MONOLITHIC LININGS & COATINGS FOR SECONDARY CONTAINMENT STRUCTURES

by

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Over the last ten years, under the Resource Conservation and Recovery Act (RCRA), the Environmental Protection Agency's regulations on the storage and treatment of hazardous waste in tank systems have led to major changes and improvements in the use of concrete for vessels and other structures. Since the use of concrete for secondary containment is one of the key elements of the EPA's proposed strategy, the need for improved products and methods to repair, seal, and protect concrete from a widening variety of chemicals has increased significantly.

This article will review recently-developed products and repair methods designed to address the growing range of hazardous materials and chemical wastes, temperatures, and environmental effects which can reduce the ability of concrete structures to maintain positive containment. Particular attention will be paid to concentrated sulfuric acid, caustic, and other acids and chemicals commonly encountered in the chemical process, power, pulp & paper, and other industries.

Before addressing the topic of protecting and sealing concrete structures, it is pertinent to discuss some of the problems commonly encountered when using concrete as a building material, as well as some of the design and repair techniques for dealing with common causes of its deterioration.

Concrete Design Standards/References

With the increasing focus on the design and use of concrete for secondary containment systems, many owners, architects, engineers and contractors have had to become more familiar with the American Concrete Institute's "Recommended Practice for Concrete Floors and Slab Construction" (ACI 302), the standard document of floors. A voluminous collection of reprint articles which deal with many topics related to the use of concrete as a building material have also been published as "Problem Clinic" articles by Concrete Construction magazine[1] and other concrete construction trade journals.

In addition to the increased awareness of good concrete floor and structures construction practice, more attention is being focused on the use of impervious linings or coatings to minimize leaks. Leak detection equipment or methods for below grade sumps or trench systems may also be employed to reduce seepage.

Troubleshooting Concrete Repair Problems

This article will not attempt to review the myriad of classifications of concrete damage or deterioration. They are already thoroughly covered in the ACI's "Recommended Practice" and a variety of reprint articles. A veritable arsenal of repair materials and techniques have been developed for dealing with all types of concrete damage or deterioration. In fact, there are so many rehabilitation methods available that concrete structures have the unique distinction of rarely being "beyond repair."

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[1] A collection of articles reprinted from Concrete Construction have appeared in the following publications: Concrete Floor Construction, Troubleshooting Concrete Flatwork and Paving Problems, Repair of Concrete, Concrete Repair Techniques.

Sometimes, the cause of deterioration is readily apparent. More frequently, however, it is not, and determining the cause of a particular problem may require a skilled specialist and/or an in-depth examination.

A number of the common problems with secondary containment structures and neutralization basins that must be protected against hazardous materials or aggressive chemicals that severely attack concrete are highlighted below:

Bug Holes and Honeycomb: These are air pockets, either visible or invisible, directly beneath the surface of the concrete. Correct preparation involves shotblasting or sandblasting the surface to open up those "bug holes" that are not completely visible and enlarging those that are so they can be filled prior to installation of the protective coating or lining. The fill material must be compatible with the protective system which is to be installed.

A number of latex-modified portland cement compositions are available for use with certain light-duty linings; however, they require a somewhat extended cure time prior to topcoating. For heavy-duty linings, a combination of the resin normally used with the lining system and a thixotropic filler is preferable, applying the compound with a trowel to fill the holes. This filling procedure is particularly important in two situations:

1. It is good practice to fill the bug holes where the protection is provided by a relatively thin film coating of 30-40 mils or less. The cavities below the thin film coating are potential fracture sites, especially as the size of the cavity increases.

2. When the lining/coating must be applied in the direct sunlight without the use of a covering for shade.

In either case, bug holes which are not completely filled will trap pockets of air. This entraped air will expand when warmed by the sun or other means, forming bubbles or pinholes in the protective system, and can lead to lining failure.

Cracks in Concrete - Active or Dormant: The causes of cracks in large concrete structures include poor structural design, overloading, excessive shrinkage, alkali-aggregate expansion and low strength concrete.

The pattern of the cracking, its location, the depth and width of the cracks, the presence of foreign material on the cracked surfaces and differences in elevation between two contiguous cracked concrete masses are factors that help determine the causes of crack formation.

In most cases, cracks must be considered active when their cause cannot be determined. Cracks that appear and continue to develop after the concrete has hardened are also considered active.

Cracking can be considered dormant when it is caused by a factor that is not expected to occur again. This category includes plastic cracks, cracks resulting from temporary overloading (such as from the movement of a piece of machinery over a slab), and random cracks caused by improper timing of concrete sawing operation. A dormant crack usually can be permanently repaired after the full extent of cracking has occurred.

Large concrete containment structures have been known to crack, usually before the lining has been installed, but often after the lining is in place. The cracks open and close during temperature changes, thus straining or cracking the lining.

