

DESIGN AND INSTALLATION OF CHEMICAL-RESISTANT LININGS FOR CONCRETE STRUCTURES

DEP 30.48.60.12-Gen.

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DESIGN AND ENGINEERING PRACTICE



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1. INTRODUCTION

1.1 SCOPE

This DEP specifies requirements and gives recommendations for the design, installation, testing and inspection of chemical-resistant linings for concrete structures used in the petroleum, chemical and gas industries.

This DEP is a revision of the DEP of the same number dated May 1993 and has incorporated DEP 30.48.60.33-Gen., which is now withdrawn. A summary of the main changes since the previous edition of this DEP is given in (1.5).

Excluded from the scope of this DEP are rubber linings, for which reference is made to DEP 30.48.60.10-Gen., and (acid-resistant) refractory bricks and shapes, for which reference is made to DEP 44.24.90.31-Gen. Chemical-resistant linings for process equipment are covered by DEP 30.48.60.13-Gen. Painting and coating systems are covered by DEP 30.48.00.31-Gen.

This DEP principally covers ceramic types of lining materials (e.g. bricks, tiles and mortars) and their underlying membranes, but also non-ceramic linings such as synthetic-resin-based systems.

Chemical-resistant ceramic linings are used to protect concrete elements (such as floors and gutters) against chemical attack. A combination of a ceramic lining and a membrane is mostly used for this purpose. The membrane is designed to prevent penetration of chemicals to the underlying concrete surface. The ceramic lining serves to protect the membrane against chemical, mechanical and/or thermal loads (e.g. scaffolding, steam cleaning).

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

The specified properties shall be tested in accordance with internationally accepted standards, or local standards if they exist. For convenience, specific standards are mentioned in various cases.

For a further comparison of the chemical resistance between the materials, reference is made to DEP 30.10.02.13-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

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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

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, authorised to act for the Principal.

The word **shall** indicates a requirement.

The word **should** indicates a recommendation.

1.4 CROSS-REFERENCES

Where cross-references to other parts of this DEP are made, the referenced section number is shown in brackets. Other documents referenced in this DEP are listed in (11).

1.5 SUMMARY OF MAIN CHANGES SINCE PREVIOUS EDITION

The previous edition of this DEP was dated May 1993. This edition was made primarily to incorporate the contents of DEP 30.48.60.33-Gen., which is now withdrawn. There have been no significant technical changes in this edition.

2. SELECTION CRITERIA FOR CHEMICAL-RESISTANT LININGS

2.1 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. Because the concrete has a relatively high open porosity and concrete surfaces become increasingly permeable over time, attack on the underlying reinforcement becomes a major risk as well.

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.

Structural and other steels not only have limited resistance against chemical loads, but are often susceptible to various systems of stress corrosion cracking or embrittlement. Under specific conditions special steels can be used for use with chemicals.

A chemical-resistant lining will, in general, consist of at least two lines of defence, i.e. a membrane and a chemical-resistant 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.

Less expensive solutions, consisting of one or more layers of a synthetic-resin-based system, either with or without a reinforcement, or full plastic-sheet membranes which are mostly proprietary systems, can be applied but should be justified as well.

Where possible, 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.).

For an initial selection of a chemical-resistant lining Table 2-1 may be used as guidance. For further and/or detailed comparisons or selections reference is made to DEP 30.10.02.13-Gen.

Chemical-resistant lining materials shall comply with Appendix 1 and DEP 30.10.02.13-Gen.

2.2 SELECTION CRITERIA

The need for a chemical-resistant protection and the selection of the type of protection required for the envisaged duty shall be based on:

- Service/operating conditions or environment
 - of prime importance are the nature, composition and temperature of the chemicals against which a construction shall be protected. Exact knowledge is required of the behaviour of these chemicals and the materials for which protection is required;
- Existing (mechanical as well as chemical) load
 - taking into account not only the present situation but also any future changes, thereby avoiding expensive alterations;
- Condition of construction/installation

- this often has a decisive influence on the costs. Each material or construction requires greatly differing working conditions, e.g. temperature, dryness, ventilation, material-specific required sequences, etc.;
- Economics
 - the most economical lining is the one which is adequately resistant to the loads that arise and is quickly and cheaply applied, thus being likely to achieve the desired service life;
- Service life
 - it is economically not justifiable to select protections which will outlive the constructions they must protect. Sometimes it may be better to use a simple, inexpensive application, even one requiring minor repairs, rather than more reliable and sophisticated but costly applications;
- Selection results
 - besides the above criteria, thorough consideration should be given to specific site and operational conditions, and the required safety margins within which operations and/or the effectiveness of the protection can vary;
- Types of chemical-resistant material
 - in general terms as low, medium (normal) and high protection, or as types (in ascending order), e.g. impregnation, sealing, coatings, fillers, synthetic resin screeds, tiles in various types of mortars, including possible combinations.

