Concrete and Building in Haiti

Corrosion, Chlorides, and Reinforced Concrete

Draft report as of November 14, 2013
By Herb Nordmeyer

Introduction

A survey of buildings in Haiti has revealed that much of the rebar is so corroded that it is damaging the concrete. In portions of Haiti, the water is brackish, and this accelerates the corrosion of the rebar. Very little stucco lath is used in Haiti; however, in coastal environments in the US, galvanized stucco lath has been observed to telegraph rust through the stucco within six months of application.

Solutions to the degrading rebar have been suggested, ranging from replacing the steel rebar with basalt rebar, to using stainless steel rebar. This paper is designed to add a little clarity to the subject.

This paper is not intended to provide engineering or architectural advice. Others who are more knowledgeable in those areas will be asked for their input. If chemistry does not fascinate you, you may skip the next section.

Figure 1. The underside of a "flat" concrete roof in Gonaives, Haiti

The Mechanism

Rebar is made from steel. Steel's major component is the element iron. Iron is reactive. When iron is in the presence of oxygen and water, the iron oxidizes to

form ferrous and / or ferric oxide hydrates. These are also sometimes referred to as ferrous and / or ferric hydroxides. In laymen's terms, the iron rusts. The volume of the rust is greater than the volume of the iron it replaces, so if the iron is encapsulated, stress is applied to the substance (concrete) that surrounds the original iron. The rust does not provide any protection for the underlying iron, so if oxygen and moisture once migrated to the iron, they can continue to migrate through the rust and continue the process of producing more rust.

When the iron is in the presence of chloride ions (table salt and a little moisture), the iron and the chloride ion react to form ferrous and / or ferric chloride hydrates. In laymen's terms, the iron corrodes. Since the chloride ion is much more aggressive than the oxygen, the rate of reaction is much faster than the rusting. Since the volume of the chloride reaction is greater than the volume from a similar oxidation reaction, greater stresses are applied. As with rust, the corrosion chemicals do not protect the underlying iron, so as long as chloride ions can form, the reaction will continue.

As soon as either reaction produces enough stress on the concrete to exceed the tensile strength of the concrete, the concrete will crack. This usually exposes the rebar to further degradation.

This ends the chemistry lesson. The two reactions will be referred to as rusting and corrosion in the remainder of this document.

Interruption of the Rusting and Corrosion Mechanisms

There are several ways to interrupt the rusting and corrosion mechanisms. If there were no oxygen or chloride ions, the reactions would not take place. If there were no moisture, the reactions would not take place. If there was no iron present, the reactions would not take place. These approaches are addressed below. Relative prices for the different technologies have been derived from an internet search and from contacting various vendors. Steel rebar made with 60,000 psi tensile strength steel is assumed to have a relative price of 100. No adjustments are made for importation into Haiti, or the relative availability of the products. Most of the rebar used in Haiti is probably 40,000 psi steel.

Removing the black iron

The steel rebar can be replaced, in whole or in part by

Basalt rebar

- Relative cost 135
- Produced by melting and making fibers from basalt rock. The fibers are bundled and "glued" together into bars. Bonding is good. When shapes are needed, they need to be bent at the factory. Basalt rebar is lighter in weight than steel rebar, and it has a tensile strength about 60% greater than the 60,000 psi steel, so even though the cost per pound ($2.62 per lb plus shipping from Europe) is significantly higher than the cost of steel rebar (varies with the steel price, but is about $0.60 per lb), the cost per job is only about one-third more. Basalt Products Group, LLC

reports, *"Please note that we have an agent from Haiti based in Miami ready to deliver materials to Haiti. He has suppliers and approvals for our materials already in place with the Haitian government and agencies like USAid, the United Nations and the Clinton Global Foundation. We are preparing to supply materials for port reconstruction."*

Fiber-Reinforced Plastics

- Relative cost 150
- This is "fiberglass" rebar. It is produced from fibers, and the fibers are encased in a resin.

Bamboo rebar

- Relative cost appears to be slightly less than the use of steel rebar.
- Bamboo does not have the tensile strength of steel rebar, so more needs to be used. It needs to be coated to prevent it from absorbing moisture during the curing process of the concrete. Only bamboo that is at least 3 years old should be used.
- Tests at Calvin College indicate that even with coating the bamboo still absorbs moisture during the concrete curing process.

Basalt rope

- Relative cost appears to be about the same as basalt rebar.
- Basalt rope consists of basalt roving that is twisted into a rope. It is flexible, but does not hold up well when it is knotted or sharply bent.
- Basalt fiber is soluble in the interstitial water of concrete, so it needs to be protected with a coating.
- Basalt rope appears to provide a substantial improvement for dome construction since it molds to the shape of the dome.

MM FX-2

- Relative cost 200
- MM-FX-2 is a modified steel with a higher tensile strength than black rebar and has a much greater resistance to corrosion than black rebar.
- MM-FX-2, with the higher cost is probably not an option for use in Haiti.