Concrete Repair Techniques

Some of the techniques and methods that have been used successfully to repair cracks in concrete structures include:

Epoxy injection grouting - This method of repairing cracks by injection grouting of an epoxy resin, as shown in Figure #1, is described by R.W. Gaul/E.D.Smith[2] and by William H. Kuenning. Prior to installation of the coating or lining, this method can

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[2] R. W. Gaul and E. D. Smith, "Effective and Practical Structural Repair of Cracked Concrete," American Concrete Institute Publication SP-21, "Epoxies with Concrete".

be successful for repairing cracks, provided the cracks are non-moving. If the cracking is from settling or loading that can continue to stress the structure, cracks may reoccur elsewhere.

Routing and sealing - As illustrated in Figure #2, the crack is routed out to a groove 1 inch in depth by at least 1/2 inch in width for the length of the crack. The lining is applied into the groove and the remaining space filled with a flexible sealant. This technique can be successful only as long as the sealant resists the elements and chemicals.

Fiberglass cloth tape - Narrow, short cracks in areas with little temperature variation can usually be covered with a layer of fiberglass cloth tape before lining. This method is shown in Figure #3.

Elastomeric "slip sheet" - This method, illustrated in Figure #4, is used in concrete vessels and concrete neutralization basins involving immersion service conditions. Large cracks or joints in the structure that are expected to move are bridged with fiberglass that is disbonded over an elastomeric strip, one or two inches on each side of the crack and then lined as shown in Figure #5 . This method provides two basic functions: a) It reduces the stress-straining of the lining when cracks or joints in the concrete structure open and close during temperature changes, and b) it eliminates exposure of the joint sealant to immersion service conditions. Figure #6 shows an installation of a monolithic reinforced lining with the elastomeric expansion joint beneath the lining system.

Water Leaks

It is often difficult to stop water from flowing or seeping through concrete into a concrete vessel or structure. One method that has been used successfully is to groove out the wet area to a depth of an inch or more and then fill the groove with a very fast hardening cement.

For stubborn leaks, it may be necessary to drill a well or excavate and pump water until the wall dries. After the lining has been properly bonded to the dry concrete, it should hold back water pressure.

Other important factors to consider during the design, construction or rehabilitation of concrete containment structures that will have protective coatings or linings are:

Vapor barriers - Although vapor barriers are not always required for slabs on grade or below grade, thick asphalt vapor barriers and other materials are effective in preventing moisture from migrating through a slab. These vapor barriers must be lapped and sealed and carried over the edge of the footings (see Figure #7).

A barrier beneath an existing slab to be repaired may influence the type of repair product and lining system to be used. If a significant amount of water is trapped in the concrete, it could cause problems during or after application of the lining. This concern with water entrapment is why general industry standards call for a minimum of 28 days curing of new concrete prior to lining.

Drainage bed - Correctly designed floors should be placed on a bed of gravel or sand, rather than directly on soil, particularly clay. This minimizes the capillary flow of water from the soil through the concrete.

Existing slab conditions - Concrete exposed to caustic soda or other chemicals while in service may be saturated, contaminating the soil underneath the slab. Moisture passing through the slab by capillary action may carry contaminants with it to a prepared surface. Evaluation of previous service and core drill tests on an existing contaminated slab may indicate the concrete should be replaced.

Old concrete may present a variety of surfaces, ranging from a smooth, dense finish to a rough surface with a considerable amount of exposed aggregate. The concrete also may be contaminated with oils, grease, tar, or other chemicals. Figure #8 shows severe degradation of concrete from spillage of 98% sulfuric acid around chemical pumps. Figure

#9 shows the same area after the concrete was repaired and a reinforced lining system resistant to concentrated acid was installed.

The importance of good construction practice in the design, preparation, and repair of concrete cannot be emphasized too heavily. Quality concrete and substrate condition are critical to the successful application and performance of protective coatings and linings in concrete secondary containment structures.

Selecting coatings and linings for waste containment

It would be impossible to cover all the protective coating and lining systems available for varying environments; consequently, this discussion will be limited to products that protect against substances that severely attack or disintegrate concrete. Examples of these aggressive substances include acid sulphate, sulfuric acid, hydrofluoric acid, sulfates of ammonia, and sulfurous acid.

In selecting a coating or lining system for a specific environment, the most important consideration is its chemical resistance. Selection is simplified if field history reports of previous exposures in similar environments are available. If information pertaining to field service is non-existent, the specifier must rely on field or laboratory testing.

One of the most difficult tasks for any corrosion engineer or end user is the proper selection of a lining for exposure and protection against combinations of chemicals. Some examples are:

- Exposure to combinations of highly concentrated acids and alkalies, such as 98% sulfuric acid and 50% sodium hydroxide. In this case, sulfuric acid and sodium hydroxide are on opposite ends of the pH range, so coatings or linings which protect against one of these chemicals may not be resistant to the other.

