

Guide to Residential Cast-in-Place Concrete Construction

Reported by ACI Committee 332

The quality of residential concrete is highly dependent on the quality of job construction practices. This guide presents good practices for the construction of foundations, footings, walls, and exterior and interior slabs-on-grade. The concrete materials and proportions must be selected with reference not only to design strength but workability and durability.

The principles and practices described here pertain to: site preparation; formwork erection; selection and placement of reinforcement in walls, slabs, and steps; joint design, location, construction, and sealing; use of insulation; wall concreting practices and safe form stripping; slab finishing practices; curing in all types of weather; and repairing of defects.

Keywords: admixtures; aggregates; air entrainment; compacting; concrete construction; **concrete slabs**; construction joints; control joints; cracking (fracturing); curing; discoloration; drainage; driveways; floors; **footings**; formwork (construction); **foundations**; heat transfer; isolation joints; joints (junctions); mixing; mix proportioning; patios; placing; reinforced concrete; repairs; residential buildings; sawed joints; sealing; sealing; sidewalks; site preparation; skid resistance; **slab-on-ground construction**; slump tests; spalling; standards; surface defects; thermal insulation; tolerances (mechanics); vapor barriers; **walls**; workability.

CONTENTS

Chapter 1-Introduction, page 332R-1

Chapter 2-Requirements for concrete for residential construction, page 332R-2

Chapter 3-Concrete materials, page 332R-4

Chapter 4-Proportioning, production, and delivery of concrete, page 332R-5

Chapter 5-Formwork, page 332R-7

Chapter 6-Reinforcement, page 332R-9

Chapter 7-Joints and embedded items, page 332R-14

Chapter 8-Footings and walls, page 332R-18

Chapter 9-Concrete slab construction, page 332R-21

Chapter 10-Curing, sawing, sealing, and water proofing, page 332R-25

Chapter 11-Repair of surface defects, page 332R-29

Chapter 12-References, page 332R-33

Appendix-Glossary for the homeowner, page 332R-35

CHAPTER I-INTRODUCTION

1.1-Scope

This guide covers cast-in-place residential concrete work for conventional one- or two-family dwellings.* Recommended practices for foundations, footings, walls, and slabs-on-grade (interior and exterior) are included. Earth-sheltered homes are beyond the scope of this report. Specific design provisions for reinforced concrete beams, columns, walls, and framed slabs are not included, because they should be designed by a registered professional engineer.

1.2-Objective

Recommended practices are provided in this guide for those people engaged in construction of residential concrete work. Also compiled are acceptable details, standards, and code provisions assembled in one document, which are intended to assist home builders, contractors, and others in providing quality concrete construction for one and two family dwelling units.

Implementation of the recommendations in this guide should result in acceptable quality concrete construction significantly free from scaling, spalling, and cracking of driveways, walks, and patios; leaking of basement walls; and dusting, cracking, and undue surface deviations of floor slabs.

ACI Committee Reports, Guides, Standard Practices, and Commentaries are intended for guidance in designing, planning, executing, or inspecting construction and in preparing specifications. Reference to these documents shall not be made in the Project Documents. If items found in these documents are desired to be part of the Project Documents, they should be phrased in mandatory language and incorporated into the Project Documents.

*For any residence using concrete floors above the first story, see ACI 301. For building with concrete masonry, see ACI 531 for building code requirements. These are explained in detail in the commentary, ACI 531R, and specifications are given in ACI 531.1. For design and construction with precast concrete units, see ACI 512.2R.

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1.3-Standard specifications and recommended practices

American Concrete Institute (ACI) standards are referenced in this guide by number, for example, as ACI 211.1. Specifications of other organizations such as the American Society for Testing and Materials (ASTM) and Federal agencies are also referred to by number only, for example, as ASTM C 94. Full titles of these referenced documents are provided in [Chapter 12, References](#).

CHAPTER 2-REQUIREMENTS FOR CONCRETE FOR RESIDENTIAL CONSTRUCTION

2.1-General

Concrete for residential construction involves a balance between reasonable economy and the requirements for workability, finishing, durability, strength, and appearance. The required characteristics are governed by the intended use of the concrete, the conditions expected to be encountered at the time of placement, and the environmental factors affecting use of the product.

2.1.1 Workability

Workability includes placeability, consistency or “wetness,” and finishing characteristics. Good workability means concrete can be placed, consolidated, and finished satisfactorily.

2.1.2 Durability

Durability is the capacity of the concrete to resist deterioration due to weathering and traffic. This may include exposure to freezing and thawing, wetting and drying, heating and cooling, seawater, soluble sulfates in the soil, and chemicals such as deicers and fertilizers.

2.1.3 Strength

Minimum compressive strength of concrete in pounds per square inch (megapascals) at 28 days is the property usually specified for most concrete work. It is easily measurable and indicates other desirable characteristics. Proportioning for and achievement of a proper specified level of compressive strength is usually assurance that such associated properties as tensile strength and low permeability will be satisfactory for the job.

When concrete must have a specialized design, it may be necessary to specify the strength that will be required at some particular early age. For example, for post-tensioned concrete, strength at seven days may have to be specified or else strength at the time of actual post-tensioning.

However, durability may be the controlling factor in determining quality of concrete. Specified design strength alone does not always assure adequate resistance to deterioration by freezing and thawing cycles, sulfate attack, or seawater exposure. A well-proportioned air-entrained mix is always essential to attain adequate durability.

2.2-Selecting concrete

[Table 2.2](#) is a guide for use in selecting concrete strengths adequate for use in low-rise residential construction. The first consideration in using this table is to identify the design environmental exposure conditions to be resisted. Three exposures-severe, moderate, and mild-are described, together with the required strength of concrete and typical applications. Weathering areas are based on [Fig. 2.2](#). Air-entrained concrete may be needed ([Section 2.2.1](#)), and for all slabs it is necessary for the concrete producer to supply concrete of adequate finishing characteristics ([Section 2.2.3](#)).

Table 2.2-Guidelines for selecting concrete strength

Minimum compressive strength f'_c at 28 days

Type or location of concrete construction	Regional Weathering Areas ^a			Nominal slump, ^c in. (mm)
	Mild ^b	Moderate ^b	Severe ^b	
	f'_c , psi (MPa)	f'_c , psi (MPa)	f'_c , psi (MPa)	
Basement walls and foundations not exposed to weather	2500 (17)	2500 (17)	2500 (17)	6 ± 1 (150 ± 25) ^d
Basement slabs and interior slabs on grade	2500 (17)	2500 (17)	2500 (17)	5 ± 1 (125 ± 25) ^d
Basement walls, foundations, exterior walls, and other concrete work exposed to weather	2500 (17)	3000 (21) ^e	3000 (21) ^e	6 ± 1 (150 ± 25) ^d
Driveways, curbs, walks, patios, porches, steps and stairs, and unheated garage floors, exposed to weather	2500 (17)	3000 (21) ^e	3500 (24) ^e	5 ± 1 (125 ± 25) ^d

^aSee Fig. 2.2 for weathering areas.

^bConcrete should be proportioned to produce the design strength at the slump which will be used. Extra water, above the amount in the design proportions, should not be added, since it would reduce the strength.

^cWhere local experience shows a history of satisfactory performance and where local codes permit, lower-strength concrete [f'_c = 2000 psi (14 MPa) but not less], may be used.

