PORTLAND CEMENT ASSOCIATION

Concrete Floors on Ground

Second Edition

PREFACE TO THE SECOND EDITION

This second edition of *Concrete Floors on Ground* continues Portland Cement Association's tradition of providing the concrete user with information on the latest in concrete technology and its application at the jobsite.

Although the fundamentals of good floor design and construction practice do not change, reader responses and queries following publication of the first edition called for clarification and additions to the text so that new concrete floors continue to improve in serviceability and economy. This second edition includes supplemental information on—

Safety factors	Joints and joint spacing
Effective contact areas	Filling joints
Unjointed slabs	Reinforcement
Uncommon storage conditions	Finishes for slabs

New sections have been added on—

Load transfer across joints	Doweled control joints

The publication is intended for owners, architects engineers, contractors, and any others who share the responsibility for floor performance in industrial and commercial buildings.

Caution: Avoid prolonged contact between unhardened (wet) cement or concrete mixtures and skin surfaces. To prevent such contact, it is advisable to wear protective clothing. Skin areas that have been exposed to wet cement or concrete, either directly or through saturated clothing, should be thoroughly washed with water.

Cover: Ride-on triple trowel. Photograph courtesy of the Master Consolidated Corporation.

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Concrete Floors on Ground

INTRODUCTION

Large-area concrete floors for commercial and industrial buildings must be designed and constructed with the greatest possible economy to give trouble-free service year after year. The building of a good concrete floor requires close communication between owner, architect, engineer, and contractor—with a mutual understanding of the level of quality needed for its intended use.

Many erroneous notions have developed over the years as to how the rules of good concrete practice affect the serviceability of floors on ground. They have brought more complaints about poor performance of floors than any other part of a building. Advice is rarely sought before design or construction begins, indicating that floors receive little attention at any stage in the building process. Before construction begins, careful attention must be given to a number of factors that influence performance:

1. Uniformity of the subgrade and adequacy of its bearing capacity.
2. Quality of the concrete
3. Adequacy of structural capacity
4. Type and spacing of joints
5. Workmanship
6. Special surface finishes
7. Future maintenance and repair

All these factors are covered in detail in this text. The technology and details apply equally to the small-area floor in a residence, light industry, or warehouse and to the large area covering many acres typified by the heavy industrial plant and its storage facilities. Major emphasis is given to attaining the best possible balance between service requirements and costs of construction and future maintenance.

UNIFORM SUBGRADE OF ADEQUATE BEARING CAPACITY

To ensure that the concrete floor will continue to carry its design loading successfully, it is vital to design and construct the subgrade as carefully as the floor itself. A subbase, while not mandatory, can provide added benefits in construction and performance.

Subgrades

The subgrade is the natural ground, graded and compacted, on which the floor is built. The subgrade as found can be improved by drainage, compaction (see "Density"), or soil stabilization. (Site drainage is not discussed in this publication.) Because of the rigidity of concrete floor slabs, concentrated loads from forklift wheels or high-rack legs are spread over large areas and pressures on the subgrade are usually low. Thus, concrete floors do not necessarily require strong support from the subgrade. Subgrade support must, however, be reasonably uniform without abrupt changes from hard to soft, and the upper portion of the subgrade must be of uniform material and density.

Soil Properties

Proper classification of the subgrade soil must be made to identify potential problem soils.* One soil classification system in common use is Classification of Soils for Engineering Purposes, American Society for Testing and

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*See *PCA Soil Primer*, Portland Cement Association publication EB007S, 1973.

Materials (ASTM) Designation: D2487. Table 1, based on the ASTM system, shows the major divisions of soils with descriptive names and letter symbols indicating their principal characteristics. When soil is a combination of two types, it is described by combining both names. Thus, *clayey sand* is predominantly sand but contains an appreciable amount of clay. Reverse the name to *sandy clay* and the soil is predominantly clay with an appreciable amount of sand.

Density

The strength of the soil—its supporting capacity and resistance to movement or consolidation—is important to the performance of floors on ground, particularly when the floor must support extremely heavy loads. Soil strength is affected by the degree of its compaction and its moisture content.

Compaction is a method for purposely densifying or increasing the unit weight of a soil mass by rolling, tamping, or vibrating. It is the lowest-cost way to improve the structural properties of the soil. Density of a soil is measured in terms of its mass per unit volume.

Tests performed according to Moisture-Density Relations of Soils, ASTM D698, will determine the maximum density and corresponding optimum-moisture content of the soil.

Plasticity Index

When a soil can be rolled into thin threads, it is called plastic. Most fine-grained soils containing clay minerals are plastic. The degree of plasticity is expressed as the plasticity index (PI). The PI is the numerical difference between the liquid limit and plastic limit. Liquid limit (LL) is the amount of moisture present when the soil changes from a plastic to liquid state. Plastic limit (PL) is the amount of moisture present when a soil changes from semisolid to plastic.

$$PI = LL - PL$$

Table 1. ASTM Soil Classification System

Major divisions			Group symbols	Typical names	Presumptive bearing capacity,** tons per square foot	Modulus of subgrade reaction, *k*, pounds per square inch per inch
Coarse-grained soils more than 50% retained on No. 200 sieve*	Gravels 50% or more of coarse fraction retained on No. 4 sieve	Clean gravels	GW	Well-graded gravels and gravel-sand mixtures, little or no fines	5	300 or more
			GP	Poorly graded gravels and gravel-sand mixtures, little or no fines	5	300 or more
		Gravels with fines	GM	Silty gravels, gravel-sand-silt mixtures	2.5	200 to 300 or more
			GC	Clayey gravels, gravel-sand-clay mixtures	2	200 to 300
	Sands more than 50% of coarse fraction passes No. 4 sieve	Clean sands	SW	Well-graded sands and gravelly sands, little or no fines	3.75	200 to 300
			SP	Poorly graded sands and gravelly sands, little or no fines	3	200 to 300
		Sands with fines	SM	Silty sands, sand-silt mixtures	2	200 to 300
			SC	Clayey sands, sand-clay mixtures	2	200 to 300
Fine-grained soils 50% or more passes No. 200 sieve*	Silts and clays liquid limit 50% or less		ML	Inorganic silts, very fine sands, rock flour, silty or clayey fine sands	1	100 to 200
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	1	100 to 200
			OL	Organic silts and organic silty clays of low plasticity		100 to 200
	Silts and clays liquid limit greater than 50%		MH	Inorganic silts, micaceous or diatomaceous fine sands or silts, elastic silts	1	100 to 200
			CH	Inorganic clays of high plasticity, fat clays	1	50 to 100
			OH	Organic clays of medium to high plasticity		50 to 100
Highly organic soils			PT	Peat, muck, and other highly organic soils		

*Based on the material passing the 3-in (75-mm) sieve.

**National Building Code, 1976 Edition, American Insurance Association

Soils with a high PI, greater than 20, may cause future problems by expanding under changes of moisture content in the subgrade due, for example, to a rising water table.

Problem Soils

Soils are considered problem soils when they are highly expansive, highly compressible, and do not provide reasonably uniform support. Concrete-floor-on-ground design is based on the assumption of uniform subgrade support. The key word is "uniform." Where problem soils create nonuniform conditions, correction is most economically and effectively achieved through subgrade preparation methods.

Site Preparation

To construct a reasonably uniform subgrade, special care must be taken to ensure that there are no variations of support within the floor area and that the following major causes of nonuniform support are controlled:

Expansive soils
Hard spots and soft spots
Backfilling

Expansive Soils

Most soils sufficiently expansive to cause floor distortion are classified by the ASTM Soil Classification System (Table 1) as clays of high plasticity (CH), silts of high plasticity (MH), and organic clays (OH). Simple soil tests provide indexes that serve as useful guides to identify the approximate volume-change potential of soils. Following are some of these tests:

Plasticity Index, ASTM D424
Volume Change of Soils, ASTM D1883
Shrinkage Factors of Soils, ASTM D427
Soil Compaction Tests, ASTM D698
Liquid Limit of Soils, ASTM D423

The following table shows approximate expansion-plasticity relationships:

Degree of expansion	Percentage of swell	Approximate plasticity index (PI)
Nonexpansive	2 or less	0 to 10
Moderately expansive	2 to 4	10 to 20
Highly expansive	more than 4	more than 20

Abnormal shrinkage and swelling of high-volume-change soils in a subgrade will create nonuniform support. As a result, the concrete floor may become distorted. Compaction of highly expansive soils when the soils are too dry can contribute to deterimental expansion and softening of the subgrade upon future wetting. When expansive soil subgrades are too wet prior to casting a floor slab, subsequent drying and shrinkage of the soil may leave portions of the slab unsupported.

Selective grading, crosshauling, and blending of subgrade soils make it possible to obtain uniform conditions in the upper part of the subgrade. Compaction of expansive soils to 95% optimum density at 1% to 3% above standard optimum moisture (Soil Compaction Tests, ASTM D698) will minimize possible loss of support from any future increases in moisture content and give the subgrade the uniform stability that is needed for good performance.

For exceptionally heavy loadings or poor soil conditions, a soils investigation should be made by a competent soils engineer.

Hard Spots and Soft Spots

If the subgrade is of nonuniform support, the slab when loaded will tend to bridge over soft spots and ride on hard spots, all too often with the results illustrated in Fig. 1. Special care must be taken by excavating and backfilling to prevent localized soft or hard spots. Uniform support, however, cannot be obtained merely by dumping granular material on the soft spot. Moisture and density conditions of the replacement soil should be as similar as possible to the adjacent soil. At transition areas where soil types or conditions change abruptly, the replacement soil should be mixed with the surrounding soil by crosshauling and blending to form a transition zone with uniform support conditions.

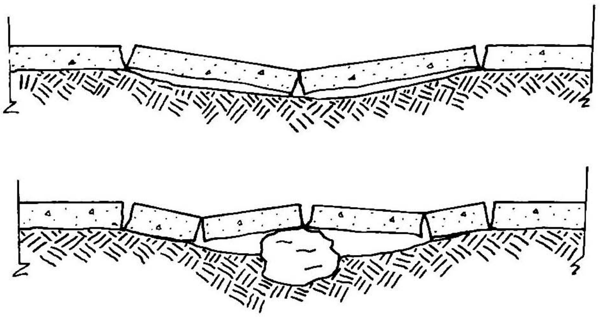

Fig. 1. Soft spots and hard spots.

Backfilling

Any fill material added to improve the subgrade or raise the existing grade should be a stable material that can be thoroughly compacted. Rubble from building or pavement demolitions must first be passed through a crusher because large pieces can cause compaction difficulties.

Underfloor pipeline and utility trenches should be backfilled with soils like those surrounding the trench and compacted in layers to duplicate moisture and density conditions in the adjacent soils. Every attempt should be made to restore as much as possible the original uniformity of the subgrade.

Poorly compacted subgrade fill can cause subsequent settlement problems and premature failure of the slab.

Modulus of Subgrade Reaction

The objective of design for thickness of concrete floors (and pavements) is to control tensile stresses within the slab. The stresses are influenced by the amount of support provided by the subgrade.

In thickness design, the subgrade support used for concrete floors on ground is taken to be Westergaard's modulus of subgrade reaction, *k*, which is determined by load tests on the subgrade at the jobsite. The modulus of subgrade reaction, *k*, is the ratio of load in pounds per square inch to a 0.05-in.* deflection of a 30-in.-diameter bearing plate:

$$k = \frac{\text{load (psi)}}{\text{deflection (at 0.05 in.)}}$$

The probable range of values for *k* on various soils is shown in Table 1 and in the following box.

k Value	
Soil type	pci
Silts and clays	50-100
Sandy soil	200
Sand-gravels	300

A reliable correlation does not exist between subgrade modulus and the bearing capacity of the soil used for foundation design. The *k* value used in floor design reflects the subgrade under temporary (elastic) conditions and small deflections—0.05 in. or less. Soil bearing capacity values from field tests—used to predict and limit differential settlement between footings or parts of a foundation—reflect total, permanent (inelastic) subgrade deformations that may be 10, 20, or more times greater than the small deflections of *k* values.

The *k* value does not reflect the effect of compressible soil layers at a depth of more than the 3 to 5 ft below subgrade surface. For exceptionally heavy floor loads distributed over large areas, the allowable bearing capacity of the underlying soil and the anticipated settlement due to soil consolidation should be determined. Long-term settlement may cause cracking and misalignment of slabs.

Subbases

A subbase—the thin layer of granular material placed on top of the prepared subgrade—is not mandatory for floors on ground. However, when a uniform subgrade is not produced by grading and compaction operations, a granular subbase will provide a cushion for more uniform support by equalizing minor subgrade defects. The granular subbase can also provide a capillary break and a stable working platform for construction equipment.

It is seldom necessary or economical to build up the supporting capacity of the subgrade with a thick subbase. Tests made by the Portland Cement Association show that increasing subbase thickness beyond 4 in. results in only minor increases in subgrade support, and these minor increases allow no appreciable reduction in the thickness of a concrete slab for given loading conditions.

Since uniform support rather than strong support is the most important function of the subgrade and subbase for a concrete floor, it follows that floor strength is achieved most economically by building strength into the concrete slab itself—with optimum use of low-cost materials under the slab.

Thus, when a subbase is used, a 4-in. thickness is suggested. A thicker subbase could contribute to poor floor performance by densifying under vibration and repetitive loads. To prevent densification, the subbase material should be compacted to high density: a minimum of 98% maximum density at optimum moisture determined by Soil Compaction Tests, ASTM D698.

Granular material for the subbase can be sand, sand-gravel, crushed stone, or combinations of these materials. A satisfactory dense-graded material will meet the following requirements:

Maximum size:	Not more than ⅓ the subbase thickness
Passing No. 200 sieve:	15% maximum
Plasticity index:	6 maximum
Liquid limit:	25 maximum

Substantial benefits in floor performance and slab-thickness reduction can be derived from a cement-treated subbase (CTSB) under a concrete floor slab that is to be subject to extremely heavy loading conditions. The high support value of CTSB will—

Reduce permeability
Eliminate subbase consolidation
Permit use of thinner concrete slabs

More information on preparing the grade is described in *Subgrades and Subbases for Concrete Pavements.***

QUALITY OF THE CONCRETE

The wear resistance of a concrete floor slab is directly related to the strength of the concrete. Research has shown that resistance to wear improves with a reduction in water content or an increase in cement content, or both, either one of which will increase strength. It is the rich quality of the mortar that is important; the hardness and toughness of the coarse aggregate becomes significant only after the surface-mortar matrix has worn away. To get the right quality concrete, the order given to the ready mixed concrete supplier must be clear and contain all the basic information stated in the job specifications.

In flatwork, the placeability of the concrete and the finishability of the surface are equally if not more important than strength, because they have a significant effect on the quality of the top ⅛ or 1/16 in. of the wearing surface. The order for ready mixed concrete should contain the following information: strength, minimum cement content, maximum size of coarse aggregate, slump, and a small amount of purposely entrained air.

Strength

A minimum strength of 4000 psi at 28 days is advisable for light industrial and commercial floor use. Specifica-

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*Use conversion table at the end of this book to convert to metric measurements.

**Portland Cement Association publication IS029P, 1971.

tions for a lower strength may be adequate for supporting the loads on the floor but will be inadequate for satisfactory wear resistance. It is also advisable to require 1800 psi strength at 3 days to build in early protection for the slab from construction traffic. Satisfying this 3-day requirement will produce 28-day strengths well above the recommended minimum shown in Fig. 2.

Classification of floors on the basis of intended use is given in American Concrete Institute (ACI) 302, Guide for Concrete Floor and Slab Construction, Table 1.1. Recommended strengths for each class of floor are given in ACI 302, Table 5.2.1.

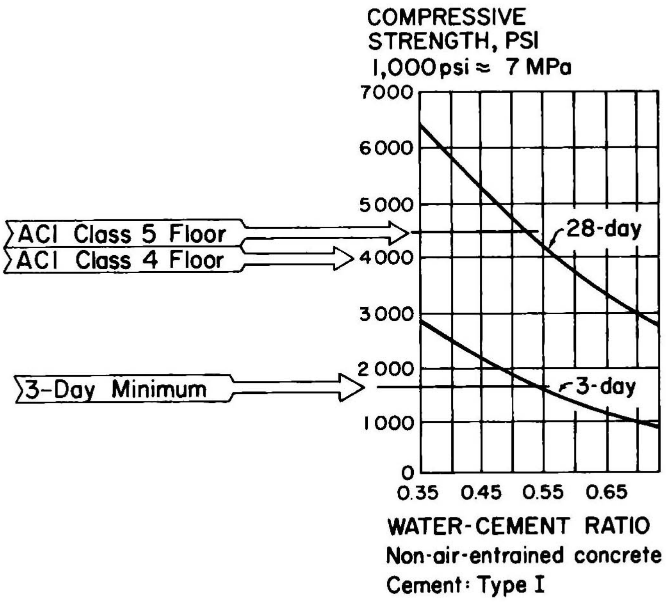

Fig. 2. Recommended minimum strengths for industrial and commercial floors on ground.

Minimum Cement Content

Floor work in particular needs sufficient cement mortar matrix for proper finishability. This is assured by specifying a minimum cement content.

With modern concrete technology, high-strength concrete can be obtained with less cement than before. Where strength alone is the decisive criteria, less cement means greater economy. Wear resistance, however, depends upon the surface hardness of the concrete as well as its internal strength and requires more cement. A minimum cement content should be specified that will ensure finishability for maximum wear resistance at the surface as well as adequate internal strength. The amount of cement should not be less than shown in Table 2. Use the largest size of aggregate possible to keep the cement content to a minimum.

Maximum-Size Coarse Aggregate

Freedom from random cracking is desired for all concrete floors. The degree to which random shrinkage cracking can be reduced is improved by using concrete with a minimum shrinkage potential that contains the correct gradation of aggregates, the maximum size of coarse aggregate, and the maximum amount of coarse aggregate consistent with placing and finishing methods. A larger aggregate size permits a lower water content in the concrete and is more effective in restraining the shrinkage of the cement paste.

The maximum aggregate size shown in Table 2 should be used if it is economically available and if it satisfies the requirement that maximum aggregate size not exceed three-fourths the clear space between reinforcing bars or one-third the depth of the floor slab.

Table 2. Minimum Cement Requirements

Maximum size of aggregate, in.	Cement, lb per cubic yard
1½	470
1	520
¾	540
½	590
⅜	610

Slump

Excessive slump and consequent bleeding and segregation are a primary cause of poor performance in concrete floors. If the finished floor is to be level, uniform in appearance, and wear resistant, it is important that all batches placed in the floor have very nearly the same slump.

Placing low-slump (2- to 4-in.) concrete flatwork is routine with the use of mechanical equipment such as a vibratory screed that rides on the side forms. When such equipment is used on floor work, less water is added at the jobsite and the wear resistance of the surface is improved. Low-slump concrete will go a long way towards

Speeding up placement and consolidation
Reducing finishing time
Reducing cracking
Eliminating surface defects

Recommended slumps for each ACI class of floor are given in Table 5.2.1 of ACI 302. A 3-in. slump is suggested for class 4 and 5 floors.

Entrained Air

A small amount of purposely entrained air is useful in almost all concrete for floors for reducing bleeding and increasing plasticity. A total air content of 2% to 3% is suggested. Concrete that will be exposed to cycles of freezing and thawing and the application of deicer chemicals needs a total air content of 5.5% to 7.5%, depending upon maximum size of aggregate, to ensure resistance to scaling. See Table 5.2.7a of ACI 302.