- Exposure to combinations of acids and organic solvents. The concern here is with potential organic separation phase and exposure of the coating or lining system to pure organic chemistry.

- Exposure to combinations of chemicals and other substances such as hydrofluoric acid, fluoride salts, and strong alkalies that attack glass and other silica fillers used in coating and lining products.

Field testing, or exposure to the actual environment, is most effective for applications involving exposure to combinations of chemicals because it takes into consideration all of the variances which may exist. Organic separation phase and exposure of products to pure organic chemistry is difficult to evaluate through laboratory testing. A classic example is failure of rubber sheet linings used for lining concentrated hydrochloric acid storage tanks or process vessels when the acid is contaminated or contains only a few hundred parts per million of organic solvents. Rubber sheet linings are subject to attack, softening, swelling, and undercutting when exposed to organic solvents.

A very high percentage of chemical exposures in containment and water treatment applications can be handled by polyester, vinyl ester, epoxy or novolac epoxy resins.

Table I provides a brief list of common definitions on thermosetting resin coating and lining systems. *Table II* provides a listing of the types of polyester, vinyl ester, and epoxy resin-based coating and lining systems used for protection against aggressive chemical service. These protective systems are classified by type of construction and film thickness -- heavy duty reinforced linings, light duty linings/thick film coatings, and thin film protective coatings.

In situations where two different coating/lining systems both appear to offer successful protection, a selection can often be made after considering the effects of the corrosion rate of the solution being contained, temperature, traffic or abrasion, other service conditions, and the desired service life of the material. For example, if a system looks successful at a film thickness of 15-40 mils, but the corrosion rate is excessive, the preferred system would be a heavy duty system for the long term, even though the other is more economical in the short term.

A detailed review of the classification of heavy duty lining systems listed in *Table II* is described by R.B. Washburn, M.J. Galloway, and W.R. Slama[3] and P. R. Nan and B.S. Fultz[4]. This overview discusses many of the considerations involved in the selection of products based on cost-performance economics and new product developments related to the protection of secondary containment structures in harsh environments.

Table III compares the estimated relative costs of both materials and installation (labor) for various floor systems that have been used as coatings and linings for concrete containment structures as classified in *Table II*.

Product selection and costs are based on projected performance and service life when exposed to varying chemical and physical conditions, ranging from very hostile environments (A-B) to light duty service (E).

The following are examples of product selections and projected performance service based on case histories and cost-performance economics related to the protection of containment and other concrete structures:

- For years, acid-proof brick construction with membrane and chemical-resistant mortar was the only proven and acceptable method for protecting concrete exposed to spillage of concentrated sulfuric acid. As the cost of acid-proof brick construction has risen, resin technology has improved, and more people have become aware of the benefits of monolithic (seamless or jointless) construction, the use of heavy-duty glass cloth reinforced trowel linings for protection against intermittent spillage of concentrated (93-98%) sulfuric acid has increased. These

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[3] R. B. Washburn, M. J. Galloway, and W. R. Slama, "Reinforced, Chemical-Resistant, Thermoset Linings," October 1985 issue of the SSPC Journal of Protective Coatings and Linings.

[4] P. R. Nan and B. S. Fultz, "Coatings and Linings for Secondary Chemical Containment in Power Plants," October 1990, Volume 7, No. 10, SSPC Journal of Protective Coatings and Linings.

monolithic heavy duty reinforced linings also offer the benefit of resistance to concentrated sodium hydroxide (caustic). As *Table III* indicates, the heavy duty reinforced systems cost half as much for material and installation labor as acid-proof brick. Acid proof brick construction is still the best choice for chemical process areas and other applications involving high temperature immersion (200°F or over) and severe mechanical conditions.

Service performance histories of monolithic heavy duty reinforced linings range from 10 to more than 20 years in hostile environments with aggressive substances such as sulfuric, nitric and hydrochloric acids, and other chemicals that rapidly attack unprotected concrete.

- Spray-applied thick film reinforced coating systems (30-60 mils) provide good resistance to fairly strong chemicals in continuous immersion (up to 150°F) or spillage conditions. These products provide the advantages of lower installed costs and ease of repair. As indicated in *Table II*, they are often used for protection of walls in conjunction with lining of trench and collection sumps in concrete containment structures with heavy duty reinforced lining systems.

New Product Developments

One of the most promising product developments in the past five to seven years is the use of new multi-functional epoxy formulations which incorporate a Novolac clycloaliphatic amine adduct curing agent. The development and resistance of this new epoxy resin/curing system to concentrated sulfuric acids is described by V. Brytus and J.S. Puglisi[5]. The Flakeline 2000 protective coating system, developed by Master Builders Technologies, ECCP Division, Master Builders, Inc. is a good example of these new formulations. This spray-applied, flake filled, high build (40 mils DFT) system uses the high cross-link density multi-functional Novolac resin/curing technology. It resists a full range of sulfuric acid from 5.3% to 98% in both immersion and spillage service. It also

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[5] V. Brytus and J. S. Puglisi, "Epoxy Resin Systems for FGD Units," Paper Number 307, NACE CORROSION/84, New Orleans, La.

provides excellent resistance to oleum, hydrochloric acid, phosphoric acid, and concentrated sodium hydroxide (caustic).

