

REINFORCEMENT FOR CONCRETE— MATERIALS AND APPLICATIONS

Developed by Committee E-701, Materials for Concrete Construction

Charles K. Nmai, Chairman David M. Suchorski, Secretary

Leonard W. Bell	Tarek S. Khan	Kenneth B. Rear
Richard P. Bohan	Paul D. Krauss	Raymundo Rivera-Villarreal
David A. Burg	Colin L. Lobo	Jere H. Rose
Darrell F. Elliot	Stella Lucie Marusin	Paul J. Tikalsky
James Ernzen	Patrick L. McDowell	Mark E. Vincent
James A. Farny	Gerald R. Murphy	Christopher H. Wright
Jose Pablo Garcia	Anthony C. Powers*	Kari L. Yuers
Morris Huffman		Robert C. Zellers

*Subcommittee Chairman.

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PREFACE

This document is an introductory document on the topic of commonly used materials for reinforcement of concrete. This primer describes the basic properties and uses of these materials. It is targeted at those in the concrete industry not involved in designing with or specifying these materials. Students, craftsman, inspectors, and contractors may find this a valuable introduction to a complex topic. The document is not intended to be a state-of-the-art report, user's guide, or a technical discussion of past and present research findings on the subject. More detailed information is available in ACI Committee Reports listed in Chapter 7, References.

CHAPTER 1—INTRODUCTION

Nearly everyone involved in construction knows that reinforcement is often used in concrete. However, why it is used and how it is used are not always well understood.

This bulletin provides some of the information important to understanding why reinforcement is placed in concrete. Most concrete used for construction is a combination of concrete and reinforcement that is called reinforced concrete. Steel is the most common material used as reinforcement, but other materials such as fiber-reinforced polymer (FRP) are also used. The reinforcement must be of the right kind, of the right amount, and in the right place in order for the concrete structure to meet its requirements for strength and serviceability.

In this document, frequent references are made to standards of the American Society for Testing and Materials (ASTM). These include test methods, definitions, classifications, and specifications that have been formally adopted by ASTM. New editions of the *ASTM Book of Standards* are issued annually and all references to these standards in this bulletin refer to the most recent edition. Other agencies have similar or additional standards that may be applicable.

1.1—Definitions

Certain terms will be used throughout this bulletin with which familiarity is important. A few of the more common and most frequently used are listed in this section. Precise technical definitions may be found in ACI 116R, "Cement and Concrete Terminology."

bar size number—a number used to designate the bar size. Reinforcing bars are manufactured in both International System (SI—commonly known as metric—measured in millimeters), and U.S. customary (in.-lb) sizes. The bar number for metric bar sizes denotes the approximate diameter of the bar in millimeters. For example, a No. 13 bar is about 13 mm in diameter (actually 12.7 mm). U.S. customary bar sizes No. 3 through No. 8 have similar designations, the bar number

denoting the approximate diameter in eighths of an inch (for example, a No. 5 bar is about 5/8 in. in diameter).

bent bar—a reinforcing bar bent to a prescribed shape, such as a straight bar with a hooked end.

compression—a state in which an object is subject to loads that tend to crush or shorten it.

compression bar—a reinforcing bar used to resist compression forces.

compressive strength—a measure of the ability of the concrete to withstand crushing loads.

elastic limit—the limit to which a material can be stressed (stretched or shortened axially) and still return to its original length when unloaded. Loads below the elastic limit result in the material being deformed in proportion to the load. Material stretched beyond the elastic limit will continue to deform under a constant, or even declining, load.

fibrillated fibers—synthetic fibers used to reinforce concrete that are bundled in a mesh resembling a miniature fish net.

FRP reinforcement—reinforcing bars, wires or strand made from fiber-reinforced polymer (FRP). (Originally, the "p" in FRP stood for "plastic," but "polymer" is now the preferred term to avoid confusion.)

monofilament fibers—discrete individual fibers used to reinforce concrete.

post-tensioning—a method of prestressing in which the tendons are tensioned after the concrete is hardened.

prestressed concrete—Structural concrete in which internal stresses (usually compressive stresses) have been introduced to reduce potential tensile stresses in the concrete resulting from loads. This introduction of internal stresses is referred to as *prestressing* and is usually accomplished through the use of tendons that are tensioned or pulled tight prior to being anchored to the concrete.

pretensioning—a method of prestressing in which the tendons are tensioned before concrete is hardened.

rebar—an abbreviated term for reinforcing bar.

reinforced concrete—structural concrete with at least a code-prescribed minimum amount of prestressed or nonprestressed reinforcement. Fiber-reinforced concrete is not considered *reinforced concrete* according to this definition.