Tensile Strength of Concrete

Modulus of Rupture

When a load is applied to a floor on ground, it causes bending that produces both compressive and flexural stresses in the concrete slab. Of the two types of stress, flexural stress is more critical because it will approach the ultimate tensile strength of the concrete (modulus of rupture), while compressive stress remains small in proportion to the ultimate compressive strength of the concrete. Consequently, *the flexural stress and the flexural strength of the concrete are used in floor-slab design to determine thickness.*

Flexural strength is determined by modulus of rupture (MR) tests in accordance with ASTM C78, Flexural Strength of Concrete Using Simple Beam with Third-Point Loading. If the size of the job does not warrant the extra cost of flexural strength tests, compressive strength test results can be used to approximate probable flexural strength. An approximate relationship between compressive and flexural strength is shown in Table 3.

Table 3. Approximate Relationship Between Compressive and Flexural Strengths

Compressive strength, psi	Flexural strength, psi
3500	445-590
4000	480-640
4500	500-670
5000	535-710
6000	585-780
7000	630-840

ADEQUACY OF STRUCTURAL CAPACITY

Many variables directly or indirectly influence the determination of correct thickness for concrete floors on ground. To include all of them in a design method would be an unduly complex procedure and could lead to overconfidence in the design as a guarantee of good floor performance. All too frequently shortcomings of workmanship are the cause of unsatisfactory floor performance rather than inadequate design or specifications. Since it is the top surface of the floor that is continually and critically appraised by the user, added attention to the construction of the top surface of the slab and to proper jointing may contribute more to user satisfaction than undue attention to the thickness of the slab itself.

Previous design information covered only a limited range of load magnitudes and wheel spacings of industrial trucks operating on industrial and warehouse floors. Design guides for plain concrete slabs were needed, because a plain slab—one without distributed steel or structural reinforcement—often has advantages of economy and ease of construction.

To prepare a design guide, Portland Cement Association turned to the field of highway pavement engineering, where extensive data had already been assembled from many years of laboratory and field research and testing.

Acknowledging the obvious similarities and differences between a road pavement and a floor slab, pavement theory was reduced to easily used thickness design charts for floors on ground. The design method is presented in *Slab Thickness Design for Industrial Concrete Floors on Grade** and is applicable as well to slabs on ground for outdoor storage and material-handling areas. As in pavement design, the factors involved in determining the required floor slab thickness are

1. Strength of subgrade and subbase
2. Strength of concrete
3. Location and frequency of imposed loads

The following procedures for thickness design are derived from *Slab Thickness Design for Industrial Concrete Floors on Grade.*

Location and Frequency of Imposed Loads

Slab cracking due to excessive loads can occur in response to flexural overstress; too much deflection; settlement due to consolidation of subsoil; and for very concentrated loads, excessive concrete bearing or shear stresses.

The strategy in designing for floor slab thickness is to keep all responses within safe limits. The controlling design consideration will differ for different sizes of load contact area. For example, for lift trucks with wheel contact areas in the range of 20 to 100 sq in., flexural stress will control thickness design.

Flexural Stresses and Safety Factors

In the design procedure based on flexure, the allowable working stresses are determined by dividing the concrete flexural strength by an appropriate safety factor. Safety factors for vehicle loads have been established from experience gained in pavement performance and take into account several influences such as load repetitions, shrinkage factors, and impact.

Fatigue and Safety Factor

Concrete is affected more by repetitive loads than by a single load of the same magnitude. The effect is called fatigue. A flexural fatigue failure occurs when the concrete cracks under continued repetitions of loads that cause flexural stress-strength ratios of less than one. Tests of concrete slabs indicate that as the number of load repetitions increases a higher safety factor must be used to prevent failure. Fatigue effects are accommodated in the design procedure by a safety factor, as follows:

1. Select a conservative safety factor of 1.7 to 2.0 for moderate-to-heavy traffic. A safety factor of 2.0 permits unlimited repetitions of design load.
2. Select a safety factor of 1.5 to 1.7 for light traffic.

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*Portland Cement Association publication IS195D, 1976.

The safety factor can be selected by either of two ways. When the full-rated capacity of the forklift truck is selected to determine slab thickness, a safety factor between 1.5 to 1.7 is suggested because forklift trucks are not always operated at full-load capacity. When realistic-load data are known and used, a safety factor of 2 is suggested.

Shrinkage Stress

Shrinkage stresses are not considered to be significant. For example, a shrinkage stress of 23 psi is computed for an 8-in. slab jointed at 20 ft using a subgrade friction factor of 1.5. Pavement research has shown, however, that the actual stress developed will be much less—only one-third or one-half of that predicted.

Impact

Some procedures for pavement design increase the wheel loads by a factor to accommodate the effect of wheel impact. A load-impact factor is not included in the PCA floor design procedure (except in the safety factor) because this procedure is based on pavement research that shows slab stresses are less for moving loads than for static loads.

Flexural Stress

The flexural stresses indicated on the design charts are computed at the interior of a slab. When the slab edges at all joints have adequate load transfer (by means of dowels, keyways, or aggregate interlock), it is assumed that the panel area acts as a portion of a continuous large-area slab.

At free edges that lack adequate load transfer, concentrated loads will produce stresses that are somewhat greater than those for the interior. Because of this, if lift trucks will pass over an isolation joint (at a doorway for instance) the slab should be thickened by 25% gradually over a distance of 5 ft. Thickened sections (edges) restrain horizontal movement that may cause cracking in the interior of the slab. Mechanical devices (dowels) may be preferable for load transfer.

The assumption of interior load placement, combined with the choice of an appropriate safety factor and adequate concrete strength, gives a reasonable basis for floor thickness design.

Preliminary Design

For preliminary design purposes, or when detailed design data are not available, Fig. 3 can be used to select slab thickness based on the rated capacity of the heaviest lift trucks that will operate on the floor. The chart was prepared for typical lift trucks from manufacturers' data shown in Table 4. It cannot be used for trucks with capacity and wheel-spacing data that differ substantially from the data in Table 4.

The combination of a low k value and a low working stress in Fig. 3 results in a conservative slab thickness.

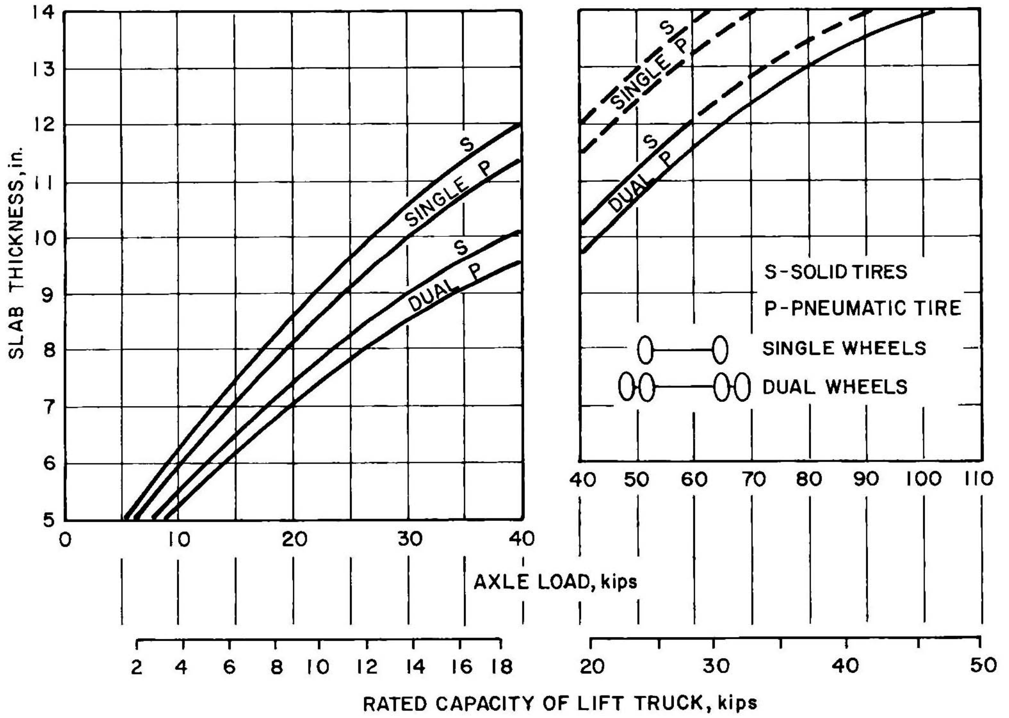

Fig. 3. Estimated slab thicknesses for lift trucks (based on average truck data shown in Table 4 and conservative design assumptions of k = 50 pci, concrete working stress = 250 psi).

Table 4. Lift Truck Characteristics (Composites Averaged from Manufacturers' Data)

Rated capacity,* lb	Load on drive axle,** kips	Range of wheel spacings, in. (c to c)		
		Single wheels, s†	Dual wheels	
			s_d†	s†
2,000	6.4	26 to 30	—	—
4,000	10.4	31 to 35	—	—
6,000	14.6	32 to 38	—	—
10,000	22.2	37 to 43	10 to 12††	41 to 53††
15,000	32.5	37 to 45	10 to 12	47 to 60
20,000	42.0	40 to 50	12 to 14	54 to 65
30,000	63.3	—	14	57
45,000	100.6	—	18	73
60,000	132.0	—	21	70

Other data:
Load Contact Pressure
  solid or cushion tires—180 to 250 psi
  pneumatic tires—80 to 100 psi (inflation pressure)
Load Contact Area (per tire)
  solid or cushion tires—3 or 4 times tire width
  pneumatic tires—wheel load divided by contact pressure
Approximately 90% of total weight (truck + load) on drive axle at rated capacity.
Maximum axle load for many lift trucks is slightly greater than twice the rated capacity.

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*Load center 24 in. from fork face, mast vertical.
**Varies by about 10%, depending on manufacturer.
†See insert drawings on Figs. 2 and 4.
††Values shown are for pneumatic tires; limited data for 10,000-lb-capacity trucks with solid or cushion tires show shorter spacings: for example, 8.5x29 in.

More accurate and more economical designs can be obtained by the complete design method given in *Slab Thickness Design for Industrial Concrete Floors on Grade.* Use of this publication is illustrated in the following design-procedure examples.

Design Procedure

Vehicle Loads

Design for industrial lift-truck loads requires knowledge of several specifics:

Maximum axle loads
Number of load repetitions
Wheel contact area
Spacing between wheels on heaviest axles
Subgrade strength
Flexural strength of concrete

Traffic and load data for past and future operating conditions for lift trucks (Fig. 4) can be gathered from plant maintenance departments, planning and operations departments, and truck manufacturers' data. Then the safety factor can be selected and used to determine an allowable working stress with which to enter the design charts.

The safety factor (flexural strength divided by working stress) reflects the expected frequency of loadings of the

Fig. 4. Traffic and load data are needed for design of industrial concrete floors on ground.

heaviest vehicles. Safety factors in the range of 1.5 to 2.0 are suggested for industrial and commercial floors. The high number should be used where the heavy load traffic is frequent and channelized. Where traffic is light and not channelized, lower safety factors of 1.5 to 1.7 can be used.

The design chart for industrial trucks with single-wheel axles, Fig. 5, was taken from *Slab Thickness Design for Industrial Concrete Floors on Grade.* This chart is entered with a calculated number for allowable working stress per 1000 lb of axle load. The number is obtained by dividing the modulus of rupture of the concrete by the safety factor and then dividing the result by the axle load in kips. The calculation makes it possible for one chart to cover a wide range of load magnitudes.

For axles equipped with dual wheels, *Slab Thickness Design for Industrial Concrete Floors on Grade* includes a chart for converting a dual-wheel axle load to an equivalent single-wheel axle load. Then Fig. 5 can be used to determine the required thickness of the slab.

The effective contact area used in the charts is the corrected area of tire in contact with the slab. If tire data are not available, the contact area can be estimated for pneumatic tires by dividing wheel load by inflation pressure. For solid or cushion tires, it can be approximated by multiplying tire width by three or four. Tire data can also be obtained from the tire manufacturers. When the tire contact area is small, it must be corrected to an effective contact area because slab stresses for small-load contact areas are overestimated using conventional theory. The same correction is used for the high-rack-storage-leg loads discussed below. The correction is made with the design chart for axles with dual wheels in *Slab Thickness Design for Industrial Concrete Floors on Grade.* (The chart is not included in this publication.)

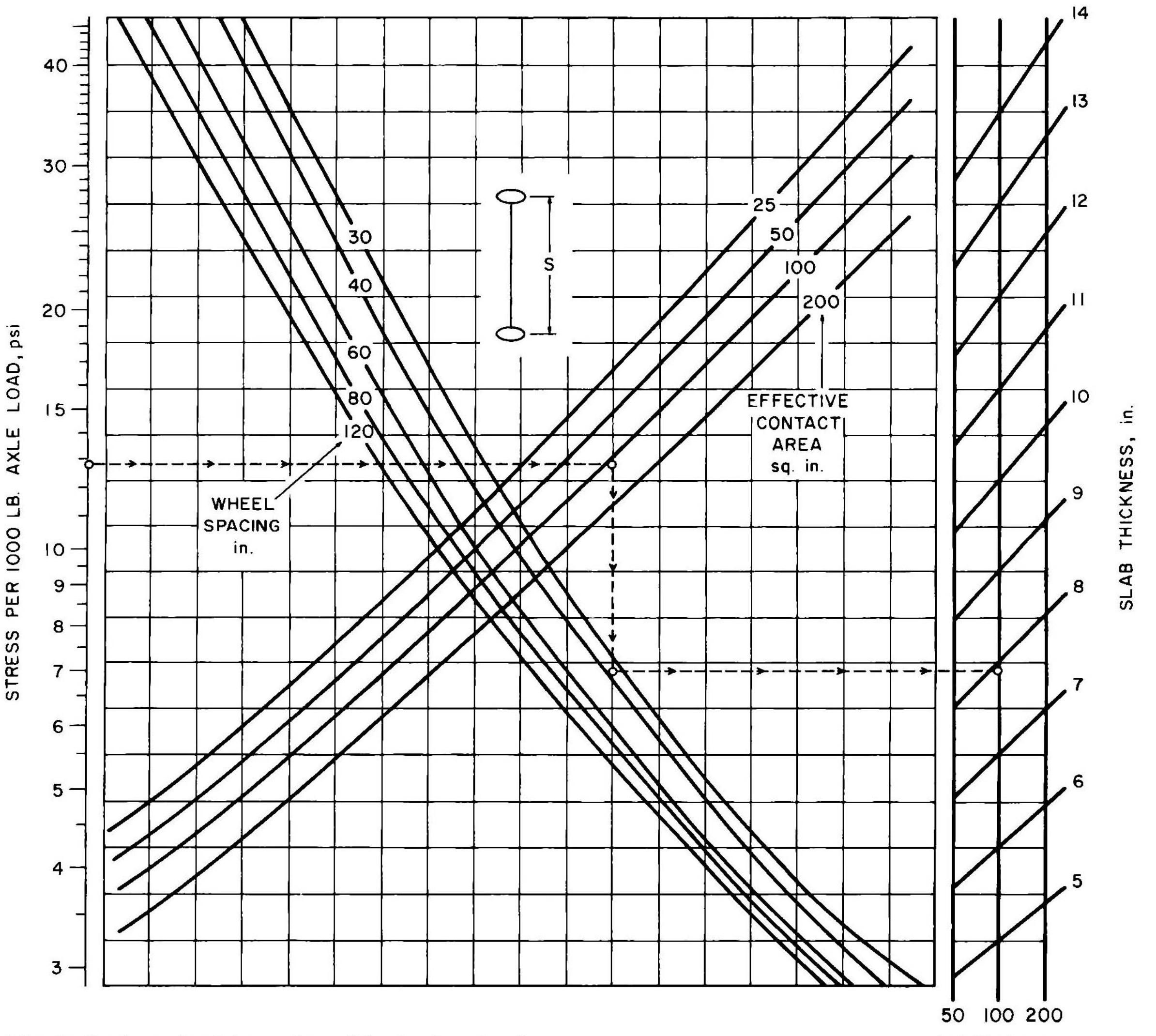


Fig. 5. Design chart for axles with single wheels.

Thickness Design Example—Single-Wheel-Axle Loads

Data for Lift Truck

Axle load	25 kips (single-wheel axle)
Wheel spacing	37 in.
Number of wheels	2
Tire inflation pressure	110 psi

Tire contact area:

$$\frac{\text{wheel load}}{\text{inflation pressure}} = \frac{25{,}000/2}{110} = 114 \text{ sq in. (large enough, correction not required)}$$

Subgrade and Concrete Data

Subgrade modulus, k	100 pci
Concrete flexural strength, MR	640 psi

Design Steps

1. Safety factor, SF:
   For frequent operations of forklift trucks in channelized aisle traffic, select a safety factor permitting unlimited stress repetitions—2.0.
2. Concrete working stress, WS:

$$WS = \frac{MR}{SF}\ \frac{640}{2.0} = 320 \text{ psi}$$

3. Slab stress per 1000 lb of axle load:

$$\frac{WS}{\text{axle load, kips}} = \frac{320}{25} = 12.8 \text{ psi per 1000 lb}$$

4. Enter Fig. 5 at left with stress of 12.8 psi, move right to contact area of 114 sq in., down to wheel spacing of 37 in., then right to read a slab thickness of 7.9 in. on the line for subgrade k of 100 pci. Use 8-in.-thick slab.

High-Rack-Storage-Leg Loads

Advancements in mechanized, computerized material-handling equipment generated the high-rack configuration now used for product storage in many warehouses. In these buildings, permanent racks of fixed dimensions rise to heights up to 60 ft. When loads on the rack legs (or posts) exceed the wheel loads of vehicles operating in the warehouse, leg loads will control the thickness design.

For leg loads, the design objective is to keep flexural stresses in the slab within safe limits. When flexural requirements are satisfied by adequate slab thickness, pressures on the soil will not be excessive; and when a correct-size base plate is used (Fig. 6), concrete bearing and punching shear stresses will remain within acceptable limits.

The design factors for high-rack-leg loads are similar to those used for vehicle loads except that a higher safety factor is selected. The specific design factors are

Maximum expected load on leg
Effective (corrected) load contact area
Spacing between legs
Subgrade strength
Flexural strength of the concrete

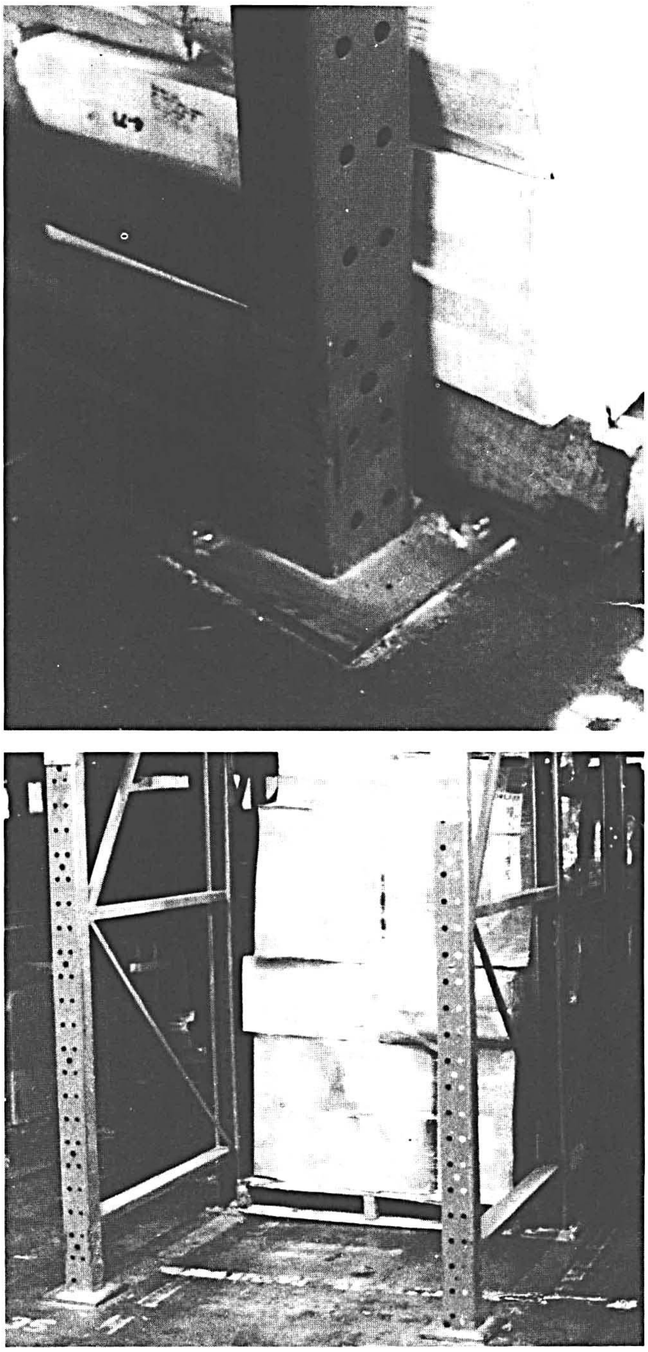


Fig. 6. Loaded legs supporting high-rack storage must have base plates of adequate size to prevent bearing or shear failure in the slab.

