MANUAL

DESIGN AND INSTALLATION OF CHEMICAL-RESISTANT LININGS FOR CONCRETE STRUCTURES

DEP 30.48.60.12-Gen.

May 1993

DESIGN AND ENGINEERING PRACTICE

USED BY

COMPANIES OF THE ROYAL DUTCH/SHELL GROUP

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APPENDICES

1. INTRODUCTION

1.1 SCOPE

This DEP covers the design criteria and general requirements for the installation, testing and inspection of chemical-resistant linings for concrete structures used in the petroleum, chemical and gas industries. It is a combined revision of, and replaces, DEP 30.48.60.12-Gen. and DEP 30.48.60.22-Gen., both dated August 1981.

Excluded from the scope of this DEP is the subject of rubber linings, for which reference is made to DEP 30.48.60.10-Gen. and 30.48.60.30-Gen.

It is not the intention to provide in this document detailed specifications for each case of chemical attack. Each case shall be looked at individually and, based on these minimum requirements, details shall be worked out and agreed between Principal, Contractor, Manufacturer and Applicator, leading to a durable protection of concrete structures against chemical attack under the particular conditions.

Chemical-resistant lining materials shall be in accordance with DEP 30.48.60.33-Gen.

NOTE: In various places in this DEP specific brands of products are specified. It is not intended to preclude the use of other products; equivalent products may be used provided the Principal so approves.

1.2 DISTRIBUTION, INTENDED USE 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 nominated by them (i.e. the distribution code is "C", as defined in DEP 00.00.05.05-Gen.).

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

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

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

The **Applicator** is the party which applies the chemical-resistant linings specified by the Contractor.

The **Contractor** is the party which carries out all or part of the design, engineering, procurement, construction and commissioning for 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 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 design and construction. The Principal will generally specify the technical requirements. The Principal may also include an agent or consultant, authorized to act for the Principal.

The word **shall** indicates a requirement.

The word **should** indicates a recommendation.

1.4 CROSS-REFERENCES

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

All publications referred to are listed in (10).

2. GENERAL

Concrete is a mixture of hydraulic cement and mineral aggregates, of which the cement is the constituent in the mix most vulnerable to chemical attack.

The alkaline character of the cement in the mix provides the concrete with a good resistance against alkalis. However, if concrete is exposed to acids, acidic solutions or an acid/alkaline condition, protection by means of a chemical-resistant lining may be required.

Concrete is resistant to most hydrocarbon solvents.

A chemical-resistant lining will, in general, consist of at least two lines of defence, i.e. a membrane and a chemical-resistant brick lining. The optimal solution is bricks or tiles laid in a synthetic resin-based mortar with a suitable membrane, but this type of construction is expensive and should only be applied when justified.

In general alternative cheaper solutions, such as bricks or tiles laid in silicate-based mortars, jointless protective layers, or a combination thereof, should be used.

A well prepared concrete surface is essential for the proper performance of chemical-resistant linings. The installation of these linings shall be carried out by specialised contractors with skilled labour under stringent supervision. The installation shall be completed with a suitable after-treatment.

Precautions shall be taken to avoid inadvertent outflow/disposal of chemicals (e.g. hydrochloric acid used for cleaning dirty floors, "acidulation" of brick lining, etc.).

3. DESIGN ASPECTS

3.1 GENERAL

Chemical-resistant linings for concrete structures shall be designed and carried out by experienced engineering contractors only. The need for such linings shall be taken into account early in the design and calculation stages of the structure, so that the required slope for drainage of floors, trenches and other provisions, and the additional weight of the lining, can be considered.

If in a later stage, due to a change in requirements or the extension of an installation, a chemical-resistant lining has to be applied, the concrete structure shall be recalculated.

If a change in chemical conditions from those originally anticipated in the design is envisaged, the effects on the chemical-resistant lining shall be carefully scrutinised.

It is stressed that optimal chemical-resistant properties will only be achieved when due attention is paid to the use of appropriate materials and installation requirements.

3.2 CONCRETE CONSTRUCTIONS

3.2.1 General

Hydraulic cements used in concrete and mortars are described below and shall be in accordance with DEP 30.48.60.33-Gen.

The degree of chemical resistance of concrete based on these types of cement largely depends on the composition of the mix.

Only concrete of high density and proper selected composition may be expected to provide good resistance against alkalis, solvents, etc.

3.2.2 Concrete based on ordinary Portland cement

Ordinary Portland cement is generally used for concrete constructions, in mortars for ordinary brick laying and exposure to light alkaline conditions.

3.2.3 Concrete based on Portland blast furnace cement

For concrete and mortars exposed to a chloride environment (such as brackish and/or sea water) this type of cement should be considered.

3.2.4 Concrete based on sulphate-resisting Portland cement

Where concrete and mortars are exposed to sulphates, or traces of sulphuric acid up to 0.5% weight, and/or alkaline solutions up to about 12 pH, the use of this type of cement should be considered.

3.2.5 Concrete based on high-Alumina cement

This type of cement is slightly resistant to diluted acids. It has a poor resistance to alkaline solutions of a pH > 9.

High-Alumina cement is allowed only for non-structural applications, and requires approval of the Principal.

3.3 JOINTLESS FLOOR CONSTRUCTIONS

3.3.1 Synthetic resin-based systems

For exposure to mildly aggressive conditions or for temporary services, the use of jointless floors based on synthetic resin should be considered. See (6.1.1). The floors should be provided with a non-slip surface layer.

The following types of floors are commonly used:

- trowelling floor
- self-levelling floor

3.3.1.1 Trowelling floor

The trowelling floor should be applied in one layer with a thickness varying from 5-10 mm.

The trowelling compound has a high content of filler material. The ratio of binder to filler material is about 1:7.5 by weight. An optimum density of the trowelling layer can be obtained by grading the filler material.

Trowelling compounds have high compressive strength, excellent adhesion to a wide range of materials and resistance against corrosive agents.