Novolac resin/curing technology has found wide acceptance in high performance coating systems for structures exposed to spillage of concentrated sulfuric acid, caustic and other chemicals widely used by the chemical processing, pulp and paper, power, and other industries. This acceptance should keep growing as these systems continue to prove their performance and durability in actual use. Field applications and service performance histories on the Flakeline 2000 system, for example, range up to five years.

Summary

Coating concrete successfully demands attention to many details of design, surface preparation, repair, application and inspection. The long-term performance of coatings and linings is directly related to the condition and the degree of surface preparation of the concrete. The better the concrete and its surface preparation, the better the bond will be between the protective system and the concrete.

The wide range of monolithic coating and lining systems available today means there are very few environments in secondary containment and chemical waste disposal that cannot be protected. These systems offer excellent performance histories in a host of waste containment and chemical processing applications.

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Biographical Note:

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TABLE I
DEFINITIONS

Film Thickness -- Thin Film: 5-15 Mils; Thick Film: 40-60 Mils; Heavy Duty: 125-160+ Mils.

Lining -- Briefly stated, linings for immersion service are mixtures of liquid thermosetting resins and inert fillers, usually reinforced with flake fillers, glass or synthetic fibers. The mixtures are applied by trowel or spray to a vessel or concrete tank at a thickness of 30 mils or more to protect the vessel or tank from corrosion or the contents from contamination.

Thermosetting Resin -- A synthetic resin used for these purposes in liquid form which hardens at normal temperatures, after addition of a catalyst or curing agent. After hardening, it will not melt.

Reinforcement -- Materials used to lend strength to the resin of the lining system.

Filler -- Materials used in powder form which are chemically stable or inert. These materials are added to the resin to reduce thermal expansion, stress concentration, permeability, build thickness and aid in application.

Curing Agent -- A chemical which either initiates the polymerization of a thermosetting resin or enters into a cross-linking reaction with the resin to solidify it.

TABLE II
MAJOR COATING AND LINING CLASSIFICATIONS

	Heavy Duty Reinforced Linings	Light Duty Linings/Heavy Duty Coatings	Thin Film Protective Coatings
Type of Construction: Reinforcement and Resin	Glass cloth or mat reinforced polyester, vinyl ester or epoxy resin	Flake filled thick film coatings with or without mat reinforced polyester, vinyl ester or epoxy resin	Unreinforced epoxy, vinyl, urethane and other thin film coatings
Methods of Application	Trowel	Spray, brush, roller	Spray, brush, roller
Thickness Range	1/8" to 3/16"	30 - 60 mils DFT without mat reinforcement layer	10 - 15+ mils DFT
Reason for Selection	1. Aggressive chemistry 2. Abrasion 3. Temperature	1. Moderate to light chemistry 2. Temperature	1. Very mild chemistry 2. Atmospheric - fumes
Typical Uses	1. Interior vessel lining 2. Harsh spillage 3. Heavy duty traffic or abrasion 4. Secondary chemical containment	1. Interior coating of vessels - mild immersion 2. Mild to aggressive spillage 3. Light duty floor traffic 4. Secondary chemical containment	1. Exterior of tanks/vessels 2. Wall protection above splash/spillage zone 3. Structural steel coating in corrosive fume service 4. Secondary containment - diesel fuel and other non-aggressive materials

Notes:

1. Carbon-filled and graphite flake filled formulations are available in the above heavy duty and light duty systems for applications requiring resistance to hydrofluoric acid, fluoride salts, and strong alkalies.

2. Heavy duty reinforced lining products are characterized by resistance to hostile environments and the capacity to withstand varying physical impositions.

