with the handling and use of explosives.

The contractor shall be responsible for determining the danger zone likely to be created during blasting operations and he shall be responsible for evacuating this area of personnel and placing the necessary safety barriers. The contractor shall also ensure, by placing heavy blasting mats, or taking similar precautions, when necessary, such that no damage is caused to personnel and property on or off site during blasting operations.

Rock shall be broken down to a size suitable for excavation, transportation, deposition and possible compaction. Where necessary field trials should be carried out.

Blasting operations shall be planned and executed such that damage to or deterioration of the parent rock is avoided.

Weathered or unsuitable rock susceptible to deterioration, encountered below foundation level, shall be replaced by well-compacted sound crushed rock or lean concrete.

The `flatness' tolerances of the formation level shall be agreed upon with the principal but in general should not exceed plus or minus 75 mm.
In certain cases it may be worth considering covering the formation level with a layer (e.g. 500 mm) of well draining sandy soil providing the `flatness' tolerances are adhered to.

4.3.4 Disposal of materials accruing

Suitable materials intended for re-use should be used as soon after excavation as possible otherwise they shall be stock-piled at a location approved by the principal.

Temporary stockpiling shall be such that the properties and composition of materials intended for use as construction materials at a later stage will not change.

The influence of stockpiling on ground water, drainage and adjacent structures and services shall be investigated and where necessary suitable measures should be taken.

Areas used for temporary stockpiling shall be kept clean and orderly and shall be restored to their original condition before completion of works.

Unsuitable materials and suitable material not intended for re-use shall be removed from the work site and disposed of at a location approved by the principal. Materials shall be disposed of in accordance with local and national laws and regulations.

4.3.5 Filling

Suitable fill materials shall be placed, spread and compacted in basically horizontal layers of equal thickness appropriate to the requirements of the selected compaction plant.

Fill shall be built up evenly over the full width of the area with a slope sufficient to allow efficient surface drainage of rain water and prevent ponding.

The placing of fill shall not commence until the area to be filled has been inspected and approved by the principal.

The settlements and stability of both fill and the subsoil underneath should, dependent on the intended use of the filled area, be monitored both during and after construction. Instruments which should be considered are piezometers, settlement gauges, inclinometers and electrical pore water pressure gauges, placed on, in, or under the fill.

The rate of filling shall be considered and shall take into account the stability of the embankment and its foundation in relation to pore water pressures. The rate of filling shall, where necessary, be determined by calculation and/or by monitoring of the dissipation of excess pore water pressures.

In certain cases subsurface drainage may be required in which case attention shall be paid to the long-term behaviour hereof (e.g. danger of clogging).

The suitability of fill material shall be regularly checked by (field) laboratory tests. (e.g. plasticity index, sit content, grain size distribution) whilst random samples should be taken as the basis of an independent thorough and detailed cross check.

4.3.6 Rockfill

Rockfill should be placed in layer thicknesses compatible with the available rock moving plant, compaction plant and the properties of the rock itself.

The best possible grading of the rockfill to be placed should be obtained in order to prevent subsequent `collapse settlements'.

Rockfill obtained from a strong or moderately strong parent rock should be watered, after placing and prior to compaction, in order to reduce frictional resistance between rock fragments and thus enhance compaction thereby avoiding subsequent `collapse settlements'.

The gradation of the rockfill in its upper layer, under roads and under other areas where finer fill material is placed, shall be such that loss of finer material due to wash-out, etc., cannot occur.

The gradation of the rockfill in its lower layers where it is placed on softer (or fine grained) materials shall be such that loss of rock into the soft material is prevented.

Rockfill placed under the foundations of structures of any importance shall consist of sound rock not susceptible to deterioration. The properties of rock used for these purposes should be determined by laboratory tests. See also DEP 34.11.00.10-Gen.

Unsuitable materials, including weathered rock and rock susceptible to deterioration, should be removed prior to commencing rockfill operation.

Rockfill obtained from a weak or poor parent rock (e.g. mud stones, shales, mar and chalk) should not be watered prior to compaction in view of the danger of rock fragment disintegration.

Thicknesses of dry rock layer should be limited in order to prevent possible `collapse settlements'.

Field trials should be carried out in order to determine the optimum layer thickness of rockfill, the method of compaction, the numbers of passes, the amount of watering, variability of grading and the type of compaction plant required to obtain optimum compaction results.

The maximum rock fragment diameter should not exceed two thirds of the layer thickness.

4.4 COMPACTION

Compaction trials should be carried out on each soil type to be placed in areas of fill, in order to confirm layer thicknesses of material placed, and the type of machine and number of passes required to obtain optimum compaction for given soil moisture contents. These trials should also be used to determine the variability of the proposed fill material for different weather conditions. A possible field trial procedure is shown in Appendix I.

The principal may decide to wave compaction trials for a material class if the properties of the fill materials have previously been related to various types of plant available, layer thicknesses of fill material placed and number of passes of the plant in question.

An indication of the number of passes of various types of compaction plant required to obtain optimum compaction for different thickness of various soil types is shown in Appendix 2. The indicated values should be confirmed by field trials.

The degree of compaction required, which is determined by the engineering properties required for the fill to carry out its design function, shall be specified in terms of minimum percentage of the maximum dry density obtained from a standard laboratory test or other approved method for each class of fill to be placed. Consideration should be given to the use of methods such as Dutch Cone Penetration, CBR or plate testing, as a means of checking in-situ density during the progress of the work especially where large areas of fill are being placed and quick results are required, the acceptance parameters for cone resistances or other approved methods shall be determined and agreed during field trials.

The compaction requirements and type of plant, based on the laboratory tests and field trials, shall be agreed with the principal prior to the commencement of the work.
A minimum of five in-situ dry density tests shall be carried out per hectare, per layer and evenly spread over the area being compacted, unless otherwise approved by the principal.

The top 500 mm of subgrade to roads and railways and under foundations shall be compacted to a minimum of 95% of the maximum density at optimum moisture content obtained by means of the modified Proctor Test unless otherwise approved by the principal.