3.3.1.2 Self-levelling floor

The self-levelling floor should be applied in one layer with a thickness varying from 2-4 mm. This type of floor has good chemical resistance but a low mechanical strength. Its surface can be made slip proof by scattering powdered quartz or Carborundum on the wet surface immediately after placement.

By adding filling materials in the ratio of binder to filling material of 1:2.5 by weight (but without adding solvents) a sufficiently self-levelling system can be obtained.

3.3.2 Epoxy paint systems

Epoxy paint systems may be applied where aggressive products are intermittently present, e.g. in trenches, concrete constructions in plants, chimneys, and on dry or wet floors where chemicals may be spilled.

Epoxy paint systems shall not be used for protection against continuous chemical attack, not even for mild aggressive conditions.

If concrete will be subjected to brackish or lightly contaminated water, an epoxy coal tar paint may be used. The dry film thickness shall be at least 400 microns.

3.3.3 Glass-or synthetic fibre-reinforced epoxy systems

For less severe chemical conditions, these systems may be considered as a possible substitute for brickwork or tiling.

The minimum thickness of such a system should be at least 4 mm.

When required, polyester resin may be used as an alternative to epoxy resin; selection of the type of resin and its reinforcement shall be made in consultation with the Principal.

3.4 CHEMICAL-RESISTANT BRICK LINING CONSTRUCTIONS

3.4.1 General

Chemical-resistant brick linings consist of bricks or tiles laid in mortar. They are part of a multi-layer system which generally consists of:

- concrete, providing rigidity and strength;
- an impervious membrane, to prevent the corrosive medium from reaching the concrete; and
- one or more layers of chemical-resistant bricks or tiles laid in a chemical-resistant mortar, mainly as a protective layer for the membrane (mechanical impact)

The chemical-resistant brick lining, including the membrane, primarily protects the concrete. It is necessary that each layer of brick, including every joint, is bonded to the next layer in order to form a composite construction with the concrete and the membrane. Great care shall be taken to avoid anything that might lead to failure of the bond between adjacent layers of brick or the complete lining and the concrete structure. Although bricks, tiles and mortars are to some extent permeable, the action of the corrosive medium within the porous material is hampered by the corrosion products formed within the pores, thus preventing further attack.

A chemical resistant brick lining is liable to crack formation due to the brittleness of the ceramic materials and the bonding strength between the cement and bricks or tiles. The difference in thermal expansion between the lining and the concrete substrate should therefore be taken into account.

Cracks in the brick lining will allow penetration of the corrosive agents/fluids through the lining, which will result in damage to the concrete if the membrane fails.

Tiles are generally applied to surfaces which are readily accessible and to floors which are not heavily loaded, otherwise bricks should be used.

Various types of mortar can be used for laying bricks or tiles, a summary of which is given in (4.4).

Standard Drawing S 19.050 shows a typical detail of chemical-resistant flooring.

3.4.2 Membranes

Membranes or protective intermediate layers between chemical-resistant brickwork and a reinforced concrete structure are of prime importance for the operation and service life of a brick lining. Membranes shall be continuous, liquid-tight and, in order to prevent damage to the joints in the chemical-resistant layer, shall be sufficiently flexible to allow for expansion and contraction induced by structural movements.

The chemical resistance of the various materials is given in DEP 30.10.02.13-Gen and DEP 30.48.60.33-Gen. A summary of the main requirements which are to be met by the various membrane materials is given in Appendix I. The materials used for membranes on concrete structures are dealt with in (4.2).

3.4.3 Expansion joints

3.4.3.1 General

Expansion joints are the weakest parts in chemical-resistant brickwork and tiling, and should therefore be installed outside the zones of chemical attack. When this cannot be avoided, they should be located in areas where the least possible chance of aggressive liquids permeating them exists, e.g. not at the lowest point of the drainage slope.

Standard Drawings S 19.051 and S 19.052 show typical details of sealing expansion joints.

3.4.3.2 Joints sealed with chemical/temperature resistant elastic sealing compound

This type of joint is the most suitable construction at locations subject to severe chemical attack.

At the expansion joint, the reinforced concrete shall have a 10 mm wide gap filled with a plastic joint filler.

The concrete fill applied on top of the concrete provides the required slope for drainage and shall have a gap at the same location and of the same width as the joint. The joint shall be sealed with a plastic sheet, adhesive-bonded to the concrete, and the gap shall be filled with a chemical/temperature resistant elastic sealing compound, based on mercaptans.

For details see Standard Drawings S 19.051 and S 19.052.

3.4.3.3 Joints filled with asphaltic bitumen

The construction shall be similar to that described above (3.4.3.2). However, in this case the joint is completely filled with Shell Cariphalte JS.

NOTE: Shell Cariphalte is a product of Shell Composites. See (1.1).

3.5 MISCELLANEOUS CONSTRUCTIONS

3.5.1 Floors

The floors shall have a slope of at least 1:50 for the discharge of rain water and spillage water, which can be best obtained by applying a concrete fill to the sub-floor.

Standard Drawings S 19.050 and S 19.055 show respectively the construction of a chemical-resistant floor and drain for the discharge of rain water and spillage water.

3.5.2 Trenches

Trenches exposed to chemical attack will normally be constructed of reinforced concrete, and shall be provided with a lining suitable for the respective chemical and thermal conditions.

Typical construction details of trenches are given in Standard Drawings S 19.060, S 19.062 and S 19.065.

The trench bottom should have a slope of 1:50 for drainage. A lesser slope may be considered for long trenches, but shall not be less than 1:200.

The slope may be obtained by the application of a concrete fill on the trench bottom.

The trench shall be wide enough to ensure that the acid-resistant tile or brick lining can be properly laid. The side walls shall be vertical.

When a trench is constructed in an acid-resistant floor, the membrane of both the floor and the trench shall be continuous.

