TECHNICAL SPECIFICATION

MOUNDED HORIZONTAL CYLINDRICAL BULK STORAGE VESSELS FOR PRESSURISED GASES AT AMBIENT TEMPERATURES

DEP 34.51.11.30-Gen.

December 1993

DESIGN AND ENGINEERING PRACTICE

USED BY

COMPANIES OF THE ROYAL DUTCH/SHELL GROUP

PREFACE

DEP (Design and Engineering Practice) publications reflect the views, at the time of publication, of:

Shell International Oil Products B.V. (SIOP)
and
Shell International Exploration and Production B.V. (SIEP)
and
Shell International Chemicals B.V. (SIC)

The Hague, The Netherlands,

and other Service Companies.

They are based on the experience acquired during their involvement with the design, construction, operation and maintenance of processing units and facilities, and they are supplemented with the experience of Group Operating companies. Where appropriate they are based on, or reference is made to, national and international standards and codes of practice.

The objective is to set the recommended standard for good design and engineering practice applied by Group companies operating an oil refinery, gas handling installation, chemical plant, oil and gas production facility, or any other such facility, and thereby to achieve maximum technical and economic benefit from standardization.

The information set forth in these publications is provided to users for their consideration and decision to implement. This is of particular importance where DEPs may not cover every requirement or diversity of condition at each locality. The system of DEPs is expected to be sufficiently flexible to allow individual operating companies to adapt the information set forth in DEPs to their own environment and requirements.

When Contractors or Manufacturers/Suppliers use DEPs they shall be solely responsible for the quality of work and the attainment of the required design and engineering standards. In particular, for those requirements not specifically covered, the Principal will expect them to follow those design and engineering practices which will achieve the same level of integrity as reflected in the DEPs. If in doubt, the Contractor or Manufacturer/Supplier shall, without detracting from his own responsibility, consult the Principal or its technical advisor.

The right to use DEPs is granted by SIOP, SIEP or SIC, in most cases under Service Agreements primarily with companies of the Royal Dutch/Shell Group and other companies receiving technical advice and services from SIOP, SIEP or SIC. Consequently, three categories of users of DEPs can be distinguished:

1) Operating companies having a Service Agreement with SIOP, SIEP, SIC or other Service Company. The use of DEPs by these Operating companies is subject in all respects to the terms and conditions of the relevant Service Agreement.

2) Other parties who are authorized to use DEPs subject to appropriate contractual arrangements.

3) Contractors/subcontractors and Manufacturers/Suppliers under a contract with users referred to under 1) or 2) which requires that tenders for projects, materials supplied or - generally - work performed on behalf of the said users comply with the relevant standards.

All administrative queries should be directed to the DEP Administrator in SIOP.

NOTE: In addition to DEP publications there are Standard Specifications and Draft DEPs for Development (DDDs). DDDs generally introduce new procedures or techniques that will probably need updating as further experience develops during their use. The above requirements for distribution and use of DEPs are also applicable to Standard Specifications and DDDs. Standard Specifications and DDDs will gradually be replaced by DEPs.

TABLE OF CONTENTS

APPENDICES

1. INTRODUCTION

1.1 SCOPE

This DEP replaces DDD 34.51.11.30-Gen., dated March 1988, and gives minimum requirements for the design, fabrication, erection, inspection and testing of mounded horizontal cylindrical bulk storage vessels for pressurised gases at ambient temperatures. It covers the storage vessels, the soil investigation, foundation, mound, corrosion protection and cathodic protection requirements. Requirements for piping and rotating equipment are not included.

The Principal shall specify the product(s) to be stored, including product design parameters, pressure testing requirements and the storage capacities with main dimensions.

1.2 DISTRIBUTION, APPLICABILITY AND REGULATORY CONSIDERATIONS

Unless otherwise authorised by SIPM, the distribution of this document is confined to companies forming part of or managed by the Royal Dutch/Shell Group, and to Contractors and Manufacturers nominated by them (i.e. the distribution code is "F", as defined in DEP 00.00.05.05-Gen.).

This DEP is intended for use in oil refineries, chemical plants, gas plants, exploration and production facilities and supply/marketing installations.

If national and/or local regulations exist in which some of the requirements may be more stringent than in this DEP, the Contractor shall determine by careful scrutiny which combination of requirements will be acceptable as regards safety, economic, environmental, and legal aspects. In all cases the Contractor shall inform the Principal of any deviation from the requirements of this document 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 document as closely as possible.

1.3 DEFINITIONS

1.3.1 General definitions

The **Contractor** is the party which carries out all or part of the design, engineering, procurement, construction, commissioning or management of a project or operation of a facility. The Principal may undertake all or part of the duties of the Contractor.

The **Manufacturer/Supplier** is the party which manufactures or supplies vessels, equipment and services to perform the duties specified by the Contractor.

The **Principal** is the party which initiates the project and ultimately pays for its implementation. The Principal will specify the technical requirements. The Principal may also include an agent or consultant authorised to act for, and on behalf of, the Principal.

The Principal will provide a site for the implementation of the project.

The word **shall** indicates a requirement.

The word **should** indicates a recommendation.

1.3.2 Specific abbreviations and definitions

ABP	=	atmospheric boiling point
AC	=	alternating current
BH	=	bore hole
BLEVE	=	boiling liquid expanding vapour explosion
CP	=	cathodic protection
CPT	=	cone penetration test
DC	=	direct current
DCT	=	deep conductivity test
HPT	=	hydrostatic pressure test
MPI	=	magnetic particle inspection
PM	=	piezometer
PWHT	=	post weld heat treatment
RT	=	radiography test
SCT	=	surface conductivity test
SPT	=	standard penetration test
UT	=	ultrasonic test (steel)
USS	=	undisturbed soil sampling (soil)
VE	=	visual examination

Cathodic protection - the process to reduce or prevent corrosion of metal structures in contact with soil by the flow of direct current from the soil into the structure surface.

Current density - the amount of current per unit area of the steel surface, coated or uncoated, in contact with the soil.

The **foundation** is that part of the earth surrounding the vessel which actually carries the load. It is located below the 120° support angle.

Groundbed - The system of buried electrodes, connected to the positive terminal of the cathodic protection voltage source to conduct the required current into and through the soil to the steel surface to be protected.

The **mound** is that part of the earth surrounding the vessel which is not part of the foundation, i.e. above the 120° support angle.

Natural potential - the structure to soil potential measured when no cathodic protection is applied and polarization caused by cathodic protection is absent.

"OFF" potential - the structure to soil potential measured immediately after the cathodic protection system is switched off and the applied electrical current stops flowing to the structure surface, but before polarization of the structure has decreased.

"ON" potential - the structure to soil potential measured while the cathodic protection system is continuously operating.

Polarization - the change of the structure to soil potential caused by the flow of DC current between an electrolyte and a steel surface.

Polarization cell - a device inserted in the earth connection of a structure that isolates for DC in the cathodic protection voltage range and has a low resistance for all AC and high DC voltages.

Reference electrode - An electrode of which the electrochemical potential is accurately reproducible and which serves as a reference for structure to soil potential measurements.

Structure to soil potential - the difference in electrochemical potential between a buried structure and a specified reference electrode in contact with the soil.

1.4 CROSS-REFERENCES

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

All publications referenced by this DEP are listed in (8.).

1.5 CONCEPT

The design lifetime of mounded storage is 25 years.

Mounded storage comprises the storage of pressurised gases at ambient temperatures in horizontal cylindrical vessels placed near ground level and covered with suitable backfill. Several vessels may be located side by side in one mound.

Mounded storage is applied because it provides additional safety compared to above ground storage of gases in spheres or bullets. Its major advantage is that a BLEVE is made virtually impossible.

Other benefits of the mound are:

- protection of the vessel(s) against:
  - heat radiation from a nearby fire,
  - pressure wave originating from an explosion,
  - impact by flying objects,
  - sabotage,
- it satisfies environmental and aesthetic requirements,
- it results in reduced site area due to less stringent inter-spacing requirements,
- the safety distance to the site boundary can be reduced considerably.

The design aspects of mounded storage projects are in general more complicated than those for above ground spheres or bullets. Particular attention is drawn to the importance of the vessel to soil interraction and to corrosion protection.

The existing pressure vessels codes, such as BS 5500, do not cover the special soil cover and/or support aspects of mounded storage. As external inspections of mounded vessels are not intended, the utmost attention is required for the coating and cathodic protection system to minimize the risk of (undetected) corrosion.

Depending on site conditions, ground water level and operational requirements, the vessels may be installed either at grade level or in an excavation, after which they shall be backfilled. Since the vessels shall be installed above the highest known ground water table, the soil cover usually protrudes above grade as an earth mound, hence the term "mounded storage".

Vessels in open underground vaults and excavations are not considered to be mounded storage vessels.

The vessels are provided with connections (e.g. manholes, pressure relief valves and instrument connections) protruding through the top of the mound. Only if dictated by operational requirements may a bottom discharge in an inspection tunnel be considered.

The vessels shall be completely covered; only the top connections (manholes and/or dome) may protrude through the mound.

If more than one vessel is placed in a single mound then the minimum distance between the vessels depends on construction activities like welding, coating, backfilling and compaction of the backfill material. A distance of 1 m is considered to be a minimum requirement.

The maximum diameter is usually determined by factors such as design pressure, fabrication, post weld heat treatment requirements, transport limitations, subsoil conditions and economy of design (8 metres may be regarded as a practical upper limit).

For vessels which are founded on a sandbed, the length of the vessel should be no more than 8 times the diameter, in order to prevent the design shell thickness being governed by longitudinal bending of the vessel due to possible differential settlements or construction tolerances of vessels and foundations.

The maximum allowable length is usually determined by the subsoil conditions (especially if differential settlements are expected), size of available site and economy of the design.

The above restrictions limit the maximum volume of a vessel to approximately 3500 m^3 gross. There is no limitation to the minimum size of the vessel, except for practical considerations.

1.6 PROJECT PLANNING

Due to the multi-disciplinary nature of a mounded storage project, thorough project planning is essential.

The MF Guidelines for Capital Investment Projects (Report MF 89-0587) and its Satellite Documents, which are directed at MF Project Managers and Operating Companies, give advice and guidance on project management in capital investment projects.

The following table shows benchmarks for mounded storage projects during the different project development phases:

Screening/Scouting Phase	Determine scope of project Assess throughputs/capacities Select potential sites Prepare screening study report
Feasibility Phase	Select suitable site, conduct preliminary soil/environmental investigation Freeze storage capacities and plant throughput Complete conceptual lay-out Complete conceptual vessel design Capex ± 20% estimate Prepare feasibility study report inclusive 502 P
Definition Phase	Detailed soil investigation BOD (Basis of Design) Vessel requisition sheets Equipment summary sheets Vessel manufacturer selection Vessel coating selection Selection CP system Cost estimate ± 10%. Prepare project definition phase report inclusive 502 F
Execution/Implementation Phase	Appoint/brief project team Prepare tender documents Contract Complete detailed design QA/QC procedures for vessel welding/coating Procure materials/equipment Construct facility

For Supply and Marketing Projects see: "A guide to the Planning and Management of large LPG Capital Projects", (SIPC-SMDF/4 Ref.No.M/L/93/D/0554).

2. SOIL INVESTIGATION

2.1 GENERAL

The soil investigation shall be carried out in accordance with DEP 34.11.00.10-Gen.

Before an optimised scope for detailed soil investigation can be established, the following information shall be made available to the Contractor:

- location and description of the construction site (including former use)
- orientation of the vessel(s) relative to Plant North
- conceptual site development plan
- elevations of the planned construction site (ground levels and ground water levels)

Also general information on the subsoil conditions shall be made available. This information should address following aspects:

- geological description of the area
- seismiscity of the area
- geotechnical description of the area

Depending on the history of the site, it should be considered whether the investigation needs to include an environmental/chemical survey of subsoil and ground water.

The minimum scope of the site investigation is described in (2.2), but may require adjustment depending on the outcome of the gathered information.

2.2 FIELDWORK

The heterogeneity/stratigraphy of the subsoil shall be investigated by Cone Penetration Tests (CPTs) and borings. If the use of CPTs is not possible, an increased number of borings shall be carried out.

All borings provided as part of the fieldwork shall be combined with recovered undisturbed samples and executed Standard Penetration Tests, both at average intervals of 1.5 metres and at change of strata.

Minimum number of field tests

With CPTs	CPT	: centre to centre 20 +/- 5 m
	BH	: at least 1, or 1 per 2 vessels
	USS/SPT	: each BH
	SCT	: at least 1, or 1 per 2 vessels
	DCT	: 1 BH location
	PM	: at least 1
With BHs	BH+USS/SPT	: centre to centre 20 +/- 5 m
	SCT	: at least 1, or 1 per 2 vessels
	DCT	: 1 BH location
	PM	: at least 1

The positions of the CPTs and Borings shall be evenly distributed over the length of the vessels:

Testing locations:

one vessel	:	along the centre line of the vessel
two vessels	:	both outside edges of the vessels in the longitudinal direction
three vessels or more	:	for outer vessels along the outside edges and for the inner vessel(s) along the centre line

The scope of work for the soil investigation may be reduced if reliable information from a geophysical survey is available (electromagnetic survey, geo-electric survey etc.).

Depending on the knowledge of the site specific geohydrology (e.g. presence of various aquifers, phreatic ground water level, piezometric levels from aquifers and level variations) the number of open standpipe piezometers should be determined. The minimum scope should include the installation of at least one open standpipe piezometer. In case an environmental survey is required, the open standpipe installation can be combined with the installation of an environmental monitoring well.

The piezometric level in the open standpipe needs to be monitored frequently during execution of the soil investigation and frequently during a period thereafter. The duration of this period depends on the local climatological conditions.

2.3 LABORATORY WORK

Laboratory tests shall be carried out on recovered samples (undisturbed and disturbed) during the fieldwork.

- Classification tests:
  - on all samples:
    - visual description
    - wet and dry unit weight
    - water content
  - on samples selected by the Contractor in consultation with the Principal:
    - particle size analysis
    - Atterberg limits
- Consolidation tests (seven loading steps + one unloading step)
- Consolidated Drained and/or Consolidated Undrained Triaxial Tests to obtain strength and stiffness parameters of the soil (subsoil and fill material)
- Chemical analysis of soil and ground water samples
- Optimum moisture content (for compaction of subsoil and fill material)
- Electrical conductivity of soil
- Environmental analysis of soil and ground water samples, the scope of which depends on history of the site and nearby industrial activity.

It is stressed that recovery, preservation, transport and storage of soil and ground water samples for environmental analysis shall be done according to stringent procedures.

2.4 REPORTING

A foundation engineering report shall be prepared by the Contractor. The topics to be covered shall include, but not be limited to, the following items:

Factual data:

- Topography and geodetic levels of the site;
- Observed ground water levels (including variations);
- Factual results from field and laboratory work;
- Stratigraphy along the axis of the vessels (indicating position of CPTs and BHs).

Engineering:

- Discussion of obtained factual data against general site geology;
- Discussion of possible local subsoil variation;
- Recommended installation level of vessels relative to ground water levels;
- Evaluation of load conditions during mound construction and operational lifetime;
    - e.g. including horizontal loads on piled foundations as a consequence of mound construction.
- Discussion of the recommended type of foundation (3);
    - Bearing capacity:
        - selection of governing load conditions for the critical stages of construction and for the operational lifetime of the mounded storage.
        - susceptibility of the subsoil to liquefaction, if relevant.
        - in case of a soil bearing foundation: subsoil bearing capacity during various stages of mound construction and during the operational lifetime of the mounded storage.
        - in case of piled foundations with a raft or saddles: axial pile bearing capacity taking into account positive/negative skin friction and end bearing, group effect and lateral bearing capacity.
    - Settlement:
        - settlement analyses to be executed shall specify elastic, consolidation and creep components.
        - selection of governing operational load.
        - settlement of the vessel during hydrotesting (during construction and during re-test conditions)
- Minimum and maximum long-term subgrade (bedding) modulus along the vessel axis.
    - Stability analysis:
        - Stability analyses of the mound slope for various load cases during construction and during operational lifetime (slip circle analyses).
    - Construction of the mound:
        - advice on the suitability of fill material for the foundation bed and the construction of the mound (including CP requirements).
        - advice on compaction of the vessel foundation bed and the fill material surrounding the vessel.
        - advice on remedial measures to overcome severe erosion during construction, if relevant.

3. FOUNDATION AND EARTH MOUND

3.1 SITE PREPARATION

Site preparation and earthworks shall be designed and executed in accordance with DEP 34.11.00.11-Gen.

3.2 TYPES OF FOUNDATION

3.2.1 Soil bearing foundation

A soil bearing foundation which supports the vessel, installed on a sandbed, over its full length is the preferred solution. This type of foundation provides continuous support, which allows an economic structural design of the vessel, an economic foundation method, and allows optimal cathodic protection.