The principal should carry out comparative field density tests during the course of the work. Should the results of the tests carried out by the contractor or the comparative tests carried out by the principal indicate that the agreed compaction requirements have not been met, the contractor shall make good the deficiencies to the satisfaction of the principal.

It should be noted that non-cohesive materials can only be compacted by vibratory equipment. Application of heavy `tracked' vehicles for compaction of thin layers can also be effective.

4.5 TRENCHES AND PITS

4.5.1 General

Trenches and pits are exavated, and where applicable provided with temporary support and drainage, to enable some form of permanent construction to be founded at the level of the bottom of the excavation and also to enable any permanent support to the ground faces to be formed.

4.5.2 Design

The design of excavations for trenches and pits should take into account the results of a soil investigation.

Aspects such as:

- variations in the soil conditions and in the geological structure
- depth of excavation
- the existence of ground water and surface water
- the type and extent of excavation
- the topography of the site
- the proximity of items such as roads, buildings and buried services
- construction traffic and activities near the excavation, e.g. stockpiling

shall be taken into account when determining whether the sides of excavations should be freestanding, sloping or temporarily supported.

The sides of trenches and pits shall be designed such that they are stable and the safety of personnel, the integrity of adjacent structures and any permanent works in the excavation itself are ensured. Deformation of soil and the temporary retaining structures (which always occurs) shall be checked and shown to be within acceptable limits.

The stability and deformation behaviour of slopes, temporary retaining structures and the base of deep excavations (e.g. heave) shall be verified by calculations. Potential vertical stability and uplift problems shall be investigated. See DEP 34.11.00.12-Gen. for the design aspects of excavated slopes and cuttings.

Temporary supports shall be designed as an earth-retaining structure, capable of resisting horizontal soil and ground water pressures. Reference is made to DEP 34.11.00.12-Gen. for the design aspects of earth-retaining structures.

Sufficient work space shall be provided in order to allow the safe working of personnel, equipment, supports and ancillaries.

Suitable drainage and/or dewatering systems shall be designed to prevent or limit ingress of surface or subsurface water into excavations. Unacceptable effects on neighbouring ground water level or pore water pressure shall be prevented.

4.5.3 Construction

Temporary supports shall be placed as soon as possible after (in some cases before) excavation.

Temporary supports shall be maintained such that the integrity of the sides of the excavation is not impaired.

Excavation materials accruing shall be disposed of in accordance with (4.3.4).

Any pockets of soft soil, loose rocks or other unsuitable materials in the bottom of pits and trenches shall be removed to firm ground and shall be backfilled with suitable materials placed and compacted in accordance with (4.4) and (4.5).

The softening and deterioration of suitable ground exposed at the bottom of an excavation shall be avoided. Where the bottom of an excavation has reached such a condition that it is unsuitable, the ground shall be treated in accordance with (4.3.2).

The bottom of all excavations for soil bearing foundation shall be compacted immediately before the placing of blinding or foundation materials.

Trenches and pits shall be backfilled with suitable materials which should be compacted to the same degree or better as the surrounding soils. Sometimes neighbouring structures or structures constructed in the excavation are governing as regards the degree of compaction.

Temporary excavation supports should be removed as backfilling and compaction proceeds, such that unacceptable movement of the supported ground does not occur.

Voids caused by extracted supports should be filled and compacted. Treatment methods of possible slips and cave-ins of the sides of excavations shall be agreed with the principal.

The monitoring of soil deformations, ground water levels, piezometric pore water pressure variations during and possibly after construction work shall be taken into consideration.
In the event excavation works are carried out in the vicinity of structures of any importance the above-mentioned monitoring shall be carried out (e.g. within a distance, from the edge of the excavation, of 5 to 15 times the excavated depth, depending on the subsoil conditions and the stability of the neighbouring structures).

Quality control of backfill materials and compaction should be carried out.

5. SHORE AND RIVER EMBANKMENT PROTECTION

When selecting a coastal location or a location near a river embankment the possible need for protection of the hinterland against flooding and the possible need for shoreline/river bank stabilization shall be investigated.

Measures shall be taken to provide the required protection with least disturbance to the environment and to current and future land use.

When analyzing the problem, hydraulic, morphological, geological, geotechnical coastal engineering and environmental aspects shall be considered.

The hydraulic aspects shall include amongst others wind, waves, currents, tides, seiches, storm surges (due to barometric pressure, wind and waves), tsunamis, rainfall intensities, storm water run off, river discharges, floating debris, iceing and the basic bathymetry/topography of the area.

The morphological aspects shall include amongst others sediment transport (rate and direction), erosion/sedimentation patterns, changes in shoreline alignment (seasonal fluctuations as well as long-term development) and changes in meander pattern and bedslope of rivers.

The geological aspects shall include long-term sea level change and general soil subsidence.

The geotechnical aspects shall include amongst others the bearing capacity and stability of the subsoil and the sensitivity for settlements and for eroslon.

Considerations shall be given to the availability and cost of construction materials, contractors equipment and the maintenance cost.

When assessing the environmental impact, consideration shall also be given to possible effects on coastal or river dynamics in adjacent areas and to the aspect of silt content and its variation.

Where protective measures may be expected to result in significant effects on physical or ecological aspects of the environment, legal and social consequences shall also be considered.

All hydraulic, meteorological and morphological data available shall be evaluated and if possible statistically analyzed in order to derive design criteria. Combinations of hydraulic parameters, that can reasonably be assumed to occur simultaneously shall be considered. The critical combination that results in maximum water levels at the structure site shall be adopted to determine the required dike and shore line levels and strength. Settlements and stability of structures/foundations shall be taken into account. The critical combination that results in maximum forces on the structure or its parts shall be adopted for structural design.

An economic evaluation, which include the frequency of occurrence of adopted design conditions and of other reasonable combinations, the damage potential of the considered combinations, the repairability of the structure and the permissible risk, should be carried out in order to find the optimal solution from economical/technical/safety point of view. If an economic evaluation would not be carried out, the critical combination having a return period of 100 years might be adopted for the design in agreement with the principal.