3.5.3 Neutralization pits

3.5.3.1 General

Trenches discharging acidic liquids need a certain slope for drainage, therefore neutralization pits should be built as near as possible to the location where the acid is discharged, to keep the depth of the trench to a minimum.

Neutralization pits should normally be constructed of reinforced concrete, (3.5.5). They shall have vertical walls and may consist of a number of compartments.

For neutralizing the acidic effluents, neutralization pits may be filled with chalk (calcium carbonate), lime (calcium hydroxide), a lime slurry or a solution of sodium hydroxide.

The contents of chalk-filled compartments into which an acidic liquid flows will generally be acidic or neutral.

The contents of compartments filled with lime, sodium hydroxide solution or a lime slurry will normally be alkaline, but may become locally acidic, or completely acidic depending on the liquid to be neutralized.

3.5.4 Pump foundations

For chemical-resistant protection of reinforced concrete pump foundations, typical details are shown on Standard Drawing S 19.071.

The membrane of the floor and that of the pump foundation shall be continuous. The membrane shall also be continuous under the pump base.

Special care shall be taken where bolts penetrate the membrane construction.

3.5.5 Concrete vessels

During initial design, attention shall be paid to possible alternative construction materials, e.g. the use of steel for neutralization pits, sulphur-containing vessels, etc.

Design and acceptance of concrete vessels shall meet the requirements of DEP 34.19.20.31-Gen.

The concrete vessel shall be water tested to ensure liquid tightness before construction of the lining, and subsequently dried in accordance with (7.1).

3.5.6 Other concrete structures

Protection of concrete shall not be limited to floors, trenches, pits and pump foundations. Parts such as concrete columns, beams, table tops, pump rooms, chimneys, foundations, etc., may also be liable to chemical attack and need therefore a protective lining system at least up to the level where attack is anticipated.

4. CHEMICAL-RESISTANT LINING MATERIALS

4.1 GENERAL

Chemical-resistant lining materials shall comply with DEP 30.48.60.33-Gen. and DEP 30.10.02.13-Gen.

The various components forming a chemical-resistant lining are:

- membranes;
- chemical-resistant ceramics (bricks, tiles, etc.);
- mortars.

4.2 MEMBRANES

4.2.1 General

The following materials should be used as membranes for concrete structures:

- asphaltic bitumen
- thermoplastic materials
- thermosetting materials

For chemical resistance of various types of protective membranes refer to DEP 30.48.60.33-Gen. and DEP 30.10.02.13-Gen.

Acid-resisting brick lining for floors, and bottoms of pits (e.g. neutralization pits) and trenches, shall be provided with membranes which can sustain mechanical loads.

NOTE: Mechanical loads may be induced by, for instance:
- the use of high pressure cleaning equipment
- mechanical cleaning equipment
- mobile transport, equipment, etc.

4.2.2 Asphaltic bitumen membranes

The asphaltic bitumen used for the construction of membranes has good physical properties and fair resistance against mineral acids (except hydrofluoric acid and low concentrations of oxidizing acids).

Asphaltic bitumen is not resistant to oils, grease and solvents (except alcohols). It shall not be exposed to temperatures in excess of 60 °C.

The selection of the type of asphaltic membrane is determined by the loading expected on the floor.

Two types of membranes are considered:

- Membranes not subject to mechanical load consisting of a 6 mm dry film thickness layer, unfilled blown bitumen "Mexphalte" R 115/15.
- Membranes sustaining mechanical load consisting of a 20 mm dry film thickness layer, filled asphaltic bitumen "Mexphalte" 20/30.

NOTE: Mexphalte is a product of Shell Composites. See (1.1).

4.2.3 Thermoplastic membranes

Unless otherwise specified, only thermoplastic membranes based on polyisobutylene shall be used. Polyisobutylene sheet lining provides a good liquid tight membrane. It shall be adhesive-bonded to the substrate and the joints shall be sealed either by an adhesive or by welding; vulcanization is not required.

Polyisobutylene has only a fair resistance against hydrocarbon solvents.

The maximum allowable operating temperature is 70 °C.

The minimum required thickness is 5 mm.

When the use of proprietary systems is considered, approval from the Principal shall be obtained.

NOTE: Other thermoplastic membranes are generally too rigid to accommodate irregularities of the concrete substrate, unless they are used as "false formwork".

4.2.4 Thermosetting membranes

For specific chemical conditions a synthetic resin-based membrane shall be used. If necessary glass fibre reinforcement shall be applied.

An optimum chemical resistance may be obtained by selection of an appropriate synthetic-resin.

The temperature resistance during operation of glass fibre reinforced synthetic-resin systems is from -40 °C up to +150 °C.

The average thickness of this membrane should be 5 mm, with a minimum of 3 mm.

4.3 CHEMICAL-RESISTANT BRICKS

4.3.1 General

Bricks and tiles are manufactured to standard sizes which shall be used whenever possible to avoid additional costs.

Tiles used for floors, trenches and neutralization pits shall be at least 30 mm thick.

For walls in pump houses, etc. glazed, split tiles or similar shall be used. The minimum thickness of the tiles should be 20 mm.

Bricks and tiles shall have a roughened, non-glazed surface finish that optimises adhesion of the mortar at the sides to be embedded.

Some acid-resistant bricks have a low resistance against penetration of liquids and/or gases. They have a high thermal conductivity and thermal shock resistance. Porosity shall be considered, particularly in the case of crystallizing liquids, where a potential danger of crystal growth within the pores can occur, resulting in expansion and subsequent destruction of the brick.

Other bricks resist the penetration of liquids, but their thermal conductivity is low; hence, high thermal gradients within the brick can occur and subsequent temperature shock will lead to thermal spalling.

Erosion resistance of the bricks and tiles shall be considered, if required.

Mechanical and physical properties of various chemical-resistant lining materials are given in DEP 30.48.60.33-Gen.