secondary reinforcement—nonstructural reinforcement such as welded wire fabric, fibers, or bars to minimize crack widths that are caused by thermal expansion and contraction, or shrinkage. Secondary reinforcement is reinforcement used to hold the concrete together after it cracks. Structural concrete with only secondary reinforcement is not considered reinforced concrete.

steel fibers—carbon or stainless steel fibers used in fiber-reinforced concrete meeting the requirements of ASTM A 820.

structural concrete—all concrete used for structural purposes including plain and reinforced concrete.

tendon—a wire, cable, bar, rod, or strand, or a bundle of such elements, used to impart prestress to concrete. Tendons are usually made from high-strength steel, but can also be made from such materials as FRP.

tensile strength—a measure of the ability of a material, for example, concrete or reinforcement, to withstand tension.

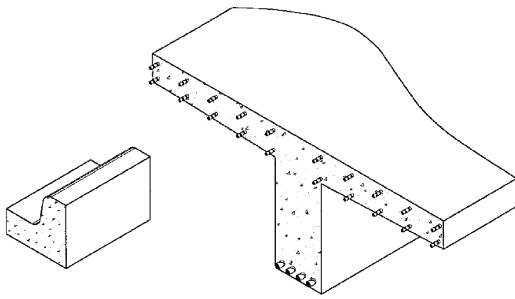


Fig. 2.2—Examples of plain and reinforced concrete: plain curb and gutter (left) and reinforced concrete T-beam (right).

Tension in both the concrete and reinforcement results when reinforced concrete bends under loading.

tension—a state in which a material is subject to loads that tend to stretch or lengthen it.

yield strength—The stress required to stretch a material to its elastic limit.

CHAPTER 2—STRUCTURAL CONCRETE: PLAIN, REINFORCED, AND PRESTRESSED

The design and construction of structural concrete, both plain and reinforced (including nonprestressed and prestressed concrete) is covered by ACI 318, Building Code Requirements for Structural Concrete, and ACI 301, Standards Specification for Structural Concrete.

2.1—Plain concrete

Plain concrete is structural concrete without reinforcement or with less than the minimum amount required by ACI 318 for reinforced concrete. It is sometimes used in slabs-on-grade, pavement, basement walls, small foundations, and curb-and-gutter.

2.2—Reinforced concrete

Plain concrete (Fig. 2.2) has compressive strength—the ability to resist crushing loads; however, its tensile strength is only about 10% of its compressive strength. Its tensile strength is so low that it is nearly disregarded in design of most concrete structures. Reinforced concrete is a combination of adequate reinforcement (usually steel bars with raised lugs called deformations) and concrete designed to work together to resist applied loads (Fig. 2.2). Properly placed reinforcement in concrete improves its compressive and tensile strength.

2.2.1 Bending and bending stresses in reinforced concrete members—Many structural members are required to carry loads that cause bending stresses. An example is a simply-supported beam, in which the top of the member is subjected to compression lengthwise while the bottom is subjected to tension lengthwise (Fig. 2.2.1(a)). This is referred to as beam action and can be illustrated by supporting a board at each end and breaking it by applying a heavy load to the center. If the board is loaded at each end and supported in the middle, as in a cantilevered beam, the top of the board over the support is in tension and the bottom is in compression (Fig. 2.2.1(b)). Unreinforced concrete structural members have little capacity for beam action because concrete's low tensile

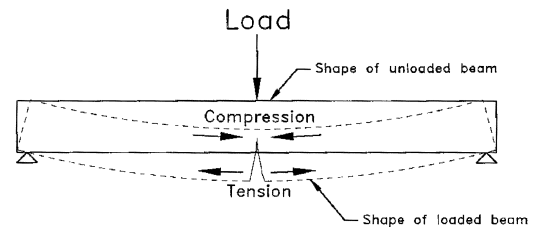


Fig. 2.2.1(a)—A simple beam loaded in the middle and supported at the ends will tend to deflect or bend down in the middle, causing tensile stress in the bottom of the beam and tending to pull it apart. That is, the bottom of the beam is in tension. Reinforcing steel near the bottom of the beam will resist this tension and hold it together.

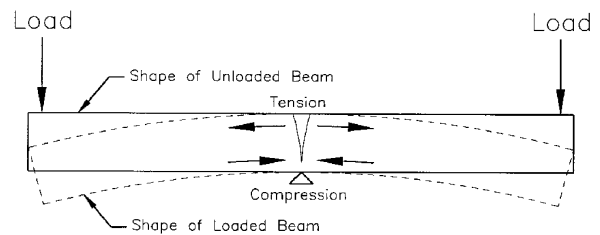


Fig. 2.2.1(b)—If the beam is supported in the middle and the ends are loaded (as in a cantilever beam, such as a balcony), the top of the beam over the support is in tension and will pull apart or crack if there is no reinforcing steel near the top of the beam.