For the design of coastal structures, the calculation methods described in the `Shore Protection Manual' of the US Army Coastal Engineering Research Center, may be used.

6. TANK BUNDS AND TANK PADS

6.1 TANK BUNDS

The function of a tank bund and its associated drainage system is to control spillages from any tank such that subsequent damage to the tank, its contents, adjacent tanks and surrounding areas is minimized.

Drainage systems shall be designed and constructed in accordance with DEP 34.14.20.31-Gen.

Tank bunds (including tank lay-outs, safety distances, bund capacities) shall be designed in accordance with the IP Model Code of Safe Practice - Part 3 - Refining Safety Code, unless otherwise indicated by the principal or this manual.

6.2 BUND WALL

6.2.1 Bund wall design

Bund walls shall preferably be designed and constructed as a liquid-tight or low permeable earthen structure with a slope not steeper than 1 vertical to 1 horizontal.

The crest of the earthen bund wall shall have minimum breadth of 0.60 m. The height of the bund wall above the bund floor shall be determined from the required net capacity of the bund plus a freeboard of 0.30 m.
The determination of the crest elevation of the bund wall shall take into account the deformations of the subsoil (e.g. by providing overheight to allow for settlements).

The consequences of possible seepage through and/or under the bund wall shall be investigated and, if required, appropriate measures shall be taken.

The stability of bund wall (i.e. horizontal stability against sliding as well as the stability of slopes/subsoil) and its foundation shall be analysed for when the bund is completely filled with water (i.e. to bund crest) for a long term. The influence of possible liquid flow through and/or under the bund wall on the stability, shall be investigated.

Factors of safety should not be less than 1.3.

The consequences of a sudden failure shall be investigated and discussed with the principal who will indicate measures to be taken.

Reference is made to DEP 34.11.00.12-Gen. for the stability analysis and the subsoil deformation aspects of bund wall design.

In view of the effects of settlements and the possibility of leakages/seepage, penetration of the earthen bund wall and that of the subsoil under the bund wall shall be avoided, e.g. by pipes, cables, etc. Should penetration of the bund wall or the subsoil under the bund wall be unavoidable the crossing shall be suitably sealed and free to expand and contract. Filter cloth shall be placed round rigid elements where a danger of wash-out of bund wall materials exists, see Standard Drawing S 12.002. For multi penetration of earthen bund walls by pipes, consideration shall be given to the use of structural elements in forming an integral part of the bund wall.

6.2.2 Bund wall materials

In order to ensure the liquid tightness of the bund wall, it shall be constructed partly or wholly of impermeable or low-permeable materials.

A bund wall constructed as a solid clay body is preferred. In locations where clay is scarce or not available the following may be considered:

- a sand body with a clay cover of at least 300 mm thick
- a sand body covered by a sand/bitumen/cement mix, at least 50 mm thick.

Structural elements such as reinforced concrete-retaining walls or steel sheet piles can also be used where economically viable, however in cases where this type of bund wall is adopted, special attention shall be paid to the following points:

- subsurface drainage of the tank bund
- flow and void formation under the structural retaining elements
- consequences of settlements and the effect of the relative rigidity of the structures
- defection or deformation of the structure during the containment of liquids.

6.2.3 Bund wall covering (erosion protection).

Solid clay or clay-covered bund walls shall be either covered with a layer of top soil 150 mm thick and sown in with grass or turfed. The grass shall provide a strong dense growth and roots and shall require a minimum of cutting. High, dry-type of grass, which may form a fire hazard, is not acceptable.

Bund walls constructed from granular material and covered by a sand/bitumen/cement mix or clay cover should be provided with toe drainage and a toe filter construction in order to prevent damage to the cover by possible liquid pressure build-up within the bund wall, see Standard Drawing S 12.002.

Rigid bund wall coverings to earthen bund walls, e.g. concrete, shall be avoided in view of the increased risk of uncontrolled cracking followed by wash-out and cavity forming under the cover and subsequent break up of the cover. In the event of the specification of rigid covering, a woven filter cloth shall be applied under joints, weep holes and areas of potential cracking.

6.2.4 Construction of bund walls

Site preparation for bund walls shall be carried out in accordance with (3.).

Placing and compaction of materials shall be carried out in accordance with (4.).

Top soil shall be lightly compacted and raked prior to the sowing of grass. The use of fertilizing, mulching and watering of grass shall be agreed with the principal.

Where necessary turf shall be laid and pegged in place. The grass type should be a locally available variety.

The sand/bitumen/cement covering shall be well-compacted and given a smooth finish. Cracks shall be repaired by taking the cover back to sound material and filling the cracks with molten bitumen.

A sand/bitumen/cement mix shall be used for repairing larger rejected areas after trimming the cover back to sound material.

6.3 BUND FLOORS

Bund floors shall slope away from the tank pad towards a drainage trench located adjacent to the bund wall. The slope shall be minimum 1 vertical to 100 horizontal.

The bund floor shall be provided with a bottom layer which prevents erosion. High dry grass or other type of vegetation covering the bund floor is not acceptable because of fire hazard. There must be an access for operation and maintenance activities. The degree of impermeabilization required shall be agreed with the principal.

6.4 TANK PADS

6.4.1 General

Foundations to vertical (atmospheric) storage tanks generally take the form of a tank pad, constructed from durable, inert, granular materials, covered by an erosion protection layer.

This tank type is rarely founded on piled concrete foundations unless the predicted differential and total settlements and tilt exceed the limits set for the tank in question.

Anchor bolts may be required to hold the tank wall down (e.g. in earthquake areas or where the internal tank pressure is high, e.g. for BHC tanks) in which case a concrete ring beam or other appropriate solution may be required, see DEP 34.51.01.31-Gen.

The following paragraphs deal only with tank pads, consisting of granular materials (i.e. sand, crushed rock, etc.). Application of non-granular materials for tank pads or unpiled concrete raft foundations is in principle not allowed.