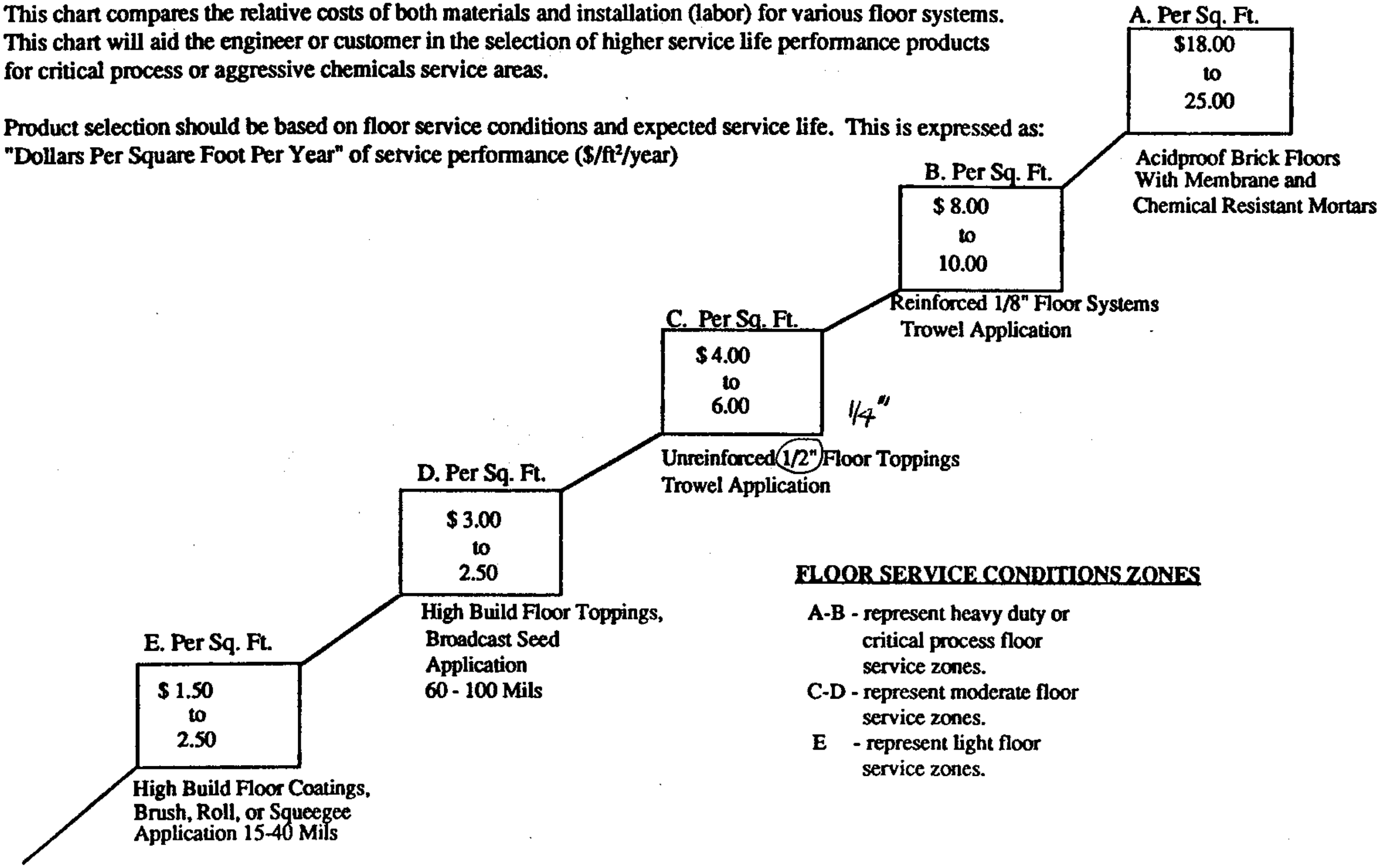
3. Combinations of the above products/systems can be utilized for protection of secondary chemical containment structures, i.e., use of heavy duty reinforced systems for lining floor, trench, collection sump, and splash zone of walls combined with the use of light duty linings/thick film or thin film coatings for upper walls.