Stainless steel

- Relative cost 530
- Stainless steel is harder to work with and with the much higher cost should not be considered for home construction in Haiti.

Various non-metallic fibers.

- This has been suggested as a viable option, but non-metallic fibers do a better job of replacing reinforcing mesh than they do for replacing rebar. Texas A&M is doing work with coconut fiber and this work will be reviewed.

Protecting the iron

The steel rebar can be protected by coating it with

Galvanizing (Zinc)

- Relative cost 130

- When chlorides attach the zinc, which is a sacrificial coating, the resulting zinc chloride can migrate through the concrete, so stresses are not built up in the concrete which increase the volume of matter. Galvanizing does an excellent job of protecting rebar, but it does not do an adequate job of protecting metal lath. This is caused by using a trowel, and the sand in the stucco erodes the zinc coating and exposes the underlying steel.

Epoxy

- Relative cost 150
- Epoxy needs to be factory applied, and the epoxy needs to be protected during shipping and handling. Any cut ends need to be touch-up coated. Any spot damage to the coating will result in an aggressive attack on the steel near the damage. Bond to the concrete is less than with steel rebar.
- For use in home construction in Haiti, epoxy coatings do not appear to be a realistic option.

Purple ECR

- Relative cost 250
- Cut ends need to be coated. Rebar shapes can be ordered with the coating on all of the cut ends. This coating is much more robust than epoxy coating.
- Due to the cost, Purple ECR coatings do not appear to be an option for home construction in Haiti.

Painting

- Painting is not considered effective, reduces the bond between the steel and concrete, and is not considered permanent.

Eliminating chlorides from the mix

Steps should be taken to keep chlorides out of the concrete. This can be done by

- Using mix water that is low in chlorides. Standards call for using potable water for mixing concrete. The EPA standard for chlorides in drinking water is 500 mg/liter.
- Using aggregate that do not contain significant amounts of chlorides.
- Installing a barrier between any chloride sources in the ground and the concrete.
- Protecting the concrete from salt spray.

Reducing the migration of ions and moisture

If quality concrete, which is well consolidated, is used that imbeds the rebar at least three inches into the concrete, the amount of migration of oxygen, moisture, and chlorides to the rebar is greatly reduced. This will reduce the amount of degradation of the rebar. This could be used in foundations and footings, but wall and roof panels are normally not thick enough for that level of rebar embedment.

If concrete is maintained in a dry state, the rate of degradation of steel rebar is reduced substantially.

Maintaining concrete in a dry state has traditionally been a problem in the Gonaives area since the area periodically floods and up to four feet of mud was deposited in some areas of the city during the 2008 flood.

Footings and Trenches

One of the problems encountered in the low-lying areas of Gonaives is that when trenches are dug for foundations, brackish water seeps into the trenches. A common practice is to pour concrete into the trenches to above the height of the water table and then, if funding is available, to apply a vapor barrier and then pour steel-reinforced concrete above the water table. Often the brackish water wicks up into the reinforced concrete and leads to corrosion of the steel, which leads to cracking of the concrete.

The wicking of the brackish water is enhanced by the high levels of clay in much of the aggregate. The high levels of clay result in deterioration of the concrete, which exposes the rebar to more chloride attack.

An additional problem will occur when building multistory, disaster-resistant housing. If Structural Concrete Insulated Panels are used, the weight of the structure may be such that a slab foundation will not provide sufficient resistance to overturning during a high wind event. This will result in footings and / or anchors being placed further into the ground and thus being located nearer to or actually in the brackish water table.

If an effective moisture barrier is placed between the concrete which is poured in contact with the brackish water table and the reinforced concrete that is poured higher up, there may not be a low-cost and effective way to provide strong reinforcing between the upper and the lower concrete pours.

It is a common practice in Haiti to build a one-story, flat-roofed building and at a later date add a second and possibly a third story. Crack patterns in the walls of existing one-story structures, which are designed for adding additional stories, indicate that many of the current foundations are not adequate to support even the current loading. Structural Concrete Insulated Panel construction would hold up with a reduced foundation, but may not be able to resist overturning during high wind events.

Proposed Solutions

- Identify different soil conditions in Gonaives and have an engineer design foundations that would be adequate to support a three-story building in hurricane or earthquake conditions.
- Improve the quality of aggregate used to pour foundations, footings, and slabs.
- Improve techniques for consolidating concrete that is poured.

- Stress the need for moisture barriers under all slabs, footings, and foundations.
- In areas where brackish or high-chloride water is near the surface or where footings and / or anchors will extend close to the high-chloride water table, concrete poured in these areas should be well consolidated and should be reinforced with either basalt rebar or galvanized rebar.
- In areas where the well water contains over 500 mg/l of chlorides, do not use that water for concrete which contains steel.
- Ensure that all water around each structure drains away from the structure.
- For Structural Concrete Insulated Panels, use only steel that is galvanized and ensure that the sand used to produce the stucco coating does not contain more than 5% clay.
- When domes are constructed, use Basalt rope for reinforcing.