6.4.2 Tank pad functions and requirements

The functions of a tank pad are:

- to spread and transfer the load from the tank and its contents via the tank pad body and shoulder to the subgrade which will accept the load with settlements, both total and differential, within those allowable
- to raise the tank bottom above ground water, capillary water, surface water and minor spillages
- to provide a smooth surface with sufficient bearing capacity for tank construction.

The requirements of the shoulder to the tank pads are:

- to provide sufficient lateral support to the tank foundation under all conditions. The shoulder shall be capable of resisting damage due to construction, operating and maintenance activities
- to resist edge cutting beneath the tank shell
- to resist wash-out of the tank foundation as a result of tank bottom leakages and possible ingress of rain water.

6.4.3 Design

The tank pad shall be designed as a flexible foundation with sufficient strength to ensure that the pad is capable of:

- absorbing subsoil deformations to a certain degree
- distributing the possible unequal foundations pressures.

The relative rigidity of the tank wall with respect to the bottom slab and the subsoil shall be taken into consideration.

Total rigidity of the tank pad (i.e. concrete slab resting on soil) and/or rigid elements in, around and under the tank shall be avoided.

Under certain circumstances soils improvement (e.g. soils replacement) under the tank pad shall be considered in order to:

- provide a foundation with sufficient strength
- eliminate large even settlements as well as excessive differential settlements.

The initial tank pad level shall be selected such that settlements, differential settlements and tilt as a result of hydrostatic testing and a number of years of operational service agreed with the principal remain within the limits set for the tank.

Consideration should be given, where possible, to the relevelling of a tank (under the tank shell), rather than the complete jacking of a tank, to compensate for differential settlements or tilt since this may technically be acceptable and often proves to be the most economic solution.

The minimum elevation of the tank pad measured at the tank wall above the highest point of the floor of bunded area or adjacent terrain after hydrostatic testing and an agreed number of years of operational service, shall be 0.60 m.

The initial tank pad profile under the tank (i.e. cone up and subsequent cone down) shall be selected such that any predicted differential settlement (as a result of a hydrostatic test and operation) between tank centre and tank edge, is allowed for.

Any upward slope (cone up) however shall not exceed 1 vertical to 120 horizontal with a maximum vertical difference of 300 mm in order to minimize the possibility of the formation of ripples in the tank bottom during settlements.

Settlements and stability calculations based on the results of a soils investigation, shall be carried out and agreed with the principal.

Reference is made to DEP 34.11.00.12-Gen. and DEP 34.11.00.10-Gen. for the geotechnical aspects of settlements and to DEP 64.51.01.31-Gen. for the structural limits.

A stability analysis of the shoulder and tank pad shall take into account aspects such as initial height above adjacent ground level, highest possible ground water level, angle of slope to the shoulder, geotechnical properties of the tank foundation materials and subsoil, load provided by the tank and its contents and operational and maintenance requirements. A suitable factor of safety shall be selected and should not be less than 1.5 under normal and 1.1 under earthquake conditions.

The shoulder width shall be selected such that the stability of the foundation, shoulder and subsoil is ensured. The minimum shoulder width shall equal 1 m for tanks up to 15 m high and 1.5 m for tanks higher than 15 m. The shoulder shall be angled at 1 vertical to 10 horizontal. The slope to the shoulder shall not exceed 1 vertical to 1.5 horizontal.

The tank foundation analysis shall take into account the possible effect of wind and earthquakes on the tank, tank contents, tank foundation and the subsoil. Possible liquefaction of the subsoil shall be investigated.

The rate of tank filling during hydrostatic testing shall take into account the stability of the tank foundation in relation to pore water pressure, squeezing and creep.

The rate of filling shall, where necessary, be determined by calculation and shall in any case be cross-checked by the monitoring of tank settlement behaviour and the dissipation of excess pore water pressures (see also Appendix 6).

6.4.4 Materials

The tank pad shall be constructed from granular materials which meet the following requirements:

- low compressibility
- favourable friction properties
- low silt content
- reasonable permeability
- insensitive to weathering, oxidation, chemical changes, changes in mechanical properties or permeability
- easily compactible
- not sensitive to liquefaction (especially when constructed in earthquake zones).

For example:
Well-compacted sand, especially coarse sand with a plasticity index below 4 amply meets these requirements providing the chemical and mechanical stability of the minerals is guaranteed.
In order to prevent capillary rise of the ground water the upper 200 mm of the tank pad should at any rate consist of coarse sand.

A foundation ring (i.e. the shoulder and the zone under the tank shell) constructed from hard crushed rock would be preferable. This material has a greater resistance to edge cutting and damage during construction.

The tank pad body may be constructed from granular materials which are finer than those of the `foundation ring' providing a filter is installed between the sand body and shoulder material in order to prevent wash-out.

Sand may be used in the `foundation ring' providing special attention is given to compaction, protection from damage during tank construction and prevention of disturbances under the tank shell (which could result in edge cutting and possible tank deformation/failure).

The use of a concrete ring in order to prevent edge cutting or accommodate anchor bolts, requires special attention since poor construction may damage the tank bottom and influence the settlement behaviour of the shell.

6.4.5 Construction

Site preparation including possible soils improvement shall be carried out in accordance with (3.).

Foundation materials shall be placed and compacted in accordance with (4.3) and (4.4). The degree of compaction of the placed and compacted material shall be checked preferably by means of Dutch Cone Penetration Testing (DCPT) where fine granular materials are used.

If DCPTs are adopted as the checking method, the following minimum testing frequency shall be adopted:

- 3 DCPTs for tanks up to 15 m diameter
- 5 DCPTs for tanks up to 50 m diameter
- 9 DCPTs for tanks above 50 m diameter.

The penetration depth shall be between 3 m and 5 m under foundation level in order to confirm also the condition f/improvement in the subgrade.

See Appendix 5 for examples of typical DCPT values.

6.4.6 Tank pad finishes

The function of the covering to the tank pad (under the tank) is to promote a uniform distribution of stress from the tank bottom or the tank pad, to act as a barrier to corrosion promoted by water or water vapour together with chemicals which may be present in the tank pad or subsoil and to allow easy thermal expansion of the tank bottom.