In order to reduce settlements, it may be required to apply soil improvement. In that respect a preload embankment, preferably consisting of fill material to be used during sandbed and mound construction, is an economic solution. In some cases additional fill material will be required to optimize the preload period against subsoil condition and/or project schedule. The duration of the preload period depends on the subsoil condition, especially the duration of the hydrodynamic period. During construction of the embankment and the subsequent preload period, settlements shall be monitored and recorded. To that purpose at least three settlement beacons shall be installed along the future axis of each vessel. Monitoring of settlements during construction and the preload period allows for (foundation) design verification.

In addition, at specific locations soil improvement by replacement of the subsoil may be required. The combination of soil replacement and preloading is also a feasible option.

Although a soil bearing type of foundation is the preferred solution, it will not always be possible. If, for example, long-term settlements are too large, a sound and/or economic structural design of the vessel may not be possible. Also, seismiscity may affect the selection of the foundation type.

3.2.2 Sandbed on piled concrete slab

If for settlement reasons the project does not allow the application of a soil bearing foundation, a piled foundation supporting a concrete slab may be considered. The vessel shall then be installed in a sandbed (having a minimum thickness of 1 m) on top of the concrete slab.

3.3 SETTLEMENT OF SOIL BEARING FOUNDATIONS

3.3.1 Immediate settlements

Settlements of the vessel and/or preload embankment occurring immediately during construction shall be analysed and compared with predicted and monitored settlements.

3.3.2 Long-term settlements

Settlement analyses should also address long-term settlements of the vessel during its operational lifetime. Long-term settlements shall be used to derive a subgrade modulus required for vessel design purposes.

3.3.3 Total and Differential settlements

In the settlement analysis both the total and differential settlements of the vessel shall be addressed.

The maximum allowable total settlement of the vessel depends, amongst other things on connecting piping and/or a tunnel to house a bottom discharge pipe.

Differential settlements of the vessel will affect the longitudinal slope of the vessel and the uniformity of vessel support.

Settlements of the vessel may be considerably reduced by the application of soil improvement (see 3.2.1).

3.4 SETTLEMENT MONITORING

3.4.1 Settlement monitoring during preloading

Prior to installation of a preload embankment, settlement plates shall be installed on the original ground level. The settlement plates may consist of vertical bars connected to a base plate of e.g. 1 x 1 metre. The settlements of the subsoil shall be monitored in accordance with the table below.

<table>
<tr><th colspan="2">Phase</th><th>Frequency</th></tr>
<tr><td colspan="2">During construction</td><td>Weekly</td></tr>
<tr><td rowspan="3">During preload period</td><td>Month 1 and 2</td><td>Weekly</td></tr>
<tr><td>Month 3 and 4</td><td>Every 2 weeks</td></tr>
<tr><td>Month 5 onward</td><td>Every month</td></tr>
</table>

In case of doubt on the stability of the preload embankment and/or mound as a consequence of the presence of a top clay, excess pore water pressures should be monitored during preload embankment and/or mound construction.

3.4.2 Settlement monitoring of mound and vessel

Permanent reference points shall be installed/identified on top of the vessel to monitor the vessel settlements. The maximum spacing of these reference points should be approximately two times the vessel diameter. A minimum of three reference points shall be installed to be able to identify possible vessel bending (i.e two near the vessel ends and one in the middle).

During the operational lifetime the vessel settlements shall be monitored. The monitoring frequency depends on the magnitude of the predicted settlements and on the associated period. The results shall be compared with the predicted settlements. If actual settlement exceeds that predicted and/or the rate of settlement increases, the Principal shall be informed immediately. The Principal should then obtain specialist advice whether corrective action needs to be taken.

During the hydrostatic pressure test (HPT) settlement monitoring should be performed for site fabricated vessel(s) which usually undergo this test on their foundation (7.2). The occurring settlements should be monitored for the relatively high hydrostatic loads at 0, 25, 50, 75 and 100% filling and after 48 hours with the vessel completely filled. The settlement rate during this testing period must diminish with time as otherwise there would be a danger of instability. If the latter would be the case, the Principal shall be informed immediately, the vessel must be (partly) emptied and a geotechnical engineer and a mounded vessel specialist should be consulted.

3.5 FOUNDATION DESIGN

3.5.1 General

Foundations shall be designed, constructed and monitored in accordance with DEP 34.11.00.12-Gen. In all phases of the project, the load cases described below shall be distinguished.

The vessels should be installed at least 0.6 m above the highest groundwater level in a sand foundation of at least 1 m thickness in order to obtain proper "bedding".

The foundation of the vessel shall be constructed such that for the operational lifetime of the vessel, its longitudinal slope shall be in 1:200 minimum and 1:50 maximum. The minimum of this range is applicable for drainage reasons whilst the maximum is applicable in view of dead stock. Hence in the design phase the predicted immediate and long-term settlements along the axis of each vessel shall be taken into account in determining the slope.

3.5.2 Operational phase

For the operational phase, it is assumed that the vessel is supported over an angle of 120 °.

- Contact pressure at the vessel/foundation interface is shown in (A.4.2.10, Figure A3).
- The loads on the vessel, and hence on the foundation, are shown in (A.4.2).
- The minimum safety factor during operations is 2.

3.5.3 Construction phase

During construction, it may be advantageous to support the vessel over an angle of less than 120° (with a minimum of 60°).

In case of on-site vessel assembly, the maximum foundation loading will occur during hydrostatic pressure testing. The maximum load will consist of the weight of the vessel and the contained water. The bearing capacity of the foundation shall be verified for this load condition. Special attention shall be given in that respect to the presence of welding trenches.

The minimum safety factor for the bearing capacity and overall vessel stability during the hydrostatic pressure test is 1.5.

Also, the vessel shall be checked for a reduced angle of support, as the magnitude of the design coefficients K_m, K_n and K_s depends on the angle of support (A.4.4 - A.4.6).

3.6 MOUND

The purpose of the mound is to protect the vessel against external events such as e.g. radiation in case of a fire, flying objects and sabotage and hence the thickness of the cover should be at least 1 metre.

The slope of the mound shall not exceed the natural slope of the fill material and should be 1:1.5 maximum. Following the results of the soil investigation, a slip circle analysis shall be performed to verify the stability of mound. When performing such a calculation it should be noted that the angle of friction along the vessel/soil interface and the effective stress in a zone next to the vessel is reduced.

The mound slopes and top shall be protected against erosion. Several types of covers, such as a flexible bituminous layer, prefabricated stone elements, open concrete tiles or grass, may be used. If grass is used, the sandfill shall first be covered with at least 0.3 m of fertile cohesive soil. A continuous impermeable cover shall not be installed, to prevent the possibility of gas accumulation inside the mound.

Open drain channels shall be constructed alongside the toe of the mound as soil weakening shall be avoided in this area. These channels shall be able to cope with the design rain water run-off from the mound and, if applicable, the run-off from surrounding higher areas. The mound top shall have a slight downward slope in the direction of the mound top edge following the slope of the vessels and shall not be horizontal. There shall only be minimal rain water percolation through the erosion protection. Rain water accumulation inside the mound shall be avoided as this can lead to instability of the mound. No irrigation system shall be installed on the mound as this may increase the corrosivity of the mound material.

3.7 FOUNDATION AND MOUND MATERIAL

In selecting the material for the foundation and the mound, consideration shall be given to the following:

In the case of multiple vessels there is limited accessibility for mechanical fill and compaction equipment to the area in between the vessels. In these cases fill material should be easy to handle.

The fill material shall be compactable in order to minimise settlements.

The fill material shall be suitable to allow proper functioning of the cathodic protection system (6.3). However, sea sand or any other unsuitable fill material which is undesirable for corrosion reasons shall not be used.

Although it is not the intention to remove any of the mound for inspection, excavation of the vessel(s) may be required (e.g. by govermental regulations).

For the above reasons sand should be used for the sandbed and mound. The sand shall fulfil the following requirements:

- the sand shall be clean,
- the maximum silt content (particles smaller than 0.063 mm) shall not exceed 10% by weight and the maximum organic material content shall not exceed 3% by weight,
- maximum particle size shall be less than 2 mm,
- grain size distribution shall have a uniformity coefficient (D60/D10) of between 4 and 10.

In areas where sand is difficult to obtain, at least 0.3 m of sand shall be placed around the vessel to protect the coating.

3.8 CONSTRUCTION OF FOUNDATION AND MOUND

3.8.1 Foundation

The sandbed foundation, the bedding associated to the 120° bottom support angle, shall be prepared in layers of maximum 0.3 m thick. Each layer shall be compacted to at least 95% of the maximum dry density. The maximum dry density shall be determined according to ASTM D1557. The in-situ density shall be determined either by Cone Penetration Testing or the replacement method according to ASTM D2167.

The cylindrical bottom profile of the vessel should later be cut in the sandbed by excavation. A steel template with the curvature of the vessel should be used to shape the sandbed to the required profile. Over excavation should be avoided.

Due to construction tolerances, the axis of the vessel may only deviate from a straight line by up to 0.3% of the vessel length.

The construction procedure for the foundation depends on the fabrication method for the vessel but shall provide the required uniform vessel support.

If the vessel has been assembled elsewhere before it is placed on its foundation, the deviations of the vessel axis from a straight line shall be measured and the sandbed shall be shaped accordingly to obtain a good fit of the vessel in the sandbed and hence an even support.

If the vessel is assembled on its foundation, the shape of the sandbed should be made in sections with a length equal to the length of the vessel section to be placed on it. Each foundation section shall be completed just before the corresponding vessel section is placed on it and after the previous vessel section has been at least tackwelded in place. This procedure will help to obtain an even support of the vessel.

Depending on the fabrication method, it may be necessary to dig trenches in the sandbed for welding and inspection of circumferential seams of the vessel sections. The sides of the trenches shall be properly supported, for example with sand bags. After the weld inspection has been carried out, the hydrostatic pressure test successfully finished and the coating applied, the trenches shall be carefully backfilled with properly compacted sand. Coating of welds shall only be applied after hydrostatic presure testing. As it will be difficult to achieve the same compaction rate as for the bed already placed, the number and sizes of the trenches shall be restricted to a minimum. The method of backfilling and compaction shall be approved by the Principal.

Depending on the distance between the trenches, the local code requirements (which might require full vessel support during hydrostatic pressure testing) and the calculations, it may be required to temporarily backfill the trenches prior to the hydrostatic pressure test. In this way the maximum load on the sandbed is reduced.

To avoid too much disturbance of the foundation during construction, the shoulders of the foundation should have a horizontal part of at least 2 m wide before sloping down to grade.

After completion of construction of the vessel, but prior to the hydrotest, the foundation shall be repaired and recompacted where required.

3.8.2 Mound

Horizontal support of the vessel by the mound is not assumed in the vessel design and is therefore not required. Too much compaction during installation of the mound may in fact have a negative influence on the vessel. In view of this, it is advised that the mound should be compacted to 90% of the maximum dry density to prevent excessive settlements of sand only, having due regard for the material suitability from a stability and cathodic protection point of view.

If during construction a foundation with a reduced angle of support has been used, the foundation shall be built-up with well compacted sand (95% of the maximum dry density) to an angle of support of 120° before the mound with reduced compaction may be started.

4. VESSEL

The vessel designer and manufacturer shall be approved by the Principal.

4.1 DESIGN

4.1.1 General

The recommended calculation method is described in Appendix A. Other methods may be used only with the approval of the Principal.

The principle of the design of the vessel is that the axisymmetrical loads are carried by the shell plates, while the bending due to the non-axisymmetrical loads is carried by stiffening rings (except for small diameter, unstiffened vessels).

The vessels are subjected to internal vapour and hydrostatic liquid pressure and to external loads due to the mound (in axial and radial direction). Moreover they may be subjected to live loads, earthquakes and blast waves due to exploding gas clouds, depending on local conditions.

If a vessel will be hydrostatically pressure tested on its foundation longitudinal seams shall be avoided in the bottom 120°.

The vessel heads shall have a torispherical or hemispherical shape.

NOTE: For an optimal vessel design the thickness of the shell plates should be determined by the maximum internal design pressure or the external load caused by the mound in combination with internal vacuum (if applicable), whichever is governing. For long vessels with a relatively small diameter it should be avoided that the longitudinal stresses caused by bending, friction etc. govern the shell plate thickness. This can be achieved with a maximum vessel length to vessel diameter ratio of 8.

Nozzles and manholes may be designed to withstand both internal loads and external loads transmitted via the soil and the connected piping (BS5500). Alternatively these connections could be enclosed in a sleeve (5.6).

The following guidelines may be used in the design to determine the vessel dimensions:

- The vessel length should not exceed 8 times the vessel diameter;
- The ratio of plate thickness to vessel diameter should be not less than 1/400;
- The ratio of distance between stiffeners to vessel diameter is in the order of 1:2;
- For vessels with a diameter of 3.50 m and greater, internal stiffening rings are normally required;
- The maximum distance between the stiffeners is determined by the circumferential buckling stress in the shell plates;
- The size of the stiffening rings depends on the load on the vessel and the distance between the rings. The thickness of the stiffener web and flange should not exceed the thickness of the shell plates in view of material selection criteria (4.2).

4.1.2 Design conditions

The pressure/temperature curves for butane, propane and mixtures thereof are included in DEP 30.06.10.12-Gen.

The ABP of the product shall be used as the lower design temperature and shall be specified by the Principal.

If it can be made certain that due to operational safeguards, the ABP can never be reached a lower design temperature higher than the ABP may be used. Confirmation from the Principal shall be obtained. See also DEP 30.10.02.31-Gen.

4.2 DESIGN LOADS

The following design loads shall be taken into account for the design, if applicable:

4.2.1 Dead weight of the vessel

Refer (Appendix A.4.2.1).

4.2.2 Weight of the liquid in the vessel

Refer (Appendix A.4.2.2).

The mass of liquids for design pressure shall be taken as follows.
For Propane ($C_3 H_8$): 510 kg/m^3 at 15 °C
and Butane ($C_4 H_{10}$): 585 kg/m^3 at 15 °C

4.2.3 Internal pressure

Refer (Appendix A.4.2.3, and 4.1.3).

4.2.4 Internal vacuum

Refer (Appendix A.4.2.4, full vacuum)

4.2.5 Loads due to the mound

Refer (Appendix A.4.2.5)

The weight of the mound above the vessel is transmitted by the vessel to the foundation and will result in radial loads on the vessel (A.4.2.5.1).

If a vessel is installed in an excavation, it is possible that after filling the sides of the excavation exert a horizontal supporting pressure on the vessel. This beneficial effect depends very much on the quality and compaction of the fill material. For vessels installed above grade level no horizontal support pressure should be expected from the soil. Consequently, for the design of the vessels no horizontal support pressure shall be taken into account.

The passive and active soil pressures at the heads of the vessels shall also be taken into acount in the design (A.4.2.5.2).

Mounded storage vessels should not be exposed to traffic or similar live loads on top of the mound. If this cannot be avoided, a suitable live load shall be taken into account. The weight of pipelines, pipe bridges, etc. shall also be taken into account, if applicable.

4.2.6 Loads due to uneven support by the foundation

Refer (Appendix A.4.2.6, C)

Uneven support of the vessel may occur due to:

- Variation in subsoil characteristics along the length of the vessel, which may cause a variation in support, as the vessel will settle as a rigid body.
- Construction tolerances of the vessel and the foundation, due to which the vessel will normally not fit perfectly on the foundation, resulting in variations in support.

To make an allowance in the design for the tolerance effects, a maximum and a minimum soil reaction has been assumed, as shown in Appendix C. Both soil reaction distributions shall be taken into account. Appendix C also shows the formulae leading to the resulting bending moments, shear loads, soil reactions and vessel deflections based on these assumptions.

Based on the soil investigation data, a calculation, taking into account the long-term bedding/subgrade modulus of the subsoil, shall be carried out using a "beam on elastic foundation" method. The outcome of this calculation shall be compared with the outcome of the calculation following the guidelines of Appendix C. The largest bending moments, shear forces, etc., shall be used for the design of the vessel. This calculation may be dispensed with if it is obvious from the variation in subgrade modulus that the resulting bending moments, etc. will be smaller than those resulting from Appendix C.

NOTE: The bedding/subgrade modulus as mentioned above is not the elastic short-term bedding modulus, as sometimes determined by a field test, but is the load of the vessel divided by the long-term settlement at that location (kN/m).

4.2.7 Loads due to temperature and internal pressure variations

Refer (Appendix A.4.2.7)

Variations in vessel temperature and internal pressure will cause variations in the length and the radius of the vessel.