Table 2-1: Comparison of the chemical resistance of various materials at 20 °C

	Water			Ammonia liquid 25%	Hydrochloric acid 35%	Sulphuric acid 98%	Nitric acid 25%	Hydrofluoric acid 50%	Alkalis	Sulphates	Chlorides	Other salts	Hydrocarbons			Mineral oils	Alcohols	Ketones	Phenols	Esters
	Sea	Brackish	Potable										Chlorinated	Aromatic	Aliphatic					
Concrete based on: Portland cement	-	(+)	+	+	-	-	-	-	+	-	-	-	+	+	+	+	+	+	-	(+)
Portland blast-furnace cement	+	+	+	+	-	-	-	-	+	-	(+)	(+)	+	+	+	+	+	+	-	(+)
High-alumina cement	+	+	+	+	-	-	-	-	+	+	(+)	+	+	+	+	+	+	+	-	(+)
Sulphate resisting Portland cement	+	+	+	+	-	-	-	-	+	+	(+)	+	+	+	+	+	+	+	-	(+)
Protective membranes: Asphaltic bitumen	+	+	+	+	+	+	-	+1]	(+)	+	+	+	-	-	-	-	+	-	-	-
Poly-isobutylene sheet	+	+	+	+	+	(+)	+	+	+	+	+	+	-	-	+	-	+	(+)	-	-
Cold-cured epoxy	+	+	+	+	+	-	+	+1]	+	+	+	+	+	+	+	+	+	-	-	+
Mortar/coating based on: Phenol-furfuraldehyde resin	+	+	+	+	+	+	-	+1]	(+)	+	+	+	+	+	+	+	+	+	+	+
Phenol-formaldehyde resin	+	+	+	+	+	-	-	+1]	+	+	+	+	+	+	+	+	+	+	+	+
Furane resin	+	+	+	+	+	-	-	+1]	+	+	+	+	+	+	+	+	+	+	+	+
Epoxy resin	+	+	+	+	+	-	(+)	-	+	+	+	+	-	+	+	+	+	(+)	-	+
Polyester resin	+	+	+	+	+	-	(+)	(+)	(+)	+	+	+	(+)	+	+	+	+	(+)	-	+
Sodium silicate ^{2]}	-	-	-	-	+	(+)	+	-	-	(+)	+	(+)	+	+	+	+	+	+	+	+
Potassium silicate ^{2]}	-	-	-	-	+	+	+	-	-	+	(+)	(+)	+	+	+	+	+	+	+	+

+ Resistant (+) Resistant to a limited extent - Not resistant

- NOTES:
1. The filler shall also be resistant.
 2. Has a porosity of 7 - 16% and should never be used as a membrane.
 3. Sodium and potassium silicate cements are not resistant to ammonium fluoride and sodium bicarbonate.

Although concrete has a certain degree of chemical resistance (4.2) it should be treated as a substrate to be protected. The selection of the type of concrete shall be primarily based on structural considerations, with its chemical resistance as a 'bonus'.

3. CHEMICAL-RESISTANT LINING MATERIALS

3.1 MEMBRANES

3.1.1 General

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

- asphaltic bitumen;
- thermoplastic materials;
- thermosetting materials.

Acid-resisting brick lining for floors, and bottoms of pits (e.g. neutralisation pits) or vessels 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.

3.1.2 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 oxidising acids).

Asphaltic bitumen is not resistant to oils, grease and solvents (except alcohols). Generally 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.

3.1.3 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 fusion welding; vulcanisation is not required.

Polyisobutylene only has a fair resistance against hydrocarbon solvents.

NOTE: Thermoplastic membranes are generally too rigid to accommodate irregularities of the concrete substrate, unless they are used as "false form work".

3.1.4 Thermosetting membranes

For specific chemical conditions a synthetic resin-based membrane shall be used (with or without a fibre reinforcement).

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

3.2 CEMENTS AND MORTARS

3.2.1 Mortars based on hydraulic cements

Hydraulic mortars are generally used in building construction.

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

Furthermore, layers of these mortars can be applied to structures to provide slopes for drainage. However, layers shall be suitably proportioned to reduce the risk of possible delamination or spalling. It should be good practice to incorporate the required slope or level already in the finished structural concrete or equipment.

3.2.2 Silicate-based mortars

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

If contact with sulphuric acid is expected, potassium silicate-based mortar is preferred to sodium silicate-based mortar (see notes).