4.3.2 Acid-resistant bricks and tiles

Bricks commonly used in a chemical-resistant brick lining are silica-alumina type acid-resistant bricks as specified in DEP 30.48.60.33-Gen.

4.3.3 Carbon bricks

Carbon bricks as specified in DEP 30.48.60.33-Gen. shall be used if hydrofluoric acid, or alkali solutions of >20% by weight, and/or alkalis at elevated temperatures (higher than room temperature) are present.

Carbon has a moderate thermal conductivity and is very hard. These properties make it an excellent material for corrosive and erosive services with high thermal loads. For these conditions unimpregnated carbon bricks may be used, relying on mortars and membrane to effectively protect the concrete.

4.4 MORTARS

4.4.1 General

Cements for mortars for chemical-resistant ceramic linings shall comply with

DEP 30.48.60.33-Gen.

4.4.2 Mortars based on hydraulic cements

Hydraulic mortars are generally used in building construction.

These mortars can be used as bedding mortar for tiles in mild aggressive conditions.

The mortar used as bedding mortar should normally have a cement/sand ratio of 1:3 by volume.

Furthermore, layers of these mortars, suitably proportioned, can be applied to structures to provide slopes for drainage.

4.4.3 Silicate-based mortars

Silicate-based mortars are commonly used for the construction of acid-resistant brick linings.

Silicate-based mortars are two component systems. They consist of a sodium, or potassium, silicate solution mixed with inert fillers, e.g. quartz flour. The mortar cures as silica is deposited from the alkali silicate solutions, a process which is accelerated by the presence of a catalyst, e.g. salts of fluosilicic acid or dimethylformamide.

When contact with sulphuric acid is expected, potassium silicate-based mortar is preferred to sodium silicate-based mortar (see Note 1).

Mild alkaline media can be tolerated at ambient temperature after careful "acidulation" of the mortar. Alternating acid and alkaline service, however, cannot be tolerated.

Silicate-based mortars have only slight resistance against erosion, especially from flowing hot water, steam or alkali. Washing out of mortar from the joints may occur. The use of other types of mortar, mainly synthetic resin-based, shall then be considered for jointing and laying the bricks.

A properly mixed fresh mortar reacts readily and cures even when air is excluded.

Silicate mortars do not adhere to rubber membranes.

NOTES:

1. Under these conditions the sodium sulphate, formed in the sodium silicate mortar, crystallizes with an increase in volume due to the release of crystallization water. Potassium sulphate, on the other hand, crystallizes without increase of volume.

2. Halogen-containing silicate-based mortars may, in contact with strong acids, produce hydrofluoric acid which would attack the substrate on direct contact with it. For such conditions, halogen-free silicate-based cements have been developed.

3. The porosity of silicate-based mortars, which is between 7 and 16% depending on the type, is a major disadvantage and therefore they shall not be used as a membrane.

4. Silicate-based mortar may be used as a bedding material, applied on an asphaltic bitumen membrane. The joints between brick and tiles should then be sealed with a synthetic resin-based mortar.

4.4.4 Synthetic resin-based mortars

Synthetic resin-based mortars are commonly used for the construction of acid-resistant brick linings. They cure as a result of a chemical reaction between the synthetic resin and a curing agent. They adhere very well to a rubber membrane.

4.4.4.1 Mortars based on phenol furfuraldehyde resin

These mortars consist of phenol formaldehyde resin and furane derivatives with an inert filler. They are supplied as two components, a liquid resin solution and an inert powder (both of which also contain part of the reactive agent), which shall be thoroughly mixed together.

Modified phenolic resin-based mortars have been developed to cover a wider range than pure phenol formaldehyde resin or furane resin mortars. These modified phenolic resin-based mortars provide excellent resistance against both acidic and alkaline conditions and have good resistance against mildly oxidizing solutions.

If resistance to hydrofluoric acid is required, graphite, not sand or barytes, shall be used as a filler.

Generally, for chemical resistance, curing should be done for one week at 15-20 °C. Mortars not fully cured can be damaged by moisture and free alkalis which tend to neutralize the acid catalyst.

The time lapse between application and curing shall be kept to an absolute minimum. In order to give the mortar its full chemical resistance (in particular to caustic alkalis) the cement requires a heat treatment at 80 °C for 24 hours after it has fully cured.

The operating temperature limit of these mortars is 140 °C.

These mortars, when properly applied, are erosion resistant and free of pores. They can be used both as a membrane and for embedding and sealing the joints between bricks or tiles.

4.4.4.2 Mortars based on furane resin

In general the properties of furane resin-based mortar resemble those of the mortars based on phenol resin, but curing at high temperatures is not required to obtain full chemical resistance.

They are supplied as two components (a powder and a liquid) which give the mortar excellent adhesive qualities when mixed correctly. The liquid cures to a hard solid resin on addition of suitable catalysts. The mortar cures at 15-20 °C in about 3 days. Optimum chemical resistance can be obtained by heating at 80 °C for at least 16 hours after application.

The furane resin-based mortars have a good chemical resistance. If a filler such as graphite is added, resistance against hydrofluoric acid is also obtained.

Furane resin-based mortars are erosion resistant and free of pores when properly applied.

The operating temperature limit of furane resin cement is approximately 140 °C.

4.4.4.3 Mortars based on polyester resin

Mortars based on (unsaturated) polyester resin are supplied in two or more components, i.e. liquid resin, catalyst, accelerator, filler, etc., which shall be mixed together. These mortars have a good chemical and erosion resistance.

The addition of inert fillers such as graphite to the mortar extend its resistance even to hydrofluoric acid and its resistance against alkalis increases.

The operating temperature limit of polyester resin-based mortars is 120 °C.

4.4.4.4 Mortars based on epoxy resin

Mortars based on epoxy resin are supplied in two or more components. Curing starts immediately after mixing and the rate of curing is influenced by the ambient temperature.

Various formulations will have different properties, according to the different curing agents used. The curing agent generally used is a cold-curing type, which limits the maximum operating temperature but facilitates processing. In tropical conditions a hot-curing type is recommended due to its prolonged pot life.