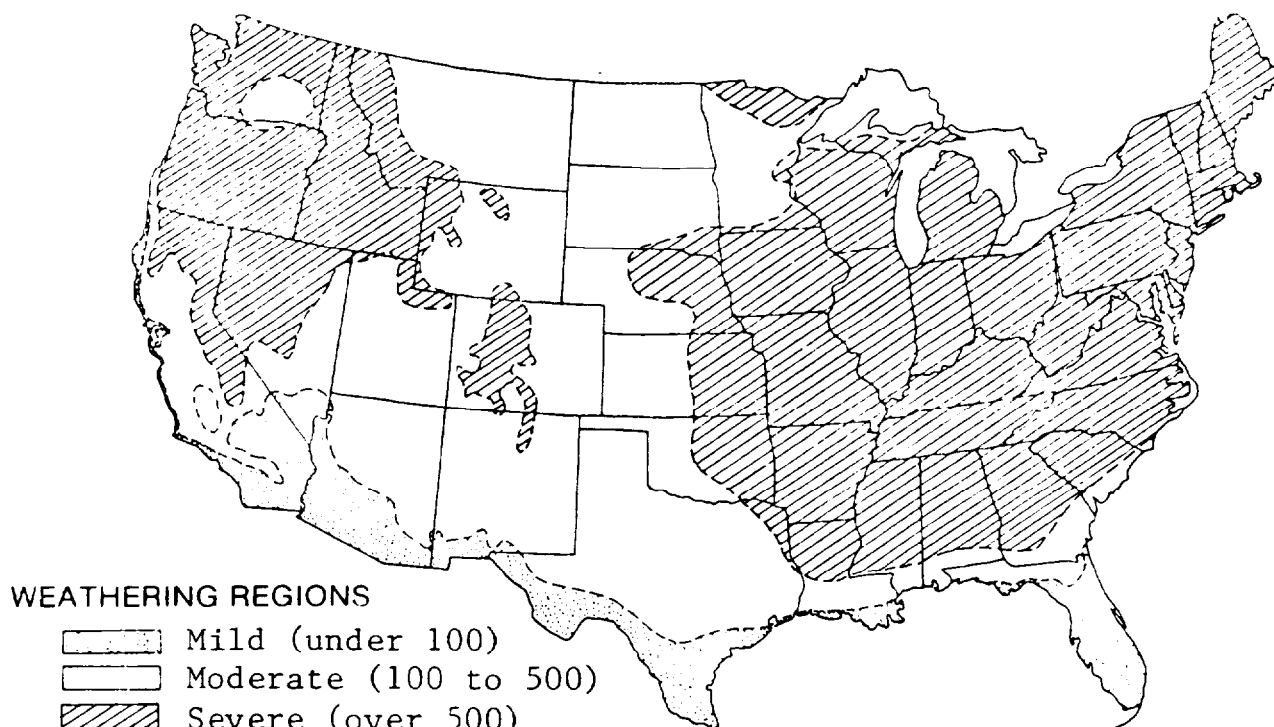
^dAir-entrained concrete as recommended ([Table 2.2.1](#)).

^eStandard Test ASTM C 143 should be used to measure slump. Slump for lightweight aggregate concrete should not exceed 3 in. (75 mm).

^fWhen water-reducing, set-controlling admixtures are used to produce flowing [7 in. plus (175 mm plus) slump] concrete, all the required qualities of concrete expected should be maintained.

^gExperience has shown that use of f'_c = 4000 psi (28 MPa) in areas subject to use of deicer salts, rather than the minimum f'_c shown, gives superior durability.





The weathering index for any locality is the product of the average annual number of *freezing-cycle days* and the average annual *winter rainfall* in inches, defined as follows:*

A *freezing-cycle day* is any day during which the air temperature passes either above or below 32 F (0 C). The average number of freezing-cycle days in a year may be taken to equal the difference between the mean number of days during which the minimum temperature was 32 F or below and the mean number of days during which the maximum temperature was 32 F or below.

Winter rainfall is the sum, in inches, of the mean monthly corrected precipitation (rainfall) occurring during the period between and including the normal date of the first killing frost in the fall and the normal date of the last killing frost in the spring. The winter

rainfall for any period is equal to the total precipitation less one tenth of the total fall of snow, sleet, and hail. Rainfall for a portion of a month is prorated.

The map indicates general areas of the United States in which concrete is subject to severe, moderate, and mild weathering. The severe weathering region has a weathering index greater than 500. The moderate weathering region has a weathering index of 100 to 500. The mild weathering region has a weathering index of less than 100.

*Data needed to determine the weathering index for any locality may be found or estimated from the tables of Local Climatological Data, published by the Weather Bureau, U.S. Department of Commerce.

Fig. 2.2-Weathering indexes in the United States

Table 2.2.1 -Recommended air content for normal weight concretes for various exposures*

Nominal maximum size aggregate		Typical air contents of non-air-entrained concretes, percent	Recommended average air content, percent, for air-entrained concretes ^b		
in.	mm		Mild exposure ^c	Moderate exposure	Severe exposure
3/8	10	3.0	4.5	6.0	7.5
1/2	13	2.5	4.0	5.5	7.0
3/4	19	2.0	3.5	5.0	6.0
1	25	1.5	3.0	4.5	6.0
1 1/2	38	1.0	2.5	4.5	5.5

*See Fig. 2.2 and Table 2.2 for descriptions of exposures.

^bTolerance on air content ± 1.5 percent.

^cTo prevent scaling or spalling, any concrete that is likely to be exposed to freezing in a saturated condition should have the air content indicated. This includes concrete that will remain uncovered, as in an open basement, during a winter season in a northern climate.

^dAir entrainment used to improve workability and cohesiveness.

The values set forth in the table are necessary since an inadequate air content in outdoor flatwork in moderate or severe climates can lead to surface scaling, especially if deicers are used on the surface (Section 11.2.2). The table also gives air contents for mild exposures; entrained air is not required in concretes for mild exposures, but it is sometimes useful for improving workability and cohesiveness in mixes that might otherwise be too harsh.*

Air-entrained concrete can be achieved through the use of commercially available air-entraining agents or the use of air-entraining cement. It is recommended that concrete mixes be specifically proportioned for air entrainment because addition of air-entraining admixtures to mixes already having sufficient fines can lead to concrete finishing problems (Section 4.1.1).

2.2.1 Air-entrained concrete

Concrete that will be subjected to severe or moderate exposures should contain entrained air in accordance with the values given in Table 2.2.1.

*For additional information on the effect of air entrainment, see ACI 212.1R, Chapter 4, and ACI 212.2R, Chapter 3.

2.2.2 Concrete for sulfate resistance

Types of cement and water-cement ratios suitable for concrete resistant to sulfate attack are given in Table 2.2.2. Sulfate concentration can be determined by laboratory tests.

2.2.3 Finishing characteristics

One of the keys to a good quality surface for a slab is concrete with good finishing characteristics. This means that there must be a good balance between the amount of coarse and fine materials so that the mix is neither too harsh nor too sticky. The mix should be proportioned to stiffen neither too rapidly nor too slowly at the temperature it will be used. For a discussion of proportioning, see [Section 4.1.1](#).

2.2.4 Testing concrete

To verify that the delivered concrete meets the proper specifications, the purchaser may want to request a certified copy of the mix proportions.

Testing of concrete is not normally done on small residential work. On projects with a sufficient number of homes, the purchaser may want to employ a testing laboratory to test the slump, compressive strength, and (if applicable) air content.