The function of the covering of the tank foundation shoulder is to protect the foundation from damage resulting from weathering and erosion, and construction, operation and maintenance activities.

Tell-tale/weep hole drains shall be placed around the circumference of the foundation (if completely closed) in order to detect leakages and to prevent a pressure build-up due to liquid which would force the covering from the foundation.

Filter cloth shall be installed under the covering to the shoulder and slope to shoulder where the possibility of wash-out of fine materials exists, e.g. where asphalt is applied to a compacted sand shoulder. See Standard Drawing S 12.001.

The finish under the tank shall be a bitumen-sand mix. The sand of this mix shall be clean and have a low silt content. The exact composition of the dry sand bitumen mix shall be based on the assessment of field trial results. Guidelines for the design and placing of dry sand mixes are shown in Appendix 3.

The finished levels of the placed and compacted flexible covering, under the tank edge, shall not vary by more than plus or minus 6 mm in 3 m or 13 mm between any two given points.

The tank pad shoulder may, similar to bund walls, be covered by a sand/bitumen/cement mix (i.e. a wet sand mix). The exact composition, which depends on the sand grain size distribution, particle shape, etc., shall be based on the assessment of field trial results. Guidelines for the design and placing of bitumen-sand mixes are shown in Appendix 4.

6.4.7 Hydrostatic testing of tanks

The hydrostatic testing procedure of tanks, which is governed to a great extent by the behaviour of the subsoil, shall be approved by the principal.

Examples of hydrostatic testing procedures for different soil types are shown in Appendix 6.

7. REFERENCES

In this manual, reference is made to the following publications.

NOTE: The latest issue of each publication shall be used together with any amendments/supplements/revisions to such publications.

It is particularly important that the effect of revisions to international, national or other standards shall be considered when they are used in conjunction with DEPs, unless the standard referred to has been prescribed by date.

Site investigations	DEP 34.11.00.10-Gen.*
Geotechnical and foundation engineering	DEP 34.11.00.12-Gen.*
Roads, paving, surfacing, slope protection and fencing	DEP 34.13.20.31-Gen.
Refinery drainage systems	DEP 34.14.20.31-Gen.
Standard vertical tanks - Design and fabrication	DEP 34.51.01.31-Gen.
Erection and testing	DEP 64.51.01.31-Gen.

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US Army Coastal Engineering
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England

8. STANDARD DRAWINGS

Tank foundation - Typical details	S 12.001
Bund wall - Typical details	S 12.002

9. APPENDICES

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APPENDIX 1 FIELD COMPACTION TRIALS - POSSIBLE PROCEDURE

A test area 20 m long by 15 m wide should be prepared on the actual site of construction from which the top soil has been removed. The fill material to be used should then be spread over this area in three strips 5 m wide, the depth of the loose material in the strips being varied over the range of thicknesses. Normally, the range of values investigated would be from 150 to 450 mm. No adjustment should be made to the moisture content of the fill material which, apart from minor fluctuations, should be in its natural moisture condition.

The test area should then be compacted with the plant it has been decided to use and the mean dry density of the full depth of each strip determined after 2, 4 and 8 passes for all types of plant except for sheepsfoot rollers, for which the measurements of dry density should be made after 4, 8 and 16 passes. The dry densities of the soil should be determined by either the core-cutter or sand-replacement method, whichever is most suitable, and it is recommended that the mean of five determinations should be obtained for each soil condition.

This procedure should be repeated, if possible, at two other moisture contents, the values suggested being the optimum moisture content given by the BS compaction test and a moisture content intermediate between this value and the natural moisture content of the soil. If the natural moisture content of the soil is similar to the optimum moisture content, it is suggested that the additional tests be made at moisture contents 3% on either side of this value. These tests should be made on strips of fresh fill material laid on an adjacent area from which the topsoil has been removed.

The test procedure has been described in detail, but it can usually be considerably shortened by noting the trend of the early results, and by the experience of the engineers carrying out the tests. These trials would take about a week to complete, and could be started as soon as the necessary plant arrives on the site, while the preliminary clearing operations are in progress. The trials can thus be completed before the main construction starts. From the results of the trials and a knowledge of the costs of the various procedures, it is possible to determine the most economical procedure to be adopted to obtain the specified degree of compaction, and the subsequent control work can be simplified.

APPENDIX 2 INDICATIONS REGARDING COMPACTION

Type of compaction plant	Category	Cohesive soils		Well-graded granular and dry cohesive soils		Uniformly graded material	
	Mass per metre width of roll:	**D**	**N**	**D**	**N**	**D**	**N**
Smooth-wheeled roller	over 2100 kg up to 2700 kg	125	8	125	10	125	10*
	over 2700 kg up to 5400 kg	125	6	125	8	125	8*
	over 5400 kg	150	4	150	8	unsuitable	
Grip roller	over 2700 kg up to 5400 kg	150	10	unsuitable		150	10
	over 5400 kg up to 8000 kg	150	8	125	12	unsuitable	
	over 8000 kg	150	4	150	12	unsuitable	
Tamping roller	over 4000 kg	225	4	150	12	250	4
Pneumatic-tyred roller	Mass per wheel						
	over 1000 kg up to 1500 kg	125	6	unsuitable		150	10*
	over 1500 kg up to 2000 kg	150	5	unsuitable		unsuitable	
	over 2000 kg up to 2500 kg	175	4	125	12	unsuitable	
	over 2500 kg up to 4000 kg	225	4	125	10	unsuitable	
	over 4000 kg up to 6000 kg	300	4	125	10	unsuitable	
	over 6000 kg up to 8000 kg	350	4	150	8	unsuitable	
	over 8000 kg up to 12000 kg	400	4	150	8	unsuitable	
	over 12000 kg	450	4	175	6	unsuitable	
Vibrating roller	Mass per metre width of a vibrating roller		12				
	over 270 kg up to 450 kg	unsuitable	8	75	16	150	16*
	over 700 kg up to 1300 kg	100	4	125	12	150	6
	over 1300 kg up to 1800 kg	125	4	150	8	200	10*
	over 1800 kg up to 2300 kg	150	4	150	4	225	12*
	over 2300 kg up to 2900 kg	175	4	175	4	250	10*
	over 2900 kg up to 3600 kg	200	4	200	4	275	8*
	over 3600 kg up to 4300 kg	225	4	225	4	300	8*
	over 4300 kg up to 5000 kg	250	4	250	4	300	6*
	over 5000 kg	275	4	275	4	300	4*
Vibrating-plate compactor	Mass per unit area of base plate:						
	over 880 kg up to 1100 kg	unsuitable		unsuitable		75	6
	over 1100 kg up to 1200 kg	unsuitable		75	10	100	6
	over 1200 kg up to 1400 kg	unsuitable		75	6	150	6
	over 1400 kg up to 1800 kg	100	6	125	6	150	4
	over 1800 kg up to 2100 kg	150	6	150	5	200	4
	over 2100 kg	200	6	200	5	250	4
Vibro-tamper	Mass:						
	over 50 kg up to 65 kg	100	3	100	3	150	3
	over 65 kg up to 75 kg	125	3	125	3	200	3
	over 75 kg	200	3	150	3	225	3
Power rammer	Mass:						
	100 kg up to 500 kg	150	4	150	6	unsuitable	
	over 500 kg	275	8	275	12	unsuitable	
Dropping weight compactor	Mass of rammer over 500 kg						
	Height of drop:						
	over 1 m up to 2 m	600	4	600	8	450	8
	over 2 m	600	2	600	4	unsuitable	