Epoxy resin-based mortars have very good chemical resistance. If a filler such as graphite is added, resistance to hydrofluoric acid is also obtained. An outstanding characteristic of epoxy resin-based mortars is their very good adhesion. For application on concrete substrate no pre-treatment, other than proper surface cleaning, is necessary.

The temperature limit of epoxy resin-based mortars is 90 °C.

The mortar can be used for continuous floors and for embedding and sealing purposes.

5. HANDLING AND STORAGE OF LINING MATERIALS

Bricks and tiles shall be carefully handled, unloaded and stacked by hand or by using brick tongs.

They shall be stored and protected from extreme weather conditions and exposure to sun or frost.

The individual constituents of mortars shall be stored and used in accordance with the Manufacturer's instructions. The shelf life of the materials indicated by the Manufacturer shall be carefully observed. Materials which have been stored for a period longer than six months shall be subjected to new quality control tests and a test report shall be required before using them.

Hydraulic cements stored longer than three months shall have their suitability checked by determination of the setting time.

Cements of different brands shall not be mixed; labels indicating the name, quality and quantity of the contents shall not be removed.

In cold climates materials may freeze and must be thawed before use by means of storing in a warm place.

Skin contact with synthetic resin-based materials shall be avoided. They may also produce stains on clothing. Applicators shall therefore observe strict personal hygiene and care when handling these materials in the uncured liquid state.

Skin contact should be prevented by using rubber gloves and barrier creams, and any accidentally contaminated skin areas should be thoroughly washed with soap and water or, if necessary, the Manufacturer's special instructions shall be followed. Subsequent rubbing of the skin with lanolin-containing creams may be beneficial.

Additional recommendations for handling of these materials, e.g. ventilation requirements when using in confined areas, shall be provided by the Manufacturer.

6. LINING SELECTION

6.1 FLOORS

6.1.1 General

For the selection of chemical resistant membranes reference is made to DEP 30.10.02.13-Gen. and DEP 30.48.60.33-Gen.

Chemical-resistant floors can be subdivided as follows:

- floors without continuous chemical attack
- acid-resistant floors
- acid- and alkali-resistant floors
- acid- and/or alkali-resistant and solvent-resistant floors
- floors for mildly to moderately aggressive conditions

6.1.2 Floors without continuous chemical contact

Concrete floors without a finish layer can produce considerable dust when they are dry. Moreover, they are vulnerable to incidental spillage of e.g. oils, fat and various chemicals. For such conditions an epoxy paint system should be used (3.3.2).

6.1.3 Acid-resistant floors

Floors for acid service only and not exposed to traces of alkali, steam or hot water shall be provided with a layer of bricks or tiles, which are laid in silicate cement-based bedding mortar on the selected membrane. The thickness of the mortar layer should be 3-5 mm.

When the mortar has cured, after about 4 days, an acidification treatment is essential, see (7.5.3).

6.1.4 Acid- and alkali-resistant floors

Floors exposed to alkali or alkaline solutions, and to acids, shall be provided with acid-resistant bricks or tiles, which shall be laid in synthetic resin-based mortar on the selected membrane.

6.1.5 Acid- and/or alkali-resistant and solvent-resistant floors

Thermoplastic materials, if resistant against the specified solvents, may be used.

Generally a mortar based on polyester or epoxy resin, or a mortar of the same base material as used for laying the bricks or tiles, shall be applied as the membrane.

6.1.6 Floors for mild aggressive conditions

For exposure to mild aggressive conditions or for temporary service, two methods of protection are recommended:

- a layer of bricks or tiles which are embedded in a hydraulic mortar and joined with a synthetic resin-based mortar, or
- a jointless floor based on synthetic resin (3.3)

6.2 TRENCHES

6.2.1 General

Chemical-resistant trenches can be subdivided as follows:

- trenches without continuous chemical attack
- acid-resistant trenches
- acid- and alkali-resistant trenches
- acid- and/or alkali-resistant and solvent resistant trenches

6.2.2 Trenches without continuous chemical contact

Drains, sewer systems, pits, etc., are often attacked by chemical products present in the waste water. For this condition a trowelling compound (3.3.1.1) or an epoxy paint system (3.3.2) should be applied.

6.2.3 Acid-resistant trenches

Trenches for acid service only, and not exposed to traces of alkali, steam or hot water, shall be provided with a layer of acid-resistant bricks or tiles. They shall be laid in silicate mortar on the membrane, as described for acid resistant floors, see (6.1.3).

6.2.4 Acid- and alkali-resistant trenches

Trenches exposed to alkali, alkaline solutions or acids shall be provided with acid-resistant bricks or tiles, which shall be laid in synthetic resin-based mortar on the membrane, as described for acid- and alkali-resistant floors, see (6.1.4).

6.2.5 Acid- and/or alkali-resistant and solvent-resistant trenches

For trenches designed for transport of corrosive effluents containing petrochemical solvents, the recommendations as laid down in (6.1.5) shall be followed.

6.3 NEUTRALIZATION PITS

6.3.1 General

Deep pits should be lined with acid-resistant bricks instead of tiles because of mechanical impact due to filling of the compartments or removal of the fill and scraping for cleaning during maintenance.

Acid-resistant bricks shall also be used for:

- partition walls
- lining of compartments to be filled with chalk or lime, because tiles may be damaged when the compartments are scraped out.

For selection of the membrane, see (4.2).

6.3.2 Compartments to be filled with chalk

The contents of these compartments will generally be acidic or neutral.

The acid-resistant bricks shall therefore be laid in silicate mortar on the selected membrane. See (4.4.3).

6.3.3 Other compartments

The contents of compartments are normally alkaline but may become locally or completely acidic, depending on the nature of the liquid to be neutralized.

The acid-resistant bricks shall therefore be laid in synthetic resin-based mortar on the selected membrane. See (4.4.4).