CHAPTER 3 - CONCRETE MATERIALS

3.1 - Ingredients

Concrete consists of four basic ingredients. A fifth ingredient (admixture) may be added to modify the concrete as described in [Sections 3.1.5](#) and [3.1.6](#). The materials* are

- Portland cement
- Sand (fine aggregate)
- Gravel or crushed stone (coarse aggregate)
- Water
- Admixtures (chemical and/or mineral)

3.1.1- Cement

Cement with water acts as the paste that bonds together the aggregate particles to form concrete. Cement used in residential concrete is usually portland cement Type I or II, or air-entraining portland cement Type IA or IIA. Blended cements, if available, made by combining portland cement with pozzolan, or blast furnace slag, may also be used. These cements are designated Type IP or IS, or (if air entrained) IP-A or IS-A. In geographic areas where aggregate is reactive with alkalis, low-alkali cements should be used (see also [Section 3.1.6](#)).

For moderate sulfate exposure (150-1500 parts soluble sulfates per million) and seawater, Type II, IP-MS, or IS-MS is recommended. For severe exposures (over 1500 parts soluble sulfates per million), Type V cement may be required.

3.1.2 - Sand (fine aggregate)

Sand for use in concrete should meet the requirements of ASTM C 33. A clean sand, to be suitable, should not contain harmful quantities of organic mat-

Table 2.2.2-Recommendations for normal weight concrete subject to sulfate attack

Exposure	Water soluble sulfate (SO ₄) in soil, percent	Sulfate (SO ₄) in water, ppm	Cement	Water-cement ratio, maximum ^a
Mild	0.00-0.10	0-150	—	—
Moderate ^b	0.10-0.20	150-1500	Type II, IP (MS), IS (MS)	0.50
Severe	0.20-2.00	1500-10,000	Type V	0.45
Very severe	Over 2.00	Over 10,000	Type V + Pozzolan	0.45

^aA lower water-cement ratio may be necessary to prevent corrosion of embedded items.

^bSeawater also falls in this category.

^cUse a pozzolan which has been determined by tests to improve sulfate resistance when used in concrete containing Type V cement.

ter, clay, coal, loam, twigs, branches, roots, weeds, or other deleterious materials. For aggregates that are reactive with cement, low-alkali cement should be used and, in some cases, a mineral admixture ([Section 3.1.6](#)) as well.

3.1.3 - Gravel or crushed stone (coarse aggregate)

Coarse aggregate for use in residential concrete should meet the requirements of ASTM C33. It may range in size from a ½ in. (13 mm) maximum size to a 1½ in. (38 mm) maximum size, depending on the application. Generally, the larger the aggregate size, the more economical the concrete mixture will be. However, concrete with smaller coarse aggregate is easier to handle and finish. For aggregates that are reactive with cement, low-alkali cement should be used and, in some cases, a mineral admixture ([Section 3.1.6](#)) as well.

3.1.4 - Water

Almost any water that is drinkable and has no pronounced taste or odor is satisfactory as mixing water for making concrete.

3.1.5- Chemical admixtures

Chemical admixtures, or air-entraining admixtures, may be added to concrete to achieve certain desirable effects such as

- Reduction in the quantity of mixing water needed.
- Increase in workability at the same water and cement content without loss of strength.
- Acceleration of the set of the concrete.
- Retardation of the set of the concrete.
- Entrainment of proper quantities of air for both durability and workability.⁺

If an admixture containing chloride ion is used in concrete containing reinforcing steel or other embedded metal, or is used in concrete placed on metal deck, the amount of water-soluble chloride ion should conform to the limits set forth in [Table 3.1.5](#).

*Specifications for ingredients are portland cement, ASTM C 150; blended cement, ASTM C 595; sand, gravel, and crushed stone or structural lightweight aggregate, ASTM C 33 or ASTM C 330; and admixture, ASTM C 260, ASTM C 494 and ASTM C 618.

⁺For additional information on chemical, mineral, and miscellaneous admixtures, refer to ACI 212.1R and ACI 212.2R.

Table 3.1.5—Maximum chloride ion content for corrosion protection

Category of concrete service	Maximum water-soluble chloride ion (Cl ⁻) ^a in concrete, percent (by wt) of cement
Prestressed concrete	0.06
Reinforced concrete that will be exposed to chlorides in service, such as sea-retaining walls	0.15
Reinforced concrete that will be dry or protected from moisture in service	1.00
Reinforced concrete that will not be exposed to chlorides but may be wet in service	0.30

^aTest concrete at 28- to 42-day age.

3.1.6 - Mineral admixtures

Natural pozzolans, fly ash, and blast furnace slag are admixtures that may be used in concrete for such purposes as increasing strengths at later ages, reducing excessive expansion due to alkali-silica reaction, or as a source of additional fines when required in the mix to improve workability.

CHAPTER 4-PROPORTIONING, PRODUCTION, AND DELIVERY OF CONCRETE

4.1-Concrete

4.1.1 Proportioning concrete

Concrete proportioning is normally the responsibility of the ready-mixed concrete producer. Only the main considerations are outlined here. The objective in proportioning is to determine the most economical and practical combination of the materials available to produce a concrete that will perform satisfactorily under the usage conditions expected. This requires a good working knowledge of the basic functions and characteristics of the available concrete materials, the job requirements for placement and construction, and the long-term characteristics required of the concrete in place.

In the process of working out the proportions, the mix proportioner seeks to achieve the desired quality with respect to all of the following characteristics: designed strength, durability needed for the job, and adequate workability and proper consistency so that the concrete can be readily worked into the forms and around any reinforcement.

For the finishing qualities needed for concrete slabs, the mix designer will have to select the right amounts of whatever materials are being used, including cement, coarse and fine aggregates, water, and chemical and mineral admixtures. Too much cement plus mineral fines (Section 3.1.6) or too much sand passing the No. 50, No. 100, and No. 200 sieves can make the mix sticky.* Likewise, if an air-entraining admixture is added to a mix, it may be necessary to cut down on these fines to avoid stickiness in concrete finishing. If there is not enough fine material, the concrete may bleed excessively and cause a delay in finishing. A mix that contains too much coarse aggregate will be harsh and difficult to finish.

Unless job conditions demand an adjustment in mix proportions, it is usually best not to change the proportions after the job has started. Such changes can lead to trouble with deicer scaling from too low an air content (Section 11.2.2); discoloration from changes in cement content, changes in water content, or use of calcium chloride (Sections 11.1.8 and 11.1.8.1); or blistering that may be caused in part by excessive air or too many fines (Section 11.2.1).

Generally, a mix made with finely divided mineral admixture, color admixture, or color pigment requires a higher proportion of air-entraining agent to produce a given air content than a similar mix made without these materials.

When concrete made with such finely divided materials will be subjected to freezing and thawing conditions, the air content should be monitored for each delivered batch.

4.1.2 Ready-mixed and other concrete mixtures

Most concrete for residential construction is mixed and delivered in a revolving drum truck mixer. It is generally referred to as ready-mixed concrete. The proportioning, batching, mixing, and delivery are all done by the ready-mixed concrete supplier.[†] Some concrete producers now have truck- or trailer-mounted mobile continuous mixers in which the concrete is volumetrically batched and mixed at the job site.[‡]

The user should select concrete by strength (Section 2.2) for the intended use. To obtain the correct concrete for the job, it is advisable to order from a reputable and qualified ready-mixed concrete producer, and to specify the strength for the class selected, the exposure requirements, whether air entrainment is required,[§] and the intended use of the concrete.