Variations of the vessel length:

The following effects shall be taken into account in the vessel design:

- Increase of the soil pressure on the domed ends of the vessel;
- Longitudinal stresses in the vessel caused by friction and restrained expansion

The magnitude of these effects depends on the length and the diameter of the vessel, the thickness of the soil cover and the configuration of the soil cover over the domed ends.

NOTE: The effects of temperature and pressure variation are directly proportional to the change in length of the vessel. For example, a temperature variation of 40 °C will cause, for an unrestrained 40 m long carbon steel vessel, a change in length of 19 mm. The length of an unrestrained 40 m long propane vessel will increase by some 15 mm when the vessel is fully pressurised. The surrounding soil will be unable to fully restrain the vessel and the ends of the vessel will tend to move through the soil.

4.2.8 Loads due to earthquake

Refer (Appendix A.4.2.8)

If the vessel has to be designed against earthquakes, the earthquake load is usually introduced as a horizontal load on the vessel. A vertical component may also be taken into account, although its overall effect is usually not significant.

The required design earthquake load is usually specified in local building codes, expressed in terms of horizontal acceleration and sometimes also vertical acceleration. Refer also to DEP 34.00.01.30-Gen.

For large vessels the effect of liquid sloshing should be considered.

NOTE: The consequences of liquefaction of the subsoil, if relevant, shall also be considered.

4.2.9 Loads due to an external explosion

Refer (Appendix A.4.2.9)

An explosion of a gas cloud in the vicinity of a mounded storage vessel would result in a pressure increase on the soil cover. This increase in pressure can be taken into account for the analysis as an increase of the weight of the soil cover (refer Appendix A).

The magnitude of the overpressure shall be stated by the Principal. It may typically vary between 0 and 0.15 bar (ga). The overpressure shall be multiplied by a suitable reflection coefficient.

Because of the damping effect of the mound, a reflection coefficient of 1.5 should be used instead of the normally used reflection coefficient of 2.

4.3 LOAD COMBINATIONS

In the design of the vessel the loads previously described shall be combined, as applicable, with: the hydrostatic pressure test, normal operating phase, retest and during emergencies. Explosion and earthquake loads shall be assumed not to occur at the same time, and not during (re)pressure testing.

NOTE: The soil cover will not be present during the initial hydrostatic pressure test, but it will be during a possible retest after a period of operation.

4.4 MATERIALS

Recommended materials for all parts of the vessel, including those welded directly to

that vessel, are given in Appendix D.

All materials for use in vessels shall fulfil the following requirements:

The minimum impact values (Charpy V notch) at the required impact test temperatures shall be:

- 27 Joules for steels with R_m less than 450 N/mm^2
- 41 Joules for steels with R_m equal to or greater than 450 N/mm^2

The carbon content of steels used shall not exceed 0.23%, except for forgings, for which the carbon content shall not exceed 0.25%.

In addition, one of the following requirements based on ladle analysis, shall be satisfied:

- Ceq = C + Mn/6 = < 0.43 (1)
- Ceq = C + Mn/6 + (Cr + Mo + V)/5 + (Cu + Ni)/15 = < 0.45 (2)

Formula (1) may be used if the material standard specifies C and Mn only. Otherwise formula (2) shall be used, in which case all the elements mentioned shall be determined per heat.

All steel plates shall be through thickness tensile tested in accordance with BS 6780. The steel plates shall have a reduction in area of at least 35%.

All steel plates shall be ultrasonically tested at the mill in accordance with the requirements of BS 5996, acceptance level LC4.

Materials not included in Appendix D may be used provided they meet the criteria given above plus the following restrictions:

- Their specified minimum yield strength does not exceed that of the steel grades given in Appendix D.
- Steels shall have guaranteed impact properties at test temperature in accordance with the requirements laid down in Appendix D.
- Only fully killed steels shall be used.

Production weld test plates shall be performed at a rate of two test plates per 100 m of butt weld or part thereof (circumferential plus longitudinal). These shall represent the welding on the vessel or on a group of similar vessels made of the same material, ordered to the same specification and the same welding procedure. One plate shall be subjected to test, the other shall be retained for retesting if necessary.

All procedure qualification and production weld test plate welds shall be subjected to hardness testing, in accordance with BS 709. The maximum acceptable hardness in the weld, HAZ or parent plate shall be 248 HV 10.

4.5 CONSTRUCTION

4.5.1 Tolerances

For general fabrication requirements, BS 5500 shall apply. However, because of the relatively high external pressure on the vessels, some of the tolerances shall be reduced for mounded storage vessels as follows:

- For circumferential joints, the misalignment of the centre lines of plates shall not exceed 10% of the thickness of the thinner plate or 3 mm, whichever is the smaller.
- The out-of-roundness of the cylinder sections, i.e. the difference between the maximum and minimum internal diameters measured at any one cross section, shall not exceed 0.5% of the nominal diameter.

4.5.2 Stiffeners

Stiffeners shall be provided with mouse holes in the top to release the air during HPT.
Stiffeners shall be provided with suitably sized drain holes in the bottom part to allow the

vessel to be drained and to allow sufficient flow towards either the bottom discharge or to the submersible pump.

4.5.3 Welding

No production welding shall be carried out before welding procedures and welders are approved according to applicable code requirements.

4.5.4 Heat treatment

4.5.4.1 Preheat Treatment

For preheating requirements reference is made to BS 5500; the requirements shall be specified for each type of weld including those for all attachments (including temporary attachments) and tack welds, taking into account climatological effects.

Welded temporary attachments shall be kept to a minimum and may only be used for alignment or for lifting of vessel segments during construction.

4.5.4.2 Post-Weld Heat Treatment (PWHT)

The vessel shall be post weld heat treated in accordance with the requirements of Appendix D.

If the whole vessel is to be post weld heat treated, all welding on the vessel (including attachments) shall be completed before the heat treatment is carried out.

5. OPERATIONAL FITTINGS

5.1 GENERAL

For the required number of pipe connections and manholes, reference is made to DEP 30.06.10.12-Gen.

The number of nozzles welded to the vessel shall be minimized. If several small pipe connections are required they should be welded in the horizontal manhole cover of a large nozzle. Alternatively, a nozzle capped with a dome with several (small) pipe connections may be fabricated.

To avoid the risk of gas pockets and to simplify construction, flanges of the nozzles shall be located above the top of the mound. Thermal protection in the form either a sprinkler installation or a passive fire protection system shall be provided in this area.

For the design of nozzles and manholes, reference is made to BS 5500 and DEP 31.22.10.32-Gen.

For instrumentation, PRV's and valves, reference is made to DEP 30.06.10.12-Gen.

Gaskets to be applied shall be in accordance with those specified in relevant piping classes.

Gussets and lugs shall not be welded directly to the vessel but shall be welded to a circular pad plate, which shall be of the same grade as the shell plate to which they are welded.

Structural steel may be applied for ladders and internal inspection facilities (refer DEP 34.28.00.31-Gen.).

5.2 PRODUCT HANDLING

For the arrangement of a product inlet refer to DEP 30.06.10.12-Gen.

For a product outlet one of the following alternative arrangements should be used for safety reasons:

- a top-outlet arrangement using a submerged canned motor pump,
- a top-outlet arrangement using a compressor,

Only if product and/or operational requirements dictate and if the expected differential settlements allow (< 50 mm) may a bottom discharge in combination with an inspection tunnel be considered. The relevant operational requirements are:

1) due to ageing of the stored product, complete vessel drainage is a requirement

2) operational requirements dictate more than one submersible pump per vessel

If a bottom outlet inside an inspection tunnel can be justified based on the above criteria, special precautions to ensure the long term integrity of the vessel shall be taken.

These precautions concern the transition from the inspection tunnel to the vessel, the sizing of the tunnel, the adjustability of the supports of the bottom outlet pipe, and the corrosion protection of the vessel bottom in the area of the bottom outlet.

The sizing of the tunnel shall be such that it provides adequate and safe access for inspection and maintenance activities. In addition the tunnel shall be fitted with gas detection equipment.

The vessel bottom in the area of the bottom outlet is exposed to the atmosphere. The coating for this area should be either an epoxy or urethane system (6.2.1.2). A glass-fibre reinforced bitumen coating (6.2.1.1) shall not be used as it would deteriorate under atmospheric conditions.

No water should enter the tunnel from the outside surroundings. In this respect the long term settlements and the tunnel construction are of relevance. The tunnel should be sloping slightly away from the vessel so that no water can enter via the open end. If constructed out of concrete, the tunnel should be monolithic and should therefore be cast in situ.

5.3 PIPING

Flanges in horizontal piping shall be avoided for safety reasons (flame impingement in case of fire).

The vessel will be subjected to settlements. Also, the ends of the vessel will move in longitudinal direction due to changes in temperature and internal pressure. These effects shall be taken into account in the piping design.

5.4 DRAINAGE FACILITIES.

For drain facilities reference is made to DEP 30.06.10.12-Gen. Draining will normally require the installation of a drain pipe with top-connected drain valves at the lowest end of the sloping vessel (3.5.1).

5.5 MANHOLES

At least two manholes, one at each end of the vessel, shall be installed.

Instrument connections may be incorporated in the manhole covers.

Manholes shall be fabricated with minimum nominal pipe sizes DN 600 (24 in).

5.6 SLEEVES AROUND NOZZLES AND MANHOLES

Due to the horizontal movements of the vessel (4.2.7), passive soil pressure may generate large forces and high bending moments on the nozzles and manholes. This can be prevented by creating free space around nozzles and manholes. The installation of a sleeve structure made of GRE (Glass Reinforced Epoxy) or UPVC (Unplasticised Poly Vinyl Chloride) can be considered. An example of such an arrangement is shown in Appendix E. The sleeve shall consist of two half cylindrical parts to enable installation and easy removal if inspection is required.

6. CORROSION PROTECTION

6.1 GENERAL

The foundation and mound shall be regarded as a potentially corrosive environment. Therefore a heavy duty corrosion protection system shall be installed, consisting of a combination of coating and cathodic protection. Because access to any external part of the mounded storage vessel is normally not possible, the corrosion protection system shall be so designed to provide full protection for the design life of the vessel.

The design of the corrosion protection system shall be fully compatible with the vessel design conditions, materials of construction, fabrication, foundation and earth mound.

6.2 COATING

6.2.1 External coating

The vessel shall be provided with an external coating system which shall

- be an effective barrier for corrosive agents present in the soil
- be compatible with the cathodic protection system to be installed (6.3)
- be able to resist the normal and frictional forces between the vessel and the surrounding soil under all operating conditions (e.g. cold shock)
- be resistant to any contaminant present in the subsoil (e.g. hydrocarbons)

The external coating system shall be either a multilayer, glass-fibre reinforced bitumen coating or an epoxy or urethane-based coating system.

All edges to be coated shall be ground to a radius of at least 6 mm.

A suitable epoxy or urethane-based coating system shall be applied to the vessel where there is a likelihood that solvents are present in the ground. Alternatively a "ventilation layer" could be considered.

6.2.1.1 Glass-fibre reinforced bitumen coating system

The coating shall consist of two or more layers of glass-fibre reinforced bitumen, applied over a suitable primer, with a minimum total thickness of 6 mm.

The grade of bitumen used shall be suitable for the prevailing climatic conditions.

Before coating, the steel surface shall be cleaned to grade SA 2½ (ISO 8501-1) and a "medium" surface roughness in accordance with ISO 8503-1.

The bitumen coating system shall be applied in accordance with MFS 372/91.

A bitumen coating shall not be used for parts exposed to atmospheric conditions as the bitumen will deteriorate. See also (5.2). For these parts either one of the coating systems recommended below shall be applied.

6.2.1.2 Epoxy or urethane coating system

The epoxy or urethane coating shall be a solvent-free, hot or cold applied, coating system with a minimum thickness of 800 microns.

The steel surface shall be prepared prior to coating application by means of blast cleaning to obtain a degree of cleanliness equal to or better than SA 2½ (ISO 8501-1) and a surface roughness (ISO 8503-1) as specified by the coating supplier.

Adhesion of the applied coating shall not be less than 3 N/mm^2 when tested in accordance with ISO 4624. Adhesion tests shall be carried out on the vessel at least three times per batch of coating, or three times per day, whichever is more frequent.

6.2.1.3 Coating application

The coating shall be applied in accordance with the Manufacturer's recommendations.

All blast cleaning and coating shall be carried out while the steel temperature is 3 °C or more above the dew point.

During application of primer and coating the surface shall be free from contamination and moisture.

If required, the climatic conditions during surface preparation and application shall be fully controlled by application indoors or by application under full cover using heating and/or dehumidification equipment.

The coating film thickness shall be measured at least once per square metre, in accordance with ISO 2808.

The applied coating shall be fully tested for the absence of holidays using a high voltage spark tester. The test equipment and voltage setting shall be in accordance with NACE RP-

02-74. The coating shall be fully cured before moving/lifting/backfilling.

6.2.1.4 Coating prequalification

To qualify the proposed coating system, the Contractor shall submit full details of the proposed coating system and a detailed method of application for approval by the Principal. Information on electrical insulating density shall also be included.

This document shall contain as a minimum:

- Full details of the coating materials and primers (if applicable).
- Full details of the blasting and spraying equipment and/or equipment to apply the bitumen sheets.
- A detailed method of application of the coating system.
- A full description of proposed methods and equipment to control the climatic conditions as described under (6.2.1.3).
- A schedule of all blasting, priming and coating operations in conjunction with the vessel construction schedule. This shall include a specification of minimum and maximum overcoating times and drying/curing times.
- Full quality control procedures and schedules to ensure that the applied coating complies with the afore-mentioned requirements.
- Repair procedures in detail.
- Troubleshooting list related to local circumstances.

6.2.2 Internal coating

Internal coating may be required if water layers can be expected inside the vessel. Coating of the bottom 90° section of the vessel is usually sufficient.

The coating shall consist of an amine cured epoxy coating, compatible with the product to be stored, and shall be approved by the Principal.

Edges to be coated shall be ground to a radius of at least 3 mm. Such edges and welds shall recieve one "stripe coat" prior to full system application.

6.3 CATHODIC PROTECTION

6.3.1 General

This section gives the minimum requirements for the design of cathodic protection systems for mounded storage vessels. It is based on a mounded vessel design using a sand bed foundation without additional supporting structures such as saddles, piles, rafts etc. The presence of the latter type foundations as well as access tunnels as used for bottom outlets will influence the regular current distribution such that special requirements may apply (6.3.7).

The cathodic protection system shall be designed by and installed under the supervision of a specialised cathodic protection Contractor/Consultant.

The design of the cathodic protection system shall be an integral part of the total vessel design. Electrical isolation of piping and a suitable coating system shall be provided for in the vessel design.

6.3.2 Protection criteria

In this specification only the structure-to-soil potential is used as a criterion for effective cathodic protection.

For the vessels to be considered fully cathodically protected, the "OFF" potential on all parts of the vessels shall be equal to or more negative than -850 mV vs Cu/$CuSO_4$ (+250 mV vs Zinc) reference.

If anaerobic conditions and activity of sulphate-reducing bacteria are present or likely, the "OFF" potential shall be equal or more negative than -950 mV vs Cu/$CuSO_4$ (+150 mV vs Zinc) reference.

To avoid detrimental effects on the applied coating or on the metal due to overprotection, "OFF" potentials shall not be more negative than -1150 mV vs Cu/$CuSO_4$ (-100 mV vs Zinc) reference.

6.3.3 Design

6.3.3.1 Required design data

The Principal shall make the following data available to the Contractor to carry out the cathodic protection design:

- number of vessels with dimensions and locations
- design life of the installation
- external coating specifications
- plotplans, showing location of vessels, piping etc.
- piping diagrams and electrical diagrams showing electrical isolation and earthing systems
- relevant construction drawings of the vessels and foundation
- soil and groundwater conditions including resistivities
- adjacent buried metal and reinforced concrete structures
- existing and planned cathodic protection systems
- possible sources of interference
- availability of electrical supply
- hazardous areas classification
- further requirements by the Principal regarding potential control, monitoring facilities.

6.3.3.2 Soil resistivity measurements

Soil resistivity measurements shall be carried out at the proposed construction site in accordance with (2.2).

The soil resistivity measurements shall be representative for the prevailing soil conditions and sufficient as a basis for the design. Acceptable methods for soil resistivity measurements are:

- four-terminal resistivity method (Wenner) (field test).
- two-terminal resistivity method (Shepard) (field test).
- soil sample (soil box) resistivity method (laboratory test).

When the soil resistivity measurements are used to locate suitable places for groundbeds, the four-terminal method (Wenner) shall be used to determine the resistivity at greater depths, although this information is to be regarded as "indicative" only. Actual resistivity measurements for deep ground beds shall be carried out on soil samples recovered by borings during the soil investigation.