When the contents of a trench leading to a neutralization pit are expected to occasionally become alkaline, the bricks in the neutralization pit (including the compartments to be filled with chalk) shall be laid in synthetic resin-based mortar. See (4.4.4).

NOTE: If the contents of a neutralization pit may become contaminated with petrochemical solvents, the directions given in (6.1.5) shall be followed.

6.4 PUMP FOUNDATIONS

The sides and top of the pump foundation shall be protected by the same lining as the floor on which it is placed.

Acid-resistant bricks or tiles shall be applied to the pump foundation membrane, as described for chemical-resistant floors in (6.1).

For pump foundations exposed to petrochemical solvents, the directions given in (6.1.5) shall be followed.

If the floor is provided with a trowelling compound, the pump foundations shall have the sides and top protected with the same material and construction.

On the top of the foundation the trowelling compound shall have a liquid-tight joint with the grouting of the pump.

If the floor is painted (3.3.2), the whole pump foundation shall be treated with the same paint system.

6.5 CONCRETE VESSELS

The lining shall be selected in accordance with the previous sections of this DEP, for the corrosiveness of the fluid to be contained.

6.6 OTHER CONCRETE STRUCTURES

Concrete columns, beams, table tops, pump rooms, chimneys, foundations, etc. liable to chemical attack, may have to be provided with a lining system.

Generally, the application of an epoxy paint system (3.3.2) is sufficient. For underground concrete constructions an epoxy coal tar paint should be used (3.3.2).

7. LINING INSTALLATION

7.1 SURFACE PREPARATION

Before the lining is installed the concrete structure shall be inspected for cracks and other surface defects. The structure shall be free from cracks wider than 0.3 mm and surface defects (for instance fins, air holes, honeycombs, etc.). All such cracks and defects shall be repaired in consultation with the Principal.

In liquid retaining structures, cracks wider than 0.20 mm shall be repaired with synthetic resin injection.

Small defects, up to a depth of approximately 50 mm, shall be sealed with a quartz-filled epoxy mortar (composition 75% by volume quartz and 25% by volume resin). Larger repairs shall be carried out with non-shrink cement-based mortars.

The surface of the repaired defects shall be smooth and flush with the surrounding surfaces. The final surfaces shall be smooth and even without any sharp edges. Walls and floor shall not bulge inwards, as this could cause the brick lining to break away as a result of uneven expansion during operation.

Concrete which has already been damaged by chemical products shall be neutralized or if necessary removed to sound concrete and renewed. This repair shall be carried out in consultation with the Principal.

Prior to the application of any lining system, the concrete surface shall be prepared to avoid air inclusions and to ensure sound attachment of the lining. The concrete substrate shall be freed from cement skin, loose sand, dust, laminate, oil, grease or other contaminants by means of blast cleaning.

For already used or dirty concrete floors, the preparation shall be carried out by first completely wetting with water, then etching with a diluted hydrochloric acid (5-10% by weight), then neutralizing with a dilute ammonia solution (approx. 15% by weight), and then washing the floor with an excess of water. If the concrete floor contains cracks, an acid treatment shall not be performed because it may cause corrosion of the steel reinforcement. Alternatively the surface may be prepared by means of grinding the concrete until a sound and clean surface has been reached.

If required, the concrete surface shall be made level by an appropriate cement/sand mortar 1:3 (by volume). Slopes are made by applying a concrete fill to the sub-floor of at least 25 mm thickness or a cement/sand mortar of at least 2.5 mm thickness. Before these layers are applied the concrete shall be pre-treated, e.g. with an appropriate cement-rich mortar slurry.

The moisture content of the concrete surface (approximately 15 mm deep) shall not exceed 4% by volume. Generally, this may be reached after 28 days' hardening and drying. The moisture content of the substrate shall be checked regularly during installation of the lining. Measuring equipment, which shall be calibrated, and the method of establishing moisture content shall be approved by the Principal.

7.2 EXPANSION JOINTS

The expansion joint provided in the reinforced concrete structure (3.4.3) shall be filled with semi-rigid polyurethane foam, insulation cord, or other appropriate material. Concrete fill shall be applied on top of the concrete to provide the required slope for drainage and shall have a gap at the same location, and of the same width, as the joint.

The joint shall be sealed with a plastic, e.g. polyisobutylene foil (e.g. Rhepanol type ORG, 3 mm thick) or other suitable material.

NOTE: Rhepanol is a product of Steuler Industriewerke GmbH. See (1.1).

The foil shall be installed as shown in Standard Drawing S 19.051, and adhesive-bonded to the substrate; the adhesive should be of a bituminous or rubber type. The membrane and a layer of bricks or tiles shall then be applied, keeping the joint open.

The joint shall then be cleaned and filled with a chemical/ temperature resistant elastic sealing compound.

7.3 MEMBRANES

7.3.1 General

Prior to the application of a membrane or a coat of primer, concrete shall be at least 28 days old, after which it shall be repaired (if required), cleaned and dried in accordance with (7.1).

Additional treatment of the concrete surface is required for furane resin-based mortars, see (7.5.5).

The membranes shall be clean, free from dust, oil, grease or other contaminants.

7.3.2 Asphaltic bitumen membranes

Membranes of asphaltic bitumen shall be applied to a surface primed with Shell Pipe Primer.

NOTE: Shell Pipe Primer is a product of Shell Composites. See (1.1).

The surface of the membrane shall be sanded for good adhesion of the subsequent mortar layer, e.g. by brushing with a solution of bitumen and spreading quartz sand (0.7-1.2 mm grain size) onto the bitumen coating whilst it is still tacky.

The asphaltic bitumen shall be spread by 'squeegees' or brush until it is smooth, even and free from irregularities. For pump foundations, the membrane shall be applied before the pump base plate is installed. The surface of the membrane shall be sanded as mentioned above.