4.1.3 Placing and finishing

It is not common for concrete slabs to blister, and workmen are often surprised that blistering occurs. Major contributing causes are sticky mixes, finishing practices that bring excessive amounts of fine material to the surface, any condition (such as a combination of warm weather and cold subgrade) that causes the surface to harden faster than the concrete below it, finishing the surface too soon, or handling of tools in ways that tend to close the surface too soon.** Finishers should be alert to these hazards and try to plan and carry out the work in ways that avoid them. For repair of blisters, see Section 11.2.1.

4.1.4 Job-mixed concrete

Small jobs can be done with prepackaged mix^{††} or by mixing the separate ingredients.^{‡‡}

*Ranges of aggregate gradings in ASTM C 33 and ASTM C 330 are usually satisfactory.

†Proportioning is done by weight, generally in accordance with ACI 211.1. Ready-mixed concrete should comply with ASTM C 94.

‡Concrete made in a mobile continuous mixer should comply with ASTM C 685.

§Concrete to be exposed to freezing and thawing should be air entrained.

**See ACI 302.1R for more information.

††Complying with ASTM C 387.

‡‡A good reference is the publication, "Concrete for Small Jobs," Reference 1.

Table 4.1.4.1—Concrete proportions for job site mixing

Maximum size of coarse aggregate, in. mm	Minimum cement content, 94-lb bags per cu yd	Maximum water content, gal. per bag of cement ^c	Approximate proportions by volume, ft ³ per bag of cement ^b		
			Cement	Fine aggregate	Coarse aggregate
¾ 9	6.4	5	1	2½	2¾
½ 13	6.3	5	1	2½	2½
¾ 19	6.0	5	1	2½	2¾
1 25	5.8	5	1	2½	3
1½ 38	5.4	5	1	2½	3½
2 ^a 50	5.2	5	1	2½	4

^aIncludes moisture in aggregate.

^bFor concrete that will not be subject to freezing and thawing, these proportions may be varied to use up to 5 percent less cement and 10 percent more fine aggregate. One bag of cement weighs 94 lb (42.6 kg) and is counted as 1 ft³ (0.0283 m³).

^cNot recommended for slabs or other thin sections.

4.1.4.1 Mixing separate ingredients- Field batching and mixing for small jobs in accordance with Table 4.1.4.1 will provide acceptable plain concrete. The amount of water used should not exceed 5 gal. per 94-lb bag (water-cement ratio = 0.44 by weight) or even less if freeze-thaw durability requires less. These mixes have been determined in accordance with recommended procedures, assuming conditions applicable to an average small job with common aggregates. Proportions in Table 4.1.4.1 are for aggregates in a damp and loose condition. Mixing should be done in a batch mixer operated in accordance with the manufacturer's recommendations. For severe exposures, an air-entraining admixture should be added according to the manufacturer's instructions.

4.2-Concrete production

There is ample evidence that good concrete can be produced and placed as economically as poor concrete. The first requirement for producing good concrete of uniform quality is that the materials must be measured accurately for each batch.

Another requirement is that mixing be complete. Concrete should be mixed until it is uniform in appearance and all materials are evenly distributed. With truck-mixed concrete, this means 70 to 100 revolutions of the drum at mixing speed, with the drum not filled beyond its rated capacity. If the job is close to the concrete plant, the concrete should be mixed before leaving the plant. This is because during truck driving the mixer turns slowly, and its action is sufficient only to agitate already mixed concrete but not to thoroughly mix the previously unmixed materials. It may be desirable to add another 2 minute mixing cycle at the delivery site. Concrete that has an obviously non-uniform appearance or is obviously misbatched should be rejected.

CAUTION. In severe climate areas, concrete intended for outdoor exposure should have the entrained air content checked prior to the start of placement. This is particularly important for walks, driveways, curbs and gutters, and street work likely to receive applications of deicing salts. If air content cannot be checked,

the ready-mixed concrete producer should be willing to verify the air content at the beginning of placement.

4.3-Concrete delivery

Fresh concrete undergoes slump loss to varying degrees depending on temperature, time en route, and other factors. Water should not be added after its initial introduction to the batch, except that if on arrival at the job site the slump of the concrete is less than that specified. When water is added under these conditions to regain lost slump, a minimum of 30 revolutions of the drum at mixing speed is necessary to uniformly disperse the water throughout the mix (but note the following limitation on drum revolutions).

4.3.1 Limitation on delivery time

After the water has been added to the concrete mix, the concrete should be delivered and discharged within 1½ hours and before the drum has revolved 300 times. If the concrete is still capable of being placed at a later time than this, without adding more water, the purchaser may waive the 1½ hour and 300-revolution maximums.

Slump decreases as time passes, and it is not allowable to compensate for the possibility of a slow delivery or of prolonged standby time at the job site by starting with a mix that is above the slump specified. The purchaser should require concrete to be delivered at a specified slump. If a delay in delivery or use is anticipated, use of a retarder in the mix might be considered.

In hot weather, or under other conditions that contribute to quick stiffening, the limitation of 1½ hours before discharge may have to be decreased. *

4.3.2 Scheduling and planning

To insure successful delivery and placement, attention must be given to scheduling ready-mixed concrete deliveries and providing satisfactory access to the site for truck mixers. The men and equipment required to properly place, finish, and cure the concrete should be on hand and ready at the job site when it is time to start placement.

*Requirements for delivery time are given in ASTM C 94. Proper procedures for batching, mixing, and transporting concrete to the job site are in ACI 304.

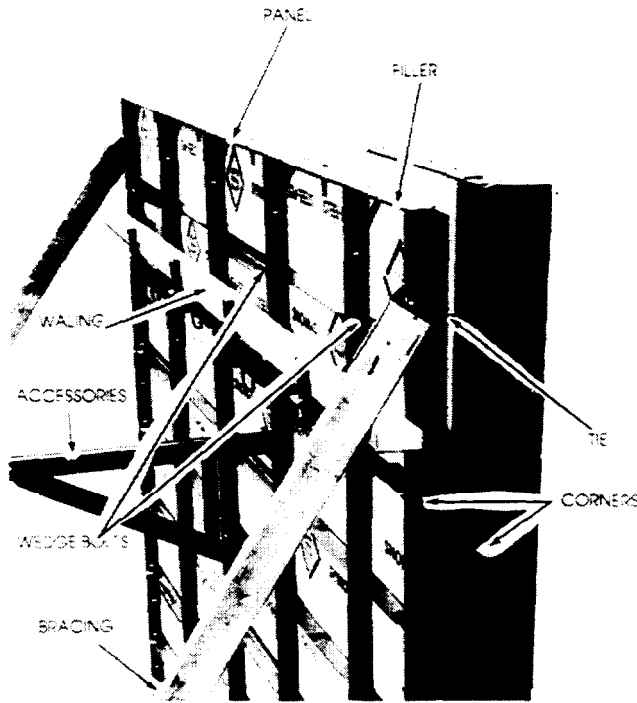


Fig. 5.1(a)--Manufactured plywood forms on steel frame



Fig. 5.1 (b)--Manufactured all-aluminum forms. This set produces brick texture

CHAPTER 5-FORMWORK

5.1-Introduction

Formwork is used to contain the freshly placed concrete in the shape, form, and location desired. Residential formwork may be job-fabricated of plywood or dimensional lumber, or it may be constructed of modular forms of wood, steel, aluminum, or fiberglass. Manufactured forms, rented or purchased, account for most of the residential formwork used today because of the precision of their dimensions, rapid assembly, rapid stripping, and the large number of possible reuses. The many proprietary systems available fall into five types:

- plywood on steel frame,
- all aluminum,
- plywood, attached steel hardware,
- plywood, and
- all steel.