6.3.3.3 Electrical separation

Each vessel shall be electrically isolated from other vessels, pipelines, plant, buried metal structures and electrical and instrument earthing systems.

Monoblock isolating joints shall be installed above ground in all piping attached to each individual vessel. These joints shall be suitable for the expected temperature range as given in the design data.

The resistance across isolating joints shall be measured immediately before welding into the pipeline. The minimum resistance shall be 1 mega-ohm (10^6 ohm).

Isolating joints shall be painted in a contrast colour for easy identification.

Safety and instrument earthing installed on the vessels shall be provided with polarization cells to avoid loss of cathodic protection current while maintaining a low resistance to earth.

If more than one vessel is installed, polarization cells shall be installed in the earthing of each individual vessel to ensure electrical insulation between the vessels.

The polarization cells shall be suitably rated for the expected voltages and currents.

6.3.3.4 Choice of cathodic protection system

For the cathodic protection of mounded storage vessels an impressed current system shall be used.

Sacrificial anode systems shall not be used unless explicitly requested by the Principal.

6.3.3.5 Transformer/rectifiers

Transformer/rectifiers shall comply with IEC 146.

Transformer/rectifiers shall be of a special design for cathodic protection service.

The output voltage shall be adjustable from zero to the rated maximum voltage. A stepless (continuous) adjustment shall be used, without adjustment by tapping switches.

Electronic voltage and/or current control may be proposed, possibly in combination with automatic potential control (6.3.3.6).

The rectifier shall be constructed using high current density selenium cells or silicon diodes so arranged to provide full wave rectification. The AC-component of the secondary voltage under the most unfavorable load conditions shall not exceed 10% of the DC-output.

The transformer/rectifier shall be provided with a moulded case circuit breaker on its incoming circuit and suitably sized fuses shall be installed in the incoming AC and negative DC output circuit.

The transformer/rectifier shall be provided with meters to read the output voltage and current. The measuring accuracy shall be 2% of full scale or finer.

The polarity of the DC terminals and AC supply cables shall be clearly marked. AC and DC cables shall be physically separated by an insulating panel.

A built in timer unit shall be provided. The timer unit may be mechanical or electronic and shall be capable of switching the full output current. The switching sequence shall be adjustable to 10 - 60 seconds ON and 3 - 30 seconds OFF.

Transformer/rectifiers should be installed in a non-hazardous area. The Contractor shall obtain the required information of area classification from the Principal if required.

When installed outdoors, the enclosure shall be weather-proofed in accordance with the minimum degree of protection IP 54 of IEC 529.

6.3.3.6 Automatic potential control

The cathodic protection system shall be provided with automatic potential control. A switch shall be provided to switch the system between automatic and manual operation.

In automatic operation mode, the control circuit shall be capable of controlling the current output such that the structure-to-soil potential at the connected reference cell is maintained within 10 millivolts of the set value at the prevailing current demands during any period in the design life.

The potential measuring circuit shall have an input resistance of more than 100 mega-ohms and be capable of working with both $Cu/CuSO_4$ and Zinc reference cells.

The control system shall be provided with adjustable voltage and current limiting circuits and/or alarms to avoid overprotection of the vessel in case of failure of a reference cell.

A panel mounted meter to read the structure-to-soil potential at the selected control reference cell shall be provided.

6.3.3.7 Groundbeds

Provided that the soil conditions are suitable, deep-well groundbeds should be used.

The groundbed shall be designed such that:

- its mass and quality is sufficient to last for the design life of the system;
- its resistance to earth allows the predicted current demand to be met at 80% of the voltage capacity of the transformer rectifier;
- its location is remote from the vessels and any other buried structure, to provide a regular distribution of current to all surfaces of the mounded vessels;
- the risk of causing harmful interference on other buried structures is minimized.

The selection of the location and the type of groundbed shall depend on local conditions such as:

- Soil conditions and resistivity at various depths;
- Groundwater levels and resistivity;
- Available terrain;
- Risk of shielding.

The Contractor shall include in his design a calculation of the groundbed resistance based on the most accurate soil resistivity data available, using established methods and formulae.

The Contractor shall specify in his detailed design the method of drilling the deep-well, establishing the resistivity of the soil at depth, completion of the borehole and the method of installation of the anodes, backfill, cables and vent pipes.

Anode material shall be either high silicon iron/chromium alloy or metal oxide-plated metal.

The anode weight and dimensions and the selected anode material shall be suitable to supply the required anode current output to cover the design life of the cathodic protection system and shall be compatible with the soil composition.

If, as a result of anodic reaction, aggressive gases are anticipated, a dedicated chemically resistant insulation material should be used.

Deep-well groundbeds should be provided with an adequate vent pipe, carried to a sufficient height that gases developed by anodic reaction may be dissipated into the atmosphere.

To meet the above criteria, a carbonaceous backfill or other low resistivity backfill material shall be used.

6.3.3.8 Monitoring facilities

Monitoring facilities shall be designed to ensure effective survey of the level of the cathodic protection at different locations of the vessel. The minimum requirements for monitoring facilities are as follows.

Permanent Cu/$CuSO_4$ reference cells shall be installed in three locations under each vessel and in three locations at both sides of each vessel at a depth level with the centre line of the vessel. The longitudinal positions of the Cu/$CuSO_4$ reference cells shall be at the centre of the vessel and at three metres from each end of the vessel. Prepackaged zinc reference cells shall be installed in three locations under the vessel adjacent to the Cu/$CuSO_4$ reference cells.

The permanent reference cells shall be buried at a distance of 0.10 to 0.15 m from the vessel wall.

Two negative test cables shall be connected to each vessel, one at each end. **All** monitoring cables shall terminate in a junction box installed in an accessible place at the foot of the vessel mound. From this box the required cables for the potential control equipment shall be run to the transformer rectifier.

The installation of the reference cells shall be closely coordinated with the installation of the vessel and the mound to allow timely installation and to prevent damage of test cables and the sandbed foundation.

On the top of the mound there shall be access to the soil cover to allow monitoring using hand-held reference cells.

6.3.3.9 Cables and distribution boxes

The connections of electrical cables to the vessel shall be designed to ensure adequate mechanical strength and electrical continuity and to prevent damage to the vessels.

The cable connections may be made by, welding, pin brazing or by mechanical means. Thermit welding or brazing to the vessel wall shall not be used (5.1).

Mechanical connections shall be made above ground only using cable lugs, nuts and serrated washers.

All below-ground electrical connections to the vessel shall be fully encapsulated to comply with the original vessel coating standards and shall be holiday tested before backfilling.

All cables shall be sized such that no excessive voltage drops occur which reduce the capacity of the system.

All cables shall be insulated and sheathed to withstand the prevailing soil conditions. Drain cables and groundbed feeder cables shall be armoured. All cables shall be buried in soft sand at a depth of at least 0.5 metre, provided with cable protection tiles or warning tape as considered suitable for the area.

All cables shall be identified by cable tags where they come above ground.

6.3.3.10 Design documents

The cathodic protection design shall be submitted to the Principal before the construction of the vessel has commenced.

These design documents shall contain as a minimum:

- results of site surveys carried out for the design;
- calculation of current requirements and resistance and current capacity of groundbeds;
- a schematic diagram of the proposed cathodic protection system;
- diagram of the proposed monitoring facilities;
- material schedules;
- installation procedures with all relevant construction drawings and details;
- commissioning requirements and procedures.

6.3.4 Installation

The written installation procedures and drawings shall be adhered to during the installation of the cathodic protection system.

The installation of the cathodic protection system shall be carried out in close cooperation with the main construction contractor. Due attention shall be paid to the installation of electrical isolation equipment (isolating joints and polarization cells).

The installation of the permanent reference electrodes shall be planned to fit into the construction schedule of the foundation, the vessel and the earth mound to exclude the risk of cable or foundation damage due to other activities. Where necessary, additional mechanical protection shall be provided.

A record of all cable identification marks shall be kept during construction.

The construction of deep-well groundbeds shall be carried out under the supervision of an experienced cathodic protection engineer.

6.3.5 Commissioning

The commissioning of the cathodic protection system shall be carried out by an experienced cathodic protection engineer, and witnessed by an inspector appointed by the Principal.

The commissioning shall comprise as a minimum:

- visual examination of all system components, checking of all cable connections and polarity;
- checking of all permanent reference cells with respect to a portable reference cell before energizing the system;
- measurements of groundbed resistance to remote earth;
- measurements of natural potentials at each permanent monitoring location;
- energizing the system and current adjustment to obtain approximate protection potentials;
- checking of the electrical isolation of each vessel;
- "OFF" potential measurements after at least 48 hours of polarization;
- any other monitoring and readjustments required to meet the protection criteria.

A commissioning report shall be written containing as a minimum:

- a brief description of the system;
- all information on the deep-well groundbeds (depth, resistivity/depth profiles, active depth and length, anode arrangements);
- results of all commissioning test procedures.

6.3.6 Operation and maintenance

The Contractor shall write an operation and maintenance manual for the cathodic protection system covering as a minimum:

- description of the system and system components, controls and connections;
- as-built drawings;
- manufacturer documentation;
- a schedule of all monitoring facilities;
- potential criteria for the system;
- monitoring schedules and requirements for monitoring equipment;
- monitoring procedures for regular (ON/OFF) measurements;
- test procedures for electrical isolation integrity;
- methods for readjustment of the system;
- guidelines for the safe operation of the system.

6.3.7 Special design considerations

Mounded storage designs other than those using sandbed foundations require additional buried metal or reinforced concrete structures to support the vessel. Those buried structures are sources for shielding and interraction with the vessel's cathodic protection system. Because of this, such designs are not optimal from a corrosion protection point of view; however, conditions may exist which prohibit the use of sand bed foundations.

When those foundation designs are used, the following points shall be considered in the cathodic protection design:

- foundation piles, rafts and supports shall be electrically isolated from the vessel using suitable isolating sheets where metallic contact might occur;

- in locations where the vessel's surface is covered by insulating materials, e.g. resilient material, or where settlement of soil may prevent intimate soil contact, effective cathodic protection may be inhibited. Where such a situation is expected, additional measures shall be proposed to ensure adequate corrosion protection. Such measures may consist of e.g. additional coating or corrosion allowance and shall always be proposed together with inspection methods to prove the effectiveness of these measures;
- shielding effects by foundations and access tunnels may require special groundbed designs, e.g. anodes inside the mound. Such designs are not covered by this DEP and shall be accompanied by full justification and design calculations for approval by the Principal.

6.4 LIGHTNING PROTECTION

Depending on the area a suitable lightning protection system shall be incorporated in the design. The system shall be designed in conformity with DEP 33.64.10.10-Gen.

7. INSPECTION, TESTING AND CERTIFICATES

The Principal shall indicate if he wishes to perform surveillance inspection during manufacture and/or fabrication, in which case the Principal shall indicate the extent to which he will be involved.

7.1 VESSEL INSPECTION AND PROCEDURES/STANDARDS

7.1.1 Procedures/Standards

The inspection procedures shall be carried out in accordance with:

- UT (weld edges)	:	BS 5996, acceptance level E
- UT (butt and partially penetrated weld seams)	:	BS 3923
- MPI (wet method, with AC yoke technique)	:	BS 6072
- RT (butt welds)	:	BS 2600 part 1
- Welders qualification	:	BS 4871
- VE (visual examination)	:	BS 5500

7.1.2 Inspection prior to vessel assembly

Weld edges of plates shall recieve 100% UT over a width of 50 mm.

7.1.3 Inspection during vessel assembly

See Appendices G, H1 and H2.

7.1.4 Inspection after vessel assembly

In case the HPT is to be carried out on its foundation, that part of the bottom circumferential welding which can not be visually inspected from the outside shall be subjected to 100% MPI from the inside after the HPT. Note that welding trenches may have to be temporarily backfilled during the HPT.

The welds in the (temporarily backfilled) trenches remain subject to full scope of inspection procedures. (Appendix G)

Coating of the welds shall only be carried out after the HPT has been completed.

7.2 HYDROSTATIC PRESSURE TEST

The vessels shall be given a full HPT (1.25 x maximum operating pressure unless vessel design codes stipulate otherwise) in accordance with the specified procedure. The pressure testing may be carried out in the shop or at the site on the foundation. For shop tested vessels, the pressure shall be measured with a gauge having a range of 1.5 times the test pressure and an accuracy of ± 0.6 percent or finer. For field tested vessels a pressure recorder (same or finer accuracy than the pressure gauge) shall also be used. In both cases, the temperature of the test water and the ambient temperature shall be continously recorded.

For the settlement monitoring during the hydrotest reference is made to (3.5.3).

Fresh water should be used, but salt or brackish water may be used. The pH of the water shall be kept between 6 and 7. The vessel shall be completely drained, cleaned (in case of salt or brackish water, cleaned with fresh water) and dried by hot air.

7.3 MANUFACTURING REPORT

The Manufacturer shall supply for each vessel a manufacturing report, in accordance with DEP 31.22.10.35-Gen.

7.4 CERTIFICATES OF ACCEPTANCE FROM AUTHORITIES

The Manufacturer shall take all actions to obtain the required certificates of acceptance for the storage vessels from the authorities, unless stated otherwise in the purchase order.

7.5 INSPECTION DURING OPERATION

7.5.1 Vessel

Independent of the requirements for statutory inspection as set by authorities in the country of operation, the following specifies the minimum requirements.

In case no local regulations exist, mounded/buried LPG storage vessels should be inspected internally once every five years, using visual and ultrasonic test methods.

Special attention shall be given to those areas where external coating deterioration is most likely to occur (near supports, fittings, reinforcement rings, field welds, etc).

Rehydrostatic pressure testing (1.25 x design pressure) is required at least every 10 years, but local regulations may require shorter intervals, and if welding to the vessel (repairs or new connections) has been carried out.

7.5.2 Vessel settlement

The responsible operations department shall monitor the vessel(s) settlement during the operational lifetime.

For frequency of measurements reference is made to (3.4.2).

8. REFERENCES

In this DEP, reference is made to the following publications:

NOTE: Unless specifically designated by date the latest issue of each publication shall be used (together with any amendments/supplements/revisions thereto).

SHELL STANDARDS

Index to DEP publications and standard specifications	DEP 00.00.05.05-Gen.
LPG bulk storage installations	DEP 30.06.10.12-Gen.
Metallic materials	DEP 30.10.02.31-Gen.
Painting and coating for new construction projects	DEP 30.48.00.31-Gen.
Pressure vessels (Amendments/Supplements to BS 5500)	DEP 31.22.10.32-Gen.
Manufacturing report pressure vessels	DEP 31.22.10.35-Gen.
Minimum requirements for structural design and engineering	DEP 34.00.01.30-Gen.
Site investigations	DEP 34.11.00.10-Gen.
Site preparation and earthworks	DEP 34.11.00.11-Gen.
Geotechnical and foundation engineering	DEP 34.11.00.12-Gen.
Steel structures	DEP 34.28.00.31-Gen.
Recommended practice for the application of reinforced bitumen coating for mounded storage vessels	MFS 372/91
MF Report "Guidelines for Capital Investment Projects"	MF 89-0587
SIPC Report "A guide to the Planning and Management of large LPG Capital Projects"	SIPC M/L/93/D/0554

AMERICAN STANDARDS

Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort	ASTM D1557
Standard Test Method for Density and Unit Weight of Soil in Place by the Rubber Balloon Method	ASTM D2167

Issued by:
American Society for Testing and Materials
1916 Race Street, Philadelphia
19103, USA.

High voltage electrical inspection of pipeline coatings prior to installation	NACE RP-02-74

Issued by:
National Association of Corrosion Engineers

1440 South Creek, Houston
Texas 77084, USA.

BRITISH STANDARDS

Specification for the use of structural steel in building	BS 449
Methods of destructive testing fusion welded joints and weld metal in steel	BS 709: 1983
Methods of test for soils for civil engineering purposes	BS 1377
Radiographic examination of fusion welded butt joints in steel	BS 2600
Methods for ultrasonic examination of welds	BS 3923
Welding procedure qualification	BS 4870
Welder Performance Qualification	BS 4871
Specification for unfired fusion welded pressure vessels	BS 5500
Methods of testing and quality grading of ferritic steel plate by ultrasonic methods	BS 5996
Method for magnetic particle flaw detection	BS 6072
Specification for through thickness reduction of area of steel plates and wide flats	BS 6780: 1986

Issued by:
British Standards Institution
2 Park Street, London
W1A 2BS, England
United Kingdom.