Fig. 7, taken from *Slab Thickness Design for Industrial Concrete Floors on Grade*, is used to determine slab thickness requirements for rack configurations and loads. The x- and y-leg spacings used in Fig. 7 are the smallest dimension in the rack configuration (except the spacing between legs on opposite sides of a joint).

The procedure is similar to that for wheel loads. In the grid at the left side of the chart, locate the point corresponding to stress per 1000-lb-leg load and effective (corrected) contact area. Move right to the y-post spac-

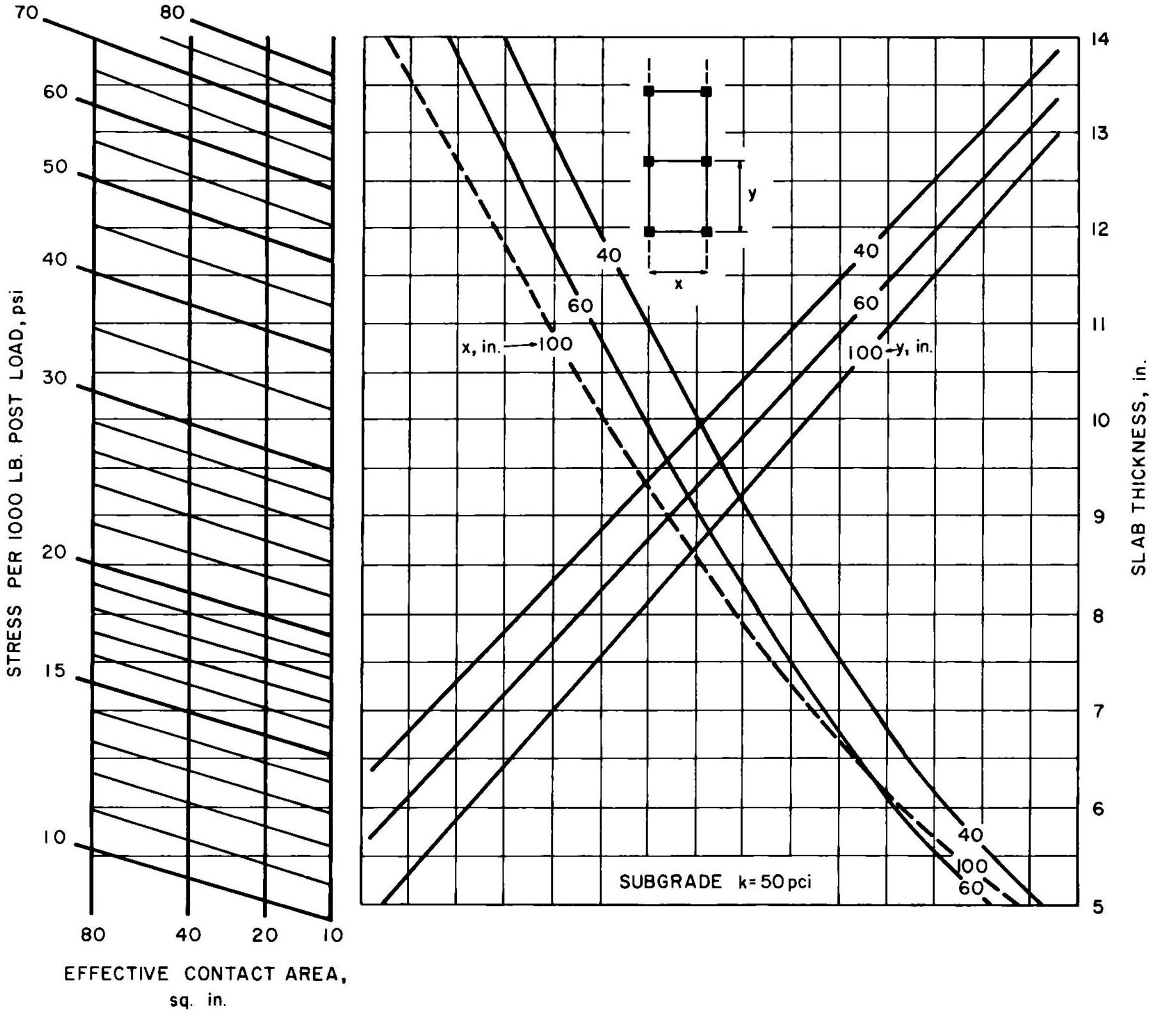


Fig. 7. Design chart for leg (post) loads, subgrade k = 50 pci.

ing (length or long axis dimension of the racks); then move up (or down) to the x-spacing and right to read the slab thickness.

For loads on high racks, use high safety factors. High-rack loads require conservative safety considerations because the effects of differences in movement at the base of the rack are magnified at the top. In addition, if the rack layout and the slab joint layout are not coordinated, it is possible that some rack legs could be located near a joint. Unless the slab edges are intentionally thickened, this would result in higher floor slab stresses than those shown in Fig. 7, which are based on loads at the slab interior. Safety factors should be chosen to include the possibility of rack loads being applied close to slab edges or corners.

Since there is little available data on performance experience with rack loads on slabs, safety factors cannot be suggested with as much confidence as for vehicle loads.

Safety factors in the range of 3.9 to 4.8 will satisfy building code requirements when the rack leg is regarded as a supporting column and the slab is regarded as an unreinforced spread footing.

A safety factor in the range of 3.0 to 4.0 can be used with Fig. 7 to establish a tentative slab thickness based on flexure. Shear stress and concrete bearing stress should also be computed to determine if these values are within safe limits.

For exceptionally heavy rack loads on plain concrete slabs, the thickness required may be so great that alternate design methods should be considered, such as:

Integral or separate footings under the leg lines
Structural reinforced slabs
Use of cement-treated subbase under the concrete slab

The economic and construction practicality of these alternative designs should be considered along with the effects of thickness on stresses and deflections of the floor.

Uniform Loads

Uniform loads are defined as loads distributed over a large area. For most warehouse and industrial floors, concentrated loads are the controlling design factor since distributed loads do not usually produce flexural stresses of the same magnitude. However, after an adequate slab thickness has been selected to support the heaviest vehicles and storage racks, as previously described, the effects of uniform loads should also be examined.

Design for uniform (distributed) loads has two objectives: (1) to prevent cracks in the aisleways or unloaded areas due to excessive negative moment; and (2) to avoid objectionable settlements due to consolidation of the foundation soils.

Cracking in an unjointed aisle can be controlled by adequate slab thickness. Slab settlement, however, cannot be eliminated by making the slab thicker—this is a foundation-soils-improvement problem. Normally, the magnitude of distributed loads placed on floors with properly prepared and compacted subgrades and subbases is not sufficient to cause excessive settlement; but for very heavy distributed loads on compressible subgrades, the possibility should be examined by a structural foundation engineer.

Allowable Uniform Loads to Prevent Cracking in Aisleway. In an unjointed aisleway between uniform load areas, the maximum negative bending moment may be up to twice as great as the moment beneath the loaded area. Hence, the thickness design should limit the resulting stresses so that a crack will not occur in the aisleway.

Allowable loads based on this consideration can be found in Tables 5 and 6 for fixed and variable storage layouts. Note that the *k* value of the subgrade, rather than the *k* value on top of the subbase (if there is one), is used in these tables.

Storage Layout. The magnitudes of flexural stresses and deflections due to distributed loads vary with slab thickness and subgrade strength. They also vary with aisle width, dimensions of the loaded area, and the existence of joints or cracks in the aisleway. In Table 5 for fixed layout, the critical aisle width and its allowable distributed load are identified and the loads for other aisle widths are given. Table 5 is used when the storage layout is preplanned and will remain unchanged (Fig. 8).

The allowable loads shown in Table 6 for a variable storage layout represent the most critical conditions and are suggested for practical design use when the aisle and storage layout is unknown at planning time (Fig. 9). There are no restrictions on where the load is placed or on the uniformity of loading for the allowable loads in Table 6. When there are joints in the aisleways or if cracks should occur, the limit of load will depend on the tolerable settlement of the slab.

For wheel and rack loads, increased slab thickness effectively reduces the unit pressure transmitted to the subgrade soil. Under uniform distributed loads, however, soil pressure is not reduced by slab thickness, but is equal to the uniform load on the slab plus the slab weight plus the weight of any fill material. Therefore, when the loads are exceptionally heavy, as in Fig. 10, the amount of settlement should be estimated by methods used in foundation engineering for spread footings or raft foundations.

Table 5. Allowable Distributed Loads, Unjointed Aisle (Uniform Load, Fixed Layout)

Slab thickness, in.	Working stress, psi	Critical aisle width, ft**	Allowable load, psf†					
			At critical aisle width	At other aisle widths				
				6-ft aisle	8-ft aisle	10-ft aisle	12-ft aisle	14-ft aisle
Subgrade *k* = 50 pci*								
5	300	5.6	610	615	670	815	1,050	1,215
	350	5.6	710	715	785	950	1,225	1,420
	400	5.6	815	820	895	1,085	1,400	1,620
6	300	6.4	670	675	695	780	945	1,175
	350	6.4	785	785	810	910	1,100	1,370
	400	6.4	895	895	925	1,040	1,260	1,570
8	300	8.0	770	800	770	800	880	1,010
	350	8.0	900	935	900	935	1,025	1,180
	400	8.0	1,025	1,070	1,025	1,065	1,175	1,350
10	300	9.4	845	930	855	850	885	960
	350	9.4	985	1,085	1,000	990	1,035	1,120
	400	9.4	1,130	1,240	1,145	1,135	1,185	1,285
12	300	10.8	915	1,065	955	915	925	965
	350	10.8	1,065	1,240	1,115	1,070	1,080	1,125
	400	10.8	1,220	1,420	1,270	1,220	1,230	1,290
14	300	12.1	980	1,225	1,070	1,000	980	995
	350	12.1	1,145	1,430	1,245	1,170	1,145	1,160
	400	12.1	1,310	1,630	1,425	1,335	1,310	1,330

**k* of subgrade; disregard increase in *k* due to subbase.

**Critical aisle width equals 2.209 times radius of relative stiffness. Critical aisle width has maximum negative bending moment (tension in top slab at aisle centerline due to loads on each side of aisle). For other aisle widths, bending moments are not maximum.

Assumed load width = 300 in., allowable load varies only slightly for other load widths. Allowable stress = one-half flexural strength.

†There is an explanation in *Slab Thickness Design for Industrial Concrete Floors on Grade*, from which this table is reproduced, for what appear to be anomalous allowable loads.

Table 6. Allowable Distributed Loads, Unjointed Aisle (Nonuniform Loading, Variable Layout)

Slab thickness, in.	Subgrade *k** pci	Allowable load, psf**			
		Concrete flexural strength, psi			
		550	600	650	700
5	50	535	585	635	685
	100	760	830	900	965
	200	1,075	1,175	1,270	1,370
6	50	585	640	695	750
	100	830	905	980	1,055
	200	1,175	1,280	1,390	1,495
8	50	680	740	800	865
	100	960	1,045	1,135	1,220
	200	1,355	1,480	1,603	1,725
10	50	760	830	895	965
	100	1,070	1,170	1,265	1,365
	200	1,515	1,655	1,790	1,930
12	50	830	905	980	1,055
	100	1,175	1,280	1,390	1,495
	200	1,660	1,810	1,965	2,115
14	50	895	980	1,060	1,140
	100	1,270	1,385	1,500	1,615
	200	1,795	1,960	2,120	2,285

Reproduced from *Slab Thickness for Industrial Concrete Floors on Grade*, Portland Cement Association publication IS195D.

**k* of subgrade; disregard increase in *k* due to subbase.

**For allowable stress equal to one-half flexural strength. Based on aisle and load widths giving maximum stress.

Fig. 8. Preplanned storage area with uniform loads.

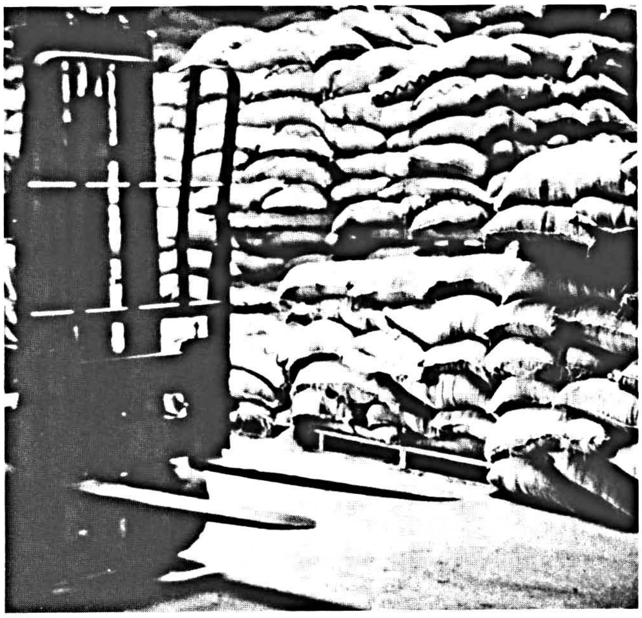


Fig. 9. Variable storage area with no restrictions on where load is placed or on uniformity of loading.

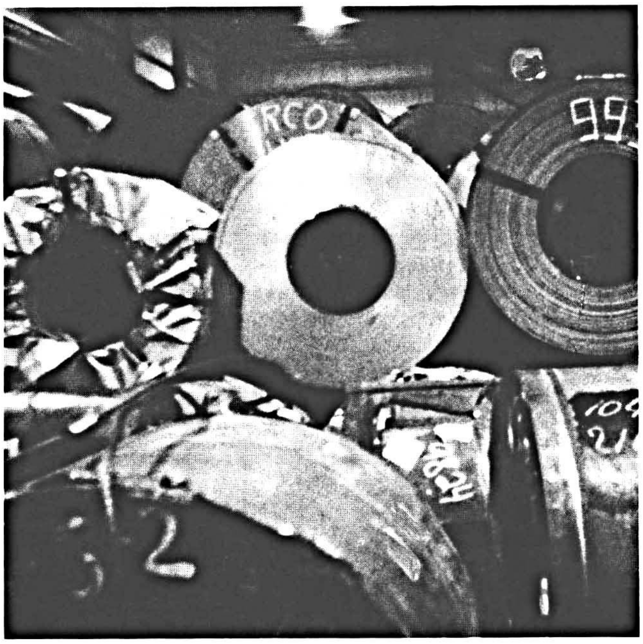


Fig. 10. Exceptionally heavy loads require special consideration in slab design.

Uncommon Storage Conditions

Unusual and exceptionally heavy loadings require structural analysis of the slab to determine adequate thickness. A wide range of unusual design conditions can be fitted into computer programs that analyze and design foundation mats and combined footings as plates on elastic foundations or programs that determine flexural stresses in concrete pavement slabs supported by dense liquid subgrades.

Thickness Design Summary

The foregoing is a simple and concise approach to the thickness design of floor slabs supported directly on the ground. It is derived from the wealth of information available in highway and airport concrete pavement design practice. Normal design situations can be conservatively resolved by this method. Unusual conditions can be analyzed by more advanced techniques including the use of computer programs, influence charts, and structural engineering. But in most situations the method presented here can serve as a guideline that has been proved through practice and the measured observation of results in actual floors.

JOINTING PRACTICE

Good jointing practice is one way of ensuring crack-free floors. Most cracks in concrete floors are the result of three actions: volumetric change due principally to drying shrinkage, direct stress due to applied loads, and flexural stress due to bending. Cracks can be the net result of all three. Cracks will appear at any time and any place where the stress within the concrete to pull it apart exceeds the strength of the concrete to hold itself together.

The magnitude of drying shrinkage in concrete is affected by the water content of the mix. More coarse aggregate and less water mean less shrinkage (thus, less cracking) in the concrete. Type of cement and cement content have very little effect on drying shrinkage. The use of an accelerator admixture containing calcium chloride can increase drying shrinkage significantly. The rate of drying is influenced by thickness of the slab, humidity and temperature of the surrounding air, and duration of exposure. Drying shrinkage is an unavoidable, inherent property of concrete, so the possibility of cracking exists. Control measures are taken to induce concrete to crack in predictable, straight lines by proper jointing.

Kinds of Joints

Building use dictates the joint design and spacing for a concrete floor on ground. The designer is always confronted with the need to eliminate random cracking, so crack control is an important aspect of floor performance to be included in the floor design. Three kinds of joints are used:

1. Isolation joints (also called expansion joints)—to allow movement between the floor and other fixed parts of the building such as columns, walls, and machinery bases
2. Control joints (also called contraction joints)—to induce cracking at preselected locations
3. Construction joints—to provide stopping places during construction

Isolation Joints

Isolation joints are placed wherever complete separation between the floor and adjoining concrete is needed to allow them to move independently without damage. Isolation joints permit horizontal and vertical movement between the abutting faces of the floor slab and other parts of the building because there is no keyway, bond, or mechanical connection across the joint (Fig. 11).

Columns on separate footings are isolated from the floor slab either with a circular- or square-shape isolation joint. The square shape should be rotated to align its corners with control and construction joints, as shown in Fig. 12.

Where traffic will cross isolation joints, provision should be made for adequate load transfer.

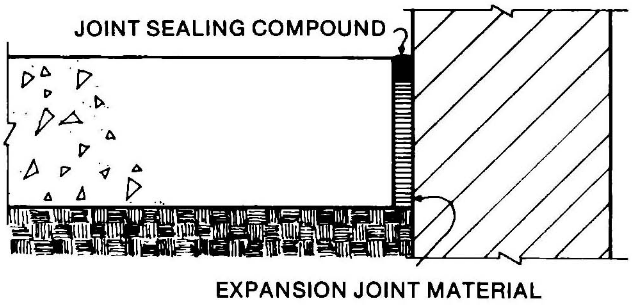


Fig. 11. Isolation joints are used between the floor slab and fixed parts of building such as walls, columns, and machinery bases.