They are illustrated in Figs. 5.1(a) to 5.1(e).*

5.2-Economy in formwork

It is important for the builder to exercise sound judgment and planning when designing formwork. When dimensional lumber and plywood are used for job-fabricated forms, economy is achieved when pieces are of standard sizes. When commercial modular forms are used, economy comes with maximum use of standard form panel units. Embedments, inserts, and penetrations should be designed to minimize random penetration of the formed structure.

5.3-Formwork design and planning

The amount of planning required will depend on the size, complexity, importance, and possible number of reuses of the form. Complex building sites may neces-

sitate formwork drawings and specifications. In addition to selecting types of materials, sizes, lengths, spacing, and connection details, formwork planning should provide for applicable details such as:

- a. Erection procedures, plumbing, straightening, bracing, timing the removal of forms, shores, and breaking back of ties.
- b. Anchors, form ties, shores, and braces.
- c. Field adjustment of form during placing of concrete.
- d. Waterstops, keyways, and inserts.
- e. Working scaffolds and runways.
- f. Joint-forming strips of wood or other material attached to inner faces of forms.
- g. Pouring pockets, weep holes, or vibrator mountings where required.
- h. Screeds and grade strips.
- i. Removal of spreaders or temporary blocking.
- j. Cleanout holes and inspection openings.
- k. Sequence of concrete placement and minimizing time elapsed between adjacent concrete placements.
- l. Form release agents and coatings.
- m. Safety of personnel.

5.3.1 Design and erection

Formwork should be designed so that concrete slabs, walls, and other members will be of correct dimension, shape, alignment, and elevation, within reasonable tolerance. The following tolerances* are suggested for variations from plumb and level.

*For a more detailed understanding of concrete formwork, see Reference 2.

*For other permissible tolerances, see ACI 117.

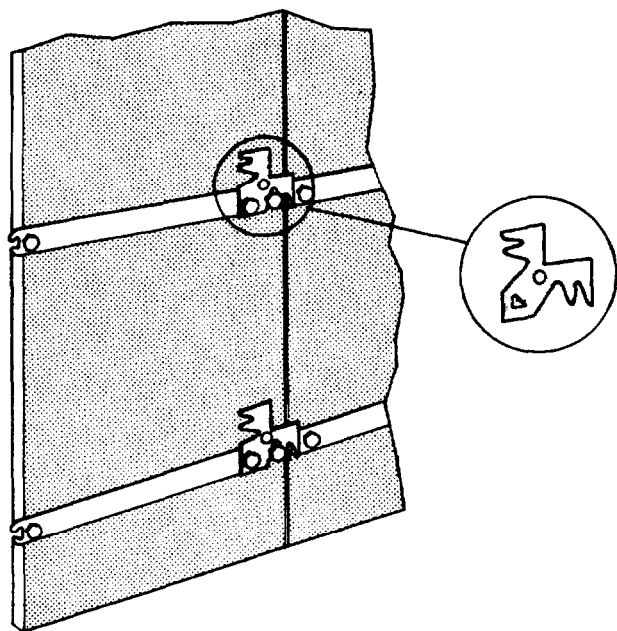


Fig. 5.1(c)-Manufactured plywood forms with attached steel hardware

Variations from the plumb.

In the lines and surfaces of columns, piers, and walls and in arrises, contraction-joint grooves, and other conspicuous lines

in any bay or 20-ft maximum	$\pm \frac{1}{2}$ in.
in conspicuous length in excess of 20 ft	$\pm \frac{3}{4}$ in.

Variation from the level or from the grades indicated on the drawings.

- In slab soffits* ceilings, beam soffits, and in arrises in any 10 ft of length $\pm \frac{1}{2}$ in.
- In exposed lintels, sills, parapets, horizontal grooves, and other conspicuous lines in any bay or any 20 feet of length $\pm \frac{1}{2}$ in.

These values are greater than provided in ACI 117.

Formwork should also be designed, erected, supported, braced, and maintained so that it will safely support all loads that might be applied until such loads can be safely supported by the hardened concrete.

When prefabricated formwork, shoring, or scaffolding units are used, manufacturers' recommendations for allowable loads should be followed. Erection of wall formwork on the footings can usually be started any time after the footing concrete is hard enough to permit forms to be stripped, to support the wall formwork, and to resist the construction activities associated with form setting.

5.3.2 Loads to be supported by formwork during construction

5.3.2.1 Vertical loads- vertical loads consist of dead load and live load. The weight of formwork plus the weight of freshly placed concrete is dead load. Live load includes the weight of workmen, equipment, material storage, and runways, as well as impact load.

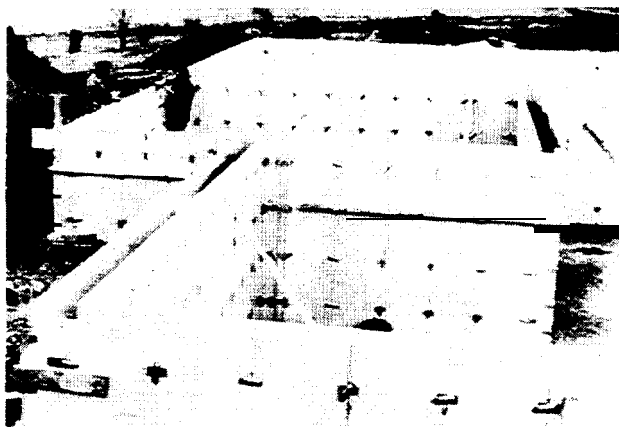


Fig. 5.1(d)-Manufactured plywood forms. Predrilled unframed plywood panels $1\frac{1}{8}$ in. (29 mm) thick are aligned by base plates, using few wales or none. Locking and tying hardware is loose

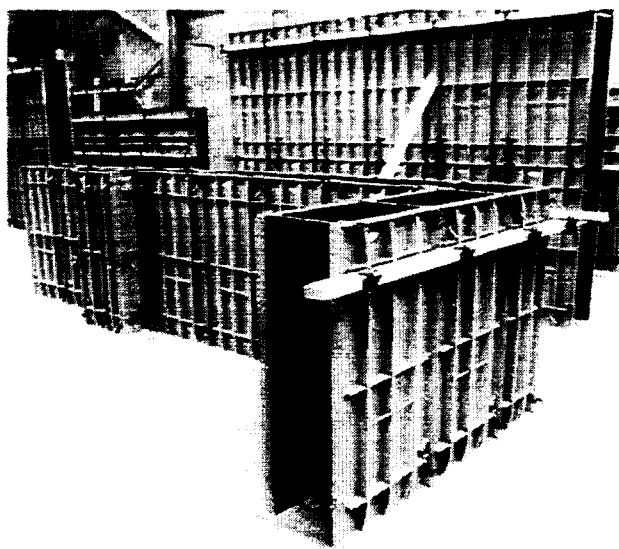


Fig. 5.1(e)-Manufactured all-steel forms

5.3.2.2 Horizontal loads-- Braces and shores should be designed to resist foreseeable horizontal loads including those from wind, cable tensions, inclined supports, dumping of concrete, starting and stopping of equipment, and other shock loads such as impact.