INTERNATIONAL STANDARDS

Paints and varnishes - Determination of film thickness	ISO 2808
Paints and varnishes - Pull off test for adhesion	ISO 4624
Preparation of steel substrates before application of paints and related products - Visual assessment of surface cleanliness - Part 1: Rust grades and preparation grades of uncoated steel substrates after overall removal of previous coatings	ISO 8501-1
Preparation of steel substrates before application of paints and related products - Surface roughness characteristics of blast cleaned steel substrates - Part 1: Specification and definitions for ISO surface profile comparators for the assessment of abrasive blast cleaned surfaces	ISO 8503-1

Issued by:

International Organisation for Standardisation
1, Rue de Varembé
CH-1211 Geneva 20
Switzerland.

Semiconductor convertors	IEC 146
Degrees of protection provided by enclosures (IP code)	IEC 529

Issued by:
Cental Office of the IEC
3, Rue de Varembé
CH 1211 Geneva 20
Switzerland.

9. RECOMMENDED LITERATURE

The following publications, although referenced by this DEP, do not form an integral part of this DEP. Nevertheless they provide useful further information if the user of this DEP so requires.

(1) Mang, F., "Berechnung und Konstruktion ringversteifter Druckrohrleitungen", Springer-Verlag, Berlin/Heidelberg/ New York 1966.

(2) Mang, F., "Groszrohre und Stahlbehälter, Festigkeits- und Konstruktions probleme" Verlag für angewandte Wissenschaften GmbH, Baden-Baden, 1971.

(3) Mang, F., "Design study - mounded LPG storage" 17th October 1985.

(4) Timoshenko, S.P., Woinowsky - Krieger, S., "Theory of plates and shells", McGraw-Hill, New York/Toronto/London

(5) Timoshenko, S.P., Gere, J.M., "Theory of elastic stability", McGraw-Hill, New York/Toronto/London

(6) Roark, R.J., "Formulas for stress and strain" 5th edition, 1976 McGraw-Hill, New York/Toronto/London

APPENDICES

APPENDIX A STRESS ANALYSIS OF MOUNDED STORAGE VESSELS

A.1 INTRODUCTION

The difference between the stress analysis for a mounded storage vessel and that for a conventional pressure vessel is caused by the mound and the method of support.

The mound and the support cause bending moments, normal forces and shear forces in the wall of the cylinder.

In the following paragraphs a calculation method for mounded storage vessels will be shown, which may be used for the design of the vessel. Emphasis is placed on those aspects where mounded storage vessels differ from conventional pressure vessels. Only mounded storage vessels on a continuous sand bed will be considered in this calculation.

A.2 CIRCUMFERENTIAL BENDING

Several loads, such as dead weight, weight of liquid, mound loads, etc. would cause circumferential bending moments in the wall of the cylinder (in addition to in-plane stresses). The relatively thin shell plates of the cylinder cannot carry these bending moments.

A.2.1 Unstiffened cylinders

In vessels without stiffening rings the circumferential bending moments will be transmitted to the domed ends by shear stresses in the shell. The domed ends are, in conjunction with the cylindrical shell, quite rigid and may be capable of carrying these bending moments provided the distance between the heads is limited.

For diameters over approximately 3.5 metres the required plate thickness of the cylinder tends to become uneconomically heavy (due to vacuum and/or external pressure) and it is therefore usually more economic to use cylinders provided with stiffening rings at regular intervals.

The analysis of the domed ends of unstiffened vessels, subjected to loads 1 through 10 (refer A.4.2) is best carried out by using a finite element method.

A.2.2 Stiffened cylinders

When stiffening rings are used, the circumferential bending moments in the shell plates are transmitted to the stiffening rings by shear stresses.

If the distance between two stiffeners is L, the bending moment due to all the loads on a part of the cylinder with a length L must be allocated to one stiffening ring. In order to avoid that the domed ends will act as stiffening rings, and would have to be analysed as such (refer A.2.1), a stiffening ring should be provided near the transition from cylinder to domed end.

A.3 NORMAL FORCES AND SHEAR FORCES

The shear stresses acting on the stiffening rings will cause bending moments and also normal forces and shear forces in the stiffening rings. It should be noted that the shear stresses imposed on the shell by the stiffening rings eliminate the bending moments in the shell plates but not the normal tensile and compressive stresses.

A.4 CALCULATION METHOD (FOR STIFFENED CYLINDERS)

A.4.1 Nomenclature

R	=	mean radius of cylinder	(m)
t	=	thickness of shell plates	(m)
L	=	distance between stiffening rings	(m)
W	=	estimated weight of stiffening ring	(kN)
ψ	=	circumferential angle between top of cylinder and point under consideration	(-)
Q, P	=	loads	(kN)
Q', P'	=	loads per metre length of vessel (unit loads)	(kN/m)
q, p	=	pressures	(kN/m^2)
γ_l	=	weight per m^3 of liquid	(kN/m^3)
γ_s	=	weight per m^3 of soil	(kN/m^3)
γ_m	=	weight per m^3 of steel	(kN/m^3)
s	=	primary circumferential hoop stress	(kN/m^2)
s'	=	secondary longitudinal bending stress	(kN/m^2)
τ	=	shear stress	(kN/m^2)
w	=	shell working width	(m)

A.4.2 Loads

A.4.2.1 Dead weight (load 1)

The dead weight Q_1 is the weight of the shell over the centre-to-centre distance between two stiffeners, together with the estimated weight of one stiffening ring. This weight is allocated to one stiffener and equals:

$$Q_1 = 2\pi R \times t \times \gamma_m \times L + W \qquad \text{(kN)}$$

A.4.2.2 Weight of liquid fill (load 2)

The weight of the maximum volume of liquid to be allocated to one stiffener is:

$$Q_2 = \pi R^2 \times \gamma_l \times L \qquad \text{(kN)}$$

A.4.2.3 Internal pressure (load 3)

With regard to the stiffener design, the internal pressure only affects the normal force N_3 in the stiffening ring, not the bending moment or the shear force. A part of the shell plates will act together with the ring to carry the loads to which the rings are subjected. This part, the working width w, is according to (10), ref (4):

(m)

$$w = 2 \times 0.78 \times \sqrt{(R \times t)} \quad \text{(m)}$$

The internal pressure, acting on the working width, will cause a normal tensile load which is carried by the combination of stiffening ring and working width of the shell plate.

N_3 = p_3 x w x R (kN)

where p_3 = the internal pressure.

A.4.2.4 Internal vacuum (load 4)

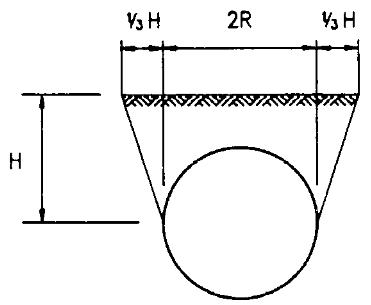
The internal vacuum only affects the normal force N_4 in the stiffener, not the bending moment or the shear force. For the same reasons as described in A.4.2.3 the internal vacuum p_4 will cause a compressive normal load N_4 in the stiffening ring and the plates of the working width.

N_4 = p_4 x w x R (kN)

A.4.2.5 Pressure due to mound, (load 5)

A.4.2.5.1 Pressure of mound on cylinder (load 5) (refer Figure A.1and A.2).

Figure A.1

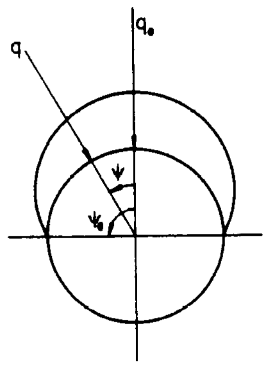


The weight of the mound assumed to be resting on top of the cylinder is:

Q_5 = $(2RH - 1/2\ \pi R^2 + 1/3\ H^2) \times \gamma_s \times L$ (kN) per ring, refer Figure A.1

It is further assumed that this weight results in a radial pressure q on the cylinder, as shown in Figure A.2 (ψ_0 = 90°)

Figure A.2



q = $q_0 \cos \psi$ (q_0 is maximum pressure at $\psi = 0$)

$$q_0 = \frac{2Q_5}{\pi RL}$$ (kN/m^2)

A.4.2.5.2 Pressure by mound on domed ends

The mound will also exert pressure on the domed ends of the vessel. This soil pressure p will increase linearly with the depth.

p = C x γ_s x h (kN/m^2),

where C = soil pressure coefficient

and h = depth below top of mound

C depends on the slope of the mound and on the movements of the domed ends. For a slope of 30° the neutral coefficient $C_{neutral}$ = 0.3. If the vessel contracts and the ends move approximately 0.02 m (or more), C decreases to C_{active} = 0.2. If the vessel expands and the movement of the ends exceeds 0.02 m, C increases to $C_{passive}$ = 1.7. For end movements less than 0.02 m the change in C will be proportional.

If the mound does not slope at the ends of the vessel, e.g. if the vessel is completely buried below grade:

C_{active} = 0.33

$C_{neutral}$ = 0.5

$C_{passive}$ = 3

For the determination of the shell thickness of the domed ends (refer A.4.3), the maximum soil pressure shall be used (occurring at the lower side of the vessel).

The pressure p will result in a total load in longitudinal vessel direction equal to the product of average soil pressure and surface area of the cylindrical cross section. This load will affect the longitudinal stresses and shall be used for the longitudinal stress verification.

Fdome = C x γ_s x H x π x R^2 (kN)

where H is as defined in A.4.2.5.1

A.4.2.6 Load due to uneven support of the vessel (load 6)

For determination of the uneven support, two calculations shall be made (refer 4.2.6), using the selected shell plate thickness:

- Using an assumed subgrade modulus distribution as shown in Appendix C and loads 1, 2 and 5. In Appendix C the resulting maximum and minimum support pressure, maximum unit shear load (stiffener design), maximum shear load, maximum bending moment on cylinder and maximum deflection are also shown. The assumptions in Appendix C are a minimum requirement and are also meant to cater for uneven support caused by construction tolerances of vessel and foundation.
- A beam on elastic foundation analysis, using the long-term subgrade moduli determined in the soil investigation (refer 3.3.2) and loads 1, 2 and 5.

The latter calculation may be dispensed with if it is obvious from the variation in subgrade modulus that the resulting bending moments, etc. will be smaller than those resulting from Appendix C.

From these two calculations the governing result shall be used for:

- The stiffener design (resulting Q_6)
- The evaluation of the stresses in the cylinder

The difference between the maximum supporting load and the total of loads 1, 2 and 5 is the unit shear load Q_6^1 in the vessel.

For one stiffening ring: $Q_6 = L \times Q_6^1$ (kN/m)

A.4.2.7 Axial loads due to changes in vessel length (load 7)

Axial loads have to be considered for the verification of longitudinal stresses.

When the vessel expands or contracts due to temperature or pressure variations, the surrounding soil will exert a friction on the vessel. A friction coefficient = 1 is conservatively assumed (this corresponds with an angle of internal friction = 45° of the surrounding sand).

The unit friction force F^1_{soil} will be:

$$F^1_{soil} = Q^1_1 + Q^1_2 + 2Q^1_5 \qquad \text{(kN/m)}$$

The axial load due to friction will be maximum at midspan of the vessel and will be equal to F^1_{soil} x half vessel length, provided the movement of the vessel is enough to develop the full friction. The resulting longitudinal stress due to friction will be compressive if the vessel expands, and tensile if the vessel contracts.

When the vessel expands, the soil pressure on the domed ends will increase (refer A.4.2.5.2), which will result in an increased axial compressive load.

A.4.2.8 Earthquake loads (load 8)

The effect of earthquake on design loads shall be taken into account. The effect of the horizontal acceleration (specified as a percentage of the vertical acceleration due to gravity g) shall be taken into account as a horizontal lateral force. This force is equal to the percentage mentioned above of the weight (loads 1, 2 and 5).

Sometimes a vertical acceleration due to earthquake is also specified, which is taken into account by increasing the weight proportionally.

The resultant of the horizontal force and the (increased) weight shall be determined separately for loads 1, 2 and 5. These resultant forces, not the weights, shall be used in the calculations discussed below.

Those calculations may then be carried out in the same manner as for the case without earthquake, albeit that the line of symmetry is no longer vertical.

A.4.2.9 External pressure caused by explosion of gas clouds (load 9)

If the overpressure and the reflection coefficient shown in (4.2.9) are used the pressure to be taken into account is 1.5 x 15 = 22.5 kN/m^2. The load per stiffening ring is:

Q_9 = (2R + 2/3 H) x L x 22.5 (kN)

Q_9 may be considered as an increase in the weight of the mound and shall be treated in the calculations in the same manner as Q_5.

A.4.2.10 Supporting pressure by the foundation (load 10)

Using the approach as described in A.4.2.6, the supporting load P by the sand bed foundation to be allocated to one stiffening ring is the maximum found from the two analyses.

When using the assumed support distribution from Appendix C:

P = 1.33 x {Q_1 + Q_2 + Q_5 (+ Q_9, if applicable)} (kN)

In case of earthquake loads Q_1, Q_2 and Q_5 shall be replaced by the modified loads as discussed in (A.4.2.8).

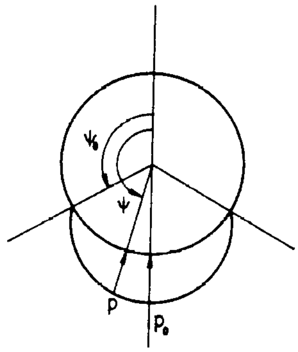
When using the beam on elastic foundation approach:

P = P^1 x L (kN)

where P^1 is the maximum unit support load.

It is assumed that the sand bed will exert a radial pressure on the cylinder. The angle over which the cylinder is supported depends on the foundation, but for a properly prepared sandbed an angle of 120° is a realistic assumption (refer Figure A.3 where ψ_0 = 120°).

Figure A.3



Conservatively it is assumed that pressures are cosine-like distributed according to:

p = p_0 cos 3/2 (180° - ψ) for 120° < ψ < 240°

The maximum pressure p_0 at ψ = 180° is:

p_0 = P/(1.2 x R x L) (kN/m^2)

This pressure shall be added to the internal vacuum when determining the shell plate thickness of the cylinder.

During construction and initial hydrotest it may be advantageous to support the vessel on a narrower foundation, for instance a support angle of 90° (ψ_0 = 135°) or even (as a minimum) 60° (ψ_0 = 150°), refer (3.5.3). For those cases the maximum pressure exerted by the foundation will be:

90° support angle: p_0 = P/(0.943 x R x L) (kN/m^2)

60° support angle: p_0 = P/(0.65 x R x L) (kN/m^2)

A.4.3 Selection of shell plate thickness

The thickness of the shell plates and the domed ends is selected on the basis of internal pressure and vacuum (loads 2, 3 and 4) in accordance with BS 5500 (Art. 3.5 and 3.6) and relevant DEPs (i.e. DEP 31.22.10.32-Gen. and DEP 30.10.02.31-Gen.). Refer, however, A.4.9.1.4.

For the cylinder the supporting pressure exerted by the sand bed, refer (A.4.2.10), shall be added to the internal vacuum. This loading condition may be determinative for the shell plate thickness of the cylinder (butane vessels).

For the domed ends the soil pressure, as discussed in (A.4.2.5.2), shall be added to the vacuum.

A.4.4 Bending moments, normal (i.e. axial) forces and shear forces in stiffening rings

These moments and forces are calculated using dimensionless coefficients K as follows:

Bending moment	M = Q x R x K_M	(kNm)
Normal force	N = Q x K_N	(kN)
Shear force	S = Q x K_S	(kN)

These coefficients K have been derived from reference 1 in (10) and depend on the angle ψ, the type of loading and the angle over which the vessel is supported by the foundation.

It is assumed that, when the vessel and the mound have been completed, the vessel is supported by the foundation over an angle of 120°. For this case the moments and forces will be shown in A.4.4.1, A.4.4.2 and A.4.4.3 (valid for a sand bed foundation only).

During construction and during the initial hydrotest it may be advantageous to support the vessel on a narrower foundation, for instance a support angle of 90° or even (as a minimum) 60°, refer (3.5.3). For those cases, the moments and forces will be shown in A.4.5 and A.4.6.

The maximum stresses due to bending moments and normal forces occur at ψ = 100° and ψ = 180°. However, if the stiffener is heavier at ψ = 180° than at the remainder of the ring, the stresses at ψ = 0° also need to be checked.

A.4.4.1 Bending moments for 120° support angle

For ψ = 0°:

M_0 = $(Q_1 + Q_2 + Q_6) \times R \times 0.063 + (Q_5 + Q_9) \times R \times 0.117$ (kNm)

For ψ = 100°

M_{100} = $-(Q_1 + Q_2 + Q_6) \times R \times 0.077 - (Q_5 + Q_9) \times R \times 0.121$ (kNm)

For ψ = 180°

M_{180} = $(Q_1 + Q_2 + Q_6) \times R \times 0.091 + (Q_5 + Q_9) \times R \times 0.135$ (kNm)

A positive bending moment tends to increase the radius of curvature of the stiffening ring and causes tensile bending stress on the inside of the ring. A negative bending moment will have the opposite effects.