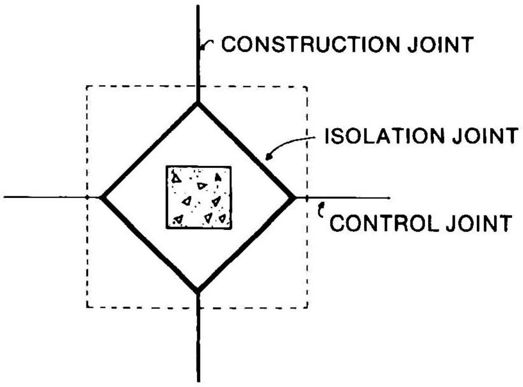
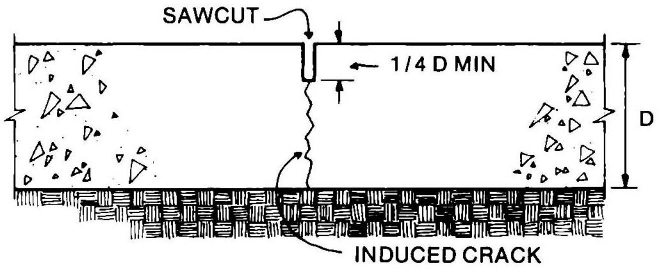


Fig. 12. Isolation joints around columns are circular or square shaped.

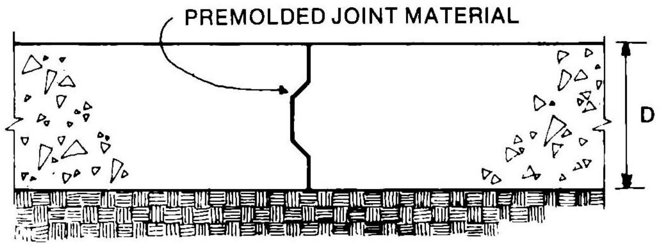
Control Joints

Control joints act to relieve stress and with proper spacing they eliminate the cause of uncontrolled random cracking. They allow horizontal movement of the slab. Control joints in industrial and commercial floors are usually cut with a saw. They should be constructed to a depth of generally one-fourth the slab thickness. In thick slabs a crack inducer anchored to the subgrade immediately below the joint can be added to reduce the section.

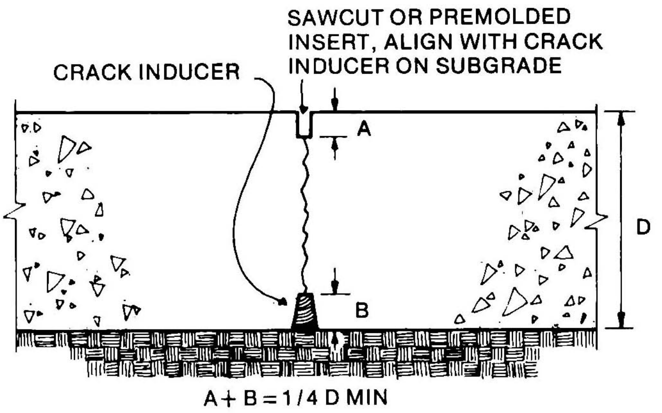
The objective is to form a plane of weakness in the slab so that the crack will occur along that line and nowhere else, as shown in Fig. 13. Load transfer across a control joint is provided by the interlocking of the jagged face



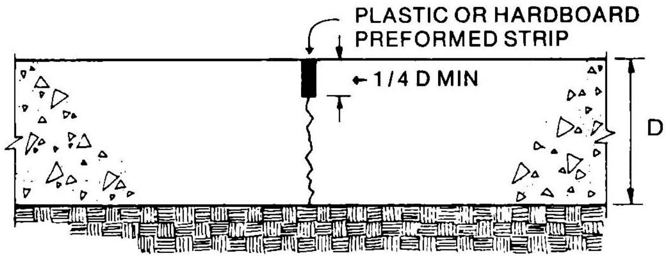
SAWED CONTROL JOINT



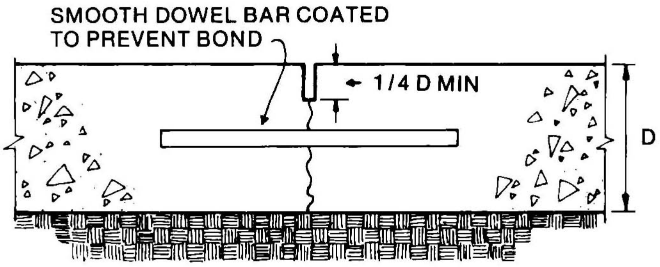
TONGUE AND GROOVE CONTROL JOINT



CONTROL JOINT IN THICK FLOOR SLABS



PREMOLDED INSERT CONTROL JOINT



CONTROL JOINT WITH DOWELS

Fig. 13. Varieties of control joints.

formed at the crack. With long joint spacings or heavily loaded slabs, dowel bars (coated to prevent bond with the concrete) are used as load transfer devices. Dowel sizes and spacings are shown in Table 7.

Table 7. Dowel and Tiebar Sizes and Spacings

Slab depth, in.	Diameter, in.	Total length, in.	Spacing, in. c to c
	Dowels		
5	⅝	12	12
6	¾	14	12
7	⅞	14	12
8	1	14	12
9	1⅛	16	12
10	1¼	16	12
	Tiebars		
5	#4	30	30
6	#4	30	30
7	#4	30	30
8	#4	30	30
9	#5	30	30
10	#5	30	30

Construction Joints

Construction joints usually form the edges of each day's work. They are located to conform to the floor jointing pattern and detailed and constructed to function as and align with control joints or isolation joints.

Where there is no control or isolation joint, a butt-type construction joint is satisfactory for thin floors, as shown in Fig. 14. For thicker, more heavily loaded floors, a tongue-and-groove joint is used or dowels are added to the butt joint. Whenever continuous concrete placement will be interrupted for 30 minutes or more, a bonded construction joint should be inserted to avoid the formation of a cold joint. A bonded construction joint in a plain slab is a butt-type construction joint with tiebars as shown in Fig. 14. Tiebar sizes and spacings are shown in Table 7. Any reinforcement in the slab is continuous through the bonded construction joint.

Filling Joints

The movement at control joints in a floor is generally very small. For some industrial and commercial uses, these joints can be left unfilled. Where there are wet conditions, hygienic and dust-control requirements, or considerable traffic by small, hard-wheeled vehicles such as forklifts, joint filling is necessary.

In many places, a resilient material such as an elastomeric sealant is satisfactory, but to provide support to the edges and prevent spalling at the joints, a good quality rigid or semirigid filler with a durometer Shore *A*-scale hardness number of approximately 80 should be used.*

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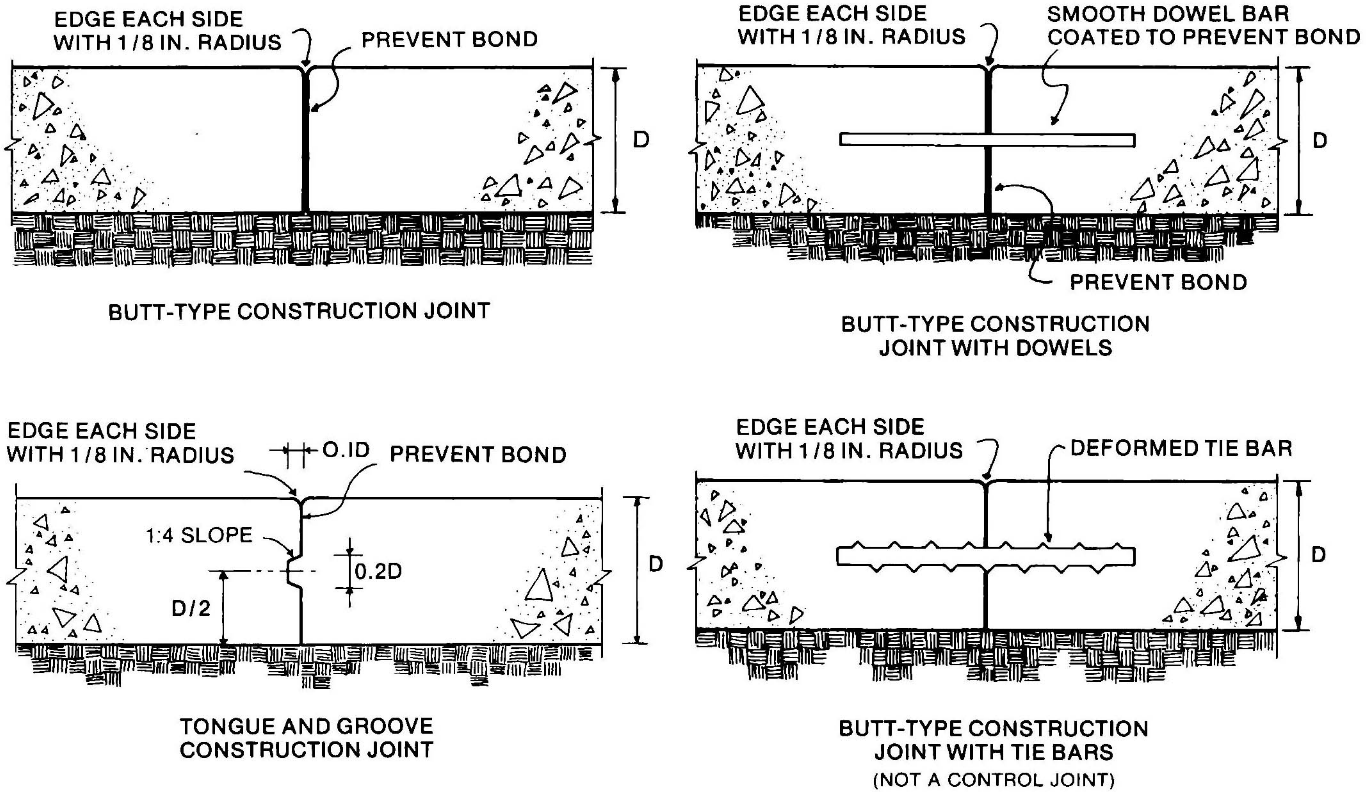
*ASTM Designation: D2240 and D676.



BUTT-TYPE CONSTRUCTION JOINT

BUTT-TYPE CONSTRUCTION JOINT WITH DOWELS

TONGUE AND GROOVE CONSTRUCTION JOINT

BUTT-TYPE CONSTRUCTION JOINT WITH TIE BARS
(NOT A CONTROL JOINT)

Fig. 14. Varieties of construction joints.

The *A* scale is used for measuring the indentation hardness of rubber, soft plastics, and other elastomers. A hardness number of 80 would be considered as medium hard. A rubber automobile tire has a hardness of approximately 65. The *D* scale is designed to measure the hardness of plastics and other semihard or hard materials. ACI 302, paragraph 4.10, requires a *D*-hardness number of 50.

Extruded-lead strips embedded in control joints give support to the edges and thereby reduce spalling. Lead strips, where permitted, are highly successful for heavy-duty concrete floors where trucking is severe, especially of the steel-wheel type.

Isolation and expansion joints are intended to accommodate movement, thus a flexible, elastomeric sealant should be used.

Joint Layout

A joint layout is illustrated in Fig. 15. Isolation joints are provided around the perimeter of the floor where it abuts the walls and around all fixed elements that restrain movement of the slab in a horizontal plane. This includes columns and machinery bases that pierce the floor slab. With the slab isolated from other building elements, the remaining task is to locate and correctly space control joints to eliminate random cracking. Construction joints can be located by the floor contractor to accommodate

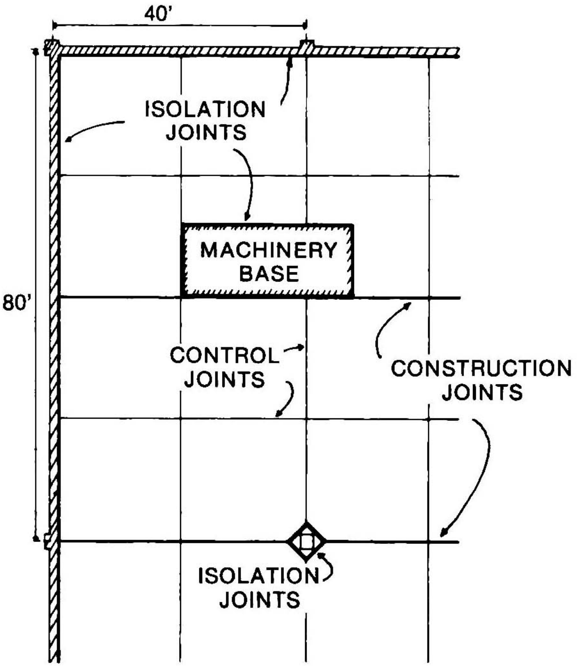


Fig. 15. Typical joint layout for concrete floor on ground with no reinforcement.

work schedules with the restriction that they coincide with the control-joint pattern. Pipe trenches under slabs on ground (Fig. 16) require control joints placed directly above each side of the trench.

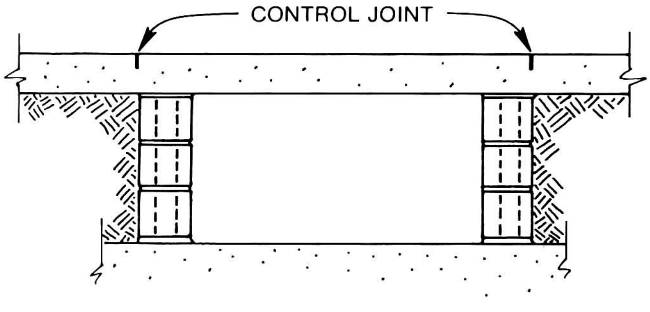


Fig. 16. Pipe trench jointing.

Spacing of Joints

Maximum spacing between joints depends primarily on

- Slab thickness
- Shrinkage potential of the concrete
- Subgrade friction
- Curing environment
- Absence or presence of distributed reinforcement

Slabs made of high-slump concrete improperly cured in a dry environment, with or without reinforcement, will shrink excessively and crack extensively. Slabs made of low-slump concrete properly cured in a moist environment, with or without reinforcement, will have minimum shrinkage and few cracks. Jobsite practices are somewhere between these extremes. Local practice and materials may give satisfactory control of cracking at joint spacings greater than shown in Table 8. Joint spacing to eliminate cracking within the panel is not the same as joint spacing to limit width of the opening at the joint.

The most economical floor construction is a plain (no reinforcement) concrete slab with short joint spacing supported by a uniform subgrade. A rule of thumb for plain slabs constructed with 4- to 6-in.-slump concrete is that joint spacing (in feet) should not exceed 2 slab thicknesses (in inches) for concrete made with less than ¾-in.-top-size coarse aggregate or 2½-slab thicknesses for concrete containing greater than ¾-in. coarse aggregate. For low-slump concrete, less than 4-in. slump, 3 slab thicknesses are suitable. Suggested joint spacings are given in Table 8.

Table 8. Suggested Spacing of Control Joints

Slab thickness, in.	Less than ¾-in. aggregate: spacing, ft	Larger than ¾-in. aggregate: spacing, ft	Slump less than 4 in.: spacing, ft
5	10	13	15
6	12	15	18
7	14	18	21
8	16	20	24
9	18	23	27
10	20	25	30

Note: Given spacings also apply to the distance from control joints to parallel isolation joints or to parallel construction joints. Refer to text for other factors that may call for different spacing. Spacings greater than 15 ft show a marked loss in effectiveness of aggregate interlock to provide load transfer across the joint.

Load Transfer Across Joints

The passage of heavy loads on vehicles with small, hard wheels over improperly made joints in a warehouse floor can lead to spalling of joint edges and progressive deterioration of the concrete. The building owner will be faced with the prospect of expensive repairs that could have been avoided had more attention been given to joint filling and to the factors that influence load transfer at joints.

Load transfer across joints in concrete pavements has been investigated in the laboratories of the Portland Cement Association (Fig. 17).* Following are summarized observations from the investigation that are applicable to industrial floors on ground.

Aggregate Interlock

Load transfer across control joints in slabs on ground takes place through the shear developed by interlocking aggregate particles, provided there are no dowel bars or reinforcing steel running through the joints. The effectiveness of load transfer depends on

- Joint opening
- Slab thickness
- Subgrade support
- Load magnitude and number of repetitions
- Aggregate angularity

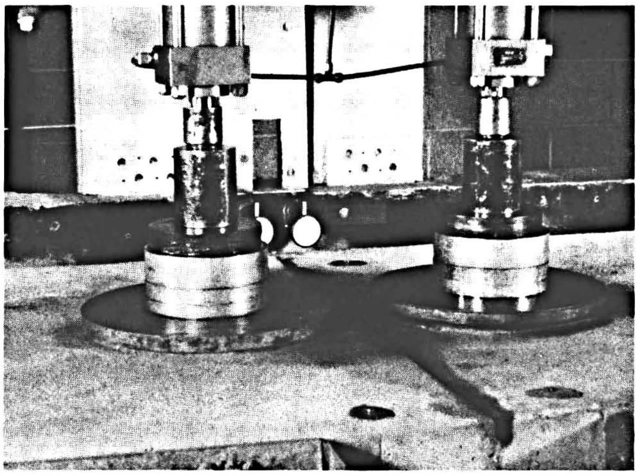


Fig. 17. Laboratory testing device developed to apply repetitive loads of known magnitude in a manner closely simulating the action of wheel loads passing over a joint.

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*B. E. Colley and H. A. Humphrey, *Aggregate Interlock at Joints in Concrete Pavements*, Research Department Bulletin DX124, Portland Cement Association, 1967.

Control joints are constructed in slabs on ground to relieve tensile stresses caused by drying shrinkage. When properly spaced, they control the location and direction of cracks. At the plane of weakness produced by the joint, restrained shrinkage forces are relieved by the crack that forms below the saw cut (Fig. 18).

Load transfer across the crack is developed either by the interlocking action of the aggregate particles at the fractured faces of the crack (aggregate interlock) or by a combination of aggregate interlock and mechanical devices such as dowel bars. When load transfer is effective, the stresses and deflections in the slab near the joint are low and forklift and industrial trucks move smoothly across the joint without damaging it.

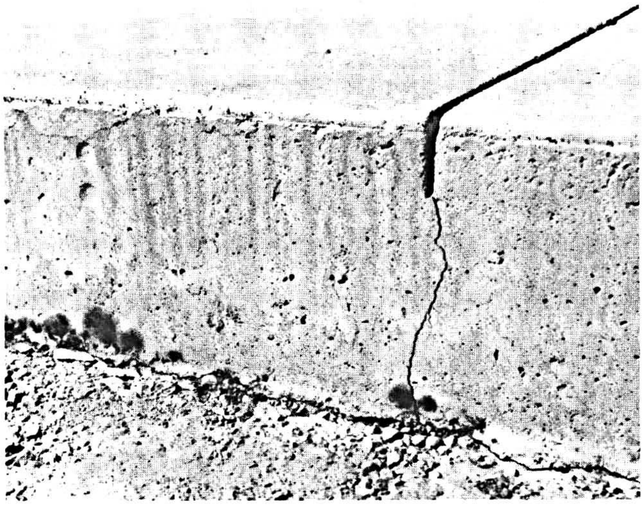


Fig. 18. Irregular faces of crack that forms below sawed control joint provide adequate aggregate interlock for load transfer when short joint spacings are used.

Load Transfer Effectiveness

Joint effectiveness is measured as a percentage of the ability of the joint to transfer load from the loaded slab to the unloaded slab. If load transfer at a joint were perfect, the deflections of the loaded and unloaded slabs would be equal and the effectiveness would be 100%. If, however, there was no load transfer at a joint, only the loaded slab would deflect and the effectiveness would be zero.