Table III

RELATIVE INSTALLED UNIT COSTS (LABOR & MATERIALS) OF FLOOR SYSTEMS - March 1991

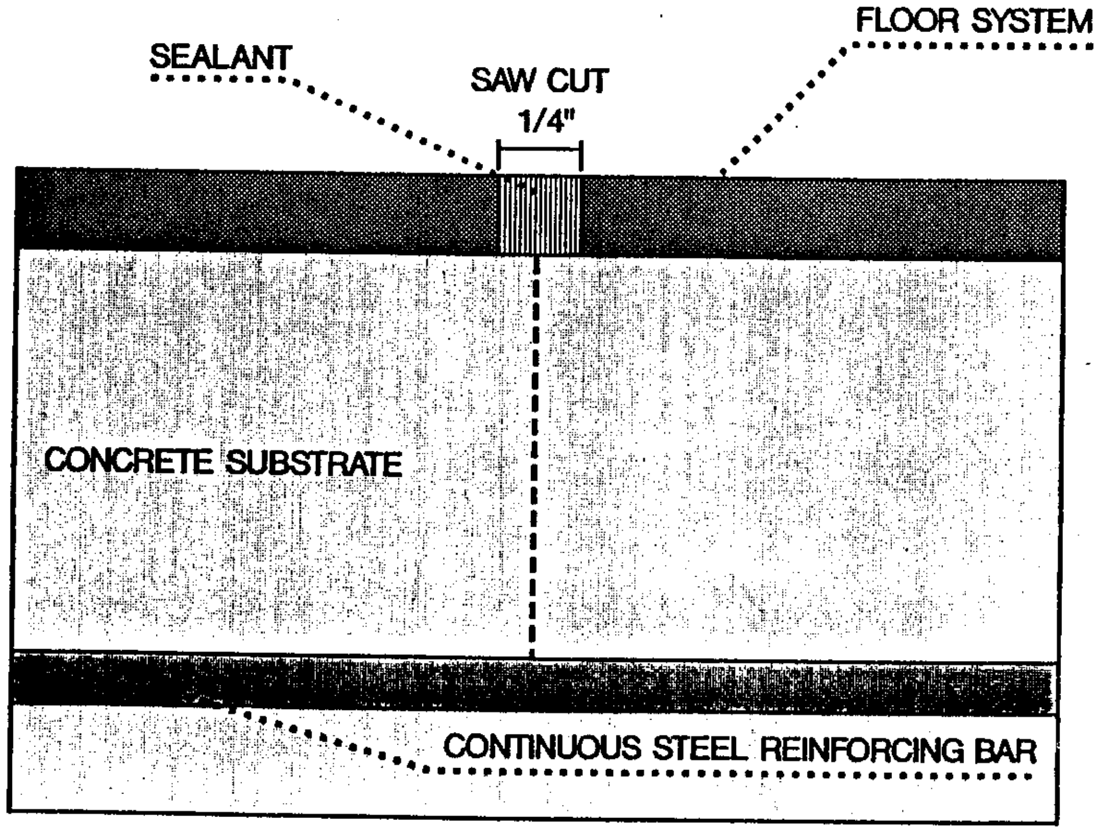
This chart compares the relative costs of both materials and installation (labor) for various floor systems. This chart will aid the engineer or customer in the selection of higher service life performance products for critical process or aggressive chemicals service areas.

Product selection should be based on floor service conditions and expected service life. This is expressed as: "Dollars Per Square Foot Per Year" of service performance ($/ft²/year)