A.4.4.2 Normal (i.e. axial) forces for 120° support angle

The maximum normal forces do not necessarily coincide with the maximum bending moments. However, the bending moments are the dominating sources of stress and therefore the normal forces shall be calculated for the locations of maximum bending, as follows:

For ψ = 0°:

N_0 = $(Q_1 + Q_2 + Q_6) \times 0.205 + (Q_5 + Q_9) \times 0.373$ (kN)

For ψ = 100°

N_{100} = $-(Q_1 + Q_2 + Q_6) \times 0.309 - (Q_5 + Q_9) \times 0.499$ (kN)

For ψ = 180°

N_{180} = $(Q_1 + Q_2 + Q_6) \times 0.429 + (Q_5 + Q_9) \times 0.582$ (kN)

A negative normal force is compression, a positive normal force is tension.

N_{180} is a tensile force. The reason for this is as follows:

The foundation pressure p, refer (A.4.2.10), will cause a circumferential compressive stress in the shell plate, equal to:

s = $(p \times R)/t$ (kN/m^2)

This stress will be maximum at ψ = 180° and will decrease to zero at ψ = 120° and ψ = 240°. The decrease in this compressive stress will have to be compensated by shear stress in the shell plate in order to maintain equilibrium. These shear stresses are transmitted to the stiffening ring and cause a tensile normal force at ψ = 180°.

Moreover, a normal load will be caused in the stiffening ring by the internal pressure (p_3) or vacuum (p_4), refer (A.4.2.3 and A.4.7). This load is constant along the circumference of the ring and is:

N = $p \times w \times R$ (kN)

where:

p = p_3 or p_4 (as applicable) (kN/m^2)

w = working width of the shell plate (m)

N is tensile in case of internal pressure and compressive in case of internal vacuum (kN)

A.4.4.3 Shear forces for 120° support angle

The shear forces in the stiffeners are virtually nil at the location of the maximum bending moments, and maximum at ψ = 140°, where the bending moment is practically nil.

For ψ = 140°:

$S_{140} = (Q_1 + Q_2 + Q_6) \times 0.197 + (Q_5 + Q_9) \times 0.113$ (kN)

A.4.5 Bending moments and forces for 90° support angle

The mound has not yet been installed, therefore $Q_5 = Q_9 = 0$

For ψ = 0°:

$M_0 = (Q_1 + Q_2 + Q_6) \times R \times 0.070$ $N_0 = (Q_1 + Q_2 + Q_6) \times 0.219$

For ψ = 100°:

$M_{100} = - (Q_1 + Q_2 + Q_6) \times R \times 0.088$ $N_{100} = - (Q_1 + Q_2 + Q_6) \times 0.312$

For ψ = 180°:

$M_{180} = (Q_1 + Q_2 + Q_6) \times R \times 0.124$ $N_{180} = (Q_1 + Q_2 + Q_6) \times 0.692$

For ψ = 140°:

$S_{140} = (Q_1 + Q_2 + Q_6) \times 0.250$

A.4.6 Bending moments and forces for 60° support angle

Mound not yet installed, $Q_5 = Q_9 = 0$

For ψ = 0°

$M_0 = (Q_1 + Q_2 + Q_6) \times R \times 0.075$ $N_0 = (Q_1 + Q_2 + Q_6) \times 0.229$

For ψ = 100°:

$M_{100} = - (Q_1 + Q_2 + Q_6) \times R \times 0.095$ $N_{100} = - (Q_1 + Q_2 + Q_6) \times 0.314$

For ψ = 180°:

$M_{180} = (Q_1 + Q_2 + Q_6) \times R \times 0.160$ $N_{180} = (Q_1 + Q_2 + Q_6) \times 1.209$

For ψ = 160° (location of maximum shear force):

$S_{160} = (Q_1 + Q_2 + Q_6) \times 0.320$

A.4.7 Dimensions of stiffening rings

When the bending moments, normal forces and shear force have been determined, the dimensions of the stiffening rings shall be selected, after which the resulting stresses can be calculated. In this calculation the working width w of the shell (refer A.4.2.3) acts fully effectively as part of the ring stiffener, and shall be included in determination of the moment of inertia, section modulus and cross-sectional area of the stiffener.

A.4.8 Secondary bending stresses

Due to the internal pressure (load 3) circumferential stress and consequently strain will develop in the shell of the vessel. Near the stiffening rings, however, the shell plates will be restrained in radial direction and therefore the circumferential stress and strain of the shell plates near the stiffeners will be less than at some distance from the stiffeners. This causes secondary bending stresses in longitudinal direction in the shell plates.

The magnitude of these secondary bending stresses depends on the cross-sectional area of the stiffeners and the thickness and radius of the shell plates and can be calculated for instance by using from (10) ref. (6) table XIII, case No. 8. This secondary bending stress can exceed the circumferential hoop stress. For example, for a stiffener infinitely rigid in radial direction, the secondary bending stress would be:

s' = (1.82 x p x R) / t (kN/m^2)

while the primary hoop stress is: s = (p x R) / t (kN/m^2);

where p = pressure perpendicular to plate. (kN/m^2)

Since the secondary bending stress is self-equilibriating, its magnitude is not necessarily a problem (ref. BS 5500, Art. A.3.4.2.4 and Figure A.3).

A.4.9 Summary of stresses

A.4.9.1 Stresses in the shell plates

A.4.9.1.1 Circumferential stress in the shell plates

In this direction membrane stresses (tensile or compressive) in the shell plates will be caused by most of the loads 1 through 10.

For loads 1, 2, 3, 4, 5 and 10 the membrane stress is:

s = (p x R) / t (kN/m^2)

where

p_1 = weight of shell plate x cos ψ

p_2 = hydrostatic pressure by liquid

p_3 = internal pressure (refer 4.1.3)

p_4 = internal vacuum (refer 4.1.3)

p_5 = q as defined in (A.4.2.5)

p_{10} = p as defined in (A.4.2.10)

s is tensile if p is radially outward, and s is compressive if p is radially inward.

The effect of load 6 is included in p_{10}

for load 8 (refer A.4.2.8)

for load 9 (refer A.4.2.9)

The bending moments and normal forces in the stiffening rings will cause tensile or compressive stresses in the shell plates near the rings (the working width).

Fortunately the hoop stresses due to internal pressure (or vacuum) in this area are reduced, because the internal pressure (or vacuum) on the working width is assumed to be carried by the shell plate in the working width plus the stiffening ring. This will result in a considerably reduced hoop stress, refer (A.4.2.3) and (A.4.2.4).

A.4.9.1.2 Longitudinal stress in the shell plates

In this direction tensile or compressive stresses are caused by:

1. internal pressure or vacuum (loads 3 and 4);
2. bending of the vessel in longitudinal direction due to uneven foundation support or due to construction tolerances of vessel and/or foundation (load 6, refer A.4.2.6);
3. changes in length of vessel due to changes in temperature and internal pressure (load 7, refer A.4.2.7).

   These changes in length cause friction between the vessel and the surrounding soil and variation of the soil pressure on the domed ends of the vessel, refer (A.4.2.7) and (A.4.2.5.2). The resulting stresses can be estimated and depend very much on the length of the vessel as well as the diameter and the wall thickness;

4. secondary bending moments in the shell plates, (refer A.4.8).

A.4.9.1.3 Shear stresses in the shell plates

These are caused by the presence of the stiffening rings (refer A.2.2) as well as by uneven support (refer A.4.2.6).

The maximum shear stress will occur at ψ = 120° and can be determined from:

τ = (0.62 P + 0.28 Q) / (t x R) (kN/m^2)

where

P = support load allocated to one stiffening ring, refer (A.4.2.10)

Q = maximum shear load on vessel from beam on elastic foundation analysis or from assumption according to Appendix C, whichever is governing, refer (4.2.6 and A.4.2.6).

In case of an initial hydrotest on a narrow sand bed (refer A.4.2.10) the maximum shear stress may be determined from:

for a support angle of 90°:

τ = (1.06 P + 0.225 Q) / (t x R) at ψ = 135°

for a support angle of 60°:

τ = (2.31 P + 0.16 Q) / (t x R) at ψ = 150°

A.4.9.1.4 Stress intensities in the shell plates

After calculating the longitudinal, circumferential and shear stresses, the principal stresses and the stress intensities have to be evaluated, refer BS 5500, Appendix B4.

The area where the shear stress is maximum (ψ = 120°) may be governing for the plate thickness.

For long vessels with a relatively small diameter the longitudinal stresses may be governing for the shell plate thickness. This should be avoided if possible (refer 4.1.1).

For this situation, the following two combinations of load conditions need to be analysed:

1. Load combination 1:
   - maximum internal pressure
   - maximum longitudinal bending (using the side of the vessel under compressive stress)
   - maximum longitudinal thermal expansion of vessel

The stress intensity f1 - f2 at midspan of the vessel (f1 and f2 are principal stressses) must be calculated.

2. Load combination 2:
   - zero internal pressure
   - maximum longitudinal bending (refer Load combination 1 above)
   - maximum longitudinal thermal expansion of vessel

The maximum longitudinal compressive stress at midspan of the vessel must be calculated.

A.4.9.2 Stresses in the domed ends

These are caused by:

- internal pressure and vacuum (loads 2, 3 and 4);

- external pressure due to the soil cover, refer (A.4.2.5.2);
- in case of unstiffened cylinders the domed ends act as stiffeners. The resulting stress situation in the heads will be difficult to calculate by hand, especially when combined with non-symmetrical external soil pressure, refer (A.2.1).

A.4.9.3 Stresses in the stiffening rings

These can be calculated using the bending moments and forces as shown in (A.4.4), (A.4.5) and (A.4.6) and the section properties in accordance with (A.4.7).

The maximum bending moment and the maximum shear force in a stiffening ring do not coincide, refer (A.4.4).

The shear force is mainly carried by the web of the stiffener and is normally not critical. To avoid the need of having to determine the worst combination of bending moment, normal force and shear force along the circumference of the stiffener, the following criterion may be adopted:

$$\tau \leq 0.5\,f$$

where

τ = maximum shear force at ψ = 140° (refer A.4.4), divided by the cross sectional web area

f = the nominal design stress

In that way it would still be acceptable if at ψ = 140° a combination of bending stress and normal stress, totalling up to 0.5 x f, should occur, since the requirement:

$$f \geq \sqrt{s^2 + 3\tau^2}$$

would be fulfilled.

A.4.9.4 Stresses in the welds between stiffening rings and shell plates

The welds between stiffening rings and shell will be subjected to the following loads:

- a radial load, found from the calculation of secondary stresses in the shell, refer (A.4.8), or from:

  radial load = $p \times w \times A_{nett} / A_{gross}$ (kN/m^2)

  where:

  p = internal pressure (kN/m^2)

  w = working width of shell plates (m)

  A_{nett} = cross sectional area of stiffener excluding working width of shell plates (m^2)

  A_{gross} = cross sectional area of stiffener including working width of shell plates (m^2)

- a shear load, caused by the shear force in the stiffening ring, refer (A.4.4), and equal to that shear force divided by the cross sectional web area and multiplied by the web thickness (maximum at ψ = 140°)
- a shear load caused by the change in circumferential stress in the shell, refer (A.4.4.2), last paragraphs. This shear load is maximum at ψ = 120° and can be determined from:

$$F_s = \frac{2 \times 0.62\ P}{R} \times \frac{A_{nett}}{A_{gross}} \quad \text{(kN/m)}$$

where

F_s = max. shear load (kN)

P = support load allocated to one stiffener, refer (A.4.2.10) (kN)

Above shear loads are loads per unit length of weld and both act in the longitudinal direction of the weld.

In case of an initial hydrotest on a narrow sand bed (refer A.4.2.10) the shear load Fs may be determined from:

for a support angle of 90°:

Fs = 2 x 1.06 P x Anett / (R x Agross) at ψ = 135°

for a support angle of 60°:

Fs = 2 x 2.31 P x Anett / (R x Agross) at ψ = 150°

A.4.9.5 Stability of stiffening rings

The flange of the stiffening rings is, between approximately ψ = 50° and ψ = 140°, subjected to circumferential compressive stresses due to bending moments and normal forces in the rings with a maximum at ψ = 100°.

Because of the circular shape of the flange, these compressive stresses will result in a radial compressive load F_r exerted by the flange on the web of the stiffening ring.

$$F_r = \frac{s \times A_f}{R_f} \quad \text{(kN/m)}$$

where

s = compressive stress in the flange (kN/m²)

A_f = cross-sectional area of the flange (m^2)

R_f = radius of the flange (m)

The web is also subjected, at least partly, to circumferential compressive stresses due to bending moments and normal forces in the ring. This will result in radial compressive stresses in the web, in the same way as (and in addition to) those exerted by the flange as indicated above.

In view of these compressive stresses, the stability against buckling of the flange and the web has to be checked.

Both flanges and web may tend to buckle out in lateral direction, i.e. in the longitudinal direction of the vessel, and it is therefore possible that they cannot support each other in the area of compressive stresses.

Flange Stability:

Assume that the flange is a compressive member which is laterally supported by the web only in the areas where there are no compressive stresses anymore in the web, i.e. at ψ = 50° and ψ = 140°. The buckling length of this compressive member is then approximately one quarter of the circumference of the flange. The relevant moment of inertia of the flange is:

$$I = \frac{1}{12} t\, w_f^3 \quad (m^4)$$

where

t = thickness of the flange (m)

w_f = width of the flange (m)

The axial load is:

$P = s \times A_f$ (kN) at $\psi = 100°$

The resistance against buckling of the flange can now be calculated in the conventional way, assuming pivot supports at the ends of the member.

The flange must at least be able to support itself.

Web Stability:

The web has to be analysed as a plate loaded in compression in radial direction, as well as in tangential (circumferential) direction.

It may be assumed that this plate is laterally supported at $\psi = 50°$ and $\psi = 140°$ (due to the absence there of significant compressive stresses), at the shell of the vessel and possibly at the flange. The latter depends on whether the flange is strong enough to provide support to the web in addition to carrying its own axial load.

For such an analysis reference is made to relevant textbooks or codes, such as BS 5400, part 3 "Code of Practice for Design of Steel Bridges", or DASt Richtlinie 012 "Beulsicherheitsnachweise für Platten".

In many cases, the flange will not be able to provide adequate lateral support to the web without buckling or being overstressed. Especially in that case a somewhat crude, but useful, simplification may be made by considering radial strips of the web as members loaded in compression by the radial load F_r shown above. It is assumed that these strips are not laterally supported by the flange and that at the shell the strips are fixed rigidly.

The radial buckling load F_b (per unit width) would be:

$$F_b = \frac{\pi^2 EI}{(2h)^2}$$

in which:

$I = 1/12\ t_w^3$

(where: t_w = web thickness)

h = height of web

Using a safety factor of 2.5, it has to be shown that

$$F_r \leq \frac{F_b}{2.5} = \frac{\pi^2 E t_w^3}{120 h^2} \text{ (approximately equal to } \frac{E t_w^3}{12 h^2}\text{)}$$

In case the flange can support the web, the above simplified method would yield rather conservative results.

A.5 STRESS AND STABILITY CRITERIA

A.5.1 Shell plates

BS 5500, Appendix B gives stress criteria which have to be satisfied for combined loadings, including internal pressure.

Article A.3.5 of Appendix A gives criteria for allowable longitudinal compressive stress, in which the risk of buckling is covered.

Buckling of the shell plates in circumferential direction due to external pressure (loads 1, 4, 5, 8, 9 and 10) shall be checked in accordance with BS 5500, Article 3.6.2.1.

For mounded storage vessels the buckling strength in one direction does not have to be reduced because of compressive stresses in a direction perpendicular to the first one.

This is different from ultimate strength considerations, where longitudinal stresses have an influence on the allowable circumferential stresses and vice versa (refer BS 5500 App. B.4).

For secondary bending stresses refer to BS 5500 Appendix A, Article A.3.4.2.4 and Figure A.3.

A.5.2 Domed Ends

Domed ends under internal pressure shall be designed in accordance with BS 5500, Chapter 3.5.

For external pressure domed ends shall satisfy the requirements of BS 5500, articles 3.6.4 through 3.6.7. It should be realized that the external pressure due to loads 5, 7, 8, 9 and 10 is not equally distributed, which has an unfavourable effect on the buckling behaviour. Therefore sufficient safety margin should be maintained. For a hemispherical end, which is the most economical (and therefore preferred) solution, the minimum wall thickness is 12 mm.