Influence of Joint Opening

The opening of a control joint depends primarily on the environment and on the spacing between joints. Load transfer effectiveness was determined in the PCA laboratory for joint openings ranging from 0.015 to 0.085 in. Effectiveness decreased as the joint opening became wider. An opening of 0.035 in. or less showed good load transfer effectiveness and endurance. Larger joint openings were less effective at transferring load. Joint openings of 0.025 in. were almost 100% effective.

Concrete in service exhibits less drying shrinkage than laboratory test prisms. Therefore, a reduced shrinkage coefficient can be used to calculate joint spacings that will limit the width of joint openings. For example, if the reduced coefficient is 275 millionths, control joints at 10.5 ft will limit joint openings to 0.035 in. and 7.5 ft will limit openings to 0.025 in. Use a short spacing between joints to limit opening width.

Influence of Slab Thickness

Investigation of the effect of slab thickness on load transfer demonstrated that a thick slab with wider joint openings can be equally as effective as a thin slab with narrow openings. For an effectiveness of 60%, the openings in joints of 7- and 9-in.-thick slabs were 0.025 and 0.035 in., respectively.

Influence of Subgrade Support

While it is true that concrete floors on ground do not necessarily require strong support from the subgrade to successfully carry design loads, strong support from the subgrade (as measured by k value) will increase joint effectiveness. Silts and clays have low support values, that is, $k = 50$ to 100 pci, and hasten the loss of aggregate interlock effectiveness after only a few repetitive loading cycles. Sandy soils with midrange support values of $k = 200$ pci can keep joint effectiveness at an acceptable percentage limit of 50% through one million load cycles. Sand-gravel and cement-treated subbases with high support values, $k = 300$ pci and higher, keep aggregate interlock effectiveness at high percentages through one million load cycles.

Influence of Load Magnitude

Light loads of 5000 lb or less usually cause little or no joint deterioration and probably do not need to be considered. Significant differences in aggregate interlock effectiveness, however, develop under repetitive heavy loads. Effectiveness decreases as the magnitude of load increases. Joints that successfully provide load transfer for one load condition may break down under a new, heavier load condition.

Influence of Aggregate Shape

Aggregate interlock is more effective in load transfer when the aggregate is crushed gravel or crushed stone rather than natural gravel. The higher effectiveness is attributed to the angularity of the coarse crushed aggregate particles.

How to Improve Load Transfer Across Joints

The ability of a joint to effectively transfer repetitious loading will be improved by

Keeping a small joint opening, 0.035 in.
Increasing the slab thickness
Strengthening the subgrade support
Using an angular coarse aggregate
Using dowel bars

Doweled Control Joints

In most industrial and commercial floors on ground, two mechanisms are used to help transfer moving loads across joints: keyways and dowels.

A keyed joint is made by attaching a beveled strip of wood, or a preformed key, to the bulkhead against which the slab is cast. The depression left in the edge of the slab after the bulkhead is stripped is coated with bondbreaker and then filled with concrete when the next slab is placed, thus, in theory, keying the slabs together. But in practice a keyed joint does not always remain tight. As the floor slabs shorten due to drying shrinkage, the key loses contact with its matching recess. Then as loads roll over the joint, the slab edges deflect. This loss of load transfer is an inherent weakness of keyed joints, especially in heavily loaded floors.

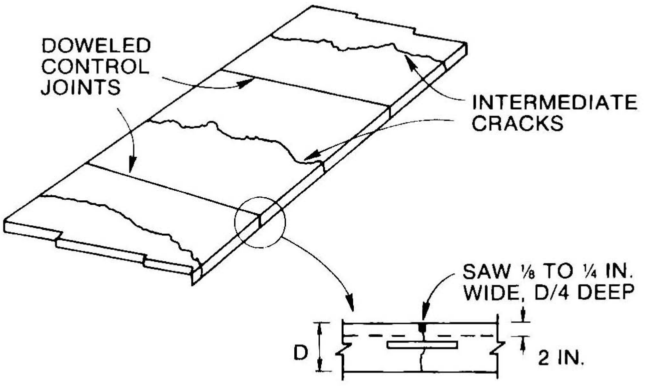
The other method of load transfer—steel dowels—seems to work better. The dowels continue to distribute the load after the slabs shrink and pull apart. As noted previously, control joints that open wider than 0.035 in. are less than 100% effective at transferring wheel loads across the joints in a concrete floor. However, dowels can be used to supplement the load transfer produced by aggregate interlock.

Placed at middepth in the slab, dowels resist shear as loads cross the joint and thus help to reduce deflections and stresses at the joint. Dowels should be smooth round steel bars conforming to ASTM A615. Recommended dowel dimensions and spacing are in Table 7.

Dowels should be free to move longitudinally in their slots to accommodate joint movements due to expansion or contraction of the concrete slab. Accordingly, before delivery to the jobsite, at least one-half of each dowel bar should be coated with a bondbreaking substance such as one coat of lead or tar paint. If this is not done, lubricants must be applied in the field to reduce friction. Plastic dowel sleeves may be used instead of coating.

Dowels in Reinforced Slabs

In floor slabs reinforced with distributed steel for crack control, the control joints are usually spaced too far apart—more than 15 ft— to gain much benefit from aggregate interlock. Load transfer at these joints can be enhanced by using dowels (see Fig. 19).



FILL JOINT WITH SEALANT HAVING MINIMUM SHORE A HARDNESS OF 80 (ASTM D2240)

Fig. 19. Reinforced (mesh-dowel design) floor slab.

The integrity and serviceability of intermediate random cracks that may occur between control joints is ensured by the distributed steel in reinforced slabs. But the distributed steel must be properly sized, located 2 in. below the slab surface, and discontinued at all control joints in order to keep intermediate cracks tightly closed and ensure aggregate interlock for effective load transfer at the cracks.

Since dowels are designed to slip, permitting slab movement at the joints, they must be accurately aligned parallel to the floor surface and the centerline of the slab.

REINFORCEMENT FOR FLOORS ON GROUND

Is reinforcement necessary?

NO
- WITH UNIFORM SUPPORT AND SHORT JOINT SPACING

YES
- WHEN LONG JOINT SPACING IS REQUIRED
- WHEN JOINTS ARE UNACCEPTABLE IN FLOOR USE

When a long joint spacing is selected to minimize the number of joints (shrinkage cracks may occur within the panel) or when joints are unacceptable in floor use, then distributed-steel reinforcement is placed in the slab.

The primary purpose of reinforcement in a slab on grade is to hold tightly closed any cracks that may occur between the joints so that aggregate interlock can function. It does not prevent cracking nor does it increase significantly the load-carrying capacity of the floor. Since critical flexural stresses occur in the top as well as the bottom of concrete floors, the steel would have to be placed in two layers to resist the stresses. To illustrate, if the relatively small amount of reinforcement normally used in floor slabs could be placed near both the top and bottom of the slab, in a 6-in. slab the load-carrying capacity would be increased by approximately 3%.

The amount of steel reinforcement needed can be determined by the traditional subgrade-drag method as in pavement design. This method provides sufficient steel area to resist the tensile stress carried by the steel across cracks that develop as a result of subgrade restraint to slab movement. The formula to determine the amount of steel per linear foot is

$$A_s = \frac{FLw}{2f_s}$$

in which

A_s = cross-sectional area of steel, in square inches per linear foot of slab.

F = coefficient of subgrade friction. (Designers use 1.5 or 2.0 for pavements; 1.5 is recommended for concrete floors on ground.)

L = slab length (or width if appropriate) between free ends, in feet. (A free end is any joint free to move in a horizontal plane.)
w = weight of slab, in pounds per square foot. (For regular weight concrete, designers use 12.5 pounds per inch of floor thickness.)
f_s = allowable working stress of reinforcement, in pounds per square inch. (The working stress of steel is usually 0.67 or 0.75 times the yield strength of the steel in pounds per square inch.)

The values shown in Fig. 20 were calculated by the subgrade-drag method. A value of 0.75 of the yield strength was used because the consequences of a reinforcement failure are much less important than in normal reinforced concrete structural work.

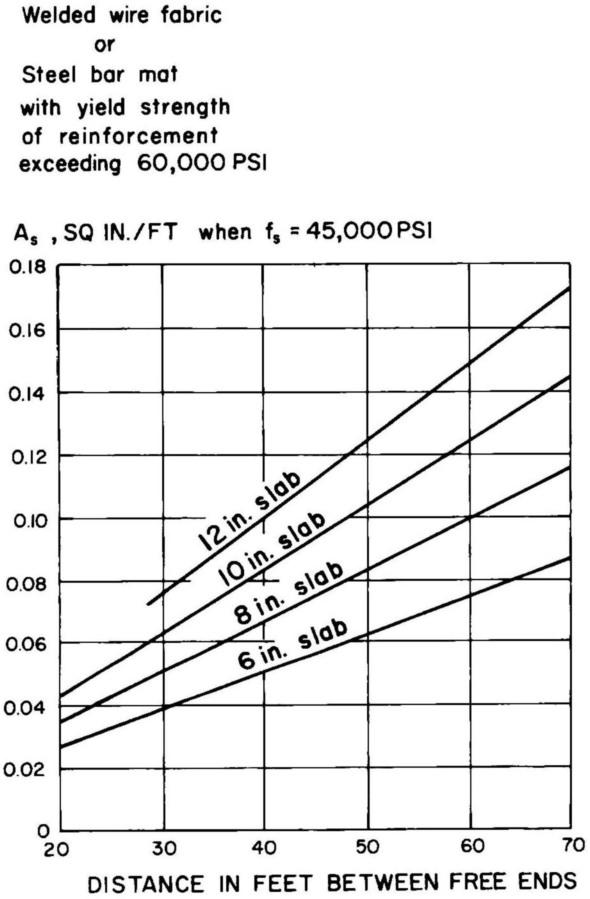


Fig. 20. Selection chart for distributed steel.

UNJOINTED FLOORS

An unjointed floor can be constructed when joints are unacceptable. Three methods are suggested:

1. A prestressed floor can be built through use of post-tensioning, a method in which steel strands are pulled taut after the concrete hardens to put a compressive stress in the concrete. This will counteract the development of tensile stresses and provide a crack-free surface. Large areas, 10,000 sq ft and more, can be constructed in this manner without joints.
2. Concrete made with expansive cement can be used to offset the amount of drying shrinkage to be anticipated after curing. Control joints are not needed when construction joints are used at intervals of 40 to 120 ft. Large areas, to 20,000 sq ft, have been cast in this manner without joints.
3. Large areas can be cast without control joints when the amount of distributed steel is about one-half of 1% of the cross-sectional area of the slab. Special effort should also be made to reduce subgrade friction in floors without control joints.

CONSTRUCTION

Workmanship

All parties—owner, designer, contractor—must agree prior to bidding on the level of quality or class of workmanship that will be necessary for the floor job they want. A good concrete floor on ground is the result of sensible planning, careful design and detailing, complete specifications, proper inspection, good workmanship, and the good intentions of each person sharing responsibility for the end result.

Subgrades

Good construction begins with a well-prepared subgrade. Many floor problems can be traced to poor subgrade preparation. A poorly compacted and prepared subgrade ranks high as a cause of settlement cracking and failure to carry the applied loads.

The subgrade should be uniform, firm, and free from all sod, grass, humus, and other rich organic matter as these materials will not compact to give good support to the floor. Subgrade support should be reasonably uniform with no abrupt changes from hard to soft spots within the floor area. To construct a reasonably uniform subgrade, special care must be taken to ensure that there is control of the three major causes of nonuniform support: (1) expansive soils, (2) hard spots and soft spots, and (3) backfilling.

The subgrade must be brought to within required tolerances at the specified grade and level. The use of laser alignment tools to control grading operations will make the surface as level as possible; or a scratch templet can be used to reveal high and low spots. Occasionally a choker fill should be added to bind the surface before final compaction with a vibratory roller, heavy-plate vibrator, or a tandem roller. A reasonably accurate, level subgrade will ensure that the correct thickness of concrete is placed. If the surface is too uneven, concrete will be wasted and the potential for random cracking will be increased. The subgrade should be moist when concrete placement begins (Fig. 21).

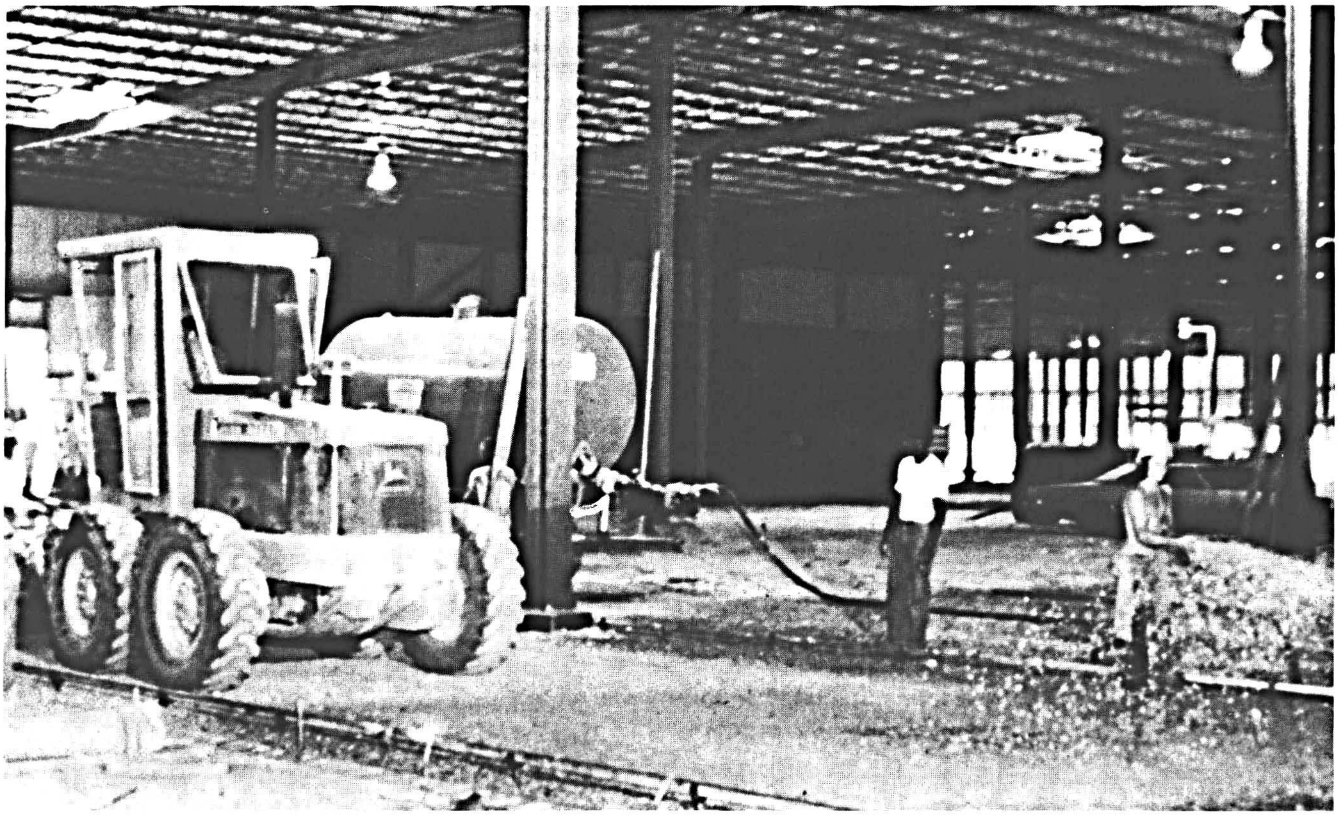


Fig. 21. Subgrade must be moist when concrete is placed.

Expansive Soils

Excessive differential shrinkage and swelling of expansive soils causes heaving in the subgrade and creates nonuniform support. As a result, the floor slab may become distorted and crack. Compaction of highly expansive soil when it is too dry can lead to detrimental expansion and softening of the subgrade as it takes on moisture with time. If an expansive-soil subgrade is too wet when the slab is cast, subsequent drying and shrinkage of the soil can cause settlement and leave the slab edges unsupported and likely to crack under applied loads.

Selective grading, crosshauling, and mixing of subgrade soils make it possible to obtain uniform conditions in the upper part of the subgrade. Compaction at 1% to 3% above standard optimum moisture* minimizes subgrade weakening due to changes in moisture content and gives it relatively uniform stability. Placement of a densely graded blanketing layer (subbase or cushion) on the subgrade will minimize changes in the moisture content of the subgrade and provide a stable working platform for floor construction.

Hard Spots and Soft Spots

To prevent bending and cracking of the slab from subgrade settlement or riding on hard spots and bridging over soft pockets, special care must be taken to dig out hard and soft spots and backfill them with soils similar to those in the surrounding area. The moisture content and density of the replacement soil should be as similar as possible to the adjacent soils. At the edges of the area, the replacement soil should be intermixed with in-place soil to form a gradual transition zone.

Backfilling

Backfilling at footings, foundations, and utility trenches should consist of soils like those surrounding the trench and should be compacted or consolidated in moderate layers. Every attempt should be made to restore as much as possible the original uniformity of the subgrade.

Subbase or Cushion

A satisfactory floor on ground can be built without a subbase, but a subbase is frequently used as a leveling course for fine grading and a cushion that will equalize minor surface irregularities and contribute to uniform support. It also serves as a capillary break between the floor slab and a subgrade that is water soaked most of the time.

Where a subbase is used, the floor contractor should place a 4-in.-thick layer of material. The subbase should

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*ASTM Designation: D698

be fine-graded and compacted to maximum density immediately before placing concrete. Unless the subbase is well compacted, it is better to leave the subgrade uncovered and undisturbed. Subgrades and subbases can be compacted with small portable vibrators and rollers. Hand tampers can be used in confined places. On large floor projects, compaction equipment similar to that used in highway or airport construction can be used.

Vapor Barrier

Many of the moisture problems associated with floors on ground can be minimized or eliminated by proper preliminary grading, correct selection of fill or subbase materials, and installation of a vapor barrier.

A vaporproof barrier should be placed under all concrete floors on ground that are likely to receive an impermeable floor finish or used for any purpose where the passage of water vapor through the floor is undesirable.

Good quality, well-consolidated concrete at least 4 in. thick is impermeable to the passage of liquid water from the ground unless the water is under considerable pressure; but concrete several times that thick is not impermeable to the slow passage of water vapor.

Water vapor normally passes through the concrete and evaporates at the top surface if it is not sealed. Floor coverings such as linoleum, felt- or fabric-backed compositions, cork tile, carpet, wood, and synthetic surfacing effectively seal the moisture within the slab where it eventually may cause problems with the covering. When furniture, boxes, pallets, and other objects are placed on a floor lacking a vapor barrier, moisture can condense beneath them, causing dampness and mildew.

Vapor-barrier materials with a permeance of less than 0.30 perms are suitable for floor-on-ground construction. Acceptable materials are available in preformed sheets or mastics that will resist deterioration and punctures from subsequent construction operations.

Vapor-barrier material placed directly under the slab also functions as a slipsheet to reduce subgrade drag friction, permitting freer slab movement and reducing cracking in the slab. It will prevent the loss of mixing water down into the subgrade and, therefore, requires a compensating adjustment in the mix design.

A vapor barrier may contribute to the slab's upward warping (curling). A layer of sand below the slab will allow some moisture loss at the bottom of the slab. When a vapor barrier is used, a 3-in.-thick layer of sand should be placed over the vapor barrier to prevent or minimize warping. The sand layer also protects the vapor barrier from puncture during construction operations.

Insulation Under Slabs

Placing insulation under slabs on ground to conserve energy cannot be justified. Tests by the National Bureau of Standards* proved the temperature of the slab averages only 5° F to 6° F below room temperature to within 24 in. of an outside wall. In cold climates, therefore, insulation is needed only at the perimeters of the slab. This practice is recommended by Model Code for Energy Conservation** and other major codes and standards.