D = Maximum depth of compacted layer (mm)
N = Minimum number of passes

DEFINITIONS AND REQUIREMENTS ASSOCIATED WITH THE TABLE

A. The depth of compacted layer is the height by which the embankment is raised by each successive compacted layer.

B. The number of passes is the number of times that each point on the surface of the layer being compacted has been traversed by the item of compaction plant.

C. The compactive effort of each compactor is a function of the mass of the machine and the compaction plant in Appendix 2 - page 1 is listed in terms of their masses. The mass per metre width of roll is the total mass on the roll divided by the total roll width. Where a smooth-wheeled roller has more than one axle, the machine shall be assessed on the basis of the axle giving the highest value of mass per metre width.

D. A tamping roller, for the purposes of this manual, is a machine with a roll or rolls from which `feet' project. The projected end area of each `foot' shall exceed 0.01 m^2 and the sum of the area of the feet shall exceed 15% of the area of the cylinder swept by the ends of the feet. The requirements for tamping roller apply to machines that have 2 rolls in tandem. If only one tamping roll traverses each point on the surface of the layer on any one pass of the machine, the minimum number of passes shall be twice the number given in the tabel.

E. (i) For pneumatic-tyred rollers mass per wheel is the total mass of the roller divided by the number of wheels.

(ii) In assessing the number of passes of pneumatic-tyred rollers the effective width shall be the sum of the widths of the individual wheel tracks together with the sum of the spacing between the wheel tracks provided that each spacing does not exceed 230 mm. Where the spacings exceed 230 mm the effective width shall be the sum of the widths of the individual wheel tracks only.

F. Vibrating rollers are self-propelled or towed smooth-wheeled rollers having means of applying mechanical vibration to one or more rolls.

(i) The requirements for vibrating rollers are based on the use of the lowest gear on a self-propelled machine with mechanical transmission and a speed of 1.5-2.5 km/h for a towed machine, or a self-propelled machine with hydrostatic transmission. If higher gears or speeds are used an increased number of passes shall be provided in proportion of the increase in speed of travel.

(ii) Where the mechanical vibration is applied to two rolls in tandem, the minimum number of passes shall be half the number given in the table for the appropriate mass per metre width of one vibrating roll. If one roll differs in mass per metre width from the other, the number of passes shall be calculated as for the roll with the smallest value. Alternatively the machine may be treated as having a single vibrating roll with a mass per metre width equal to that of the roll with the higher value.

(iii) Vibrating-type rollers operating without vibration will be classified as smooth-wheeled rollers.

(iv) Vibrating rollers shall be operated with their vibratory mechanism operating only at the frequency of vibration recommended by the manufacturers. All such rollers shall be equipped or provided with a device automatically indicating the frequency at which the mechanism is operating.

G. Vibrating-plate compactors are machines having a baseplate to which is attached a source of vibration consisting of one or 2 eccentrically weighted shafts.

(i) The mass per unit area of baseplate of a vibrating-plate compactor is calculated by its working condition by its area in contact with compacted soil.

(ii) Vibrating-plate compactors shall be operated at the frequency of vibration recommended by the manufacturers. They shall normally be operated at travelling speeds of less than 1 km/h but if higher speeds are necessary the number of passes shall be increased in proportion to the increase in speed of travel.

H. Vibro-tampers are machines in which an engine-driven reciprocating mechanism acts on a spring system through which oscillations are set up in a baseplate.

I. Power rammers are machines which are actuated by explosions in an internal combustion cylinder, each explosion being controlled manually by the operator.

J. In the case of power rammers and dropping-weight compactors one pass will be considered as made when the compacting shoe has made one strike on the area in question.

K. For items marked the rollers shall be towed by track-laying tractors. Self-propelled rollers are unsuitable.

APPENDIX 3 BITUMEN-SAND MIXES FOR TANK PADS

The sand shall be clean and have a silt content of less than 5%. The amount of material passing the 200 mesh (.74) sieve should be 3 to 5% (this can usually be obtained by blending sands from different sources if the preferred source is unsuitable). It is not possible to give precise grading limits as satisfactory mixes can be made from a large variety of sands of widely different grading.

Cutbacks or penetration grade bitumens may be used. The following table lists potentially suitable grades together with recommended mixing temperatures. These mixing temperatures should be strictly complied with to ensure that good coating of the minerals is obtained and that the bitumen is not damaged by excessive heat.