For the above it is required that a stiffening ring is provided near the transition from cylinder to domed end. If such a ring is not provided, the analysis of the domed end will be more complicated, refer (A.2.1).

A.5.3 Stiffening rings

The stresses due to the bending moments, normal forces and shear forces have to satisfy conventional criteria for steel structures, refer DEP 34.28.00.31-Gen. or BS 449.

This includes the stresses in the welds with which the stiffening rings are attached to the shell plates. Refer also BS 5500, Art. 3.10.3.

The bending moment and normal force in the stiffening rings at $\psi = 180°$ are usually appreciably greater than at $\psi = 0°$ and $\psi = 100°$. Therefore, it may be advantageous to use a heavier cross section for the lower part (one quarter) of the stiffener (for $135° < \psi < 225°$) and a lighter cross section for the rest of the stiffener.

If very heavy stiffening rings would have to be provided in order to maintain acceptable stresses, it may be considered to install columns between the top and bottom of the rings. This will reduce the bending moments in the rings considerably. The columns should be able to transmit compressive loads only, not tensile loads. This will avoid secondary bending moments due to internal pressure.

The stiffening rings shall be analysed for buckling failure due to combination of compressive normal forces and bending moments, refer (A.4.9.5).

A.6 DEFORMATION OF STIFFENING RINGS

The deflection of the top of the ring with respect to the bottom is:

$$y = \frac{R^2}{EI} \times \int_0^{\pi} M_\psi \sin\psi \, d\psi$$

where

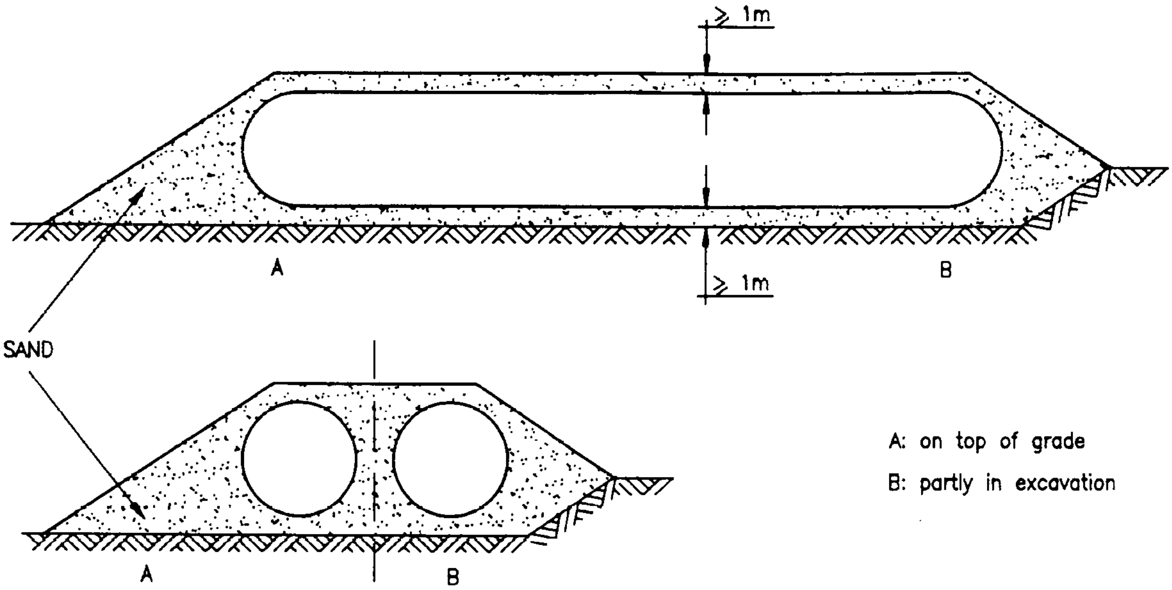
y	=	vertical deflection of top of ring	(m)
R	=	diameter of ring	(m)
E	=	modulus of elasticity	(kN/m^2)
I	=	moment of inertia of ring	(m^4)
M_ψ	=	bending moment for circumferential angle ψ	(kNm)

($\psi = 0$ at top and $\psi = \pi$ at bottom)

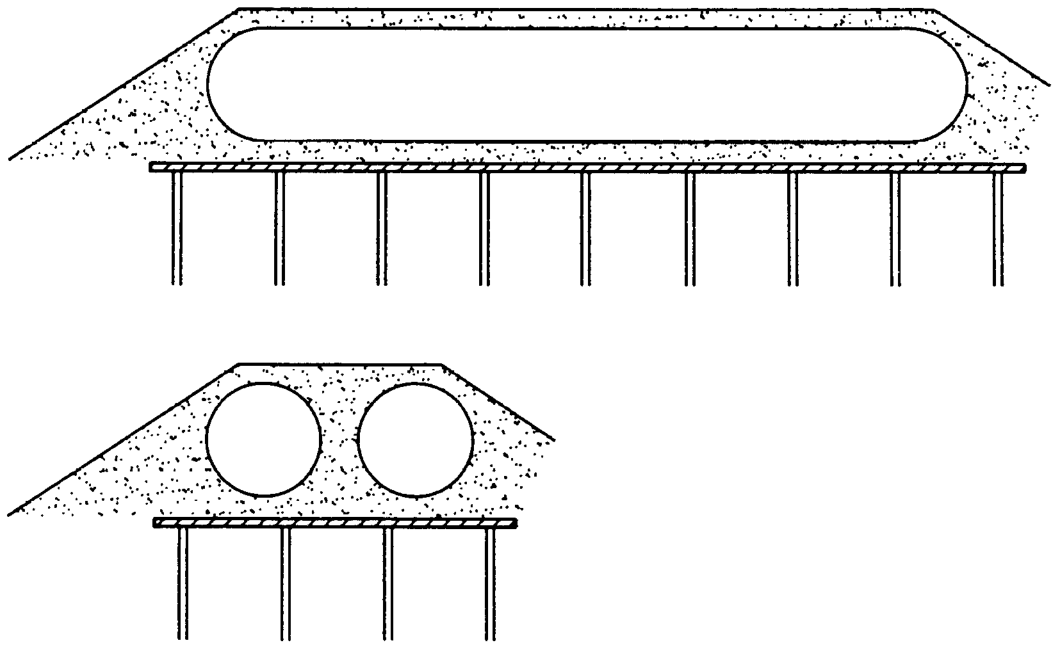
Due to the complexity of M, caused by combining the various loads, y can probably best be determined by numerical integration, either by hand or by computer.

Spangler (ref. 7 in 13) has given deflection coefficients for buried pipelines. However, the load distribution used by Spangler is not sufficiently representative for storage vessels, which usually have a larger diameter than pipelines. The results of calculations using these coefficients would not be sufficiently reliable for storage vessels.

APPENDIX B TYPICAL FOUNDATION MODES

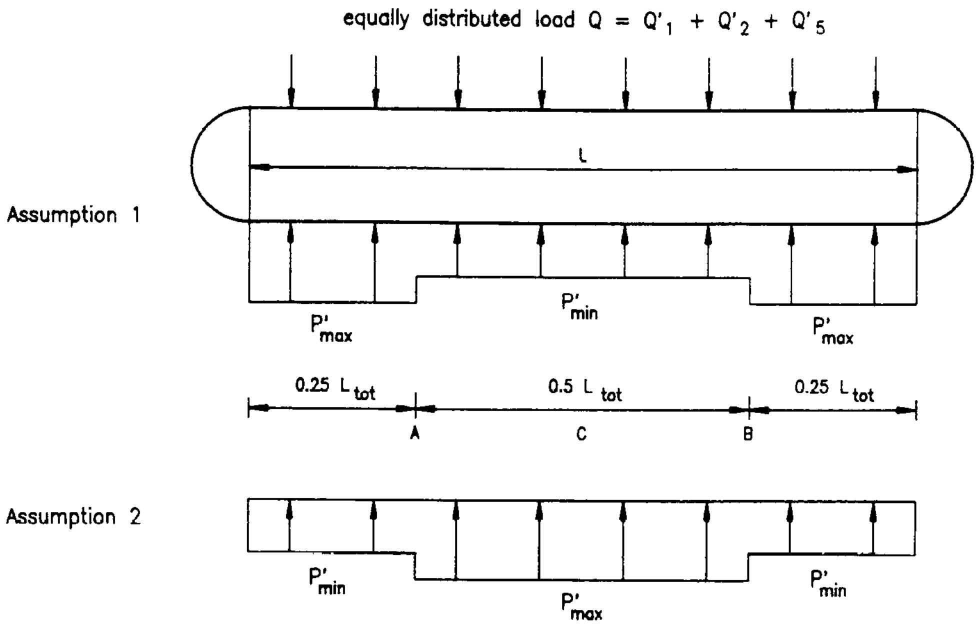


FOUNDATION ON SAND BED



CONTINUOUS RAFT FOUNDATION ON PILES

APPENDIX C DISTRIBUTION OF SOIL REACTION (SUPPORTING LOAD)



Assumptions 1 and 2 have to be taken into account for the structural analysis of the vessel.

<u>Results</u>		$P_{max} = 2\,P_{min}$
Soil reaction P_{max}	(kN/m1)	1.33 Q '
Soil reaction P_{max}	(kN/m1)	0.67 Q '
Unit shear load Q_6	(kN/m1)	0.33 Q '
Shear load to be carried by one stiffener: $Q_6 = Q_6 \times L_r$	(kN)	$0.33\,Q'.L_r$
max. shear load in cylinder (at A and B): $Q_6' \times \frac{1}{4} L_{tot}$	(kN)	$0.0825\,Q'.L_{tot}$
max. bending moment (at C)(kNm)		$\pm 0.0206\,Q' L_{tot}^2$

$$\text{max. deflection } f = \frac{2.125}{384} \times \frac{0.33\left(Q_1' + Q_2' + Q_5'\right) L_{tot}^4}{EI}$$

where L_r = distance between stiffening rings

L_{tot} = total length of cylinder + 2 x 0.5 x radius for hemispherical heads

or L_{tot} = total length of cylinder for torispherical heads

f = max. deflection of middle of cylinder with respect to the ends

I = moment of inertia of cylinder

APPENDIX D RECOMMENDED STEEL GRADES AND HEAT TREATMENTS FOR MOUNDED STORAGE VESSELS

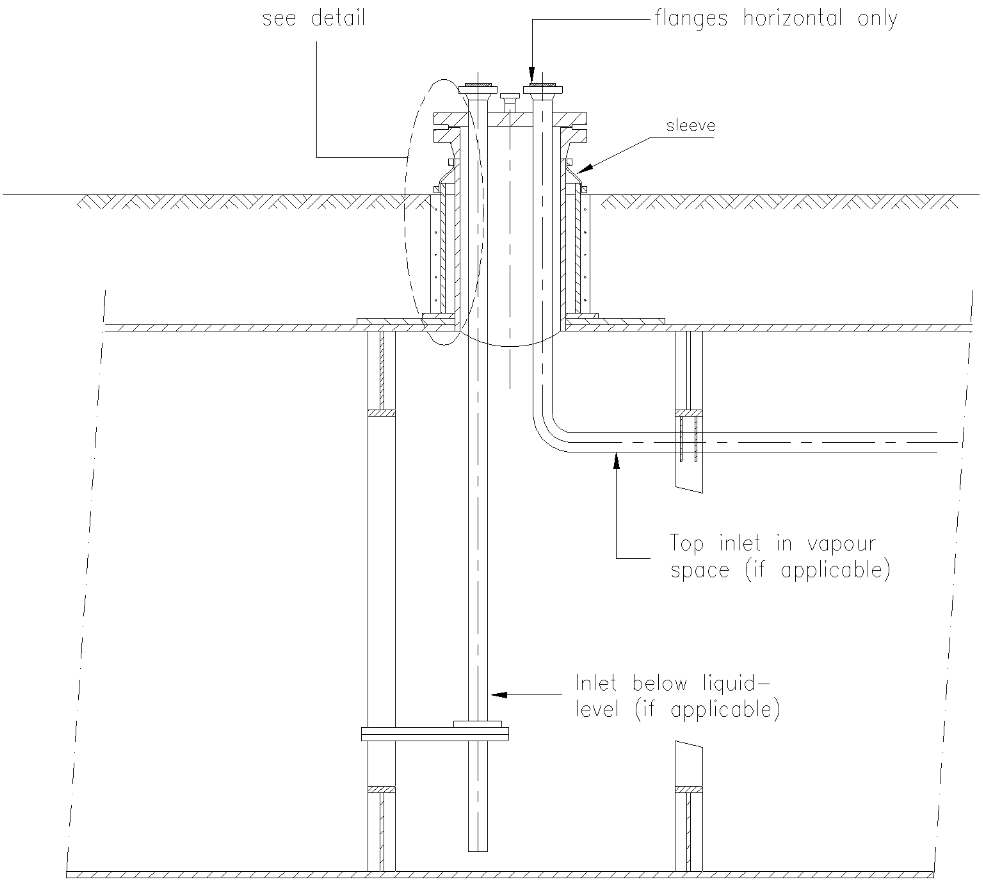
PRODUCT (1)	VESSEL HEAT TREATMENT	THICKNESS (mm)	REQUIRED IMPACT TEST TEMPERATURE in °C (2)	PLATE (3)	RECOMMENDED MATERIAL (3) FORGINGS	PIPE (3)
BUTANE	Fully as welded (4)	T < 25	-20	BS 1501-224-430 LT20 ASTM A516 Grade 60, S5	BS 1503-224-430 LT20 ASTM A350 LF2	BS 3603 HFS LT50 cat. 2 ASTM A333 Grade 6
		25 < T < 35	-50	BS 1501-224-430 LT50	BS 1503-224-430 LT50	BS 3603 HFS LT50 cat. 2 ASTM A333 Grade 6
	Full PWHT	All thicknesses	-20	BS 1501-224-430 LT20 ASTM A516 Grade 60, S5	BS 1503-224-430 LT20 ASTM A350 LF2	BS 3603 HFS LT50 cat. 2 ASTM A333 Grade 6
PROPANE	Fully as welded (4)	T < 18	-50	BS 1501-224-430 LT50	BS 1503-224-430 LT50	BS 3603 HFS LT50 cat. 2 ASTM A333 Grade 6 (5)
	Full PWHT	T < 30	-20	BS 1501-224-430 LT20 ASTM A516 Grade 60, S5	BS 1503-224-430 LT20 ASTM A350 LF2	BS 3603 HFS LT50 cat. 2 ASTM A333 Grade 6
		All thicknesses	-50	BS 1501-224-430 LT50	BS 1503-224-430 LT50	BS 3603 HFS LT50 cat. 2 ASTM A333 Grade 6 (6)

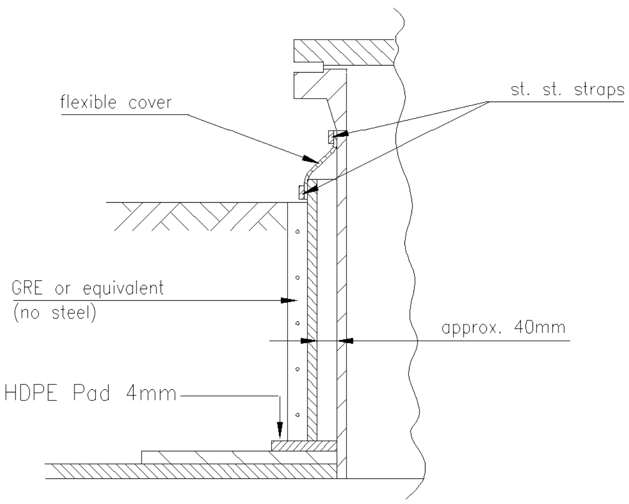
Notes:

1. For gas mixtures it will be necessary to conduct a full appraisal using BS 5500.
2. Charpy impact testing temperatures given here are derived from BS 5500.
3. Materials not specified here may be used provided they have guaranteed minimum charpy impact values at the required test temperature and meet the requirements of section 4.4
4. For thicknesses greater than specified here, full PWHT must be applied.
5. T < 12 mm.
6. T < 40 mm.