Slab Thickness Tolerances

Acceptable thickness tolerances for slab-on-ground construction as stated in ACI 117, Standard Tolerances for Concrete Construction and Materials (Section 2.1.5), are +3/8 in. and −1/4 in. for slabs with cross sections up to 12 in. thick and +1/2 in. and −3/8 in. for slabs of more than 12-in. thickness.

Finishing Concrete Floors

Finishing concrete floors never should be done by inexperienced, unskilled workers. Finishing is a critical task that for best results requires the work of skilled cement masons. Two stages are usually required in producing a finished surface: (1) placing, compaction, and truing (to a rather rough surface) of the struck-off or screeded surface by the use of a hand or power-driven float; and (2) the final compaction and smoothing (to a fine texture) by steel-troweling with a hand or power-driven trowel. If a coarse texture is desired, the steel-troweling may be omitted. A very fine grained (nonslip) swirl finish can be attained by light troweling; a very smooth hard finish is the result of repeated troweling.

There are three basic finishes for a concrete slab surface: screeded, floated, and troweled.

A *screeded* finish is the result obtained when the surplus concrete is removed immediately after consolidation by striking off with a straightedge or templet across edge forms or screeds set as guides. There are instances in building where a screeded finish is all that is needed.

A *floated* finish is normal for outdoor slab surfaces. Floating follows screeding and should not be done until some stiffening has taken place and the water sheen has disappeared. Floating should work the concrete no more than necessary to produce a surface that is level, uniform in texture, and free of foot and screed marks. If a troweled or broomed finish is to be applied, floating should leave a small amount of mortar, without excess water, on the surface to permit effective troweling or brooming.

A *troweled* finish is used on inside floor slabs. Troweling should not be done until after the moisture film and sheen have disappeared from the floated surface and the concrete has hardened enough to prevent an excess of fine material and water from being worked to the surface. Steel-troweling is performed with a firm pressure that will close the open, sandy surface left by floating into a hard, dense, uniform surface free of blemishes, ripples, and trowel marks.

A hard steel-troweled (burnished) finish is a special finish that provides added resistance to abrasion and wear. After the first troweling the surface is troweled again (and

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*BMS Report 103, 1945.

**U.S. Department of Energy, December 1977.

again) until it has a somewhat polished (glossy) look.

A fine-textured, swirl finish that is not slick can be obtained by retroweling the surface with the trowel held flat and moved in a circular motion immediately after the first regular troweling.

A steel-troweled floor has increased strength near the surface and therefore greater wear resistance. Steel troweling helps the cosmetic appearance and provides a surface that is easier to clean.

Industrial and commercial floor slabs should have a troweled finish. There are no compelling reasons to trowel finish an outdoor slab. If a light broom finish is wanted, broom the surface after troweling it. If a rough broom finish is desired, rough broom over a floated finish.

Concreting Procedures

Floors cast under the protective cover of a tight roof with the building sidewalls in place are apt to be better constructed than floors cast out of doors. Outside work can be adversely affected by the weather (sun, heat, cold, wind, and rain) and have a greater risk of future problems such as cracking, crazing, curling, and surface dusting.

The semimanual methods recommended here for placing, consolidating, and finishing concrete floors require the use of mechanical equipment for striking off, compacting, and finishing.

Edge Forms

The surface-finish tolerance of the floor slab depends on careful setting of the edge forms and temporary intermediate screed guides with the use of a leveling device. Edge forms and screed guides must be supported firmly by wood or steel stakes driven solidly into the ground to prevent any movement during mechanical strikeoff and consolidation. Loose edge forms cause uneven floors. Temporary screed guides that are not positively positioned can be displaced, causing uneven floors. All forms should be straight, free from warping, and of sufficient strength to resist concrete pressure without bulging. Edge forms should be full slab depth and continuously supported on the compacted subgrade or subbase; for this reason steel road-type forms are preferred. Vibratory strikeoff and compaction equipment slides easily on a steel surface. A form release agent must be applied to the forms before concreting for easier form removal.

When a continuous vapor barrier is required under the floor slab, special care is needed to place the barrier sheet correctly under the edge forms before the pins are driven.

Positioning Reinforcing Steel

Reinforcing bars or welded-wire fabric (wire mesh) are used in floor slabs for crack control. In order for reinforcing bars or mesh to bond properly with the concrete, they should be free of mud, oil, or other coatings that would adversely affect the bonding capacity. The reinforcement should be placed at or above the center of the slab—2 in. below the surface is suggested—and if it is to function properly for crack control, some failproof way must be used to hold it in that position. Reinforcement can be supported on chairs, slab bolsters, or small concrete bricks and blocks. Support accessories for wire mesh must be more closely spaced than for reinforcing bars. The practice of laying the mesh on the subbase or subgrade before concrete is placed and hooking it up into position after concrete has been placed is not recommended because this gives no assurance that the mesh will stay in the concrete in straight lengths or on a true plane at the correct distance below the surface.

Flat-sheet mesh can be placed by the sandwich method in two-course work. This involves first placing a layer of concrete struck off 2 in. below the finished grade. The mesh is laid on this layer and then the top 2-in. layer of concrete is placed. Work must be completed quickly so that the top layer is placed while the bottom is still plastic.

Flat-sheet fabric can be depressed into the slab by what is termed walking in. The concrete is placed full depth and struck off. The flat sheet is then placed on the surface and the finishing crew carefully walks on it, forcing it into the concrete. Accurate positioning of the steel fabric is difficult with this method.

Wherever dowels or tiebars are placed in joints, they must be accurately aligned and spaced and held parallel to the surface during concreting.

Placing and Spreading

Rutted or marred subgrade or subbase surfaces must be regraded and recompacted before placing concrete. There are several ways to place fresh concrete where it is needed, including directly from a truck mixer's chute, by buggy on wooden ramps, by crane with bucket, by conveyor belt, or by pump.* Concrete should be placed continuously as closely as possible to its final position and slightly above the top of the edge forms or screed guides. It is then spread with shovels, special concrete rakes, or come-alongs. Air is trapped in the concrete during mixing and placing, and this air must be removed by consolidation.

Striking Off and Consolidating

Concrete is brought to its initial level and surface by the first operations of strikeoff, consolidation, and darbying or bullfloating. Striking off is best done with mechanical equipment riding on the side forms (Figs. 22, 23, and 24). Where surface tolerance is important, the strikeoff lane width should be limited to 20 to 24 ft. The limited width makes it possible to bullfloat and use a crossrod or straightedge more accurately.

Surface vibration is recommended for slabs of up to 8-in. thickness. When floors contain heavy reinforcement and conduit or when they are thicker, internal spud vibrators must also be used, or the slab should be placed in layers while the concrete remains plastic. When a thick slab has been compacted by internal vibrators, final compaction of the surface should be done with a beam- or

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*See *Transporting and Handling Concrete*, Portland Cement Association publication IS178T, 1974.

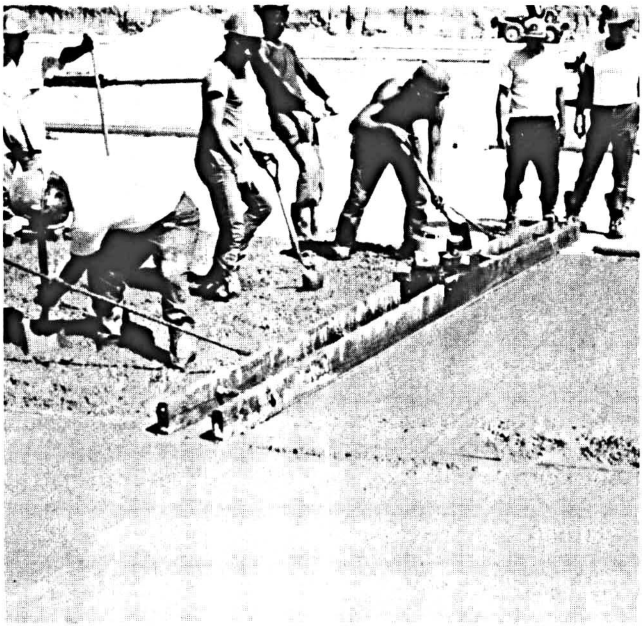


Fig. 22. Strikeoff can be done with a double-beam vibratory screed.

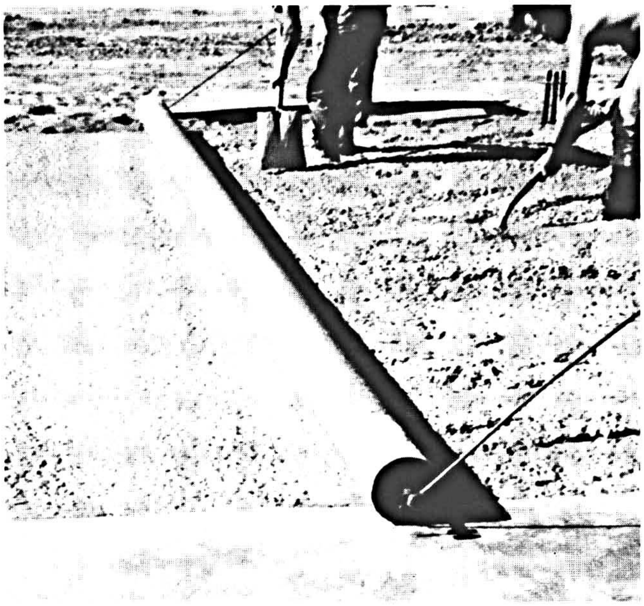


Fig. 23. A roller screed can be used to strike off and level the concrete.

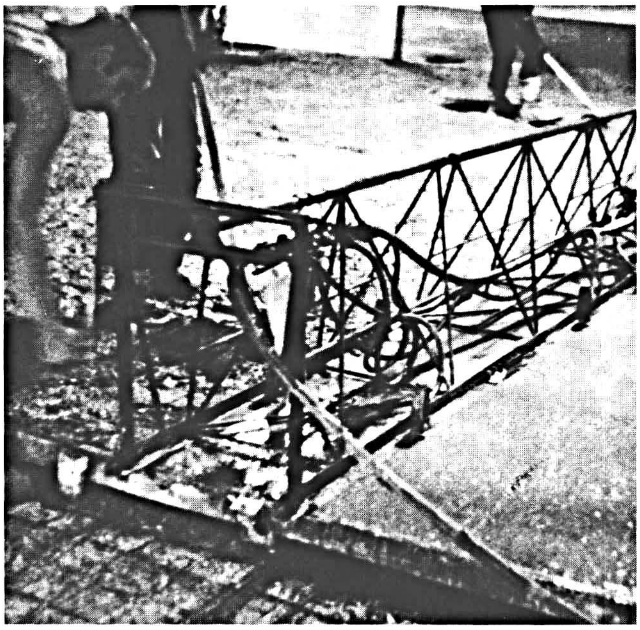


Fig. 24. After strikeoff with vibratory equipment, the surface may be ready for finishing without darbying or bullfloating.

truss-type surface vibrator. The initial strikeoff and consolidation of the concrete will have a greater effect on surface tolerances and levels than subsequent operations of floating and finishing. The secret of proper strikeoff and compaction is to maintain an adequate surcharge of concrete at the screed face; a 6-in.-thick slab needs a surcharge of about 1 in.

Strikeoff and consolidation must be completed before any excess water bleeds to the surface. If power-driven equipment is used properly to strike off low-slump concrete, the surface will be ready for edging and finishing with power floats and trowels with very little handwork necessary.

Leveling

Bullfloating to bring the surface to the specified level (Fig. 25) should immediately follow screeding and must be completed before any bleed water is present on the surface. *Any finishing operation performed while there is excess moisture or bleed water on the surface can cause surface defects.* This is the basic rule of concrete finishing and it cannot be overemphasized. One of the purposes of the bullfloat is to eliminate ridges and fill in surface voids left by striking off and consolidating. In addition, it should slightly embed the coarse aggregate. This prepares the surface for subsequent edging, floating, jointing, and troweling.

Darbying is done for the same reason as bullfloating, that is, to correct small irregularities and smooth out ridges left by striking off (Fig. 26). Because of its long handle, the bullfloat is easy to use on a large area, but the length of the handle detracts from the leverage, so that close tolerances are difficult to achieve. The bullfloat may slightly depress the surface near an edge form and a darby must then be used to relevel the surface.

Where close tolerances are required, a scraping straightedge can be used to advantage. Minor surface irregularities and excess laitance are removed by scraping with a 10-ft straightedge (Fig. 27). It should be used with a smooth, continuous action to float the surface; a jerky, cutting action is used only for removing high spots. Each pass should overlap one-half the length of the previous pass. Surface smoothness should be checked as late in the finishing operations as possible but while the concrete is

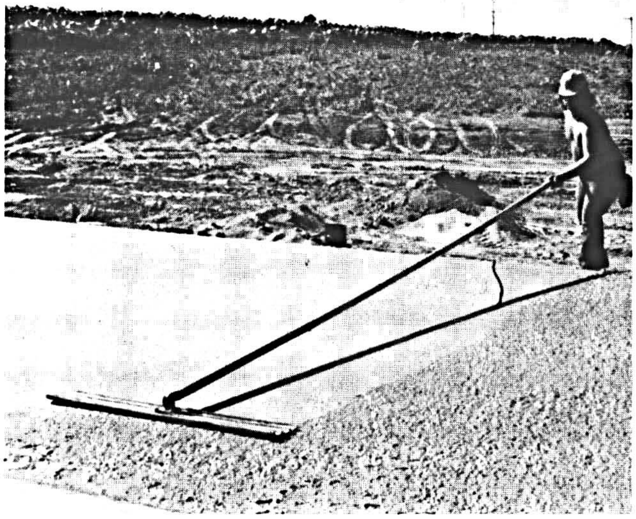


Fig. 25. Bullfloating corrects small irregularities and smooths out ridges.

Fig. 26. Darbying brings the surface to the specified level.

still plastic enough to permit surface corrections. Testing is done by lifting and lowering a checking straightedge in successive positions.

A slight stiffening of the concrete is necessary before proceeding with finishing operations. Depending on job conditions, it is usually necessary to wait for a time. No operation should follow until the concrete will sustain foot pressure with only about ¼-in. indentation (Fig. 28).

Edging

Edging may be required along isolation and construction joints. The purpose is to densify the concrete at the edge of the slab, making it more durable and less vulnerable to spalling and chipping. Edging should be done when all bleed water has left or been removed from the surface. Before running the edger, the concrete should be cut away from the forms with a pointed mason's trowel or margin trowel (Fig. 29). An alternative to using an edging tool at construction joints is to lightly grind the edges with a silicon carbide stone after the forms are stripped and before the adjacent slab is placed.

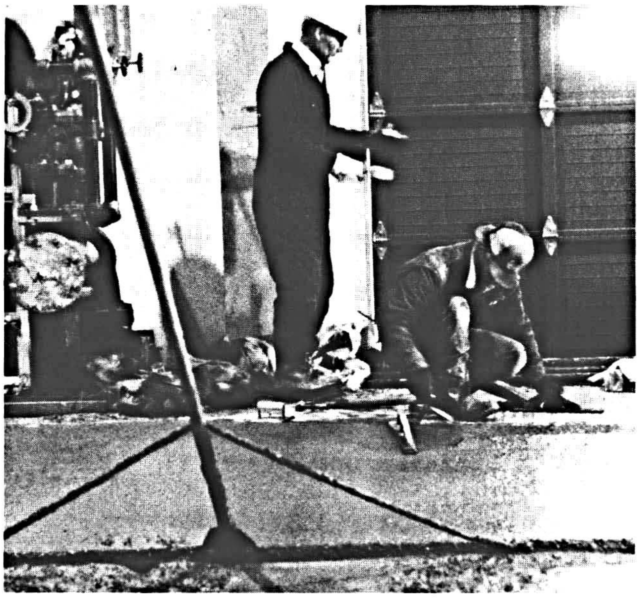


Fig. 27. A scraping straightedge removes minor surface irregularities and excess laitance.

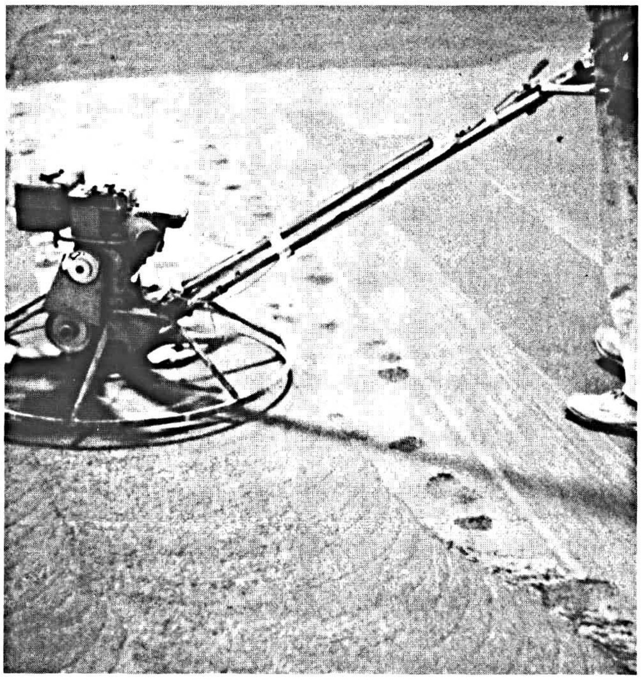
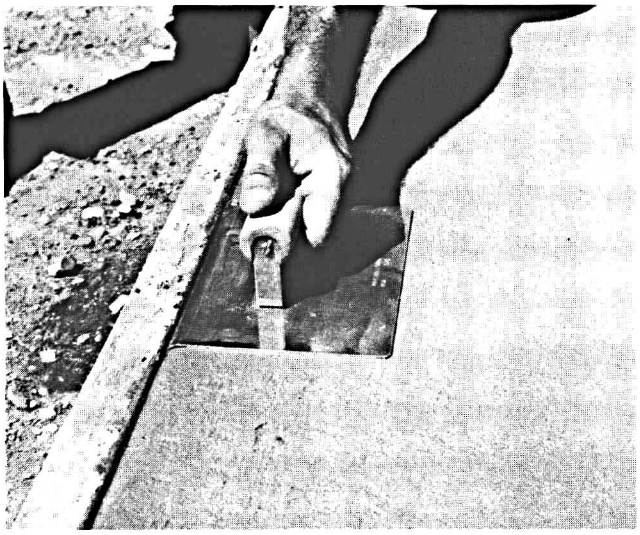


Fig. 28. Floating is begun when the water sheen has disappeared and the weight of a person leaves only a slight indentation on the concrete surface.

a



b

Fig. 29. Edging densifies the concrete at the edge of the slab: (a) cutting away with a margin trowel, (b) running the edger.

Floating

Floating has four purposes: (1) to depress large aggregates to just slightly beneath the surface; (2) to remove slight imperfections and even out humps and voids for a level or plane surface; (3) to compact the mortar at the surface in preparation for later finishing operations; and (4) to keep the surface open so excess moisture can escape.

Floating the stiffened concrete is done by machine. Either a power float with rotating steel disc or a troweling machine equipped with float blades is used almost flat on the surface. Changes in concrete temperature, air temperature, relative humidity, and wind make it difficult to set a definite time to begin floating. In cold weather, it might be 3 hours; in hot weather, the concrete may stiffen very rapidly. However, when the water sheen has disappeared, when the concrete will support the weight of a person (leaving a footprint with only a slight indentation on the surface), and when mortar is not thrown by the rotating blades, the concrete is ready to be floated (Fig. 28). Floating should start along walls and around columns and then move systematically across the surface, leaving a matte finish.