Grade	Recommended mixing temperature, °C
Shelmac 50/100	65 - 95
Shelmac 150/200	80 - 95
Shelmac 200/300	85 - 105
Shelmac 300/400	95 - 110
Shelmac 400/500	100 - 115
Shelmac 500/700	110 - 120
Shelmac S.125	105 - 135
Shelmac SRO	70 - 100
MC 800	80 - 115
MC 3000	95 - 120
MC 3	65 - 95
MC 4	80 - 100
MC 5	100 - 120
Mexphalte 80/100	135 - 160
Mexphalte 60/70	145 - 170

The most suitable bitumen content is best assessed by mixing trials using the equipment available, on the basis of workability, visual and handling characteristics of the mix. A guide can be obtained from the grading of the sand by using a method based on the specific surface area of the particles.

A conventional bitumen asphalt mixer of either the batch or continuous type, having a twin-shaft pugmill, is generally necessary. At remote sites this may not be possible and it may sometimes be necessary to mix by hand, although this is only possible when using low viscosity cutbacks. The sand must be dried on a steel plate over a fire and the bitumen heated prior to mixing by turning over with shovels.

The mix can be spread by hand, using wooden side forms and screeds but for large-scale work where equipment is available, a grader or asphalt paver may be more appropriate. When spreading by hand, the mix should be tipped on to shovelling plates outside the area on which it is to be placed and then moved from the heap and placed in position for screeding. The total compacted thickness required will depend on the state of the subgrade: if it is uniform and well-compacted a total compacted thickness of 50 mm of bitumen-sand mix will normally be sufficient but if the subgrade is poorly compacted, it may be desirable to place two 50 mm layers of mix.

Sand mixes compact easily and a few passes of light pneumatic tyred rollers or tractors provide effective compaction: the marks caused by the tractor tyres soon iron out with further passes and the use of a steel tyred roller or vibrating-plate compactor will usually provide an adequate finish.

APPENDIX 4 WET SAND MIX FOR TANK PAD SHOULDERS AND BUND WALLS

The majority of sands is suitable but they shall not have a silt content of more than 3%. It is not appropriate to give any definite limits to the grading required since satisfactory mixes can be made with a large variety of sands of widely different gradings. It is, however, desirable that there should be 3 to 10% of material passing the 200 mesh sieve.

The bitumen is a specially prepared kerosine cutback known as Shelmac SRO (Special Road Oil) with a viscosity of 40-50 s STV (standard tar viscosity)* at 25 °C, containing an additive. For use in the tropics a grade made with a harder basic bitumen, known as Tropical SRO should be used. SRO can be made available on special order from some Shell refineries.

* For further information, see BS 2000, Part 72.

In order to coat the wet sand an activator is required in conjunction with the additive in the SRO. The most effective activator is hydrated lime with a calcium hydroxide content of 90%. Although less is required for the chemical reaction, 2%, based on the total mix, is used to ensure good dispersion in the sand. If hydrated lime is not available, Portland cement may often be used in which case 3 to 4% is required, primarily due to the greater density of cement. The activator is dispersed in the sand before mixing with the SRO. Larger quantities of activator should not be used as it is not required for the chemical reactions; it will require additional SRO because of the high specific surface area of the activator and may result in a rather brittle mix of reduced durability.

Water is an essential component in the process and even if the sand is damp it will usually be necessary to add additional water to bring the total water content of the sand to at least 5%.

The minimum SRO content is determined by a simple cohesivity test. A mix is made using dry sand, 4% SRO, 2% hydrated lime and 10% water: the mix may be prepared by hand mixing. The mix is introduced into a wide mouthed glass jar to give a loose layer of about 15 mm and covered to a depth of about 50 mm with water. The mix is then broken up by stirring and then compacted under water using a tamping rod with a base of about 20 mm diameter. If the mix compacts well and resists disintegration when the jar is rotated to swirl the water, the mix is considered to be cohesive. Other mixes should then be prepared with increasing or decreasing quantities of SRO, usually in steps of ½ %, to determine the minimum quantity required to obtain a cohesive mix. A suitable working SRO content is considered to be the minimum plus 1½ %. If the working SRO content is less than 4%, as may be the case with sands lacking fines, it may be desirable to increase the fines content.

All percentages are in terms of weight.

In general, a mix made with the working SRO content will be satisfactory but there are conditions where due to impermeability, which prevents evaporation of the water and the solvent from the cutback, the mix will not harden up.

This is most likely to occur with fine-graded or dirty sands which require a high SRO content. A small sample should therefore be prepared by rolling some mix in a tray. As the mix is rolled out excess water should be expelled if the mix is sufficiently permeable. If water is not expelled, it is likely that the mix is impermeable and should thus be rejected.

The mix is placed and compacted in the same manner as for dry sand bitumen mixes.

APPENDIX 5 EXAMPLES OF DCPT VALUES TO CHECK COMPACTION/QUALITY OF TANK PADS

Tank pads are normally constructed of sand and compacted to such a degree that the tank foundation finally meets the stability and settlement requirements.

The quality of sand (i.e. sit content, pockets, etc.) and the degree of compaction can be reliably checked with the aid of DCPTs. Examples of minimal required DCPT values for various cases are listed below.

Diameter storage tank (m)	12	12	24	36	45
Height storage tank (m)	10	15	16	20	24
Shoulder width tank pad (m)	0.7	1	1	1.3	1.5
Safety factor against edge sliding	1.4	1.4	1.4	1.4	1.4
Table min. DCPT values	1	2	3	4	5

Ground water level: 1.5 m below top tank pad.

TABLE 1

Depth underneath top tank pad (m)	Minimal DCPT value in kgf/cm^2
0.25	40
0.50	55
0.75	60
1.00	65
1.50	70
2.00	75

TABLE 2

Depth underneath top tank pad (m)	**Minimal DCPT value in kgf/cm^2**
0.25	50
0.50	65
0.75	75
1.00	80
1.50	85
2.00	90

TABLE 3

Depth underneath top tank pad (m)	Minimal DCPT value in kgf/cm^2
0.25	55
0.50	70
0.75	80
1.00	85
1.50	90
2.00	95

TABLE 4

Depth underneath top tank pad (m)	Minimal DCPT value in kgf/cm^2
0.25	65
0.50	80
0.75	85
1.00	90
1.50	95
2.00	100

TABLE 5

Depth underneath top tank pad (m)	Minimal DCPT value in kgf/cm^2
0.25	70
0.50	85
0.75	90
1.00	95
1.50	100
2.00	105

Should the actual DCPT values appear to be below the calculated minimum value, a further compaction or replacement of the sand will be required.