7.3.3 Thermoplastic membranes

Before the membrane is adhesive bonded to the concrete surface, the latter shall be prepared in accordance with the Manufacturer's instructions. A primer shall be applied to the concrete surface if required.

The membrane shall not be applied at substrate or ambient temperatures below 5 °C.

7.3.4 Thermosetting membranes

The cement skin of the concrete surface shall be removed by means of grit blasting and the surface shall be freed from grit and loose debris.

The cleaned/rough surface shall be given an epoxy resin-based primer, and then within 24 hours the epoxy resin, and the glass fibre reinforcement (if any) shall be applied to the specified thickness.

An epoxy membrane shall not be applied during rain if the surface is not suitably protected, or at substrate/atmospheric temperatures below 10 °C.

7.4 BRICKS AND TILES

Bricks and tiles shall be clean and dry and should have a temperature of at least 15 °C on application.

If a brick lining has to be applied in winter, provisions shall be taken to protect the area from cold, rain, snow, etc.

For narrow joints the bricks or tiles should fit correctly, which requires that they shall be selected at site with regard to their squareness and dimensions.

Vertical parts should be lined before horizontal parts.

Acid-resistant bricks or tiles shall be applied to pump foundations before the bricks or tiles are laid on the adjoining floors.

7.5 MORTARS

7.5.1 General

The mortar shall be mixed in accordance with the Manufacturer's instructions. The tools and mixer shall be clean and dry. Specific constituents to be used for mixing a certain type of mortar shall never be mixed with constituents for other type of mortars.

Mortars shall not be applied under freezing conditions.

As the setting time of most resin-based mortars is influenced by atmospheric conditions, special attention should be paid to the Manufacturer's instructions.

7.5.2 Mortars based on hydraulic cements

Layers of these mortars, applied to provide slopes, shall be kept wet during curing (for about one week) to obtain optimum strength and to avoid hairline cracks.

Hydraulic cement supplied in paper bags should be used within 8 hours of opening the bag.

7.5.3 Mortars based on silicate cement

The mortar supplied in two components, a liquid and a powder, shall be thoroughly mixed and used immediately.

The mixture has a certain pot-life, i.e. time during which it can be readily used. To avoid using mortar which has already started to cure, the quantity mixed should be limited.

On completion of the lining, "acidulation" of the brick lining is required as the alkali hydroxide formed during curing is detrimental to the joint and would eventually destroy it.

Four days after application, the brickwork shall be washed with dilute acid, e.g. a 10% wt solution of hydrochloric acid.

7.5.4 Mortars based on phenol furfuraldelhyde resin

The mortar supplied in two components, a liquid and a powder, shall be thoroughly mixed and used immediately.

The mixture has a certain pot-life, i.e. time during which it can be readily used. To avoid using mortar which has already started to cure, the quantity mixed should be limited.

The rate of setting and curing of the mortar is influenced by temperature. In general at 15-20 °C the mortar starts to set in about four hours and cures in 1-2 days. This also depends on the catalyst used. At a lower temperature the mortar starts to set and cure at a lower rate.

Generally, for optimum chemical resistance, curing should be done for one week at the above temperatures.

If the temperature falls below 15 °C, consideration may be given to accelerate the curing by heating, e.g. 16 hours minimum at 80 °C. However, care should be taken to ensure that the temperature does not exceed 80 °C, as the difference in expansion between tile, substrate and the top surface may adversely affect adhesion.

Contact with water and/or water vapour during curing shall be avoided. The heating should therefore be carried out by means of electric heaters.

It is essential that during the curing the mortar does not come into contact with free alkali, since this alkali would tend to neutralize the acid catalyst. Consequently the concrete floor shall be primed with two coats of a suitable primer when these mortars are used as a membrane. The primer shall be in accordance with the Manufacturer's recommendations.

7.5.5 Mortars based on furane resin

Furane resin-based mortar cannot be applied directly to concrete surfaces. When a membrane of this mortar has to be applied, the concrete shall be pre-treated with a primer in accordance with the Manufacturers instructions.

The precautions which have to be taken as regards pot-life and mixing are identical with those for phenol-based mortars.

For application of these mortars the same rules apply as for the application of cements based on phenol furfuraldehyde resin (7.5.4).

7.5.6 Mortars based on polyester resin

The components, in the form of a powder and a liquid resin, shall be mixed immediately before use. They are self-curing at 15-20 °C; a complete cure at this temperature can be obtained in 24 hours. For optimum chemical resistance a longer curing period is recommended. The curing time and pot-life are affected by temperature.

Contact with water or water vapour shall be avoided during curing.

7.5.7 Mortars based on epoxy resin

These mortars are generally supplied as a paste of putty-like consistency, together with a liquid curing agent.

After the two components have been mixed the mortar cures within one hour at temperatures of 10-30 °C. The curing time is affected by temperature.

Contact with water or water vapour shall be avoided during curing.

7.6 JOINTING BRICKS AND TILES

The mortar layer between the bricks or tiles and the membrane should have a thickness of about 5 mm. The width of joints between bricks or tiles shall be between 3 and 5 mm. However, the width shall be between 5 and 8 mm for certain hot pour jointing materials or if the joints require sealing. When re-jointing may be required after a period of service, the joint shall be made at least 5 mm wide.

The width of the joints shall be consistent over the full depth of the joint and the filling free from cavities.

7.7 JOINTLESS FLOORS

7.7.1 General

Concrete floors to be provided with jointless flooring shall have an even, smooth surface, prepared in accordance with (7.1) and shall be at least 6 weeks old prior to application of the flooring.

To obtain good adhesion between the flooring and the concrete, the latter shall be sealed with one or more coats of an unfilled solventless resin primer. In general the unfilled liquid component of the flooring compound is used as a primer.

7.7.2 Application of the trowelling floor

The floor shall be applied in accordance with the Manufacturer's instructions.

The trowelling floor shall be applied "wet in wet" until the specified thickness has been obtained.