- NOTES:
1. Under these conditions the sodium sulphate, formed in the sodium silicate mortar, crystallises with an increase in volume due to the release of crystallisation water. Potassium sulphate, on the other hand, crystallises without increase of volume.
 2. Halogen-containing silicate-based mortars may, in contact with strong acids, produce hydrofluoric acid which would attack the substrate in 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.

Mildly 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. During reaction and curing the mortar remains soluble and shall be protected against rain or other possible 'wash-out' by water.

Silicate mortars do not adhere to rubber membranes.

3.2.3 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.

The main types are filled phenolic, furane, polyester and/or epoxy-resin-based cements.

Phenolic-resin-based 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. The modified phenolic-resin-based mortars provide excellent resistance against both acidic and alkaline conditions and have good resistance against mildly oxidising solutions.

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

Polyester-resin-based mortars have good chemical and erosion resistance.

Epoxy-resin-based mortars can be used for continuous floors and for embedding and sealing purposes. An outstanding characteristic of epoxy-resin-based mortars is their very good adhesion. For their application on a concrete substrate no pre-treatment other than proper surface cleaning is necessary.

3.3 CHEMICAL-RESISTANT BRICKS AND TILES

3.3.1 General

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

Tiles used for floors, trenches and neutralisation 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 or split dove-tailed grooves that optimise adhesion of the mortar at the faces to be embedded.

Some acid-resistant bricks have low resistance against penetration of liquids and/or gases, as against high thermal conductivity and consequently often good thermal shock resistance. Attention shall be paid to their open porosity particularly if crystallising liquids may be present 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, in conjunction with low thermal conductivity (closed porosity); 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 Appendix 1.

3.3.2 Acid-resistant bricks and tiles

Bricks commonly used in a chemical-resistant brick lining are silica-alumina type acid-resistant bricks as specified in Appendix 1.

3.3.3 Carbon bricks

Carbon bricks as specified in Appendix 1 shall be used for the following:

- if hydrofluoric acid is present;
- alkali solutions with a mass fraction greater than 0.2;
- alkali solutions at temperatures above 20 °C.

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 non-impregnated carbon bricks may be used, relying on mortars and membrane to protect the concrete effectively.

3.3.4 Special ceramic materials

The use of these special ceramic materials, as specified in Appendix 1, are in principle allowed but the Manufacturer/Supplier shall prove evidence of the "long term" reliability of such systems to the Principal.

4. LINING, COATING SELECTION AND DESIGN

4.1 GENERAL

Chemical-resistant linings for concrete structures shall be designed and installed by a qualified and experienced engineering contractor 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 a chemical-resistant lining has to be applied at a later stage, due to a change in requirements or the extension of an installation, the concrete structure or equipment shall be recalculated for the additional loads and/or the thermo-mechanical stresses.

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 maximum attention is paid to the use of appropriate materials and installation requirements.

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.

4.2 NON-LINED CONCRETE SYSTEMS

4.2.1 General

For the design and construction of reinforced concrete structures reference is made to DEP 34.19.20.31-Gen.

Hydraulic cements used in concrete and mortars as described below shall be in accordance with Appendix 1.

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.

4.2.2 Concrete based on normal Portland cement

Normal Portland cement is generally used for concrete constructions, in mortars for ordinary brick laying and if the concrete is exposed to mildly alkaline conditions.

4.2.3 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.

4.2.4 Concrete based on sulphate-resisting Portland cement

Where concrete and mortars are exposed to sulphates, or traces of sulphuric acid up to 0.5% by weight, and/or alkaline solutions up to about pH =12, the use of this type of cement should be considered. Reference is also made to DEP 34.19.20.31-Gen., Appendix 1 tables 2 and 3.

4.2.5 Concrete based on High-Alumina cement

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

High-alumina cement may be used only for non-structural applications, and requires the approval of the Principal.

4.3 JOINTLESS (FLOOR) PROTECTION SYSTEMS

4.3.1 General

Although the following descriptions mainly relate to application on floors, they can also be applicable to adjacent walls, corbels, foundation blocks, columns, etc., which are subject to the same chemical loads.

Chemical-resistant floors can be subdivided as follows:

- Floors without continuous chemical attack
Concrete constructions, e.g. 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 lining system, optionally fibre-reinforced, should be used (4.3.3 and 4.3.4).
- 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 (6.4.3).
- Acid-resistant 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.
- Acid-resistant, alkali-resistant and solvent-resistant floors
Thermoplastic materials, if resistant against the specified solvents, may be used.
Generally a mortar based on polyester, vinyl-ester 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.
- Floors for mildly to moderately aggressive conditions
For exposure to mildly 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.

NOTE: Laboratory floors should be included as well.

Jointless systems shall be continuous, liquid-tight and resistant to the chemicals to which they may become exposed.

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

Figure 4-1: Typical construction of flooring