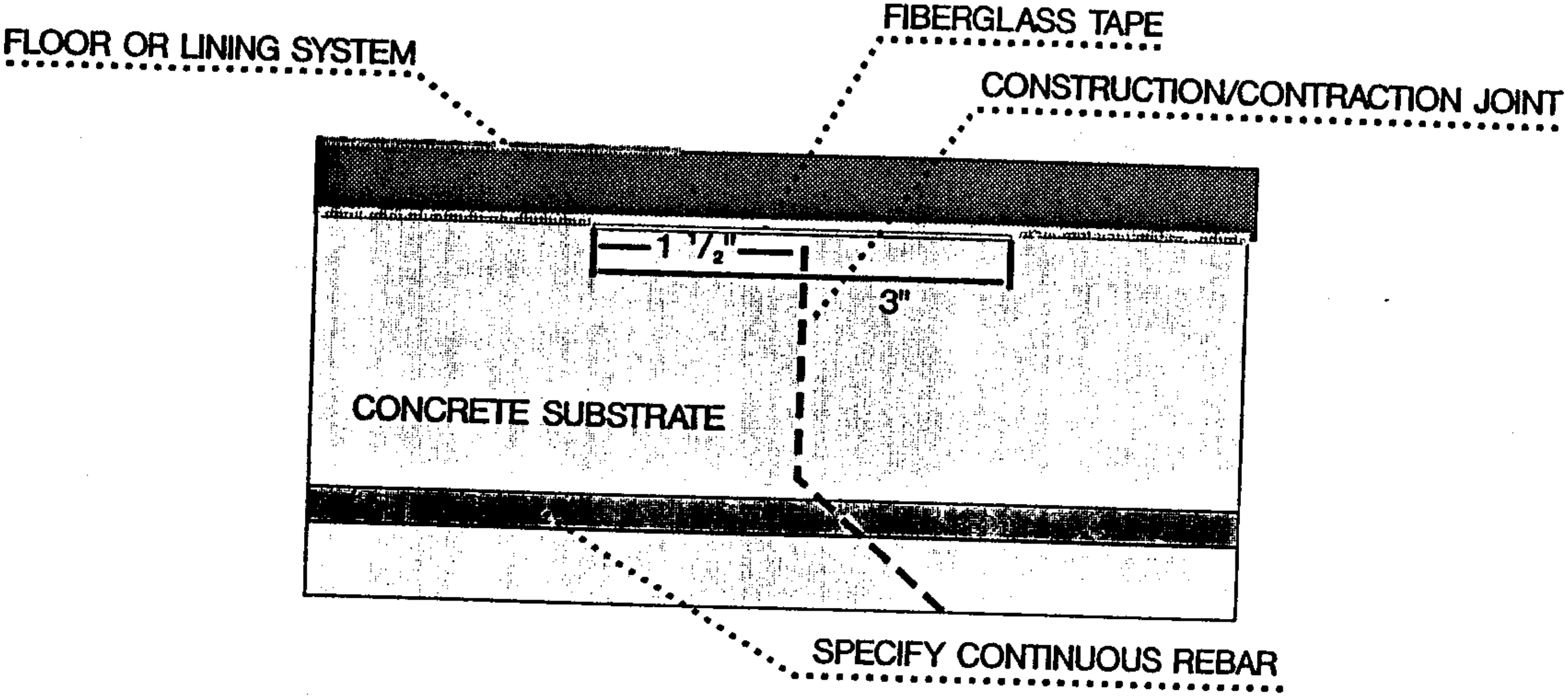


FLOOR SERVICE CONDITIONS ZONES

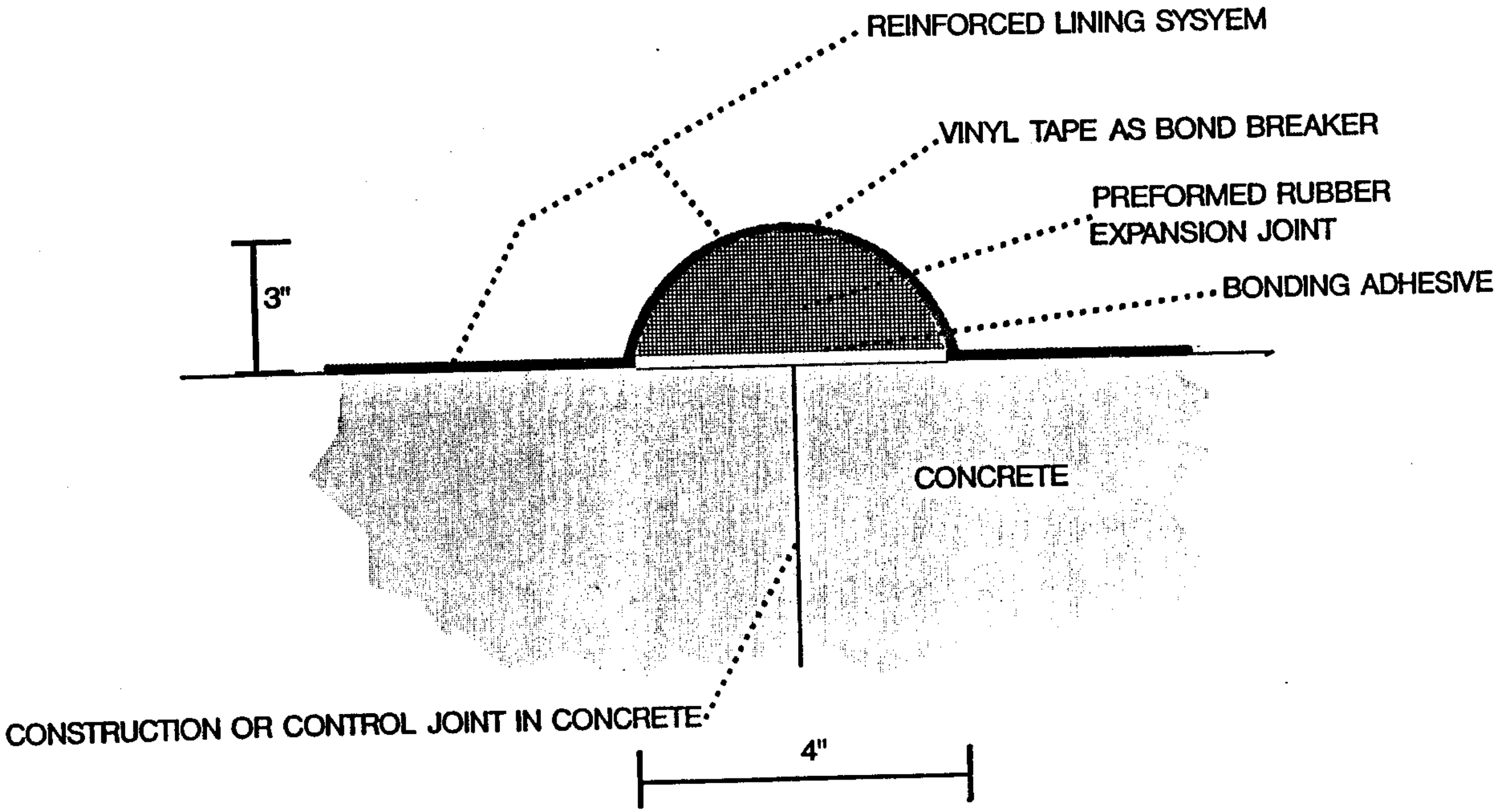
A-B - represent heavy duty or critical process floor service zones.
C-D - represent moderate floor service zones.
E - represent light floor service zones.