The surface of the trowelling layer may be compacted by the use of mechanical equipment.

7.7.3 Application of the self-levelling floor

The floor shall be applied in accordance with the Manufacturer's instructions.

The application can be carried out by casting or spraying to the specified thickness.

In order to make the floor slip proof (if required), sand or powdered quartz shall be scattered on at the moment of gelling of the flooring, so that sagging into the material will not occur.

7.7.4 Application of a glass fibre reinforced epoxy resin

After preparation of the concrete surface, an epoxy primer consisting of a mixture of resin and curing agent shall be sprayed or brushed onto the concrete.

Subsequently various layers of glass fibre or synthetic fibre reinforcement, impregnated with epoxy resin, shall be applied until the specified thickness has been obtained.

7.7.5 Application of an epoxy paint system

The concrete should be lightly grit blasted and made dust free.

The surface shall be levelled (if required) using an epoxy filling system.

The epoxy paint shall be applied to a clean and dry concrete surface by means of a brush, roller or spraying equipment.

The system shall consist of an epoxy primer and two or more coats of high-build epoxy paint or epoxy coal tar paint, applied to a total dry film thickness of at least 400 micron. The application of the paint to the concrete shall be in accordance with the Manufacturer's instructions.

8. INSPECTION

Prior to the application of lining systems concrete vessels, sumps, pits etc., shall be water tested to ensure liquid tightness in accordance with DEP 34.19.20.31-Gen.

Before the application of a membrane, the concrete surface should be inspected for cleanliness, dryness and defects, see (7.1).

The specified slope, if any, shall be checked and approved by the Principal.

A summary of the main requirements for membranes is given in Appendix I.

During application of the membrane inspection shall be carried out and due attention should be paid to the following points:

- sufficient adhesive shall be applied
- the membrane shall be applied without air inclusions or other visible defects.

Brick lining shall not start until the applied membrane has been inspected and accepted by the Principal.

Upon completion the brick lining shall be inspected for the following conditions:

- general appearance of the brick lining
- the specified dimensions of the joint
- the execution of the jointing.

Until brick linings are fully cured, they shall be protected against mechanical abuse, welding activities, scaffolding, etc., and detrimental weather effects, for example cold, heat and rain.

9. MAINTENANCE AND REPAIR

Chemical-resistant linings shall be regularly inspected for defects. They shall be carefully treated and protected against damage by mechanical loads, impact and impermissible local chemical and thermal attack (steam, leaking flanges, etc.).

NOTE: When a defect is detected, repairs shall be carried out immediately in order to prevent serious attack of the concrete substrate.

The main defects are spalling of the bricks or tiles, erosion effects, cracks in the lining and degradation of the chemical-resistant lining materials.

Spalling of the brick lining may be due to:

- inadequate brick quality; e.g. composition, porosity
- exposure to exceptional operating conditions; e.g. thermal, chemical or other loads more severe than those foreseen
- local spalling may be due to impact by a falling object.

Damaged areas or spots shall be opened up to sound material and shall be repaired by replacement with new material, either of the original quality or of another quality, providing the latter is fully compatible with the adjacent original material with respect to physical and chemical properties.

If the effects of erosion or attack by chemicals are slight, the joints can be repaired, by means of scraping out to sound material and filling with fresh mortar. If the depth of the scraped out joint is 75% or more of the thickness of the brick layer, all the cement in the joint shall be removed and replaced. If necessary the bricks shall be re-laid.

When cracks in the lining are present, they shall be opened completely to establish the condition of the membrane and/or the substrate. Care shall be taken not to extend the damage because of removal of the effected parts.

Degradation of the lining materials may indicate an excessive chemical attack. The chemical conditions causing the degradation shall be established and appropriate countermeasures shall be taken.

If defects other than those described above are found, the cause of these other defects should be determined and the construction reviewed to avoid further attack of the concrete construction.

For repair a sufficient number of bricks shall be taken out to restore the brick lining configuration.

10. REFERENCES

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

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

SHELL STANDARDS

DEPs:

Index to DEP publications and standard specifications	DEP 00.00.05.05-Gen.
Index to standard drawings	DEP 00.00.06.06-Gen.
Non-metallic materials selection and application	DEP 30.10.02.13-Gen.
Design and installation of rubber-lined process equipment, piping and concrete structures	DEP 30.48.60.10-Gen.
Requirements for rubber linings for process equipment and piping	DEP 30.48.60.30-Gen.
Requirements for chemical-resistant (ceramic) lining materials	DEP 30.48.60.33-Gen.
Reinforced concrete foundations and structures	DEP 34.19.20.31-Gen.

STANDARD DRAWINGS

NOTE: The latest edition of each drawing can be found in DEP 00.00.06.06-Gen.

Flooring	S 19.050
Detail of expansion joint in floors	S 19.051
Detail of expansion joint between floor and wall	S 19.052
Drain construction in floors	S 19.055
Trench construction with Gres split tiles and Gres components	S 19.060
Trench construction with Gres split tiles and half Gres pipe elements (Fodder trough)	S 19.062
Open trench construction lined with bricks or tiles	S 19.065
Detail of foundation	S 19.071

APPENDIX 1 SUMMARY OF THE MAIN REQUIREMENTS FOR MEMBRANES

Property	Test method/criteria	Membrane material	
		Asphaltic bitumen (4.2.2)	Plastics (4.2.3/4.2.4)
Surface condition	Visual examination. No surface defects.	x	x
Adhesion	Check by careful knocking. No lack of adhesion.	x	x
Porosity	Visual examination. No porosity.	x	x
Thickness 1)	Physical measurement.	x	x
Curing	No softening after 1 minute rubbing with acetone.		x 2)

NOTES:

1. Depending on the type of membrane, thickness measurement may be done before or after application. Layer thickness meters are unsuitable for use on concrete substrates, so only physical measurements shall be made if measured after application.

2. Applies only to glass fibre reinforced epoxy resin-based membranes.