Marks left by the edger should be removed by floating. During the interval between power-floating and the first power-troweling, a steel hand trowel should be used along the edges to give an improved surface and keep the concrete level with the side forms.

Jointing

While the edging is being done, or immediately after, the control joints should be made unless they are to be sawed. Jointing is a most important finishing step since proper jointing can eliminate unsightly random cracks.

Control joints can be made with a hand groover, a preformed insert, or a power saw. The joint should extend into the slab one-fourth of the slab thickness. A cut this deep weakens the slab and induces a crack to form beneath the joint where it is inconspicuous.

There are few instances in industrial and commercial floor work when a hand groover is used to make joints, however when used its thin bit must be deep enough to cut the slab one-fourth of the depth. An alternative is to press a preformed insert into the fresh concrete until the top is flush with the surface; finishing operations can then continue.

On large floors it is more convenient to cut joints with a power saw fitted with an abrasive or diamond blade (Fig. 30). Again, saw cuts must be one-fourth the slab

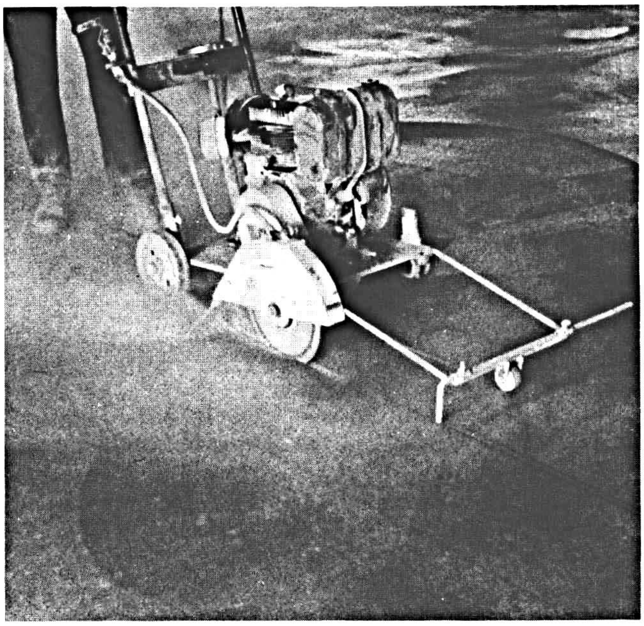


Fig. 30. Control joints can be made by a power saw. These joints induce straight-line cracking at predetermined locations.

thickness. Sawing usually begins as soon as the surface is firm enough so that it will not be torn or damaged by the blade, usually within 4 to 12 hours after the concrete hardens.

The method of constructing control joints must relate to the service use of the floor. Wide joints and inserts, for example, may perform poorly under small hard wheels.

Troweling

A power trowel is like a power float except that it is fitted with smaller, individual steel-trowel blades that can be tilted slightly to exert pressure on the surface. Generally, greater tilt will produce a smoother, more dense, burnished slab surface.

Power-troweling should start when the excess moisture brought to the surface by initial power-floating has evaporated and the concrete is not sticky (Fig. 31). The waiting time between floating and troweling depends upon the absence or presence of an admixture in the concrete and the atmospheric condition at the surface.

Fig. 31. Power troweling is begun when excess moisture brought to the surface by floating has evaporated and the concrete is not sticky. Two or more passes frequently are required.

Power-troweling should be done in a systematic pattern. Two or more passes frequently are required to increase the compaction of fines at the surface and give greater resistance to wear. Time must be allowed between each troweling for the concrete to stiffen and the water sheen to disappear. The tilt of the trowel blades should be increased with each pass to exert additional pressure as the concrete hardens. Each successive troweling should be made in a direction at right angles to the previous pass.

Curing

Curing the concrete has a significant influence on the strength, wear resistance, final quality, and performance of the wearing surface. When done correctly, curing reduces the risk of cracking, crazing, curling, and dusting.

The purpose of curing is to maintain favorable conditions under which concrete hardens and continues to gain strength and wear-resistance by keeping it moist and warm for a fixed period of time. A concrete floor slab has a large exposed surface area in relation to its volume. This means that water will evaporate very quickly from an unprotected surface causing early drying and leaving a weak, cracked, crazed, dusting floor. Prompt and adequate curing, therefore, is mandatory. The slab should be continuously moist-cured for at least 7 days. A longer period is desirable.

Three alternate methods of curing are suggested:

1. Wet-cure by fully covering the surface with wet burlap as soon as it can be placed without marking the surface (Fig. 32). Keep the burlap continuously wet and in place as long as possible.

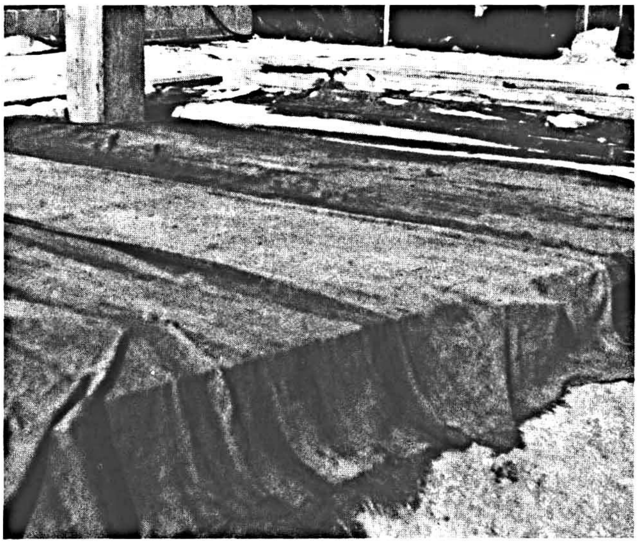


Fig. 32. One method of wet-curing is to completely cover the surface with wet burlap, keeping it continuously wet during the curing period.

2. Wet-cure by fully covering the previously wetted surface with plastic sheeting or waterproof paper as soon as it can be placed without marking the surface (Fig. 33), and keep in place as long as possible.
3. Seal the slab surface and edges by spraying a liquid-membrane-forming curing compound on the finished surface. The curing compound should be a type that leaves no permanent discoloration on the surface and does not interfere with the application of any subsequent surface treatment or overlay.

A combination of these methods can be used. For example, a cover of burlap, plastic, or paper can be kept on for 5 days and then a liquid-membrane-forming curing compound can be applied so that the concrete will dry out slowly and extend the period of curing.

Fig. 33. Wet-curing can also be done by covering the previously wetted surface with plastic sheeting for as long a period as possible.

When moist-curing is completed, the concrete should not be subjected to forced or rapid drying out. Drying out should be a long, slow process.

The surface of a newly completed floor slab should be protected. Subsequent construction activities must not be allowed to damage the surface through neglect and carelessness. These rules should be followed:

1. Keep foot traffic off for 1 day.
2. Keep light, rubber-tired vehicles off for 7 days.
3. Leave plastic or waterproof-paper curing sheets in place as long as possible.
4. Protect the surface with sheets of hard board where heavy traffic is expected.

Acceptable Surface Tolerances

ACI 302, Guide for Concrete Floor and Slab Construction, gives four classes of surface finish tolerances:

Class AA Surface Finish Tolerance. Depressions in floors between high spots shall not be greater than ⅛ in. below a 10-ft-long straightedge.

Class AX Surface Finish Tolerance. Depressions in floors between high spots shall not be greater than 3/16 in. below a 10-ft-long straightedge.

Class BX Surface Finish Tolerance. Depressions in floors between high spots shall not be greater than 5/16 in. below a 10-ft-long straightedge.

Class CX Surface Finish Tolerance. Depressions in floors between high spots shall not be greater than ½ in. below a 10-ft-long straightedge.

When an especially flat, smooth floor is required (at increased cost), limits can be set for deviations from datum and tolerances across joints. For example, for large open areas, ½ in. from end to end and side to side can be tolerated. In other words, the entire floor surface would fall within a plane of ±½ in. from the datum floor elevation shown on the building plans. The tolerance across a joint should be 1/12 in. Surface irregularities can be measured with a profilograph floor-contour-measuring instrument. The instrument can be used to monitor placing and finishing techniques on a day-to-day basis.

High-density industrial warehouses using high-rise-storage racks and high-lift-turret trucks require especially flat floor surfaces for efficient operation. Known as super-flat floors, the differences in elevation of the surface of these slabs must be minimal over distances of from as little as 12 in. to as much as 10 ft, often a maximum of 1/32 in. in the former and ⅛ in. in the latter. Since construction of such closely toleranced floors can be expensive, the exact requirements for a project must be established through consultation between the handling equipment manufacturer, owner, and specifier, and then clearly outlined in the job specifications along with the method of measurement as well as corrective techniques (usually grinding) to bring an out-of-tolerance area back to a satisfactory degree of flatness.

SPECIAL FINISHES FOR CONCRETE FLOOR SLABS

A variety of methods and proprietary products are available that will, in specific instances, improve wear resistance or chemical resistance, reduce dusting, or improve the appearance and ease of maintenance of concrete floors.

The finish and the method of obtaining it depend largely on how the floor is to be used. Manufacturers' directions should be closely followed, but first the floor surface must be of good quality before treatment, otherwise the benefits will be short lived.

Dry-Shake Finishes

Wear resistance can be improved for light-to-medium-wear floors or heavy-wear floors by embedding into the concrete surface a selected natural or metallic aggregate, usually blended with portland cement. The procedure can be as follows. For light-to-medium wear, after floating the surface, apply half of the shake quantity and float it in. Wait for the concrete to set hard enough to resist a heel imprint, then apply the remainder of the shake and power steel trowel the surface.

For heavy-wear floors, apply one-third of the shake quantity immediately after strikeoff. Wait for bleed water to disappear, then apply the second third of the shake and float it in. Wait for the concrete to partially harden enough to resist a heel imprint, then apply the remaining shake material and power steel trowel to a dense, hard surface. Shake finishes require special skills and should be entrusted only to experienced craftsmen.

High-Strength-Concrete Toppings

Where close tolerances are needed or abrasive conditions require concrete of exceptionally high strength, it becomes economic to apply a deferred concrete topping. Toppings are put in place before the base slab hardens (monolithic) or after hardening (separate).

Monolithic Toppings

The thinnest topping can be used, between ½ in. to 1 in., consequently the base concrete slab should be placed and compacted to leave the surface below the finished level by this amount. The topping concrete then is placed and vibrated while the base remains plastic. In this way the topping becomes part of the structural thickness of the slab. Construction procedures, panel sizes, joints, and jointing arrangements are the same as those specified for the slab itself.

Separate Bonded Toppings*

Separate bonded toppings ¾ to 1½ in. thick** are applied after the base structural slab has hardened. A fully bonded topping is considered a part of the structural thickness of the floor because the base slab and the topping act together as a monolithic slab. Thickness is based on the flexural strength of the base slab. Being thin, these toppings have little load-carrying capacity of their own and their satisfactory performance depends upon their being fully bonded to the base slab. The slab must be roughened with the coarse aggregate exposed, blown clean of dust and debris, and dampened. Immediately before the topping concrete is placed, a 1:1 cement-sand slurry or a neat cement paste, each of a creamy consistency, should be brushed into the surface. The topping must be placed before the slurry dries out.

High-strength-concrete-topping mixes (monolithic or bonded) should be made with special aggregates selected for hardness, surface texture, and particle shape that will produce concrete with a hard, wear-resistant finish.

These toppings should have high strength, low shrinkage, and finished surfaces that are resistant to abrasion and not slippery—properties achieved by limiting the aggregate-cement ratio and the type of aggregate selected. A water-cement ratio of 0.40 (by weight) or less, an aggregate-cement ratio of 3 (by weight), and good-quality coarse aggregate with a natural sand have proved to be suitable.

Separate Unbonded Toppings*

Unbonded toppings are used when the existing floor slab is cracked or otherwise not suitable to receive a fully bonded topping. The base slab should be covered with a separation sheet of polyethylene or waterproof paper to ensure there is no bond between the existing and new concrete. A minimum thickness of 3 in. is recommended, but for floors subject to very heavy moving loads or severe impact, a 6-in. thickness is suggested for the topping. Joints in the new topping can be laid out in panels to the most suitable size and shape, taking into account the thickness of the topping and the amount of reinforcement provided (if any). Isolation joints in the base slab, however, should be extended up through the topping.

Vacuum Dewatering

Vacuum dewatering of the floor slab immediately after placing and compaction is a method of reducing water content in the concrete. The process quickly prepares the surface for final finishing and can reduce shrinkage of the concrete, increase compressive strength, and improve the wear resistance of the slab surface.

A vacuum system consists basically of a plastic-sheet top cover and a bottom filter cloth of nylon netting that are placed over the fresh concrete immediately after striking off and leveling. The top sheet is fitted with suction channels leading to a single vent connected to the vacuum generating unit. The system is claimed so effective that water is drawn out of the concrete down to a depth of about 10 in. at an extraction rate of about 2½ minutes for each 1 in. of slab thickness.

Surface Grinding

Surface grinding is a technique that claims to eliminate dusting of the floor surface due to laitance brought to the surface by the troweling. The concrete is placed, compacted, and brought to as true a surface as possible by bullfloating and a scraping straightedge. Instead of further finishing in the usual way, the surface is immediately covered with polyethylene sheets and cured for 36 to 48 hours. The sheets are then removed and the entire surface is ground with a special machine. The low-speed grinding action removes all laitance, leaving a smooth, hard, durable surface. For best results, high-quality concrete must be used.

Sealing Concrete Floors

Floor sealing products are not floor finishes, but are mentioned here since they are a means of upgrading a floor's wear resistance, reducing dusting, and improving chemical resistance. Sealer products normally used are based on sodium silicate or a type of silicofluoride. It is important to note that these products will not convert a poor-quality floor into a good-quality floor.

Sodium Silicate (Water Glass)

The cement hydration reaction that takes place during curing produces hydrated lime [$Ca(OH)_2$] within the concrete that is converted to calcium carbonate after prolonged exposure to air. When a dilute solution of sodium metasilicate (Na_2SiO_3) soaks into the surface, the silicate reacts with calcium compounds to form a hard,

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*See also *Resurfacing Concrete Floors*, Portland Cement Association publication IS144T, 1981.

**Minimum and maximum recommended by ACI 302.

glassy substance within the pores of the concrete. This new substance fills the pores and after drying gives the concrete a denser, harder surface. The degree of improvement is dependent upon the depth of penetration by the silicate solution. Therefore, the solution is diluted significantly to allow adequate penetration.

The treatment consists of three or four coats applied on successive days. On new concrete, a period of air-drying for 10 to 14 days after moist-curing ends gives a reasonably dry surface to gain maximum penetration. The first coat should be a solution of 4 gal of water to 1 gal of silicate. The second coat should be the same solution applied after the first one has dried. The third coat should be a 3-to-1 solution applied after the second coat has dried. The treatment is completed as soon as the concrete surface gains a glassy, reflective finish. Water-glass treatment will stop dusting, improve hardness, and increase resistance to chemical attack, such as from organic acids.

Silicofluorides

Zinc, sodium, and magnesium silicofluoride sealers are applied in the same manner as water glass. Each of the fluoride compounds can be used separately or in combination, but a mixture of 20% zinc and 80% magnesium gives excellent results. For the first application, 1 lb of the fluoride compound should be dissolved in 1 gal of water. For subsequent coatings, the solution should be 2 lb to each gallon of water. The floor should be mopped with clear water shortly after the preceding application has dried to remove encrusted salts. Safety precautions must be observed when applying fluorides owing to the toxicity of the fluorine salts. Fluoridation of concrete surfaces increases the chemical resistance and hardness of the surface.

Linseed Oil

One of the oldest proved techniques to protect exterior concrete slab surfaces from cycles of freeze-thaw and deicer chemicals is a linseed-oil treatment. The treatment consists of two or more applications of commercial-grade boiled linseed oil mixed with a solvent such as mineral spirits. The first application should be a mixture of equal parts of oil and solvent applied on a dry surface with a coverage of 400 sq ft per gallon. The second application can be from one-half to full-strength oil applied to cover 600 sq ft per gallon after the first treatment has been absorbed. Linseed oil-water emulsions also are available.

Floor Coatings

Numerous synthetic floor coatings are available such as epoxies, polymers, polyurethanes, chlorinated rubbers, and phenolics. These products in appropriate circumstances offer good abrasion and chemical resistance and also can be pigmented for attractive color.* The manufacturer's directions must be followed closely.

Seamless Floor Surfacings

Various types of plastic-reaction products (that is, two-part mixes that harden in place by chemical reaction) and plasticized synthetic resin are used as seamless surfacings on concrete floors. The three principal systems used for these products are polyesters, polyurethanes, and epoxies.

Resin suppliers can adjust their formulations to suit a particular application. Whatever the variations made, each has been found to have its own limitations, peculiarities, and special uses. A factor common to all three is the need for a good-quality, well-constructed floor slab and for attention to detail in application.

Polyesters have a high shrinkage factor that limits their use to systems where this volume change can be easily controlled. They have good adhesion as well as good wear resistance.

Polyurethanes are suitable for use in clear, decorative, multicoat systems. They require a dry floor, which means a considerable drying period must follow moist-curing before these products are applied.

Epoxies are made from a wide range of resins and hardeners and are available in a wide variety of products. They possess hardness, high strength, good bonding strength, and chemical resistance. They are available as paints—pourable or flow applied—and as mortars.

REPAIRS AND OVERLAYS

Correct design, quality materials, and good construction should produce a floor that theoretically will be free of major maintenance. In actual use, however, conditions arise that expose the concrete to chemical attack, mechanical impact, and abrasive wear not anticipated in the design. If good maintenance practices are neglected, the floor may never provide the long-life serviceability for which it was intended.

Normal maintenance cleaning will keep the floor attractive, safe to work on, and free of harmful chemicals and abrasive objects. When a floor slab becomes badly worn with broken areas or utility cuts and spalling at cracks and joints, countless materials and methods are available for repairs as well as a wide divergence of views on how the repairs should be made. In many instances, expediency dictates that the work be done without adhering to correct basic principles and the result is an unsatisfactory repair.

The basic principles of successful repairs include determining the cause and extent of the damage, careful preparation of the old concrete, the placement and curing of high-quality replacement concrete, and rejointing where needed. The information and recommendations that follow are a guide to obtaining satisfactory results.

Evaluation of Damage

Evaluation of damage is necessary not only to determine the method of repair to be used but also to ensure that the

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*For information on painting concrete, see *Painting Concrete*, Portland Cement Association publication IS134T, 1980.

repair will be permanent and the damage will not extend into the concrete surrounding the repaired area. Following are the principal factors to be considered before making a final decision on repair:

1. The general condition of the floor slab,* that is, loss of slab support, strength and thickness of the concrete, the extent of badly worn areas, joints, cracks, and contamination of the surface by oil or grease, paint, chemical attack,** and staining.†
2. Intended use of the floor after repair—which may be quite different from its previous or present use.
3. Limitations to raising the level of the finished floor.
4. Time allowed for repair work.

Preparation of Old Concrete

Surface preparation is vital to production of a satisfactory concrete repair. Irrespective of materials, method, system, or thickness to be used, the keystone of success is a clean, strong bonding surface with a suitable mechanical key that is free of contamination, laitance, and dust. Selection of a suitable method of surface preparation can be made from the following:

Cleaning Concrete Floors

Wet Cleaning. A floor can be brought to an acceptably clean standard by wet cleaning. Two materials, one acid based and the other alkali based, are commonly used in three separate operations: (1) degreasing, (2) acid treatment, and (3) neutralizing. Cleaning operations should be performed only under conditions where appropriate safety precautions are taken.