The penetration depth shall be preferably between 3 m and 5 m under top tank pad in order to confirm also the quality of the subsoil underneath the tank pad.

APPENDIX 6 HYDROSTATIC TESTING PROCEDURE

1. BASIC DATA

   Filling height = H (metres)

2. RECOMMENDATIONS

   a. Storage tanks placed on clayey, silty or sandy subsoil should be filled in four stages. Duration and interval between the various stages depend on the subsoil conditions and the settlement behaviour during hydrostatic testing.

   b. Soil data as well as settlement and stability calculations must be available before the tank is tested, and the calculated safety factors must meet the requirements.

   c. The settlement behaviour during and after hydrostatic testing must be monitored.

3. TESTING RATE

Stage 1
Filling of the tank to 0.5 H; the rate of filling should not exceed `a' metres per day. The total filling per day should be completed in a period of not less than 3 hours. During the ensuing balance of hours in the day's total of 24, the foundation will be allowed to equilibrate/consolidate/be monitored. A minimal equilibration/monitoring period of 6 hours is considered to be necessary.
At the end of stage 1, there will be an X-hour equilibration/monitoring period before commencement of stage 2.

Stage 2
Filling of the tank from 0.5 H to 0.67 H; the rate of filling should not exceed `b' metres per day. The total filling time and equilibration/monitoring period per day should be as for stage 1 above. A minimal equilibration/monitoring period of 8 hours is considered to be necessary.
At the end of stage 2, there should be an Y-hour equilibration/monitoring period before commencement of stage 3.

Stage 3
Filling of the tank from 0.67 H to 0.83 H; the rate of filling should not exceed `c' metres per day. The total filling time and equilibration/monitoring period per day should be as for stage 1 above. A minimal equilibration/monitoring period of 8 hours is considered to be necessary.
At the end of stage 3, there should be a Z-hour equilibration/monitoring period before commencement of stage 4.

Stage 4
Filling of the tank from 0.83 H to 1.00 H; the rate of filling should not exceed `d' metres per day. The total filling time and equilibration/monitoring period per day should be as for stage 1 above. A minimal equilibration/monitoring period of 10 hours is considered to be necessary.
At the end of stage 4, the tank must be left fully filled and monitored for at least 4 more days.

The daily filling rates and the duration of the various equilibration/observation periods depend on the subsoil conditions, and the following limit values shall be taken into consideration:

Subsoil conditions underneath tank pad	**a**	**b**	**c**	**d**	**X**	**Y**	**Z**
	(max. value in m)				**(min. value in hours)**		
Soft clay or silt	2	1	0.75	0.5	48	48	48
Stiff clay	2	1.25	0.75	0.5	36	36	48
Clayey, silty sand	2.5	1.25	0.75	0.5	24	36	48
Sand	2.5	1.5	1	0.75	12	12	24
Weathered rock, cemented soil	-	-	-	-	-	12	48
Sound rock	-	-	-	-	-	-	24

4. MEASUREMENT OF SETTLEMENTS DURING TESTING

Measurement of the tank shell settlements should be taken from at least 8 points, evenly distributed around the wall at a distance of 12 metres max. In accordance with the filling rate of minimal 3 hours per day, the following daily schedule of measurements could be used:

- prior to filling
- just after filling
- 2 hours after filling (optional, depending on the results)
- 5 hours after filling.

Also during each equilibration period between the various stages, during the period when the tank is filled after completion of stage 4 and during the draining of the tank, 3 measurements should be taken daily.
Exception: in the event of rocks subsoil (incl. weathered rock and cemented soil) the measurements may be limited to (a) prior hydrostatic testing, (b) equilibratIon period between stages 3 and 4 and (c) end of stage 4.

5. SETTLEMENT BEHAVIOUR DURING TESTING

A. ***General***
The measured daily settlement rate during the equilibration/monitoring period between the various stages and during the period after the tank is filled (i.e. after completion of stage 4) must diminish with time (e.g. the settlement rate of the second day must be less than that of the first day).

In the case of increased settlement rate during the above-mentioned equilibration/monitoring period between the various stages and during the period just after filling is completed (stage 4), there is a danger for instability. In such a case the principal shall be informed, the tank must be (partly) emptied and a geotechnical engineer as well as a tank specialist should be consulted.

B. **Floating roof tanks**
Floating roofs are equipped with rim seals which can compensate the out-of-roundness of the tank shell. Out-of-roundness of the tank shell may occur due to:

a. Limits in accuracy of construction. A tank shell could easily show an out-of-roundness up to approximately 50 mm (depending on diameter) due to practical limits of accuracy.

b. Out of roundness caused by **uneven soil settlement.** In one direction the shell will increase in diameter in the other direction it will decrease in diameter.

When the ultimate outward movement is reached, a gap is formed between seal plates and shell at some locations. At other locations the ultimate inward movement may be reached, which may result in the roof becoming stuck so that the roof seal would be damaged.

6. EVALUATION OF TANK SETTLING CHARACTERISTICS

Compliance with the above recommended procedures and specifications will theoretically ensure that a part of the maximum overall tank settlements will occur during the water testing period. Extending the period of testing over that scheduled in above will increase the percentage of total settlement thereby accordingly.

It should be noted that observations regarding the time/settlement behaviour and total settlements occurring during the period of water testing, will be found useful in making a more precise evaluation of further settlement behaviour expected to occur during the operational period.

7. FILLING RATE AFTER HYDROSTATIC TESTING

Depending on the results of the hydrostatic testing, some limitations as regards the filling rate during the first few operational fillings, just after the hydrostatic testing, may be required.

In the event of poor results of the hydrostatic testing, a geotechnical/foundation engineer should be consulted hereon.