5.3.2.3 Lateral pressure on formwork- Manufactured forms are designed to resist the lateral pressures normally exerted by the concrete against the sides of the forms in residential wall construction.*

5.3.3 Form ties

Form ties maintain the wall thickness and resist the lateral pressures exerted by the freshly placed concrete. As a rule, form ties should be adequate to withstand 1.5 times the computed lateral pressure for light formwork and walls not more than 8 ft (2.5 m) in height and 2 times the lateral pressure for walls greater than 8 ft

*Variations in slab soffits are to be measured before removal of supporting shores; the contractor is not responsible for variations due to deflection, except when the latter are corroboratory evidence of inferior concrete quality or curing, in which case only the net variation due to deflection can be taken into account.

†If loads must be calculated, refer to ACI 347.

(2.5 m) in height. The strength of individual form ties varies by manufacturer. Number and spacing of form ties may also vary with size and type of form used. Tie and form manufacturer's loading recommendations should be followed when planning tie spacing for formwork. The form ties used should be a kind that has outer ends that may be removed so as to be flush or slightly below the surface of the concrete wall. Tie holes on exposed exterior surfaces may require coating or patching to prevent rusting of the tie.

5.4-Form coatings or release agents

5.4.1 Coatings

Form coatings or sealers may be applied to the form contact surfaces, either during manufacture or in the field, to protect the form surfaces, facilitate the action of form release agents, and sometimes, prevent discoloration of the concrete surface.

5.4.2 Release agents

Prior to each use, form release agents are applied to the form contact surfaces to minimize concrete adhesion and facilitate stripping. Care must be exercised not to get any of the material on the reinforcing steel or surfaces where bond with future concrete placements is desired.

5.4.3 Manufacturers' recommendations

Manufacturers' recommendations should be followed in the use of form coatings, sealers, and release agents, but it is recommended that their performance be independently investigated before use. If color uniformity is a criterion for acceptance of concrete, a release agent that does not cause discoloration should be chosen. Where concrete surface treatments such as paint, tile adhesive, or other coatings are to be applied to formed concrete surfaces, it should be ascertained whether the form coating, sealer, or release agent will impair the adhesion or prevent the use of such concrete surface treatments.

5.5-Form erection practices

Before each use, forms should be cleaned of all dirt, mortar, and foreign matter, and they should be thoroughly coated with a release agent. Blockouts, inserts, and embedded items should be properly identified, positioned, and secured prior to placement of concrete.

When forms are erected, effective means should be applied to hold alignment and plumb during placement and hardening of the concrete. No movement to align forms after concrete has achieved initial set should be permitted. However, it is normal to make minor adjustments for alignment during and immediately after concrete placement.

When ribs, wales, braces, or shores need splicing, care should be taken to achieve the strength and safety equivalent to that of a nonspliced element. Joints or splices in sheathing, plywood panels, and bracing should be staggered. All ties and clamps should be properly installed and tightened.

5.6-Removal of forms and supports

The contractor is responsible for a safe formwork installation and should determine when it is safe to remove forms or shores. When forms are stripped, there must be no excessive deflection or distortion and no evidence of damage to the concrete, due either to removal of support or to the stripping operation. Adequate curing and thermal protection of the stripped concrete should be provided, as described in [Sections 10.2 and 10.3](#). Supporting forms and shores must not be removed from beams, floors, and walls until these structural units are strong enough to carry their own weight and any anticipated superimposed load.* Forms and scaffolding should be designed so they can be easily and safely removed without impact or shock to the concrete and to permit the concrete to assume its share of the load gradually and uniformly.

Where building code or building official requires demonstrated strength before forms and shores are removed, it is necessary to employ a testing laboratory to make and break concrete test cylinders. When no tests are required, formwork and supports for walls, columns, and the sides of beams and girders may be stripped after 12 hours when the temperature surrounding the structural units is 50 F (10 C) or more; forms and supports for slabs may be removed after 14 days of temperatures of 50 F or more. However, if spans are greater than 20 ft (6 m), the supports for slabs must remain in place for 21 days at such temperatures. On basement walls the interior braces should be left in place until after backfilling.

When permitted by building codes, strengths may be confirmed by nondestructive testing procedures such as the rebound hammer, penetration resistance probe, or other appropriate equipment.†

CHAPTER 6-REINFORCEMENT

6.1 -General

Steel reinforcing is usually not required in one and two family residential construction. However, reinforcement may be needed to satisfy local acceptable practices and building code requirements.‡ Soil conditions in certain areas of the country warrant designs using conventional reinforcing steel systems or post-tensioned systems.

6.1.1 Types of reinforcement

Reinforcement for concrete construction is readily available as either deformed reinforcing bars or welded wire fabric,§ which comes in flat sheets or rolls.**

6.1.2 Walls

Basement walls should be constructed to meet the requirements of local codes.

*See ACI 347 for specific, detailed information.

†Test methods for such equipment are given in ASTM C 803, ASTM C 805, ASTM C 873, and ASTM C 900.

‡See References 3, 4, 5, and 6.

§Steel reinforcing bars and welded wire fabric are covered by various ASTM specifications listed in the reference.

**See Reference 7.

In the absence of local codes, basement walls may be constructed of unreinforced concrete [see Fig. 6.1.2(a)] where unstable soils or groundwater conditions do not exist and in Seismic Zones 0 and 1 [see Fig. 6.1.2(b), 6.1.2(c), and 6.1.2(d)]. Also in the absence of local codes, wall thickness should be in accordance with Table 6.1.2(a).

In the absence of local codes where unstable soil conditions exist or in Seismic Zones 2, 3, or 4, concrete basement walls should be reinforced as set forth in Table 6.1.2(b). Basement walls subject to unusual loading conditions, surcharge loads, or excessive water pressure should be designed in accordance with accepted engineering practices.

Separate concrete members such as porches, stoops, steps, or chimney supports should be connected to foundation walls or footings with reinforcing steel bars. These anchorages are recommended to prevent separation and to minimize differential settlement of the adjoining members.

6.1.3 Footings

Continuous wall footings and spread footings need only be reinforced to support unusual loads or where unstable soil conditions are encountered. Footings that span over pipe trenches or are placed over highly variable soils should be reinforced in accordance with local building code requirements.

6.1.4 Slabs

Reinforcement is generally not required in concrete slabs-on-ground used for single family residential con-

struction. Reinforcement, however, can help limit cracking caused by drying shrinkage or large temperature changes. When it is desirable to extend the distance recommended between joints in outdoor slabs (Section 7.1.3.2), welded wire fabric can be used to reduce sizes of cracks and minimize infiltration of water, deterioration of concrete, or other effects that could be costly to repair. For such slabs and slabs in areas where there are expansive or compressible soils that change in volume in response to weather and affect the concrete, reinforcement is used as discussed in Section 6.2.3.1.2.