SEALANT
SAW CUT
1/4"
FLOOR SYSTEM
CONCRETE SUBSTRATE
CONTINUOUS STEEL REINFORCING BAR

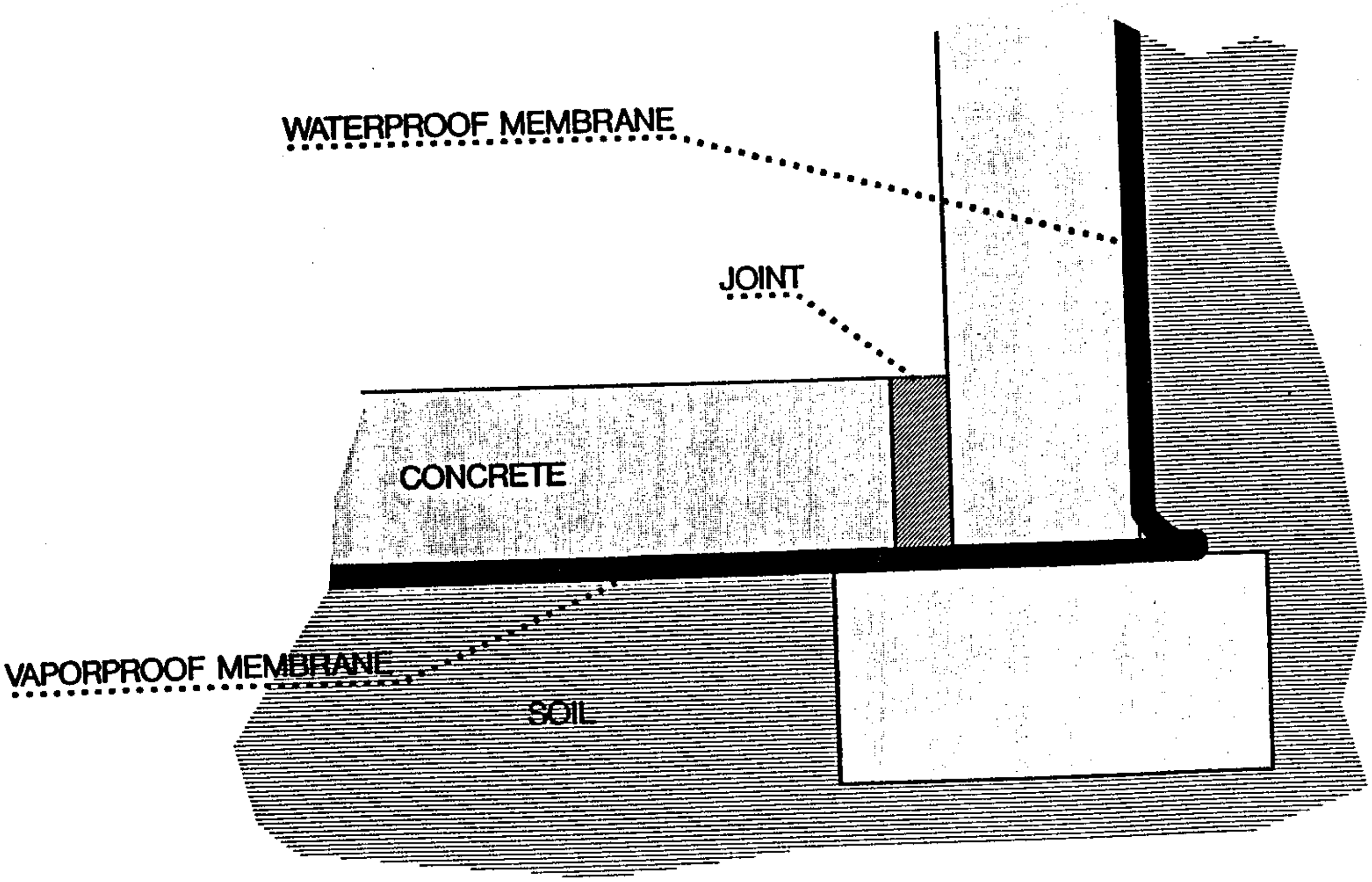
(FIGURE 2)


FLOOR OR LINING SYSTEM
FIBERGLASS TAPE
CONSTRUCTION/CONTRACTION JOINT
1 ½"
3"
CONCRETE SUBSTRATE
SPECIFY CONTINUOUS REBAR

(FIGURE 3)


REINFORCED LINING SYSYEM
VINYL TAPE AS BOND BREAKER
PREFORMED RUBBER EXPANSION JOINT
BONDING ADHESIVE
3"
CONCRETE
CONSTRUCTION OR CONTROL JOINT IN CONCRETE
4"

(FIGURE 4)


WATERPROOF MEMBRANE
JOINT
CONCRETE
VAPORPROOF MEMBRANE
SOIL

(FIGURE 7)