Degreasing is accomplished by a mixture of a cleaner and curing-compound remover (a chlorinated, emulsifiable solvent), an industrial grease remover (a highly alkaline, low-phosphate, biodegradable detergent), and liberal amounts of water. The mixture is used to scrub the surface—repeatedly if necessary—for added cleaning effect. The surface finally is rinsed and scrubbed with clear water, vacuumed damp-dry, and then allowed to air-dry.

Acid treatment of the surface is accomplished by applying an etching solution (a mild organic acid combined with detergents, emulsifiers, and solvent) to the *dry* floor. The solution is scrubbed over the floor, followed by a vacuum machine to pick up residual material. The surface is then rinsed, scrubbed clean of acid solution, and dried.

Neutralization of the surface for any residual acid is necessary. This is done by wetting the surface with clear water, sprinkling on a detergent cleaner (highly alkaline, high-phosphate, nonresidue detergent), scrubbing, rinsing with water, and vacuuming damp-dry. The surface is then rinsed again with clear water, vacuumed damp-dry, and allowed to air-dry before applying the new surface finish.

An acid treatment is recommended only for cleaning floor surfaces that are to receive a new surface finish.

Other wet cleaning methods include high-pressure water-jet blasting and steam cleaning. Selection of method depends on the type and severity of contamination.

Drycleaning. Mechanical methods offer an efficient and economical way to dryclean a concrete surface. Equipment is available for scabbling, scarifying, grinding, shotblasting, planing, and flame cleaning. Some machines have a variety of interchangeable cutting and brushing heads.

Scabbling uses an air-driven machine that has a varying number of pistons mounted in a block. Each piston is fitted with a tungsten carbide bit. Operating much the same as a bushhammer or chipping hammer (Fig. 34), the striking action shatters away the surface contamination, exposing a clean, sound concrete with a good mechanical key for bonding.

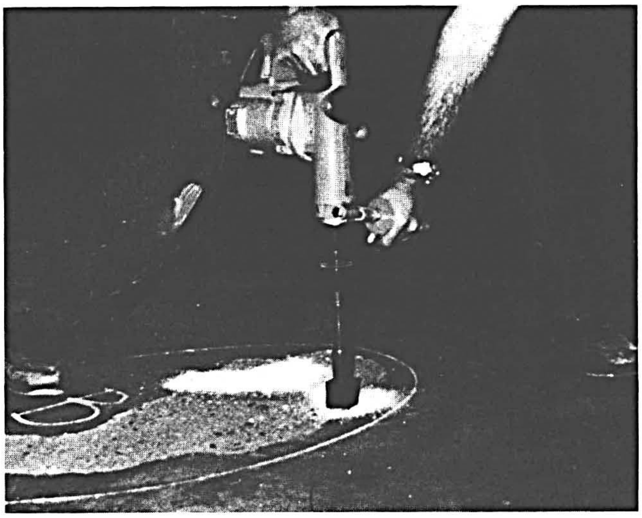

Fig. 34. Weak, defective concrete can be removed with a chipping hammer.

Scarifying uses a power-driven tool with a rotary head that can be fitted with a wide variety of scrubbing brushes, cutting wheels, scouring brushes, and steel scarifying brushes.

Grinders can be used to remove weak, friable laitance; improve levels; and remove high spots and trowel and other marks. Grinding also can be used to produce a smoother, more wear-resistant floor.

Shotblasting is done by closed-cycle steel-particle bombardment that is virtually dust-free to remove any surface contaminants.

Planing machines can remove laitance, paint marks, pitch adhesives, and thermoplastic adhesives and can reduce the level of the concrete. Other uses include grooving the concrete and making nonskid surfaces. The machines have hardened-steel cutting wheels for hammering off the surface.

***How to Prevent Concrete Slab Surface Defects*, Portland Cement Association publication IS177T, 1977.

***Effects of Substances on Concrete and Guide to Protective Treatments*, Portland Cement Association publication IS001T, 1981.

†*Removing Stains and Cleaning Concrete Surfaces*, Portland Cement Association publication IS214T, 1982.

Flame treatment involves moving a multiflame blowpipe with an oxygen-acetylene flame over a floor surface at a uniform speed. Oils, paints, and other organic substances are burned away, moisture in the surface of the concrete is evaporated, and the surface layer is melted or spalled off. The treatment removes laitance to a depth of 0.04 to 0.08 in.

After drycleaning a concrete surface, all residue must be removed. Various industrial vacuum machines are available to remove microdust particles from the prepared surface.

Concrete Overlays

When surface wear has reached a point considered detrimental to building operations, action is required to rebuild and restore the original surface. The choice of repair method depends on cost, volume of the repair area, acceptable downtime, required strength, required chemical and abrasion resistance, and ambient conditions while repair is under way. The resurfacing methods available can be classified as those using—

1. Normal or high-early-strength portland cement concretes and mortars
2. Polymer- and resin-modified portland cement concretes, that is, PVA- and latex-modified concrete.
3. High-alumina-cement concrete and mortar
4. Plastic concretes, that is, resin-bound mortars—usually epoxy or polyester based in two-component systems

Following are basic recommendations for repairing concrete floors with normal or high-early-strength portland cement concretes and mortars.

Bonded Patching* (¾ to 2 in. Thick)

Surface preparation is the key to producing a well-bonded, shallow concrete patch. Failure of a patch to tightly bond usually is due to a lack of preparation so that bond is prevented by laitance, dust, and contamination on the floor surface.

All weak and defective concrete must be removed, preferably by saw-cutting ¾ in. deep around the perimeter of the patch, followed by removal of defective concrete with a jackhammer not heavier than the nominal 30-lb class. Chipping hammers not heavier than the nominal 15-lb class can be used to remove concrete surrounding any reinforcing bars. Handtools such as hammers and chisels should be used to remove all final particles of unsound concrete. Sandblasting or water-jet blasting should be used to clean the exposed reinforcement of all visible rust and clinging concrete and clean all surfaces against which new patch concrete will be placed. Prior to placing new concrete, the surface should be blown clean by airblast and then flushed with water. Puddles of free water must be removed before placing the patch.

Just before the new concrete is placed, the cleaned surface should be brushed with a thin (⅛-in.) coat of freshly mixed grout consisting of sand, cement, and water. This bonding grout should have equal parts of fine sand (No. 8 maximum size) and portland cement mixed with water to give a creamy consistency.** Neat cement grout (without sand) also may be used. The grout should be applied at a rate that will keep it from drying out before it is covered with new concrete.

Mix Proportions for Patching Concrete. When normal or high-early-strength portland cement is used for the repair, the mix proportions for concrete and mortar should be as follows:

Mortar (for patches less than 1 in. thick):
  1 part portland cement
  2½ to 3 parts sand
Concrete (for deeper patches):
  1 part portland cement
  2½ parts sand
  2½ parts coarse aggregate—maximum size about one-half the patch depth

The materials are proportioned to make a low-slump mix using not more than 5 gal of water per bag of cement (a water-cement ratio not to exceed 0.44 by weight). Exterior concrete subjected to freeze-thaw cycles and deicer chemicals needs an adequate system of air entrainment with a 5% to 7% total air content (9% for mortar). Where rapid reuse of the patched area is needed, calcium chloride, not to exceed 2% by weight of cement (added to the mixing water at the jobsite), can be used to accelerate hardening and early-strength gain of the concrete.

CAUTION: Calcium chloride should not be used when dissimilar metals or electrical conduit are encased in the concrete.

Placing and Finishing the Concrete. Some type of surface vibration is mandatory for compacting surface patches. A hand-operated vibratory screed or strikeoff is effective as is a portable plate vibrator or compactor float. Hand tampers can be used when power equipment is not available.

New concrete should be placed and struck off slightly above the final grade and then mechanically vibrated, screeded, and floated to final grade. When a stiff, low-slump mix is used, there will be no water gain on the surface and troweling can begin immediately. Troweling should not be done when there is free water on the surface and should not be done to the extent that free water will be brought to the surface. When the surface has become quite hard, it should be given a second and third troweling to produce a very hard, dense finish.

Curing. Evaporation of water from thin-concrete patches is rapid and if not prevented immediately after the concrete is finished, rapid evaporation may cause surface crazing, cracking, and curling. Rapid drying can be prevented by covering the patch with wet burlap. The

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*Bonded patching applies to relatively small areas on the concrete surface. The basic principles are the same for large areas, but large areas can be repaired more efficiently with customary mechanical finishing equipment supported on guide rails. Such construction is called thin-bonded resurfacing rather than patching.

***Bonding Concrete or Plaster to Concrete*, Portland Cement Association publication IS139T, 1976.

surface should be kept continuously wet for 24 hours, and then covered with polyethylene film or waterproof paper for an additional 48 hours. Ambient conditions (hot or cold, dry or humid, calm or windy) dictate the choice of a satisfactory curing method.

Thin Bonded Overlay*

A fully bonded concrete topping can be ¾ in. or more thick, while for unbonded construction the minimum is 3 in. The thickness of overlays limits where they can be used because they raise the level of the floor.

The best surface preparation for a bonded overlay is obtained with one of the drycleaning methods described previously. If contamination is present after drycleaning, then wet-cleaning methods should be used to further cleanse the surface. An effective check for contamination is to sprinkle water on the concrete: if the water forms little globules, contaminants are present that will interfere with bond. If the water is immediately absorbed, it can be assumed that the concrete is clean.

Mix Preparation for Bonded Overlays. Volume proportions are suitable for small patches; but for large resurfacing jobs, weight batching should be used to eliminate variations in quality. The mix design varies, depending upon the depth of concrete to be placed. The water-cement ratio can range from 0.45 to 0.33, using 6 to 9 or 10 bags of portland cement per cubic yard, and producing concrete strengths at 28 days from 4500 psi to 9000 psi. Aggregates can be selected for their hard-wearing and abrasion-resisting qualities. A low-slump concrete, 2 in. to 4 in., generally works well. Adjustments in consistency depend on thickness of topping, temperature, and equipment available to do the work. A water-reducing admixture can improve workability of low-slump concrete, and a superplasticizer can produce high-strength concrete at normal consistencies.

Formwork. The same principles that apply to edge forms in general apply to topping forms. The method of installing and anchoring varies greatly depending on the job conditions. The forms and intermediate screeds must be set to grade and positively anchored in position to maintain a true level.

Laying the Topping. The topping should be placed in small panels. The rate at which this work is completed should not be overestimated. The topping must be well compacted to ensure bond, strength, and durability. On large projects, a self-propelled finishing machine with vibrating screed should be used. On smaller jobs, a manually operated vibratory screed or tamper can give satisfactory results.

Various methods of finishing floor slabs have already been discussed. The new surface must be cured for at least 3 days. One practical and satisfactory method is to cover the surface with polyethylene sheets, with laps sealed and all edges held down. After removing the sheets, an application of curing compound will extend the curing period.

All joints in the original floor must be duplicated exactly in the new topping; that is, they must be located directly over the joints in the original slab and must be of equal or slightly greater width. Duplicating joints can be done without difficulty by placing inserts in the new concrete after screeding the surface. Saw cuts must be timed to avoid reflective cracking from the joint in the old slab below.

Unbonded Toppings

The minimum thickness of an unbonded topping is 3 in. with 6 in. suggested for floors carrying heavy moving loads and subjected to severe impact. The amount of work required to prepare the old slab is negligible, consisting only of sweeping clean and filling in badly worn areas and holes with a cement and sand mortar.

A separation layer should be used to ensure that there will be no bond between the old and new concrete. A 4-mil polyethylene sheet is adequate for this purpose. The separation layer prevents cracks in the old floor from being reflected through into the new topping. It also reduces friction at the interface so that the new topping can move (from drying shrinkage and thermal changes) independently of the floor below.

The concrete mix proportions should be the same as those suggested for bonded toppings or for new floor construction.

Placing and finishing operations are similar to those used to construct a new concrete floor. An unbonded overlay permits control and construction joints in the old slab to be ignored. The new topping can have a jointing arrangement designed for the most convenient panel size and shape, taking into account the thickness of the topping and the amount of reinforcement provided (if any). However, isolation joints in the old slab must be repeated in the new topping.

Repair of Cracks and Joints

Although joints are placed in concrete floors to provide crack control, sometimes problems arise from heavy usage, improper joint design or location, and careless construction methods. The greatest portion of floor maintenance is for crack and joint repair.** The principal causes of distress are

Poor subgrade support
Inadequate load transfer
Floor overloads
Excessive joint spacing
Joint filler failures

When a problem develops, its cause should be found and corrected before any repair is undertaken.

Filling Cracks (Sealing)

Only those cracks that are open wide enough to permit the entry of a pourable joint filler or a mechanical routing

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*_Resurfacing Concrete Floors_, Portland Cement Association publication IS144T, 1981.

**For repair of outdoor paving, storage yards, driveways, etc., see _Maintenance of Joints and Cracks in Concrete Pavement_, Portland Cement Association publication IS188P, 1976.

tool should be filled. Tightly closed cracks subject only to light industrial traffic should be left alone, but kept under observation and filled only if they open up or show signs of spalling.

Each side of the open crack must be refaced so that the surfaces are completely free of dust, dirt, debris, and anything else that might prevent bonding of the new filler material. Special tools such as random-cut saws or crack grinders and vertical-bit routers should be used. The crack should be refaced to a 1-in. minimum depth or its full depth without deepening, whichever is less, and then blown out with compressed air ahead of refilling.

Fig. 35. Joints and cracks that move can be refilled with flexible sealant.

High-strength epoxy resin adhesives should not be used to rebond and seal cracks where subsequent appreciable movement is expected, since this could lead to cracking elsewhere in the floor. A flexible epoxy or an elastomeric filler should be used in cracks that move (Fig. 35).

If further movement is unlikely, a rigid mortar such as cement and sand; cement, sand, and latex; or epoxy and sand should be used. The crack should first be cut out with a special tool and thoroughly cleaned, as described for patching, before the mortar is put in place. The mortar must be thoroughly compacted and cured in a manner suitable to the particular material used.

Refilling Joints (Resealing)

Where joint filler has failed, the old filler must be removed to a depth that will accommodate the new sealant. The same procedures and sealant materials for filling cracks are used for refilling joints.

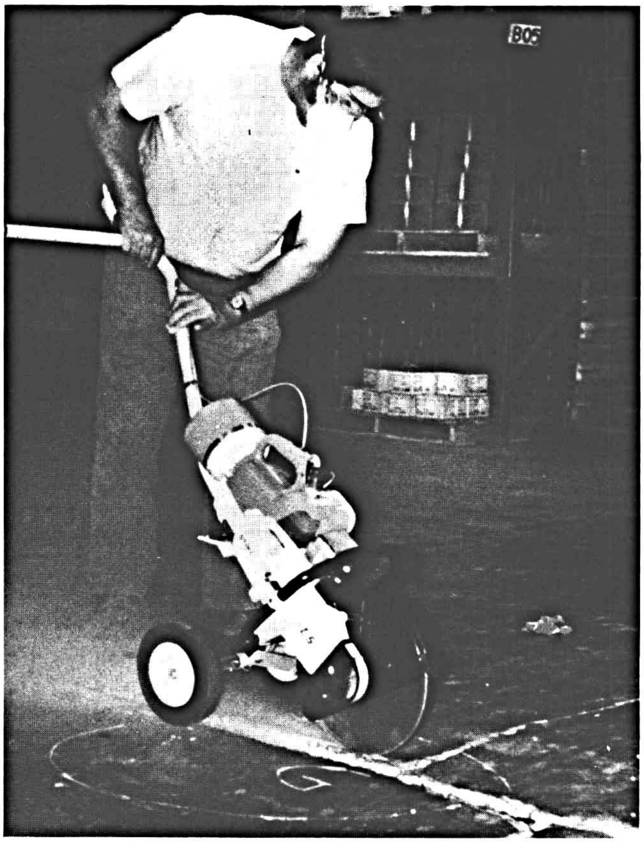

Fig. 36. Spalled concrete at a joint can be removed by cutting with a saw.

Patching Spalls

Spalling is the dislodging of fragments of concrete from the slab at the joint edges, usually from the repeated impact of hard wheels moving across the joint.

The procedures for bonded patching should be used to repair spalls. The spalled concrete should be removed to at least a 2-in.-minimum depth and the area blown clean (Fig. 36). A coating of bonding grout should then be applied and the patching mortar compacted into place, finished, and wet-cured. The joint can be reformed by placing in the joint groove a thin strip of wood, metal, or plastic that has been coated or covered with a bond-breaking material. The patching mix should then be compacted from one or both sides against the form.

Individual spalls that occur on both sides of a joint can also be repaired by patching the entire cavity and reforming the joint with a saw cut as soon as possible after the patch is placed. The joint in the patch must be equal in width to the old opening or slightly wider and it must be to the full depth of the patch to avoid subsequent spalling.

There is a lesson to be learned from the patching and repair of concrete floors: At the time a new building is constructed, it is essential that the concrete work be properly designed and executed and that the quality of the concrete work be correct for the intended use. If the lesson is ignored, great annoyance and expense can arise from the resultant repairs.

Metric Conversions

Following are metric conversions of the measurements used in this text. They are based in most cases on the International System of Units (SI).

1 in. = 25.40 mm
1 sq in. = 645.16 mm^2
1 ft = 0.305 m
1 sq ft = 0.093 m^2
1 sq ft per gallon = 0.025 m^2/L
1 gal = 3.8 L
1 kip = 4.5 kN
1 lb = 0.454 kg
1 lb per cubic yard = 0.5933 kg/m^3
1 pci (or psi/in.) = 0.27 MPa/m
1 psf = 4.88 kg/m^2
1 psi = 0.0069 MPa
No. 4 sieve = 4.75 mm
No. 200 sieve = 75 μm
1 bag of cement (U.S.) = 94 lb = 42.7 kg
1 bag of cement (Canadian) = 88 lb = 40 kg
1 bag per cubic yard (U.S.) = 55.8 kg/m^3

For permeance:
1 perm = 1 grain/h·ft^2 in. Hg = 0.659 metric perm

KEYWORDS: aggregates, bonding, cement content, concrete, construction, curing, design (thickness), doweled joints, fatigue, finishes, forms, grinding, high racks, joints, loads, load transfer, modulus of subgrade reaction, reinforcement, repairs, resurfacing, safety factors, sealing, soil properties, strength, subbase, subgrade, vacuum dewatering, vapor barrier.

ABSTRACT: Revised edition discusses design and construction of large-area concrete floors on ground for commercial and industrial buildings. Factors influencing performance are explained including subgrade support, concrete quality, adequate thickness for applied loads, jointing practice, steel reinforcement, unjointed floors, forming, placing, finishing, curing, special finishes, repairs, and overlays. Emphasis is on proper design and execution of the concrete work.

REFERENCE: *Concrete Floors on Ground* (EB075.02D), Portland Cement Association, 1983.

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RELATED PUBLICATIONS

The publications cited in this text as sources for the procedures presented can be purchased from Portland Cement Association. The following are particularly useful:

Bonding Concrete or Plaster to Concrete (IS139T)
Effects of Substances on Concrete and Guide to Protective Treatments (IS001T)
How to Prevent Concrete Slab Surface Defects (IS177T)
Maintenance of Joints and Cracks in Concrete Pavements (IS188P)
Painting Concrete (IS134T)
PCA Soil Primer (EB007S)
Removing Stains and Cleaning Concrete Surfaces (IS214T)
Resurfacing Concrete Floors (IS144T)
Slab Thickness Design for Industrial Concrete Floors on Grade (IS195D)
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