Floors to be covered with thinset tile or other inflexible covering should be jointless slabs in which any cracks that may form are held tightly closed by adequate amounts of welded wire fabric or other steel re-

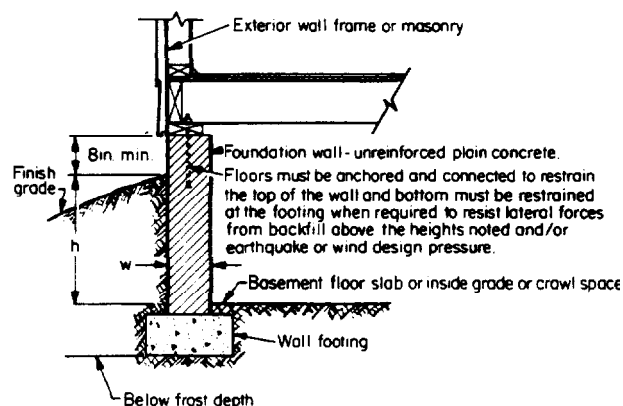


Fig. 6.1.2(a)—Unreinforced basement walls [see Table 6.1.2(a)]

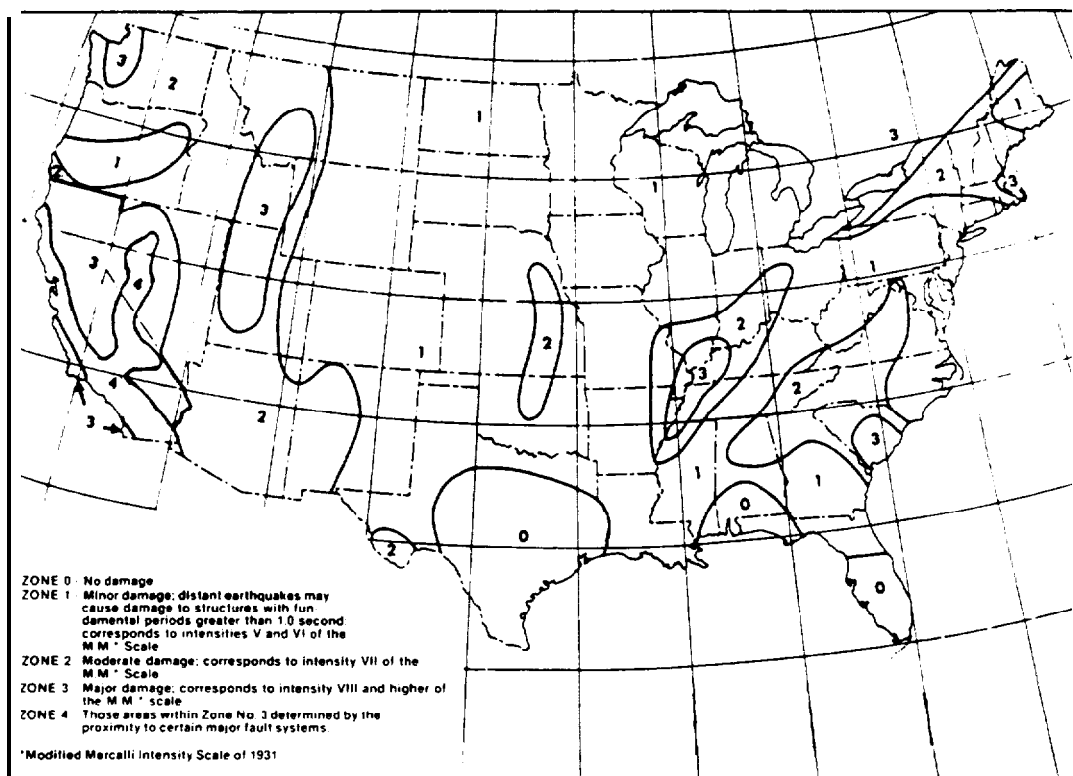


Fig. 6.1.2(b)—Seismic risk map, continental United States

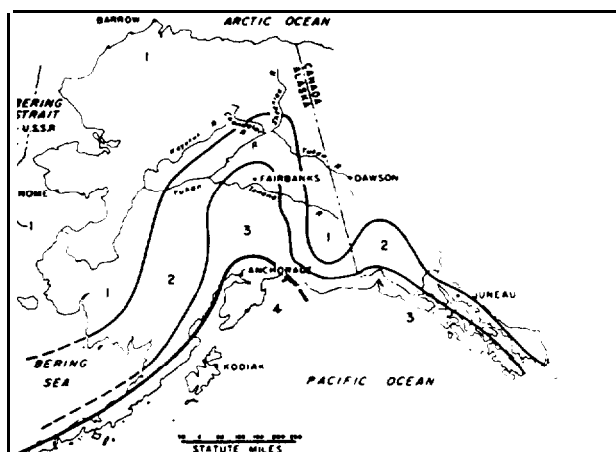


Fig. 6.1.2(c)—Seismic risk map, Alaska

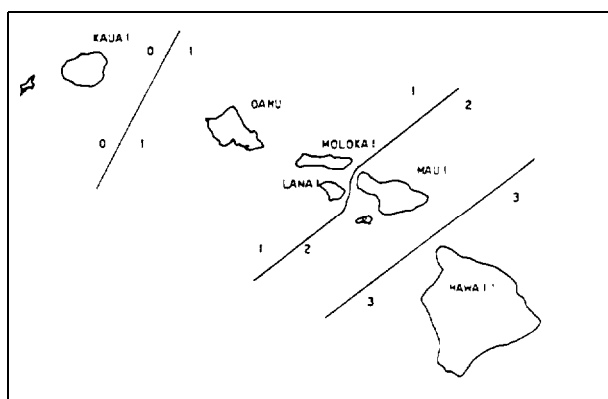


Fig. 6.1.2(d)—Seismic risk map, Hawaii

inforcement. Otherwise, cracks or joints are likely to reflect through the floor covering.

Recent developments in post-tensioning systems that may be useful in outdoor slabs on expansive or compressible soils provide an alternative to conventionally reinforced systems.*

6.2-Reinforcement requirements

6.2.1 Walls

Generally, reinforcement for walls is required only at joints between separately cast concrete elements and around openings. However, temperature steel can help to control thermal and shrinkage cracking (Section 7.1.4.2). Walls that retain soil or that will otherwise be excessively loaded may also require reinforcement (Section 6.1.2).

Adequate provisions should be made to assure that separate concrete components do not pull apart at the joints. When concrete porches or other concrete elements are placed after the concrete foundation walls, reinforcing steel bars and a support ledge or corbel should be provided at the connecting joint. No. 4 (12.77 mm diameter) bar dowels spaced not more than 24 in. (610 mm) on centers should be provided across the joint.

Where reinforcement is required in basement walls over 8 in. (200 mm) thick, bars should be located at

Table 6.1.2(a)—Minimum thickness and allowable depth of unbalanced fill for unreinforced concrete basement walls where unstable soil or ground water conditions do not exist in seismic zones No. 0 or 1*

See also Fig. 6.1.2(a)

These provisions apply to walls not covered by local codes

Nominal thickness, ^a w		Maximum depth h of unbalanced fill, h	
in.	mm	ft	m
6"	150 ^b	4	1.2
8 to 12	200 to 300	7	2.1

^aUnreinforced plain concrete walls should be designed in accordance with local building codes and standard engineering practices.

^bActual thickness is permitted to be $\frac{1}{2}$ in. less than nominal thickness.

^cUnbalanced fill is the height of outside finish grade above the basement floor or inside grade.

^dSix in. (150 mm) plain concrete walls should be formed on both sides.

least 1 in. (25 mm) but not more than 2 in. (50 mm) from each face of the wall. If the thickness is 8 in., the steel should be placed at the centerline of the wall. In 6-in. (150-mm) walls, the steel should be placed at least 1 in. (25 mm) but not more than 2 in. (50 mm) from the face of the wall, that is, opposite (away from) the earth [Table 6.1.2(b), Footnote b]. Concrete cover for reinforcing steel adjacent to contraction joint grooves should be at least 1 in. (25 mm).

