Reinforced concrete

Reinforced concrete (ferro concrete) is concrete in which reinforcement bars ("rebars") or fibers have been incorporated to strengthen the material that would otherwise be brittle.

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History

The use of reinforced concrete is a relatively recent invention, usually dated to 1848 when Jean-Louis Lambot became the first to use it. Joseph Monier, a French gardener, patented a design for reinforced garden tubs in 1868, and later patented reinforced concrete beams and posts for railway and road guardrails. Most reinforcement is made of steel, but fiber-reinforced plastic materials are available.

The major developments of reinforced concrete have taken place since the year 1900; and from the late 20th Century, engineers have developed sufficient confidence in a new method of reinforcing concrete, called post-tensioned concrete, to make routine use of it.

Physics and statics

Plain concrete will carry extremely high compressive stresses, but any appreciable tension will cause rupture and consequent failure. For this reason, plain concrete is limited in its use as a structural member subject to bending or direct tensile action. When reinforcement like steel bars are incorporated into concrete, a reinforced concrete section is created. This reinforced concrete section is much more efficient in carrying tensile forces due to bending or direct tension than a plain concrete section with the same dimensions.

The general rule is: *concrete takes the compression, steel takes the tension*. However, initially a newly-formed concrete member will behave according to general mechanics, until the concrete cracks in tension.

There are three physical characteristics which are responsible for the success of steel reinforced concrete. Firstly, the coefficient of thermal expansion of concrete is very nearly identical to that of steel, preventing internal stresses due to differences in thermal expansion or contraction. Secondly, when concrete hardens it grips the steel bars very firmly, permitting stress to be transmitted efficiently between both materials. Usually steel bars are roughened or corrugated to further improve the bond or cohesion between the concrete and steel. Third, the alkaline chemical environment provided by portland cement causes a passivating film to form on the surface of steel, making it much more resistant to corrosion than it would be in neutral or acidic conditions.

Although the ridges on rebar help, there is sometimes not enough length (actually surface area) of embedment of reinforcing steel in the concrete to fully bond or transfer force between concrete and rebar. In these cases the rebar may be bent into a 180 degree hook, which itself will transfer half of the capacity of the rebar between the rebar and concrete.

In some structural members where minimum cross-section is desired, steel may be used to carry some of the compressive load as well as tensile load. This occurs in columns. Continuous beams in buildings generally require some compressive steel at the columns, but beams and slabs usually have reinforcing steel only on the tension side. In the case of continuous girders where the tensile stress alternates between top and bottom of the member, the steel is bent accordingly into a zig-zag shape within the beam.

The amount of steel required for adequate reinforcement is usually quite small, varying from 1% for most beams and slabs to 6% for some columns. The percentage is usually based on the area in a right cross section of the member. Reinforcing bars are round and vary by eighths of an inch from 0.25 in to 1 in in diameter (in Europe from 8 to 30 mm in steps of 2 mm). Also galvanized rebar is available. Typically, concrete will have reached its nominal design strength at most 28 days after the water was mixed into the cement mix.

Reinforced concrete structures sometimes have provisions such as ventilated hollow cores to control their moisture.

Corrosion and frost may damage poorly designed or constructed reinforced concrete. When rebar corrodes, the rust expands, cracking the concrete and unbonding the rebar from the concrete. Frost damage occurs when water penetrates the surface and freezes. The expansion of freezing water in microscopic cracks widens the cracks, causing flaking, and eventual structural failure.

In wet and freezing climates, reinforced concrete for roads, bridges, parking structures and other structures that may be exposed to deicing salt may require epoxy-coated rebar or a well composited concrete well planes structure. Epoxy coated rebar can easily be identified by the light green color of its epoxy coating.

Penetrating sealants must be applied some time after curing, when the concrete has dried to at least several inches of depth. One especially exotic process is to surround the cured concrete member with a vacuum bag filled with resin monomer, and then after the monomer has penetrated several inches into the concrete, the monomer is cured with a gamma ray source. This produces a very hard, attractive surface that can be dyed through the material, so chips and scratches are less visible.

Less expensive sealants include paint, plastic foams, films and aluminum foil, felts or fabric mats sealed with tar, and layers of bentonite clay, sometimes used to seal roadbeds.