APPENDIX E VESSEL CONNECTIONS

(CONCEPTUAL)

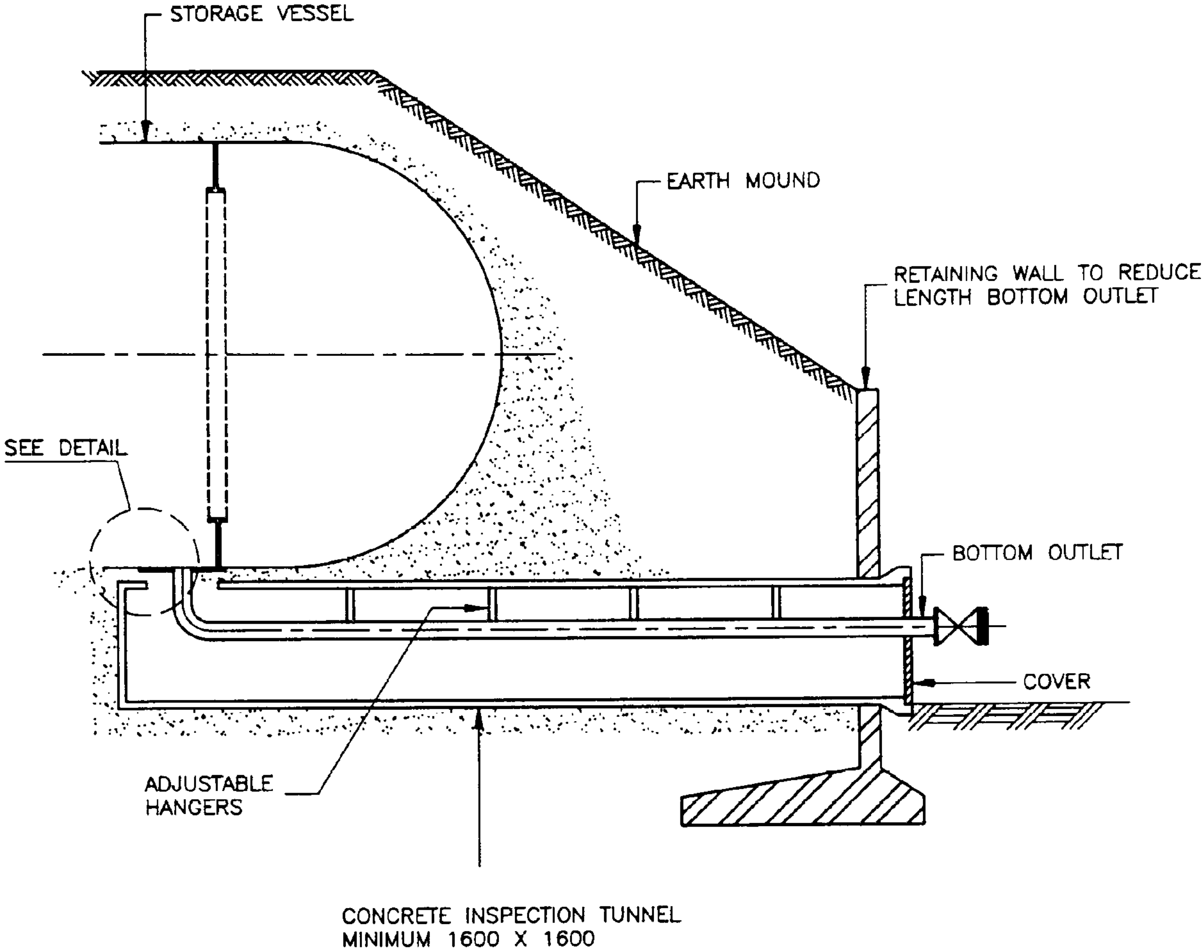

see detail
flanges horizontal only
sleeve
Top inlet in vapour
space (if applicable)
Inlet below liquid-
level (if applicable)

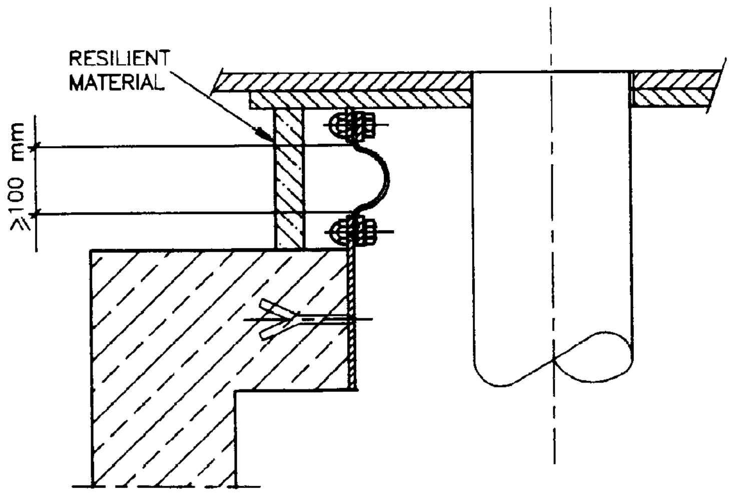

flexible cover
st. st. straps
GRE or equivalent
(no steel)
approx. 40mm
HDPE Pad 4mm

DETAIL

APPENDIX F BOTTOM OUTLET WITH INSPECTION TUNNEL

(CONCEPTUAL)





DETAIL

APPENDIX G NON-DESTRUCTIVE TESTING REQUIREMENTS

	Vessel Weld	Type of weld	Before PWHT or if no PWHT is to be applied				After PWHT			After HPT			
			MPI		RT	UT	MPI		UT	MPI	UT	VE	
			int.	ext.			int.	ext.		int.		int.	ext.
1	shell (incl. dome)	butt	100%	100%	100%	---	100%	100%	100%	10% (2) (5)	10% (3)	100%	100%
2	shell to stiffener	fillet	100%	---	---	10% (1)	100%	---	100%	10% (2)	10% (3)	100%	---
3	web to flange	fillet	100%	---	---	10% (1)	100%	---	10% (1)	---	---	100%	---
4	reinforcement of flange (stiffener)	fillet	100%	---	---	---	100%	---	10% (1)	10% (2)	---	100%	---
5	stiffener (web + flange)	butt	100%	---	100%	---	100%	---	100%	---	---	100%	---
6	nozzles/manholes	butt	100%	100%	---	10% (1)	100%	100%	100%	---	10% (3)	100%	100%
7	reinforcement plates/pads	fillet	100%	100%	---	---	100%	100%	10% (1)	---	---	100%	100%
8	vessel accessories	fillet	100%	---	---	---	---	---	---	---	---	---	---
9	temporary weld attachments (6)	location	100%	100%	---	---	10%	10%	---	---	---	---	---
10	weld edges 50 mm	all	---	---	---	100% (4)	---	---	---	---	---	---	---

MPI = Magnetic Particle Inspection
RT = Radiographic Test
* UT = Ultrasonic Test
PWHT = Post weld Heat Treatment
HPT = Hydrostatic Pressure Test
VE = Visual examination

(1) In case of defect, 100% inspection of subject weld required.
(2) For T-crossings of butt welds and for crossings of butt and fillet welds around mouse holes; in case of defect, 100% inspection of subject weld required.
(3) Random but not at the same locations as (2) above.
(4) For lamination control (7.1.2).
(5) See (7.1.4).
(6) After removal / grinding.
(7) For hardness testing, see appendix H1.

* Procedures and acceptance criteria shall be in accordance with (7.1.1)

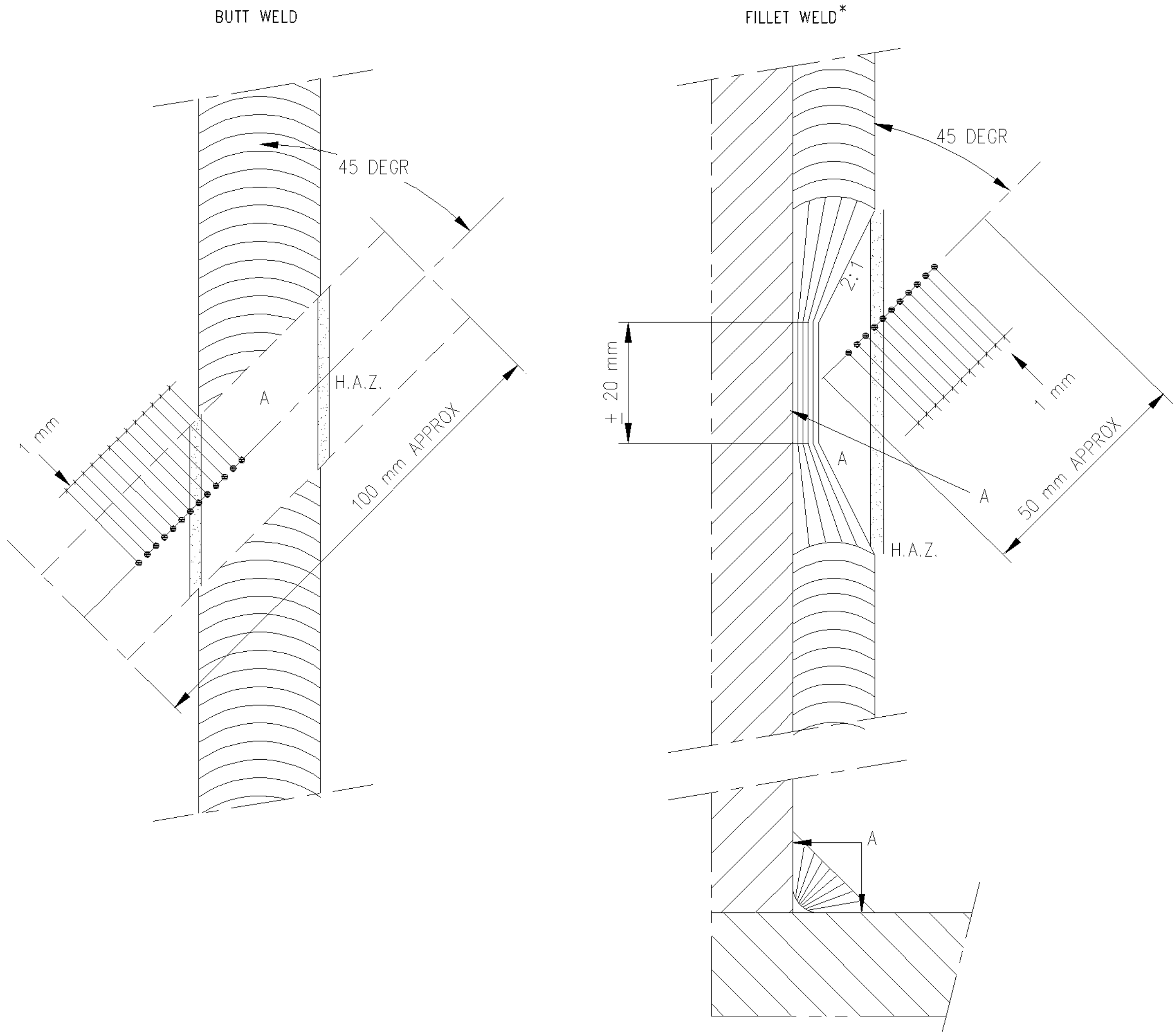
APPENDIX H1 HARDNESS TESTING ON MOUNDED VESSEL WELDS

Vessel Weld (Note 2)		Type of Weld	Welding Process	Inside Vessel Number Of Locations (Note 6)	Outside Vessel Number Of Locations (Note 6)
1	shell (including dome) seams	butt	SAW SMAW	2 per 3 m of weld 4 per 3 m of weld	1 per 3 m of weld 2 per 3 m of weld
2	shell to stiffener	fillet	SAW SMAW	2 per 3 m of weld 4 per 3 m of weld	
3	web to flange	fillet	SAW SMAW	2 per 3 m of weld 4 per 3 m of weld	
4	reinforcement of flange (stiffener)	fillet	SAW SMAW	2 per 3 m of weld 4 per 3 m of weld	
5	stiffener (web + flange)	butt	SAW SMAW	2 per side of each weld 4 per side of each weld	
6	nozzles/manholes	butt	SAW SMAW	2 per weld 4 per weld	1 per weld 2 per weld
7	reinforcement plates/pads	fillet	SMAW	4 per 3 m of weld (minimum 4 per weld)	2 per 3 m of weld (minimum 2 per weld)
8	vessel accessories	fillet	SMAW	1 per weld	1 per weld
9	temporary attachments	location after removal	SMAW	25% of removed locations (Note 7)	10% of removed locations (Note 7)

NOTES:
1. The maximum hardness shall be 248 HV 10.
2. The welds are numbered the same as in Appendix G.
3. Recommended procedure for hardness measurements is shown in Appendix H2.
4. SAW = Submerged arc welding.SMAW = Shielded metal arc welding.
5. Hardness testing shall be carried out after production welding if PWHT is not required. Hardness testing shall be carried out after PWHT if PWHT is required
6. For each measurement in excess of 248 HV 10, four more measurements shall be made in the same weld for each 3m weld length
7. If more than 3 spots are in excess of 248 HV 10, all temporary attachment removed areas shall be hardness tested.
8. If any hardness measurements are in excess of 248 HV 10, the vessel manufacturer shall

notify the Principal and advise proposed corrective action for Principal's approval.

APPENDIX H2 RECOMMENDED PROCEDURE FOR HARDNESS MEASUREMENTS

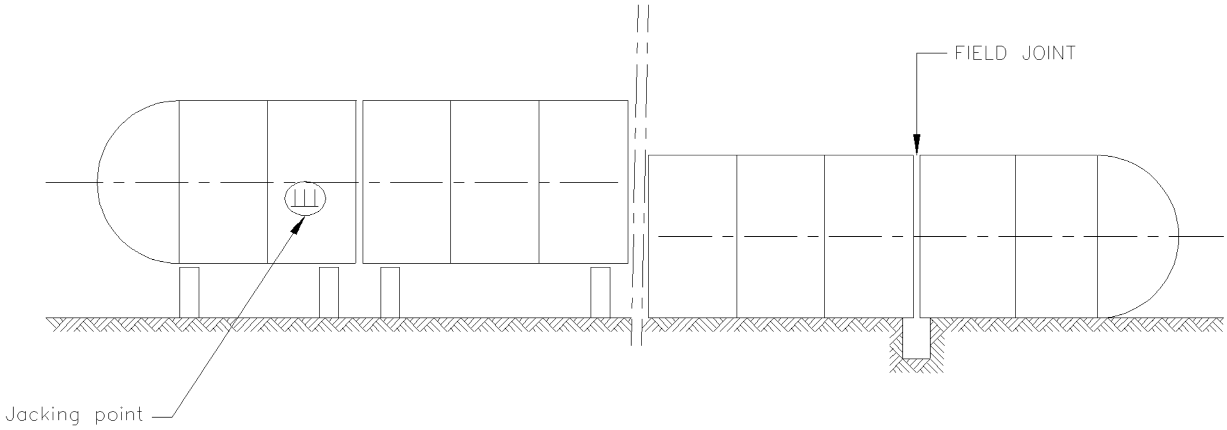


* Applies for full fillet weld as well as partially penetrated fillet welds.

1) Proper Grinding - A -
2) Polishing with sandpaper or tool, if possible to grit 250
3) Etching polished weld area to make HAZ visible (Nital solution)

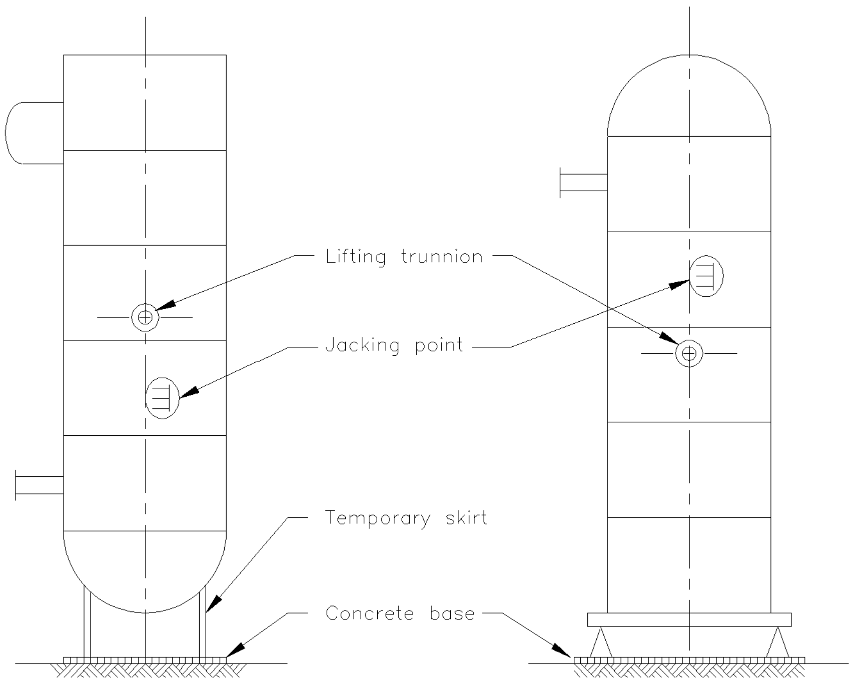
Abbreviation: HAZ : Heat Affected Zone

APPENDIX I INSTALLATION/FABRICATION ALTERNATIVES



SHOP PREFAB – SITE FIELD JOINTS

A B



C D