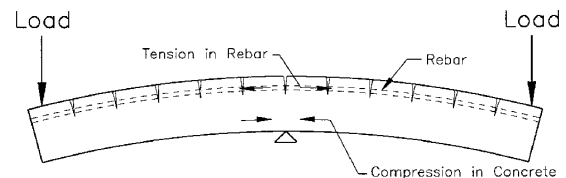


Fig. 2.2.1(c)—Properly placed reinforcement in this cantilever beam will resist tension and control cracking.

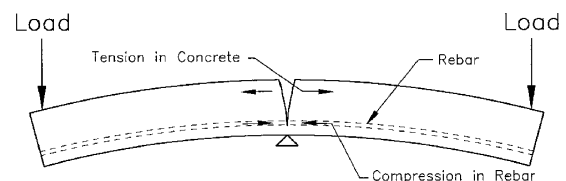


Fig. 2.2.1(d)—Incorrectly placed or missing reinforcement is not effective in resisting tension and will allow uncontrolled cracking in the beam.

strength provides little resistance to the tensile stress in the tension side of the member. This is one of the most important functions of reinforcement in concrete members—to resist the tension in these members due to beam action (Fig. 2.2.1(c)). Steel is remarkably well-suited for concrete reinforcement because it has high tensile strength, and therefore relatively small amounts are required. Also, concrete bonds to steel, and both expand and contract to about the same degree with temperature changes. The good bond between concrete and steel allows an effective transfer of stress or load between the steel and concrete so both materials act together in resisting beam action. For these reasons, steel is the most

common material used to reinforce concrete. However, other materials such as FRP are also used for reinforcement.

Many structural members must perform like a beam to fulfill their function in the structure. Among such concrete structural members are beams, girders, joists, structural slabs of all kinds, some columns, walls that must resist lateral loads,

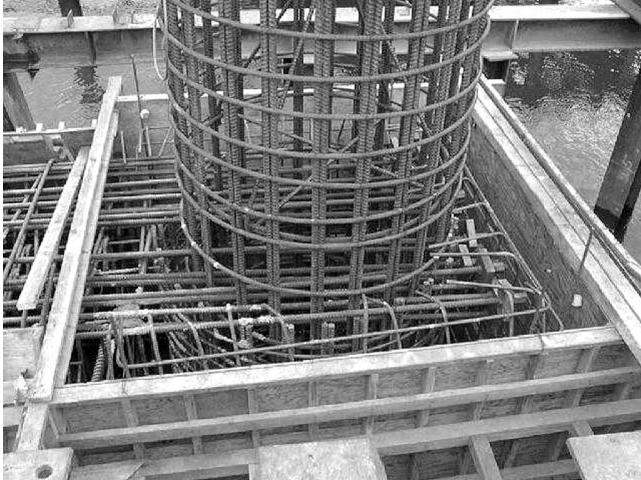


Fig. 2.2.2(a)—Reinforcement in a concrete column (courtesy of HDR Engineering, Inc.).

and more complex members such as folded plates, arches, barrels, and domes. In addition to unintentional omission of part or all of the reinforcement, improper placement of the reinforcement designed to resist tension is one of the most common causes of structural concrete failures (Fig. 2.2.1(d)). If the tensile steel is not properly placed in the tension zone of a structural member, it will not be effective in resisting tension, and failure may occur.

2.2.2 Other reinforcement applications—In addition to its use to resist tension in structural members, reinforcement is used in concrete construction for other reasons, such as:

- To resist a portion of the compression force in a member. The compressive strength of steel reinforcement is about 20 times greater than that of normal-strength concrete. In a column, steel is sometimes used to reduce the size of the column or to increase the column's carrying capacity (Fig. 2.2.2(a)). Compression steel is sometimes used in beams for the same reasons.
- To resist diagonal tension or shear in beams, walls, and columns. Reinforcement used to resist shear in beams is commonly in the form of *stirrups* (Fig 2.2.2(b)), but may also consist of longitudinal reinforcement bent up at an angle near the ends of the beam, or welded wire fabric. In columns, shear reinforcement is typically in the form of ties, hoops, or spirals.



Fig. 2.2.2(b)—Stirrups to resist shear in a concrete box girder bridge (courtesy HDR Engineering, Inc.).



Fig. 2.2.2(c)—Hoop reinforcement in a reinforced concrete column (courtesy of HDR Engineering, Inc.).