Common failure modes of steel reinforced concrete

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Carbonation

The water in the pores of the cement is normally alkaline, this alkaine enviroment is one in which the steel is passive and does not corrode. According to the pourbaix diagram for iron when it is alkaline the metal is passive.[1] The carbon dioxide from the air reacts with the alkali in the cement and makes the pore water more acidic. Carbon dioxide will start to carbonate the cement in the concrete from the moment the object is made, this process will start at the surface and slowly move deeper and deeper into the object. If the object is cracked through vandalism or some other damage the carbon dioxide of the air will be more able to penitrate deep into the object. As a result it is normal in the design of a concrete object to state the depth within the object that the rebar will be. If the rebar is too close to the surface then an early failure due to corrosion may occur.

One method of testing a strucutre for carbonation is to drill a *fresh* hole in the surface and then treat the surface with Phenolphthalein, this will turn pink when in contact with alkaline cement. It is then possible to see the depth of carbonation. An existing hole is no good as the surface will already be carbonated.

Chlorides

Chlorides such as salt which is used for deicing roads is able to promote the corrosion of steel rebar.

concrete cancer

This is a rather ill defined term which means different things to different experts.[2]

Alkali silica reaction

This is found when the cement is too alkaine, it is due to a reaction of the silica with the alkali. This is nothing to do with the disease cancer in humans or animals, you will not catch cancer from living in a house with concrete cancer.

The silica (SiO_2) reacts with the alkali to form a silicate in the *Alkali silica reaction (ASR)*, this causes localised swelling which causes cracking.

See [3] and [4] for details

High alumina cement

This cement is banned in the UK in 1976 it was greatly used after world war two for making precast concrete objects.[5].

sulphate attack

Sulfates can attack cement which can lead to an early failure.[6]

Fiber-reinforced concrete

Fiber-reinforcement is mainly used in shotcrete, but can also be used in normal concrete. Fiber-reinforced normal concrete are mostly used for on-ground floors and pavements, but can be considered for a wide range of construction parts (beams, pilars, foundations etc) either alone or with hand-tied rebars.

Fiber (steel or "plastic" fibers) reinforced concrete is less expensive than hand-tied rebar, while still increasing the tensile strength many times. Shape, dimension and length of fibre is important. A thin and short fibre, for example short hair-shaped glass fiber, will only be effective the first hours after pouring the concrete (reduces cracking while the concrete is stiffening) but will not increase the concrete tensile strength. A normal size fibre for European shotcrete (1 mm diameter, 45 mm length—steel or "plastic") will increase the concrete tensile strength.

Steel is the strongest commonly-available fiber, and come in different lengths (30 to 80 mm in Europe) and shapes (end-hooks). Steel fibres can only be used on surfaces that can tolerate or avoid corrosion and rust stains. In some cases, a steel-fiber surface is faced with other materials.

Glass fiber is inexpensive and corrosion-proof, but not as strong as steel. Recently, spun basalt fiber, long available in Eastern Europe, has become available in the U.S. and Western Europe. Basalt fibre is stronger and less expensive than glass, but historically, has not resisted the alkaline environment of portland cement well enough to be used as direct reinforcement. New materials use plastic binders to isolate the basalt fiber from the cement.

The premium fibers are graphite reinforced plastic fibers, which are nearly as strong as steel, lighter-weight and corrosion-proof. Some experimeters have had promising early results with carbon nanotubes, but the material is still far too expensive for any building.

Non steel reinforcement

Some construction cannot tolerate the use of steel. For example, MRI machines have huge magnets, and require nonmetallic buildings. Another example are toll-booths that read radio tags, and need reinforced concrete that is transparent to radio.

In some instances, the lifetime of the concrete structure is more important than its strength. Since corrosion is the main cause of failure of reinforced concrete, a corrosion proof reinforcement can extend the life substantially.

For these purposes some structures have been constructed using fiber-reinforced plastic rebar, grids or fibers. The "plastic" reinforcement can be as strong as steel. Because it resists corrosion, it does not need a protective concrete cover of 30 to 50 mm or more as steel reinforcement does. This means that FRP-reinforced structures can be lighter, have longer lifetime and for some applications be price-competitive to steel-reinforced concrete.