Lintels over wall openings should be reinforced, and precast units for this purpose are usually available from building material suppliers. However, lintels for large openings over 6 ft. (1.8 m) in width, or openings that have unusual loading conditions, should be designed by a registered professional engineer.

6.2.2 Footings

Deformed steel bars should be used in footings where reinforcement is required. Footings that cross over pipe trenches should be reinforced with at least two No. 5 (15.88-mm) bars, extending at least $1\frac{1}{2}$ times the trench width. Footings spanning pipe trenches over 3 ft (0.9 m) in width should be designed by a registered professional engineer.

6.2.3 Slabs

6.2.3.1 Slab types- Concrete slabs-on-ground for single-family dwellings are classified in four types that cover almost all slabs encountered in practice. The slab appropriate to any given set of conditions should be adequate in terms of performance and economy.

6.2.3.1.1 Slab Type A. Slab Type A, the most commonly used type, is unreinforced except at special locations; all other slab types are reinforced. Slab Type A may contain reinforcement around depressions, openings, and heating ducts [Fig. 6.2.3.1. I(a) and Fig. 6.2.3.1.1(b)] and at pipe trenches.[†]

*Any such system should be designed by a registered professional engineer. It should be installed and inspected by competent personnel thoroughly familiar with such work and with the necessary safety procedures (Reference 8).

[†]It is a good idea to follow the provisions of Section 6.3 of ACI 318 regarding the use and amount of reinforcement because of the many requirements for type of pipe, prevention of corrosion, maximum allowable pressures, maximum allowable temperature of pipe liquids, preparation of the pipe, putting pipe into service for the first time, and other matters.

Table 6.1.2(b)-Basement walls, reinforced: Reinforcement required for basement walls subjected to no more pressure than would be exerted by backfill having an equivalent fluid weight of 30 pcf (480 kg/m³) or located in seismic zone No. 2, 3, or 4.

These provisions apply to walls not covered by local codes
Walls must be designed by a registered professional engineer

Height of unbalanced fill ^a		Length of wall between supporting concrete walls		Minimum wall thickness ^b		Number and size of horizontal bars in upper 12 in. (300 mm) of wall		Size and spacing of vertical bars	
ft	m	ft	m	in.	mm	ASTM	SI equivalent	ASTM	SI equivalent
4 or less	1.2 or less	unlimited		8	200	not required		not required	
4	1.2	8	2.4	8	200	2 #3	2 9.52-mm dia.	#3 at 18 in. o.c.	9.52-mm dia., 460 mm o.c.
8 or less	2.4 or less	8 to 10	2.4 to 3	8	200	2 #4	2 12.70-mm-dia.	#3 at 18 in. o.c.	9.52-mm dia., 460 mm o.c.
8 or less	2.4 or less	10 to 12	3 to 3.7	8	200	2 #5	2 15.88-mm-dia.	#3 at 18 in. o.c.	9.52-mm dia., 460 mm o.c.
8	2.4	design required		design required		design required		design required	

^aUnbalanced fill is the height of outside finish grade above the basement floor or inside grade. Backfilling should not be started until after the wall is anchored to the floor.

^bThickness of concrete walls may be 6 in. (150 mm) provided reinforcing is placed not less than 1 in. (25 mm) nor more than 2 in. (50 mm) from the face of the wall not against the earth.

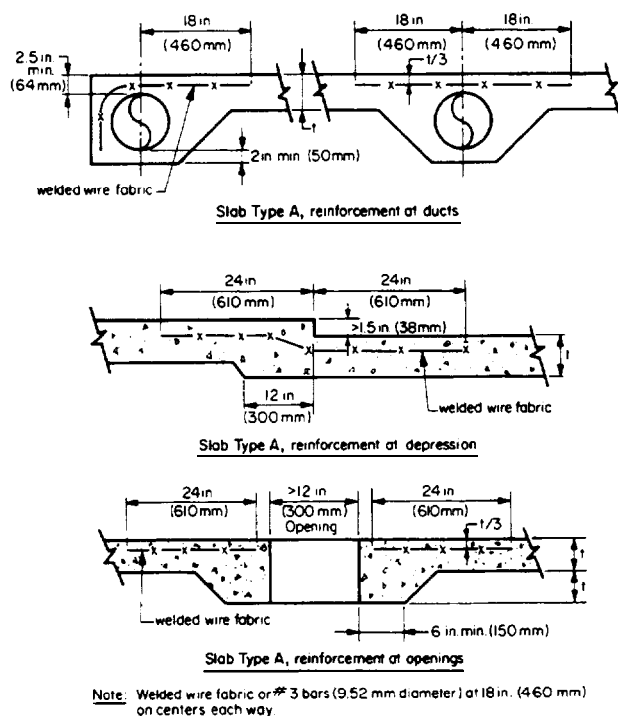


Fig. 6.2.3.1.1(a)-Details for Type A slabs

Type A slabs are intended for use on firm ground where no soil volume change is expected. These are slabs of a 4 in. (100 mm) minimum thickness cast directly on a properly prepared gravel or sand base and unreinforced except at pipe trenches or the locations shown in Fig. 6.2.3.1.1(a). This type of slab serves basically as a separator between ground and living space for basements or slabs-on-ground.

Type A slabs may also be used for driveways or parking pads for passenger vehicles. If heavy vehicular loads are expected, however, a thicker slab may be required. This type of slab should have contraction joints spaced not more than 15 ft (4.6 m) on centers to control shrinkage cracking. When slabs are located outdoors, especially where subjected to extreme differences in temperature, the maximum distance between

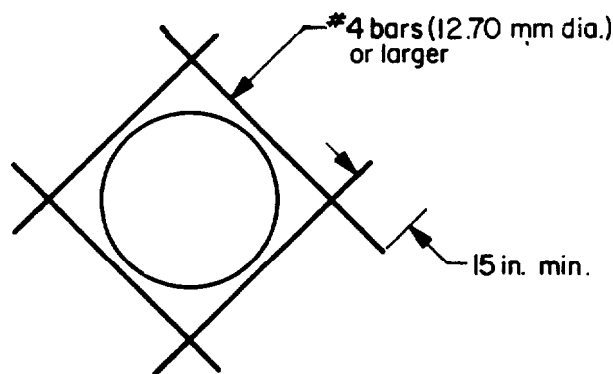


Fig. 6.2.3.1.1 (b) - Reinforcement around openings larger than 12 in. (300 mm) in slabs

joints should be 10 to 12 ft (3 to 3.5 m). At isolation joints, such as at the intersection of driveway and curb, the pavement should be thickened and detailed to comply with the local building code.

6.2.3.1.2 Slab Type B (lightly reinforced). This 4-in. (100-mm) slab is normally used on ground that may undergo small movements (shrinkage or expansion) caused by changes in soil moisture from heavy rains or drought. It is also used when it is necessary to locate the joints farther apart than allowed in Type A slabs. To withstand these small movements as well as accommodate the stresses of drying shrinkage and thermal change without serious damage, the slab is provided with light reinforcement. This reinforcement will also minimize damage caused by minor soil movements. Welded wire fabric (or an equivalent amount of reinforcing steel bars) should be provided throughout the slab in accordance with Table 6.2.3.1.2, and details should comply with local building code provisions. Thicker slabs may be recommended for driveways and parking areas when vehicles larger than passenger cars are expected or where subsoil support is marginal. Pavement slabs should be thickened at isolation joints where vehicular traffic occurs.

6.2.3.1.3 Slab Type C (heavily reinforced). This type of slab transmits all superstructure loads to the