- To resist bursting stresses resulting from high compressive loads in columns or similar members, in which spiral steel reinforcement, hoops (Fig. 2.2.2(c)), or ties are used.
- To resist internal pressures in round structures such as circular tanks, pipes, and bins.
- To minimize cracking, or more precisely, to promote numerous small cracks in place of fewer large cracks, in concrete members and structures.
- To limit widths and control spacing of cracks due to stresses induced by temperature changes and shrinkage (shortening of the concrete due to drying over time) in slabs and pavement.

2.3—Prestressed concrete

Prestressed concrete is structural concrete in which internal stresses have been introduced to reduce potential tensile stresses in the concrete resulting from loads. This introduction of internal stresses is called *prestressing* and is usually accomplished through the use of tendons that are tensioned or pulled tight prior to being anchored to the concrete. Tendons can consist of strands, wires, cables, bars, rods, or bundles of such elements. Tendons are usually made from high-strength steel, but can also be made from other materials such as FRP.

2.3.1 Bending and bending stresses in prestressed concrete members—As with reinforced concrete members, the most common type of prestressed members are bending members or beams. The tendons in prestressed concrete beams, like the nonprestressed reinforcement in reinforced concrete beams, are placed near the top or bottom of the beam where the applied loads will cause tension. For example, in a beam spanning between two supports carrying a load in the middle, the load would cause tension at the bottom of the beam, so the tendons would be placed near the bottom of the beam to resist this tension (Fig. 2.3.1). Similarly, in a beam supported at the center and loaded at the ends, the loads would cause tension on the top part of the beam, so the tendons would be placed near the top of the beam to resist this tension. The difference between the reinforced concrete beams and the prestressed concrete beams in these examples is that, in the nonprestressed

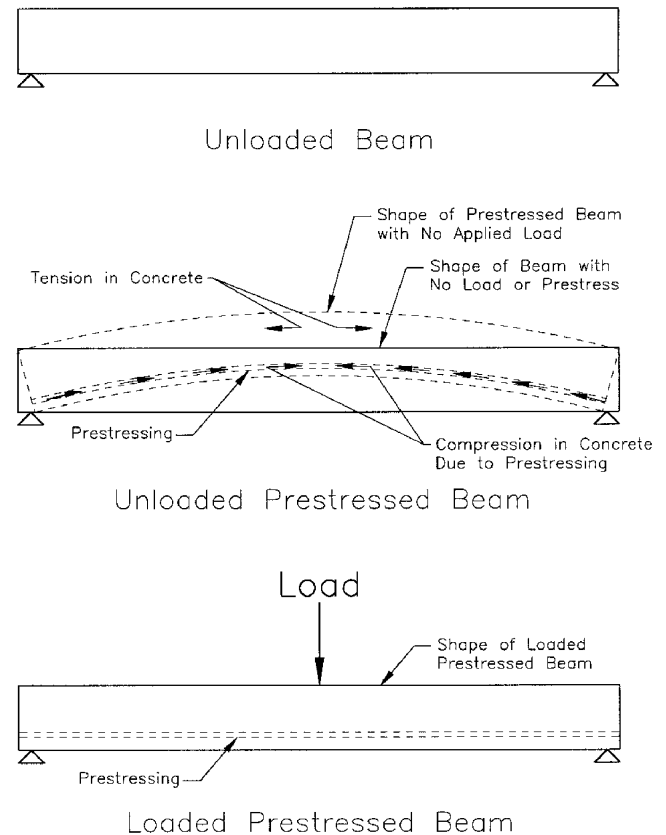


Fig. 2.3.1—In a prestressed simple beam, the prestressing steel is placed near the bottom of the beam, just like regular reinforcing steel. But in the prestressed beam, the prestressing causes the unloaded beam to bend upward in the middle, opposite to the downward bending caused by the applied load. The combined effect is a beam that bends less, and therefore cracks less, under load.

beams, the reinforcement is not subjected to tension until the beam is loaded, whereas in the prestressed beam, the tendons are tensioned before the beam is loaded. By tensioning the tendons before loading the beam, the concrete on the side of the beam with the tendons is squeezed or compressed. When the beam is loaded, the tension in the concrete caused by the load is offset by the compression caused by the prestress.

2.3.2 Advantages of prestressed concrete—There are several benefits to prestressing concrete:

- Prestressed beams make more efficient use of the best qualities of the concrete and tendons (that is, the compressive strength of concrete and the tensile strength of steel). Therefore, a prestressed beam using a given amount of concrete can be made stronger than a comparable reinforced concrete beam.
- A prestressed concrete beam can be designed such that the cracks in the concrete due to applied loads are smaller than in a comparable reinforced concrete beam, or can be virtually eliminated. This makes for a more durable, longer lasting member by preventing water, chlorides (deicing salt), and other corrosive materials from coming into contact with the tendons.